ADVANCED ENGINEERING SYSTEMS

MIXER LINEARIZATION BY MODIFIED BASEBAND SIGNALS

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Abstract:

In this paper, the linearization of the Gilbert downconverter mixer at the receiver is performed by two different methods that exploit the modified baseband signals. The signals for linearization in both methods are formed and processed in digital domain after demodulation. In the first method, the modified baseband signal is adjusted in amplitude and polarity and injected at the mixer. The linearization signals in the second method, which are also formed in the baseband and set on the appropriate amplitude and phase, modulate the fundamental carrier second harmonic and then lead to the mixer. The linearization effects of the linearization methods on the third- and fifth-order intermodulation products are compared for the case when the signals for linearization are driven at the transistors' drain of the RF stage differential pair in the Gilbert cell. The influence of the linearization signals delay on the results is analysed as well.

Key words:

Gilbert mixer, baseband signal, downconversion, intermodulation products, linearization.

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1. INTRODUCTION

In modern wireless communication systems, a very important feature is the linearity of the transceiver which is predominantly determined by power amplifier in the transmitter and mixer in the receiver. Mixers allow the conversion process and frequency modulation/demodulation of the digital information in the transmitters/receivers. Since Gilbert mixer is characterized by good conversion gain over a wide frequency range it finds application in frequency downconverter in the receiver.

Various techniques for the linearization of the mixer (Ellis, 1998; Kim *et al.*, 2002; Liang *et al.*, 2008) have been proposed in the literature, such as feedforward, predistortion, 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 analog domain (Ock *et al.*, 2001; Lou *et al.*, 2008; Theodoratos *et al.*, 2007).

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This paper analyses the impact of the two different linearization techniques that use the modified signals in the baseband in order to linearize the mixer used as a downconverter (Atanasković *et al.*, 2013, 2015).The modified baseband signal is the product of the second-order nonlinearity of a nonlinear system induced by the useful baseband signal. In both methods, the baseband I and Q components of the signal are digitally processed and prepared for the linearization. In the first method, properly formed signals for linearization are adjusted in amplitude and polarity and led to the mixer. The second linearization method uses also adequately modified signals for linearization that are set in amplitude and phase in the baseband. The formed signals modulate the fundamental carrier second harmonic and modulated signals are inserted at the mixer.

This paper encompasses the brief theoretical basis behind the applied linearization methods and compares the mixer linearization results achieved by two linearization approaches. The results are obtained in the simulation process for QAM signal where I and Q components are sinusoidal signals with frequency spacing between spectral components of 200 kHz and 2 MHz. The effects of linearization are deliberated for two levels of the input signal. Additionally, the impact of linearization signals delay on the intermodulation products suppression is investigated.

2. THEORETICAL ANALYSIS

The theoretical approach of the proposed linearization methods is based on nonlinearity of the transistor output current. The FET's dominant nonlinearity can be represented by polynomial model in the form of Taylor's series as given by equation (1) (Pedro and Perez, 1994; Aikio and Rahkonen, 2005; Heiskanen *et al.*, 2003):

$$\begin{aligned} i_{ds} &= g_{m1}v_{gs} + g_{m2}v_{gs}^2 + g_{m3}v_{gs}^3 + \\ &\quad + g_{d1}v_{ds} + g_{d2}v_{ds}^2 + g_{d3}v_{ds}^3 + \\ &\quad + g_{m1d1}v_{gs}v_{ds} + g_{m2d1}v_{gs}^2 v_{ds} + g_{m1d2}v_{gs}v_{ds}^2 + \ldots \end{aligned} \tag{1}$$

The transistor's drain current (i_{ds}) depends on the voltage between the gate and the source (v_{gs}), which is expressed by transconductance terms g_{mx}. The dependence of the drain current on the voltage between the drain and the source (v_{ds}) is represented by the drain conductance terms g_{dy}. In addition, the drain current is expressed as a function of voltage between the gate and the source and voltage between the drain and the source by using mixed coefficients g_{mxdy}. The order of each coefficient can be calculated as x+y.

Figure 1 shows the schematic diagram of the receiver including the mixer linearization circuits of both methods.

Equation (2) represents the two signal components in the baseband, in-phase, I and quadrature phase, Q components, at the demodulator output in the receiver:

$$\begin{aligned} I &= (c(t)\cdot v_s)\cos(\phi(t)) \\ Q &= (c(t)\cdot v_s)\sin(\phi(t)) \end{aligned} \tag{2}$$

In the first method, the signal for linearization is generated in the baseband in the following form:

$$BB_{\mathrm{mod}} = I^2 + Q^2 \tag{3}$$

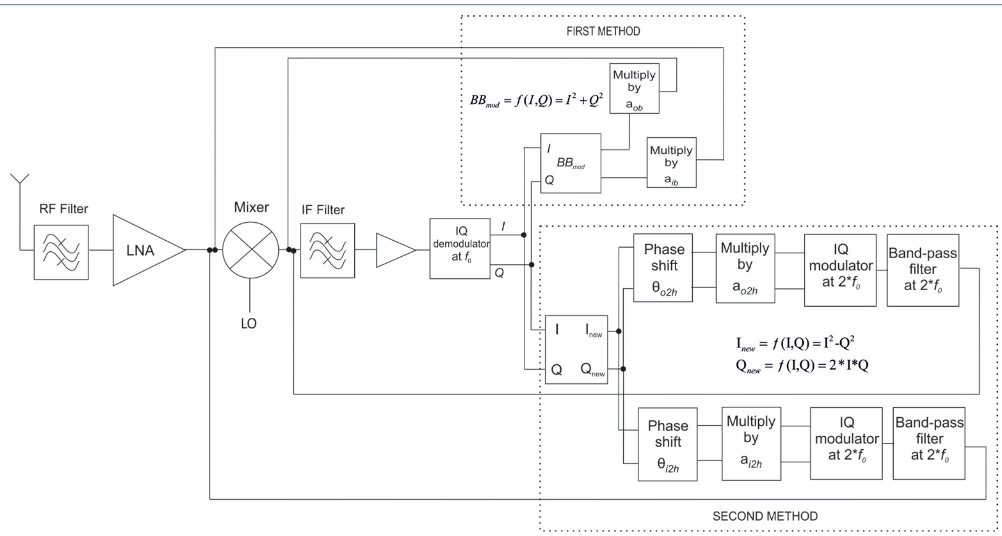


Figure 1. Schematic diagram of the receiver with the mixer linearization circuit

It is further processed in the baseband multiplied by coefficients $a_{\{ib|ob\}}$ in order to be adjusted in the amplitude and polarity. The shaped signals for linearization are fed to the mixer circuit through the serial LC circuit.

In the second method, I and Q components are modified in the baseband to form the in-phase and quadrature-phase components of the signal for linearization in the forms:

$$I_{new} = I^2 - Q^2$$
$$Q_{new} = 2Q \quad (4)$$

The created signals for linearization are separately tuned in phase $\theta_{\{i2h|o2h\}}$ and amplitude $a_{\{i2h|o2h\}}$ across two branches. Properly adjusted signals modulate signal at frequency of the fundamental carrier second harmonic and run to the mixer through the bandpass filters designed at the second harmonic central frequency. Indexes *ib*, *ob, i2h* and *o2h* in subscript refer to the signals for linearization prepared for insertion in the mixer cell, as indicated in Figure 1. The signals for linearization are injected at the drain of RF stage differencial pair in the Gilbert mixer.

Due to the transistor nonlinearity in the Gilbert cell, the modified linearization signals and the desired useful signals are interfered through the transconductance and the mixed terms of the second-order, according to the analysis performed in (Atanasković *et al.*, 2013, 2015). The influence of conductance terms g_{dx} in (1) can be neglected based on the analysis carried out in (Aikio and Rahkonen, 2005; Heiskanen *et al.*, 2003). As a result, the additional third-order nonlinear products are generated to reduce the original intermodulation products distorted by the transistor nonlinear characteristic.

3. LINEARIZATION RESULTS

The impact of the deployed linearization methods on the reduction of the intermodulation products was analyzed for the mixer in the heterodyne receiver (Figure 1). The linearization was applied to the Gilbert mixer that performs frequency downconversion of the RF input signal from 1 GHz to 200 MHz. In the process of ADS simulations and analysis, the transistor MOSFET model in the mixer cell was used.

The Gilbert mixer cell was tested for QAM modulated signals which comprise the I and Q single tone baseband components. The frequency spectrum of such a signal contains two components spaced around the carrier frequency and we analysed the cases when spectral components are separated by 200 kHz and 2 MHz.

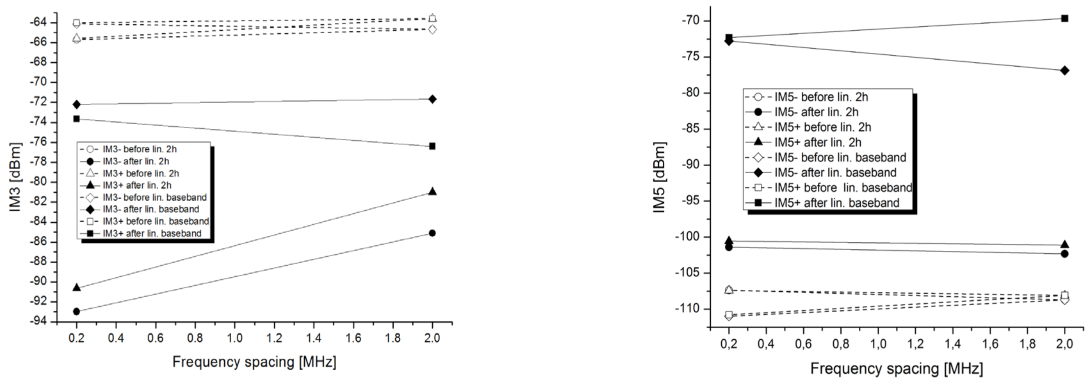
Linearization of the mixer was performed for the case when the signals for linearization are driven at the transistors' drain of the RF stage differential pair in the Gilbert cell. The frequency of the local oscillator is 1.2 GHz and carrier frequency of the input signal is 1 GHz. Also, the input power 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.

In both methods, the optimization of adjustable parameters of linearization signals was carried out to suppress the third-order intermodulation products, IM3 and to restrain the fifth-order intermodulation products, IM5 at the levels below the reduced IM3 products.

Figures 2 and 3 show intermodulation products, IM3 and IM5, before and after the linearization for both linearization methods. The graphs clearly indicate that greater reduction degree of the IM3 products was achieved by applying the second linearization method for both RF carrier input power levels. The nonlinear IM3 products are reduced to a maximum of 10 dB in the first linearization approach, while the suppression levels in the second method range from 18 to 25 dB for -20 dBm RF signal input power until maximum 30 dB for -30 dBm power level. However, it should indicate that conversion gain of the mixer is by 1 dB lower in the second linearization method comparing to the first method due to the bandpass filters in the linearization circuit connected to the mixer.

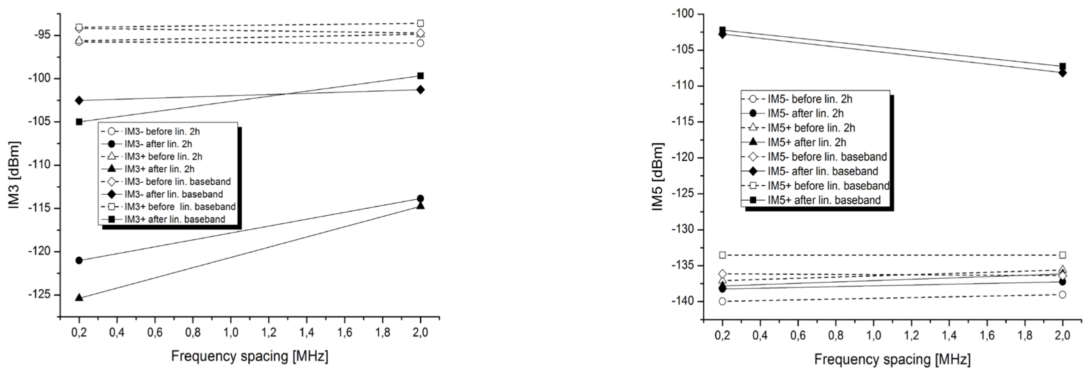
Additionally, it is noted that different linearization results regarding the IM5 products are gained by two linearization methods. In the first method, power of the IM5 products increase significantly compared to the levels before the linearization but retain at levels of the same order as linearized IM3 products. However, in the second method, levels of the IM5 products in the linearization process are dwelled close to the IM5 power before the linearization.

The impact of the linearization signal delay on linearization results is also evaluated. The analysis shows that for the delays up to 50 ns, the results of the IM3 suppression for spacing between the signals of 200 kHz stay unaltered. As for the 2 MHz frequency spacing, it was concluded that the increase of the delay reduces the ability of the IM3 products reduction. Table I represents the levels of the IM3 products before and after the linearization for both methods when the linearization signal delay is included in the simulation process. The effects of the signal delay of 10, 30 and 50 ns are investigated



a) b)

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



a) b)

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

for both input power levels. It should be noted that with the increase of the delay, the reduction of the IM3 products slightly recedes, so that the levels of IM3 products remain barely beneath the unsuppressed IM3 products for 50 ns signal delay.

	PinRF = -20 dBm				PinRF = -30 dBm			
Delay [ns]	IM3- [dBm] I method	IM3+ [dBm] I method	IM3- [dBm] II method	IM3+ [dBm] II method	IM3- [dBm] I method	IM3+ [dBm] I method	IM3- [dBm] II method	IM3+ [dBm] II method
Before lin.	-64.67	-63.53	-64.67	-63.59	-94.72	-93.60	-95.9	-94.863
After lin.- without delay	-71.65	-76.39	-81.115	-79.939	-101.26	-99.66	-113.849	-114.749
10	-70.37	-67.50	-75.783	-79.351	-99.9	-97.42	-107.1	-110.637
30	-67.875	-64.367	-70.095	-74.182	-97.677	-94.254	-101.058	-102.88
50	-65.82	-62.17	-67.331	-69.978	-95.82	-92.12	-97.933	-99.06

Table 1. The Impact of the Linearization Signal Delay

4. CONCLUSION

This paper describes two different approaches of exploiting the modified baseband signals for linearization of the Gilbert mixer in the receiver. The main role of this mixer is downconversion of the input signal carrier frequency from 1 GHz to 200 MHz. The test was performed for the QAM signal whose I and Q components are sinusoidal signals and the spectrum contains two frequency components symmetrical around the carrier frequency. The proposed linearization methods use I and Q signals that are adequately processed in the digital domain at the receiver with the aim to form signals for linearization. Linearization effects for different input power levels and different frequency spacing between signal spectral components are examined for the case when the signals for linearization are fed at the transistors' drain of the RF stage differential pair. It is inferred that the results accomplished in reducing the intermodulation products of the third- and fifth-order are better for the second linearization approach. Additionally, it is observed that the linearization signal delay does not affect the results of the IM3 products suppression for signal separation of 200 kHz. However, for the 2 MHz frequency spacing, decrease of the IM3 products with the increase of the linearization signals delay slightly aggravates, so that for 50 ns signal delay the levels of IM3 products remain slightly under the levels of the non-linearized IM3 products. It should be noted that the typical values of the signal delay in commercially available receivers are of the order of a few tens of the picoseconds.

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