Design Of a Ka-Band Low Noise Amplifier using MMIC

Major Project

Submitted in partial fulfillment of the requirements

for the degree of

Master of Technology

in

Electronics & Communication

(Communication)

By

Attara Bansi

18MECC02

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

Dec 2019

Design Of a Ka-Band Low Noise Amplifier using MMIC

Major Project

Submitted in partial fulfillment of the requirements

for the degree of

Master of Technology

in

Electronics & Communication

(Communication)

By

Attara Bansi

(18MECC02)

Guided By

External Guide

Piyush Sinha

Sci/Engr. 'SF', MSRD

SAC-ISRO

Internal Guide

Prof. Bhavin Kakani

Professor, EC Department

Nirma University.

DEPARTMENT OF ELECTRONICS & COMMUNICATION

INSTITUTE OF TECHNOLOGY, NIRMA UNIVERSITY

AHMEDABAD-382481

Dec 2019

Declaration

This is to certify that

a. The thesis comprises my original work towards the degree of Master of Technology in Communication at Nirma University and has not been submitted elsewhere for a degree.

b. Due acknowledgment has been made in the text to all other material used.

- Attara Bansi

18MECC02

NIRMA UNIVERSITY

INSTITUTE OF TECHNOLOGY

NAAC ACCREDITED 'A' GRADE

Certificate

This is to certify that the major project entitled **"Design Of a Ka-Band Low Noise Amplifier using MMIC"** submitted by **Attara Bansi (Roll No: 18MECC02)**, towards the partial fulfillment of the requirements for the award of degree of Master of Technology in Computer Science and Engineering (Specialization in title case, if applicable) of Nirma University, Ahmedabad, is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

Date: Place: Ahmedabad.

Prof./Prof. Bhavin Kakani
Guide & Assistant Professor,
EC Department,
Institute of Technology,
Nirma University, Ahmedabad.

Prof./Dr. Yogesh Trivedi
Professor,
Coordinator M.Tech - EC(Communication)
Institute of Technology,
Nirma University, Ahmedabad

Dr. Dhaval Pujara
Head, EC Department,
Institute of Technology,
Nirma University, Ahmedabad.

Dr R. N. Patel
Director,
Institute of Technology,
Nirma University, Ahmedabad.

Certificate

This is to certify that the Major Project entitled **"Design Of a Ka-Band Low Noise Amplifier using MMIC"** submitted by **Attara Bansi (18MECC02)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Communication, Nirma University, Ahmedabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination.

- Piyush Sinha
Sci/Engr. 'SF', MSRD
SAC-ISRO Goverment of India
Ahmedabad

Acknowledgements

I take this opportunity to express my profound gratitude and regards to my internship project guide **Prof. Bhavin Kakani** for his exemplary guidance, monitoring and constant encouragement.

I would like to thank **Piyush Sinha**, external guide of my internship project from **Indian Space Research Organization.**, for his valuable time and efforts during the implementation of this project.

I would also like to thanks my Parents, faculty members, friends and colleagues for their constant support and encouragement during this project work.

- Attara Bansi

18MECC02

Abstract

This thesis is about the design of a Ka-band Low Noise Amplifier(LNA) operating between frequency ranges of 26.5-30 GHz. The technical specification of any LNA includes gain, which is approximately between 15-20 dB and minimum low noise figure < 3 dB. The transistor used to design is a p-HEMT model manufactured by United Monolithic Semiconductor which is a low noise transistor model.

The thesis commits the results of the LNA designed for overall frequency range i.e.26.5-30 GHz. It also satisfies the use of Cascode transistor which assists in providing a gain between 16-14dB and a minimum Noise Figure(NFmin) of 2.12-2.13 dB and Noise Figure(NF) < 3 dB. The essential benefit of using Cascode topology is to get high gain and further more application of resistor on drain side provides necessary stability to the design. The matching networks attached at input and output ports helped in achieving gain stability at the respective ports.

Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Background

Communication is only transferring information from one point to another and can be classified into two types i.e. Wired or Wireless and the channel used for communication is Guided or Unguided channels. Wired communication uses a guided medium for communication such as Coaxial cable, Twisted pair and Optical fibers, etc while in wireless communication uses the unguided medium, as there is no physical medium for communication, Antennas are used as a medium.Earlier, wireless communication has played an essential role in human life and still,it is an important part.Smoke signals, flags, and flashing mirrors were used for communication and now the era of modern wireless communication i.e. using electrical signals and radio waves for communication has been evolved. In the year 1897, for the first time, Guglielmo Marconi successfully demonstrated the Wireless Telegraphy by transmitting EM Waves for a short distance around 100 meters which have paved way for Radio communication and the term Radio is derived from Radiant Energy and in early 1990's Marconi successfully communicated using Morse Code which leads to advancement in wireless communication over long distances using cheap devices at low cost. Mobility is one of the important and primary benefits. Along with mobility, flexibility, and ease of use, Ease of installation and reliability etc are also the benefits for wireless communications.

1.2 Introduction

Any wireless system comprises the three important components known as transmitter, receiver, and transmission medium as shown in figure 1.1.

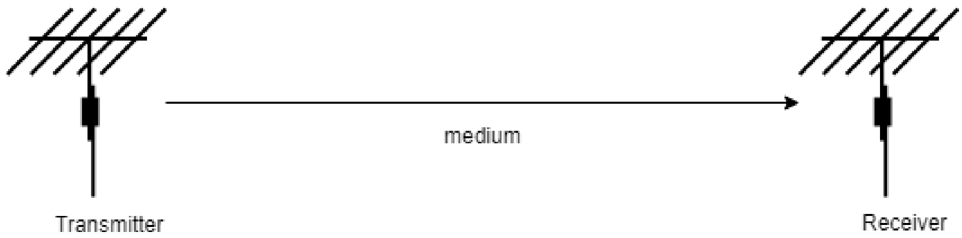

Figure 1.1: Schematic Diagram of wireless communication

- Transmitter: A transmitter is an electronic device that produces radio waves and generates a radio frequency current applied to the antenna, thus it radiates radio waves for communication, radar, and navigational purposes. It can be a separate part of electronic equipment or an integrated circuit (IC) assembled with another electronic device, which includes audio from a microphone, video from a TV camera, or a digital signal for wireless networking devices. It combines the information signal that is to be passed with the RF signal which generates the radio waves (the carrier) and the combining of information signals with RF signal is known as modulation.

- Receiver: A radio receiver is a device that receives radio waves using an antenna and converts the information into a usable form. It can be an integrated circuit (IC) with another device. Several manufacturers have manufactured an integrated receiver circuit such as wireless receiver IC, RF receiver IC, FM receiver IC.

- Transmission medium: Wireless Communication intends to propagates the signal through space. Since, signal transmission in space is possible without any guidance, the medium used in wireless communication is called unguided medium. As there is no physical medium, the transmission and reception of signals are accomplished with Antennas.

- Antenna: Antennas are electrical devices that transform the electrical signals to radio signals in the form of Electromagnetic (EM) waves and vice versa. These EM waves propagates through space. Hence, both the transmitter and receiver consist of an antenna.

The two very important points are to be kept in mind are as follows:

- For long-distance communication, the transmitter should provide a high-power to the antenna so that the signal is received without degradation.
- The receiver should be sensitive enough to detect even the smallest signals and amplify the same with the low possible system noise.

According to the statements mentioned, it is essential that the receiver should be sensitive enough to react to the small signals and provides high gain to it. The receiver comprises different components such as Low Noise Amplifier(LNA), filters, mixer, etc. To make the receiver sensitive, each component must be designed very carefully. But, LNA has to be taken extra care as it is the first module after the antenna in the receiver architecture. LNA is an electronic amplifier that amplifies a low power signal without disturbing its Signal to Noise Ratio (SNR). A microwave amplifier amplifies the power of both the signal and noise present at its input. LNA is designed such that its self-noise is low.

1.3 Motivation

Earlier, the main focus on research was errorless transmission and reception of the signals. With the improvement in the capacity of integration of silicon on a chip which helps a lot in improving performance in generating high integration at low cost. In recent times research for microwaves is replacing costly receivers with a small size and hand-held high-performance receivers' modules which should be highly linear in nature, cost-effective and must also provide high gain and also be receptive to noise.Due to the advancement in semiconductors,new ideas are driven in the direction of high integration including low cost, compactness,low power, significant Research and Development funding, innovations, processing advancement, and electronic circuit developments, the MMIC (Monolithic Microwave Integrated Circuit) is used to replace many discrete circuits with individual transistors, resistors, capacitors, inductors, and element interconnections and because of the circuit size is reduced which is the advantage for using MMIC.The pHEMT (Pseudomorphic High Electron Mobility Transistor) is more used in the field of microwave and millimetre-wave monolithic integrated circuits because of the outstanding high-frequency characteristics, power characteristics and low-noise characteristics, and it is one of the most competitions in the field of microwave and millimetre-wave monolithic integrated circuits.The LNA is the most important component in any front end receive chain, which commands the dynamic range of the receiver and MMIC LNAs with Low noise, high gain, good return loss, low power dissipation, high reliability and compact size are required for many system applications.

1.4 Problem Statement

In RF Circuit Design, the most difficult task is to design an LNA circuit because it is the first block in the receiver part.There will be a trade-off between parameters such as minimum Noise Figure(NF), maximum gain, and stability which has to be also taken into account while designing. To obtain a minimum noise figure, there will be compromise in the gain i.e. it will decrease. While stabilizing the LNA, trade-off between transistor size, Noise figure and Gain will be observed. Thus to avoid the trade-offs, it is necessary for the amplifier to be a low noise amplifier. By comprising impedance matching, selection of the amplification gain, linearity, and choice of the desired range of frequencies, LNA's noise can be minimized.

1.5 Objective

The goal is to design a narrowband LNA operating between 26.5-30 GHz using Microwave Monolithic Integrated Circuit (MMIC) technique. Design can be carried out in such a way that it could achieve specification mentioned in Table 1.1.

Table 1.1: LNA Specification

Parameters	**Expected**
minimum Noise Figure (Nfmin)	< 3dB
Maximum Gain (MaxGain)	between 15-20 dB
S_{21}	between 15-20 dB
S_{11}	< -10 dB
S_{22}	< -10 dB

1.6 Project Scope

The primary focus of this thesis is to design a high frequency band LNA whose parameters must be as mentioned in Table 1.1. The secondary focus of this thesis is to optimize the trade-offs, and successfully obtain the expected values of parameters such as Nfmin, MaxGain and S parameters so that the design can be used for general purpose applications of wireless communication.

1.7 Outline of the thesis

The rest of the thesis is organized as follows.

Chapter 2 starts with literature survey and followed by basics of RF, design, Technology used to design the LNA (i.e. 0.25μm PH25 low noise process design kit) and about various active and passive components used for designing LNA. Chapter 3 describes functioning of the LNA and the design parameters such as stability, s-parameters, Noise Figure, Signal to Noise Ratio, and Gain which used for designing LNA.

Chapter 4 discusses the schematic design of the LNA including the results. Chapter 5 includes the conclusion of the thesis which consistes of challenges faced during LNA design and solution to them and the future work.

Chapter 2

Literature Survey

2.1 Literature review

S.D. Nsele, C. Robin, et al. explains that Low noise amplifiers in receivers are typically addressed by III-V (narrow bandgap) technologies: however once the receivers are subject to EM exposure or jamming, the requirement for protection devices before the active low noise electronic equipment (LNA) degrades the noise figure, and reduces the effective radio link budget. This vulnerability of the LNA is overcome thanks to robust technologies or designs. Nitride technologies are investigated for power modules in transmitters and stand as promising solutions to avoid the employment of limiters for robust low noise circuits in receivers. This work focuses on HF noise in InAlN/GaN HEMT devices and circuits for Ka-band SATCOM applications. completely different versions of LNA are designed at 30 Ghz, in hybrid and MMIC technologies. For these designs, 1-stage and 3-stages LNAs are realized; 1-stage amplifiers are designed to assess and study the strain tolerance under RF signal, whereas 3-stages LNAs are designed as demonstrators of operational module for receiver's blocks (Gain $>$ 20 dB that includes rock bottom noise figure achievable).[1]

David Cuadrado-Calle, Danielle George, and Gary Fuller shows that a low noise electronic equipment (LNA) has been designed to operate across the Ka-band from 26 GHz to 36 GHz. it's been designed employing a commercial 100 nm GaAs method, and according to the simulations, it presents a mean gain of 13 dB, a noise figure $<$ 1.8 dB and return loss better than -12 dB at each the input and therefore the output. To the data of the authors, the performance of this LNA would be superior to any other GaAs based mostly LNA to date according within the same frequency band at temperature.

By increasing demand of arrays and multi-pixel systems in astronomy, the utilization of this affordable LNA during this new thought is mentioned in this paper Two possible applications of this LNA, in the new 13.2 meter astronomical telescope of Yebes (Spain), and a use in large format arrays, are going to be highlighted and a attainable 10 percent reduction in observant time are shown in this paper.[2]

Hiren V Bhalani and N. M. Prabhakar presents the basic study and literature survey on LNA and Advance style System (ADS). Low noise electronic equipment (LNA) is one in all the essential building blocks of a communication system. The aim of the LNA is to amplify the received signal to acceptable levels whereas minimizing the noise it adds. The low noise electronic equipment is employed in communication systems to amplify terribly weak signals captured by associate antenna. It's usually settled terribly about to the antenna thereby creating losses within the feed-line less essential. .Gain, noise figure, return loss, P1dB, third order intercept point are most the vital parameter in LNA. Here design flow for LNA is enclosed. The foremost vital task within the style is to ascertain a trade-off between the noise figure and gain of the electronic equipment. Advanced style software system (ADS) is employed to carry out simulations for observation how the design is corresponding to the specifications.[3]

The two major applications of microwave remote sensors are radiometer and radar. Lots of researches are conducted on the many aspects of radiometer and radar but internal logical design is generally unnoticed by researchers thanks to its digital logic and sophisticated nature. This paper concentrate on meter from a style purpose of read and a coffee noise electronic equipment is meant and proved mathematically to confirm the high performance and dealing. The paper stress on a study of frequency communications and engineering, as well as understanding of the Radio Frequency (RF) circuits. Moreover, sensible implementation and performance analysis of low noise electronic equipment for meter is additionally mentioned during this paper. Scientifically, the paper is split into two components. Within the initial half, some study concerning the radiometer and its types was carried out in order that a basic understanding are often developed by the reader. And within the second half low noise electronic equipment (LNA) for the radiometer was designed.[4]

C. S. Wu et al. presents good performance, high yield Ka-band multifunctional MMIC results victimisation our recently developed 0.25 μm gate length pseudomorphic HEMT

(PHEMT) manufacturing technology. Four sorts of MMIC transceiver components-low noise amplifiers, power amplifiers, mixers, and voltage controlled oscillators-were processed on an equivalent PHEMT wafer, and were made-up using a common gate recess process. High performance and high producibility for all four MMIC elements was achieved through the improvement of the device epitaxial structure, a method with wide margins for critical method and design that afford diffetent process, leading to important performance margins. They obtained glorious results for the Ka-band power amplifier:greater than 26 dBm output power at center frequency with 4.0 percent variance over the 3-in. wafer, 2-GHz information measure, greater than 20 percent power-added efficiency , over eight decibel associated gain, and over ten decibel linear gain. the most effective performance for the Ka-band LNA was over 17 dB gain and 3.5 dB noise figure at Ka-band. during this paper, we have a tendency to report our device, process, and circuit approach to realize the progressive performance and producibility of our MMIC chips.[16]

2.2 Radio Frequency

Radio frequency (RF) is any of the electromagnetic wave frequencies that lie in the range starting from around 3 kHz to 300 GHz. RF field can be used for various wireless Broadcasting and Communications with the help of antennas, transmitters and receivers. RF spectrum is separated into several ranges and bands. Except for low-frequency segment, each band signify an increase of frequency equivalent to an order of magnitude (power of 10). The following table 2.1 describes the eight bands in the RF spectrum, showing frequency and bandwidth ranges. The Super High Frequency (SHF) and extremely High frequency (EHF) bands are denoted as the microwave spectrum. The purpose of using a high frequency spectrum is because its spectrum is quite evenly segmented, it also includes efficiency in propagation, immune to some noises and losses as well as the size of the required antenna. Generally, antenna size is related to the wavelength of the signal and practically it is $1/4^{th}$ wavelength. Increase in demand of high frequency application leads to development in receivers which in turn increases the demand in LNA designing.

Table 2.1: RF frequency spectrum [12]

Designation	**Frequency**	**Free-space wavelengths**	**Application**
Very Low Frequency (VLF)	9kHz-30kHz	33km to 10km	Maritime radio, navigation
Low Frequency (LF)	30kHz-300kHz	10km to 1km	Maritime radio, navigation
Medium Frequency (MF)	300kHz-3MHz	1km to 100m	AM radio, aviation radio, navigation
High Frequency (HF)	3MHz-30MHz	100m to 10m	Shortwave radio
Ultra-High Frequency (UHF)	300MHz-3GHz	1m to 100mm	UHF television, mobile phones, GPS, Wi-Fi, 4G
Super High Frequency (SHF)	3GHz-30GHz	100mm to 10mm	Satellite communication, Wi-Fi
Extremely High Frequency (EHF)	30GHz-300GHz	10mm to 1mm	Radio astronomy, satellite communication

2.3 MMIC Technique

2.3.1 Introduction

The abbreviation MMIC stands for Monolithic Microwave Integrated Circuit. The word “Monolithic” describes the characteristics of MMIC’s (i.e. they are manufactured from a single part of semiconductor material.). The word “Microwave” refers to the signal frequency range for which they are used, which covers the wavelength from 1 mm to 1 m and relates to frequencies from 300 MHz to 300 GHz. The word “Integrated Circuit” indicates that the semiconductor material does not contain only transistors, diodes and many more active devices but also passive devices such as resistors, inductors, and capacitors, composed with all their interconnections, framing a whole system.

2.3.2 History

Table 2.2 shows the evolution of MMIC which started in the year 1961 and still the growth of MMIC continues.

Table 2.2: Evolution of MMIC [7]

Year	Evolution	Inventor
1961	The first step towards monolithic circuits	Jan Czochralski[17]
1959	Patented first IC made of germanium (Ge) using photolithography	Jack Kilby of Texas Instruments[18]
1966	First silicon ICs operating at microwave frequencies was an X-band transmit/receive switch was developed	A Ertel[19]
1962	Interest in other semiconductor material was increasing and the liquid-encapsulated Czochralski (LEC) method was developed for growing single crystals of materials with high vapour pressures at their melting points, initially applied to lead selenium (PbSe) and lead tellurium (PbTe).	J. Mazelski, R.C. Miller[20]
1965	First GaAs field effect transistors were fabricated	Jim Turner at Plessey Research, Caswell, in the United Kingdom[21] and by C.A. Mead at the California University of technology in the United States.[22]
1967	Produced a 4µm-gate-length GaAs metal-semiconductor field effect transistor (MESFET)	W. W. Hooper and W. I. Lehrer[23]
1976	First monolithic microwave integrated circuit, or MMIC, using a field-effect transistor was reported	R. S. Pengelly and J. A. Turner[24]

MMIC growth was speeded up in 1979, the Institute of Electrical and Electronics Engineers (IEEE) established the first symposium dedicated to GaAs IC developments, and in 1985, the increased optimism in the industry was observed when Plessey Caswell accredited a 0.7-µm-gate-length MESFET MMIC process on 2-in.-diameter GaAs wafers. In the year 1985 also publicized the period of "band-gap engineering", which is the technique of mixing various semiconductor materials to create transistors with specific solid-state properties and finally led to the development of a high-electron-mobility-transistor (HEMT) low noise amplifier (LNA) MMIC in 1989.[25] Other discoveries along the MMIC development pathway involves the representation of an indium phosphide (InP) 5-100 GHz travelling wave amplifier in 1990 and the launch of Plessy's commercial 0.2-µm-gate-length pseudomorphic HEMT (pHEMT)[26] process in 1996. At present, there are MMIC processes on various semiconductor materials with transistors that exhibit gain over the whole of the microwave frequency range. Silicon MMICs are also in betterment of using transmission line techniques that defeat the substrate loss problems[27][28][29] and silicon-germanium (SiGe) transistors with frequency responses comparable with GaAs.[30] The future of MMICs looks convinced to continue in the focus of even more exotic semiconductor materials and even more complicated design techniques, where the ultimate capabilities of the chips will be limited only by engineer's imaginations. To sum up the history of MMIC development, MMICs appered because they combines high performance microwave transistors with low-loss passive components and transmission lines and can be formed as complex circuits with multiple interconnections using just a few photolithographic process steps.[7]

2.3.3 Comparision of MMICs over Hybrid MIC

Table 2.3: Comparison of MMIC over Hybrid MIC [7]

MMICs	**Hybrid MICs**
Cheap in large quantities; especially economical for complex circuits	Simple circuits can be cheaper, automatic assembly is possible
Very good reproducibility	Poor reproducibility due to device placement and bondwires
Small and light	Compact multilayer substrates with embedded passives now available
Reliable	Hybrids are mostly 'glued' together and so reliability suffers
Fewer parasitic- more bandwidth and higher frequencies	The best transistors are always available for LNAs and Pas
Space is at a premium; the circuit must be made as small as possible	Substrate is cheap, which allows microstrip to be used abundantly
Very limited choice of components	A vast selection of devices and components is available
Very expensive to start up	Very little capital equipment is required

2.3.4 Applications of MMICs

The major applications of MMICs are military, space and civil which further includes applications such as communication satellites, Phased array radar, Radiometers, and many more.

2.4 Technological Overview

MMIC design has its own design rules or design kits which are manufactured by companies such as Agilent, UMS, National semiconductor, and many more. Some of the process kits are GH15, PH25, PH15,etc. All the circuits in this thesis are developed in a 0.25μm PH25 P-HEMT process supported by United Monolithic Semiconductor (UMS) and designed in Advanced Design System (ADS). For all transistor-level design and analysis, software packages developed for ADS from Keysight is used. The 0.25μm P-HEMT process is optimized for low noise and multipurpose operation up to 60 GHz. The process comprises two metal interconnect layers, TaN resistors, TiWSi resistors, MIM capacitors, air-bridges, and via-holes through the substrate. The PH25 process is developed to enable the production of LNA up to 60GHz. FET characterization was prepared by means of 2-60GHz S-parameter on-wafer measurements, as well as additional on-wafer DC measurements.

The conventions used in the manual are:[11]

- L: gate length: 0.25μm
- N: number of gate fingers
- Nd: number of drain fingers
- W: total gate width(μm)
- Wu: unit gate finger width(μm)
- Ft: current gain cut-off frequency

Table 2.4: Values of Parameter of pHEMT transistor in PH25 process [11]

Pinch-off voltage	V_{ds}=2.5V ;$I_{ds}=I_{dss}/100$	V_p	-0.75V
Optimum current	V_{ds}=2.5V ; $V_{gs}=V_{gsopt}$	I_{dsopt}	220mA/mm
Optimum transconductance	V_{ds}=2.5V; $I_{ds}=I_{ds}$ (Gmopt)	Gm_{opt}	500mS/mm
Optimum gate voltage	V_{ds}=2.5V; $I_{ds}=I_{dsopt}$	V_{gsopt}	-0.25V
Breakdown voltage	$I_{ds}=I_{ds}/100$	V_{bds}	$>$ 6V
Cut-off frequency		F_t	90GHz

2.5 Active Component

2.5.1 Evolution of Active Components

Bipolar junction transistors (BJT)

A bipolar transistor is a current controlled device. It is perhaps due to the current gain beta β, which is a ratio between the base current and the collector current. BJT works likewise to FET and is indeed voltage controlled. The difference is that it requires other control voltages on base. Commonly biased with V_{cc} +5 V on the collector while the emitter is grounded, so that current can flow from collector to emitter. In simple, the current is controlled by the voltage (V_{BE}). If $V_{BE} = 0$ V, then the transistor is turned "off" and no current will pass through it and if the voltage between the base and the emitter is higher than 0.7 V, $V_{BE} > 0.7$ V, then the current will begin to flow and the transistor will be turned "on". Bipolar transistor regions (collector, base and emitter) can be doped n-p-n or else p-np, where n-type is for negative charge and p-type is for a positive charge, directing it to have a p-n junction. They are not in much use because of their low electron mobility. As BJT's have low electron mobility and high base resistance, they are used often.

Heterojunction bipolar transistors (HBT)

Heterojunction bipolar transistors are similar to BJT. The difference is the base-emitter junction which is a link between two different substrates. Examples of various base-emitter substrates are, AlGaAs emitter and GaAs base, InGaP emitter and GaAs base, InP emitter and InGaAs base. It is mandatory to have high injection efficiency which is a ratio between electrons that are injected from the emitter into the base and holes that are injected from the base into the emitter. They obtain its injection efficiency by having different band-gap energy levels at the junction which means the base can get heavily doped which leads to less base resistance. If the base resistance reduced, the device transit time is also reduced and frequency is increased.

Field Effect Transistor (FET)

FETs operate with a positive drain voltage,V_{DD}, however, the source is grounded. The consequent effect is that current flows from drain to source, known as the drain current I_D. The gate-source voltage V_{GS} is controlling the drain current. For example, if the V_{GS} = 0V then the drain current will pass which means the FET is switched "on". Instead of the gate voltage is large or negative, for example, -5 V, then no current will pass and FET is switched "off".The current is flowing across the substrate surface and passing under the gate contact. Categorization of FETs is metal-semiconductor field effect transistor (MESFET) and high electron-mobility transistor (HEMT).

Metal Semiconductor Field Effect Transistor (MESFET)

The name MESFET is called Metal Semiconductor Field Effect Transistor because there is a metal to semiconductor junction at the gate contact. It includes two ohmic contacts and metal-semiconductor Schottky barrier (gate). When operational, the current passes via conduction channel from source to drain under the gate contact. In Unipolar device, current flows parallel via the surface of the device, while in the bipolar device the current flows perpendicular to the surface. MESFET is unipolar because the current is carried either by electrons or holes and flows in a parallel direction. In bipolar devices, the transport relies upon both electrons and holes. In general, MESFETs, the current is moves by electrons which makes the channel n-type and if it is moved by holes than it is said to be p-type.

High Electron Mobility Transistor (HEMT)

HEMTs are similar to FETs in operation. The channel has a junction of two different semiconductor materials which gives the free electrons higher channel mobility is the only difference. Furthermore, other improvements are high frequency noise and gain characteristics. An example of a HEMT is a material combination between GaAs with AlGaAs where AlGaAs forms doped and undoped layers.

Pseudomorphic High Electron Mobility(pHEMT)

GaAs based pseudomorphic HEMT (pHEMT) has arisen as one of the most important technologies for advanced microwave and millimetre wave systems. It is usefull for multifunctional applications such as high power, high efficiency, and low noise at frequencies ranging from C-band up to W-band due to its broad applicability to a multitude of system requirements and there is an growing demand for pHEMT-based products. pHEMT manufacturing technology desperately needs to be formed to cope with this increasing demand at microwave and millimetre wave frequencies. In the past some years, scientists had worked intensively on the development of advanced pHEMT technology for microwave and millimetre-wave applications for achieving a high- yield, high-performance pHEMT manufacturing technology. One can optimize the device structure and demonstrate superior performance Ka-band multifunctional pHEMT MMIC LNA's, power amplifiers (PA's), mixers, and voltage-controlled oscillators (VCO's), all fabricated on the same wafer.

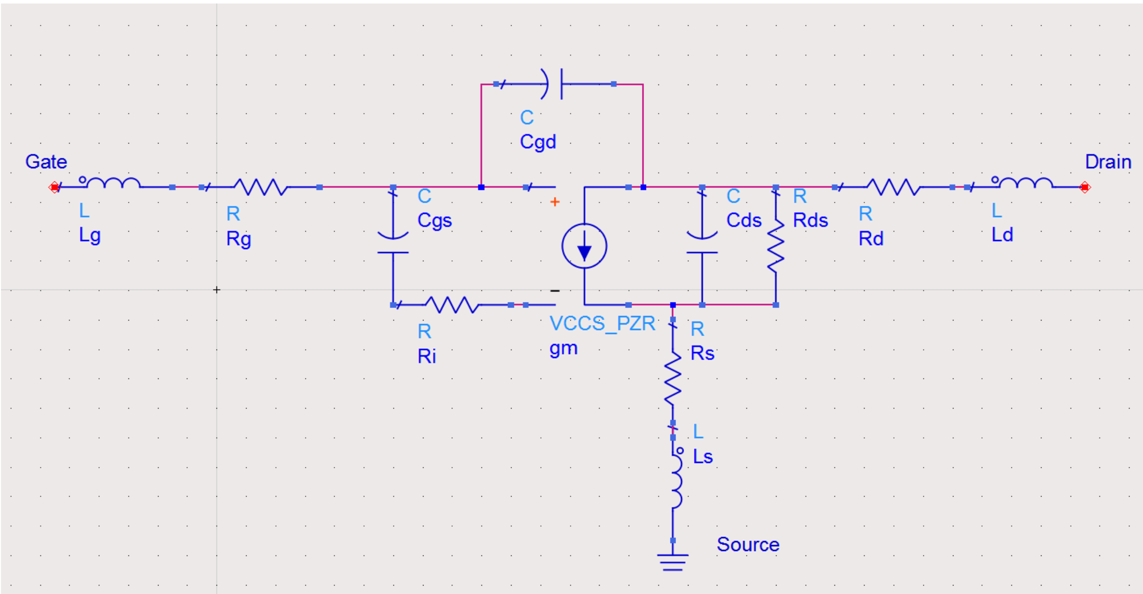

Figure 2.1: P-HEMT Small-Signal Model[11]

A single-stage microwave transistor amplifier can be modelled in figure 2.1. The process selection of MMIC's for LNA is mostly determined by the operating frequency and required efficiency. At low microwave frequencies (< 10 GHz) MESFET and HBT can be used and HBT is usually more efficient. Instead at millimetre-wave frequencies (> 10 GHz) HEMT and p-HEMT are the most commonly used processes.

2.6 Passive Component

2.6.1 Spiral Inductor

Inductance is a calibrate the distribution of the magnetic field near and inside a current carrying conductor and it is the property of the physical layout of the conductor, that has the capability to measure the conductor to link magnetic flux or to store magnetic energy. Magnetic energy storage circuit elements are called as inductors which come in a variety of shapes and sizes, ranging from toroids and solenoids for relatively large-scale circuits to monolithic structures for integrated circuits. An example of the monolithic type is a planar microstrip spiral inductor which is an integral part of many radio frequency (RF) circuits.

The effects that limit a spiral inductor's performance at high frequencies are as follows:

- Electric field penetration into the substrate
- Skin effect—current redistribution within the metal conductor cross-section
- Proximity effect—current redistribution due to neighbouring current carrying conductors
- Magnetic field penetration into the substrate.

The Electric fiel inserting into the substrate effect is caused by time-varying electric fields and the remaining three effects are due to their time-varying magnetic fields. As spiral inductors are the vital part of many RF circuits, and a perfect model for microstrip spiral inductors can accurately anticipate the device performance.Planar spiral inductors have limited Quality factor(Q) as it is frequency dependant (i.e. if frequency increases Q increase and vice-versa). Square or rectangular spirals are popular because of the ease of their layout and analysis. Table 2.5 consists of valid values used in designing given by MMIC process.A commonly used model for designing planar inductors is illustrated in Figure 2.3.

Table 2.5: Values of Spiral inductor [11]

Inductance	L	0.12 to 12.65nH
Number of turns	N	1 to 9.75(accord. W)
Number of vertices	–	4 per turn
Strip width	W	5, 10, 15, or 20μm
Strip spacing	S	5μm
Bridge Width	Wb	22μm
Metal sheet resistance	-	11mΩ
Maximum Direct Current	-	37mA for W=5μm; 44mA for W=10, 15, or 20μm

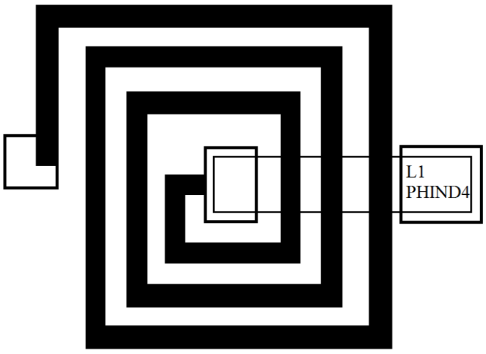

Figure 2.2: MMIC – Spiral inductor[11]

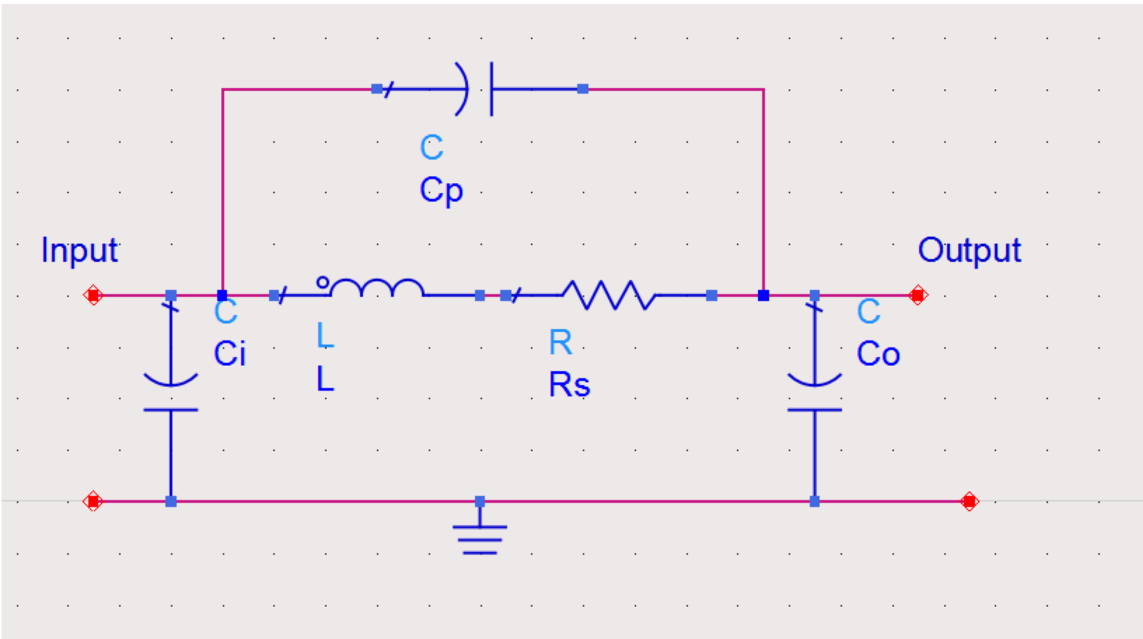

Figure 2.3: Equivalent model of the spiral inductor[11]

2.6.2 MIM Capacitor

MIM stands for metal insulator metal. A MIM capacitor contains a dielectric cap that increases the performance and reduces the damage to MIM insulators during manufacture. An insulative substrate there is a gap called cavity and the first metal layer and insulator layer are conformally deposited. A second metal layer may be deposited conformally and/or to fill a remaining portion of the cavity. The dielectric cap may be an extra layer of insulative material deposited at ends of the insulator at an opening of the cavity and may also be formed as part of the insulator layer. The size of MIM capacitors is limited because it usually includes two metal plates with an insulator between the plates because of different geometries. From different designs, rectangular ones are used commonly.Table 2.6 consists of valid values used in designing given by MMIC process.A commonly used model for designing MMIC Capacitor is illustrated in Figure 2.5.

Table 2.6: Values of Spiral inductor [11]

Capacitor range	0.2 to 10 pF
Capacitor density	330 $\pm$ 40 pF/mm^2
Maximum operating DC voltage	15 V
Minimum breakdown voltage	30 V
Maximum unit air-bridge width	20 μm

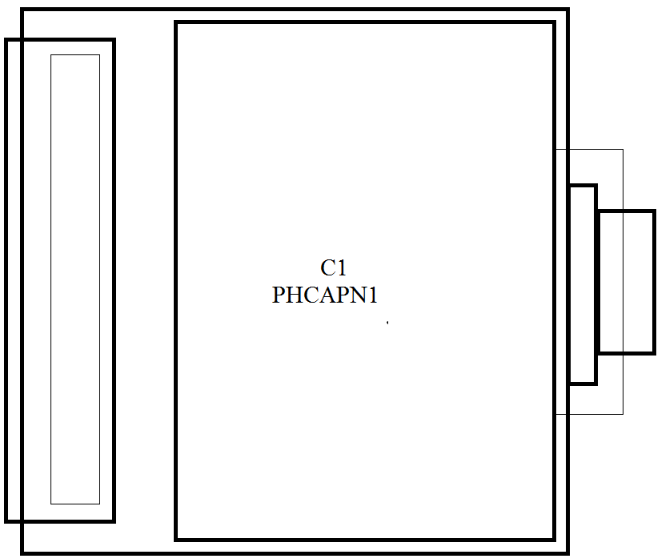

Figure 2.4: MMIC – MIM Capacitor[11]

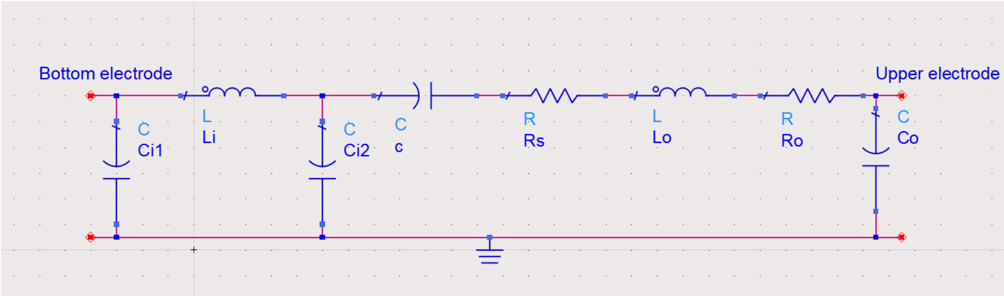

Figure 2.5: Equivalent model of MIM Capacitor[11]

2.6.3 Resistors

Tantalum Nitride (TaN) Resistor[11]

RM metallic resistors are made by depositing a tantalum nitride layer (TaN) which is protected by a Si3N4 layer. Contacts are made using metal layer N1 and metal layer EL.Table 2.7 consists of valid values used in designing given by MMIC process.

Table 2.7: Values of TaN resistor [11]

Minimum TaN strip width	4μm
Sheet resistance (300K)	30±4 Ω/sq
Maximum DC current/unit width	0.4 mA/μm
Temperature coefficient	-275 ppm/ ℃

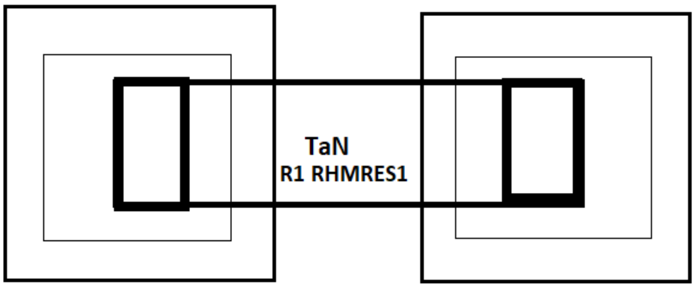

Figure 2.6: MMIC – TaN resistor[11]

Titanium Tungsten Silicon (TiWSi) Resistor[11]

RHRW metallic resistors are made by depositing a TiWSi layer protected by Si_3N_4. Contacts are made using metal layer N1 and metal layer EL.Table 2.8 consists of valid values used in designing given by MMIC process.

Table 2.8: Values of TiWSi resistor [11]

Minimum TaN strip width	4μm
Sheet resistance (300K)	1000±200 Ω/sq
Maximum DC current/unit width	0.10 mA/μm
Temperature coefficient	-1500 ppm/℃

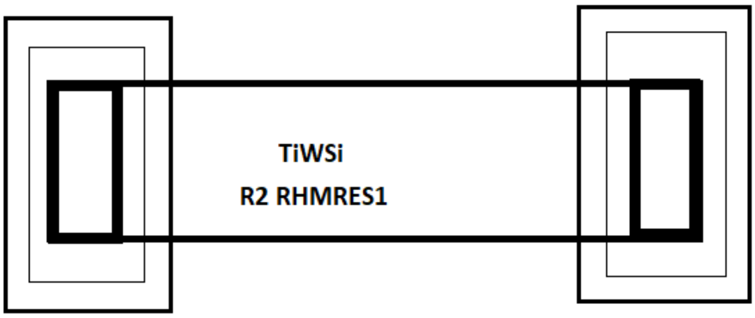

Figure 2.7: MMIC – TiWSi resistor[11]

Gallium Arsenide (GaAs) Resistor[11]

GaAs resistor parameters are summarized in the following table 2.9

Table 2.9: Values of TaN resistor [11]

Sheet resistance	Rsq	120 ± 20 Ω/sq
Contact resistance	Rco	150 Ω* μm
Temperature variation	(I/R)*(dR/dT)	+1700 ppm/℃
Minimum width	Wmin	4μm
Maximum electrical field	Emax = Vmax/L	0.1 V/ μm
Maximum current	Imax/W	0.8 mA/ μm

A commonly used model for designing Resistors in RF is illustrated in Figure 2.9.

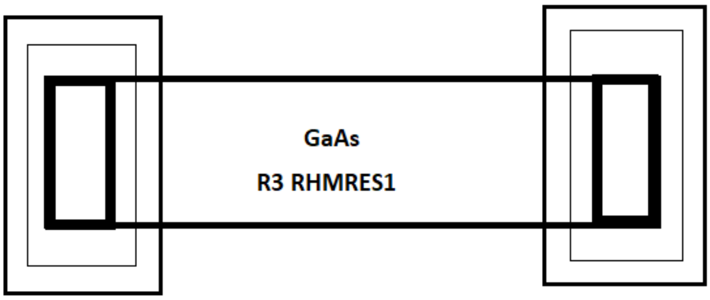

Figure 2.8: MMIC – GaAs resistor[11]

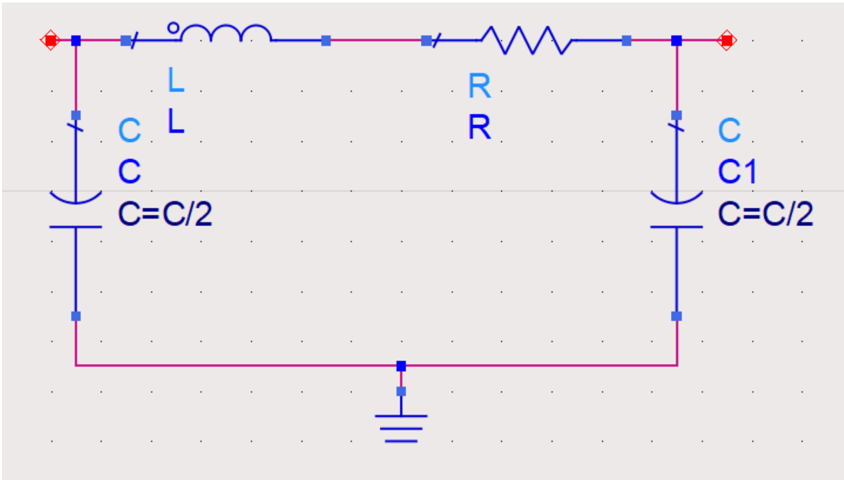

Figure 2.9: Equivalent model of TaN ,TiWSi ,GaAs resistor[11]

Chapter 3

LNA parameters

3.1 Microwave Amplifier

An amplifier is an electronic device that amplifies the voltage, current, or power of a signal. They are used in wireless communications and broadcasting, and in acoustic equipment of all kinds.They can be classified as either weak-signal amplifiers or power amplifiers.

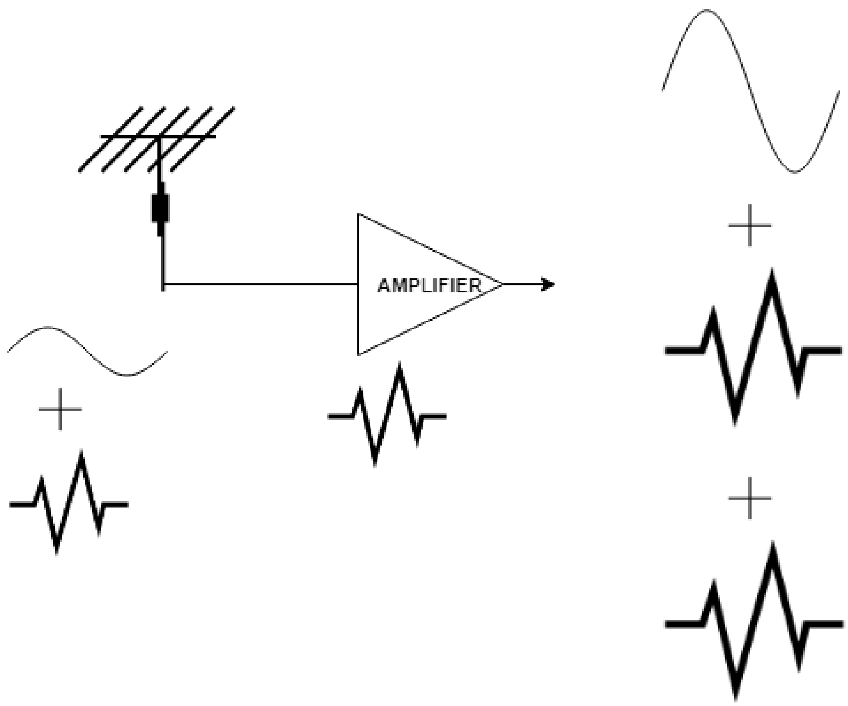

Figure 3.1: Functioning of an amplifier

Figure 3.1 shows the working of an amplifier. The data will have some amount of noise and message signal, this data is passed through an amplifier.As the amplifier also has its own noise which will also get amplified with the data.

3.2 Low Noise Amplifier

An LNA is an electronic amplifier that amplifies a very low-power signal without much degradation in its signal-to-noise ratio (SNR). An amplifier increases not only signal power but also noise power present at the input.

3.2.1 Functioning of an LNA

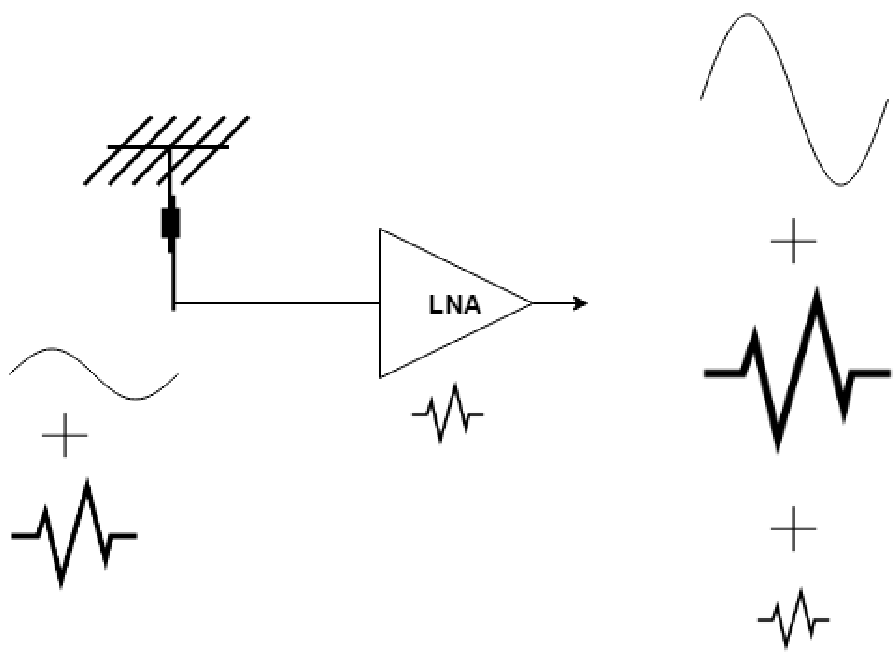

Figure 3.2: Functioning of an LNA

$$SNR_{in} = \frac{Signal\,power}{Noise\,power} \tag{3.1}$$

$$SNR_{out} = \frac{Gain * Signal\,power}{Gain * Noise\,power \; + \; Amplifier\,noise} \tag{3.2}$$

Equation 3.1 and 3.2 illustrates the SNR at the input of the LNA and the SNR at the output of the LNA respectively. According to equation 3.2, SNR_{out} is inversely proportional to Amplifiers noise and as SNR should be high value but as the operation of the amplifier is to amplify the data signal which will also amplify the amplifier's noise which will degrade the SNRout. Thus the job of the LNA is to decrease the Amplifier's noise and amplify the data signal.

3.2.2 Design Flow of LNA

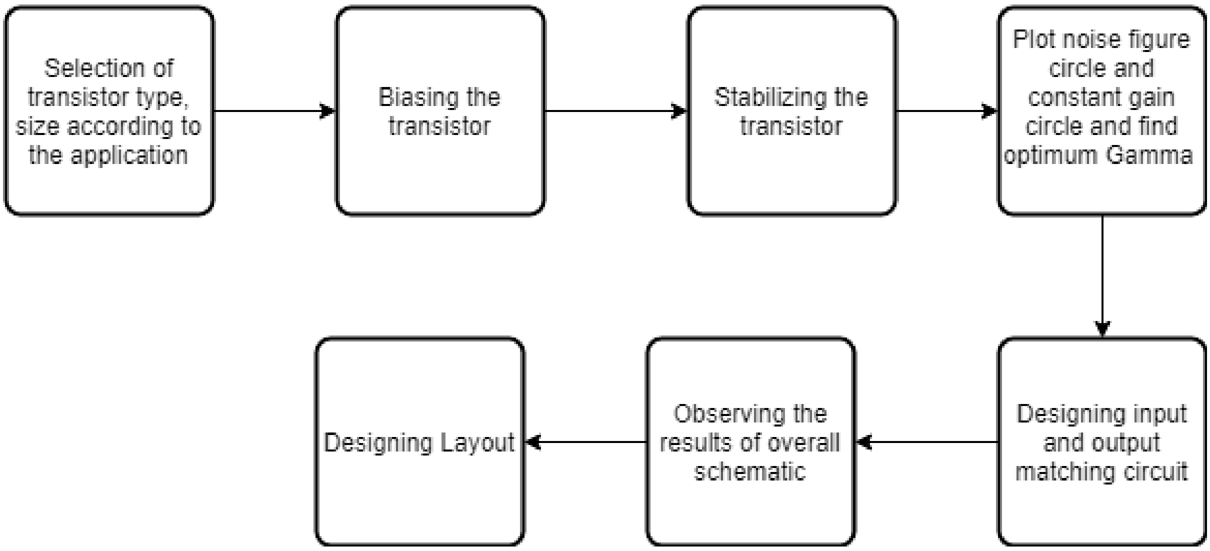

Figure 3.3: Flow of an LNA Design

Figure 3.3 describes the Design flow for designing the LNA. The design process will start with transistor selection followed by biasing, stabilizing, matching and end with layout designing. The purpose of biasing is to set the transistors DC operating voltage or current conditions to the correct level so that any AC input signal can be amplified correctly by the transistor while reason for stabilizing the transistor is to avoid oscillations when it is used practically and motive for designing matching circuit is to transfer maximum power in the LNA circuit. If the results are satisfactory then layout is designed.The typical value of Noise Figure(NF) of any LNA operating around Ka-Band is nearly to 3dB.

3.3 Parameter of LNA

3.3.1 Scattering parameters

For high frequencies, it is easy to define a given network in terms of waves instead of voltages or currents. Microwave theory which is about power quantities rather than Voltage or current. Measurement of high-frequency voltages and currents in labs seems very difficult but measuring the average power is comparatively easy. The parameter used for measurement of power quantities of microwave theory models devices and circuits. These parameters are known as scattering parameters or S- parameters which helps in measuring the gain and impedance matching and also the information regarding frequency, characteristcic impedance, assigning the ports and operating environment known as temperature and bias voltage using s-parameter tool in ADS.
S-Parameters for any two-port network is defined as:

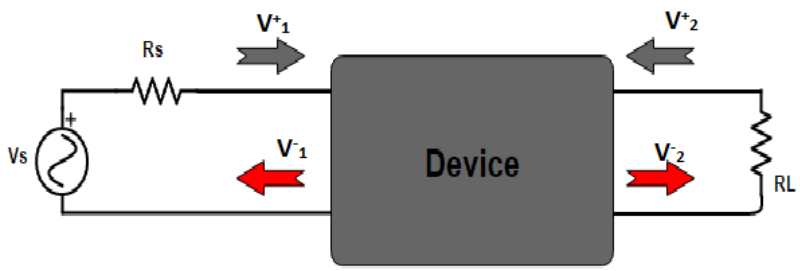

Figure 3.4: 2-port device[13]

Figure 3.3 describes a 2-port device showing reflected and incident waves of the device where
V_1^+ = incident wave at the input side
V_1^- = reflected wave at the input side
V_2^+ = incident wave at the output side
V_2^- = reflected wave at the output side
The S-parameter for 2 port device are commonly used.

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \tag{3.3}$$

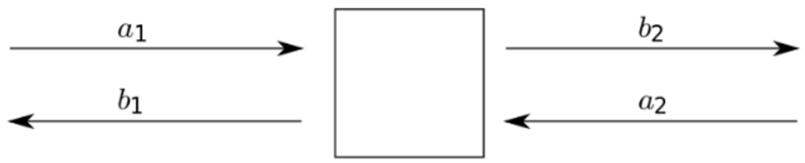

Figure 3.5: Block diagram for representing the S-parameter matrix [13]

$$b_1 = S_{11}.a_1 + S_{12}.a_2 \tag{3.4}$$

$$b_2 = S_{21}.a_1 + S_{22}.a_2 \tag{3.5}$$

Equation 3.3,3.4 and 3.5 shows the S-parameter matrix and it's solution respectively and from the above equations, we can derive 4 parameters which are S_{11}, S_{12}, S_{21}, and S_{22}.

3.3.2 S_{11}

S_{11} represents the accuracy of the Input matching. It is also known as input return loss.

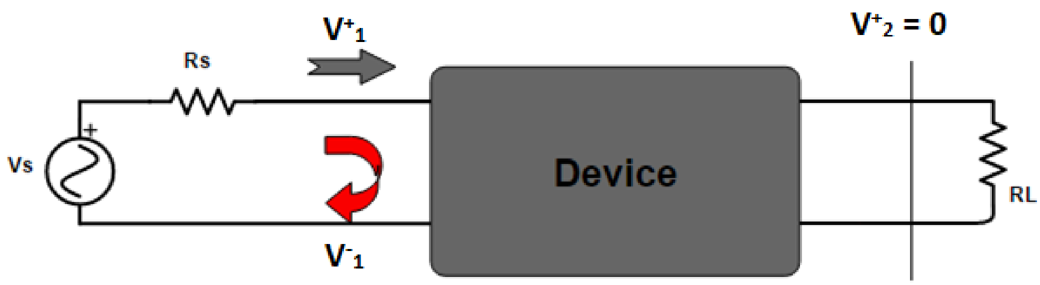

Figure 3.6: 2-port device model representing the S_{11} parameter[13]

$$S_{11} = \frac{V_1^-}{V_1^+} \, for \, V_2^+ = 0 \tag{3.6}$$

$$S_{11} = 10 \log \frac{V_1^-}{V_1^+} \, dB \tag{3.7}$$

$$S_{11} \leq 10 \, dB \tag{3.8}$$

3.3.3 S_{12}

S_{12} shows the reverse isolation of the circuit. Reverse isolation means how satisfactory the signal applied is isolated at the output device from the input device.

Figure 3.7: 2-port device model representing the S12 parameter[13]

$$S_{12} = \frac{V_1^-}{V_2^+} \, for \; V_1^+ = 0 \tag{3.9}$$

$$S_{12} = 10 \log \frac{V_1^-}{V_2^+} \, dB \tag{3.10}$$

3.3.4 S_{21}

S_{21} shows the Gain of the circuit. It is also known as insertion loss.

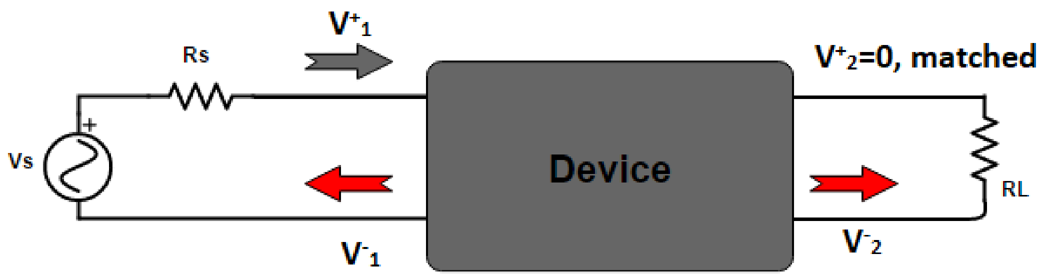

Figure 3.8: 2-port device model representing the S21 parameter[13]

$$S_{21} = \frac{V_2^-}{V_1^+} \, for \; V_2^+ = 0 \tag{3.11}$$

$$S_{21} = 10 \log \frac{V_2^-}{V_1^+} \, dB \tag{3.12}$$

3.3.5 S_{22}

S_{22} shows the accuracy of the output matching. It is also known as output return loss.

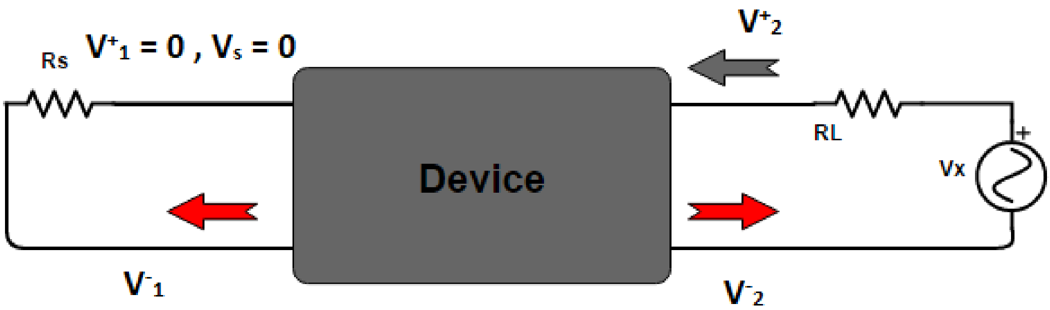

Figure 3.9: 2-port device model representing the S22 parameter[13]

$$S_{22} = \frac{V_2^-}{V_2^+} \, for \, V_1^+ = 0 \tag{3.13}$$

$$S_{22} = 10 \log \frac{V_2^-}{V_2^+} \, dB \tag{3.14}$$

$$S_{22} \leq 10 \, dB \tag{3.15}$$

3.3.6 Noise

Noise is random. It spreads in various forms across the frequency spectrum but does not have the same amplitude every time. According to the frequency distribution, noise is categorised in different forms.

- White Noise: It is the type of noise which will affect all frequencies and can spreads from zero frequency upwards with a flat amplitude.

- Pink noise: It does not have a flat response and its power density decreases with increasing frequency.
- Band Limited noise: It can have its frequency band-limited using filters or the circuit through which it passes.

Noise can affect the data through variation in amplitude, can cause data errors, increase in bit error rate and also affect the SNR.

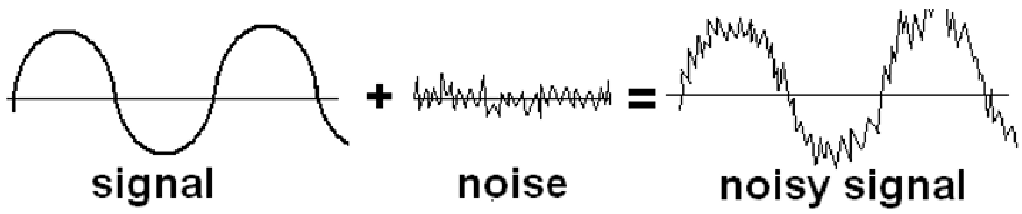

Figure 3.10: Output of a 2-port noisy device [14]

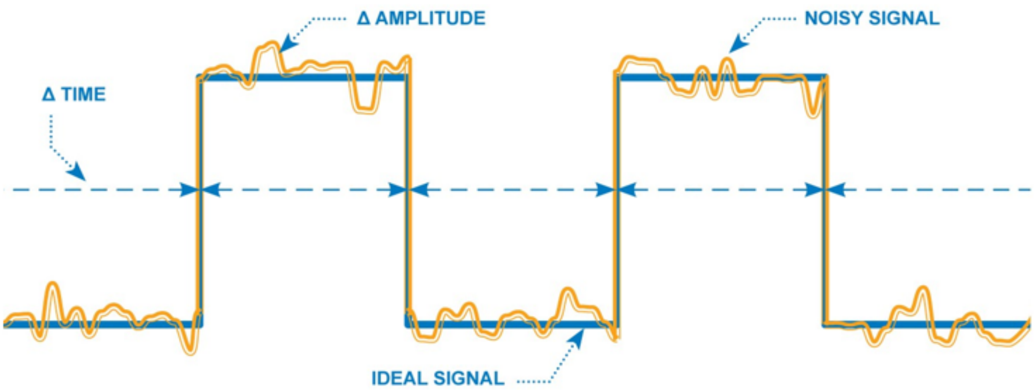

Figure 3.11: Error in amplitude due to noise[14]

Figure 3.10 and 3.11 describes the output signal of a noisy device and the amplitude error occurs when the signal is passed through the noisy device. It is assumed that the output signal will have amplitude A but there will Δ error in the amplitude.

Different types of Noise are:[14]

- Thermal noise: Thermal excitation of charge carriers – generally electrons - in a conductor.
- Shot noise: It arises from the fluctuation in electrical current which is time-dependant originated from the discrete nature of electric current.
- Phase noise: It is a form of RF noise which is visible on Phase noise is a form of RF noise which visible on radio-frequency and appears in the form of phase jitter or agitation on the signal.
- Flicker noise, (1/f noise): Flicker noise occurs practically in all electronic components. It is proportional to the inverse of the frequency and has a variety of effects but it usually occurs as a resistance fluctuation.
- Avalanch noise: It is a form of noise which occurs in pn junctions which are operated in a region at or near to the point of avalanche breakdown.

3.3.7 Signal-to-noise ratio (SNR)

SNR is a measure used to compare the level of the desired signal to the level of background noise in science and engineering.It is described as the ratio of signal power to the noise power, usually expressed in decibels.

$$SNR = \frac{P_{signal}}{P_{noise}} \tag{3.16}$$

$$SNR_{dB} = 10\log_{10}\frac{P_{signal}}{P_{noise}} \tag{3.17}$$

3.3.8 Noise Figure

Noise figure is an amount by the which the noise performance of an amplifier or a radio receiver.The value should be low because of lower the value better the performance. Fundamentally the noise figure describes the amount of noise an element which add to the overall system. Frequently the noise figure may be used to explain the performance of a receiver and it can be used instead of the SNR. Noise figure is an important parameter for a wide variety of radio communication system from stationary or mobile radio communication system, satellite radio communications system, and many more.

It is defined as a ratio of SNR_{input} to the SNR_{output} and it can also be measured in decibels.

$$Noise\ Figure(NF) = \frac{SNR_{input}}{SNR_{output}} \tag{3.18}$$

$$NF_{dB} = 10\log_{10}\frac{SNR_{input}}{SNR_{output}} \tag{3.19}$$

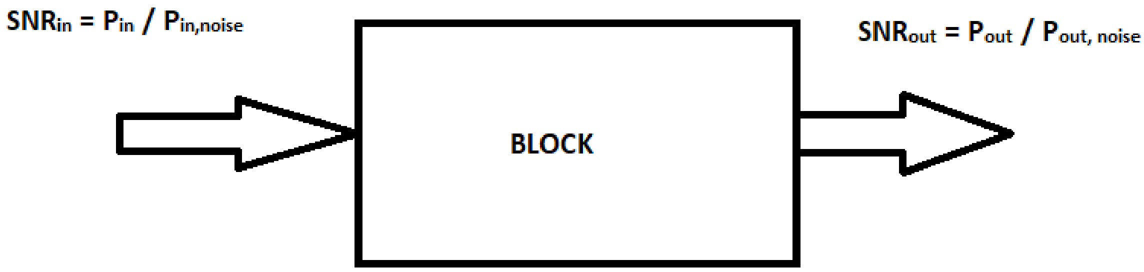

Figure 3.12: Block diagram of Noise Figure[14]

If the circuit has no noise, then $SNR_{input} = SNR_{output}$. But if the circuit is noisy then $SNR_{input} > SNR_{output}$, therefore the fact is NF will be always greater than 1.

3.3.9 Noise Figure in cascade form

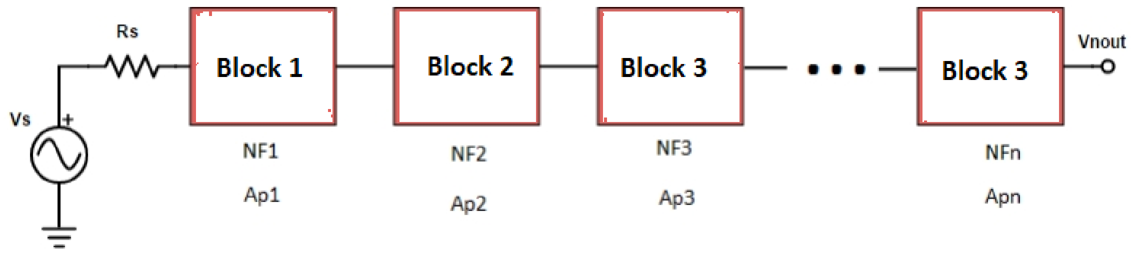

Figure 3.13: Block diagram of Noise figure in cascade form[14]

If numerous devices are cascaded, the total Noise figure can be found with Friis equation

$$F = 1 + (F_1 - 1) + \frac{(F_2 - 1)}{Ap_1} + \frac{(F_3 - 1)}{Ap_1 Ap_2} + ... + \frac{(F_n - 1)}{Ap_1....Ap_n} \tag{3.20}$$

where F_n is the noise factor for the n-th device, and Apn is the power gain (linear, not in dB) of the n-th device. The first block in the chain usually makes the effect on total noise figure because of the noise figure of the subsequent stages are reduced by the gain. Thus the LNA being the first block of the receiver section it should have low noise and if its that so then there will be no issues in the noise of the other stages.

3.3.10 Reflection coefficient and Voltage Standing wave ratio

- **Reflection coefficient:** It specifies how much amount of an electromagnetic wave is reflected by an impedance breaking in the transmission medium. It is a ratio of the amplitude of the reflected wave to the wave incident at the junction and denoted by gamma. The magnitude of the reflection coefficient depends upon the load impedance and the impedance of the transmission line. A perfect match will not have a reflection.

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \tag{3.21}$$

$$\Gamma = \frac{VSWR - 1}{VSWR + 1} \tag{3.22}$$

- **Voltage standing wave ratio:** VSWR (Voltage Standing Wave Ratio) is the measure of how well RF power is transmitted into a load. Considering an example, ideally, there will be no reflections and all the signal from the power amplifier will be transmitted to the antenna if a power amplifier is connected to an antenna through a transmission line. But in the real world, there will be some mismatches which will create some of the signal to get reflected back into the transmission line. VSWR is the measure of how much amount of signal gets reflected back into the system. It is the ratio between transmitted and reflected waves. VSWR having a high value will indicate poor transmission-line efficiency and reflected energy. It can also be defined as the ratio of the maximum voltage of a line to the minimum voltage of the same line.

$$VSWR = \frac{V_{max}}{V_{min}} \tag{3.23}$$

$$VSWR = \frac{\Gamma + 1}{\Gamma - 1} \tag{3.24}$$

For perfect matching; Γ=0,VSWR=1
For imperfect matching; Γ=1,VSWR=∞
Thus, reflection coefficient ranges from 0 to 1 while VSWR ranges from 1 to ∞ .

3.3.11 Power

- **Instantaneous Power:** The power dissipated by the body at a given instant of time is known as instantaneous power. Mainly in devices where the current and voltage are not steady, like in the instance of AC devices, calculation of power dissipation can be done as a function of time as current and voltage changes with time.

$$p(t) = v(t).i(t) \; or \; \frac{v^2}{R} \tag{3.25}$$

- **Average Power:** The energy transferred over a total period of time divided by the time taken is known as Average power.

$$p_{av} = \frac{1}{T}\int_0^T p(t) \;=\; \frac{1}{T}.\frac{1}{R}\int_0^T v^2(t) \tag{3.26}$$

Average $v_2(t)$ overtime $= <v^2(t)> = \frac{1}{R}\int_0^T v_2(t)$

Therefore $V_{rms} = \sqrt{< v^2(t) >}$ = Root Mean Square or RMS voltage

$p = \frac{\sqrt{<v^2(t)>}}{R}$ or $\frac{V_{rms}}{R}$ is the Power dissipated in R.

- **Complex Power:** It is the complex sum of real and reactive powers. It is measured in terms of Volt-Amps (or) in Kilo Volt-Amps (kVA). Where S is complex or apparent power, P is real power measured in terms of Watts and Q is reactive power measured in terms of Volt-Amps Reactive (generally in kVAR).Furthermore, the complex power has magnitude and phase angle.

  If,

  $V = |V|e^{j\theta_v}$; $v(t) = |V|\cos(wt + \theta_V)$

  $I = |I|e^{j\theta_I}$; $i(t) = |I|\cos(wt + \theta_I)$

  then Complex Power will be: $S{=}\frac{1}{2}(VI^*) = \frac{1}{2}|V||I|\cos(\phi) + j\frac{1}{2}|V||I|\sin(\phi)$

  Thus,

$$P = \frac{1}{2}|V||I|\cos(\phi) \tag{3.27}$$

$$Q = \frac{1}{2}|V||I|\sin\sin(\phi) \tag{3.28}$$

  where,

  P = Average power or active power = Real(S)

  Q = Reactive power = Img(S)

- **Active power - P :** The power which is actually consumed in an AC Circuit is called True power or Active Power or real power and it is measured in watts (W).

- **Reactive inductive Power - Q :** It is measured in volt-amperes reactive (VAR) and stored in or discharged by inductors and capacitors. The power that continuously bounces back and forth between source and load is known as reactive Power.

Table 3.1: Power in Components[15]

Component	Active power P	Reactive power Q
Resistor	Absorbs $P > 0$	Q=0
Inductor	P=0	Absorbs $Q > 0$
Capacitor	P=0	Generates $Q > 0$

- **Maximum Power:** The power which is available at the source and largest amount of power that can be delivered by the source is known as Maximum power.

$$P_{avl} = P_{max} \tag{3.29}$$

  By making the load impedance the complex conjugate of the source impedance the power can be delivered to its maximum power. And if we do not do the complex conjugate of load impedance we will not be able to transfer maximum power which will create a mismatch.

3.3.12 Matching

Basically, impedance matching is the way of designing the input impedance of an electrical load or the output impedance of its equivalent signal source to increase the power transfer or decrease signal reflection from the load. The purpose of the matching network is to transform the load impedance into impedance which is conjugately matched to the source and to make sure that the available power is delivered. The matching network must be lossless and designed entirely with reactive elements (C or L) or transmission line. The reason for doing matching is to avoid reflections and transfer maximum power. Matching is performed with reference to 50 ohms. The reason for matching to 50 ohms is because it is a compromise between power handling and low loss. Originally the arithmetic mean between best power handling capacity (i.e. 30 ohms) and lowest loss (i.e. 77 ohms) is 53.5, therefore, compromising the choice with 50 ohms between power handling capacity and signal loss per unit length, for the dielectric.
Condition for designing a matching circuit is:

$$S_{11}^* = \Gamma_s \tag{3.30}$$

$$\Gamma_s^* = \Gamma_{in} \tag{3.31}$$

$$S_{22}^* = \Gamma_l \tag{3.32}$$

$$\Gamma_l^* = \Gamma_{out} \tag{3.33}$$

where,

Γ_s= source reflection coefficient

Γ_l= load reflection coefficient

S_{11}= input return loss/ input reflection coefficient

S_{22}= output return loss/ output reflection coefficient

3.3.13 Stability

Stability is a major concern in RF amplifiers. If LNA is unstable, it will act as an oscillator. The first step after designing the bias circuit is to check the stability. The stability factor is used for measuring the amplitude stability of the amplifier.Circuit stability is defined by the final stability factor given in the conditions.

$$\mu = \frac{1 - |S_{11}|^2}{|S_{22} - \Delta S_{11}| + |S_{21} \times S_{12}|} \tag{3.34}$$

$$K = \frac{1 + |\Delta|^2 - |S_{11}|^2 - |S_{22}|^2}{2|S_{21}||S_{12}|} \tag{3.35}$$

$$\Delta = S_{11}S_{12} - S_{21}S_{22} \tag{3.36}$$

where,

K=Rollet's stability factor = tells about the circuit whether it will have oscillation or not.If $K > 1$, the circuit will not oscillate otherwise it will oscillate (i.e. $K < 1$).

μ=Geometric mean = tells about how far the circuit is from oscillations. If $\mu > 1$, the circuit is far from oscillations otherwise it will near to oscillation (i.e. $\mu < 1$). Δ=Delta

Generally, Stability is of two different types:

- Conditionally stable or potentially stable: The system is stable for specific values of passive source and load impedances. Conditions for conditional stability is $\mu < 1$,$K < 1$,$\Delta < 1$.

- Unconditionally stable: The system is stable for any values of passive loads. Conditions for unconditional stability is $\mu > 1$,$K > 1$,$\Delta < 1$.

The goal for the designer is to design an unconditionally stable amplifier and if the amplifier is not stable then the oscillation might take place after the attachment to the matched output.

3.4 RF measurement devices

Equipment used for testing RF devices are:

- Spectrum Analyzer
- Signal Analyzer
- Network Analyzer
- Power Meter
- Signal Generator

Chapter 4

LNA schematic and results

4.1 Design 1

The design of the LNA started with a single transistor common source topology shown in Figure 4.1. At first, the LNA was biased at V_{ds}=2.5V and V_{gs}=0V and simulated at the frequency range of 26.5-30 GHz. Then stability of the transistor was observed for the cut-off frequency range of 10 MHz – 90 GHz. The stability result was not acceptable (i.e. K and $\mu < 1$ which is conditionally stable condition) but the design rule suggests that the transistor should be unconditionally stable (i.e. K and $\mu > 1$). To achieve unconditional stability, source degeneration technique (i.e. in this design a low value of the spiral inductor(56 pH) connected at the source and another of 1nH at the gate) and a TaN resistor of around 20 ohms was connected to the drain of the transistor. Resistors, when directly connected to the gate and drain, can degrade the noise figure of the overall amplifier so to avoid the degradation resistors are decoupled with the inductors at the gate and drain which has helped in stabilizing the transistor. Resistors are used to avoid degradation to gain and noise figure caused by the source degeneration inductor connected to the source.

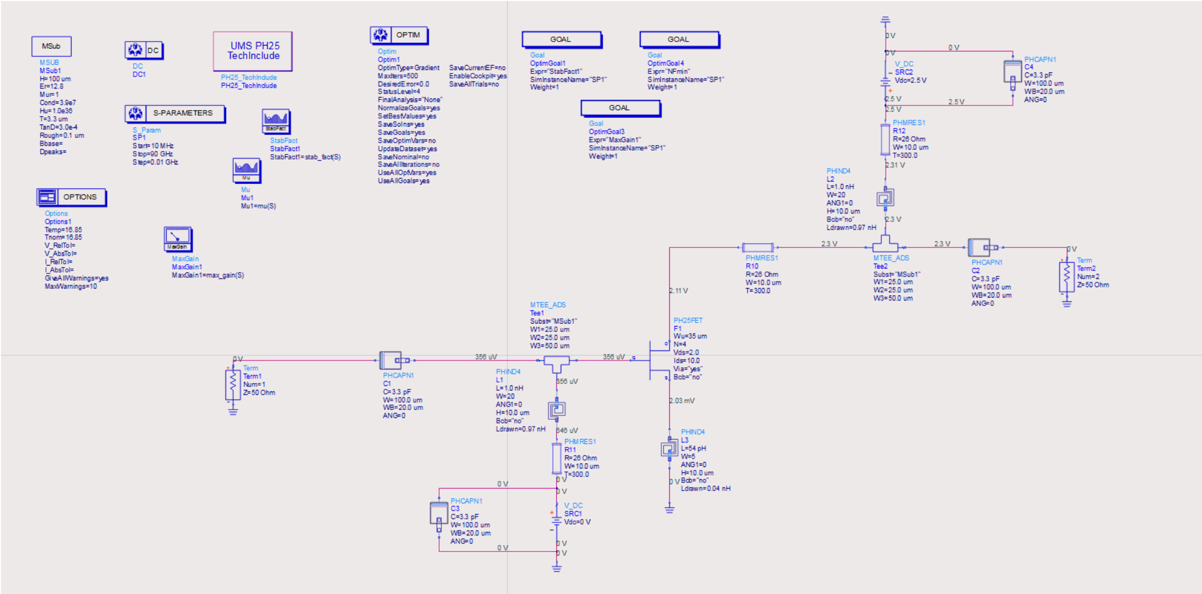

Figure 4.1: Schematic of Single Transistor LNA

4.1.1 Result of Design 1

Figure 4.2,4.3,4.4,and 4.5 shows the result after stabilizing the transistor. The minimum noise figure of the design is around 1.468 dB at 26.5 GHz (minimum frequency of the range) and 1.542 dB at 30 GHz (maximum frequency of the range). The maximum gain of the design is around 5.071 dB at 26.5 GHz and 5.975 dB at 30 GHz. The values of the minimum noise figure are better but the maximum gain value is not expectable according to the objective. Thus to achieve better maximum gain value Cascoded transistor topology was used.

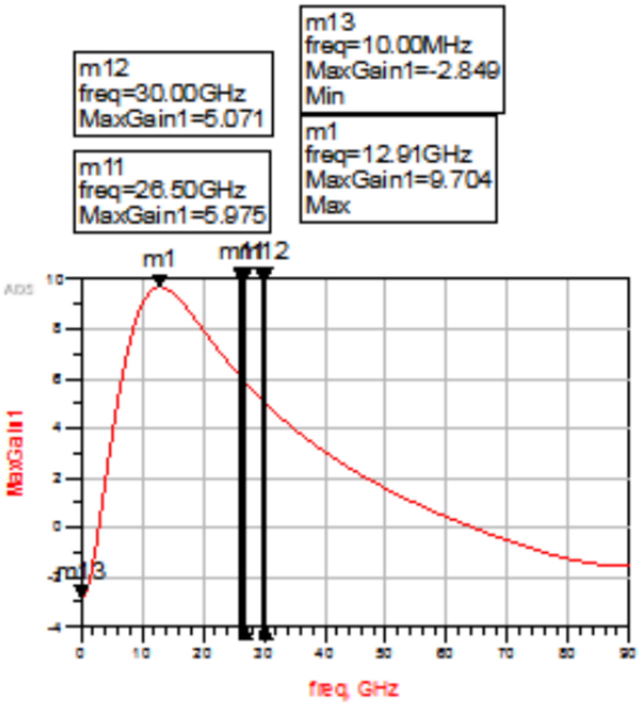

Figure 4.2: MaxGain Plot

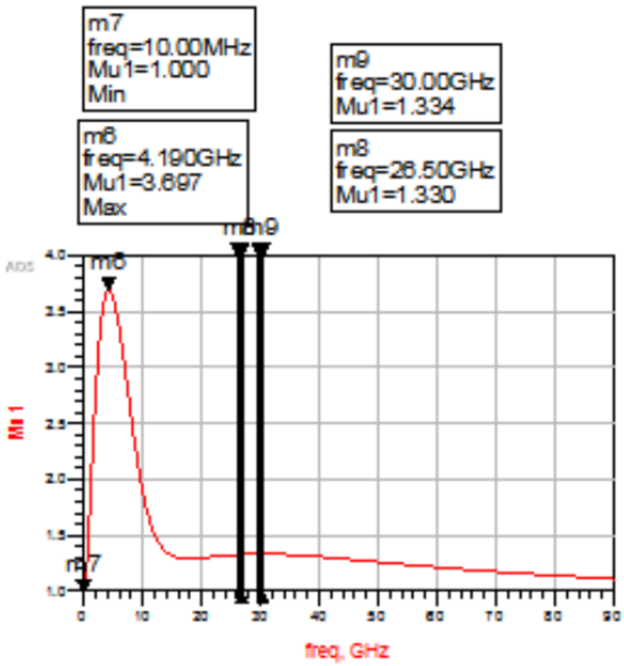

Figure 4.3: Stability plot

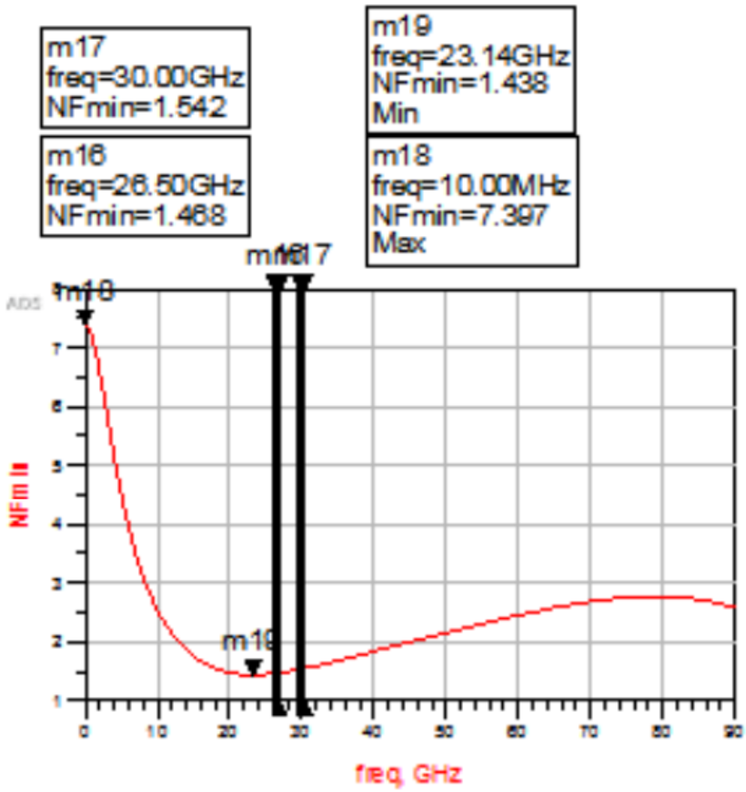

Figure 4.4: NFmin plot

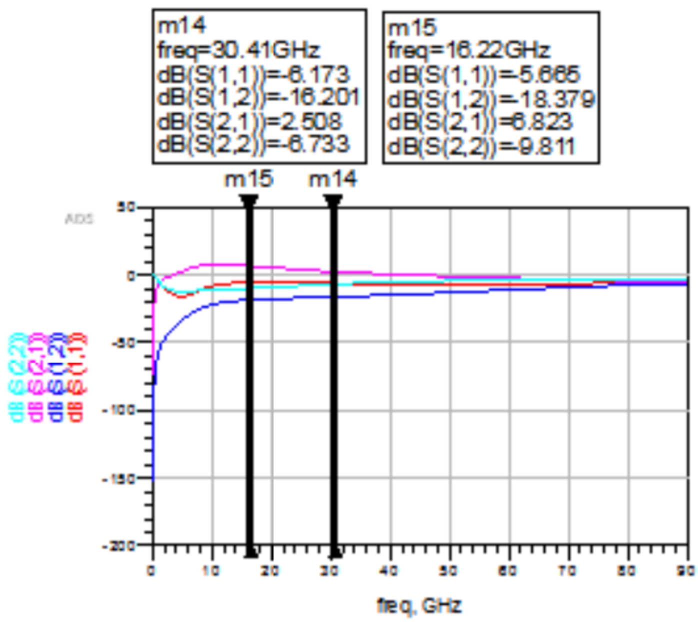

Figure 4.5: S-parameter Plot

4.2 Design 2

Figure 4.3 shows the Cascoded transistor topology (i.e. there will be two transistors in a stack form). This topology provides higher gain, high isolation, better noise performance compared to source degeneration technique used in a single transistor. This topology is stabled by using a single resistor of 20 ohms connected to the drain in series and the output bias tee circuit was connected to the 2nd transistor and input bias tee connected to 1st transistor.

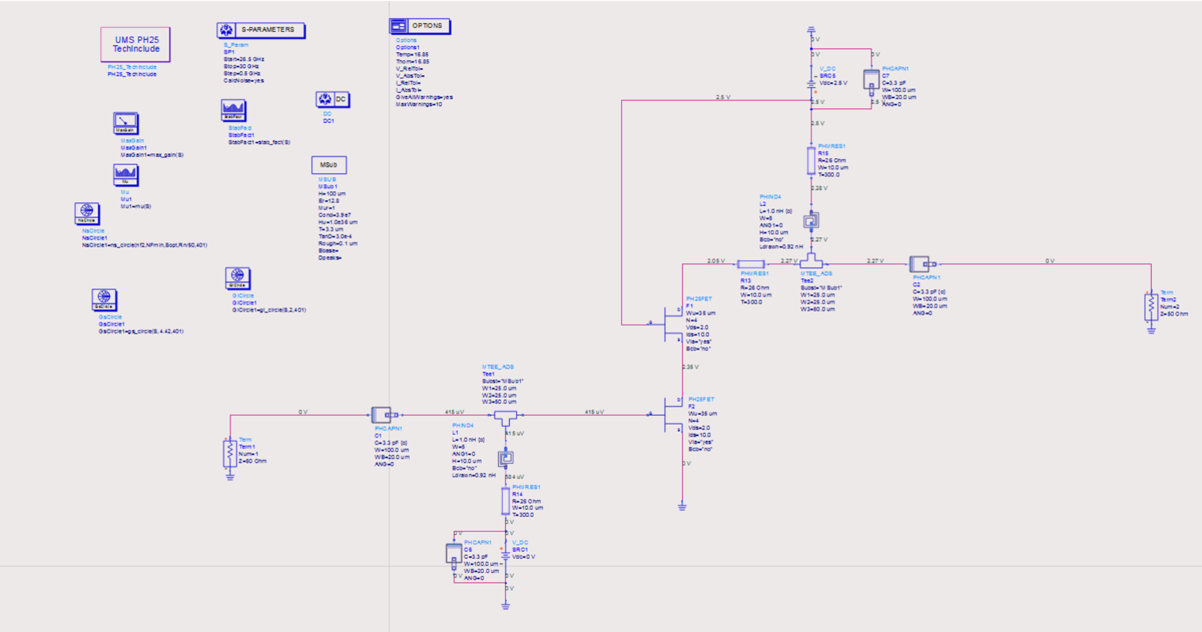

Figure 4.6: Schematic of Cascode Transistor LNA

4.2.1 Result of Design 2

Figure 4.6,4.7,4.8,4.9 and 4.10 indicates the results of the parameters such as stability, minimum noise figure, maximum gain and S-parameters respectively. The parameter values with the expected values are shown in Table 4.1.

Table 4.1: Parameteric Results of Cascode transistor LNA.

Parameters	**Design 2: Simulation results**
Nfmin	1.42 dB at 26.5GHz; 1.54 dB at 30GHz
MaxGain	19.92dB at 26.5GHz; 18.79 dB at 30GHz
S_{21}	9 dB at 26.5GHz; 8 dB at 30GHz
S_{11}	-1.77 dB at 26.5GHz; -1.35 dB at 30GHz
S_{22}	-1.76 dB at 26.5GHz; -1.42 dB at 30GHz

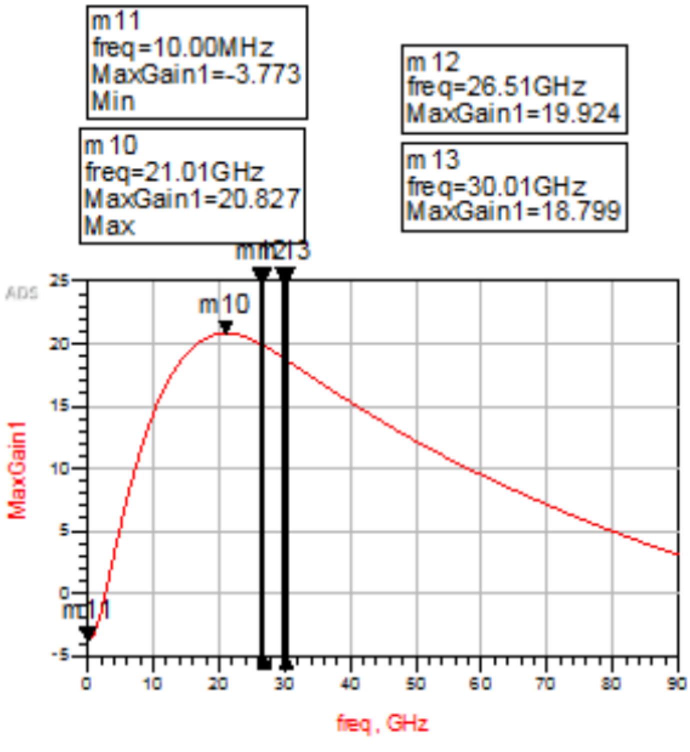

Figure 4.7: Maxgain plot

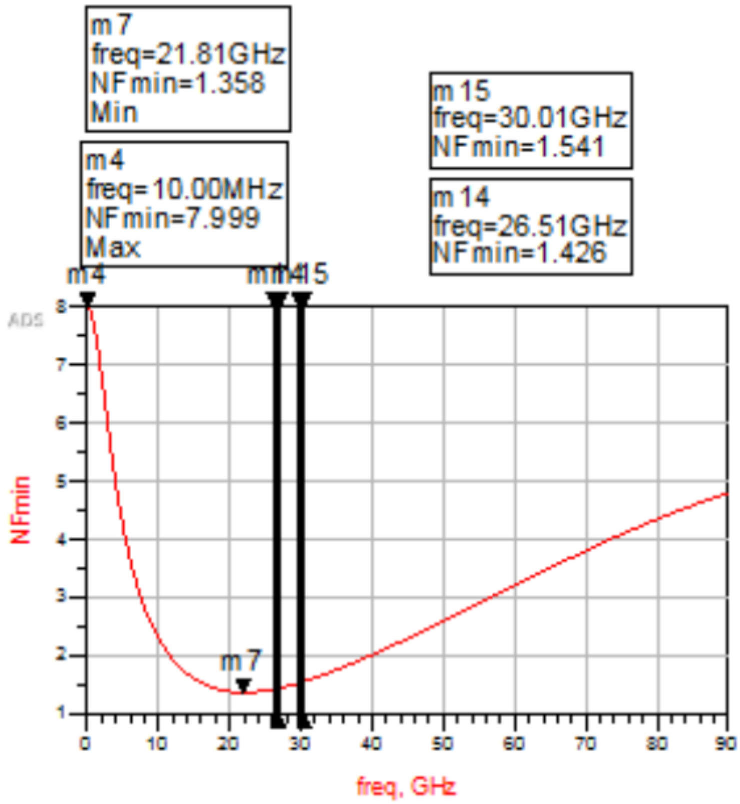

Figure 4.8: NFmin plot

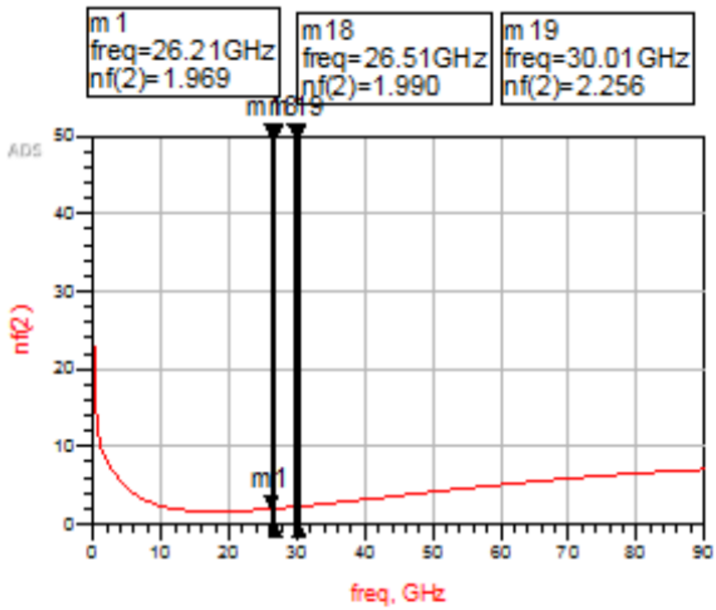

Figure 4.9: Noise Figure plot

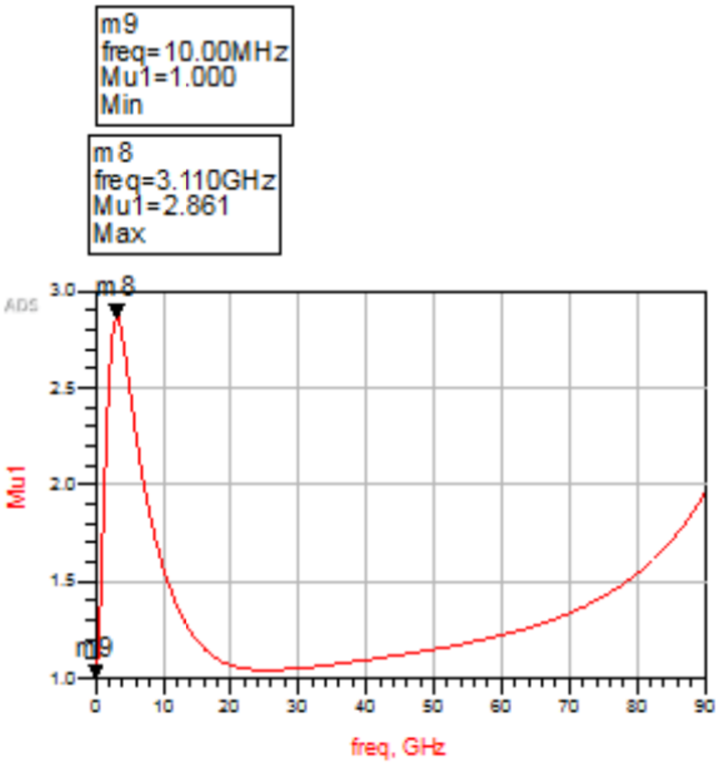

Figure 4.10: Stability Plot

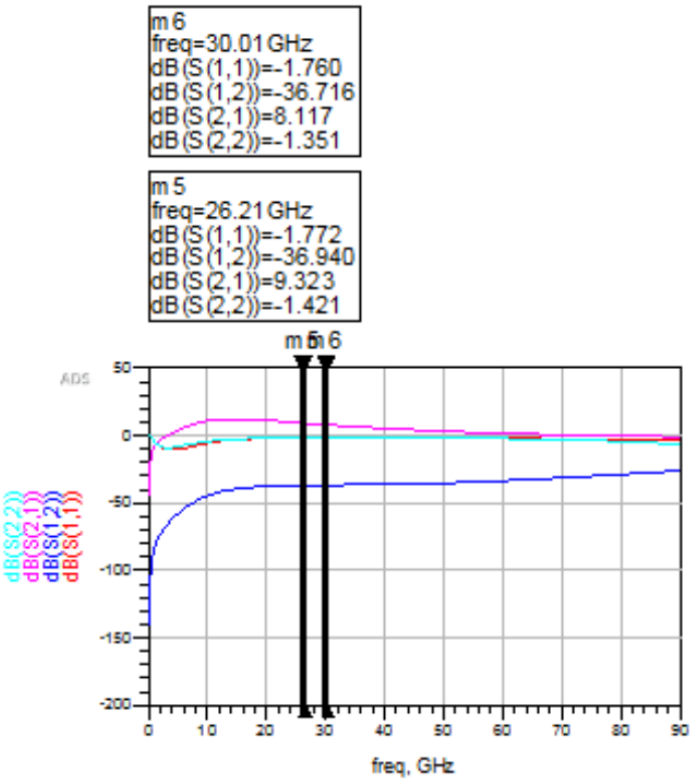

Figure 4.11: S-parameter plot

The results obtained from Design 2 were near to the expected values thus input and output matching circuit can be designed. But before designing input and output circuit Γ_{opt} value is obtained by finding the intersecting point between constant gain circles and noise figure circles.In this design, Γ_{opt} value is found by intersecting the constant gain circle of 26.5 GHz frequency and noise figure circle of 26.5 GHz frequency because at 26.5 GHz frequency the gain is maximum and the noise figure is minimum. Γ_{opt} obtained for this design was 9+j*14.

4.3 Final schematic

Using the Γ_{opt} value a circuit is to be designed which matches to 50 ohm impedance.In this design using the value 9+j*14, a circuit using optimized values of inductors and capacitors was designed at the input side which matches to 50 ohm impedance that is said to be input matching circuit which shown in Figure 4.5.

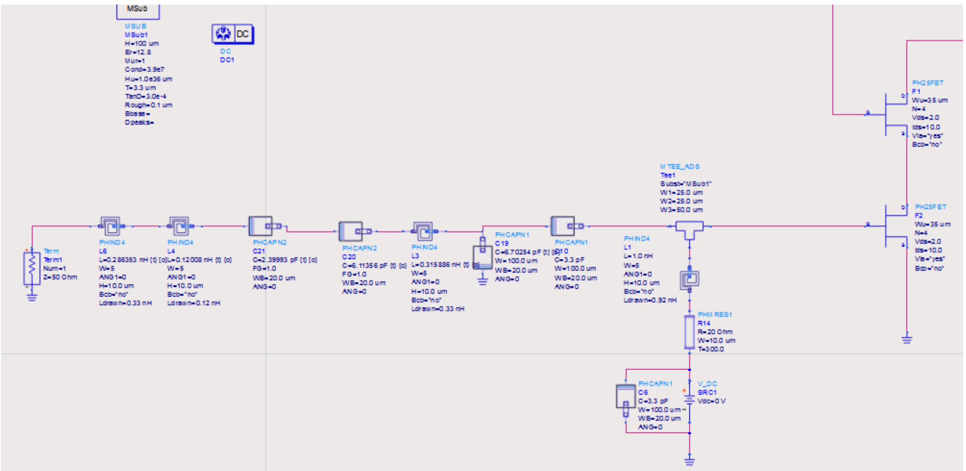

Figure 4.12: 1^{st} Half Schematic of LNA

After designing the input circuit, output impedance is obtained and accordingly the output circuit will be designed. In this design, the output impedance value was 18+j*53. Using this value a circuit designed just like input circuit was designed. The output matching circuit schematic is shown in Figure 4.6.

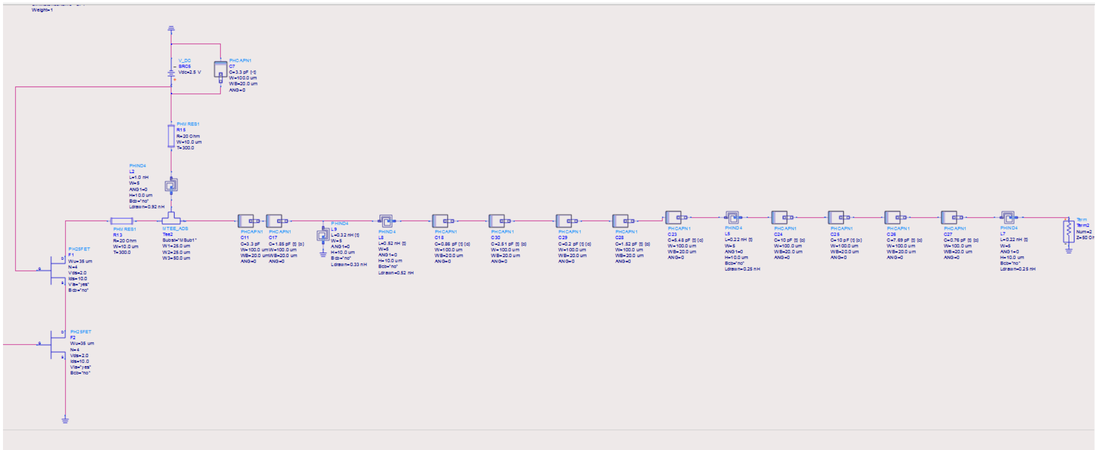

Figure 4.13: 2^{nd} Half Schematic of LNA

4.3.1 Result of Final Schematic

Figure 4.14, 4.15, 4.16, 4.17, 4.18, 4.19 indicates the results of the parameters such as stability, minimum noise figure, maximum gain and S-parameters respectively. The parameter values with the expected values are shown in Table 4.2

Table 4.2: Parameteric Results of Final Schematic.

Parameters	**Final Simulation Results**
Nfmin	2.126 dB at 26.5GHz; 2.131 dB @ 30GHz
MaxGain	16.3 dB at 26.5GHz; 14 dB at 30GHz
S_{21}	16 dB at 26.5GHz; 13.6 dB at 30GHz
S_{11}	-15.7 dB at 26.5GHz; -17.1 dB at 30GHz
S_{22}	-13.67 dB at 26.5GHz; -10.89 dB at 30GHz
S_{12}	-30.9 dB at 26.5GHz; -31.6 dB at 30GHz

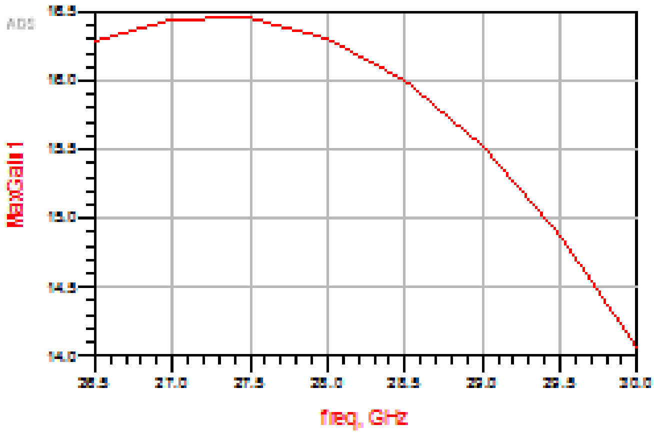

Figure 4.14: Maximum Gain Plot

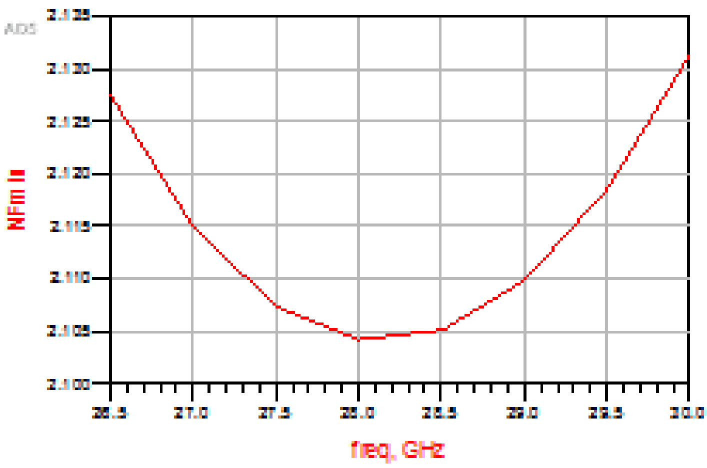

Figure 4.15: Minimum Noise Figure Plot

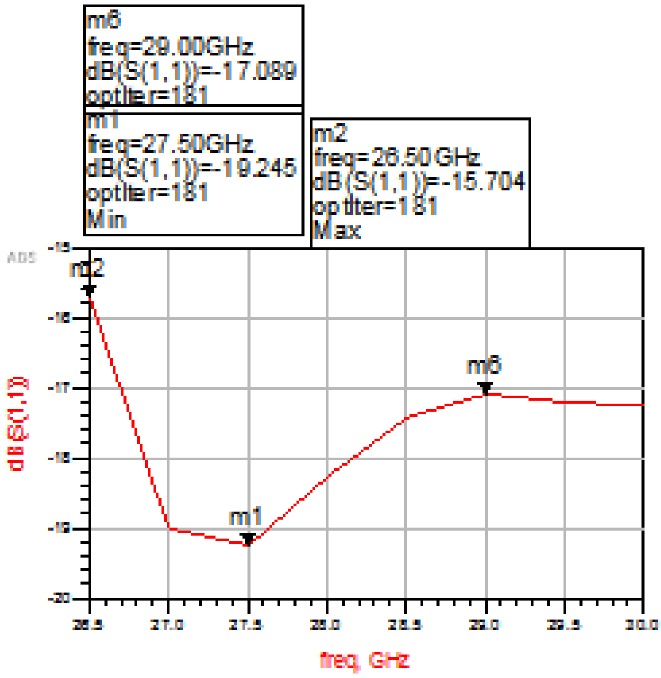

Figure 4.16: Input return loss(S_{11}) plot

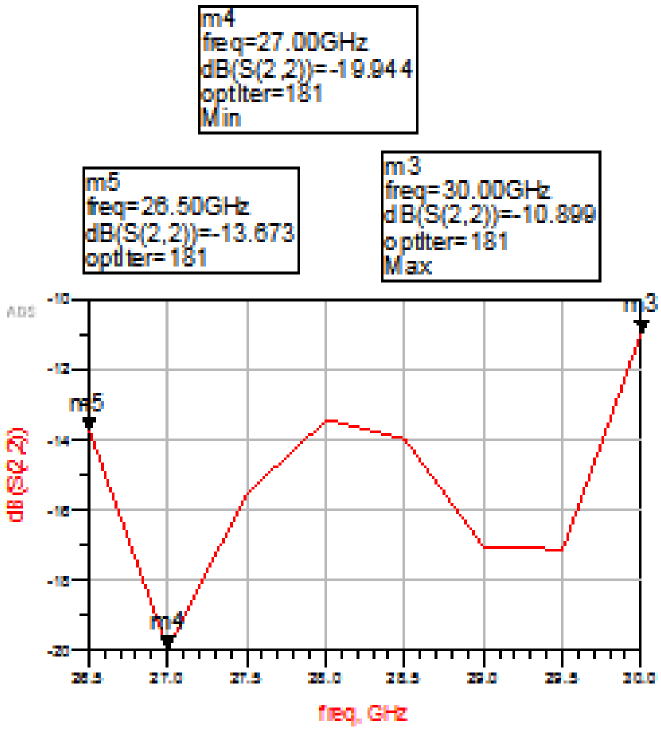

Figure 4.17: Output return loss(S_{22}) plot

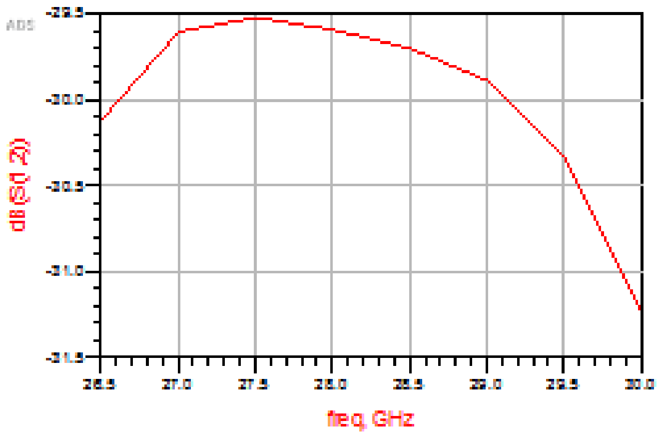

Figure 4.18: Reverse Gain(S_{12}) plot

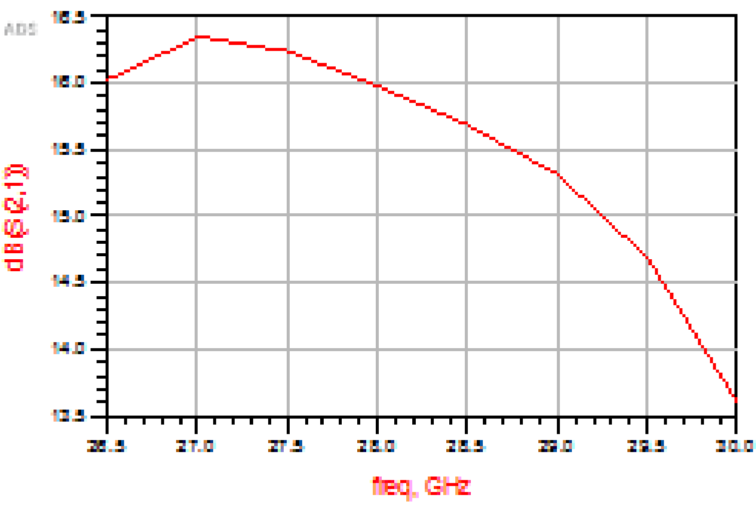

Figure 4.19: Gain(S_{21}) plot

Chapter 5

Conclusion and Future Work

5.1 Conclusion

The development of the low-power and noise design of the radio system has led to the emergence of a wide range of applications in microwave and radio communications. Low Noise Amplifier (LNA) improves low-quality signal received from an antenna where they are barely detectable and ought to be amplified without including any noise, otherwise significant data might be lost. As its name suggests, it adds minimum number of undesired signals in the received signals because weak signals might already be falsified and the LNA is the first stage of the RF receiver system which should provide a satisfactory gain and low noise level. However, there is always a compromise between gain and noise due to the design of an LNA. This means if the gain increases, the noise in the received signal increases, otherwise, noise reduction may result in a reduced gain.

As its performance greatly affects the overall receiver performance, thus the target of this LNA design was to amplify the received signal while at the same time add a minimum amount of additional noise and design a narrowband low noise amplifier for Ka-band applications. The LNA has been designed operating at frequency ranges of 26.5-30 GHz using a 0.25 μm p-HEMT process using Agilent's Advanced Design System.

The designing started with a single-stage transistor topology. But after observing the stability of the design and making appropriate changes for stabilizing the transistor (i.e. using source degeneration technique with a small resistor in series at the drain side of the pHEMT) Maxgain in this design was around 5-6dB which was not acceptable. So, to achieve the gain of 15-20dB, the topology is changed to Cascode topology.The schematic includes 2 transistors size of 30 X 4 μm in Cascode form with input bias circuit and input matching circuit connected at the gate terminal of transistor 1.The input bias circuit consists of a magic tee and a MIM capacitor of 3.3pF to allow AC signal at port 1 of magic tee while an Spiral inductor of 1 nH at port 2 to allow DC signal and along with inductor TaN resistor is used for stabilizing the circuit and also the Decoupling capacitor. The input matching circuit has combinations of inductors and capacitors. Inductors and Capacitors are added until we match the impedance to 50 Ohms.The other half schematic also includes bias circuit, and matching circuit, as they are connected at output side thus can be named as output bias circuit and output matching circuit. The output bias circuit is similar to input bias circuit and output matching circuit was designed in the same way as input matching circuit (i.e. combination of inductors and capacitors connected till the impedance is matched to 50 Ohms) attached at the drain of 2^{nd} transistor with a resistor of 20 Ohms to stabilize the transistor, simulated at 26.5-30 GHz and the results obtained are shown in Table 4.2

The design of a Ka-Band LNA have achieved minimum Noise Figure (Nfmin) $<$ 3dB (i.e. 2.126 dB at 26.5 GHz and 2.131 dB at 30 GHz), Maximum Gain (MaxGain) approximately between 15-20 dB (i.e. 16.3 dB at 26.5 GHz and 14 dB at 30 GHz), S_{21} approximately between 15-20 dB (i.e. 16 dB at 26.5 GHz and 13.6 dB at 30 GHz), S_{11} better than -10 dB (i.e. -15.7 dB at 26.5GHz and -17.1 dB at 30GHz) and S_{22} better than -10 dB (i.e. -13.67 dB at 26.5GHz and -10.89 dB at 30GHz).

5.2 Future work

The LNA schematic is successfully designed. Now the design can be carried forward for the layout process and Design rule check(DRC). After finishing the last step with the optimized results the design can be sent for manufacturing and after that, the design can be used for wireless communication applications.

Bibliography

[1] S. D. Nsele et al., ”Ka-band low noise amplifiers based on InAlN/GaN technologies,” 2015 International Conference on Noise and Fluctuations (ICNF), Xian, 2015, pp. 1-4, doi: 10.1109/ICNF.2015.7288577.

[2] D. Cuadrado-Calle, D. George and G. Fuller, ”A GaAs Ka-band (26–36 GHz) LNA for radio astronomy,” 2014 IEEE International Microwave and RF Conference (IMaRC), Bangalore, 2014, pp. 301-303, doi: 10.1109/IMaRC.2014.7039046.

[3] H. V. Bhalani and N. M. Prabhakar, “Rudimentary Study and Design Process of Low Noise Amplifier at Ka Band ,” International Journal of Engineering Development and Research, vol. 3, no. 2, 2015.

[4] S. Hameed, A.J. Butt, U.F. Khan and A. Badii, “Performance analysis, design and assessment of broadband low noise amplifier (LNA) for radiometer,” International Journal of Physical Sciences, vol. 7, 2012.

[5] D M. Pozar, Microwave and RF Design of Wireless System, John Wiley and Sons.

[6] I. D. Robertson and S. Lucyszyn, RFIC and MMIC design and Technology, London: The Institute of Electrical Engineers, 1995.

[7] Steve Marsh, Practical MMIC Design, Boston, London: Artech House, 2006.

[8] P H Ladbrooke, MMIC design GaAs FETs and HEMTs, Boston, London: Artech House,1989.

[9] Circuit Design Cookbook 2.0, Advanced Design System: Agilent EEs of EDA.

[10] G. Gonzalez, Microwave Transistor Amplifier, Analysis and Design, Upper Saddle River, New Jersey: Prentice Hall, 1996.

[11] MMIC Foundary Design Manual PH25 process v3.1,United Monolithic Semiconductor,France, 2002.

[12] A. Sarrafinezhad,A. Ghoncheh,’RF Components and Basic Concepts 1.1 - What is Radio Frequency ???’,Rahsoft Courses, 2016.

[13] A. Sarrafinezhad,A. Ghoncheh,’RF Components and Basic Concepts 1.18 - S-Parameters’,Rahsoft Courses, 2016.

[14] A. Sarrafinezhad,A. Ghoncheh,’Topic 2 - RF Design Theory and Principles 2.4 - Noise’,Rahsoft Courses, 2016.

[15] A. Sarrafinezhad,A. Ghoncheh,'Topic 2 - RF Design principles and Fundamentals 2.1-Power',Rahsoft Courses, 2016.

[16] C. S. Wu et al., "Pseudomorphic HEMT manufacturing technology for multifunctional Ka-band MMIC applications," in IEEE Transactions on Microwave Theory and Techniques, vol. 43, no. 2, pp. 257-266, Feb. 1995, doi: 10.1109/22.348082.

[17] Czochralski J.,"Ein neues VerFahren zur Messung der Kristallisationsgeschwindigheit der Metalle" Z. Phys. Chem., vol. 92, No. 219, 1918(In German).

[18] J.S. Kilby,"Miniaturized Electronic Circuits", U.S. Patent No. 3,138,743, filed February 1959, issued in 1964.

[19] A. Ertal,"Monolithic Microwave Duplexer Switch", U.S. Patent No. 3,475,700, filed in December 1966, issued in 1969.

[20] E.A. Metz, R.C.Miller, and J. Mazelski, J. Appl. Phys., vol. 33, 1962, p.2016.

[21] J. Arnold,"FET Technology for Low-Noise Front Ends", IEEE Communication Magazine, September 1983, pp. 1237-1238.

[22] J. Greiling,"The Historical Development of GaAs FET Digital IC Technology",IEEE Trans. Microwave Theory Tech., vol. 32, September 1984, pp. 1144-1156.

[23] W. W. Hooper and W. I. Lehrer,"An Epitaxial GaAs Field Effect Transistor", Proc. IEEE, vol. 55, July 1967, pp.1237-1238.

[24] R. S. Pengelly, and J. A. turner,"Monolithic Broadband GaAs FET Amplifiers", Electronics Letter, vol. 12, No. 10, May 1976, pp. 251-252.

[25] E. C.Niehenke, R. A. Pucel,and I. J. Bahl,"Microwave and millimeter-wave integrated circuits", IEEE Transactions on Microwave Theory and Techniques, vol. 50, 2002, pp. 846-857.

[26] H. Morkoc, et al.,"Semiconductor with strained InGaAs layer",U.S. Patent No. 4,827,320, May 2, 1989.

[27] H. Henri, S. Gonzague, V. Matthieu, C. Alain and D. Gilles, "Ultra low loss transmission lines on low resistivity silicon substrate," 2000 IEEE MTT-S International Microwave Symposium Digest (Cat. No.00CH37017), Boston, MA, USA, 2000, pp. 1809-1812 vol.3, doi: 10.1109/MWSYM.2000.862331.

[28] L. L. W. Leung, Wai-Cheong Hon and K. J. Chen, "Low-loss coplanar waveguides interconnects on low-resistivity silicon substrate," in IEEE Transactions on Components and Packaging Technologies, vol. 27, no. 3, pp. 507-512, Sept. 2004, doi: 10.1109/TCAPT.2004.831780.

[29] D. C. Laney et al., "Low-loss microwave transmission lines and inductors implemented in a Si/SiGe HBT process," Proceedings of the 1998 Bipolar/BiCMOS Circuits and Technology Meeting (Cat. No.98CH36198), Minneapolis, MN, USA, 1998, pp. 101-104, doi: 10.1109/BIPOL.1998.741889.

[30] T. Whitaker, "IEDM Highlights Include SiGe HBTs Operating At 350 GHz"Compound Semiconductor Magazine, Institute of Physics Publishing Ltd., London, January 2003.