Design of Low Noise Amplifier at 8.72 GHz

Dwijendra Parashar [1] Nisha Chugh [2]
1.M. Tech. (Communication Engg.) Scholar
Deptt of Electronics and Communication Engineering
Shobhit University, Meerut (Uttar Pradesh)
Email-dwijendra.parashar@gmail.com
2. Asstt. Prof. E&CE Deptt.
Department of Electronics and Communication Engineering
Shobhit University, Meerut (Uttar Pradesh)
Email- nishachugh0711@gmail.com

ABSTRACT

Low noise amplifiers are one of the basic building blocks of any communication system. The purpose of the LNA is to amplify the received signal to acceptable levels with minimum self generated additional noise. A Low Noise Amplifier (LNA) is placed at the front end of the radio receiver which poses a challenge in terms of meeting high gain, low noise figure, good linearity and low power consumption requirement. Using an LNA, the effect of noise from subsequent stages of the receive chain is reduced by the gain of the LNA, while the noise of the LNA itself is injected directly into the received signal. Thus, it is necessary for an LNA to boost the desired signal power while adding as little noise and distortion as possible, so that the retrieval of this signal is possible in the later stages in the system. In this paper, we introduce a systematic method to design a CMOS low noise amplifier (LNA) for a radio receiver.The developed LNA implemented in 0.18µm UMC technology using Cadence Virtuoso (R) Schematic editor XL tool by 1.8V supply.

Keywords: -Low-noise amplifier (LNA), Radio Frequency (RF) and CMOS, Single stage amplifier, Active Passive component, RF front end.

I. INTRODUCTION

Low noise amplifier is an electronic amplifier used to amplify possibly very weak signals (for example, captured by an antenna). It is usually located very close to the detection device to reduce losses in the feed line. The LNA function, play an important role in the receiver designs. Its main function is to amplify extremely low signals without adding noise, thus preserving the required Signal-to-Noise Ratio (SNR) of the system at extremely low power levels. Additionally, for large signal levels, the LNA amplifies the received signal without introducing any distortions, which eliminates channel interference. The design of a LNA in Radio Frequency (RF) circuit requires the trade-off many importance characteristics such as gain, Noise Figure (NF), stability, power consumption and complexity. The goal of this paper is to illustrate the use of the cadence software to simulate the performance of a LNA at 8.72 GHz frequency. The LNA can be designed as single ended as well as differential LNA. The single ended LNA architecture having one shortcoming that is its sensitivity to parasitic ground inductance. In the design of the single ended LNA there is difference between the degenerative inductance potential and the ground return of the source signal because there is always some nonzero impedance between the two points. An alternative is the differential LNA design in which the incremental ground located at the symmetrical point. The differential LNA is having several advantages such as a real part of the input impedance purely controlled by the source degeneration inductance (*Ls*) because the virtual ground formed removes the sensitivity to parasitic ground inductance. There are two widely used types of devices S parameter and normal device to design LNA.S parameter is a built in device which does not require any type of external biasing because it has fixed S parameters, normal devices like other transistor to which external bias can be applied, in designing LNA the S parameter designing must used. In designing proper selection of transducer is used should have maximum gain and minimum noise figure. In designing stability plays an important role at the time of noise itself generated in LNA, we enhance the stability by adding series and source resistance or a small resistance added in series with the gate of transistor, resistance generate thermal noise so we do not use this techniques. As an ideal inductor has zero resistance it generates the thermal noise it reduces the stability by reducing the gain of amplifier by a small factor. Cadence cad tool is used to make the entire design, Specification table and comments from Preliminary simulations to the Final Layout. Simulations using Cadence allowed the LNA to be optimized for better performance.

II. BACKGROUND INFORMATION OF RADIO RECEIVER

In radio communications, a radio receiver is an electronic device that receives radio waves and converts the information carried by them to a usable form. It is used with an antenna. The antenna intercepts radio waves (electromagnetic waves) and converts them to tiny alternating currents which are applied to the receiver, and the receiver extracts the desired information. The receiver uses electronic filters to separate the wanted radio frequency signal from all other signals, an electronic amplifier to increase the power of the signal for further processing, and finally recovers the desired information through demodulation. The information produced by the receiver may be in the form of sound (an audio signal), images (a video signal) or data (a digital signal) [2]. A radio receiver may be a separate piece of electronic equipment, or an electronic circuit within another device. Devices that contain radio receivers include television sets, radar equipment, two way radio, cell phone, wireless computer networks, GPS navigation devices, satellite dishes, radio telescope, Bluetooth enabled device, garage door openers, and baby monitors.

Alexander Stepanovich Popov designed and implemented the first radio receiver in 1896. It was based on electromagnetic waves, which were proven to exist by James Clerk Maxwell only a few years earlier in 1887. It took only a few more years until the first radio system was able to transmit communications across the Atlantic in 1901. In the time between then and the present day, the radio receiver has seen a great many technological advances. One of the most significant advances was the invention of the super heterodyne, or superhet, receiver. The receiver demodulates and decodes the channel output to recover the original information to the source. Once demodulated, the channel decoder, which is typically a filter matched to the channel encoder, is used to recover one sample estimate per symbol of the channel code word. The channel encoder estimate the digital source code word, which is then converted to an estimate the original data by the source decoder.

Heterodyne architecture is probably the most commonly used receiver in current commercial receiver implementation. The low noise amplifier plays a key role in this architecture. The main objective of the super heterodyne receiver is to produce an intermediate frequency (IF) by the process of heterodyning or beating. This can be accomplished when two frequencies are mixed to produce the beat frequency.

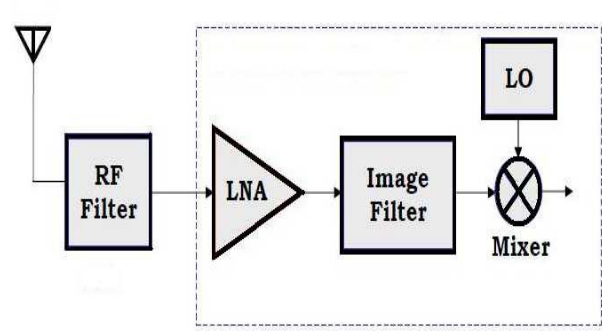

Figure1: Architecture of heterodyne receiver using LNA

The first stage of a receiver is typically a low-noise amplifier (LNA), whose main function is to provide enough gain to overcome the noise of subsequent stages (for example, in the mixer or IF amplifier). Aside from providing enough gain while adding as little noise as possible, an LNA should accommodate large signals without distortion, offer a large dynamic range, and present good matching to its input and output, which is extremely important if a passive band select filter and image-reject filter precedes and succeeds the LNA, since the transfer characteristics of many filters are quite sensitive to the quality of the termination. Figure1 shows the architecture of heterodyne receiver using LNA. The band-select filter before the LNA rejects the out-of-band interferers. The image reject filter (preselected) after the LNA attenuates the image which is 2ωIF away from the desired band [12].

III. SINGLE STAGE AMPLIFIER

Amplifiers are essential building blocks of both analog and digital systems. Amplifiers are needed to amplify a weak analog signal for further processing and reduce the effect of noise of next stage to provide proper logical levels in digital circuit. Single stage amplifier can be classified as following types such as.

- Common Source Amplifier
- Common Drain (Source follower) Amplifier
- Common Gate Amplifier
- Cascode Amplifier

A **common-source** amplifier is one of three basic single-stage field effect transistor amplifier topologies, typically used as a voltage or transconductance amplifier. Large signal model is known as DC analysis used to find out operating point and the bias condition. AC analysis can be either small signal or large signal. The Small signal AC analysis deals with circuits that are either linear or weakly nonlinear. Large signal AC analysis deals with circuits that may be quite nonlinear, such as when clipping of waveforms occurs. DC analysis is just DC analysis and sometimes also called quiescent analysis. To explain the analysis we consider an amplifier [6]. DC analysis gives the operating point of the amplifier, how much current flow in it and what the DC voltage at each terminal is. This is useful to know because it can affect the AC analysis. AC small signal analysis gives the gain and generally linear performance parameters of the amplifier. AC large signal analysis gives the result of running large signals (hence the name) through the amplifier and typically tells you things like clipping performance, distortion, etc.

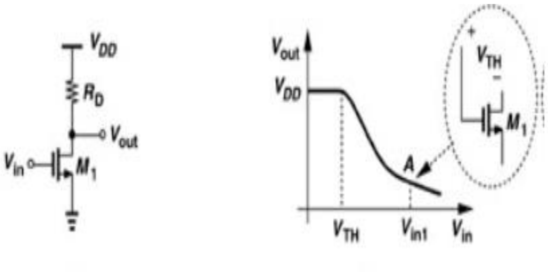

Figure 2: Large signal model of common stage with resistive single stage amplifier.

To calculate the output voltage, we assume that the input voltage is equal to V_{DD}.

$$V_{out} = V_{DD} - R_D I_D \quad (1)$$

When the input voltage V_{in} is low i.e. smaller than the threshold voltage of the driver MOSFET, the driver transistor is cut-off. Since the drain current of the driver transistor is equal to the load current, $I_D = 0$. It follows that the output voltage of the inverter under these condition is:

$$V_{out} = V_{DD} \quad (2)$$

M_1 in the saturation region:

$$V_{out} = V_{DD} - R_D \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{in} - V_{TH})^2 \quad (3)$$

$$I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{in} - V_{TH})^2 \quad (4)$$

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = \mu_n C_{ox} \frac{W}{L} (V_{in} - V_{TH}) \quad (5)$$

$$A_v = \frac{\partial V_{out}}{\partial V_{in}} = -R_D \mu_n C_{ox} \frac{W}{L} (V_{in} - V_{TH}) \quad (6)$$

$$A_v = -R_D g_m \quad (7)$$

Thus the negative sign in equation (7) is consistent with the flow of current I_D up through the resistor.

M_1 in the linear region:

$$V_{out} = V_{DD} - R_D \mu_n C_{ox} \frac{W}{L} \left[(V_{in} - V_{TH})V_{out} - \frac{V_{out}^2}{2}\right] \quad (8)$$

Small signal analysis is a method of analysis that allows us to get approximate analytic expressions (equations) for nonlinear circuits which can't be solved easily. To find the small signal model first we find the DC operating point for each element in nonlinear circuit. Second we redraw the circuit: replace each circuit element with its small-signal model. After this we solve the small-signal circuit model using all the linear analysis tools. So the total behavior is sum of DC (large signal) operating point + small signal component "riding on" DC bias from large signal operating point solution.

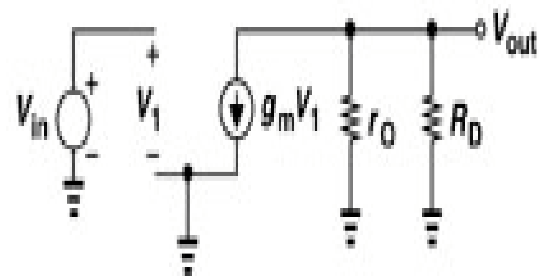

Figure 3: Small signal model of common stage with resistive single stage amplifier.

$$g_m V_1 (r_o // R_D) = -V_{out} \quad (9)$$

$$V_1 = V_{in} \quad (10)$$

$$A_v = \frac{V_{out}}{V_{in}} \quad (11)$$

IV. CMOS LNA DESIGN

The Low Noise Amplifier (LNA) is the first gain stage of a receiver. It must meet several specifications at the same time, which makes its design challenging. The signals coming from the receiver antenna are very small; therefore signal amplification is needed before it is fed into the mixer. This process sets the requirement of a certain gain to the LNA. The received signal should have a certain Signal to Noise Ratio (SNR) in order to allow proper detection. Therefore, noise added by the circuit should be reduced as much as possible. A large signal or blocker can occur at the input of LNA. The circuits should be sufficiently linear in order to have a reasonable signal reception. For portable and mobile applications, reasonable power consumption is another constraint. We design several parameters using low noise amplifier such as.

a).Noise Performance- The noise performance of an RF amplifier is represented by its noise factor or noise figure. It is defined as the SNR at the input of the network divided by the SNR at the output of the network:

$$F = (SNR_{in} / SNR_{out}) \quad (12)$$

The noise factor represents the signal's quality in terms of noise before and after the network. The noise figure is the same as the noise factor expressed in dB.

$$NF\ (dB) = 101ogF \quad (13)$$

For Cascode Stage

$$NF_{Total} = 1 + (NF_1 - 1) + \frac{NF_2 - 1}{G_1} + \ldots\ldots + \frac{NF_n - 1}{G_1 \ldots\ldots G_{(n-1)}}$$

b) S-Parameter- The scattering parameters or S-parameters are widely used in microwave and RF circuit analysis. S-parameters are used to model and characterize an n-port linear network.

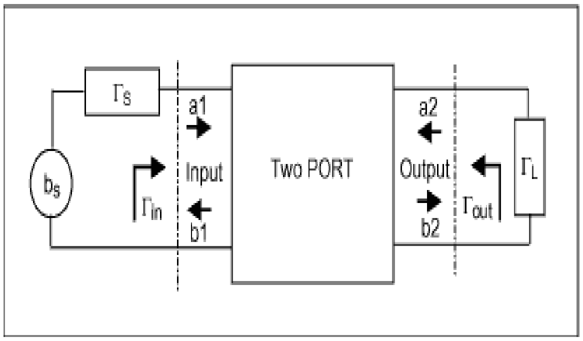

Figure4: Two-port network

The linear equations describing the behavior of the two-port network using S-parameters are

$$b_1=S_{11}*a_1+S_{12}*a_2 \qquad (14)$$

$$b2=S_{21}*a_1+S_{22}*a_2 \qquad (15)$$

Where b_1, b_2, a_1 and a_2 are traveling waves representing incident voltages at the ports.

The S-parameters S_{11}, S_{22}, S_{21} and S_{12} are defined by:

$S_{11} = (b_1 / a_1)$ where $a_2 = 0$

$S_{22} = (b_2 / a_2)$ where $a_1 = 0$

$S_{21}= (b_2 / a_1)$ where $a_2 = 0$

$S_{12} = (b_1 / a2)$ where $a_1 = 0$

c) Amplifier's gain- There are two criteria that affect the performance gain of any RF amplifier: the RF transistor itself and the input output matching network.

$$\text{Power Gain} = \frac{\textit{Available power at the output}}{\textit{Power at input}} \qquad (16)$$

Available power gain shows the maximum possible power amplification of the amplifier.

The voltage gain (A_v) is defined as the voltage at the output port divided by the voltage at the input port of the amplifier.

The transducer gain is defined as power delivered to the load divided by the power available at the source.

V. LNA SCHEMATIC AND SIMULATION

The CADENCE environment allows access to libraries containing icons of basic circuit components and the ability to place and connect theses devices in the form of a circuit within a schematic editor. In addition, the default values of the properties of the various elements can be edited and altered to fit the requirements of the actual system under design. The files can then be extracted from the graphical circuits into forms compatible with Spectra or Spice circuit simulators. The LNA usually only involves one or two transistors to achieve low noise operation. The performance of the LNA circuits is very dependent on process technology. CMOS technologies are the best choice to design an LNA because they offer high speed operation, simplicity in fabrication, and low power consumption.

The approach used in the redesign and simulation includes next steps:

• S-parameters simulation of the LNA scheme realized in 0.18μm CMOS technology;

• Drawing the LNA scheme in 0.18μm CMOS technology

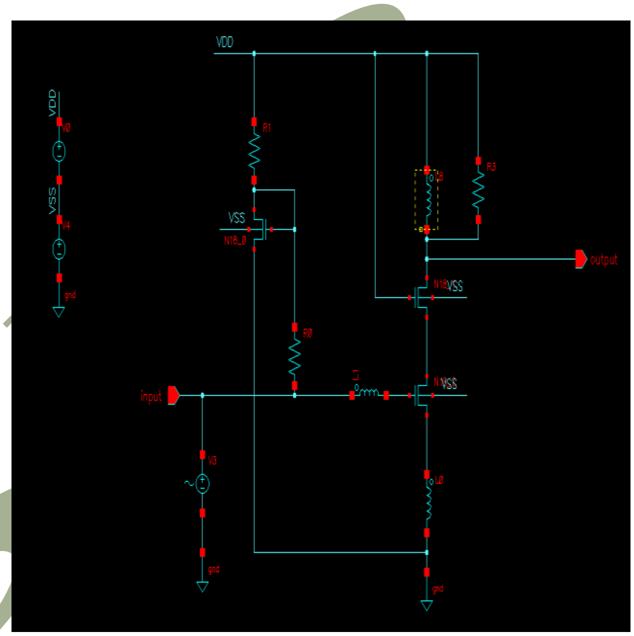

Figure5: Schematic of LNA

Simulation software allows for modeling of circuit operation and is an invaluable analysis tool. The simulators can then be called to compute and plot the various waveform results. Once the designer is satisfied with the operation of the circuit, the schematic can then be put into the form of a symbol and used as a component in higher-level circuits. In LNA design presents a considerable challenge because of its simulations requirement for high gain, low noise figure, good input and output matching and unconditional stability at the lowest possible current draw from the amplifier. The LNA is required to amplify incoming signals and extract them from the noisy environment, thus enabling signal processing by blocks further down the receiver chain. The gain provided by the LNA is generally defined in terms of the voltage gain

$A_v = V_{out} /V_{in}$

Power gain = P_{out}/P_{in}

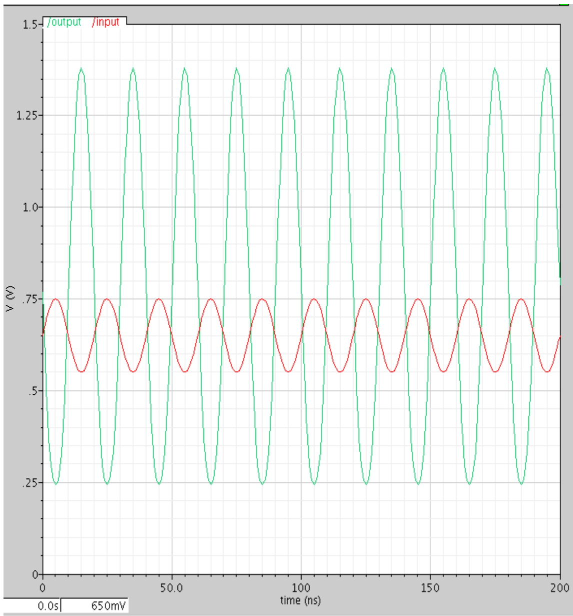

Figure (a)

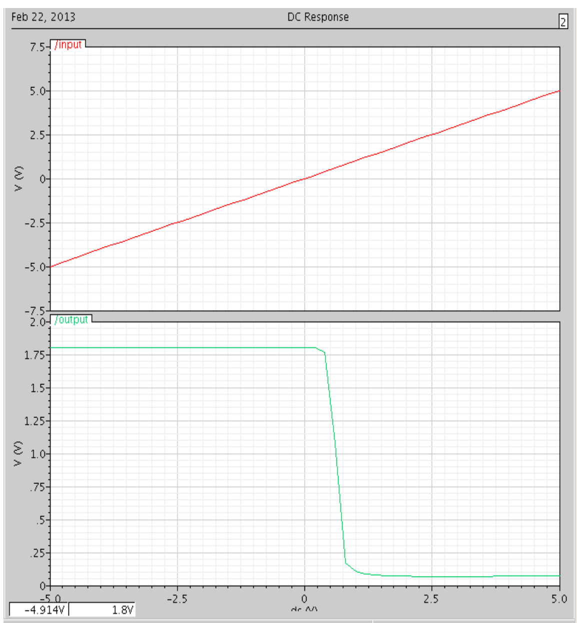

Figure (b)

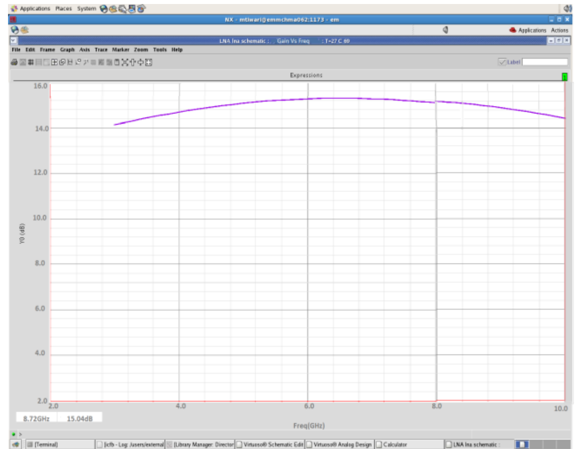

Figure (c)

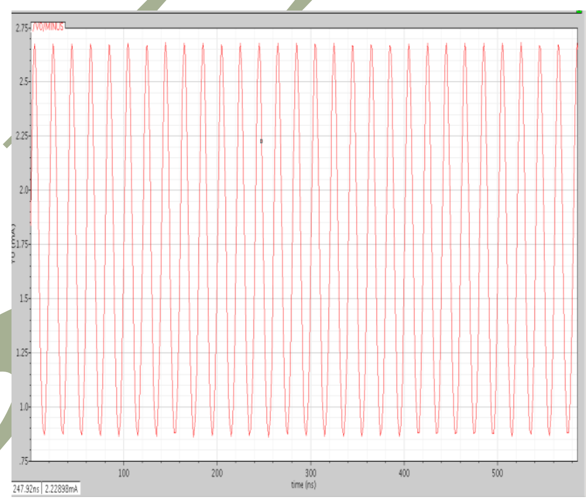

Figure (d)

Figure6: Simulation of LNA Fig (a) Transient response Fig (b) DC response Fig (c) Gain at frequency 8.72 GHz. Fig (d) Current at 1.8V

CMOS LNA designed using 0.18μm UMC technology using 1.8 V supply voltage, current 2.66mA. So we can find the power will be 4.7mW. voltage gain will be 15.04 dB at 8.72 GHz frequency.

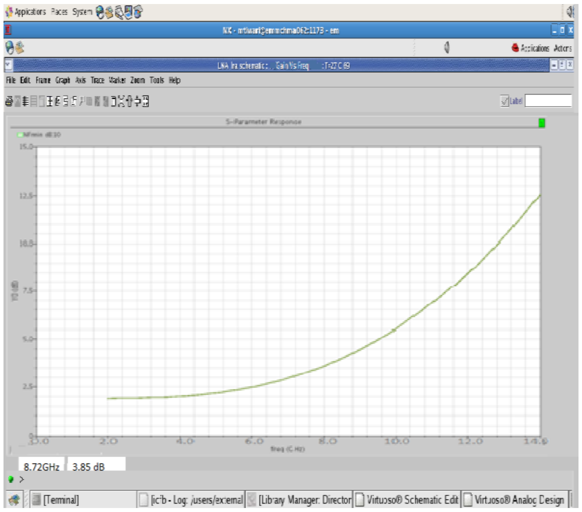

Figure 6: NF and NF_{min} parameters

The overall noise figure is mainly determined by the first amplification stage, provided that it has sufficient gain. NF is the practical noise figure of a practical RF network and NF_{min} is the ideal or a theoretical noise figure of a circuit, NF = NF_{min} + matched network factor.

VI. LNA Application

LNA is broadly applicable as an enhancing or even enabling technology within biotechnology, molecular biology research and drug development. Other Application of a low noise amplifier is as follows.

(i)ISM Radios-The industrial, scientific and medical (ISM) radio bands are radio bands (portions of the radio spectrum) reserved internationally for the use of radio frequency (RF) energy for industrial, scientific and medical purposes other than communications. Examples of applications in these bands include radio frequency process heating, microwave ovens, and medical diathermy machines.

(ii) GPS Receiver- Global Positioning System is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. The system provides critical capabilities to military, civil and commercial users around the world. It is maintained by the United States government and is freely accessible to anyone with a GPS receiver.

(iii) Wireless LAN- wireless local area network links two or more devices using any wireless distribution method (typically spread-spectrum or OFDM radio), and usually providing a connection through an access point to the wider Internet. This gives users the mobility to move around within a local coverage area and still be connected to the network. Most modern WLANs are based on IEEE 802.11 standards, marketed under the Wi-Fi brand name.

(iv) Automotive RKE- A remote keyless entry system used to gain entry to automobiles. In optics, RKE may refer to a type of Eyepiece.

(v) Satellite Communication- In a satellite communications system, the ground station receiving antenna will connect to a LNA. The LNA is needed because the received signal is weak; it is usually a little above the noise floor. Satellites have limited power, so they use low power transmitters.

VII. ACKNOWLEDGEMENT

I extend my sincere and heart felt thanks to Ms. Nisha Chigh my project guide for providing me the right ambience for carrying out this work on "**Design of Low Noise Amplifier at 8.72GHz**" and its application when it is still a new and unproven field as well as for their support, encouragement and facilities in completing this project. I am profoundly indebted to Mr. Manhar Tiwari and special thanks to Mr. Akshat Gupta for innumerable acts of timely advice and encouragement.

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