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DESIGN OF LNA AND MIXER FOR 2.4 GHZ FRONT END RECEIVER ON CADENCE

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ABSTRACT: **The demand of low-cost, low-power high speed and high volume wireless products for High Frequency Transceivers has been explosive and unanticipated. With the improvement of integrated circuit (IC) technology, the size of electronic components like transistors has consistently shrunk. Following the scale down in channel length, there has been an improvement in unity gain cut off frequency (f_T) and maximum operating frequency (f_{max}) which shows the potential of CMOS at the front end of a RF system. LNA and Mixer for 2.4 Ghz Front End Receiver were designed in 180 nm CMOS technology and operated at supply voltage of 1.8 V using Virtuoso Schematic Editor of Cadence and spectre-RF simulator tool.**

Keywords: **LNA, Mixer, RF Front End Receiver, Cadence**

I. INTRODUCTION

Wireless Communication Systems market has seen resurgence especially in the last decade. The decreasing supply voltages are making the design of Analog and RF circuits more challenging. The RF circuits are usually dominated by passive components (like resistors, capacitors and inductors), the size of which does not scale proportionately. As a result, the chip area does not shrink to the same extent. Hence there is a need to build a complete transceiver on a single CMOS chip to minimize the silicon area as well as the cost [1], [5]. Efforts are being made to bring the digital processing functions as close to the front end as possible but still most of the RF Front-end components like the Low Noise Amplifier and the Mixer are still designed in the Analog Domain. The first component of a wireless receiver front-end is a low noise amplifier (LNA). Its main function is to amplify the signal while adding as little noise as possible [3]. There are two types of LNA.

- Single ended LNA
- Differential LNA

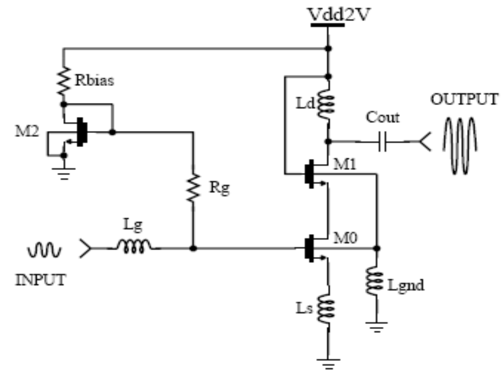

Fig 1.1: Schematic of single ended LNA [13]

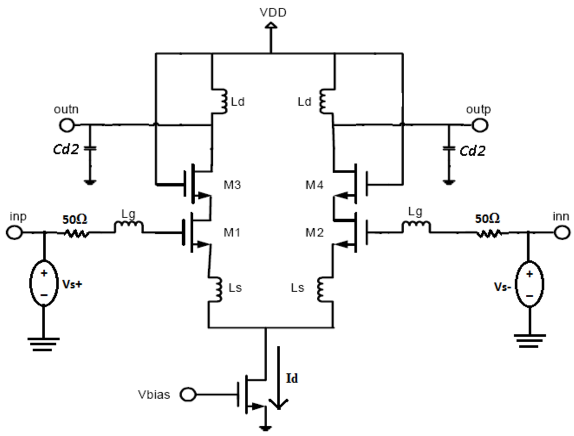

Fig 1.2: Differential LNA Topology [3]

The most important advantage of differential LNA over Single ended is much higher immunity to environmental noise. The paper presents an inductive source degenerated fully differential Low Noise Amplifier (LNA).

The second component of the receiver front-end is a Mixer. The mixer translates an incoming RF signal to a lower frequency, called the intermediate frequency (IF). The output consists of multiple images of the input signal where each image is shifted up or down by multiples of the LO frequency.

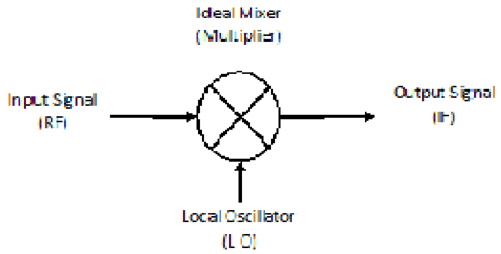

Fig 1.3: Block diagram of a mixer [13]

Mixers are, generally, classified as active and passive mixers. The major difference is the amount of conversion gain, they provide. Active mixers can achieve conversion gain and may require lower Local Oscillator (LO) power than their passive counterparts [11]. By virtue of their gain, active mixers reduce noise contributed by the subsequent stages of the receiver and are widely used in RF applications. Passive mixers, on the other hand, typically show conversion loss but exhibit excellent Inter modulation (IM) performance, high linearity and speed at the expense of high LO power requirements and find their applications in microwave and base station circuits [3].

In this paper the Resistive load Gilbert cell mixer topology has been adopted as they provided good linearity and high gain performance.

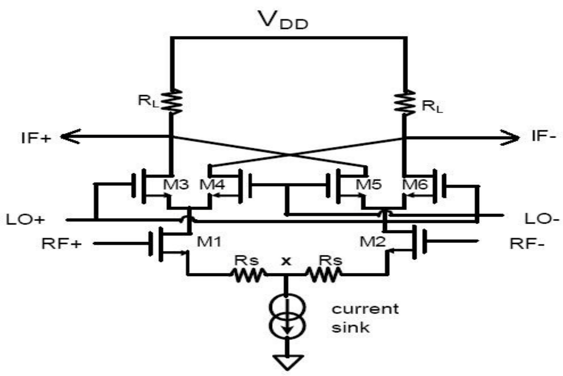

Fig 1.4: Schematic of Gilbert mixer [14]

II. PROPOSED DESIGN OF LNA & MIXER

The aim is to design a Low Noise Amplifier (LNA) and a Gilbert cell Mixer for 2.4GHz input operating frequency and 1.8V power supply RF receiver front-end. Design parameters include Noise Figure, Gain, power consumption, 1dB compression point, input referred third order intermodulation intercept point (IIP3) [7][8][9]. Each circuit is designed at transistor level and simulated on Spectre-RF Cadence simulation tool, schematic editor Virtuoso IC5141 of Cadence for design entry. The designs are implemented on Cadence UMC-18 technology with feature size of 180nm.

The components are listed below with design specification.

- Low Noise Amplifier (LNA)
    - Topology: Inductive Source Degenerated Differential LNA
    - Supply Voltage: 1.8 V
    - Operating Frequency: 2.4 GHz
    - Power Consumption: ≤ 100 mW
    - Gain: ≥ 10 dB
    - Noise Figure: ≤ 5 dB
    - Input Impedance Matching: 50 Ω
    - Output Impedance Matching: 50 Ω
    - IIP3: ≥ -12 dBm
- Mixer
    - Topology: Resistive Load Gilbert Cell Mixer
    - Supply Voltage: 1.8 V
    - Input RF Frequency: 2.4 GHz
    - Input LO Frequency: 2.25 GHz
    - Conversion Gain: ≥10 dB
    - Power Consumption: ≤100 mW
    - Noise Figure: ≤15 dB
    - IIP3: ≥-5 dBm

2.1 LNA DESIGN CONSIDERATION

LNA is the first stage of radio receiver whose main function is to amplify the signal while adding as little noise as possible. The noise figure of LNA is the main factor in overall noise figure of receiver and noise of subsequent stage is suppressed by the factor of gain of LNA.

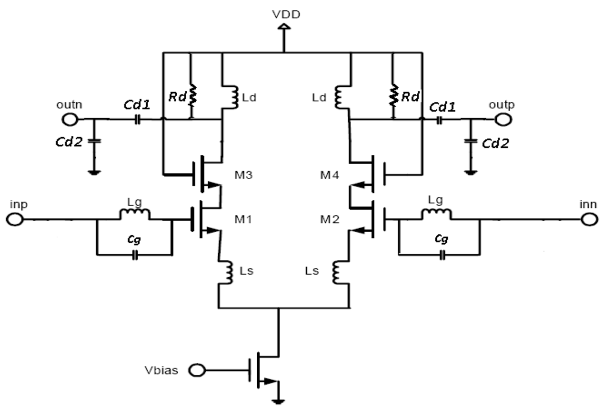

Fig 2.1: Inductive Source Degenerated Differential LNA

2.2 MIXER DESIGN CONSIDERATION

The double balanced mixer presented here is a Down conversion mixer, in which the Input RF signal is mixed with a fixed Local Oscillator (LO) frequency signal as a result an intermediate frequency (IF) signal will produce at the output. This IF signal has the value lower than the input RF signal. Therefore it named as down conversion mixer.

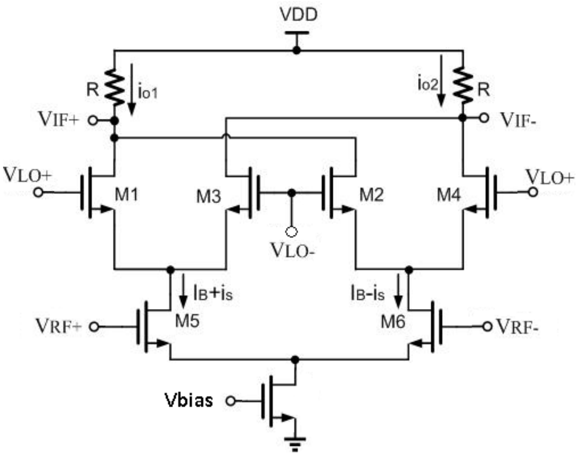

Fig 2.2: Resistive Load Gilbert Cell Mixer

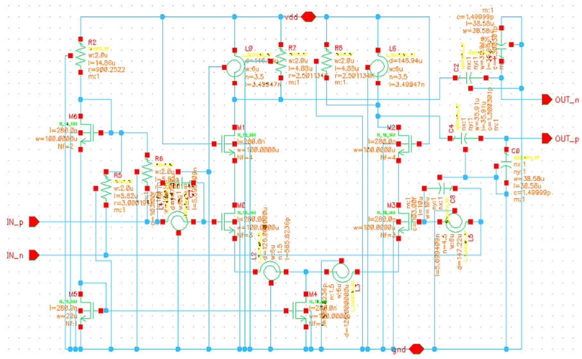

Fig 3.1: Schematic of Proposed LNA with Biasing Circuitry

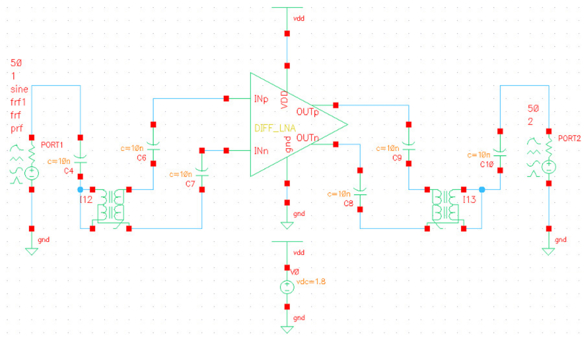

Fig 3.2: Test Bench for Proposed LNA

III. CIRCUIT DESIGN AND SIMULATION RESULTS

3.1 *LNA DESIGN*

The low noise amplifier is designed in UMC 180nm CMOS process in Cadence. A modified architecture of differential LNA has been implemented for 2.4GHz frequency as shown in figure. Following procedure has been adopted.

- Input matching has been achieved by matching real part i.e. Zin = $g_m L_s/C_{gs}$ to 50 Ω, with value of Ls chosen for maximum ω_T.
- The frequency of interested is achieved by tuning inductor and by placing a capacitor parallel to it for resonance.
- Transistor sizing has been done for minimum noise figure and acceptable gain. It has been considered to have a realizable on-chip inductance value for inductor Lg.

The component values used in this LNA schematic are listed in the following table.

Component	**Value**
$L_{M0....M4}$	0.28 µm
$W_{M0,M3}$	300 µm
$W_{M1,M2,M4}$	400 µm
L_g	585 pH
L_s	5.7 nH
L_d	3.5 nH
C_s	103 fF
C_{d1}	1 pF
C_{d2}	1.5 pF
R_s	2.5 KΩ

Table 3.1: Component values of the Differential LNA

3.1.1 SIMULATION RESULTS OF LNA

The LNA has been simulated in Cadence using Specter-RF simulator. S-parameter analysis has been used to measure gain, input-output matching, Noise figure, linearity given by 1-dB compression point and 3rd order input intercept point. Behaviors of S_{11}, S_{21}, S_{22} and NF at frequencies around 2.4GHz are shown in figures

- Measured voltage gain at typical S_{21} parameters is around 11.36 dB.
- The observed best S_{11} is around -9.75 dB and S_{22} is around -22 dB.
- The noise figure observed at 2.4 GHz is around 5 dB as expected.
- The 1dB compression point observed is -8.22dBm and The Input-referred IIP3 is found to -7.5 dBm.

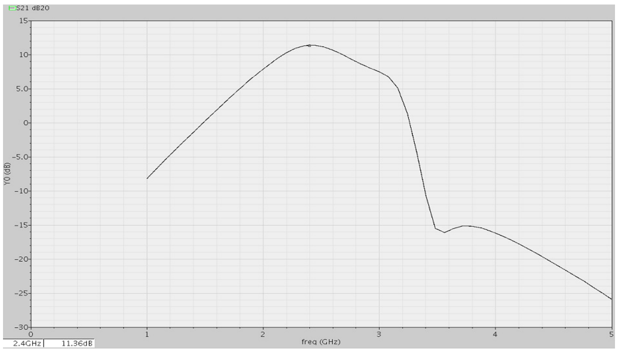

Fig 3.3: Gain (S_{21}-parameter) of LNA

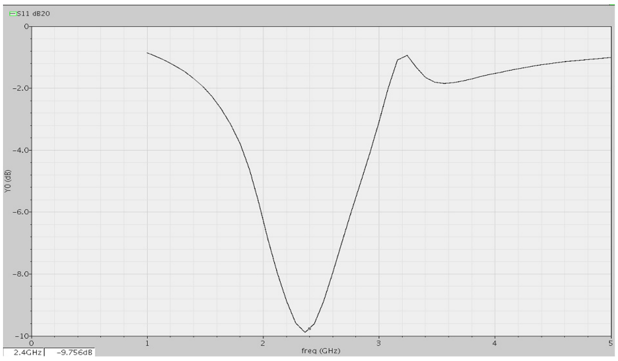

Fig 3.4: Input matching (S_{11}-parameter) of LNA

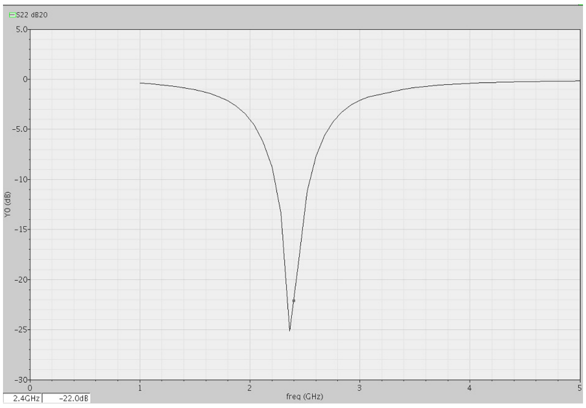

Fig 3.5: Output matching (S_{22}-parameter) of LNA

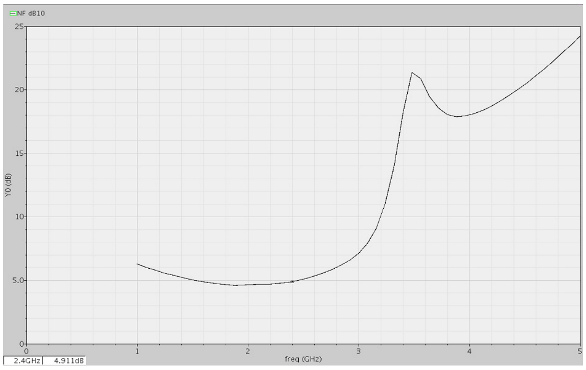

Fig 3.6: Noise Figure of LNA

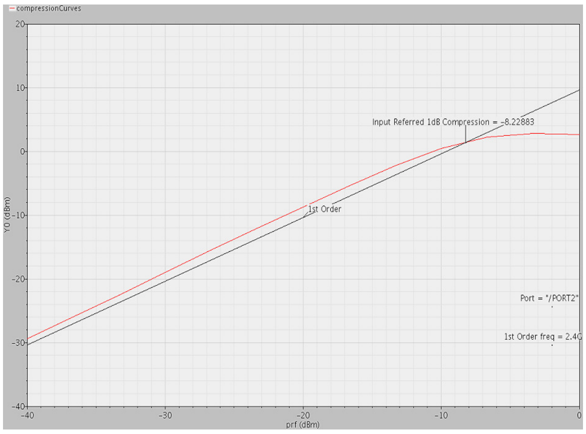

Fig 3.7: 1-dB compression point of LNA

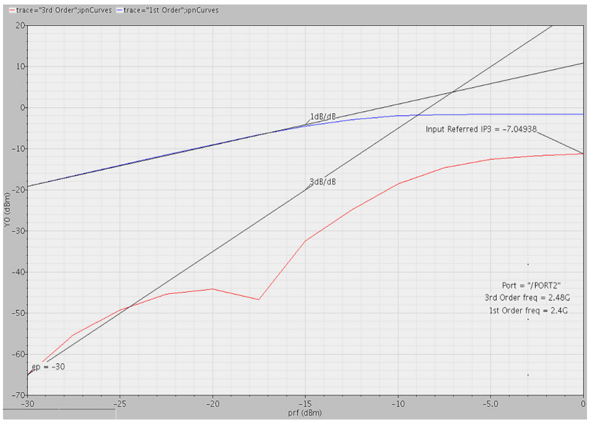

Fig 3.8: IIP3 of LNA

The proposed LNA dissipates 23.04 mW power in the core from 1.8 V supply.

3.2 *MIXER DESIGN*

The RF signal from the antenna which is amplified by the low noise amplifier is of high frequency. These signals need to be converted to digital form for digital signal processing. In order to ensure that signals can undergo proper signal processing, they are down converted to lower intermediate frequencies (IF) and then passed forward. Gilbert mixer is used in this work as the LNA was of differential topology and it gives an amplified differential output signal.

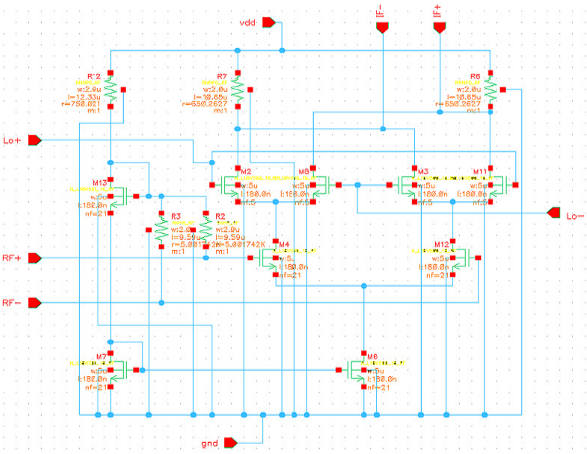

Fig 3.9: Schematic of Proposed Mixer with Biasing Circuitry

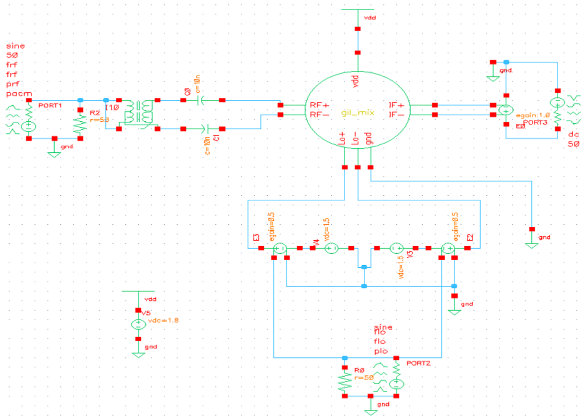

Fig 3.10: Test Bench for Proposed Mixer

RF models for transistors gives the component values in the Gilbert cell Mixer.

Component	Value
$L_{all\ transistor}$	0.18 µm
$W_{M2,M3,M8,M11}$	25 µm
$W_{M4,M8,M12}$	105 µm
R_6,R_7	650 Ω

Table 3.2: Component values for the Mixer

3.2.1 *SIMULATION RESULTS OF MIXER*

The mixer circuit is simulated in Cadence using Specter-RF simulator.

- Measured voltage conversion gain (S21 parameter) is around 14 dB.
- The Noise figure of the mixer has been found to 15.5 dB.
- The Input-referred IP3 measured to -1.5dBm and the 1-dB compression point is found to -11 dBm.

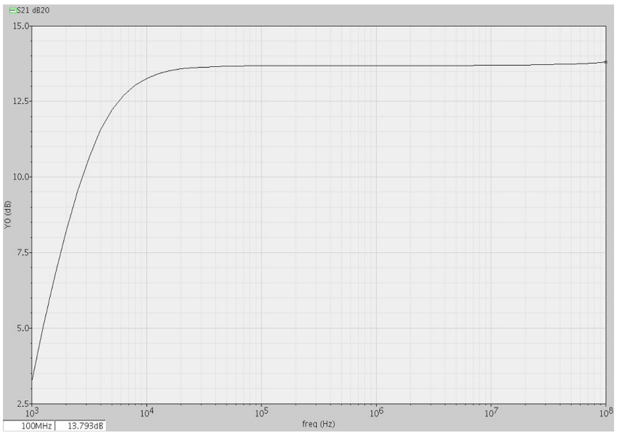

Fig 3.11: Gain (S_{21}-parameter) of Mixer

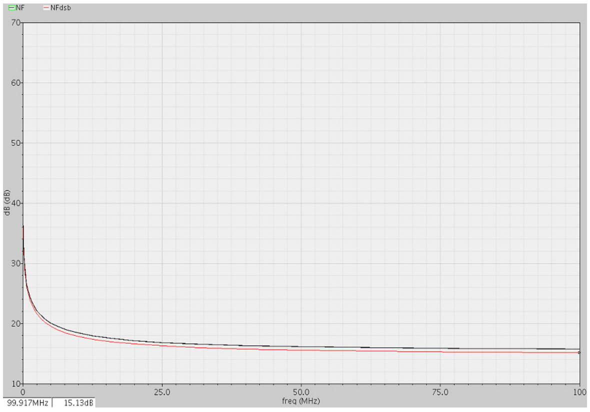

Fig 3.12: NF and NF_{dsb} of Mixer

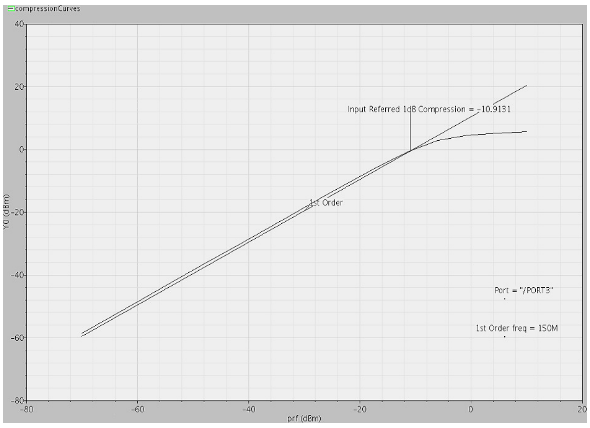

Fig 3.13: 1-dB compression point of Mixer

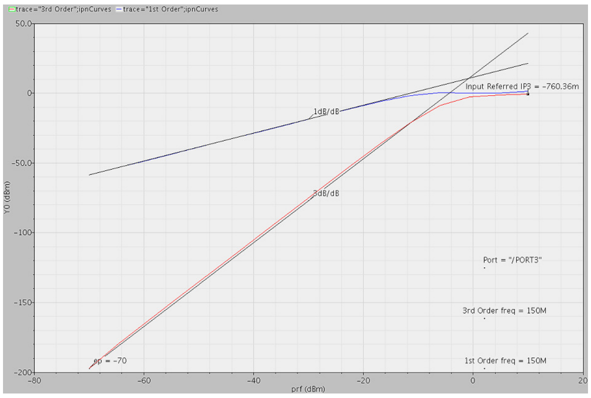

Fig 3.14: IIP3 of Mixer

The power consumption of the mixer is around 10.0 mW for 1.8 V power supply.

IV. CONCLUSION

In this paper, we concluded the design and implementation of LNA and Mixer for 2.4 GHz RF receiver front-end in 180 nm CMOS technology and operated at supply voltage of 1.8 V. Virtuoso Schematic Editor of Cadence was used to implement the circuits and spectre-RF simulator tool was used for the simulation of LNA and Mixer. Simulation results of both the circuits meet the required specification and are comparable to previous published papers [6-22]. The measured S-parameter analysis was used to find the different parameter results.

S. No.	**Parameter**	**Measured Result**
1.	Input Frequency	2.4 GHz
2.	Supply Voltage	1.8 V
3.	Technology	180 nm
4.	Gain (S-21)	11.3 dB
5.	Noise Figure	4.9 dB
6.	Input Matching (S-11)	-9.75 dB
7.	Output Matching (S-22)	-22 dB
8.	1-dB Compression Point	-8.22 dBm
9.	IIP3	-7.0 dBm
10.	Power Consumption	23 mW

Table 4.1: Measured Results of the LNA

S. No.	Parameter	Measured Results
1.	Input RF Frequency	2.24 GHz
2.	Input LO Frequency	2.25 GHz
3.	Supply Voltage	1.8 V
4.	Technology	180 nm
5.	Conversion Gain (S-21)	13.8 dB
6.	Noise Figure	15.5 dB
7.	1-dB Compression Point	-10.9dBm
8.	IIP3	-1.5 dBm
9.	Power Consumption	10 mW

Table 4.2: Measured Results of the Mixer

V. FUTURE SCOPE

The LNA and Mixer presented in this paper are appropriate for a RF front-end receiver. By combining these two components and some other component a complete heterodyne receiver front-end can be made for 2.4 GHz frequency input signal. The LNA can be made tunable for some frequency range by the use of variable capacitor Cg.

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