CARBON NANOTUBE FIELD-EFFECT TRANSISTOR FOR A LOW NOISE AMPLIFIER

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
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Specially dedicated to my beloved family, lecturers and friends
for the guidance, encouragement and inspiration
throughout my journey of education

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ABSTRACT

The demand for low power front-end receiver which works at ZigBee Standard had increased because it helps to increase the battery life and ZigBee Standard is used by many applications, such as sensor, Bluetooth, and wireless. One of the important parts of front-end receiver is Low Noise Amplifier (LNA). It helps to amplify the signal received before the signal is sent to the mixer. Nowadays, most of the LNA is produced by using the technology of MOSFET. However, the technology of MOSFET will reach its limit in 2020. There are a few different structures which can be used to replace MOSFET but they will also reach their channel length limit when MOSFET reach its limit. Among different materials, CNTFET is the best material to replace MOSFET because of its characteristics of high mobility, and can conduct larger current densities. This thesis focuses on single-ended CNTFET LNA design that can operate with low voltage supply and consumes low power. It is a big challenge to design a low power LNA as the performance of the LNA degrades at low voltage. Besides, it is even more challenging as the specifications need to consider the requirements of mixer. Among LNA topologies, cascode LNA gives the highest gain, which makes it suitable to be used. The technology used for this project is 32nm CNTFET. The model used is Stanford CNTFET Model for HSPICE. CosmosScope is used to view the waveform. The proposed CNTFET LNA operates at a supply voltage of 0.5V. It provides a gain of 18.17dB and acquires a noise figure (NF) of 1.38dB. The total power consumption is only 1.09µW. The specifications show that the CNTFET LNA can work well at voltage supply and is suitable to be integrated with a mixer.

ABSTRAK

Permintaan bagi penerima bahagian rendah yang kurang kuasa yang berfungsi dengan piawai ZigBee meningkat kerana ia membantu meningkatkan hayat bateri dan piawai ZigBee digunakan oleh pelbagai aplikasi seperti penderia, *Bluetooth* dan wayarles. Salah satu bahagian penting bagi penerima bahagian depan ialah penguat hingar rendah (LNA). Ia membantu mengguatkan isyarat yang diterima sebelum isyarat itu dihantar ke pengadun. Pada masa kini, kebanyakan LNA dihasilkan dengan menggunakan teknologi MOSFET. Walau bagaimanapun, teknologi MOSFET akan mencapai hadnya pada tahun 2020. Terdapat beberapa struktur yang berbeza yang boleh digunakan untuk mengganti MOSFET tetapi mereka juga mencapai had mereka apabila MOSFET mencapai hadnya. Antara bahan-bahan yang berbeza, CNTFET adalah bahan terbaik untuk menggantikan MOSFET kerana ciri-ciri yang lebih baik seperti mobiliti tinggi dan boleh mengalirkan kepadatan arus yang lebih besar. Tesis ini memberi tumpuan kepada reka bentuk CNTFET LNA satu tamatan yang mampu beroperasi dengan bekalan voltan rendah dan menggunakan voltan rendah ultra. Mereka bentuk LNA kuasa rendah memberi cabaran yang besar kerana prestasi LNA menurun apabila ia beroperasi di voltan rendah ultra. Ia menjadi lagi mencabar kerana spesifikasi tersebut perlu mempertimbangkan keperluan pengadun. Antara topologi LNA, topologi *cascode* memberikan gandaan yang paling tinggi. Oleh itu, ini menjadikan ia sesuai untuk digunakan. Teknologi yang digunakan untuk projek ini ialah CNTFET 32nm. Model yang digunakan ialah Stanford CNTFET Model yang digunakan untuk HSPICE. CosmosScope digunakan untuk melihat bentuk gelombang. LNA yang dicadangkan beroperasi pada bekalan voltan 0.5V. Ia membekalkan gandaan sebanyak 18.17 dB dan mencapai angka hingar (NF) sebanyak 1.38 dB. Jumlah pengunaan kuasa adalah 1.09µW. Speksifikasi menunjukkan LNA tersebut berfungsi dengan baik dan ia sesuai untuk disambungkan dengan pengadun.

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LIST OF SYMBOLS

LNA	-	Low Noise Amplifier
RF	-	Radio Frequency
NF	-	Noise Figure
VCO	-	Voltage Controlled Oscillator
IEEE	-	Institute of Electrical and Electronics Engineers
LR-WPAN	-	Low Rate Wireless Personal Area Network
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
FinFET	-	Fin Field Effect Transistor
SOI	-	Silicon on Insulator
GNR	-	Graphene Nanoribbon
CNT	-	Carbon Nanotube
GNRFET	-	Graphene Nanoribbon Field Effect Transistor
CNTFET	-	Carbon Nanotube Field Effect Transistor
MFP	-	Mean Free Path
IC	-	Integrated Circuit
IIP3	-	Third Order Interception Point
AC	-	Alternating Current
SNR	-	Signal to Noise Ratio
P_{out}	-	Output Power
P_{in}	-	Input Power
V_{out}	-	Output Voltage
V_{in}	-	Input Voltage
R_{out}	-	Output Resistance
R_{in}	-	Input Resistance
V_{in}^{+}	-	Input Voltage at 0°
V_{in}^{-}	-	Input Voltage at 180°
V_{out}^{+}	-	Output Voltage at 0°

V_{out}^{-}	-	Output Voltage at 180°
CGLNA	-	Common Gate Low Noise Amplifier
NMOS	-	N type MOSFET
PMOS	-	P type MOSFET
CMOS	-	Complementary Metal Oxide Semiconductor
L_g	-	Gate inductor
C_{gs}	-	Gate Source Capacitance
Z_{in}	-	Input Impedance
ω	-	Angular Frequency
f	-	frequency
DRC	-	Design Rule Checking
LVS	-	Layout versus Schematic Checking
PEX	-	Parasitic Capacitance Extraction
I_D	-	DC Drain Current
k	-	Process Transconductance
W	-	Width
L	-	Length
V_{GS}	-	Gate-Source Voltage
V_{SG}	-	Source-Gate Voltage
V_{TH}	-	Threshold Voltage
μ	-	Electron or Hole Mobility
C_{ox}	-	Oxide capacitance
g_m	-	Transconductance
i_d	-	AC Drain Current
v_{gs}	-	AC Gate Source Voltage
β_n	-	NMOS Device Transconductance
V_{DS}	-	Drain-Source Voltage
I_{ref}	-	Reference Current
I_{out}	-	Output Current
V_{DD}	-	Drain Supply Voltage
V_{SS}	-	Source Supply Voltage
L_S	-	Source Inductor
DC	-	Direct Current

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CHAPTER 1

INTRODUCTION

1.1 An Overview of an LNA

Low-noise amplifier (LNA) is one type of electronic amplifier which is used to amplify weak signals received, usually by antenna. An LNA is an important component which is used at the front-end part of a radio receiver circuit. It is normally connected to a mixer [1].

In RF front end receiver, an LNA is often called as RF amplifier. The purpose of an LNA is to increase the receiver's sensitivity by amplifying all the weak signals received. A good LNA should have a low Noise Figure (NF). This means it should be amplified with low noise or no noise at all if possible. After signal is amplified, it is sent to the mixer as shown in Figure 1.1 [1].

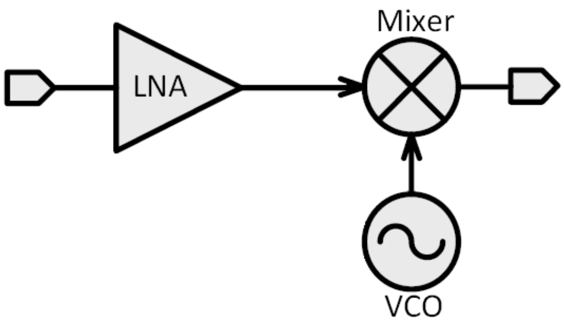


Figure 1.1: RF front-end receiver

1.2 ZigBee IEEE 802.15.4 Standard

In 2003, ZigBee (IEEE 802.15.4) standard was first introduced. ZigBee is an IEEE standard for low rate wireless personal area networks (LR-WPANs) with a high density of nodes and simple protocol has been established for low-complexity, low-cost, and low-power [2] short-range wireless connectivity among inexpensive fixed, portable, and mobile devices in unlicensed radio bands (868 MHz/915 MHz/2.4 GHz) [3]. To enable applications that are designed based on this standard and can operate for several months to a few years without frequently changing batteries, transceiver with low power consumption is required. There is also possible demand for receiver that operates with low-voltage supply such as applications powered by solar-cell.

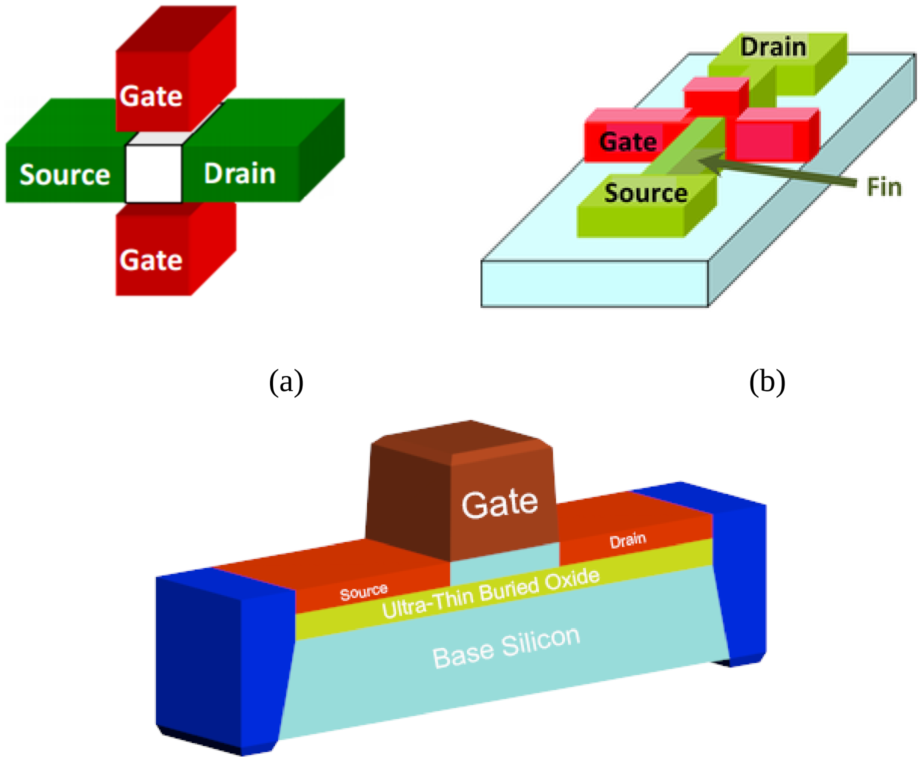
Some of the applications of ZigBee standard include [3]:

a) Sensor
b) Bluetooth
c) Wifi

1.3 Challenges of MOSFET

The technology of MOSFET will reach its limit in 2020 [4]. Hence, it is important for semiconductor industry to explore new methods to replace MOSFET. There are 2 different solutions which can be used to solve this challenge, which are using new structure or new material.

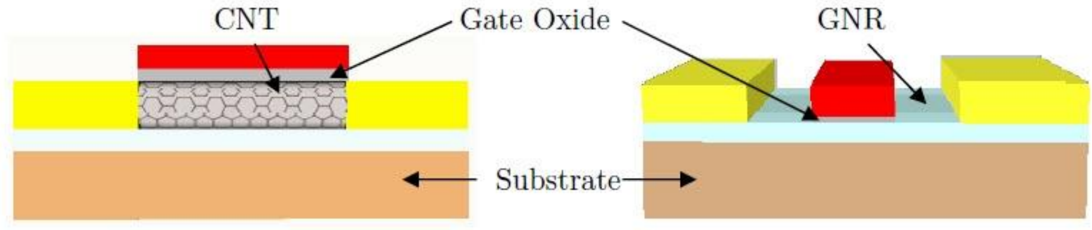
There are a few different structures which can be used, such as double gate structure, FinFET, and silicon on insulator (SOI) [5]. By using multi gate structure like double gate and FinFET, it can help to provide better electrical control of the channel. This allows effective suppression of "off-state" leakage current. Besides, by using multiple gates, the device can have better drive current. Multigate CMOS also gives a better analog performance due to a higher intrinsic gain and lower channel length modulation.[6] These advantages provides lower power consumption and produces devices with better performance. Figure 1.2(a) and (b) shows example of doublegate and FinFET. For SOI as shown in Figure 1.2(c), it provides higher isolation, higher linearity, and electro-static discharge (ESD) tolerance compare to MOSFET. However, although using different structure can provide better performance, it will reach its channel length limitation too in 2020 when MOSFET reach its limit.



(c)

Figure 1.2: (a) Double gate MOSFET, (b) FinFET, (c) SOI [7,8]

Another solution is by using different material than MOSFET, such as graphene nanoribbon (GNR) and carbon nanotube (CNT) [9]. Figure 1.3(a) and (b) shows example of GNRFET and CNTFET. CNT is one type of GNR. GNR and CNT have better on current, very high mobility (up to 200,000 cm^2) [10], have large carrier mean free path (MFP), and can conduct larger current densities[11]. However, there are some issues which exists in GNRs. GNR has edge scattering. This will reduce the effective MFP. CNT does not have the same issue. Secondly, mono-layer graphene has large MFP and conductivity. This causes multi-layer graphene to turn to graphite and it has lower conductivity per layer due to inter-sheet electron hopping [11]. Hence, after comparing GNR and CNT, CNT is used in this project.



(a) (b)

Figure 1.3: (a) CNT, (b) GNR [12]

1.4 Carbon Nanotube Field Effect Transistor

Carbon nanotube field effect transistor (CNTFET) is a tube-shaped material made of carbon. Figure 1.4 shows an example of carbon nanotube which is rolled up from carbon.

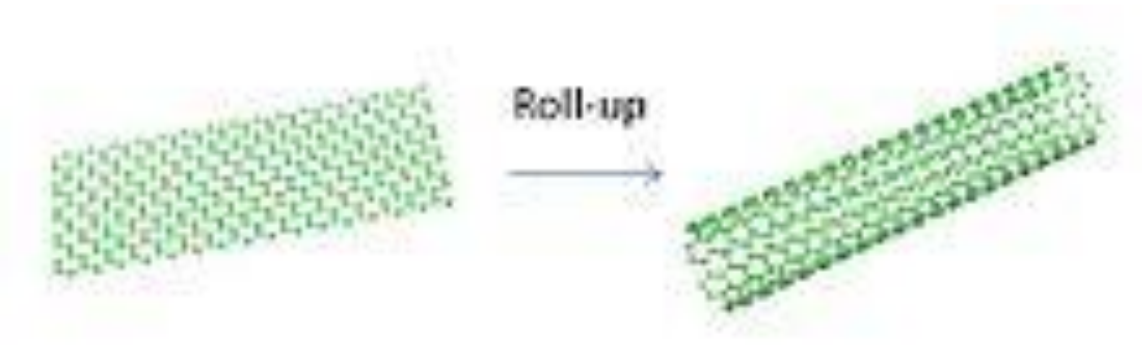


Figure 1.4: Rolled up carbon to form a carbon nanotube [13]

Then, the carbon nanotube is put in between of a transistor to form a CNTFET, as shown in Figure 1.5. Compared to MOSFET, CNTFET has better characteristics. First, it is more resistant to temperature [14]. It has higher threshold voltage, which helps it to have lower leakage power [14, 15]. Besides, it also has higher mobility and faster switching speed [15]. CNTFET is also small and lightweight [16].

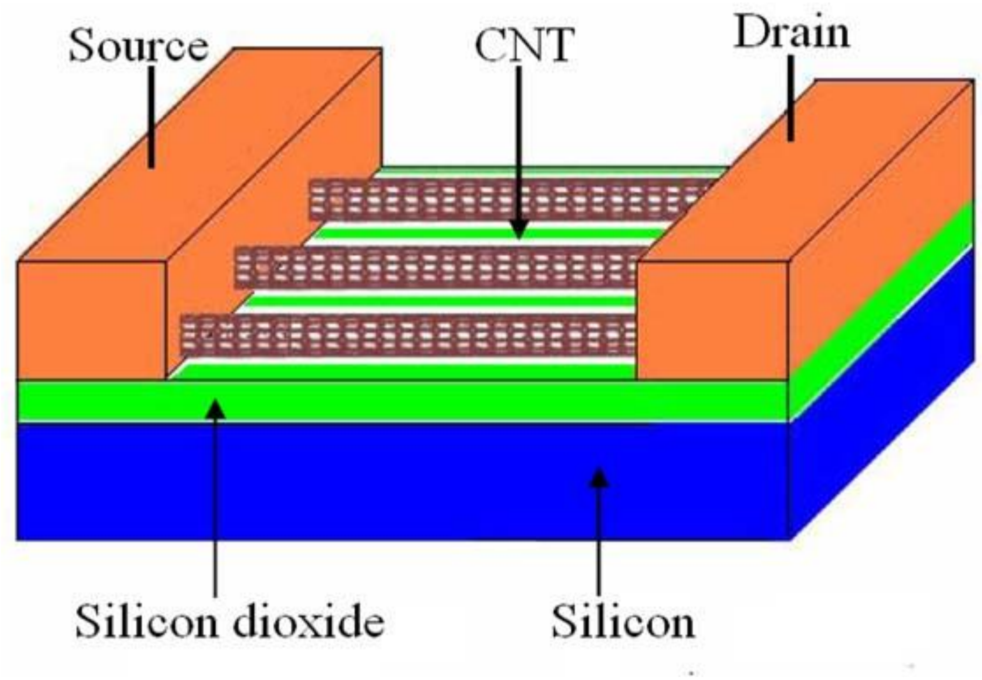


Figure 1.5: Carbon Nanotube Field Effect Transistor [17]

1.5 Problem Statement

MOSFET will reach its channel length limit in 2020. Hence, the exploration of replacement of MOSFET had become more important. Among all alternatives, CNTFET is the most suitable alternative as it had different advantages which other alternatives don't have, such as higher temperature resistance. Many researches had been done on different usage for CNTFET. However, implementation of LNA using CNTFET is still under exploration. LNA is important since it helps to amplify weak signal received, usually by antenna. Hence, it is important to explore the performance of LNA using CNTFET. Besides, exploration of CNTFET-LNA working at Zigbee Standard is important too as it is used at many applications, such as sensor, Bluetooth, and wireless. Thirdly, power consumption is also another important factor in Integrated Circuit (IC). Equipment with low-power consumption is more cost effective as it has longer battery life. Hence, it is necessary to design a CNTFET-LNA at Zigbee standard with low power consumption while maintaining its specifications.

1.6 Objectives

The objectives of this project are:

a) To explore low power CNTFET-LNA at Zigbee Standard.
b) To construct circuit modeling of CNTFET-LNA circuit using HSPICE and compare its performance with MOSFET-LNA experimental data extracted from published articles.
c) To analyze the circuit performance of LNA such as gain, power dissipation, noise and speed for high performance.

1.7 Research Scope

The demand for single chip receivers which operates at 2.4 GHz band (Zigbee Standard), which is an unlicensed universal standard has increased. This is due to the introduction of low-power consumption, long battery life, and low-cost systems. Besides, new material like CNTFET has become more important too because MOSFET will reach its channel length limit in 2020. LNA plays an important role in a RF front-end receiver. So, it is important to design an LNA with better performance to increase the performance of the receiver.

The aim of this project is to design a CNTFET-LNA of a RF front-end receiver which operates at Zigbee Standard with the following specifications:

Table 1.1: Specification

Voltage Supply	<1V
Dissipated Power	<2mW

Table 1.2: Expected Performances

Parameter	**Standard**	**Expected results**
Conversion Gain [18]	> 10dB	> 15dB
Noise Figure [18]	< 3dB	< 3dB

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