Low Power RF Front End Design for Diagnosis of Tumors-A Study

Manimala Krishnasamy
Assistant professor
Department of Electronics And Communication Engineering, EBET Group of Institutions,Kangayam,Tamilnadu-638108.

Abstract- Ultra-wideband (UWB) is an emerging wireless technology supporting high data rates and used in many sensing applications. In this paper a low power RF front end CMOS receiver is simulated which can be a part of diagnosing tool in the detection of tumors. The receiver comprises of LNA (Low Noise Amplifier), mixer, transimpedance amplifier. To achieve the required performance a single ended and differential mode LNA is used. To convert the output current from mixer into voltage the transimpedance amplifier has been designed. The simulation and analysis are carried out by using Mentor Graphics tool.

Keywords – ,LNA, Mixer, Transimpedance amplifier, Noise figure

I. INTRODUCTION

Ultra wide band receivers are used in many sensing applications. A medical application of UWB receiver is detection of malignant tumors in the breast. A suitable diagnostic tool with minimum ionizing radiation is required to do mass screening for cancer detection. In the proposed receiver, the signal path is made of a wideband LNA, linearized transconductors, quadrature current-mode passive mixers, and baseband Transimpedance Amplifiers (TIAs). Microwave radar imaging has recently been investigated for medical applications, in particular for the detection and early diagnosis of breast cancer. Breast cancer is the most incident tumors among female population, early time prevention is a key factor in delivering long term survival to patients. As compared to the more commonly used X-ray mammography, microwave radar imaging is an attractive alternative, as it avoids the use of ionizing radiations and breast compression, that cause health hazards and discomfort to patients. Radar microwave imaging leverages the contrast between the dielectric properties of healthy and cancerous tissue to identify the presence and location of significant scatterers. The concept is to illuminate the breast with an ultra wideband (UWB) pulse and collect the backscatter. From the shape and the time of arrival of the reflected pulse, information on the position and size of the scatterers are retrieved. By performing a set of measurements over different antenna positions, and by processing the obtained data in a digital beam focusing fashion, a high resolution image of the dielectric properties of the breast tissues can be derived.The motivation for developing a microwave imaging technique for detecting breast cancer is the significant contrast in the dielectric properties at microwave frequencies of normal and malignant breast tissue suggested by published measured data. The estimated malignant-to-normal breast tissue contrast is between 2: 1 and 10: 1, depending on the density of the normal tissue. Thus, while microwave technology does not offer the potential for the high spatial resolution provided by X-rays, it does offer exceptionally high contrast with respect to physical or physiological factors of clinical interest, such as water content, vascularisation/angiogenesis, blood-flow rate, and temperature. Furthermore, microwave attenuation in normal breast tissue is low enough to make signal propagation through even large breast volumes quite feasible. Microwave imaging techniques result in a three-dimensional (3-D) volumetric map of the relevant tissue properties rather than a two-dimensional (2-D) projection. The combination of these features eliminates the need for breast compression. In addition, microwave technology would be non-ionizing and non-invasive. For these reasons, microwave breast imaging has the potential to overcome some of the limitations of conventional breast cancer screening modalities. This paper presents the design of microwave front end of microwave radar imaging.

II. EXISTING METHODS

2.1 Existing Types of LNA:

An inductor less low-noise amplifier (LNA) with active balun is proposed for multi-standard radio applications between 100 MHz and 6 GHz. It exploits a combination of a common-gate (CG) stage and an admittance-scaled common-source (CS) stage with replica biasing to maximize balanced operation, while simultaneously canceling the noise and distortion of the CG-stage. In this way, a noise figure (NF) close to or below 3 dB can be achieved, while good linearity is possible when the CS-stage is carefully optimized [2]. A low noise amplifier with an active inductor for WiMAX applications is proposed. In order to obtain high gain, low noise figure (NF), and low-power consumption, a common gate configuration, high-Q active inductor loads, and a common source configuration are applied in this amplifier. The proposed amplifier circuit is designed in TSMC 0.18-μm CMOS technology. Simulation results show that the amplifier can operate at 2.6 GHz and 3.6GHz with forward gain of 35.7dB and 33.4dB with noise figure of 1.2dB and 1.4dB, respectively. The constant power consumption is about 12mW with 1.8 V power supply voltage [3].A 1.2 V, 0.61mA bias current, low noise amplifier (LNA) suitable for low-power applications in the 2.4 GHz band is presented. [4].A 90-nm CMOS low-noise amplifier (LNA) for 3–10-GHz ultra-wideband (UWB) applications is presented [8]. The circuit adopts a single-ended dual-stage solution. The first stage is based on a current-reuse topology and performs UWB (3–10 GHz) input matching. The second stage is a cascode amplifier with resonant load to enhance gain and reverse isolation. Thanks to both the circuit solution and design approach, the LNA provides input matching, low noise, flat gain, and small group-delay variation in the UWB frequency range at minimum power consumption. The design is also conceived to cope with application issues such as low-cost off-chip interfaces and electrostatic discharge robustness. Measurements exhibit a 12.5-dB power gain in a 7.6-GHz 3-dB bandwidth, a minimum noise figure of 3 dB, a reverse isolation better than 45 dB up to 10.6 GHz, and a record small group-delay variation of 12 ps. The LNA draws 6mA from a 1.2-V power supply.A noise optimization formulation for a CMOS low noise amplifier (LNA) with on-chip low-Q inductors is presented, which incorporates the series resistances of the on-chip low- inductors into the noise optimization procedure explicitly.

2.2 Existing Types of Mixer:

Basically a mixer takes an RF input signal at a frequency f_{RF}, mixes it with a LO signal at a frequency f_{LO}, and produces an IF output signal that consists of the sum and difference frequencies, $f_{RF} \pm f_{LO}$. The user provides a band pass filter that follows the mixer and selects the sum ($f_{RF} + f_{LO}$) or difference ($f_{RF} - f_{LO}$) frequency. When the sum frequency is used as the IF, the mixer called an up converter, when the difference is used, the mixer is called a down converter. In a receiver, when the LO frequency is below the RF, it is called low-side injection and the mixer a low-side down converter; when the LO is above the RF, it is called high-side injection, and the mixer a high-side down converter.

Mixers can be broadly categorized as active or passive. Passive mixers primarily use Scotty-barrier diodes, although a relatively new type of passive mixer, the FET resistive mixer, recently has become popular. FET resistive mixers use the resistive channel of a MESFET to provide low-distortion mixing, with approximately the same conversion loss as a diode mixer. Active mixers use either FET or bipolar devices. FETs (either MESFETs or HEMTs) are used for most microwave and RF applications where active mixers are employed; BJTs and occasionally HBTs are used most frequently as Gilbert multipliers.

2.3 Existing Types of Transimpedance Amplifier

Despite MOS transistors amplifiers do not perform as good compared with bipolar transistor based amplifier in high frequency, their low cost, low power consumption and small silicon area have motivated the research and Industry nowadays. However, building single-chip optical receivers in CMOS technology is challenging because low supply voltages, small transconductance, and substrate noise make it difficult to achieve high band width and good sensitivity. Infrared (IR) wireless receivers must also be able to reject dc photocurrents generated by ambient light. Sometimes the photocurrents are much larger than the signal current, resulting in reduced swing or even saturation at the optical receiver [7]. The preamplifier inside optical receiver plays a crucial role in determining many aspects of the overall performance of the receiver. For example, receiver's sensitivity is a strong function of input capacitance and preamplifier design. Optical preamplifiers may be either a high-impedance voltage amplifier or a transimpedance amplifier [8]. Data transmission at high speed demands the receiver circuits to have high sensitivity, high dynamic range and wide frequency range. In the past, fiber optic receivers are based on bipolar transistors. Some of them used shunt-series feedback over several common emitter stages to increase the bandwidth performance [9].

Compared to wideband receivers for wireless communications, the presented circuit addresses peculiar issues and design challenges. First, it features a bandwidth that is more than two times wider. Second, it requires an extremely high instantaneous dynamic range, because of the strong undesired skin backscatter, which an in-band signal is coexisting with the very weak tumour echo. Consequently, the dynamic range cannot be dealt with by varying the receiver gain, as usually done, for example, in cellular systems. Third, the quadrature accuracy is extremely important, as the imaging process is based on phase measurements. It is vital that the performance is consistent and homogeneous in the entire band without offsets or jumps in the quadrature error for different portions of the covered spectrum.

III. ANALYSIS OF RF CIRCUIT PARAMETERS

3.1 Low Noise Amplifier Design Parameters

LNA is crucial part in RF receiver. All design parameters reflect the quality of LNA.LNA is designed for amplify the weak signals, attenuate the noise level and providing an appropriate working condition to the mixer.

3.1.1 Impedance Matching

Impedance matching is important in LNA design because often times the system performance can be strongly affected by the quality of the termination. For instance, the frequency response of the antenna filter that precedes the LNA will deviate from its normal operation if there are reflections from the LNA back to the filter. Furthermore, undesirable reflections from the LNA back to the antenna must also be avoided.

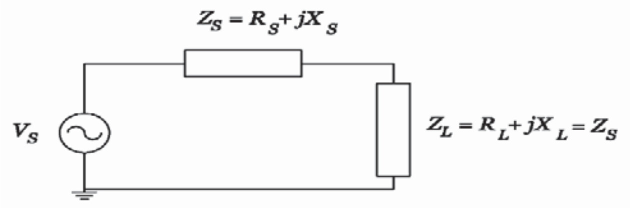

Figure.1. Condition for an Impedance Match

3.1.2 The Smith Chart

The smith chart is a classical tool in the designing of RF circuits has many uses. It is a fundamental aid in impedance matching network design.

As the radius of the chart is unity it is implied that all plotted values, whether they are impedance or admittance must be normalised with respect to the reference. This reference is usually the characteristics impedance of the system which usually is 50 ohm.

$z = Z / Z_0$ (1); $y = Y / Y_0$ (2)

Here Z_0 is the characteristics impedance and Z is the load impedance.

3.1.3 Gain Analysis

The gain of the device is its ability to amplify the amplitude or the power of the input signal. It is defined as the ratio of the output-to-input signal and is often referred to the input signal and is often referred to in terms of decibels.

Voltage gain=20log (v_{out}/v_{in}) (3)

3.1.4 Noise Figure Analysis

Before beginning an analysis of noise, it is necessary to first introduces the definition of the noise factor (noise figure is noise factor expressed in dB).

$F = (SNR_{in} / SNR_{out})$ (4)

The noise factor is a measure of the amount of noise a two-port network adds, and is the equal to the ratio between the total output noise power and the output noise power due to the input source.

3.2 Mixer Design Parameters

RF mixers are 3-port active or passive devices. They are designed to yield both, a sum and a difference frequency at a single output port when two distinct input frequencies are inserted into the other two ports.

3.2.1 Noise Analysis

The noise figure for an RF mixer is important in radio receiver front end circuits. Any noise introduced by the RF mixer at an early stage in the receiver such as the first mixer will degrade the performance of the whole receiver. In this way the noise figure for the RF mixer is important.

Noise Figure is defined as

NF=10 log NR (5); $NR = 10 \log (SNR_{input\ RF}/SNR_{output\ RF})$ (6)

Two representation of noise figure are used, namely single-sideband (SSB) NF and double-sideband (DSB) NF. When the desired signal only resides at one frequency, SSB NF is used to measure the performance of a mixer. It is obvious that the SSB NF will be normally 3dB greater than the DSB NF, since both have the same IF noise but the former has signal power in only a single sideband.

3.3.2 Conversion Gain

Conversion Gain or Loss of the RF Mixer is dependent by the type of the mixer (active or passive), is dependent by the load of the input RF circuit as well the output impedance at the IF port, and also is dependent by the level of the LO. Conversion Gain or Loss is the ratio of the desired IF output (voltage or power) to the RF input signal value (voltage or power). If the input impedance and the load impedance of the mixer are both equal to the source impedance, then the voltage conversion gain and the power conversion gain of the mixer will be the same in dB.

IV.DESIGN OF RECEIVER BLOCKS

The LNA must provide wideband input matching and gain, while featuring a low noise figure. Resistively-degenerated transconductance (G_m) stages are used in the I/Q paths to convert the LNA output voltage into Current. Current-mode passive mixers are capacitive coupled to the transconductors outputs. This choice results in both good linearity and good noise performance, preventing the flicker noise of the commutating devices to corrupt the down converted signal. Current-mode mixers are loaded by baseband transimpedance amplifiers (TIAs), based either on common-gate stages or on op-amps with resistive feedback. The combination of passive current-mode switches TIAs results in a highly linear, low noise down conversion mixer with a very low flicker noise corner.

4.1 DESIGN OF LNA

To achieve the required performance a three-stage LNA design is used.

4.1.1 FIRST STAGE OF LNA

The first stage is responsible for the input matching and the noise performance. The employed topology is instead a common-gate/common-source noise cancelling amplifier.

The noise cancelling stage allows decoupling the matching requirement from the noise figure performance. The noise generated by the matching device M1 is cancelled without impairing the useful signal by setting $|Z1|/|Z2|=g_{m2}R_S$, where R_S=50ohm is the source resistance. The common-gate branch is biased with 2mA, while the common-source branch is biased with 7mA. The widths of transistors M1 and M2, both featuring minimum channel length, are 40µm and 80µm, respectively. Biasing transistor M3 has a higher overdrive voltage (W3=10µm, L3=0.12µm) as compared to M2 to decrease its noise contribution. The combination of the series inductor Lin=520pH and the common-gate stage M1 (g_{m1}=20mS) results in good matching over a wide 1.5 to 20 GHz frequency range.

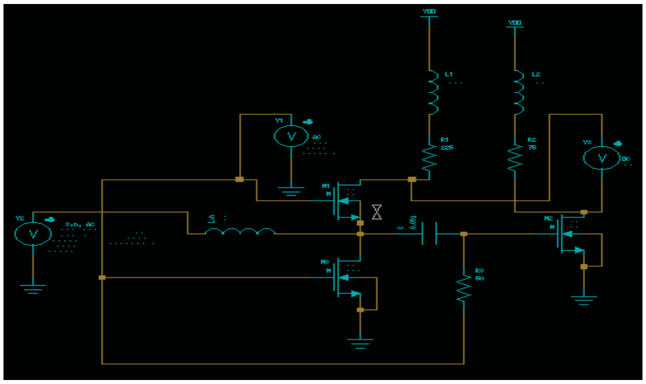

Figure.2. Schematic of the first stage of the LNA.

The parameters used in the design is M1 (L=40µm, W= 80µm), M2 (L=40µm, W= 80µm), M3 (W3=10µm, L3=0.12µm), source resistance R_S (50 ohm), series inductor Lin=520pH, R1 (225 ohm), R2 (75 ohm), L1 (900pF) and L2 (700pF). The plot between magnitude in db and frequency in Hz was obtained by the use of AC analysis. The maximum output gain obtained from this analysis is 26db at the operating frequency range lies between 1GHz to 15GHz.

4.1.2 SECOND AND THIRD STAGE OF LNA: The second stage of the LNA is biased with 6mA. It is a fully differential pair to improve the signal balance and add gain. The third stage is biased with 12mA. It is a pseudo-differential stage for better linearity.

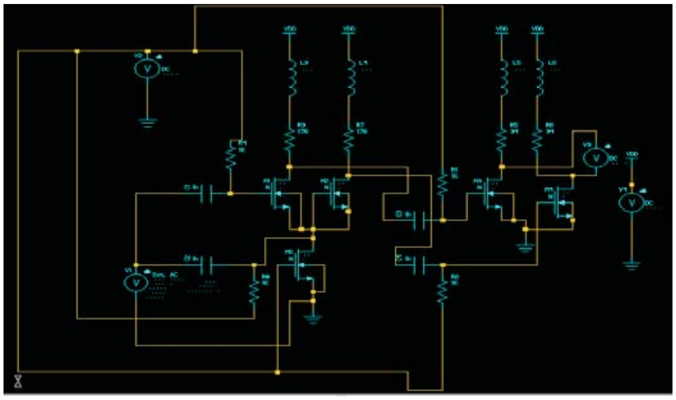

Figure.3. Schematic of the second and third stage of the LNA.

All three stages use shunt-peaked loads to expand the bandwidth. Since the loads are intrinsically low, the inductors are stacked square coils, resulting in a very compact layout that saves area and minimizes the coupling issues between the LNA stages. The resistanceR2 is implemented as a parallel combination of three resistances of valueR1 to guarantee good matching for the noise cancelling condition, at least at the lower frequencies. The three stages of the LNA are interconnected by giving the first stage of the output to the input of the combination of second and third stage.

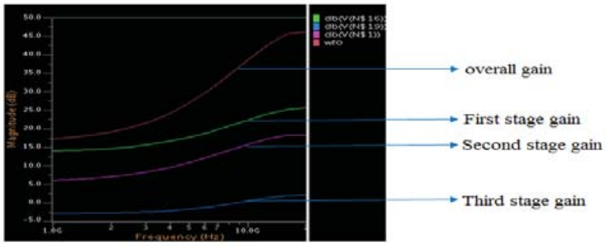

Figure.4.Frequency Vs Gain of all stages.

Overall gain can be calculated by adding the gain of first stage, second stage and third stage .From the above plot it is observed that the overall gain of the LNA is obtained as 36dB when all the three stages are interconnected.

4.1.3 NOISE ANALYSIS OF LNA

The noise figure is equivalent to ratio of the of the input and output SNR at the input and at the output of the LNA. The input and output SNR of the LNA can be calculated by the use of FFT plot .

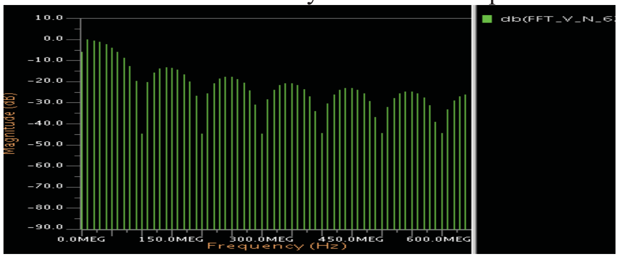

Figure.5.FFT plot of the signal

From the FFT plot the SNR can be calculated

The value of SNR for the input signal is -44.95dB, the SNR of the first stage output is -45.5dB, the SNR of the second stage output is -46.18dB and the SNR of the third stage of the LNA is -47.62dB.The NF for first stage of the LNA can be calculated as NF = (input SNR – output SNR) in dB

= -44.95 – (-45.5) dB ; NF =0.55dB.For second stage NF = -45.5 – (-46.2) dB; NF =0.7dB

For third stage of the LNA can be calculated as

NF = -46.2 – (-47.6) dB; NF =1.4dB

Therefore the noise figure of the designed LNA is lies in the range between 0.5 to 1.4dB.

4.1.4 IMPEDANCE MATCHING ANALYSIS

Impedance matching is to eliminate the reflected voltage or current on a transmission line.

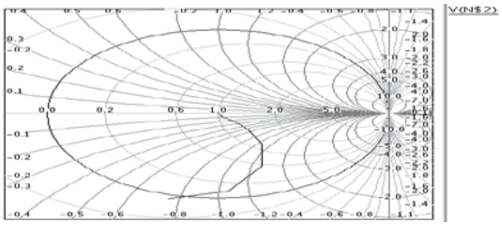

Figure.6.Smith chart analysis

It is implied that the impedance can be achieved from the smith chart analysis as its radius is unity. The bending in curve will due to the effect of inductance which is connected as parallel at the output. From the above analysis the impedance value can be measured as Z = 1- j0.8 ohm.

4.2 DESIGN OF MIXER

It consists of an RF transconductance stage followed by a double balanced switching quad. An RF current from the transconductors commutates through the time-varying switching quad, experiences frequency-translation, and flows into the transimpedance load.

The transconductance stage of the mixer consists of a differential complementary pair and a common-mode feedback circuit. The RF and the LO signals are AC-coupled into the mixer core through the coupling capacitors. AC-coupling increases biasing flexibility and suppresses low-frequency distortion interaction between stages. The current from the transconductance stage, however, is DC-coupled to the switching pairs. The switches consist of four transistors forming a double-balanced structure and the mixer has 3 ports are the Local Oscillator (LO) port, the Radio Frequency (RF) port, and the Intermediate Frequency (IF) port. The LO port is typically driven with either a sinusoidal continuous wave (CW) signal. Conceptually, the LO signal acts as the “gate” of the mixer in the sense that the mixer can be considered “ON” when the LO is a large voltage and “OFF” when the LO is a small voltage. The LO port is usually used as an input port.

When the desired output frequency is lower than the second input frequency, then the process is called down conversion and the RF is the input and the IF is the output. The relationship between input and output frequencies is given by

$f_{IF} = |f_{LO} - f_{RF}|$ -------- (4.1)

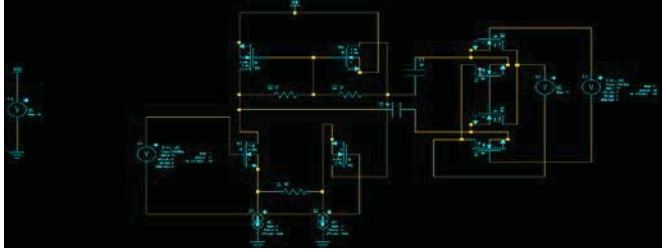

Figure.7. Schematic of mixer with Transconductance

Each G_m stage is biased with 8mA, and makes use of a degeneration resistor (R_{deg} = 46 ohm). Self-biased active loads are employed: this configuration avoids the need of an auxiliary common-mode feedback control loop. Current-mode passive mixers are capacitively coupled to the transconductor outputs. In a RF front-end the mixer receives the signal from the LNA and mixes it with the signal from a local oscillator to convert the signal to a lower frequency called intermediate frequency.

It is noted that the value of input RF is 500MHz, the value of the LO frequency is 1GHz then the IF value can be obtained as 500MHz. Therefore IF can be calculated as IF = LO – RF = (1000-500) MHz IF = 500MHz

4.2.1 Conversion Gain Analysis

Conversion Gain or Loss is the ratio of the desired IF output (voltage or power) to the RF input signal value

(voltage or power)

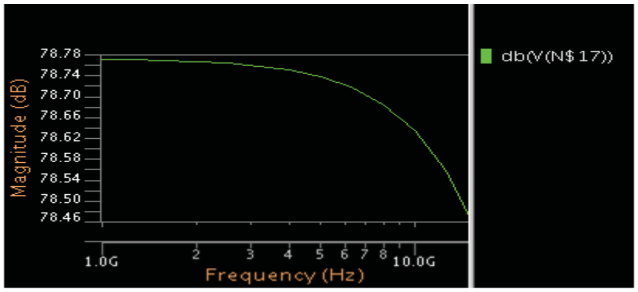

Figure.8.Gain of the mixer

From the above analysis the value of the conversion gain of the mixer can be obtained as 78dB.

4.3 DESIGN OF TRANSIMPEDANCE AMPLIFIER

A Transimpedance Amplifier, (TIA) is a current to voltage converter; most often implemented using an operational amplifier. The current source feeds into the circuit and the gain of transimpedance can be adjusted by changing the value of a single resistor.

Typically, current-mode mixers are loaded by baseband transimpedance amplifiers (TIAs) based either on common-gate stages or on op-amps with resistive feedback.The amplifier is based on a common-gate stage. Compared to an op-amp with resistive feedback approach, this choice allows decoupling the input and outputting common-mode voltages. As a consequence, the input common-mode voltage can be kept low, which is beneficial for the mixer switches (nMOS transistors), without impairing the output swing. Local feedback (transistors M3 and M8) is used around the common-gate input stage (transistors M2 and M9) to decrease the differential TIA input resistance.

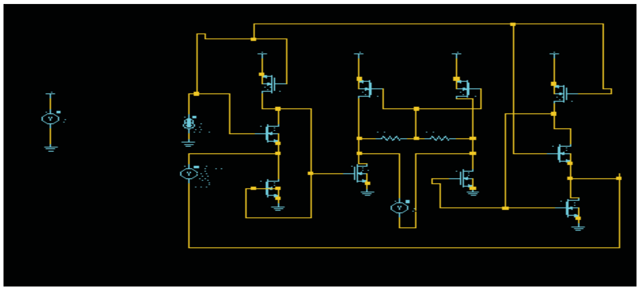

Figure 9.Schematic of the TIA

The input branches of the TIA are biased with 250µA each, such that a differential input resistance of 35 ohm is achieved at small power consumption. The input currents are mirrored to the output branches. Eventually, resistors perform the current-to voltage conversion.

Compared to an op-amp with resistive feedback approach, this choice allows decoupling the input and outputting common-mode voltages. The results obtained for different blocks of receiver are tabulated below.

PRARMETERS	**VALUE**
Gain of LNA	36dB
Noise figure of LNA	0.5 – 1.4dB
Conversion gain	78dB
Transimpedance gain	74dB

V. CONCLUSIONS

The low noise amplifier, mixer and Transimpedance Amplifier have been implemented in 90nm technology and the prototypes are validated using mentor graphics tools. The LNA operates from 1GHz to 15GHz and demonstrates a comprehensive gain of 46dB. The wideband CMOS down conversion passive mixer using current mode approach provides a gain of 78db. The implemented Transimpedance Amplifier provides a maximum gain of 74db. The structure exhibits good mid band gain and frequency response. The proposed parts of the receiver are suitable for ultra low power applications since it works at 1V input supply. The simulated blocks can be implemented in hardware to design a CMOS receiver Further the gain and noise figure of the mixer can be enhanced by changing the geometry of transistors.

REFERENCES

[1] A. Bevilacqua and A. M. Niknejad (Dec. 2004), “An ultra wideband CMOS low noise amplifier for 3.1–10.6-GHz wireless receivers,” IEEE J. Solid- State Circuits, vol. 39, no. 12, pp. 2259–2268,

[2] S. Blaakmeer, E. Klumperink, D. Leenaerts, and B. Nauta (Jun. 2008), “Wideband balun-LNA with simultaneous output balancing, noise-canceling and distortion-canceling,” IEEE J. Solid-State Circuits, vol. 43, no. 6, pp. 1341–1350.

[3] Jenn-Tzer Yang, Hsiao-Ping Fan,” A CMOS Multi-band Low Noise Amplifier for WiMAX Applications” Department of Electronics Engineering Ming Hsin University of Science and Technology.

[4] Gianluca Cornetta, David J. Santos and Balwant Godara (2009), “A Sub-mW Low Noise Amplifier for Wireless Sensor Networks”, International Journal of Electrical and Computer Engineering.

[5] Kuo-Jung Sun, Zuo-Min Tsai, Kun-You Lin and Huei Wang Fellow (April 2006),” A Noise Optimization Formulation for CMOS Low-Noise Amplifiers with On-Chip Low-Q Inductors” IEEE transactions on microwave theory and techniques, vol. 54, no. 4.

[6] Jianjun J. Zhou and David J. Allstot (December 1998),” Monolithic Transformers and Their Application in a Differential CMOS RF Low-Noise Amplifier” IEEE journal of solid-state circuits, vol. 33, no. 12.

[7] D. J. H. MacLean, Optical Line Systems: Transmission Aspects, 1st Edition, John Wiley & Sons, July 11, 1996.

[8] Bryon L. Kasper, “Chapter 18, Receiver Design”, Optical Fiber Telecommunications II, AT&T and Bell Communications Research, Inc., Holmdel, New Jersey, 1998, Academic Press, Inc.

[9] J.A.Casao, P.Dorta, J.L.Caceres, M.Salazar-Palma, J.Perez, “An Enhanced GaAs Monolithic Transimpedance Amplifier for Low Noise and High Speed Optical Communications,” IEEE MTT-S Digest, 1992