Mixer Linearization in Direct Conversion Receiver

Aleksandar Atanasković[1], Aleksandra Đorić[2] and Nataša Maleš-Ilić[1]

Abstract – **In this paper, the linearization of the mixer in direct conversion receiver is performed by the technique that exploits the baseband signals. The signals for linearization are formed and processed in digital domain, set on the appropriate amplitude and polarity and inserted at the mixer. The linearization effects of the applied linearization method on the third- and fifth-order nonlinearities are observed for the case when the signals for linearization are driven at the transistors' drain of the RF stage differential pair in the Gilbert mixer cell. Additionally, the effects of I/Q signal imbalances on the linearization of the mixer are examined. Analysis are performed for two types of the signal – ideal I/Q signal without imbalances and I/Q signal with imbalance effect (up to 30% amplitude imbalance and 50 degrees phase imbalance). Tests were performed for two different input signal power levels and for two cases of frequency spacing between signals.**

Keywords – **Direct Conversion, Mixer, Linearization method, I/Q imbalances.**

I. INTRODUCTION

The direct-conversion receivers (DCRs), also known as zero-IF receivers, over the last decade have become popular alternative approach to the classical heterodyne architecture in the development of RF integrated circuits (ICs) in modern wireless communication systems. The DCR architecture has become an attractive solution for the commercial applications due to its exquisite characteristics, such as low-cost, low-power, wide bandwidth, and highly integration with RF circuitry. On the other hand, linearity of the receiver become necessary feature and mixer is one of the influential components which can determine system performances. The mixers have frequency-conversion/demodulation function in RF and microwave receivers. The major goals of the mixer design are to minimize conversion loss, noise figure and intermodulation distortion.

Different techniques for the mixer linearization have been deployed, such as predistortion, feedforward, a technique based on transconductance cancelation of the third-order, techniques based on the insertion of the second harmonic and/or the difference frequency signal in the analogue domain [1-5].

The technique applied in this paper for the mixer linearization uses the modified signal in the baseband which is a low-frequency product of the second-order nonlinearity of a nonlinear system induced by the useful baseband signal, [6], [7]. The in-phase I and quadrature-phase Q components of the signal are digitally processed in order to create adequate signals for linearization, which are tuned in amplitude and polarity and injected at the mixer cell.

The effects of the proposed linearization method are examined through the simulation process for QAM signal at two input power levels , where I and Q components are single tones with frequency interval between spectral components of 0.2 MHz and 2 MHz. Additionally, the impact of the imbalances of the I and Q signals on the intermodulation products is investigated. Output power levels of the fundamental signal, as well as levels of the third- and fifth-order intermodulation products, are observed in terms of the amplitude and phase mismatch of the I and Q signals.

II. THEORETICAL APPROACH

The direct-conversion receivers translate the desired RF spectrum directly to DC using a local oscillator (LO) which frequency is equal to the RF-carrier frequency of the desired signal. The mixed output is the signal that is downconverted directly to the baseband, so that the IF stage is not required. Figure 1 shows the schematic diagram of the direct-conversion receiver including the mixer linearization circuit.

The theoretical approach of the proposed linearization technique is based on the nonlinearity of the transistor output current [7-9]. The in-phase, I and quadrature phase, Q components are extracted at the demodulator output in the receiver to be adequately processed in the baseband to create signals for linearization:

$$BB_{\mathrm{mod}} = f(I,Q) = I^2 + Q^2 \qquad (1)$$

The formed linearization signals are separately adjusted in amplitude and polarity $a_{\{e|o\}}$ across two branches, as indicated in Figure 1. Indexes, *e* and *o* in subscript are related to the signals prepared for the insertion in the mixer cell through the serial LC circuit.

According to the analysis performed in [6-9], the second order nonlinearity of the transistor in the mixer cell leads to the interference of the injected baseband signal for linearization and fundamental signal, which generates additional third-order nonlinear products that may suppress the original intermodulation products distorted by the transistor nonlinear characteristic.

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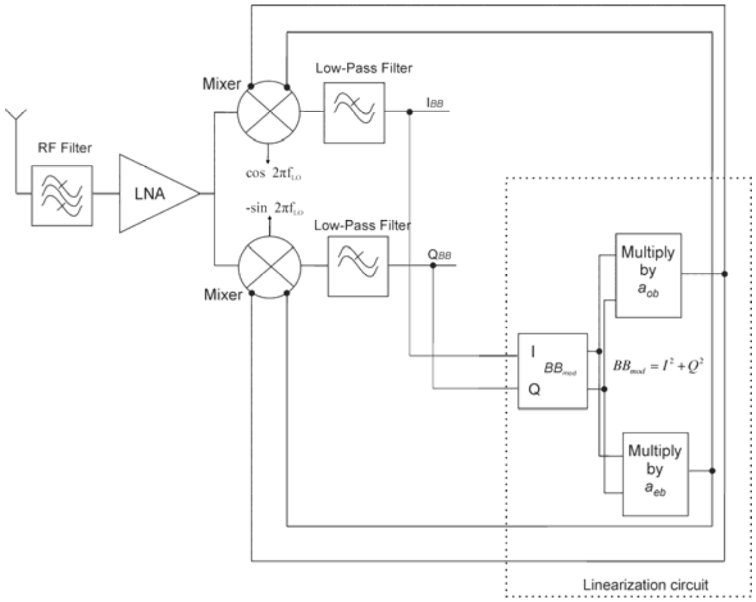


Fig.1. Schematic diagram of the DCR with the mixer linearization circuit

III. LINEARIZATION RESULTS

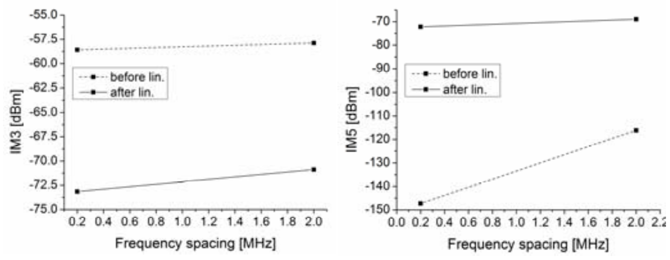
The linearization was applied to the Gilbert mixer that is used in the direct conversion receiver (Figure 1). The impact of the performed linearization method on the intermodulation products reduction was analysed through the simulation process in ADS for the mixer cell that uses transistor MOSFET model. The linearization was carried out for the ideal case where I and Q components have equal amplitudes and phase difference of 90 degrees.

The mixer cell was tested for QAM modulated signals that comprise the I and Q single tone baseband components. The frequency spectrum of such a signal contains two spectral components and we considered two cases, when the spectral components are separated by 0.2 MHz and 2 MHz.

The carrier frequency of the input signal is 1 GHz as well as the frequency of the local oscillator. Linearization of the mixer was performed for the cases when the input power of the RF carrier is Pin_{RF} = -20 dBm and -30 dBm, while the power of the signal from the local oscillator is Pin_{LO} = -3 dBm.

The optimization process of the adjustable parameters of the linearization signals was performed to reduce the third-order intermodulation products, IM3 and to restrain the fifth-order intermodulation products, IM5 at the levels below the suppressed IM3 products.

Figures 2 and 3 show the intermodulation products, IM3 and IM5, before and after the applied linearization method. After applied linearization, suppression of the IM3 products is around 12 dB for higher power level and both frequency spacing. For lower power, the IM3 products are improved about 22 dB for 0.2 MHz frequency spacing and 8 dB for 2 MHz signal separation. On the other hand, the IM5 products are aggravated, but they are still below linearized IM3 products.



a) b)

Fig 2. Intermodulation products before and after the linearization for Pin_{RF} = -20 dBm, Pin_{LO} = -3 dBm: a) IM3 i b) IM5

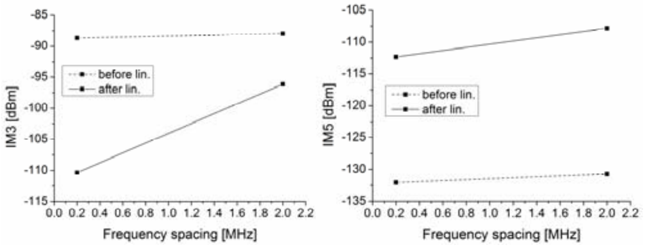


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Fig 3. Intermodulation products before and after the linearization for Pin_{RF} = -30 dBm, Pin_{LO} = -3 dBm: a) IM3 i b) IM5

IV. EFFECTS OF I/Q IMBALANCES

In ideal case, the signal from the local oscillators in the I and Q channels have equal amplitude and phase difference of -90 degrees, as depicted in Figure 1. When the asymmetry occurs, the amplitudes and phases of the LO signals in the channels deviate from the values in the ideal case. In practice, I channel is defined as a reference (0 degrees phase, amplitude value 1).

The signal at the mixer input is in the form:

$$X_{RF}(t)=I(t)\cos(\omega_c t)-Q(t)\sin(\omega_c t) \qquad (2)$$

where ω_c is the carrier frequency.

Imbalance is characterized by amplitude (α) and phase shift (θ) of the signal from the local oscillator X_{LO} in Q branch as:

$$X_{LO}=-\alpha\sin(\omega_{LO}t+\theta) \qquad (3)$$

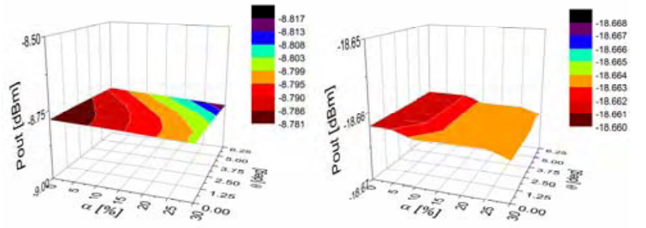
Then, the IQ imbalanced signal at the mixer output can be written as follows:

$$I_{BB}(t)=I(t)$$

$$Q_{BB}(t)=\alpha[Q(t)\cos(\theta)-I(t)\sin(\theta)] \qquad (4)$$

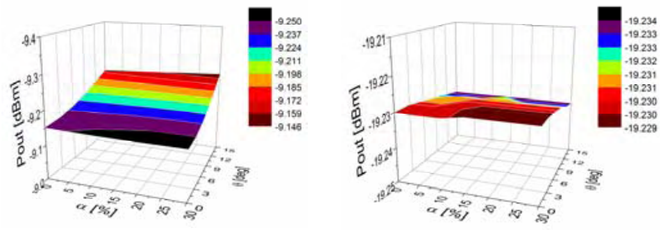
In 3D figures, 4 and 5, the output power of the fundamental signal for both, input power levels and signal spacing, in terms of amplitudes and phases misalignment of the I and Q components is presented. Figures clearly indicate that output power levels stay almost unchanged with the increase of the parameters α and θ for the considered signal separation and input signal levels.

Figures 6 to 9, represent the IM3 and IM5 products after the linearization when IQ imbalances are considered. For low level of IQ imbalances ($\alpha < 5\%$, $\theta < 3\deg$) the IM3 products after the linearization retain almost unaltered in case of 0.2 MHz signal spacing. When signal spacing is 2 MHz, the IM3 products are less susceptible to the amplitude and phase changing, especially for lower considered power. In the cases of greater IQ imbalances, values of the IM3 products after the linearization are approaching the levels of the IM3 products before the linearization. As far as the IM5 products are concerned they slightly increase with the rise of the IQ imbalances, but they still stay below the linearized IM3 products considered under the same imbalance conditions.



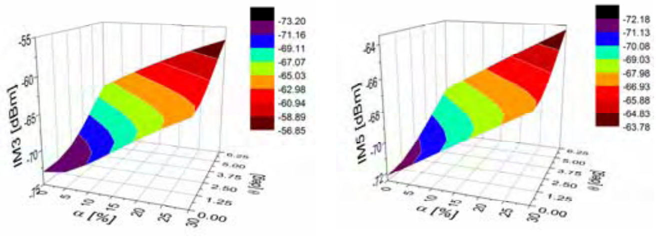
a) b)

Fig. 4. Output power of the fundamental signal for signal spacing 0.2 MHz in terms of I/Q imbalances : a) Pin$_{RF}$ = -20 dBm, Pin$_{LO}$ = -3 dBm; b) Pin$_{RF}$ = -30 dBm, Pin$_{LO}$ = -3 dBm



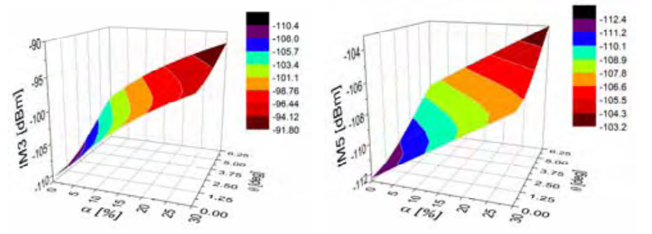
a) b)

Fig. 5. Output power of the fundamental signal for signal spacing 2 MHz in terms of I/Q imbalances: a) Pin$_{RF}$ = -20 dBm, Pin$_{LO}$ = -3 dBm; b) Pin$_{RF}$ = -30 dBm, Pin$_{LO}$ = -3 dBm



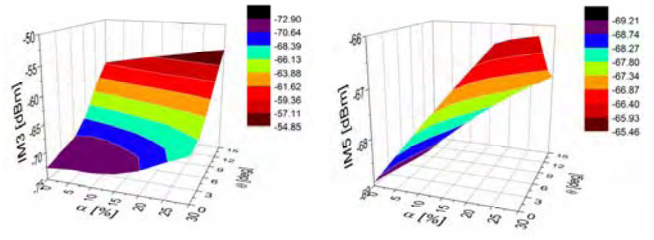
a) b)

Fig. 6. Intermodulation products of the direct converted mixer for signal spacing 0.2 MHz, Pin$_{RF}$ = -20 dBm, Pin$_{LO}$ = -3 dBm: a) IM3; b) IM5



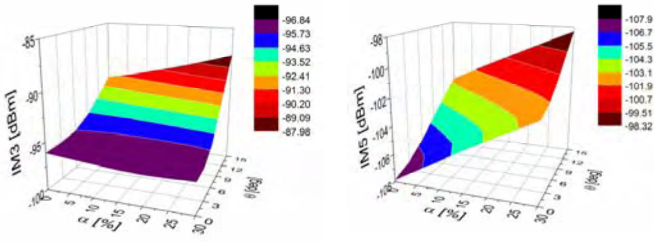
a) b)

Fig. 7. Intermodulation products of the direct converted mixer for signal spacing 0.2 MHz, Pin$_{RF}$ = -30 dBm, Pin$_{LO}$ = -3 dBm: a) IM3; b) IM5



a) b)

Fig. 8. Intermodulation products of the direct converted mixer for signal spacing 2 MHz, Pin$_{RF}$ = -20 dBm, Pin$_{LO}$ = -3 dBm: a) IM3; b) IM5



a) b)

Fig. 9. Intermodulation products of the direct converted mixer for signal spacing 2 MHz, Pin$_{RF}$ = -30 dBm, Pin$_{LO}$ = -3 dBm: a) IM3; b) IM5

V. CONCLUSION

This paper describes the linearization method that uses the modified baseband signals for the Gilbert mixer linearization in direct conversion receiver. The main role of this mixer is direct conversion of the input signal carrier frequency to the baseband. The test was performed for the QAM signal whose I and Q components are sinusoidal signals and the spectrum contains two frequency components separated for 0.2 MHz and 2 MHz. The proposed linearization method utilizes the I and Q signals that are adequately processed in the digital domain at the receiver with the aim to form the signals for linearization. Linearization effects are examined for different input power levels and different frequency spacing between the signal spectral components. The signals for linearization are fed at the transistors' drain of the RF stage differential pair in the Gilbert cell. It should indicate that very good results are achieved in the reduction of the third-order mixer nonlinearity. The fifth-order intermodulation products are deteriorated, but they are still kept at the levels below the linearized IM3 products. Additionally, it is shown that the low-levels of IQ misalignment have almost negligible effect on the linearization results, especially in case of 2 MHz spacing between signals. Also, we analyse the grade in which the linearization effects deteriorate with the increasing imbalance.

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