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Design of Combined Mixer IF Filter for Low Voltage and Low Power Automotive Radar Application

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Abstract

A low voltage, low power combined mixer-filter receiver components for automotive application is presented in this paper. Due to limited battery lifetime, the demand of compactness in devices keeps pushing the CMOS integrated circuits to support various applications. The proposed circuit includes an optimized combination of CMOS double balanced mixer and Intermediate Frequency (IF) filter operating at 76-79 GHz frequency range and designed in 45 nm CMOS technology. The proposed circuits are designed for 1V power supply and dissipated 4.9mW power. The optimized RC-extracted layout size of the mixer and IF filter circuits are 218x240μm^2, 240x265μm^2 respectively.

Keywords: Mixer, Radar, IF Filter, CMOS.

1. Introduction

Today, Automotive Radar sensors are widely used in many transportation applications to assists drivers for collision avoidance and provide comfortable environments. The transceiver used for such long range automotive Radar applications operates in 76-77 GHz frequency band[1][2]. Due to limited battery lifetime, the demand of compactness in devices keeps pushing the CMOS integrated circuits to support various applications. For better frequency translation, 45nm CMOS Technology attracted extensive research interests as it provides excellent switching performance, less power consumption and higher density in comparison to other CMOS technologies.

A mixer is a three-port electronic device from which two ports are used as an “input port” and the third one port is work as “output port”. The mixer “mixes” that two input signals in such a way that output port generate a signal whose frequency is equal to either difference or sum of two input port signals.

$$Fout = |Fin1 \pm Fin2 | \qquad (1)$$

These three ports are:

1. Local Oscillator Port (LO)
2. Radio Frequency Port (RF)
3. Intermediate frequency Port (IF)

The LO port is generally driven by a continuous and square wave input signal. In general, LO is used as an input port which takes signal from internal oscillator. The remaining two port of frequency mixer can be used as either output port or an input port which depended upon the particular application[3][4]. When the output signal frequency is less than second input signal frequency, then it is known as down-conversion. On the other side, if the output signal frequency is higher than the second input signal frequency then it is known as up-conversion as shown in Fig 1.

Mixers are mainly used to perform frequency conversion. The RF signal is translated to IF signal by multiplying it by LO frequency signal. The IF signal is the difference or sum of the these two signal. From these two output signal, one signal is required, and other is unwanted/useless signal according to the application. This unwanted signal can be easily filtered through IF filter.

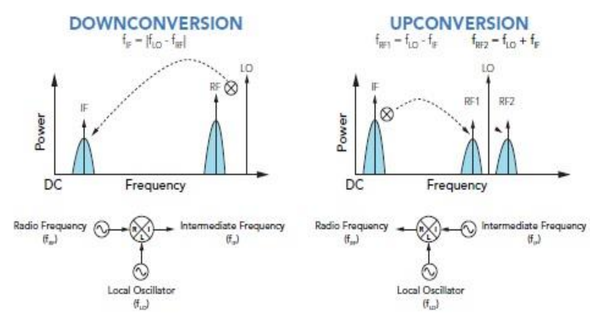

Fig. 1: Definitions of down conversion & up conversion.

$$RF = A\cos(RF.t) \qquad (2)$$

$$LO = B\cos(LO.t) \qquad (3)$$

$$IF = \frac{1}{2}[A\cos(RF.t) + B\cos(LO.t)] \qquad (4)$$

Mixers can also divided into two class: single and double balanced mixers. In comparison to double balanced mixer devices, single balanced mixer circuits are simplest but its performance is worse regarding LO to IF and RF to IF rejection. In this paper, low power, low-voltage CMOS doubled balance down-conversion along with IF filter for long range automotive Radar application. The basic architecture of combined mixer-filter in the receiver of Radar is as shown in Fig.2.

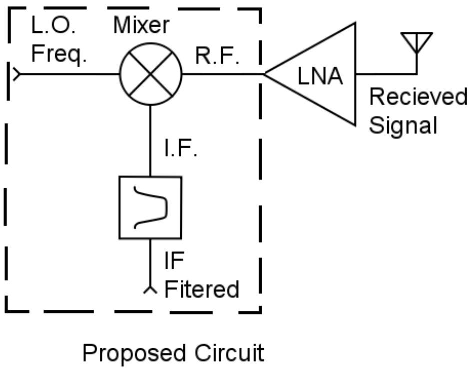

Fig. 2: Proposed combined circuit in the receiver.

The organization of this article is as follows: performance matrix of a low-power, low-voltage double balanced CMOS mixer and IF filter are discussed in section II. Power optimizing technique is applied on mixer & IF filter and presents the architecture of low power low voltage combined double balanced mixer and filter in section III. Section IV provides RC-extracted simulation results. Section V gives concluding remarks.

2. Performance Metrics Of Mixer

Selection of mixer is depend on some criteria and these criteria are known as performance metrics or we can say that what makes a mixer "Good" is performance metric.

2.1 Conversion Loss

One of the most key performance metrics of mixer circuit is Conversion Loss (CL). It is a measure the efficiency of mixer. It is known as the difference of the input RF and output IF power signal level.

$$CL = P_{RF} - P_{IF} \quad (5)$$

Where P_{IF} and P_{RF} are measure in dBm and CL is represent in dB.

CL can be improved a bit by providing less impedance at the output port for the unwanted sidebands. It is the standard mixer performance metric because it linked closely with other important mixer metrics like port isolation and 1-dB compression point.

2.2 Isolation

Second most important metric of mixer is its port-to- port isolation. Mixer port isolation is defined as the ratio of power signal available at one port to the power signal available at its other port.

2.3 Noise Figure

Noise Figure(NF) of the mixer depends on conversion loss. NF will bound the smallest detectable signal at its receiver end. Conversion losses should be as minimum as possible when choosing for low power applications[5].

$$Noise\ Figure = 10\log\left(\frac{SNR_{in}}{SNR_{out}}\right) \quad (6)$$

2.4 Intermediation Distortion

When two or more simultaneous frequency components are present in the input signal, a whole new family of spurious product results comes into account. These spurious results are known as Intermediation Distortion. It is harmonically related with the combination of signal frequencies at the input ports.

2.5 Dynamic Range

The power range over which mixer performs the useful operation is known as its dynamic range. The lower limit of the mixer is limited by noise figure of the mixer.

2.6 1 dB Compression Point

In a real circuit, the input power and output power is linearly changed up to a certain limit or point. The 1dB Compression Point for output signal calculate that point at which the output power signal level is 1dB smaller than signal of an ideally linear device .

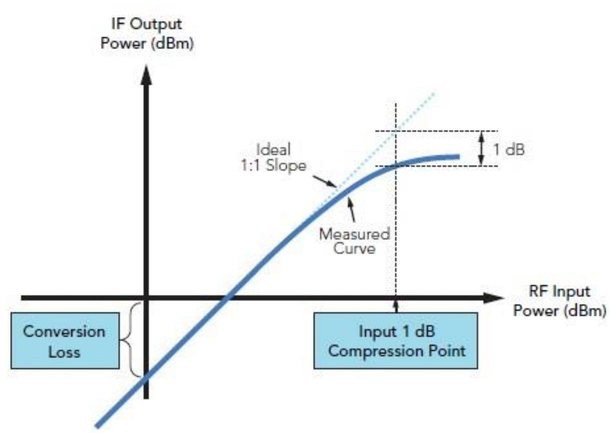

Fig. 3: Graphical representation of 1 dB compression point.

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3. CMOS Mixer Design Topologies

A CMOS Mixer design required some compromising figures of merits such as LO power, conversion Gain, noise figure, linearity, power dissipation, IF frequency and port-to-port isolation. There are two main techniques used for the mixer for performing the operation of multiplication between input signal & reference input signal and it explore the mixer non-linearity's[6][7].

3.1 Single-Balanced Mixers

A single-balanced mixer is a single-ended RF & IF signal for mixing signal as shown in fig. 4. These single-balanced configurations are hardly used because these are more susceptible to noise in the input LO signal. There are main drawback in this configuration is its IF-LO Feed through. It means that, the LO signal can leak into the IF signal if the IF signal frequency is not much lower than the LO signal frequency[8].

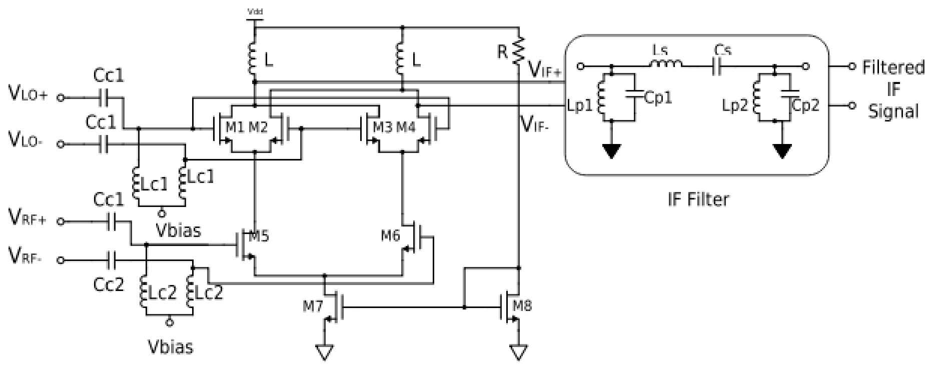

Fig. 5: Proposed combined Mixer+IF filter schematic for automotive Radar application.

3.2 Doubled-Balanced Mixers

Double Balanced Mixers are mainly used to avoid the LO products terms from the output signal. This configuration have required two single-balanced mixer circuits with two differential RF transistors which are connected in parallel and provides an anti-parallel switching pair. So, the LO product terms are cancel out and RF signal are doubled at the output signal. This configuration produces a high degree of isolation between LO and IF isolation. So, it eases the filtering requirements used after mixing the signal. For noise, these mixers are less susceptible than the single-balanced mixers because of its differential RF signal. This mixer is also known as the Gilbert Cell Mixer[9].

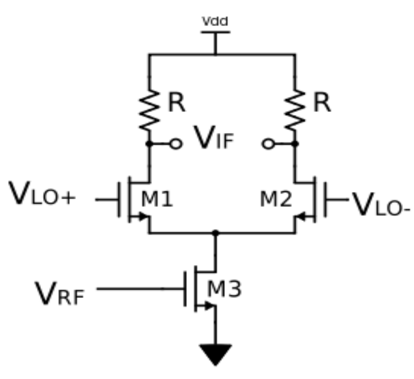

Fig. 4: Schematic of single-balanced mixer

3.3 Source Degeneration Doubled-Balanced Mixers

An important mixer performance metrics is the linearity of mixer. There are different ways to increase linearity of the mixer such as: enhanced the voltage supply or rising the current. But, the most important and effective method to enhance the linearity is by using the source degeneration configurations. Fig.5 shows the CMOS doubled-balanced mixer with inductor as a source degeneration and IF filter combined circuit. Inductor based source degeneration is mainly preferred because it has negligible thermal noise which degrade the NF. This proposed circuit also, saves headroom due to no voltage drop across it.

4. Simulation Results

The proposed CMOS Mixer+ IF filter is designed and post layout simulation analysis is carried out in a standard 45nm CMOS technology. In this proposed circuit, capacitors are realized by MOS capacitor and mixer are implemented using double balanced source degeneration technique. Table 1 gives the details of combined circuit specification parameter such as supply voltage, Inductor, MOS capacitor size, MOS parameters and output impedance used in this simulation.

Table 1: Input Parameter Specification for Combined Circuit

Device	Device Parameters Name	Parameters value
nMOS size	M1-M4	6.6µmx45nmx1
	M5-M8	13.2µmx45nmx1
MOS Capacitor	Aspect Ratio of Cp1, Cp2	70µm/7.6µm
	Cs	70µm/9.7µm
Resistor	R	5Ω
	Output Load	50Ω
Inductor	L,Lc1,Lc2	100pH
	Ls	9.8nH
	Lp1, Lp2	12.5nH
Capacitor	Cc1, Cc2	1pF
Supply Voltage	Vdd	1V

Proposed Design is simulated at operating frequency range 76-77 GHz, demonstrating a 1GHz bandwidth. A transient analysis is carried out to confirm the functionality of the circuit as shown in Fig. 6(a,b). It show that RF &

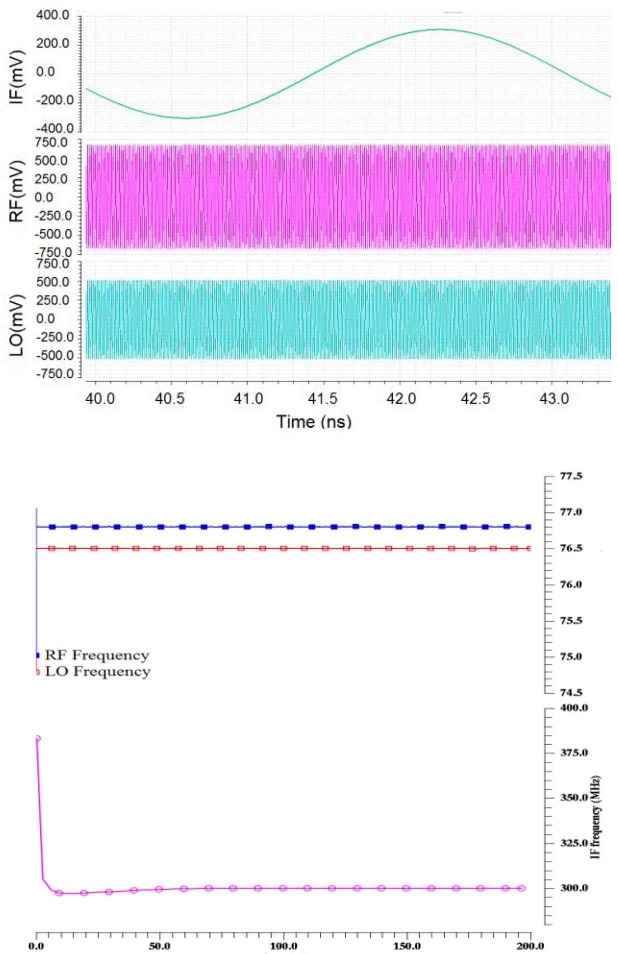

Fig. 6 Simulation analysis of Proposed circuit, (a) Voltage signal of RF, LO, and IF signal, (b) Frequency response of these three signal.

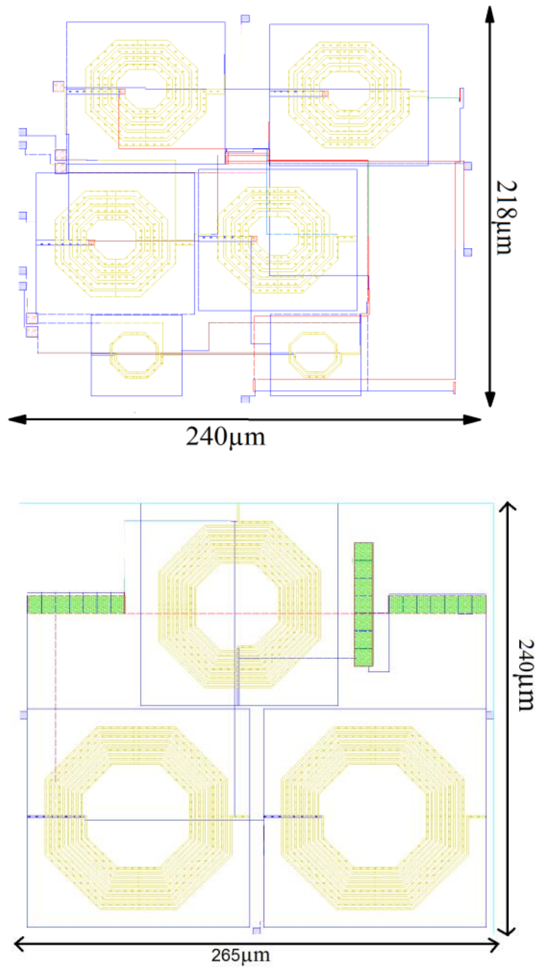

Fig. 7 RC-extracted Layout (a) CMOS Doubled balanced mixer, (b) IF filter.

LO signal for automotive Radar application is varying in range from 76-77GHz frequency range and generate IF signal(RF signal ± LO signal). IF filter are used to filtered approximately 100-500 MHz frequency i.e. the subtract of these two signal. Fig. 7(a) shows the layout of RF CMOS mixer which havinf size 240x218µm^2.

Table 2 Summary of proposed circuit performance.

Performance Parameters Name	Parameters value
Supply Voltage	1V
LO Frequency	76.5GHz
LO Amplitude	0.5V
RF Frequency	76.8GHz
IF frequency	300MHz
Technology	45nm CMOS Technology
Power dissipation	4.9 mW
Mixer size	218x240µm^2
IF filter size	240x265µm^2

RC-extracted layout of IF filter are shown in fig. 7(b). It occupies 265x240 μm^2 layout area. Proposed combined mixer+IF filter dissipates very low power 4.9mW as per today requirements. Table 2 represents the designed circuit performance.

5. Conclusion

In this paper, an overview of the various CMOS mixer parameters and topologies has been presented. It is observed that double balanced source degeneration mixer provides excellent performance and presents a 45nm CMOS Mixer+IF filter Circuit Using Cadence Virtuoso Simulation. The designed circuits are used low 1V power supply and low power dissipated 4.9mW. The optimized RC-extracted layout size of the mixer and IF filter circuits are 218x240μm^2, 240x265μm^2 respectively.

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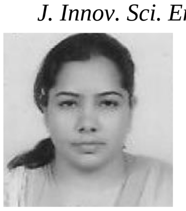

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