BALANCED MIXERS DESIGNED FOR RF

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The balanced mixers are designed in silicon (Si) substrate for AMS 0,35 µm BiCMOS technologies. The custom computer-aided-design tool CADENCE Design Framework is used for the design, analysis and optimization of the balanced mixers

Keywords: single balanced mixer, double balanced mixer, RF, design

1. INTRODUCTION

In the last few years the interest in the radio frequency applications – circuitry and design – increases. These circuits can be used in portable devices for wireless communications. The main idea is to implement all passive and active components used in the RF device on a single chip. Passive and active components such as inductors, capacitors, resistors and the transistors, implemented on a single chip are very important, because they are the core of the transceiver.

Because of their greater parameters, better capabilities, better noise factor, the balanced mixers had greater usage. For conversion elements are used a differential amplifiers, analog multipliers and 2 or 4 Shotkey diodes. Mixers released with analog multipliers and differential amplifiers are used for 2-3GHz. Mixers released with Shotkey diodes could work in 1GHz (for mixers wit high bandage filter) and could work up to 20 kHz and more (for mixers released with rejection technology). In the theory is that the function of the bipolar transistor collector current from base-emitter voltage is good approximated with exponent. The gain of the transistor and the steep of the exponent could be controlled by the emitter current, and it is enough to be included a current generator in the emitter circuit. If that current is changing by harmonic low and depends from the local generator current, then by this low the steep of the transistor must be changed to.

2. SINGLE BALANCED MIXERS IMPLEMENTED WITH DIFFERANTIAL AMPLIFIER

In Figure 1 is shown a single balanced mixer released with differential amplifier and with added blacks for signal frequency and local oscillator (high frequency signal).

The signal voltage u_s is divided equally between both bases and emitters of the differential pair transistors Q1 and Q2, and the local oscillator voltage is delivered to them in-phase. The transistor Q3 is generator of harmonic current, which is released by supplying its base with local oscillator voltage through resistor R1 (R1 is with higher resistivity than the input voltage of Q3).

The load is plugged in symmetrical to the both collectors of Q1 and Q2, because it have to be summed the collector currents with the medium frequency current of the differential pair transistors, which are out of phase. In this way the currents from the local oscillator are compensating with each other, because they are in-phase and in perfectly balanced mixer, their amplitudes are equal. Thus, in the perfect case voltage at the output of the mixer, do not have the same frequency as the local oscillator, therefore the input of the local oscillator and middle frequency output of the mixer are independent. For the real balanced mixer that independency is given by final quantity — the noise is about 20dB. Similarly, the noises at the output of the local oscillator are suppressed (more than 20dB). Typically, balanced mixers compensate the distortions from harmonic and combination signals of local oscillator voltage.

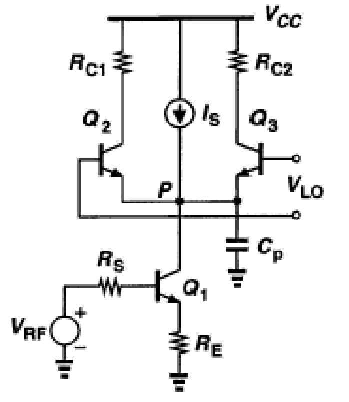

Figure 1. Single balanced mixer, released with differential amplifier

If Q2 and Q3 are truly ideal and if the input and output transistors are truly balanced, than no oscillator voltage will appear across either the input or the output transistor. Removal of the oscillator voltage from the inputs removes the radiation problem: in addition, removing the large oscillator component from the output reduces the strain.

In addition, because of the symmetrical characteristics of the differential pair, this circuit should not generate harmonic cross products of second order. To completely avoid even harmonic terms, the oscillator voltage must be true-sinusoidal wave and the variations in the collector current of Q1 must be kept small enough that no oscillator harmonics are generated. There are only tree interference signals of the desired signal and they are shown in Figure 2.The first of this interference terms corresponds to 2fy-fo=fif), the second two to f_x and its twin 2fo-fx=fif, fx'-2fo=fif. For Iko=2,5mA all those tree terms were reduced by a factor of 1/∑50 or more below of the level of the desired output term. The removal of the f_y interference term requires exact symmetry in the differential pair characteristic, whereas the removal of the fx terms requires an absolutely pure oscillator voltage. Neither of these ideas will ever be achieved in practice. The f_y term is the most troublesome, since it is closest to the desired signal and hence, it is most difficult to initially filter out. The 60/1 reductions in the f_y term that is obtained by using a practical differential pair rather than the ideal single balanced bipolar stage is impressive.

3. MIXER PROBLEMS

1. Output signals at the IF (intermediate frequency) frequency arising from other desired input signal;
2. Distortion of modulation of the desired input signal;

3. Transmission of the local oscillator frequency to the input circuit (if the local oscillator signal reaches the antenna, it may be radial and serve as an interfering signal to other receivers);

4. Noise generated in the mixer stage;

Figure 2 illustrates a frequency spectrum showing a number of possible signals that may cause a unwanted components at the mixer output's IF frequency

4.1. If a signal at $f_{image}=f_o + f_{if}$, reaches the mixer the mixer, the difference frequency will be f_{if}.. The only remedy is adequate filtering in front of the mixer. In a new system the choice of higher possible IF frequency will ease the image rejection problem.

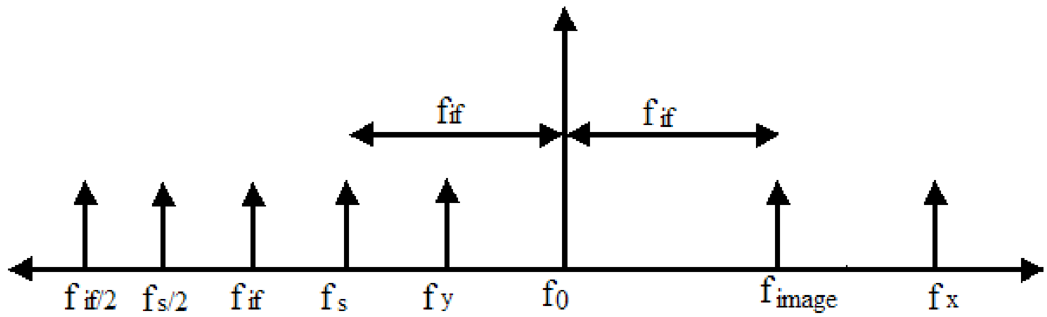

Figure 2. Input and output signals in frequency division

4.2. A signal at $f_s/2$ will cause trouble if the RF stage has enough distortion to produce a second harmonic term from the signal or if the mixer provides beat frequency between the f_o term and the second harmonic of the incoming signal:

$$I_{fo-fs/n}=2.\left[\frac{I_1(x)I_n(z)}{I_0(x)I_0(z)}\right]$$

Where z is normalized envelope of the f_s/n term, when z is small, $I_n(z)/ I_o(z)$ may be approximated as $z^n/2^n.n!$, so that:

$$\frac{G_c(w_s)}{G_c(\frac{w_s}{n})}=\frac{2^{n-1}.n!}{z^{n-1}}$$

Adequate filtering to remove the half frequency term must be provided in front of FET or square-low RF amplifiers; otherwise, those devices will double the input frequency and no subsequent stage could remove it. With linear RF amplifiers all premixer filtering is effective in reducing subharmonic terms.

4.3. If signal f_x is at f_o+f_s, it will cause troubles in any system where a beat frequency with $2f_o$ is possible. Hence it will cause trouble in transistor mixers but not in true square-low FET circuit or in differential- pair circuits, provided that the oscillator driving voltage is free of second harmonics.

4.4. The signal f_y falls at $f_{image}/2$, hence an FET RF amplifier will shift it to f_{image} and, unless the filtering between this RF amplifier and the mixer removes this distortion term, there will be unwanted output term. A single balanced bipolar transistor mixer will produce an output similar to the $f_x/2$ case.

Obviously there are many other potential sources of interference; however the above terms suffice to illustrate the problem.

At least two stages of filtering are desirable in front of the mixer to be realized the requirements for the output of the mixer.

4. DOUBLE BALANCED MIXER

The single balanced mixer released with differential amplifier gives the opportunity to make the output signal independent of the local oscillator input. Double balanced mixer is released with analog multiplier. It is better because both the inputs and the output are made independent.

This mixer as the single balanced mixer compensates in its output, the local oscillator frequency and local oscillator harmonics and voltages caused from the noises from the local oscillator. It also gives independent signal input and medium frequency output and it filters out the unwanted terms of the signal frequency and its harmonics. By using double balanced mixer released with analog multiplier the local oscillator input and the signal input are made independent and it is impossible for a unwanted signal to be transmitted to the antenna. In comparison to the single balanced mixer, the double balanced mixer eliminates the distortions, made by the mixing of harmonics of the local oscillator with even harmonics of distortion signals and eliminates the distortions from the mixing of even local oscillator harmonics with odd distortion harmonics.

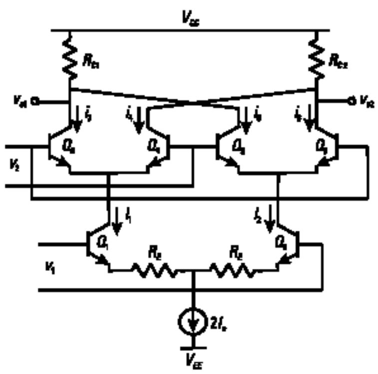

Figure 3 Double balanced mixer released with analog multiplier

Figure 3 shows double balanced mixer released with analog multiplier, where V1 is the local oscillator input (the local oscillator block should be connected to this input), and V2 is the signal frequency input (the signal generator block is connected to V2). Middle frequency output is obtained between V_{01} and V_{02}.

5. DESIGN IN CADENCE AND EXPERIMENTAL RESULTS

In the custom computer-aided-design suite CADENCE Design Framework a double-balanced mixers with analog multiplier is implemented. This schematic is chosen because of its greater quality. This schematic gives independent inputs and makes independent the inputs and the output as well.

Figure 4 shows the schematic of the double balanced mixer.

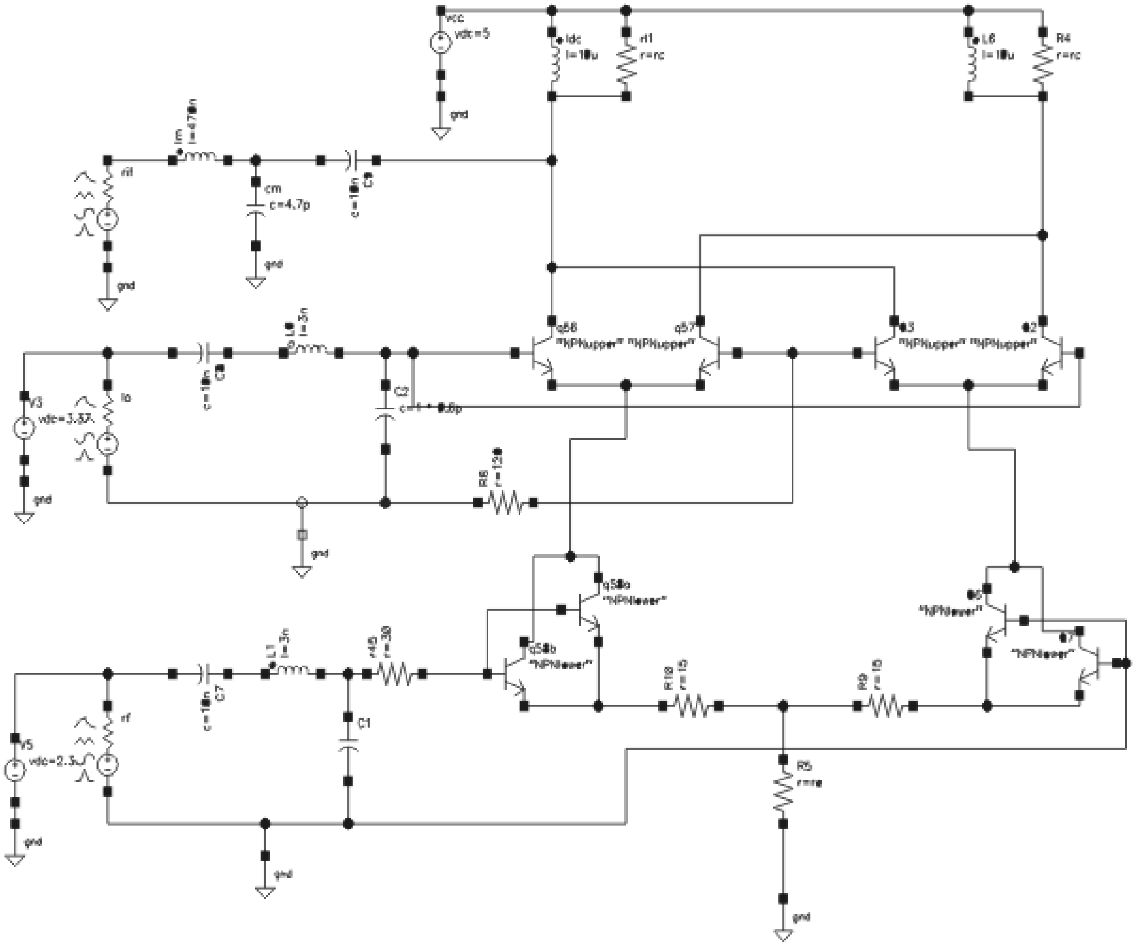

Figure 4. Double balanced mixer schematic

The RF signal is chosen with a 900 kHz frequency (from the local oscillator), and the signal generator frequency is chosen to be 560 kHz. The frequency bandwidth should be the following (see Figure 5):

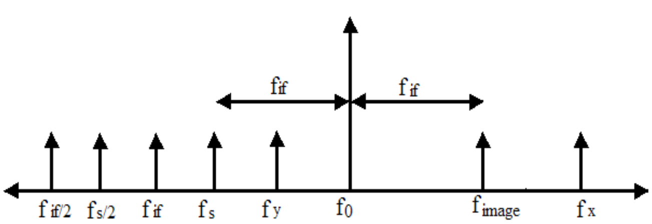

Figure 5. Input and output signals in frequency division

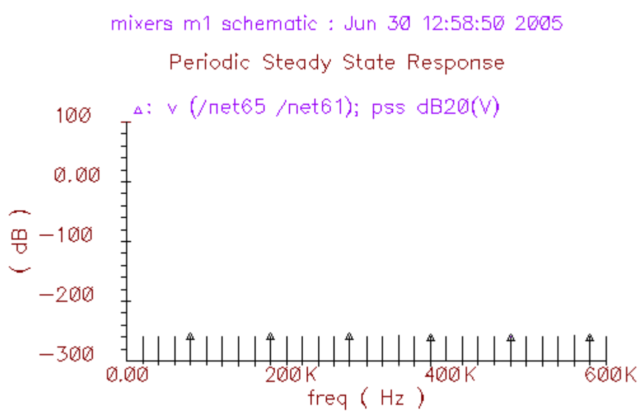

Figure 6. Results from pss analysis

Where,

— Local oscillator frequency f_0:

$f_0 = 900\text{kHz}$

— Signal generator frequency fs:

fs = 560kHz

— Middle frequency in the output of the mixer f_{if}

$f_{if} = f_0 – fs = 900k – 560k = 340kHz$

— Combination frequency f_x:

$f_x = f_0 + fs = 900k +560k = 1460kHz$

— Image frequency f_{image}

$f_{image}= f_0 +fif = 900k+ 340k = 1240kHz$

— Combination frequency f_y:

$$f_y = \frac{f_{image}}{2} = 620kHz$$

In CADENCE Design Framework a pss analysis is made to check the efficiency of the mixer from Figure 6.

Following, are the parameters that have to be set for the purpose of the analysis:

— local oscillator frequency – f_0 = 900kHz;

— RF signal frequency – fs = 560kHz;

— number of harmonics in the output of the mixer – 30

— it is set an automatically calculation of middle frequency in the output of the mixer – f_{if} = 340kHz

Results from the analysis are shown in Figure 6

6. DISCUSSION OF RESULTS

A FET or differential pair mixer should be superior to a bipolar mixer from the view point of unwanted signals. At least two stages of filtering are desirable in front of the mixer. A linear automatic gain-controlled RF amplifier is desirable in front of the mixer. The gain reduces of the mixer noise, while the gain control allows the circuit to keep excessive signals from reaching the mixer. Excessive signals inevitably lead to increased distortion.

7. CONCLUSION

We have designed a balanced mixer that met the requirements within acceptable accuracy. This is quite acceptable in the context of the technology used — 0,35 μm SiGe BiCMOS. We believe the presented work will be useful for the design and educational processes in ECAD laboratory.

7. REFFERNCES

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