A 3.1-5 GHz CMOS ACTIVE MIXER FOR UWB IEEE 802.15.3a STANDARD RECEIVERS

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Abstract: A design of active mixer suitable for the lower UWB band (3.1-5 GHz) is presented. The mixer topology is based on a doubly-balanced Gilbert cell type. Using L-input matching and small device sizes, it was possible to obtain a good operation of the proposed mixer all over this band. The simulated performances are: a conversion gain varying from 8 to 10dBm, a noise figure less than 8.9 dB, an input *IIP3* varying from -6.5 to -3dBm and a higher than -4 dB of input return loss, when the power consumption is 18 mW under 3V.

Keywords: Active mixer, ultra-wideband, Gilbert cell

I. INTRODUCTION

With the growing demand of a robust data communications, Ultra Wideband (UWB) standard has emerged as an attractive future technology for wireless communications and local area networks. UWB was adopted by the Federal communications Commission (FCC) in 2002 to be used for data communications as well as for radar and safety applications. This is a short range, low power, high data rate and wide band wireless system, having to meet the stringent requirements of 802.15.3a standard [1], [2]. The band allocated to communications is a staggering 7.5 GHz, by far the largest allocation of bandwidth to any commercial terrestrial system. There has been an increasing interest in the low-frequency band (3.1-5 GHz) of the UWB allocated frequency range (3.1-10.6 GHz). A major proposal proposes that data rates of up to 400-480 Mb/s can be obtained using the low-frequency band alone. This band has been allocated for the development of the first-generation UWB systems (>100 Mb/s) targeting low-power wireless multimedia applications and high-performance PC peripherals over a short distance up to 10 m. The UWB transmitted power spectrum mask specified by the FCC is shown in figure 1. The maximum power allowed is around -41.3 dBm/MHz, which is quite low.

The IEEE 802.15.3a committee assigned for standardizing UWB communications has selected two proposals: the impulse-radio (IR) and the multi-band OFDM (MB-OFDM) standards. The low noise amplifier (LNA) and mixer are the key building RF blocks of both the IR and MB-OFDM receivers. This is because these have to have wideband characteristics. Furthermore, they dominate the system linearity, noise figure, and determine the performance requirements of their adjacent blocks.

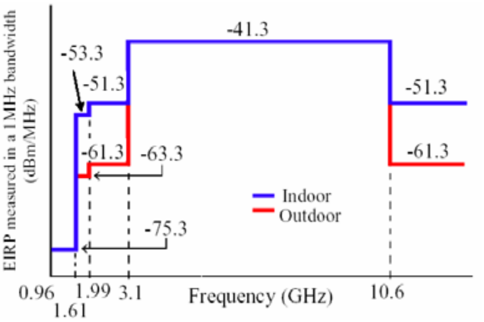


Fig.1. UWB spectral mask as set the US FCC.

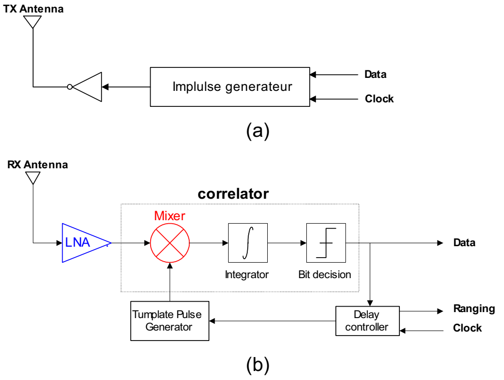
This paper presents a design of a mixer suitable for 3.1-5 GHz UWB receiver and using AMS 0.35 μm process. When very low power signals are received, an active type mixer is chosen to lighten the stringent requirement of the LNA on gain and noise.

II. UWB LINK ARCHITECTURES

There are several architectures that satisfy UWB definitions, and two standards have been discussed in IEEE 802.15 Task Group 3a and Task Group 4a as discussed previously. Task Group 3a has discussed the use of MB-OFDM and Direct- Sequence Spread-Spectrum (DS-SS) for the high-data-rate PHY. Task Group 4a has chosen UWB IR as a good candidate for low-power radio in applications like sensor networks [3].

1. UWB-Impulse Radio transceiver

Figure 2 shows a simplified UWB-IR transceiver. The emitter (figure.2-a) is aimed for higher data rates and lower emitted radio frequency power.



(a)

(b)

Fig.2. IR-UWB transceiver architecture for (a) the transmitter and (b) the receiver.

An important attribute of the impulse-radio transmitter is that the power amplifier may not be required in this case because the pulse generator needs only produce a voltage swing on the order of 100mV. Therefore, it can be designed using an all digital circuits. Only a bandpass filter (BPF) with a 7.5GHz bandwidth is used before the antenna to constrain the emissions within the desired frequency band [4].

The UWB-IR receiver is based on the impulse detection techniques. The most used technique in typical UWB receivers is founded on correlation as shown in figure.2-b. In this scheme, the incoming signal is multiplied with a template using a mixer, integrated and quantized. This technique is more detailed in [5].

The receiver architecture is very depending on the used modulation scheme. The information is modulated using several different techniques. The most known are: the pulse amplitude modulation (PAM), on/off keying (OOK), pulse position modulation (PPM), and recently transmitted reference modulation (TR). The underlying problem of impulse radio lies in the difficulty of synchronization between the received pulse and the template pulse. This problem does not exist for the TR case.

The UWB-IR transceiver can be designed at a low cost and with low power consumption. It will be low in complexity and can be implemented using CMOS technology with a few or no off-chip passive components. Also, UWB-IR can provide high accuracy in ranging due to the narrow pulse-width of a few nanoseconds. These features make UWB-IR a good solution for RF-IDs and sensor networks.

2. UWB-Multiband OFDM transceiver

In a UWB-multiband standard, the band spectrum from 3.168 to 10.560 GHz is partitioned to 14 sub-bands of 528 MHz band-width as illustrated in figure 3. Each band consists of 128 sub-channels of 4.125 MHz. The OFDM technique is employed in each band to transmit data rates as high as 480 Mb/s.

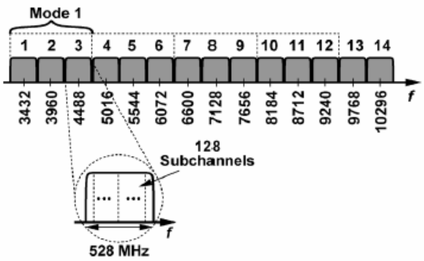


Fig.3. The band plan for the UWB multiband OFDM

In contrast to IEEE 802.11a/g, UWB-multiband OFDM employs only QPSK modulation in each sub-channel to allow low resolution in the baseband analog-to-digital (A/D) and digital-to-analog (D/A) converters (4–5 bits) [6].

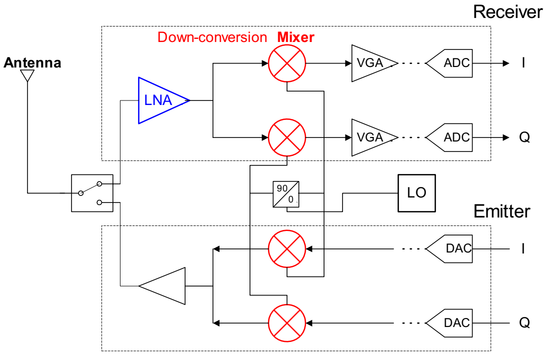


Fig.4. Conventional direct conversion transceiver used for UWB-OFDM

With a 528-MHz channel bandwidth, the RX and TX paths of UWB systems may naturally employ conventional direct conversion architecture to eliminate the need of bulky image rejection filter and increase the integration capability, most important of all, to fit for wideband. Figure 4 shows the main blocks of a conventional direct conversion transceiver. The local oscillator (LO) is centered in the desired bands. The quadrature down-conversion mixer follows the LNA. The VGA is connected to the mixer to adjust the signal magnitude [7].

As it can be seen, LNA and mixer have an important role in UWB receivers for both Impulse Radio and multiband OFDM standards. A design of 3.1-5 GHz mixer will be presented in the following section.

III. MIXER DESIGN

The design of UWB receivers faces the need for broadband circuits and matching especially for LNA and mixer. Many techniques to make wideband circuits were proposed in the literature, such as distributed circuits and recently the LC-ladder filter matching [9], [10].

Because of the low power of received signal, those blocks must produce a lot of gain. For this reason an active mixer is adopted in this application. Doubly-balanced mixer based on the Gilbert cell is one of the most used active mixers in bipolar, SiGe and CMOS process. It produces high gain with low noise figure [8].

The key to use such a kind of mixers in UWB applications is to have a good input impedance matching for the whole band of interest. Figure 5 shows a proposed Gilbert cell type doubly-balanced mixer.

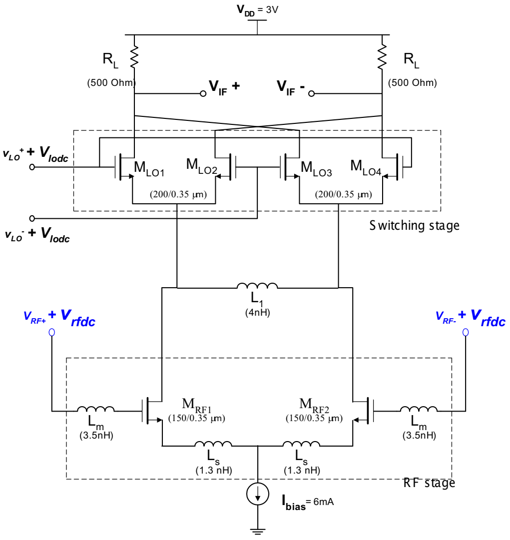


Fig.5. The proposed doubly-balanced mixer

An L-matching type is used at the input of the RF stage and insured by L_m, L_s and the gate-source capacitance C_{gs} of the RF devices M_{RF1} and M_{RF2}.

Theatrically L_m and C_{gs} have the following expressions:

$$L_m \approx \frac{Q.R_S}{w_0} \qquad (1)$$

$$C_{gs} \approx \frac{Q}{R_s.w_0} \qquad (2)$$

where Rs (=50Ω) is the source resistance, $w_0 = 2\pi.f_c$ and $Q = \frac{fc}{BW}$ is the quality factor with BW the band-width (5-3.1=1.9 GHz) and f_c (=4Ghz) is the central frequency of the band of interest. This leads to $L_m \approx 3.7$nH and $C_{gs} \approx 1.5$pf

The value of C_{gs} is essentially depending on the aspect ratio of the RF stage devices. Small sizes must be chosen for M_{RF1} and M_{RF2} to allow a high central frequency.

Inductance L_1 is used to increase linearity and decrease the 1/f noise [11].

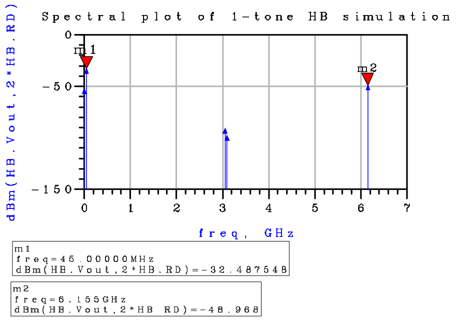


Fig.6. Simulated mixer output spectrum

Simulation results are obtained sing ADS software. Figure 6 shows the output signal spectral simulation, where f_{RF}=3.100GHz, f_{LO}=3.055GHz. This should result in an IF signal at 45 MHz. This step is aimed to verify the good operation of the circuit.

Two frequencies are obtained:

- Up-conversion 'm2' *(undesired signal)* :
  $f_{UP} = f_{RF} + f_{LO} = 6.155$ GHz
- Down-conversion 'm1' *(desired signal)* :
  $F_{IF} = f_{RF} - f_{LO} = 45$MHz

This result is in line with the theory.

Figure 7 shows the simulation results of the conversion gain and the IIP3.

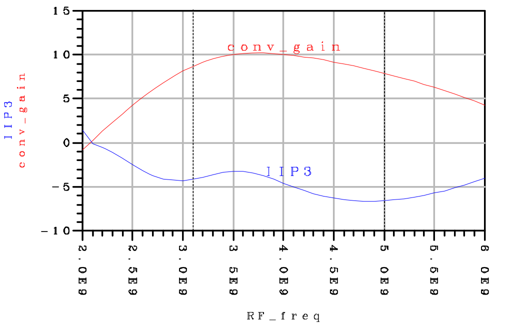
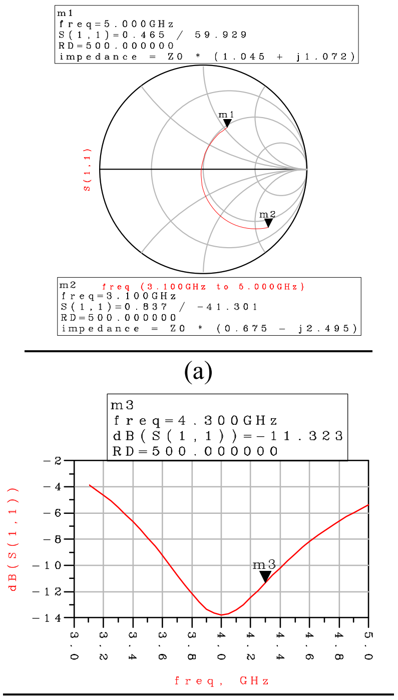


Fig.7. simulated conversion gain and *IIP3*

Figure 8 shows the S-parameters results; (a) the smith chart of S11 and (b) the S11 (dB).



(a)

(b)

Fig. 8. Simulated S11 traces, (a) the smith chart and (b) the S11 (dB).

The mixer simulated performances are summarized in Table 1. These results are acceptable for UWB applications. The proposed design tried to optimize the overall performance within the 0.35 µm technology limits. Lower features technologies (e.g. 0.18 or 0.09 µm) would lead to better performance over the whole UWB band from 3.1 to 10.6 GHz. Nevertheless, these technologies are costly.

Table.1. Simulation results of the proposed mixer

Band Widh	3.1-5 GHz
CG (dBm)	8< CG <10
IIP3 (dBm)	-6.5 <IIP3 <-3
NF (dB)	< 8.9
S11(dB)	<- 4
Power consumption	18 mW (3V, 6mA)
Process	AMS 0.35 µm CMOS

IV. CONCLUSION

Wideband mixer aimed for the lower-frequency band (3.1-5 GHz) of UWB systems is presented. Because of the low power received signal, imposed by the FFC, an active doubly-balanced mixer topology based on the Gilbert cell is chosen to lighten the stringent requirement of the LNA on gain and noise. Using a 0.35µm CMOS process, it was possible to achieve a good operation for the required band. To cover the whole band of interest, an L-input matching and small device sizes are implemented. The simulation results show a conversion gain varying from 8 to 10dBm, a noise figure less than 8.9 dB, an input *IIP3* varying from -6.5 to -3dBm and a higher than -4 dB of input return loss. The circuit consumes 18 mW under 3V.

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