THE DEVELOPMENT OF CASCODE LOW NOISE AMPLIFIER WITH DOUBLE FEEDBACK TECHNIQUE ARCHITECTURE FOR WIRELESS APPLICATION

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UNIVERSITI PENDIDIKAN SULTAN IDRIS

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ABSTRACT

This study aims to develop cascode low noise amplifier that operate at 5.8 GHz by maximizing gain and minimize the noise figure for the topic of Development of Cascode Low Noise Amplifier by using Double Feedback Technique Architecture for Wireless Application. To verify the idea, FHX76LP Super Low Noise HEMT which compliant with wireless application especially long-term evolution (LTE) standard manage to outlines the possibility to improves the design of low noise amplifier within parameters of gain, noise figure, bandwidth, sensitivity, stability, power consumption and complexity. The cascode low noise amplifier used T-matching network for input-output impedance matching and implementation an innovative double feedback technique to compliant with circuit design. The study using the Advance Design System (ADS) software in aid for collecting the data in smith chart and s-parameter that practical tool used in designing and simulating the circuit and data. Based on simulation, the approach compliant with gain (S_{21}) of 20.887 dB with noise figure of 0.341 dB. The input return loss (S_{11}) and output return loss (S_{22}) are – 14.354 dB and – 11.879 dB respectively. In conclusion, the outcome for this topic is good based on comparison simulation with other circuit method. Implications, the use of this study will contribute in providing a better wireless signal receiver especially for the LTE standard and it potentially in addressing wireless communication issues in rural areas.
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PEMBANGUNAN LITAR HINGAR RENDAH KASKOD DENGAN MENGGUNAKAN TEKNIK GANDAAN SUAPBALIK UNTUK APLIKASI KOMUNIKASI TANPA WAYAR

ABSTRAK

Kajian ini bertujuan untuk membangunkan litar hingar rendah kaskod yang beroperasi pada 5.8 GHz dengan memaksimumkan gandaan dan meminimumkan angka hingar bagi tajuk Reka Bentuk Litar Kaskod Penguat Hingar Rendah dengan menggunakan Teknik Gandaan Suapbalik untuk Aplikasi Komunikasi Tanpa Wayar. Untuk mengesahkan idea tersebut, FHX76LP Super Hingar Rendah HEMT yang mematuhi aplikasi tanpa wayar terutamanya standard Evolusi Jangka Panjang (LTE) berjaya menggariskan kemungkinan untuk meningkatkan reka bentuk penguat hingar rendah dalam parameter gandaan, angka hingar keseluruhan, lebar jalur, kepekaan, kestabilan, penggunaan kuasa dan kerumitan. Penguat Hingar Rendah Kaskod mengaplikasikan Teknik T-padanan untuk input-output padanan galangan dan menggunakan Teknik gandaan maklumbalas sebagai suatu cara inovatif dalam membuat litar. Kajian ini menggunakan perisian Advance Design System (ADS) untuk mengumpulkan data dalam bentuk smith chart dan s-parameter yang merupakan alat praktikal yang digunakan dalam membangun dan mensimulasikan rangkaian dan data. Berdasarkan simulasi yang telah dijalankan, reka bentuk kajian telah menghasilkan gandaan (S_{21}) sebanyak 20,887 dB dan angka hingar keseluruhan sebanyak 0.341 dB. Manakalan refleksi masukan (S_{11}) dan kehilangan balikan (S_{22}) ialah – 14.354 dB dan – 11.879 dB. Kesimpulannya, hasil reka bentuk bagi tajuk ini adalah baik berdasarkan simulasi perbandingan dengan kaedah litar yang lain. Implikasinya, penggunaan kajian ini mampu memberikan sumbangan kepada penerimaan isyarat tanpa wayar dengan lebih baik terutama untuk standard LTE dan berpotensi menangani masalah komunikasi tanpa wayar di kawasan luar bandar.
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LIST OF ABBREVIATIONS

ADS	Advance Design System
BJT	Bipolar Junction Transistor
BLE	Bluetooth low energy
CG	Common Gate
CMOS	Complementary Metal-oxide Semiconductor
CS	Common Source
CSMA	Carrier Sense Multiple Access
DC	Direct Current
DCR	Direct-Conversion Receiver
DL	Downlink
ETSI	European Telecommunication Standard Institute
FBB	Feedback Body Biasing
FDD	Frequency Division Duplexing
FET	Field Effect Transistor
GaAs	Gallium Arsenide
GMS	Global Mobile Communication System
HBT	Heterojunction Bipolar Transistor
HEMT	High Electron Mobile Transistor
IEEE	Institute of Electrical and Electronics Engineer
IF	Intermediate Frequency
IFA	Intermediate Frequency Amplifier
IP	Internet Protocol
ISM	Industrial, Scientifics and Medical
LAN	Local Area Network
LBT	Listen Before Talk
LNA	Low Noise Amplifier
LO	Local Oscillator

LPF	Low Pass Filter
LTE	Long Term Evolution
MAG	Maximum Available Gain
MESFET	Metal Semiconductor Field Effect Transistor
MOSFET	Metal-oxide Semiconductor Field Effect Transistor
NF	Noise figure
OFDMA	Orthogonal Frequency Division Multiplexing Access
PCSNIM	Power Constrained Simultaneous Noise and Input Matching
PSO	Particle Swarm Optimization
PTM	Predictive Technology Models
RF	Radio Frequency
SiGe	Silicon and Germanium
SNDR	Signal-To-Noise and Distortion Ratio
SNR	Signal-to-Noise Ratio
TDD	Time Division Duplexing
TSMC	Taiwan Semiconductor Manufacturing Company
UL	Uplink
UMTS	Universal Mobile Telecommunication System
UWB	Ultra-Wideband
VGA	Variable Gain Amplifier
WLAN	Wireless Local Area Network
WiMAX	Worldwide Interoperability for Microwave Access
3GPP	3rd Generation Partnership Project

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CHAPTER 1

INTRODUCTION

1.1 Overview

There is endless demand of Low Noise Amplifier (LNA) that continue to keep driving the innovation for the high-rate data of communication system. Technology today's requires high speed transmission efficiency with less power consumption and low noise amplifier is one of remarkable product that can satisfy all the parameters. LNA are a core component in the receiving end of the communication system. For an example, its performance is measured in a number of figures which is the most notable of dynamic range, loss return and stability. It is responsible when the signal that being received from the antenna is directly given to the low noise amplifiers with internal noise of the circuit is being reduces. In simple words, the LNA is a special kind of electronic amplifier that being used in communication system to amplify a very weak signals that captured by antenna

This thesis consists of five chapter. Each chapter provides details and clarification of the research. Chapter 1 provides an overview of the research including background, problem statement, aim, objectives and the purpose of research besides a brief operational definition. Chapter 2 is the literature review of recent study on low noise amplifier with feedback technique to enlighten the understanding theory in designing the circuit, how stability is determined, and study of existing techniques to understand more about the concepts done in past by the researchers. Besides, parameters that are needed such as gain, noise figure, stability and s-parameter with calculation would boast further understandings. Chapter 3 presents the methodology used in both designing and implementing the LNA purposed in details so the work will be systematic and completed on time. Chapter 4 includes the result and discussion of the project. The calculation made from the s-parameter until the value of noise figure is presented. Last but not least is Chapter 5 which is conclusion and suggesting of the project to make sure the project can achieve target in other way than it is on this project.

1.2 Research Background

The need for communication is part of human nature and long distance communication has being a challenge since the ancient times. In the last two centuries with Maxwell, Hertz, Marconi, and many others in the telecommunication evolved dramatically, who contributed to the development of radio communications we know today. Long distance broadcasting happened and the world got smaller. New technologies were developed, lowering costs, and making wireless communications more and more affordable within market competition. By referring to the demands in our daily life, mobiles users has experience new grown into a new features such as online gaming, streamed video and

instant financial services is a prove that communication grow from time to time to connect people with one and another (P.Boyland, 2019). According to Mahesh Mudavath & K.Harikishore (2016), wireless communication have an impact on people's life with enable of data, image and video to be transferred to anywhere instantaneously make radio frequency (RF) become remarkable.

In communication system there are transmitter and receiver where transmitter is an electronic device that carries radio waves and converts the information carried to a usable form with the use of antenna (Dwijendra Parashar & Nisha Chugh, 2013). The antenna block radio waves which is electromagnetic waves and switch it into insignificant alternating currents that applied to the receiver and excerpt into desired material. The material produce by the receiver may be in any form such as data (digital signal), sound (an audio signal) and images (a video signal) with different frequency of communication. The process of conversing signal received from the antenna that are functional to amplify into high frequency can be use a different type of architectures. There are three fundamental components that act as a front- end receiver which are low noise amplifier, mixer and local oscillator (G.O. Barraza, F.H. Gregorio, & J.E. Cousseau, 2017). The design of low noise amplifiers is used in communications system to amplify very weak signals that captured by an antenna playing an important position to recover data in communication system with minimal noise figure plays as important role in the architecture (Muhammad Arsalan & Falin Wu, 2019).

Low noise amplifier (LNA) is chosen because it is a main type of electronic amplifiers that being used in communication system to amplify very weak signals that

captured by antenna. O. Memioglu & A. Gundel (2018) state that signal that travelling from far usually suffer a noise degradation due to impedance mismatches between amplifier and antenna that affecting the wireless communication system. It is acceptable that LNA can amplify, boast a desired power, reduce noise, received signal and increase gain marking demand increasing in market of mobile phones, GPS and others (Dwijendra Parashar & Nisha Chugh, 2013). Thus, to earn good overall performance several parameters are required such as low power consumption, high gain, low noise figure and acceptable input and output impedance matching.

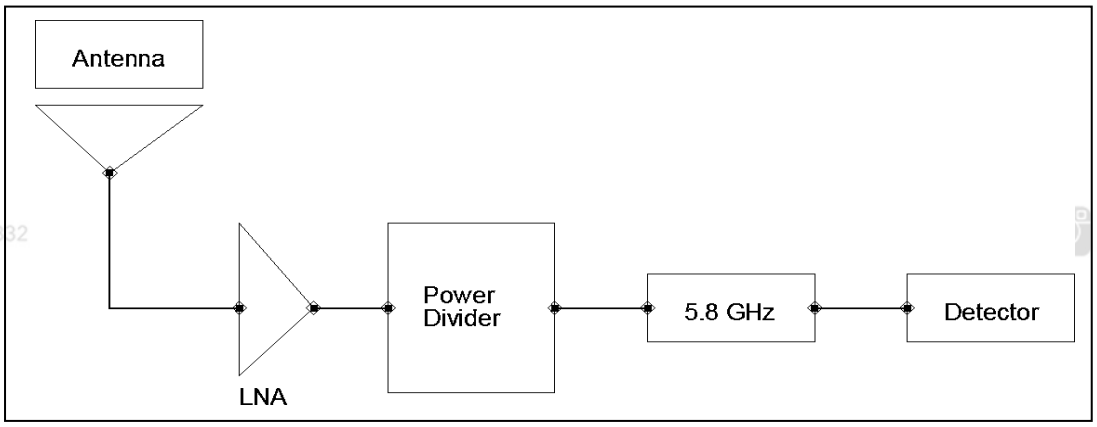

Figure 1.1. Front-end receiver block diagram

Figure 1.1 illustrates LNA is located closed to antenna that occurring losses in the feed line become less critical. LNA as a main component is placed at the front-end of a radio receiver circuit thus with high gain in LNA it can reduce noise figure rise along the path between antenna and LNA (W. Liao & J. Yang, 2016). The purpose of the LNA as it is name implies, is to amplify the received signal to acceptable levels while minimizing the noise significantly without contribute in the circuit. The low noise amplifier is considered as one of the basic building blocks of the communication system. The reduction in the signal due to losses during transmission, reception and

power dissipation in circuit components must be compensated by using a device to provide sufficient gain for the receiver circuit. The design of LNA is very crucial because of its position in receiver path as if something wrong in LNA circuit it cannot be compensated in subsequent stage (Mahesh Mudavath & K.Harikishore, 2016).

Similarly, Liu, T. (2011), describe in multi-stage communication system, where's every stage contributes noise to the entire system. According to Friis's noise figure relationship in Mahesh Mudavath & K.Harikishore, (2016), the first few stage dominated the overall noise figure of the receiver front-end as multi stage LNA would proposed higher gain compare single stage LNA. LNA reduce the noise of all the subsequent stages by the gain of the LNA while injecting the noise directly into the receiving signal. Thus, it will boost the desired signal power and adding a little noise and distortion as possible to retrieve in subsequent stages of system. In overall of noise factor (NF) F_1 and G_1 sufficient signal would be supply dominate the function of LNA being compromise between noise and gain.

$$F_{system} = F_1 + \frac{F_2-1}{G_1} + \frac{F_3-1}{G_1G_2} + \ldots\ldots\ldots\ldots + \frac{F_n-1}{G_1G_2G_{n-1}} \qquad (1.1)$$

Where;

F_n = Noise factor

G_{n-1} = Power gain

This suggested that it is important to design LNA with minimum noise figure (Prameela B. & Daniel A. E., 2016). In the same way, according to Dwijendra Parashar & Nisha Chugh (2013), to ensure LNA able to accommodate by amplifies the received

signal, it is necessary without causing distortion or adding noise making it possible to accept signal of communication system. The next block in the diagram is power divider that are functional to splitting or combining the input power more than two output port by make sure that power level are depends on number of outputs. According to A. R. Othman et al. (2010), the output port is not interference with each other's and will not interrupting the signal. This conclude that an ideal amplifier would amplify the noise at its input along with the signal, maintaining the same signal-to-noise ratio at its input and output.

Meanwhile, 5.8 GHz is the targeted frequency in communication system of Long Term Evolution (LTE) extension in communication application. In current transformation, LTE is a standard for wireless data communication technology and the evolution of Global for Mobile Communication System (GMS)/Universal Mobile Telecommunication System (UMTS) clarify by S. Azzouni, N. Khitouni, & M.S. Bouhlel (2019). Third Generation Partnership Project (3GPP) in Release 8 define that Long Term Evolution (LTE) provide user faster data speeds than 3G and have lots of advantages for end user and mobile operator. According to S. Azzouni, N. Khitouni, & M.S. Bouhlel (2019), LTE's functional to provide an upstream and downstream broadband, reducing the time accessing network, flexibility of the bandwidth and incorporating with current network. Correspondingly, Abu Bakar Ibrahim & Ashardi Abas (2017), state that LTE requirement gain interest in designing appropriate LTE devices as its compatible for accessing a network. This is supported by Ying L.L., Teong C.C., Jonathan L., & Alexey V. (2014), stated that LTE is initiate as packet switched escalated system with entirely Internet Protocol (IP) based architecture for the 3GPP specification in radio access network. In fact, Ahmad Sidik, Maulana Yusuf

Fathany & Basuki Rahmatul Alam (2015), LTE technology provide user with speed up to 300 Mbps for downlink and 75 Mbps for uplink of bandwidth that can supported by frequency division duplexing (FDD) and time division duplexing (TDD). In this rapid development of technologies, there are numerous web services provide user with audio or video sharing, media streaming and it is contributing in consuming a large amount of data that affecting in communication system. Thus, users are anticipating wireless communications to exceed the capability of demands for ubiquitous access to information.

Table 1.1 clarify standard receiver specification of LTE including the input power, noise figure, gain S_{21} and stability adapted from (Mahesh Mudavath & K.Harikishore, 2016). To summarize, recent study in designing low noise amplifier uses varies techniques to achieve low noise figure and high gain because it is most critical task that impact in overall performance of RF receiver.

Table 1.1
Specification of Long-Term Evolution (LTE). Adapted from Mahesh Mudavath & K.Harikishore (2016)

Receiver items	Specification
Input power (dBm)	- 95 to - 25dBm
Noise figure (dB)	<3dB
Gain (S_{21})	>20dB
Stability	>1

1.3 Problem Statement

In recent technologies, powered by the unpredictability of development of wireless communication led to an escalation number of low noise amplifier as receiver resulting rise of design complexity, imposing hassle on cost and power consumption in communication application. Beyond that, rapid development of devices in wireless communication such as Wi-Fi, Bluetooth, WIMAX and LTE have made the design of front-end receiver more complex than before. For instance, Muhammad Arsalan & Falin Wu (2019) state that the design of low noise amplifier for past few years has adjusted to complement between bandwidth, noise figure (NF), gain, impedance matching and stability for specification of system. Thus, solution for front-end receiver of LNA can be meticulously implemented by paying attention to achieved maximum possible gain with specific power consumption while minimized noise figure by exploring different architectures, topology, matching network, circuit design and accessibility technology in designing communication.

Literature implicates that the advancement of Long-Term Evolution (LTE) application today's meets the people's demand to some extent for wireless communication. This affecting the design specification of basic LNA constitutes the following three process which are input impedance matching circuit, amplifier stage and output impedance matching circuit. There are several publications that previously published approach to design with various topologies and techniques for high frequency LNA's to achieve desired possible low noise figure with high gain and input-output matching for wireless application. A frequently used approach is cascode amplifier which provides input and output ports with better isolation over high bandwidth and gain

due to the increase of output impedance and stabilize the performance.

Meanwhile, the input and output matching impedance varies according to the targeted signal frequency of LNA needed but focusing the key challenges to accomplish high gain and better noise execution control utilizing without influencing linearity of LNA. According to K.Raju, R.Sireesha & K. Vijay Kumar (2016), by implementing double feedback structure on balun low noise amplifier where's converting the single stage LNA to differential signal and simplify the design to avoid deterioration receiver of noise figure considered as an approach for performance improvement. On the other hands, Azman Ahmad, Abdul Hamid Hamidon, Abdul Rani Othman & Kamil Pongot (2015), executing by cascading two single stage LNA with inductive degeneration technique by placing combination of notch filter and T-matching network within frequency of 2.4 GHz and 5.75 Ghz and this approach tries to enhance the concurrent of dual band LNA for wireless communication that suitable for Wi-Fi and WIMAX only. However, this approach shows an acceptable range for using T-matching at the input port but it degrading from noise figure and gain. On the contrary, Wu T.Y. & Yang J.R. (2017) used a cascode structure with switch and feedback techniques for multiband high linearity by obtaining gain 22.98dB with power amplifier to incorporated with LTE.

At the radio frequency, more than one stage is typically needed to reach the required gain specification. Previous research on the use of WIMAX signal, it offers that can reach up to 50 km with lots of degradation in signal quality making it suitable for distance 1.5 km to 5 km compared to LTE that can supply signal up to 100 km besides offering connection with speed to 350 km/h (Z. H. Talukder et al., 2013). Thus, LNA is a vital stage in LTE that designed to have minimum noise figure at the carrier

frequency which equalizes the breakdown of bandwidth and gain.

With analytical solution to design propose research of cascode LNA which works on 5.8 GHz frequency with double feedback technique architecture for wireless communication has not been investigated thoroughly yet where past work is not supporting the specification that will be built. This is because the transistors in the feedbacks path are used for excellent noise suppression and LNA efficiency enhancement in order for verification of S-parameter purpose for analyzing process. This can emphasis trade-off between targeted specification when reach at loop of iteration and approach allowing to obtained maximum gain of LNA. Thus, in this research, the goal is to design a low noise amplifier that has higher gain and lower noise with the gain to be targeted is 20 dB and the noise figure is less than 3dB to get the optimum value of signal received where will enable to generate higher gain and lower noise besides improve either in peak data rates, efficiency and the performance.

1.4 Research Objectives

The study is conducted based on the following objectives:

1. To identify the characteristics of cascode low noise amplifier.
2. To stimulate the output of the cascode with double feedback technique architecture.
3. To design the new architecture low noise amplifier based on a double feedback technique.

1.5 Research Questions

Based on the above objectives, this following are the questions posed:

1. What the characteristic of cascode low noise amplifier?
2. How to stimulate the output of the cascode with double feedback technique architecture?
3. How to design the new architecture low noise amplifier based on a double feedback technique?

1.6 Scope of Work

The scope of the research are divided into few phases which are:

i. Understand the background of a low noise amplifier and proposed a suitable LNA topology which is cascode topology.
ii. Calculations are used to measure all of the parameters in order to design the amplifier by using software Advanced Design System (ADS) to determining the s-parameter for frequency 5.8 GHz which is not stated in the datasheet as it only stated the round value from 1 GHz to 20 GHz as part of theoretical.
iii. Mathcad software being used to calculate the stability, power gain, available gain and transducer power gain before matching; and for matching which are mismatch value and noise figure. It is a math tool that combines a computational engine, accessed through conventional math notation with a full- featured word processor and graphing tolls.

iv. Simulations and optimizations are done by software Advanced Design System (ADS) from Agilent uses to analyze besides subsequently design microwave circuit. /

v. The results are compared based on theoretical and simulation on types of circuit configuration used in the layout design.

1.7 Operational Definition

This section defines the operational definitions that being use in this study of development of cascode low noise amplifier with double feedback technique architecture for wireless application. The operational definition is cascode, low noise amplifier, double feedback technique and wireless application are defining relevantly.

1.7.1 Cascode

Cascode is the combination of two stage amplifier consists of common emitter such as NPN common emitter circuit typically use as voltage amplifier. Cascode have radio frequency (RF) amplifier that can produce large bandwidth and gain, and better isolation input and output impedance (Abu Bakar Ibrahim et al., 2012) and supported by Prameela B. & Daniel A. E. (2016), that due to increase in the output impedance, the cascode has higher gain. Similarly, Abdelhamid A. A., Ozgun M. T., & Dogan K. (2019) state cascode that have two transistors can improve the reverse isolation besides flexible for achieving input matching with lowest RF. Cascode is well known for better gain, wider bandwidth, high input impedance, better input output isolation, stability and

high ouput impedance. Cascode amplifier can construct by using field effect transistor (FET), metal oxide semiconductor field effect transistor (MOSFET), bipolar transistor and others that can reduce noise contribution. Thus, in this research FET will be used as a transistor in the cascode topology.

1.7.2 Low Noise Amplifier (LNA)

Low noise amplifier is an electronic amplifier that amplify weak signals that capture by various antennas with the present of noise (Ashwini Rajole, 2015). According to M. Bansal Aditi (2017), low noise amplifier is an integral part of wireless communication system that essential to minimize additional noise that influence block in the receiver of communication system. LNA objective mainly is low in noise figure, high gain and have wide bandwidth when designing a circuit (Ruchi Kumari, V. Vignesh, & Navin Kumar, 2018). As describe by Anishaziela Azizan, S. A. Z. Murad, R. C. Ismail, & M. N. M. Yasin (2014), LNA affecting receiver performance with parameters of low power consumption, high gain, low noise figure and input and output matching for circuit design.

1.7.3 Double Feedback Technique

Double feedback technique is a method proposed in this research by using two local feedback loops to produce higher gain and reduce noise figure. For instance, K.Raju, R.Sireesha, & K. Vijay Kumar (2016), used double feedback techniques to boost the gain and reduce the noise figure that suitable to optimize the circuit performance in the CS and CG stages under power amplifier meanwhile research are basically discussing

on implementation of double feedback within targeted frequency of 5.8 GHz and using cascode LNA. In fact, Ivan Bastos et al. (2013) proposes double feedback structure to minimize the additional noise in conventional Balun LNA with basic stages CS and CG with frequency 1.2v. It can be concluded that the techniques should be flexible and reliable to retain gain and noise figure when designing the circuit.

1.7.4 Wireless Application

For the time being, within the field of wireless networking, sepecially Bluetooth, Wi-Fi, WIMAX and wireless local area network (WLAN) have a range of drawbacks with difficulty of high power dissipation, short reach and others. With the advancement in wireless communication technologies, the difficulty in connectivity of communication in people's lives with the incorporation of Long Term Evolution (LTE) has broaden the scope and practicability in the area as it is the next generation of 4G mobile wireless broadband communication system. For instances, Paschal A.Ochang & Philip, J. Irving (2016) presented the Third Generation Partnership Project (3GPP) in Release 8 LTE is documented can provides users much faster data speeds than 3G is able to. Many consider that LTE should be labeled as 3.9G and according to the first "true 4G" is LTE advanced defined in Release 10 and LTE advanced systems have a lot of advantages for both end users and mobile operator. LTE working on very high efficiency that provide beneficial for the users (Jingjing Z. et al., 2018) besides it act as solutions to solve high demands of data rates (Paschal A.Ochang & Philip J. Irving, 2016). As describes, LTE application is the simplest form that provide high speed wireless access considering large interest to provide service to user for past few years until nowadays.

1.8 Conclusion

In a conclusion, this chapter consists of introduction of the research. Introduction is an early reflection of the research and issues that are being carried out. Research background emphasis in details related with cascode LNA and highlighting their unique pros and cons among the different topologies and analyze previous techniques used. Cascode are designed specifically for higher gain, bandwidth and reduce the noise figure meanwhile LNA contribute and determine the overall performance quality in a communication system in this study. Problem statement describe the problem occur and prediction process in solving it. Moreover, research objectives, research questions and research scope are important as it is heavily discussed for understanding purposes includes parameters such as gain, noise figure (NF), bandwidth and stability. In addition, operational definition has been explained in general. Due to communication distance according to LTE standard, the LNA can offer higher bandwidth but required high gain and low noise figure for the communication system. Thus, to improve the current performance of the receiver a new design LNA are applied which is double feedback technique that contribute in providing a better wireless signal.