LOW NOISE AMPLIFIER FOR MEDRADIO APPLICATION

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LOW NOISE AMPLIFIER FOR MEDRADIO APPLICATION

By

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Alternating Current
Av	Voltage Gain
CMOS	Combinational Metal-Oxide Semiconductor
CS	Common Source
DC	Direct Current
EIRP	Effective Isotropic Radiated Power
FCC	Federal Communication Commissions
gm	Transconductance
Id	Drain Current
LNA	Low Noise Figure
MedRadio	Medical Radio
MICS	Medical Implant Communication Service
NF	Noise Figure
RF	Radio Frequency
RSF	Resistive Shunt Feedback
UWB	Ultra-Wide Band
WBANs	Wireless Body Area Networks

PENGUAT HINGGAR RENDAH

BAGI APLIKASI MEDRADIO

ABSTRAK

Thesis ini merangkumi reka bentuk dan simulasi bagi sebuah penguat hingar rendah berkuasa rendah bagi aplikasi MedRadio dengan menggunakan standard teknologi CMOS 0.18 μm piawaian. Penguat hingar rendah tanpa induktor ini dilaksanakan dengan teknik litar suap balik pirau dan peringkat penimbal (berdasarkan simulasi). Untuk peranti perubatan yang diimplan dalam tubuh badan manusia, penggunaan kuasa yang rendah merupakan aspek yang diberi keutamaan agar peranti itu dapat digunakan lebih lama dalam tubuh badan manusia. Dengan penggunaan kuasa yang rendah, penguat hingar rendah ini akan dapat menjamin jangka masa bateri yang panjang bagi aplikasi perubatan yang diimplan dalam tubuh badan manusia. Reka bentuk dan simulasi dibuat dengan Cadence IC5 menggunakan teknologi Silterra CMOS 0.18 μm. Didapati bahawa penguat hingar rendah ini menggunakan kuasa sebanyak 1 mW disebabkan rangkaian litar suap balik pirau. Reka bentuk ini beroperasi pada kuasa rendah dengan gandaan sebesar 11.6 dB, angka hinggar serendah 7.5 dB dan kehilangan polangan masukkan sebanyak 10.1 dB pada jalur MedRadio 401 MHz hingga 406 MHz.

LOW NOISE AMPLIFIER FOR MEDRADIO APPLICATION

ABSTRACT

This work presents the design and simulation of a low power LNA for MedRadio band using the standard 0.18 μm CMOS process technology. This inductor-less LNA is implemented with resistive shunt feedback circuit technique with an output buffer. For medical device that is being implanted in human body, the power consumption is one of the domain concern in order to ensure it last longer in the human body. With low power consumption, this LNA could ensure longer battery life for the implementation of medical devices that are implanted into human body. The design and simulation were done via Cadence IC5 with Silterra's 0.18 μm CMOS technology. It is obtained that the power consumption of this LNA is just 1mW due to the resistive shunt feedback network. The design (on simulation) operates at low power consumption with gain of 11.6 dB, NF of 7.5 dB and input return loss of 10.1 dB between 401 MHz to 406 MHz MedRadio band.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Chapter 1 describes the background of the LNA and its role in the medical sector. The evolution of the Medical Device Radio communications Service (Med Radio) is shown with its impact on the implementation of wireless technology across the medical demand. The motivation and the importance of this project is clearly stated as well. The objective is derived from the problem statement related to this project and is covered in the research scope section. The research framework is also presented as an overview of the entire report.

1.2 Research Background and Motivation

As the world population is growing, the demand for health care application rises as well. The advanced of wireless technology and integrated circuit for medical use has been proven to be beneficial and crucial implementation to meet the worlds' urge in sorting medical issues. The Med Radio with the appropriate band ranged between 401 MHz to 406 MHz is introduced to replace the Medical Implant Communications Service (MICS). The Med Radio is newly designated with twenty 100-kHz BW channels to provide a total of 5 MHz of continuous spectrum and accommodate both implantable and wearable sensor devices for medical use. The need of standardizing the frequency range for the medical application is definitely an important move for health monitoring application. Concerning the aspect of reliability, and cost effective for longer durations, the Wireless Body Area Networks (WBANs) (Federal Communication Commision, 2017) should meet the low power consumption for prolonged battery life. As per the required specification for the LNA for Medical Band Amplifier, it has to reduce the current and supply voltage of the transceiver to minimize the power consumption without affecting the performance.

As the urge for medical needs increases with the rising population as millions of people are affected by heart diseases and chronic diseases, diagnosing a chronic disease in earlier stage is definitely important to ensure the necessary medical treatments can be provided to the patient to avoid complexity and further costly treatment. Presence of implanting active device with wireless capability into human body can be used to diagnose and provide early stage warning. The examples of implanted devices are such as an artificial pacemaker, drug pump and neuro-stimulators. These devices are controlled from outside the body or device parameter adjustment, transmission of stored information and real-time transmission of vital monitoring information purposes. To provide a communication path between the programmer who controls the device outside the body and the device, an inductive link is used as a conventional method. However this method has its own disadvantages. Patients usually must remain in an uncomfortable posture to allow proposer communication path. Patient with an implanted device should also avoid unwanted activation that may be derived from other electrical field, MRI machines and other mobile communication devices operating in the similar environment. The issues on interference is very crucial in an inductive-link based medical communication system because of the other communication system in the similar frequency band.

Emergence of Med Radio, and universal RF band of 401–406 MHz as the improvised version replacing MICS appears to be the solution to avoid the limitations imposed by inductive link communication. The effectiveness or the functionality of Med Radio for medical purposes has been affected by the presence of other overlapping signals near by the implanted device. To overcome this concern, designer should come up with an LNA in the design to eliminate the other existing signals produced by both the body and the surrounding else than amplifying the required signal to be produced by the implanted device to the controller located outside the body.

The purpose of the LNA is to reduce the noise to produce a clear signal in a receiver chain for Med Radio Spectrum of 401 – 406 MHz frequency band. As the basic specification, an LNA should have an operating supply voltage within the range of 1V to 10V and operating supply current in mA and temperature ranged between -30°C to 50 °C (Srivastava, 2016). In brief, by implementing an LNA close to the signal source, the noise effect from the subsequent stages of the receiver chain can be reduced by the gain signal produced by the LNA. It amplifies the desired signal power while minimizing the noise and distortion to enable optimum retrieval of the desired signal in the later stages of the Medical Band. The basic block diagram of MedRadio receiver is shown in Figure 1.1.

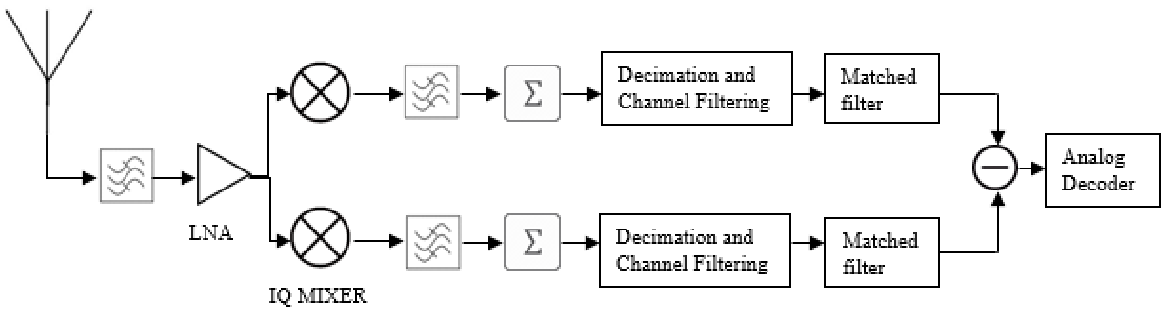

Figure 1 1: Block diagram of a Medradio receiver (Henrik Sjoland, 2014)

The implementation of UWB technology, is currently used widely in LNA designs for body mounted medical devices because of its features which is able to offer high throughput data communication and low throughput data communication in medium range (Pancera, 2010). The UWB and the Industrial, Scientific and Medical (ISM) band are used for non-implanted sensors and devices. UWB is able to provide additional through-wall capability and low circuit power consumption when the device operates in minimum frequency. Therefore, this architecture provides lower power consumption and high integration.

The main concern related to the implementation of UWB technology for the LNA is the overlapping of various existing operating wireless system. To overcome this scenario, it requires a large amount of averaging of a smart interference-cancelling scheme in Digital Signal Processing detection. Since most of the interferers are in-band, there will no longer be concern regarding the folding out-of-band interference in-band and swamping the signal due to nonlinear intermodulation (R. Sapawi, 2016). This makes the designing task of the first stage of the system, LNA to focus on minimizing the power consumption while achieving a minimum NF and linearity. The relationship between the UWB, ISM and MedRadio is illustrated in graph form in Figure 1.2. This LNA is targeted for implant medical device purpose. Thus, the design performance is mainly focused at the MedRadio band between 401 MHz to 406 MHz.

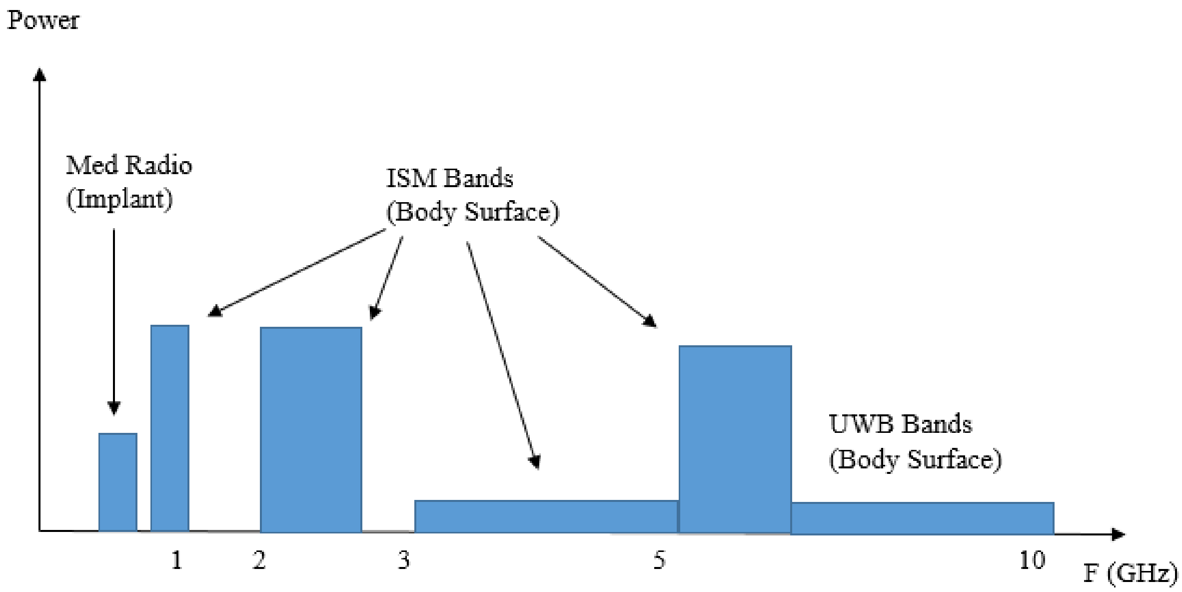

Figure 1 2: Frequency Band for Body Area Network (BAN)

Absence of inductor in the design is the significant features of the design. Inductors are used to tune frequencies in LNA. Without an inductor the device could not possibly be tuned to the respective operational frequency. The performance of this inductor-less LNA is evaluated mainly at the MedRadio band. Additionally, this LNA is expected to produce relatively high gain at low frequency, making it to operate at even lower frequency. This criteria acts as an added value for this design.

The analogue front-end circuit to tolerate the switching noise coupled through the substrate from the digital circuits is another domain concern of the design. To resolve this concern, a specific topology should be used to overcome it from affecting the output of the design. The most common amplifier used to simultaneously produce power gain and input impedance of 50Ω over a wide band width are the resistor-terminated common-source amplifier. The resistor-terminated common-source amplifier is able to decouple the input matching from the device and is able to achieve the lowest possible power while still able to provide 50 Ω in order to attain NF lesser than 10 dB. The implementation of this topology is expected to be able to produce a LNA with high gain greater than 10 dB, input return loss of 10 dB, low NF for Medical Band within the range of 401 MHz to 406 MHz.

By implementing the common source resistive shunt feedback technique, the LNA will be able to eliminate the external noise and amplify the inductive link signal with a significant gain. An additional buffer stage is implemented to preserve the gain of the LNA. In real life application, the output of the Resistive Shunt Feedback will be the supplied ad the input of an additional block such as mixer. Thus, the performance of the LNA will not be effected without the output buffer due to the input impedance from the additional block of mixer. This project contributes in analysis the performance on LNA using various topologies. It is highly expected that the final product of this thesis would be definitely appreciated and useful for the medical industry as well as the consumers due to its robustness and cost effectiveness.

1.3 Problem Statement

As the technology continues to grow, we have been introduced to various diseases that requires the technology of implanted devices to aid and contribute in medical industry to improvise the quality of medical service. It is observable that the technology of implanted devices requires improvements in order to make it more effective in the sense that the respond signal from the device should be able to be amplified with lower noise. To solve this issue, various topologies are tested and implemented to produce a robust design for LNA operating in MedRadio band. As this device is being implanted in human body, the power consumption is one of the domain concern in order to ensure it will last longer in the human body. The power consumption should be minimized as low as possible not just for cost reduction and longer lasting purpose but also for safety purpose.

1.4 Objectives of Research

1. To design an LNA with low power consumption and NF for MedRadio application.
2. To verify the design of the LNA using Cadence Virtuoso.

1.5 Scope of Research

This project focuses in the design and construction of an LNA which is able to give an amplification of 12 dB and NF as small as 8 dB within the frequency of 401 MHz to 406 MHz. The topology used is the Resistive Shunt Feedback with a buffer stage. The important parameters such as *Id* and *Vdd* are obtained referring from previous work done by researchers. Using the appropriate equation, the device size are determined. The suitable value of *Vgs* and *Vth* are obtained via multiple simulations in order to ensure the transistor operates in saturation region and the (W/L) is optimized. The parameters of the *gm, Id, Vth* and *Vsa*t are obtained through the simulation done via Cadence for further design process. The LNA designed has low power consumption and a stable value for input return loss (*S11*) and gain (*S21*). The presence of the feedback resistor that does not consume power and degrades the output impedance contributes in lowering the power consumption of the desired LNA. Additional buffer stage is analysed and designed to preserve the gain of the LNA. In real life application, the output of the Resistive Shunt Feedback will be the input of an additional block such as mixer. The linearity of the design is ensured by verifying the 3^{rd} order intercept point, *IIP3*. These parameters are verified via Cadence Virtuoso pre-layout simulation.

1.6 Thesis Outline

This thesis has been organized into five chapters, including this introduction. In Chapter 2, some descriptions of the Medical Radio Communication (MedRadio) and the function of LNA in MedRadio is presented. The existing LNA topologies, together with distinction between inductor and inductor-less LNAs are discussed. The parametric value commonly used for LNA design is presented.

In Chapter 3 the detailed description of the theoretical analysis for the Common Source Resistive Shunt Feedback and the output buffer are discussed. A theoretical analyses is made to obtain the equations of the circuit in order to optimize the circuit. It is also shown the simulations results of the optimized design. This includes the necessary steps in deciding the device size and the voltages involved. The step by step methodology is explained and investigated.

Chapter 4 is the result and discussion section. The pre layout simulation results for Dc analysis, S-parameters, NF and linearity are analysed and explained. Comparison with the state-of-the-art wideband LNAs is made to justify the performance of the LNA designed. Finally, in Chapter 5 is given the overall conclusions and further research suggestions.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

As this project is proposed to design a CMOS inductor-less LNA, the N-MOSFET is used as it has more advantages compared to the P-MOSFET. The N-MOS has higher speed due to smaller body junction area. There are several topologies or methods to establish the LNA design as per the specification mentioned such as noise cancelation method, current reuse method, and resistive shunt feedback and common-gate circuit. Prior to determining the appropriate topology to obtain the respective specification, width and length of the mosfet and the bias voltage for the circuit should be determined. To do so, the methods and the theory behind the analogy of voltage biasing is studied.

The success and the justification of the design is measured by the value of Av, NF, 3rd order intersection point, power consumption and the S-parameters obtained. The output resistance plays a very important role in maintaining a good and significantly high gain. Thus, the presence of a source follower circuit can improve performance of the LNA as the gain of the LNA is preserved.

In this chapter, the variety of topologies and methods in realizing an LNA for Medical Radio Communication are discussed. This chapter covers the literature review of the design used as the topologies. The specific topologies implemented in this design is further discussed in Chapter 3.

2.2 Medical Band Radio Communication

The Federal Communications Commission (FCC) has advanced its wireless health care agenda by adopting rules that will enable Medical Body Area Networks (MBAN), low-power wideband networks consisting of multiple body-worn sensors that transmit a variety of patient data to a control device. The BAN consist of 3 region of frequency categorized according to specific range.

Ultra-Wide Band (UWB) is a wireless technology which transmits data over wide spectrum of frequency bands from 3.1-10.6GHz with relatively low power consumption and high rate of data flow. Implementation of UWB in LNA is required to provide good input matching over the bandwidth with sufficient gain to amplify the necessary weak signal at the receiver port as well as overcome the noise from the subsequent stages.

In addition, the NF of the UWB LNA should be minimized reasonably low as it has a dominant role in defining the circuit sensitivity. The size of the LNA will be relatively small enough to ensure power efficiency, reduce power consumption and the fabrication cost as well (Rozi Rifin, 2013). The implementation of UWB is evolving as it meets the specification of technology implementation in health and medical sector. The UWB pulse is generated in a short duration of time which is within sub-nano second. It has spectrum below the allowed noise level which makes it possible to get Gbps speed by using spectrum of 10 GHz. This makes UWB suitable to be used for high speed over short distance. This key features of UWB makes it as the main advantage for medical engineering and technology advance of wireless radio-communication in biomedical (Pan, 2008).

The Medical Device Radio Communication or commonly known as MedRadio is the range of 401 – 406, 413 – 419, 426 – 432, 438 – 444, and 451 – 457 MHz. The MedRadio spectrum is implemented in the medical sector for diagnostic and therapeutic purpose in medical devices which are implanted and worn on body. Examples of device been implanted into human body are such as artificial pacemaker, neuromuscular stimulators and defibrillators.

The Medical Body Area Networks (MBANs) are low power networks of sensors worn on the body controlled by a hub located at the external body within a small parameter operates in range of 2360 to 2400MHz band. The MedRadio dates back to the 1999s when the Federal Communications Commission (FCC) established the Medical Implant Communication Service (MICS). The range of spectrum was set aside to three at 402-402MHz for implanted medical devices. In the year 2009, FCC created the MedRadio with range of 401 MHz – 406 MHz (Federal Communication Commision , 2017).

The MedRadio globally operates on a license exempt basis in more than 50 countries including Canada, US, Europe and Japan. The MedRadio implemented LNA required low power consumption as low as 1mW. The power source should be compatible with human body energy scavenge operation. Crucially, the medical devices designed for MedRadio should be reliable towards external response. Figure 2.1 below shows the power consumption for the BAN technology.

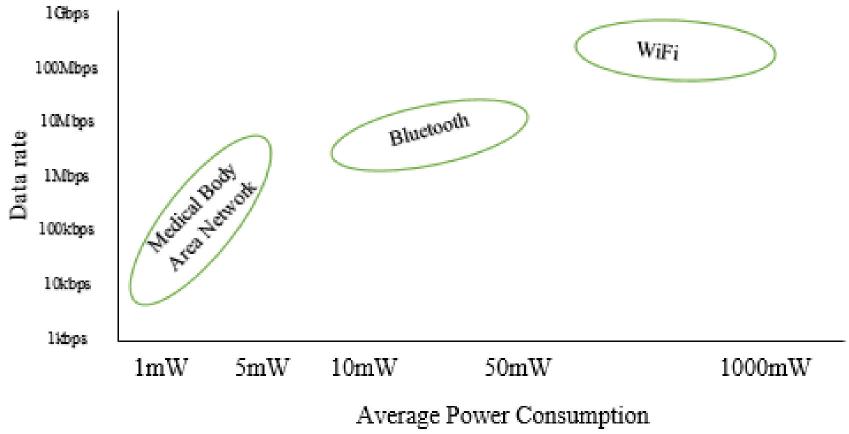

Figure 2.1: Average Power Consumption (Ekundayo, 2013)

2.3 Concept of LNA in Radio Communication

The function of LNA has taken role of wireless communication in medical field further. The basic prospect of a LNA is provide high gain of amplification with minimal NF as per its function which is to amplify the necessary signal and minimize the noise signal. The LNA implemented for Medical Radio Communication is expected to operate at the frequency of 401MHz to 406MHz as per stated by the Federal Communication Commissions in March, 2009.

An amplifier basically amplifies the output signal significantly based on the input signal injected. The amplifier has the ability to magnify the output voltage and degrade the noise signal effect. For the LNA design, CMOS has been widely implemented and become a competitive technology for radio transceiver of various wireless communication due to its technology scaling, higher level of inerrability and lower cost (Nguyen, 2004). The LNA is one of the main component in a typical radio receiver as it tends to dominate the sensitivity. The design of LNA revolves around several trade-offs between NF, overall gain, linearity, impedance matching and power consumption. In general, the main aim of a LNA design is to obtain simultaneous noise and input matching.

In the communication market, the demand of LNA is increasing with the development of trendy gadgets, medical equipment and other technology aspects approaching industry 4.0. An LNA is placed at front end of a radio receiver in the basic building block of a communication system. It acts as an electronic amplifier to amplify the receiver signals to an acceptable level with minimized self-generated unwanted noise while the radio receiver composed of amplifier, mixer and filter. The domain function of the LNA is to amplify low signal without including noise thus preserve the signal required. The LNA amplifies the received signal without introducing any sort of distortions and eliminates possible channel interference. The theory behind the implementation of LNA is that the signal coming from the transmitting antenna or device is very small, thus it requires an amplification with reasonable power consumption, linearity and NF. Considering all the parameters to be within the slightest tolerance, the performance of LNA is to be said satisfying the design specifications (Neha Rani, 2013)

2.4 Input Referred IP3 and IP1

The IP3 (Third Order Intersect) and IP1 (1 dB Compression Point) contributes in deciding the linearity of the LNA performance. When the output power is plot versus input power, a linear line acting as the theoretical reference line. As the input power increases continuously, at certain point the gain will begin to degrade. At this point, the LNA goes into compression where the output will no longer increase for an increasing input.

In the non-linear region, the amplifier will produce several harmonics of the amplified inputs. The second and third order harmonic will commonly not fall within the desired bandwidth of the amplifier, thus these harmonics will be easy to filter out. However, non-linearity will cause mixing effect with two or more signals. With the signals close together forming intermodulation products (IMD) could occur within the bandwidth of the amplifier. These signals cannot be filtered and should be controlled. The IIP3 value can be obtained with reference to the input and output. The higher the output value of the intercept, the better the linearity and the lower the IMD value.

2.5 Topologies

Over the past 10 years, there were various work done by researches in designing the LNA with various topologies as current reuse, noise cancellation and resistive shunt feedback in achieving optimum performance of LNA operating in MedRadio band. For LNA design, numerous architectures have been proposed up till today. Each of the design has its own trade-offs in meeting the design specification. However, there's no single LNA topology that could satisfy all the design specifications for all type of application. To obtain optimum result in particular aspects, several properties should be sacrificed and fall as the trade-off. The design trade-offs can be either, gain, power consumption, noise, linearity, size, input matching, process variation and quality factor (ZHANG, 2014).

For LNAs operating in MedRadio band at frequency between 401 MHz to 406 MHz, the power consumption usually fall as the main design specification. The LNA designs can be obtained with the usage of inductor or inductor-less. Inductor plays an important role in tuning the frequency of the device. As the MedRadio Band is used for implanted device, the size of the device design should be small enough to be implanted in human body. Addition of inductor into the LNA would add on the chip area of the device.

The current reuse topology is one of the commonly used topology for LNA design. The current reuse topology could be implemented in several ways. Based on (Mutanizam Abdul Mubin A. M., 2017), the utilization of a pair of NMOS/PMOS transistors in common source configuration is analysed. The current reuse topology is illustrated in Figure 2.2 below.

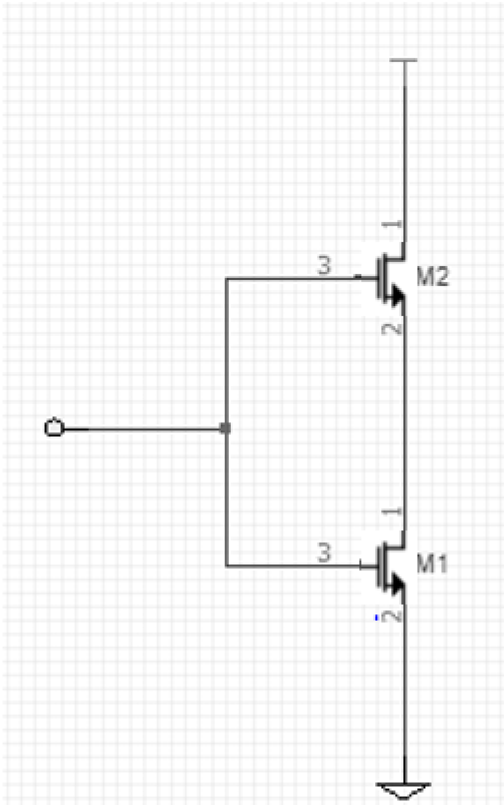

Figure 2.2: Current reuse topology (Mutanizam., 2017)

Using the current reuse method, the *gm* for both transistors, M1 and M2 can be achieved with similar value and with smaller *Id*. In initial stage, the single NMOS with have the size of (W/L) with its respective gm drawing specific amount of *Id*. As two NMOS transistors are connected in parallel as shown above, the size ratio for both M1 and M2 is reduced to (1/2) (W/L) to ensure the *Id* flowing in each of the device becomes half as well. Thus, the total *Id* of the circuit will be equivalent as it was initially for one NMOS. This causing the gm value equal to one NMOS too. This technique is able to deliver high gain with low current and power consumption as per the requirement for the medical embedded device. As this work is inductor less, the chip area is able to be minimized causing it to consume 0.6mm^2 approximately.

The Resistive Shunt Feedback (RSF) topology have proven to be visible option for implementing multiband receivers. The implementation of this circuit requires very small die area and can be implemented in a digital CMOS process without the presence of any additional RF enhancements. This topology can significantly reduce the cost of the wireless front-end implementation. RSF has the capability to achieve significantly high gain and reasonably low NF (Perumana, 2008).

Obtaining high voltage gain and good input matching with low power consumption has been the great challenge in this circuit design approach (Marcelo de Souza, 2015). This topology is often implemented in the design on wideband amplifiers to obtain good input matching. This topology takes the low power consumption and relatively high gain into consideration as it has negative feedback with the tendency to minimize the input impedance of the amplifier. It also extends its bandwidth with reduction of trade-off gain (Rozi Rifin, 2013). The comparison of state-of-the-art works are shown below in Table 2.1 using different topologies and techniques.

Table 2 1: Comparison of previous work done

Reference	Parameters					Process Technology/ μm
	S11/dB	NF/dB	S21/dB	Linearity	Power Consumption/ mW	
(Hugo Cruz, 2015)	-12	11.6	10	-97	1	0.18
(Apoorva N, 2016)	N/A	7.4	9.4	-18	1.3	0.18
(Mutanizam Abdul Mubin A. M., 2017)	-10.4	4.6	18.5	N/A	0.6	0.18

Comparing several previous work done by researchers, the table below shows the previous work by (Nga, 2012) taken as the guide in designing the LNA for this project as it is proven to function at gain of 15 dB, NF of 5 dB and *Id* of 0.98 mA.

Table 2.2: Parameter and Design Specification

Design Specification		Parameters			Reference
Gain/dB	NF/dB	Id/mA	Vdd/V	Power Consumption/mW	
15	5	0.98	1.0	0.95	(Nga, 2012)

Based on the literature review, the design specifications set for this LNA design is as shown in table below.

Table 2.3: Finalized Design Specification

Performance Matrix	Values
Noise Figure (NF)	< 5dB
Gain	> 15 dB
Power Consumption	1.0mW
IP3	-6 to -2dbm
S_{11}	<-10dB
S_{21}	>10dB

2.6 Source Follower

A source follower circuit is a general building block which is illustrated in a large number of high speed or frequency application due to their intrinsic simplicity. The drawback of this circuit is that it contributes some non-ideal effects which includes body effects, channel length modulation, signal-dependent capacitive effects and frequency-dependent distortions arising from the capacitive load.

The non-ideal factors mentioned generates a trade-off between linearity, bandwidth and power consumption that turns to be a great challenge in the design. The cascade approach of two N-MOSFET is technically proven to yield a high linearity. But this approach is said to be unsuitable for a modern large scale integration usage with low power supply (Chan, 2005).

The role of the source follower is necessary as an output buffer for measurement purpose. The figure below show a simple N-mosfet source follower.

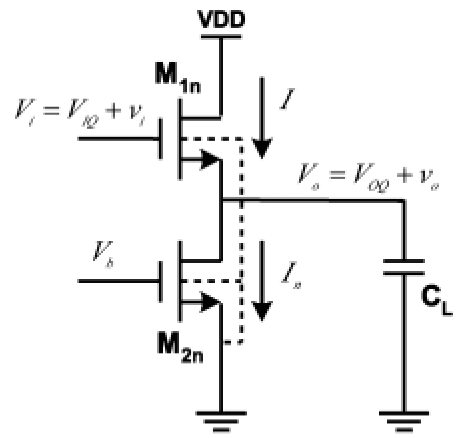

Figure 2.3: Source Follower for N-MOSFET (Fan, 2005)

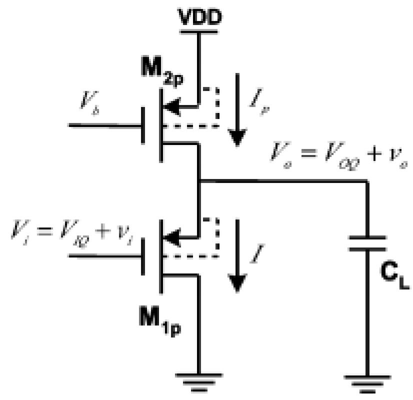

Figure 2.4: Source Follower for P-MOSFET (Fan, 2005)

2.7 Summary

Looking through the previous work done for LNA on MedRadio, it is clear that each architecture implemented comes together with a trade-off in establishing a functional LNA. This chapter sums up the review on previous work done by researches on LNAs for MedRadio and its trade-offs.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

Every existing LNA are designed to meet certain specifications such as the power consumption, NF, Voltage Gain, linearity, S-Parameters as well as the sensitivity of the device. This specifications can be achieved by implementing the appropriate topologies in the design. From system consideration, LNA NF with value ten times smaller than that of the interference is reasonable. NF is considered as the most critical performance matrix of the LNA. Along with the NF, the third order intercept point (IIP3) represents the linearity of the circuit. The power consumption has become an important performance matrix of the LNA because of increasing usage of portable devices.

This project aims to design an LNA for Medical Band for the frequency of 401 MHz to 406 MHz which gives low power consumption and moderately high gain. Taking this design criteria into consideration, the topology of Resistive Shunt Feedback with a buffer stage is used for this project. The respective parameters such as *Vsat, Vth, gm, Id* and r_o of the design are obtained via Cadence simulation.

Chapter 3 explains the method involves in developing and realizing the design of LNA with the implementation of the respective topology which meets the design requirement plus enhance the output performance of the design. The fundamental of design procedure is deciding the device size. In this chapter, the step by step procedure in design the Common Source Resistive Shunt Feedback and the Source Follower will be explained.

3.2 Flowchart of Project Procedure

The project procedure begins by reviewing the similar work done by other researchers to have a better understanding and to determine the targeted parameters to be used for this design. Parameters such as the *Id*, supply voltage (*Vdd*) and power consumption are decided from the analysis based on the comparison done in Chapter 2. With the aim to achieve the desired specifications for the LNA, the topology to design the circuit is decided. The values of the components and the sizes of the transistors for the LNA are selected to achieve an overall optimum in global design space by iterative simulations. The most important criteria in designing the LNA is deciding the W/L, the device size and bias voltage. The sensitivity of the circuit is verified via the cadence simulation. As the design specifications are met, the LNA design is completed. The flowchart in Figure 3.1 shows in brief the flow of the project procedure.

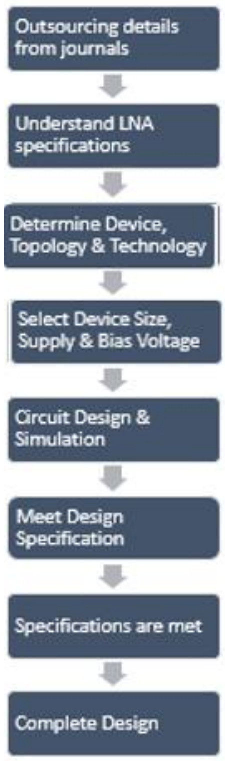

Figure 3.1: Flowchart of LNA Design Procedure