DESIGN AND SIMULATION OF LOW NOISE AMPLIFIER AT 28 GHz FOR 5G WIRELESS SYSTEM

NUR SYAHADAH BINTI YUSOF

UNIVERSITI SAINS MALAYSIA

2017

DESIGN AND SIMULATION OF LOW NOISE AMPLIFIER AT 28 GHz FOR 5G WIRELESS SYSTEM

by

NUR SYAHADAH BINTI YUSOF

Thesis submitted in fulfillment of the requirements for the degree of
Bachelor of Engineering (Electronic Engineering)

JUNE 2017

ACKNOWLEDGEMENT

Alhamdulillah, all praises to Allah s.w.t, I had completed my final year project successfully. I would like to express my gratitude to my project and thesis supervisor, Dr.Mohamed Fauzi Packeer Mohamed for all his guidance, advice, inspirations and motivational words throughout this project. I owe him big times in this wonderful journey as an undergraduate student in Universiti Sains Malaysia, specifically in School of Electrical and Electronic Engineering.

I forever in debt with Dr.Mohamad Adzhar Md Zawawi, my project and thesis examiner, Prof. Ir. Mohd. Fadzil Ain, Mohamad Faiz bin Omar and Pn. Roslina Hussin for their sincere helps and useful comments during my project.

This project would not be completed without helps and supports from the assistant engineers and technicians from the Communication and PCB laboratories. I would like to thank Mr.Ilyas for being patience with me during the fabrication process. To Pn.Zamira and En.Latip, I couldn’t repay all your kindness you showered upon me.

A special appreciation is dedicated to my parents for their endless love and supports since my first day in Universiti Sains Malaysia. I wouldn’t come this far if not because of them. May this success brings joy to Ayah and Mak. To my sister, Najwa binti Yusof, thank you for being there for me every time I need a crying shoulder, for being such a good listener and friend. I am so grateful for having these beautiful people around me.

To all my friends and coursemates, thank you for all your moral supports and helps for the past four years. Throughout the years, we went through thick and thin together and enjoyed every minute of it. You saw my ups and downs and never fail to motivate me to finish this unfinish business. Once again, thank you everyone who helps me throughout my studies and this project.

Acknowledgement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

1G	First Generation Wireless System
4G	Fourth Generation Wireless System
5G	Fifth Generation Wireless System
ADS	Advanced Design System
BJT	Bipolar Junction Transistor
CG	Common Gate
CS	Common Source
dB	Decibel
DC	Direct Current
EHF	Extremely High Frequency
FET	Field Effect Transistor
GaAs	Gallium Arsenide
Gbps	Gigabit per second
GHz	Giga Hertz
HD	High Definition
LineCalc	Line Calculator
LNA	Low Noise Amplifier
LTE	Long Term Evolution
Mbps	Megabit per second
MHz	Mega Hertz
MMIC	Monolithic Microwave Integrated Circuit
ms	milli-second

N/C	No Connection
NF	Noise Figure
PCB	Printed Circuit Board
HEMT	High Electron Mobility Transistor
pHEMT	Pseudomorphic High Electron Mobility Transistor
RF	Radio Frequency
SHF	Super High Frequency
SMT	Surface-Mount Technology

LIST OF SYMBOLS

A_V	Voltage gain
Δ	Delta
ε_r	Dielectric constant
K	Rollett stability factor
Mu	Geometrically derived stability factor (load)
Ω	Ohm
S_{11}	Input return loss
S_{12}	Reverse power gain
S_{21}	Forward power gain
S_{22}	Output return loss
Z_0	Characteristic impedance
Z_L	Load impedance

REKA BENTUK DAN SIMULASI PENGUAT HINGAR RENDAH PADA 28 GHz UNTUK SISTEM TANPA WAYAR 5G

ABSTRAK

Peningkatan yang drastik dalam industri komunikasi mudah alih telah menyebabkan permintaan kapasiti dan kelajuan yang tinggi dalam rangkaian tanpa wayar. Kelajuan 4G LTE terkini adalah sebanyak 20 Mbps hingga 1 Gbps. Teknologi 5G dijangka mempunyai kelajuan sepuluh kali ganda lebih baik daripada 4G LTE. Spektrum frekuensi yang diperuntukkan untuk terknologi terkini iaitu sistem tanpa wayar generasi keempat (4G) LTE semakin sesak. Oleh itu, jalur frekuensi yang baru diperlukan untuk menyokong teknologi komunikasi masa hadapan yang dikenali sebagai sistem tanpa wayar generasi kelima (5G). Ka-band merupakan calon yang paling sesuai untuk digunakan dalam teknologi 5G. Bagi merealisasikan idea di sebalik teknologi 5G, gabungan pemancar dan penerima radio yang baru diperlukan. Sistem gabungan pemancar dan penerima radio terdiri daripada rangkaian penerima dan pemancar. Penguat hingar rendah (LNA) merupakan komponen elektronik yang terdapat pada rangkaian hadapan penerima radio. Dalam projek ini, satu LNA direka bagi memenuhi keperluan sistem 5G. LNA tersebut direka bentuk dalam perisian Agilent Advanced Design System (ADS). Transistor yang berasaskan GaAs, FHR02X yang beroperasi pada 28 GHz daripada Fujitsu digunakan dalam simulasi memandangkan sifatnya menyerupai transistor yang digunakan dalam proses penghasilan LNA. GaAs pHEMT MMIC LNA HMC519LC4 daripada Hittite Corporation digunakan dalam proses reka bentuk dan penghasilan LNA. Reka bentuk ini kemudiannya dihasilkan menggunakan papan litar bercetak Rogers RO4003C. Pada frekuensi 28 GHz, LNA yang dicetak dalam proses penghasilan berjaya mencapai gandaan linear sebanyak 10.91 dB manakala nilai kehilangan pulangan kemasukan S_{11} dan nilai kehilangan pulangan pengeluaran S_{22} masing-masing ialah – 7.75 dB dan – 22.13 dB. LNA yang direka dalam proses skematik simulasi pula berjaya menunjukkan gandaan linear sebanyak $9.185\ dB$, noise figure (NF) sebanyak $3.840\ dB$ manakala nilai kehilangan pulangan kemasukan S_{11} ialah $-13.124\ dB$ dan nilai kehilangan pengeluaran S_{22} ialah $-15.455\ dB$.

DESIGN AND SIMULATION OF LOW NOISE AMPLIFIER AT 28 GHz FOR 5G WIRELESS SYSTEM

ABSTRACT

A tremendous growth in the mobile communication industry has increased the necessity for higher capacity and faster speed in wireless networks. The current speed of 4G LTE is about 20 Mbps to 1 Gbps. 5G technology is expected to have speed tenth times faster than 4G LTE could ever offer. The frequency spectrum allocated for current technology called as the fourth generation (4G) LTE wireless system is now overcrowded. Hence, a new frequency band is needed to support the future communication technology, which is known as the fifth generation (5G) wireless system. Ka-band is the prime candidate to be used in 5G technology. In order to manifest the idea behind 5G technology, a new transceiver system is needed. A transceiver system consists of a receiver and a transmitter network. Low Noise Amplifier (LNA) is an electronic component which is found at the front-end of receiver network. In this project, an LNA is designed to meet the 5G system requirements. The LNA is designed in Agilent Advanced Design System (ADS) software. A GaAs-based transistor, FHR02X working at 28 GHz from Fujitsu is used in the simulation as its characteristics is more likely the same as the transistor used in LNA fabrication process. An off-the-shelf GaAs pHEMT MMIC LNA HMC519LC4 from Hittite Corporation is used in layout and fabrication processes. The proposed design is then fabricated on the Rogers RO4003C board. The power gain of the LNA is measured by using a signal generator, together with a signal analyser. The input return loss S_{11} and output return loss S_{22} are measured by using a network analyser. The fabricated LNA achieves a power gain of 10.91 dB and the input return loss S_{11} and output return loss S_{22} of $-7.75\ dB$ and $-22.13\ dB$ respectively at working frequency of 28 GHz. In the schematic simulation, the LNA produces the power gain of 9.185 dB, noise figure of 3.840 dB while the input return loss S_{11} is $-13.124\ dB$ and the output return loss S_{22} is $-15.455\ dB$.

CHAPTER 1

INTRODUCTION

1.1 Project Background

We are in the era of rapid growth in communication technology. Starting with the first generation cellular system (1G) introduced in 1970s, we are now the users of the fourth generation wireless system (4G) or also known as Long Term Evolution (LTE). The massive growth of smartphone users and other data consuming devices results in higher data rates demand. Due to these factors, the cellular band below 6 GHz is becoming congested (Lin et al., 2016; Talwar et al., 2014).

To overcome this problem, researchers are now working towards the new technology, called the fifth generation (5G) wireless system. Researchers are interested in deploying a new spectrum, which is millimeter-wave frequency spectrum for 5G technology (Zhouyue et al., 2011). Millimeter-wave spectrum range is from 3 to 300 GHz. It can be further divided into super high frequency (SHF) band (3 to 30 GHz) and extremely high frequency (EHF) band (30 to 300 GHz). In order to manifest the idea behind 5G, researchers are focusing on front-end transceiver of the system. The transceiver is the combination of receiver and transmitter circuits. The components in transceiver should be able to suit 5G requirements.

Low noise amplifier (LNA) is an electronic amplifier found at the front-end of a receiver circuit. It is used to amplify weak input signals but at the same time reduces the noise. The amplified signal is the combination of the wanted and unwanted signals. The unwanted signal which is noise cannot be eliminated from the circuit, but it can be reduced. To do that, the LNA should have high gain to diminish the noise from the circuit. Figure 1.1 shows the block diagram of a single-conversion superheterodyne receiver to illustrate the position of the LNA in the front-end receiver circuit. LNA is commonly used as the RF amplifier.

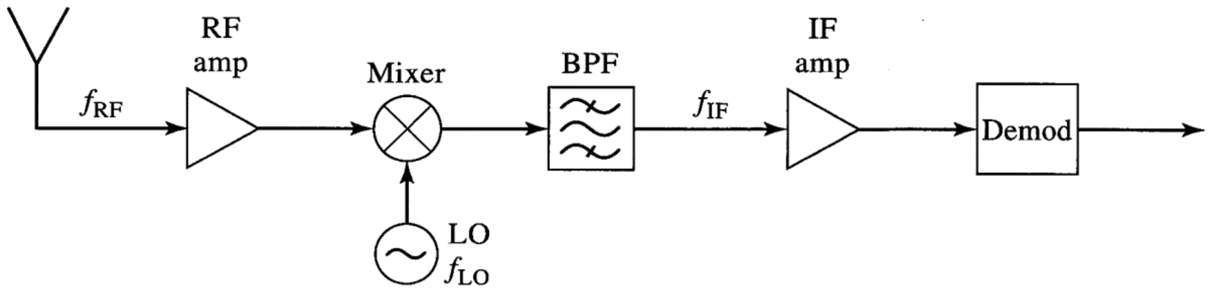

Figure 1.1 Block diagram of a single-conversion superheterodyne receiver (Pozar,2005).

1.2 Problem Statement

The tremendous growth in the use of spectrum below 6 GHz has recently caused the increasing demand to explore new frequency bands for 5G wireless system. Millimeter-wave frequency spectrum is one of the best candidates to be used in this technology. Chong et al. (2016) and Sourabh et al. (2016) in their research able to design LNA for 60 GHz frequency spectrum. 60 GHz frequency spectrum is attractive for short-range wireless communication as it offers gigabit per second (Gbps) transmission rate. Since it is unlicensed frequency band, the available spectrum resources are high and the restriction is small. This frequency band is usually accommodating for wireless remote sensing, security electronic countermeasure and radar. Unfortunately, it is unsuitable for 5G wireless technology due to the high atmospheric RF energy absorption.

Ka-Band is a popular choice among researchers to be used in 5G technology (Curtis, Zhou, Aryanfar, & Dallas, 2016). However, the commercially available components such as antenna and LNA are large in size and consumed high power, inappropriate for mobile communication (Zhouyue et al., 2011). Therefore, this project is done to design LNA for 5G wireless technology.

Transistor selection is very important in designing LNA. Yi-Shen Yeh et al. (2016) in their research used SiGe BiCMOS technology in designing the LNA. The result shows that the gain is 10 dB and the noise figure (NF) is 5 dB. The noise figure is relatively high for LNA working at 28 GHz frequency. This is because at millimeter-wave frequency SiGe BiCMOS technology has a poor noise figure. To overcome this problem, GaAs pHEMT is used as it has better noise figure at higher frequencies.

1.3 Project Objectives

Based on the issues aforementioned, the following objectives are set for this project:

- To design and simulate the performance of an LNA at 28 GHz for a 5G wireless communication system in ADS.
- To design a layout for a GaAs pHEMT MMIC HMC519LC4 LNA in ADS.
- To fabricate and obtain the power gain (S_{21}), input return loss (S_{11}) and output return loss (S_{22}) of the LNA.

1.4 Project Scope

This project is done to design and simulate the performance of an LNA working at 28 GHz frequency for a 5G wireless communication system. A GaAs pHEMT MMIC Low Noise Amplifier, HMC519LC4 is used in this project during layout design process. The designing and simulating processes will be done in Agilent's Advanced Design System (ADS) 2011. The design is later fabricated on Rogers RO4003C board. After that, the power gain, input and output return losses of the LNA are obtained by using the 83640B Analog Signal Generator, N9030A PXA Signal Analyzer and N5245A PNA-X Network Analyzer.

1.5 Outline of Report

This report is split into five chapters. It starts with Introduction in Chapter 1. Chapter 1 covers the project background, problem statement, project objectives need to be achieved, scope of the project and the outline of report.

In Chapter 2, the literature review is discussed. It describes about the theories and equations related in designing the LNA. This chapter can be divided into six sub sections which are frequency spectrum, network analysis, performance parameters, transistor selection, microstrip transmission line and circuit topologies in LNA design. All these sub sections are discussed in depth and related works are presented accordingly if applicable. The previous work of LNAs is compared at the end of the chapter.

Chapter 3 consists of project methodology. It comprises the design, simulation, layout, fabrication, and measurement processes. The project requirements are also presented in this chapter.

Results and discussion are analysed in Chapter 4. The results are obtained from simulation and hardware measurements of the LNA. Next, the LNA performances are compared in terms of power gain, input and output return losses and noise figure.

Chapter 5 tells about the conclusion of the whole project. It gives the overview on the achievement of the objectives of the project stated in Chapter 1. The project limitation and its future work is discussed and recommended at the end of the chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Low noise amplifier is one of the important blocks in the front-end receiver system. As the technology in the communication system is growing towards the fifth generation (5G) wireless system, the LNA design should evolve to meet the new technology requirements as well. This chapter reviews in details regarding the frequency band that should be used to implement the 5G technology.

It is essential to understand the parameters used in determining the LNA performance. Usually, the researchers used most likely the same parameters in designing the LNA. Hence, these parameters are reviewed in this chapter because they will be adopted in this project to ensure that the proposed LNA design has an excellent performance.

Besides, there are many topologies proposed by researchers in their LNA designs. Thus, an overview of different topologies is necessary to select the best one to be used in this project.

There are many types of transistors available in the market such as pHEMTs, FETs and BJTs. Every type of transistor has its own capability, advantages, and disadvantages. This chapter analyses the performance of different types of transistors to ease the transistor selection process.

In fabrication process, the transmission line is used at RF in and RF out to connect it with other devices such as network generator and network analyser. An understanding about the transmission line is necessary to avoid loses during the signal transmission.

2.2 Frequency Spectrum

Table 2.1 shows the classification of frequency spectrum. Every frequency band has its designated applications. Therefore, different frequencies have different LNA designs. As the frequency band below 6 GHz is currently overcrowded due to overwhelming growth in mobile data traffic, there is an urgent need to explore a new frequency band for the new 5G wireless communication system (Curtis, Zhou, Aryanfar, & Dallas, 2016). In their research, Weiquan et al. (2016), Jeffery et al. (2016), Shilpa et al. (2014) and Zhouyue et al. (2011) suggested that the millimeter-wave frequency band is one of the best candidates to implement this new technology. Even though there are many commercially available LNAs have been designed for this band, however they are not suitable for the 5G technology. The components are either too big or consumed too much power to be applied in a mobile communication.

Besides, the researchers are commonly used Ka-band in their designs (Curtis et al., 2016; Lin et al., 2016). 28 GHz frequency is good enough to be used for the 5G technology as at this frequency, the atmospheric absorption does not significantly contribute to additional path loss (Zhouyue et al., 2011). Chong et al. (2016) came out with an LNA design working at 60 GHz frequency. The gain and noise figure are great, 35 dB and less than 4 dB respectively. Nevertheless, the effect of atmospheric absorption cannot be neglected as at 60 GHz, it contributes in additional path loss.

Table 2.1 Approximation band designations (Pozar, 2005)

Frequency	**Description**
300 kHz – 3 MHz	Medium Frequency
3 MHz – 30 MHz	High Frequency (HF)
30 MHz – 300 MHz	Very High Frequency (VHF)
300 MHz – 3 GHz	Ultra High Frequency (UHF)
1 – 2 GHz	L Band
2 – 4 GHz	S Band
4 – 8 GHz	C Band
8 – 12 GHz	X Band
12 – 18 GHz	Ku Band
18 – 26 GHz	K Band
26 – 40 GHz	Ka Band
40 – 60 GHz	U Band
50 – 75 GHz	V Band
60 – 90 GHz	E Band
75 – 110 GHz	W Band
90 – 140 GHz	F Band

2.3 Network Analysis

In this section, a two-port network and scattering parameters will be discussed in detail.

2.3.1 Two-port Network

Researchers often used a two-port network in their research. A two-port network consists of four terminals which are connected to the other external circuit. Figure 2.1 shows the two-port network.

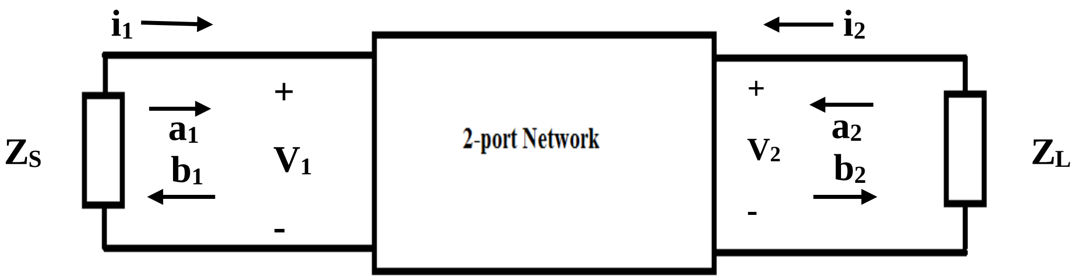

Figure 2.1 Two-port network (Rob Kalmeijer, 2017)

2.3.2 Scattering Parameters

Scattering parameters or also known as S parameters are used to describe incident, reflected and transmitted waves to provide a complete description of the network as seen from its *N* ports. It can be calculated by using network analysis technique (Pozar, 2005). S parameters are used because it is difficult to measure voltages and currents at microwave frequencies.

From Figure 2.1, variable a_n represents the incident wave while b_n represents the reflected wave. The mathematical expressions for the incident and reflected waves can be written as (Pozar, 2005):

$$a_n = \frac{1}{2\sqrt{Z_o}}(V_n + Z_o I_n) \quad (2.1)$$

$$b_n = \frac{1}{2\sqrt{Z_o}}(V_n + Z_o I_n) \quad (2.2)$$

Where,

n = Port 1 or 2

Z_o = Characteristics impedance

The S parameters, S_{11}, S_{12}, S_{21}, and S_{22} of two ports network can be represented as shown in equation [2.3] and [2.4] (Pozar, 2005).

$$b_1 = S_{11}a_1 + S_{12}a_2 \tag{2.3}$$

$$b_2 = S_{21}a_1 + S_{22}a_2 \tag{2.4}$$

The above equations can be expressed in matrix form as follows:

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \tag{2.5}$$

Where,

S_{11} = Input return loss

S_{12} = Reverse power gain

S_{21} = Forward power gain

S_{22} = Output return loss

To make the load impedance Z_L equal to Z_o, the input port driven together with the output port should be terminated by Z_o. The a_2 is set to be zero in order to obtain S_{11} and S_{21} values, i.e. (Adhyaru, 2007)

$$b_1|_{a_2=0} = S_{11}a_1$$

$$S_{11} = \frac{b_1}{a_1}$$

$$b_2|_{a_2=0} = S_{21}a_1$$

$$S_{21} = \frac{b_2}{a_1}$$

Next, to set the source impedance Z_s equal to Z_o, the output port is driven together with the output port should be terminated by Z_o. This time, the a_1 is set as zero to determine S_{12} and S_{22} values, i.e. (Adhyaru, 2007)

$$b_1|_{a_1=0} = S_{12}a_2$$

$$S_{12} = \frac{b_1}{a_2}$$

$$b_2|_{a_1=0} = S_{22}a_2$$

$$S_{22} = \frac{b_2}{a_2}$$

2.3.3 Input Return Loss (S_{11})

S_{11} is a ratio of reflected to incident waves on port 1 when port 2 is terminated by Z_o. The waves can be reflected and incident voltages or reflected and incident powers. It is usually measured in decibel (dB). Equations [2.6] and [2.7] are used to calculate S_{11} in terms of voltages and powers respectively (Zhijung Zhang, 2017). In ideal case, there should be no signal reflected to the input port. It means that, the load fully utilizes the injected signal. However, in the LNA design, designers always considered that about 10% of the injected signal is reflected to the input port, leaving 90% of the power to be utilized by the load. A good LNA design should have $S_{11} < -10\ dB$.

$$S_{11}(dB) = 20 \log \frac{b_1}{a_1} \quad (2.6)$$

$$S_{11}(dB) = 10 \log \frac{b_1}{a_1} \quad (2.7)$$

2.3.4 Output Return Loss (S_{22})

S_{22} is a ratio of reflected to incident waves on port 2 when port 1 is terminated by Z_o. It usually measured in decibel (dB). Equations [2.8] and [2.9] are used to calculate S_{22} in terms of voltages and powers respectively (Zhijung Zhang, 2017). A good LNA design should have $S_{22} < -10\ dB$ as well.

$$S_{22}(dB) = 20\log\frac{b_2}{a_2} \qquad (2.8)$$

$$S_{22}(dB) = 10\log\frac{b_2}{a_2} \qquad (2.9)$$

2.4 Performance Parameters of Low Noise Amplifier

Low Noise Amplifier (LNA) is an electronic amplifier which is used to amplify the desired signal but at the same reducing the noise as low as possible. Since it is the first block in a receiver circuit, hence it is the key factor to improve the performance of the RF front-end receiver (Pongot, Othman, Zakaria, & Suaidi, 2015). The parameters involved in LNA design are shown in Figure 2.2. Tiwari et al. (2016), Fallahnejad et al. (2015) and Z. Hamaizia et al. (2012) focused on gain, noise figure, power, and frequency in their research.

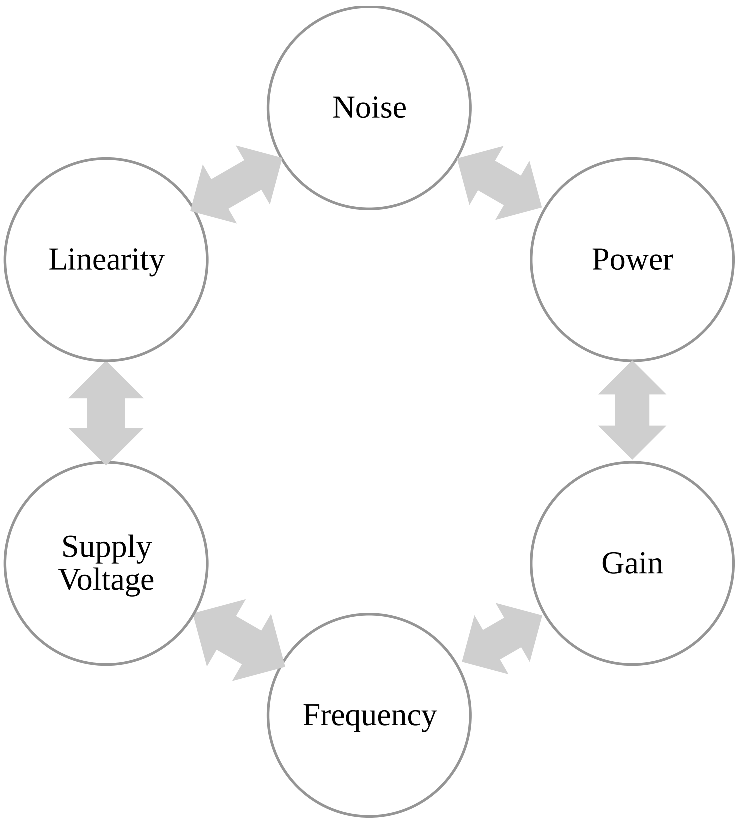

Figure 2.2 RF design hexagon (Razavi,1998)

2.4.1 Stability

Stability plays an important role in designing an LNA. It is necessary to check the stability of the transistor to prevent oscillation occurs at frequencies of interest (Fallahnejad, Najmabadi, & Kashaniniya, 2015; Pongot et al., 2015). To ensure that the transistor used is unconditionally stable, it needs to fulfill these two conditions, K > 1 and $|\Delta| < 1$. Equations [2.11] and [2.12] show how to calculate Rollet's stability factor, K and delta factor, $|\Delta|$ respectively (Pozar, 2015) by using S parameters.

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{12}S_{21}|} > 1 \tag{2.11}$$

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| < 1 \tag{2.12}$$

2.4.2 Gain

Gain can be defined as the ability of the device to amplify the power of the input signal. It shows the ratio of the output to the input signal of the device. It is also known as forward power gain S_{21}. Usually, it is expressed in terms of decibels. The gain can be expressed in terms of voltage gain or power gain as shown in Equations [2.13] and [2.14] respectively (Pozar, 2005).

$$Voltage\ gain, A_V = 20\ \log_{10} \frac{V_{out}}{V_{in}} \tag{2.13}$$

$$Power\ gain = 10 \log_{10} \frac{P_{out}}{P_{in}} \tag{2.14}$$

2.4.3 Noise Figure

Apart from gain and stability, noise also has a significant role when designing an LNA. In receiver application (Lin et al., 2016; Zhang, Wang, Sun, & Design, 2016), the noise should be as low as possible. The first stage of a receiver front-end provides the dominant noise performance of the entire system. The noise factor, F of two-port LNA can be illustrated as shown in equation [2.15] (Pozar, 2005).

$$F = F_{min} + \frac{R_N}{G_S}\left|Y_S - Y_{opt}\right|^2 \tag{2.15}$$

Where,

Y_S = Source admittance

Y_{opt} = Optimum source admittance

F_{min} = Minimum noise figure of transistor

R_N = Equivalent noise resistance

G_S = Real part of source admittance

Usually, *F* is expressed in decibels. It is called as noise figure, *NF*. Equation [2.16] shows how to express noise in decibels (Pozar,2005).

$$NF = 10\log_{10} F \tag{2.16}$$

During LNA design, it is quite challenging to ensure the LNA to have both maximum gain and minimum noise figure at the same time. Even so, this condition can be improved by using constant gain circle and circles of constant noise figure to select usable trade-off between noise figure and gain (Pozar, 2005).

2.5 Transistor Selection

There are various types of transistors commercially available in the market. Recently, GaAs-based pHEMT transistors are gaining their popularity in LNA design (Arsalan, Amir, & Khan, 2014). This is because they provide high electron mobility due to high electron confinement density in the potential well. In addition, pHEMT can improve signal to noise ratio especially at higher frequencies. Other researchers tried to use GaAs-based FET in their LNA design for high frequencies application. Even though it provides low noise figure, however the LNA suffers in terms of gain (Tiwari, Manjula, & Malarvizhi, 2016). It is essential for the LNA to have high gain and low noise figure at the same time.

Other than GaAs, Si-based transistors are being used in LNA design for 28 GHz application (Yeh et al., 2016). Yet, the performance is far behind the LNA using GaAs-based pHEMT. This is because the electron mobility in GaAs-based transistor is 50 times higher than in Si. Therefore, it is necessary to select a transistor with parameters which is correspond to the target specifications. The summary of the performance of the LNAs can be referred in Table 2.3 in Section 2.8.

2.6 Microstrip Transmission Line

Microstrip is an electrical transmission line which is formed by dielectric substrate sandwiched together between a ground plane and a conducting strip. The structure of microstrip is shown in Figure 2.3. The microstrip which is also known as the conducting strip of width W and thickness of t is printed on a thin, grounded dielectric substrate with thickness h and relative dielectric constant ε_r. It is a well-known planar transmission lines especially in RF and microwave circuit design because the microstrip can be easily fabricated by photolithographic processes and all the active components can be mounted on the top of the board (Pozar, 2005).

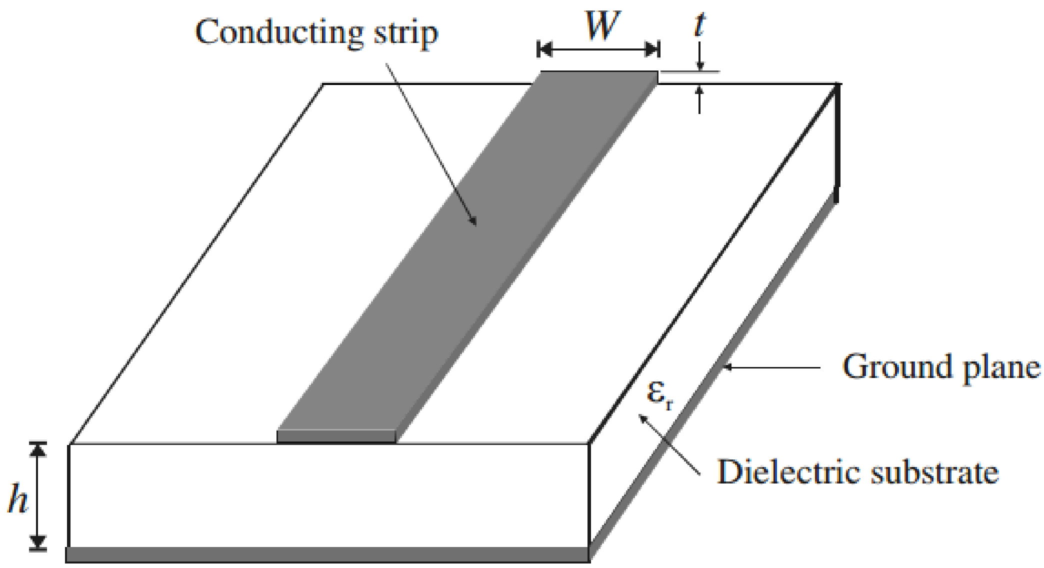

Figure 2.3 General microstrip structure (Hong & Lancaster, 2001)

The dielectric constant ε_r and thickness h of the microstrips are provided by manufacturers in the datasheet. Hence, during circuit design, we cannot simply put any value for ε_r and h as these values are significant in width calculation. In other hand, thickness t is usually very small and its effect may quite often be neglected. However, we must consider the strip thickness t for conductor loss of the microstrip line (Hong & Lancaster, 2001). In RF and microwave circuit design, microstrips are used to design 50Ω transmission lines to connect the input and output port with the external devices.

2.7 Circuit Topologies for Low Noise Amplifier

There are several circuit designs commonly used by researchers in designing an LNA such as common-source (CS), common-gate (CG) and cascode topologies. Table 2.2 shows the comparison between these three topologies. It is essential to choose the best circuit topologies in the design so that the LNA will have a high gain and noise figure as low as possible. In this section, several circuit topologies will be reviewed.

2.7.1 Common-Source Stage with Resistive Termination

Figure 2.4 shows a CS with resistive termination topology. In this topology, a resistor R_1 is placed in parallel with the input to provide 50Ω input impedance. The termination resistor however produces thermal noise as much as R_S does. Hence, the noise figure of this topology is very high. Since its performance in terms of noise is very poor, this circuit design is not suitable for low noise applications.

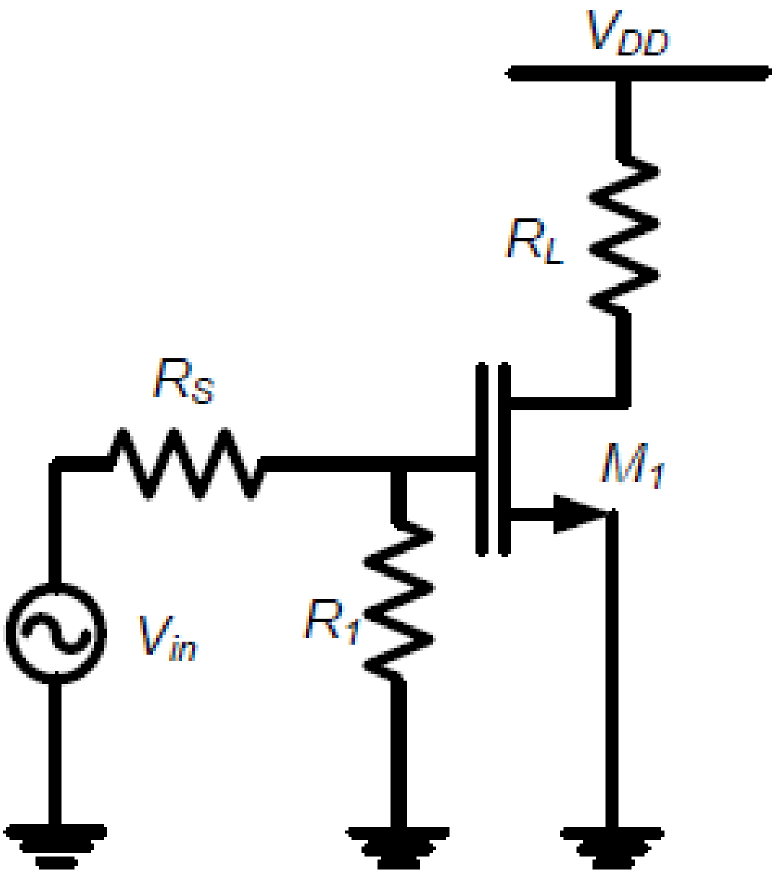

Figure 2.4 Common-source with resistive termination (Tran, 2012)

2.7.2 Common-Source Stage with Shunt Feedback

In Figure 2.5, a shunt resistive feedback is applied to a CS amplifier to achieve 50Ω input impedance. This topology is very convincing for broadband application with minimum impact on the noise performance (Norhapizin et.al., 2011). Nevertheless, it has several drawbacks. The input impedance, Z_{in} relies on the feedback resistor, R_{fb} and voltage gain, A_v, consequently it becomes very sensitive to any variation process. Besides, the noise figure might increase to undesirable level due to significant noise from the feedback signal.

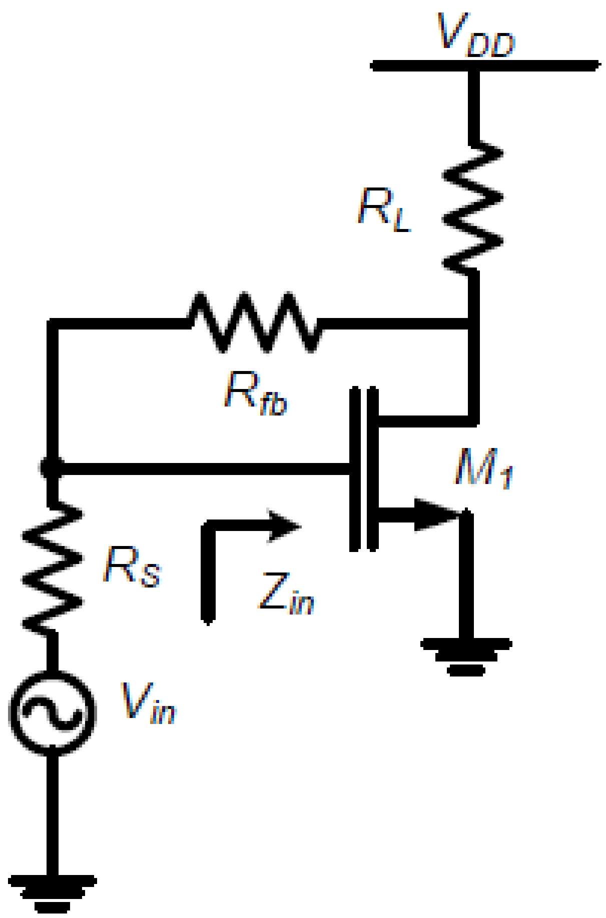

Figure 2.5 Common-source with shunt feedback (Tran, 2012)

2.7.3 Common-Source Stage with Source Inductive Degeneration

In Figure 2.6, an inductor is used rather than a resistor at the source to generate a real term in input impedance. Since an inductive element is used, the thermal noise is not produced as a pure reactant is noiseless. This circuit topology is attractive as the gain is high and it has superior noise performance (Pongot et al., 2015). However, this structure has poor performance in terms of reverse isolation.

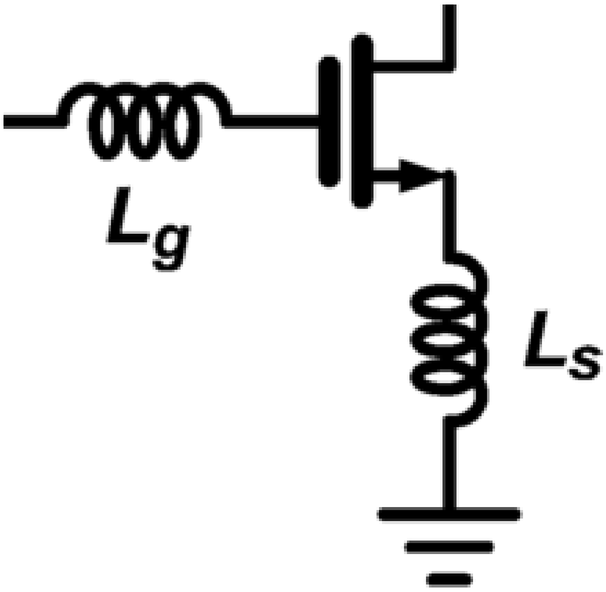

Figure 2.6 Common-source with inductive degeneration topology

(Alpana & Bodhe, 2014)

2.7.4 Cascode Topology

Cascode topology as shown in Figure 2.7 is very popular in LNA design because it produces higher gain together with higher reverse isolation and lower power consumption. Besides, the combination of the two cascode topology helps to increase the bandwidth of the amplifier (Pongot et al., 2015).

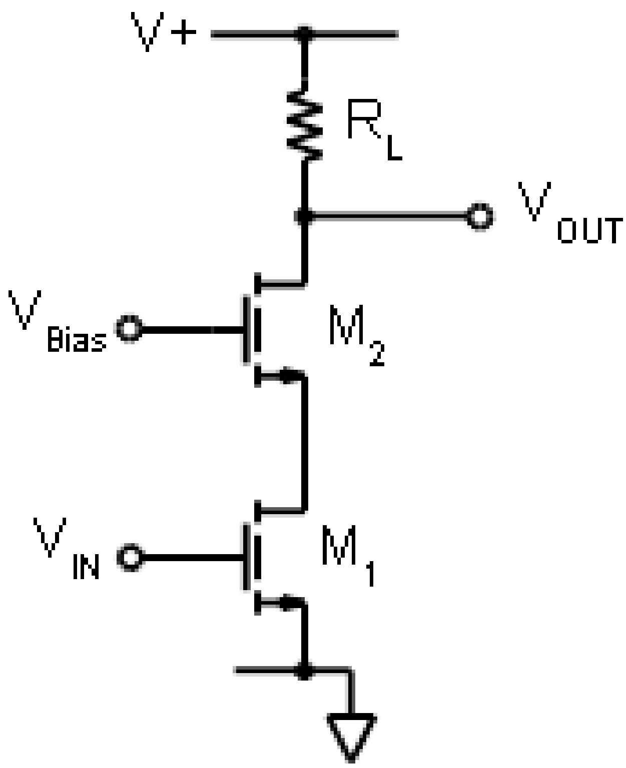

Figure 2.7 Cascode topology (Lidgey et.al., 2012)

2.7.5 Comparison between LNA Topologies

Table 2.2 shows the comparison between LNA topologies usually used by researchers. Among these topologies, many researchers opt for cascode with common-source inductive degeneration topology.

Table 2.2 Comparison between LNA topologies (Pongot et al., 2015)

Characteristic	Common-Source (CS)	Common-Gate (CG)	Cascode
Gain	Average	Inferior	Superior
Stability	Need compensation	Higher	Higher
Noise Figure	Inferior	Increase when frequency rise	Slightly higher than CS
Reverse Isolation	Low	High	High
Bandwidth	Narrow	Slightly broader than CS	Broad

2.8 Comparison between Previous LNA Performances

There are many LNAs have been designed for different applications. These five designs have been selected as references to set up the design specifications and to be compared with the LNA design in this project. Table 2.3 shows the comparison between the performances of the LNAs.

Table 2.3 Comparison between LNAs performances

Performance Matrices	**M.Arsalan et al. (2014)**	**Kamil Pongot et al. (2015)**	**Eren Curuk et al. (2016)**	**Jeffery Curtis et al. (2016)**	**Yi-Shin Yeh et al. (2016)**
Frequency (GHz)	1.9 – 2.4	5.8	19.7 – 20.2	28	28 - 32
$\boldsymbol{S_{11}}$ $(\boldsymbol{dB})$	-16.089	-12.41	< -10	< -15	< -10
$\boldsymbol{S_{22}}$ $(\boldsymbol{dB})$	-14.174	-13.88	< -10	< -10	< -10
$\boldsymbol{S_{21}}$ $(\boldsymbol{dB})$	12. 850	66.38	20 ± 0.5	18 ± 0.5	10
Noise Figure $(\boldsymbol{dB})$	0.588	0.60	0.95	3.0 ± 0.5	5.1 – 8.5
Topology	Cascode	Cascode with inductive drain feedback	Cascode	Common-Source	Fully-differential cascode
Number of Stage	2	2	2	3	2
Type of Transistor	GaAs pHEMT	GaAs HEMT	HJ – FET	GaAs pHEMT	SiGe BiCMOS
Application	4G LTE	WiMAX	VSAT system	5G	5G

2.9 The Fifth Generation (5G) Wireless System Overview

The fifth generation (5G) wireless system is a new technology in the future mobile networks invented to overcome limitations in current technology known as 4G LTE. As the number of users of this technology is keep increasing, the frequency spectrum dedicated for 4G technology is becoming congested. The speed issue is the main concern in communication system as people expect higher transfer rate from time to time. Currently, the transfer speed of 4G LTE is about 200 Mbps to 1 Gbps, relatively slow in compared to the proposed 5G technology. Table 2.4 shows the suggested 5G wireless performance.

Table 2.4 The suggested 5G wireless performance (Sandhya et al, 2016)

Parameter	**Suggested Performance**
Network capacity	10 000 times capacity of current network
Peak data rate	10 Gbps
Cell edge data rate	100 Mbps
Latency	< 1 ms

As mentioned before, user data rate is the biggest concern which triggers the development of 5G technology. From Table 2.4, 5G technology is expected to give gigabit experience to the users (Nokia, 2016). By using current technology, it takes about an hour to download a short HD movie at maximum download speed. However, this duration can be shortened in 5G technology. From 1 Gbps, users can experience 10 Gbps download speeds, tenth times faster than 4G could ever offer.

In 5G wireless system, the latency is foreseen to be zero latency. Zero latency does not mean the system does not have delay in transmission at all. Instead, it means that the technology is expected to have a very low latency as if less than 1 ms so that the radio interface will not be the bottleneck in this system (Talwar et al., 2014).

2.10 Summary

In short, to realize the idea behind 5G wireless system, the LNA needs to undergo evolution to meet the specifications of this technology. A new frequency spectrum needs to be exploited since the frequency band below 6 GHz is overcrowded nowadays. Ka-band is the best candidate to be used in 5G technology. Even though there are many commercially available LNAs for Ka-band applications in the market, however they are not suitable for wireless communication system. Hence, it is necessary to design a new LNA to be implemented in 5G wireless system. There are many topologies can be used in the LNA designs. A common-source stage with source inductive degeneration is perfect to be adopted in the input matching because it has high gain and low noise figure. Although cascode topology is very attractive due to its high gain performance, it could not be used in this project because of the budget limitation.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the procedures in designing the LNA. A theoretical background study is needed to understand the basic concepts of the LNA. Gain, noise figure, and S parameters are the important theories in this project. Hence, a deep understanding in these parameters is essential to ease the designation process.

This project can be divided into three main stages, simulation stage and layout design stage and testing measurement stage. Both simulation and layout processes are done in ADS. In simulation, different topologies for matching network is revised to obtain the most suitable topology for this project. Besides, it is necessary to check the stability of the transistor to avoid oscillation at frequency of interest. Then, the proposed design is simulated to obtain noise figure, input return loss, S_{11}, output return loss, S_{22} and power gain, S_{21} values.

In layout design, the footprint of the chip used is drawn based on the outline given in datasheet. Precision is very crucial in layout design as the dimensions should be accurate so that the chip can be mounted on the board easily. The microstrip transmission line width is calculated by using LineCalc tool in the software to ensure that the dimension is correct and precise based on the board material properties. After the design is finalized, it is fabricated on the printed circuit board (PCB). The chip, K connectors and wires for voltage supply are soldered onto the board.

In testing and measurement processes, the S_{11}, S_{22} values are measured by using a network analyser while S_{21} value is measured by using an analog signal generator and a signal generator. The measured values are then compared with the simulation and datasheet values.

3.2 Project Implementation Flow

The project implementation flow is divided into three sections which are the overall project flow, simulation design flow and layout design flow. Each section has its own flow chart and has detail explanation regarding the processes involved in that section.

3.2.1 Overall Project Flow

There are five major phases in this project. The first phase is a background research about the LNA. It includes the literature review of previous works in LNA design and understanding on the basic theories of the LNA. This is the crucial part of the project as the theory parts of the LNA must be grasped before proceeding to the proposed design. A literature review also helps in finding the best method and performance parameters to be used in designing the LNA.

After that, the specifications of this project are set as shown in Table 3.1. This project is done to design an LNA working at 28 GHz for the 5G wireless system. 28 GHz (Ka-band) is chosen in this project because many researchers proposed this frequency to be used for the 5G technology. The gain and noise figure is expected to be more than 10 dB and less than 5 dB respectively. The gain is relatively high since the proposed design is for a single stage LNA. It is essential for the LNA to have a high gain and a low noise figure to be categorised as a good performance LNA.

Table 3.1 Specifications of the project

Performance parameter	**Specification**
Frequency	28 GHz
Power Gain, S_{21}	$>$ 10 dB
Input Return Loss, S_{11}	< - 10 dB
Output Return Loss, S_{22}	< - 10 dB
Noise Figure	$<$ 5 dB