

**A 0.13- $\mu\text{m}$  CMOS RECONFIGURABLE POWER  
CONSTRAINED SIMULTANEOUS NOISE AND  
INPUT MATCHING (PCSNIM) LOW NOISE  
AMPLIFIER (LNA) FOR MULTI-STANDARD 0.9,  
1.8 AND 2.1 GHz MOBILE APPLICATION**

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LOW NOISE AMPLIFIER (LNA) FOR MULTI-STANDARD 0.9,  
1.8 AND 2.1 GHz MOBILE APPLICATION**

**by**

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**Thesis submitted in fulfillment of the requirements  
for the degree of  
Master of Science**

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## **DECLARATION**

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

8th June 2016

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P-LM0442

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## TABLE OF CONTENTS

	Page
Acknowledgement.....	ii
Table of Contents.....	iii
List of Tables.....	vi
List of Figures.....	vii
List of Abbreviations.....	x
List of Symbols.....	xii
Abstrak.....	xvi
Abstract.....	xviii
CHAPTER 1 - INTRODUCTION	
1.1 Introduction.....	1
1.2 Motivation.....	3
1.3 Objectives.....	5
1.4 Scope.....	6
1.5 Thesis Outline.....	6
CHAPTER 2 - THEORETICAL BACKGROUND AND LITERATURE	
REVIEW	
2.1 Mobile application.....	8
2.2 Low Noise Amplifier.....	9
2.2.1 Power constrained and simultaneous noise and input matching circuit (PCSNIM) topology.....	10
2.2.1 (a) Inductively degenerated circuit .....	10
2.2.1 (b) The cascode circuit.....	11

2.2.1 (c)	Simultaneous Noise and Input Matching (SNIM) LNA.....	11
2.2.1 (d)	Power-constrained Simultaneous Noise and Input Matching (PCSNIM) LNA.....	15
2.3	MOS switch.....	18
2.4	Low Noise Amplifier.....	22
2.4.1	Scattering parameters.....	22
2.4.2	Gain.....	24
2.4.3	Noise figure.....	24
2.4.4	Linearity measures.....	25
2.3	Similar work by others.....	27

## CHAPTER 3 - MULTI-STANDARD LNA DESIGN AND LAYOUT

### CONSIDERATION

3.1	Specification .....	34
3.2	Flowchart of the project implementation.....	35
3.3	Multi-standard LNA using CMOS switches.....	37
3.4	Multi-standard LNA design flow.....	42
3.4.1	Component values.....	44
3.5	Layout preparation.....	46
3.6	Layout consideration.....	46
3.6.1	Preparation of layout.....	47
3.6.2	Parasitics.....	48
3.7	General layout techniques.....	50
3.8	Measurement setup.....	51
3.9	The micrograph of multi-standard LNA.....	51

## CHAPTER 4 – DESIGN IMPLEMENTATION

4.1	Pre-layout simulation results.....	54
4.2	Post-layout simulation results.....	59
4.3	Measurement results.....	63
4.3.1	S-parameter performance.....	63
4.3.2	NF performance.....	65
4.3.3	Linearity performance.....	66
4.8	Summary and the comparison of pre-, post-layout simulation and measurement results.....	69

## CHAPTER 5 – CONCLUSION AND FUTURE WORKS

5.1	Conclusions.....	73
5.2	Future work.....	75

REFERENCES.....	77
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## APPENDICES

## LIST OF PUBLICATIONS

## LIST OF TABLES

		Page
Table 2.1	Wireless standards (Tasic, 2007)	9
Table 2.2	LNA performance metrics from similar work by others	33
Table 3.1	LNA specification	36
Table 3.2	$C_{tot}$ at different frequency	39
Table 3.3	Switches Condition	40
Table 3.4	Component values	45
Table 4.1	Optimized layout	60
Table 4.2	Pre-, post-layout simulation and measurement results	71



## LIST OF FIGURES

	Page	
Figure 1.1	Block diagram of a multi-band receiver using parallel architecture. (El-Nozahi, 2010)	2
Figure 1.2	Block diagram of a multi-standard receiver with single LNA (Gustafsson, 2006)	2
Figure 2.1	Example of an inductively degenerated transistor	11
Figure 2.2	Example of a cascode circuit	12
Figure 2.3	The SNIM cascode LNA	12
Figure 2.4	The small-signal model with noise sources of the SNIM cascode	14
Figure 2.5	The PCSNIM LNA (Noh, 2009)	16
Figure 2.6	$I_D$ vs $V_D$	18
Figure 2.7	(a) Schematic symbol of a switch; (b) NMOS as a switch; (c) equivalent circuit of MOS as switch when turned on; (d) equivalent circuit of MOS as switch when turned off (Huang et al. 2007)	19
Figure 2.8	(a) The switching capacitor; (b) when $M_{sw}$ is turned off; (c) when $M_{sw}$ is turned on (Hung, 2010)	20
Figure 2.9	Important features in LNA	22
Figure 2.10	Two-port network (Said, 2011)	23
Figure 2.11	1-dB compression point (Lee, 2004)	26
Figure 2.12	Third order intercept point (Lee, 2004)	27
Figure 2.13	Schematic of the LNA design by Mustaffa (Mustaffa, 2009)	28
Figure 2.14	Schematic of the LNA design by Liscidini (Liscidini, 2006).	29
Figure 2.15	Schematic of the LNA design by Balemarthy (Balemarthy, 2008)	30
Figure 2.16	Schematic of the LNA design by Khoo (Khoo, 2011)	31
Figure 2.17	Schematic of the LNA design by Aravint (Aravint, 2015)	32
Figure 2.18	Schematic of the LNA design by Wang (Wang, 2010)	32

Figure 3.1	Flowchart of the project implementation	36
Figure 3.2	Multi-standard LNA design	38
Figure 3.3	Small signal of the input multi-standard LNA	38
Figure 3.4	Flow chart of the multi-standard LNA design	43
Figure 3.5	Layout of multi-standard LNA	47
Figure 3.6	Capacitance in an IC	49
Figure 3.7	S-parameter measurement setup of the input and output stages (Mohd, 2010)	51
Figure 3.8	The measurement setup	52
Figure 3.9	The micrograph of multi-standard LNA	52
Figure 4.1	Pre-layout input return losses of multi-standard LNA design	54
Figure 4.2	Pre-layout output return losses of multi-standard LNA design	55
Figure 4.3	Pre-layout power gain of multi-standard LNA design	55
Figure 4.4	Pre-layout reverse isolation of multi-standard LNA design	56
Figure 4.5	Simulated NF of multi-standard LNA design	56
Figure 4.6	Simulated $IP_{1dB}$ at 0.9 GHz	57
Figure 4.7	Simulated $IP_{1dB}$ at 1.8 GHz	58
Figure 4.8	Simulated $IP_{1dB}$ at 2.1 GHz	58
Figure 4.9	Simulated $IIP_3$ at 0.9 GHz	58
Figure 4.10	Simulated $IIP_3$ at 1.8 GHz	59
Figure 4.11	Simulated $IIP_3$ at 2.1 GHz	59
Figure 4.12	Post-layout input return losses of multi-standard LNA design	60
Figure 4.13	Post-layout output return losses of multi-standard LNA design	61
Figure 4.14	Post-layout power gain of multi-standard LNA design	61
Figure 4.15	Post-layout reverse isolation of multi-standard LNA design	62
Figure 4.16	Post-layout NF of multi-standard LNA design	62

Figure 4.17	Measured input return losses of multi-standard LNA design	63
Figure 4.18	Measured output return losses of multi-standard LNA design	64
Figure 4.19	Measured power gain of multi-standard LNA design	64
Figure 4.20	Measured reverse isolation of multi-standard LNA design	65
Figure 4.21	Measured NF of multi-standard LNA design	66
Figure 4.22	Measured $IP_{1dB}$ at 0.9 GHz	66
Figure 4.23	Measured $IP_{1dB}$ at 1.8 GHz	67
Figure 4.24	Measured $IP_{1dB}$ at 2.1 GHz	67
Figure 4.25	Measured $IP_3$ at 0.9 GHz	68
Figure 4.26	Measured $IP_3$ at 1.8 GHz	68
Figure 4.27	Measured $IP_3$ at 2.1 GHz	69

## LIST OF ABBREVIATIONS

2G	Second-generation wireless telephone technology
3G	Third generation of mobile telecommunications technology
CEDEC	Collaborative Microelectronic Design Excellence Centre
CMOS	Complementary metal oxide semiconductor
CR	Current Reuse
C	Correlation coefficient
CC	Coupling capacitor
dB	Decibel
DCS	Digital Cellular System
DUT	Device Under Test
DRC	Design Rule Check
F	Noise Factor
FC	Folded Cascode
GPS	Global Positioning System
G-S	Gate-Source
GSM	Global System for Mobile
I	Current
IC	Integrated Circuits
IDCS	Inductively-degenerated common source
$IP_{1dB}$	Input 1-dB Compression Point
$IIP_3$	Input-Referred Third-Order Intermodulation Point
IM	Inter-Modulation
ISS	Impedance Standard Substrate
LNA	Low Noise Amplifier

MOS	Metal Oxide Semiconductor
MOSFET	Metal-Oxide-Semiconductor Field-Effect-Transistor
NF	Noise Figure
$NF_{\min}$	Minimum Noise Figure
NMOS	N-Metal Oxide Semiconductor
$OP_{1dB}$	Output 1-dB Compression Point
$OIP_3$	Output-Referred Third-Order Intermodulation Point
$P_{1dB}$	1-dB Compression Point
$P_{in}$	Input Power
PCSNIM	Power-Constrained Simultaneously Noise and Input Matching
PMOS	P-Metal Oxide Semiconductor
$P_{out}$	Output Power
R	Resistance
$R_{on}$	Output resistance of the MOSFET
RF	Radio Frequency
USM	Universiti Sains Malaysia
V	Voltage
W	width of MOSFET
W-CDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Networks

## LIST OF SYMBOLS

$\alpha$	alpha
$\delta$	delta
$\gamma$	gamma
$\Omega$	Ohm
$\chi$	Chi
$\mu$	micron
r	Resistivity
log	Logarithm
G	Transducer gain
$C_c$	Coupling capacitor
$C_{eq}$	Equivalent capacitance
$C_1$	Capacitor 1
$C_2$	Capacitor 2
$c_{gs}$	Gate-source capacitance
$c_{gd}$	Gate-drain capacitance
$C_{d1}$	Drain capacitor 1
$C_{ex1}$	External capacitor 1 at the input
$C_{ex2}$	External capacitor 2 at the input
$C_{ex3}$	External capacitor 3 at the input
$C_{Msw3}$	Switch 3 capacitance
$C_{Msw4}$	Switch 4 capacitance
$C_o$	Output capacitor
$C_{ox}$	Oxide capacitor
$C_t$	Total capacitance

$C_{tot}$	Total capacitance
$f$	Frequency (Hz)
$F$	Noise factor
$G$	Transducer gain
$G_a$	Available gain
$g_m$	Transconductance
$I$	Current (A)
$I_{DC}$	Current flow through a device
$I_h$	Current handling constant
$L$	Length of the transistor/material
$L_{d1}$	Drain inductor 1
$L_{d2}$	Drain inductor 2
$L_s$	Source inductor
$L_g$	Gate inductor
$M_1$	Transistor 1
$M_2$	Transistor 2
$M_{SW1}$	Transistor switch 1
$M_{SW2}$	Transistor switch 2
$M_{SW3}$	Transistor switch 3
$M_{SW4}$	Transistor switch 4
$N_a$	Noise added by the amplifier
$N_i$	Noise power levels at the input to the amplifier
$N_o$	Noise power levels at the output to the amplifier
$P$	Power
$Q_s$	Quality factor
$Q_{s,opt}$	Optimum quality factor

$R$	Resistance
$R_1$	Resistor 1
$R_s$	Sheet resistance
$S_{11}$	Input reflection coefficient
$S_{21}$	Forward transmission coefficient
$S_{12}$	Reverse transmission coefficient
$S_{22}$	Output reflection coefficient
$S_i$	Signal at the input to the amplifier
$S_o$	Signal at the output to the amplifier
$T$	Thickness of the material
$V_{BIAS\_1}$	Bias volatage 1
$V_{BIAS\_2}$	Bias volatage 2
$V_{DS}$	Drain-Source voltage
$V_{GS}$	Gate-Source voltage
$V_{in}$	Input voltage
$V_{ov}$	Overdrive voltage
$V_{th}$	Threshold voltage
$W$	Width of transistor
$W_{M1}$	Width of transistor 1
$W_{M2}$	Width of transistor 2
$W_{MSW1}$	Width of transistor switch 1
$W_{MSW2}$	Width of transistor switch 2
$W_{MSW3}$	Width of transistor switch 3
$W_{MSW4}$	Width of transistor switch 4
$\omega_o$	Omega
$\omega_T$	Transition frequency



$Z_{in}$	Input impedance
$Z_{Msw}$	Impedance switch
$Z_{Msw1}$	Impedance of switch 1
$Z_{Msw2}$	Impedance of switch 2
$Z_{Msw3}$	Impedance of switch 3
$Z_{Msw4}$	Impedance of switch 4
$Z_{opt}$	Input noise

**SATU 0.13- $\mu\text{m}$  CMOS PADANAN MASUKAN DAN HINGAR SERENTAK  
DENGAN KEKANGAN KUASA PENGUAT HINGAR RENDAH BOLEH  
KONFIGURASI SEMULA BAGI APLIKASI MUDAH ALIH BERBILANG  
PIAWAIAN 0.9, 1.8 DAN 2.1 GHz**

**ABSTRAK**

Industri komunikasi tanpa wayar sedang mengalami pertumbuhan yang luar biasa. Sebelum ini, penerima berbilang piawaian telah direka dalam seni bina yang selari untuk menampung berbilang piawai. Walaubagaimanapun, untuk setiap laluan, kawasan bentangan yang besar membuatkan kos fabrikasi meningkat. Sebagai tindakbalas terhadap permintaan untuk bahagian hadapan tanpa wayar yang berkos rendah dan berprestasi lebih tinggi, banyak kajian intensif pada CMOS frekuensi radio (RF ) litar bahagian hadapan telah dijalankan. Projek ini menggabungkan laluan-laluan selari tersebut kepada kaedah penerima tanpa wayar laluan tunggal. Matlamat utama adalah untuk meminimumkan “trade-off” atau mencapai keseimbangan antara prestasi tinggi, saiz yang lebih kecil dan kos rendah pada reka bentuk penggunaan kuasa yang rendah. Sasaran projek ini adalah untuk mereka bentuk penguat hingar rendah (LNA) berbilang piawaian bagi tiga piawai operasi jalur frekuensi. Bagi mendemonstrasi keberkesanan teknik, satu reka bentuk LNA laluan tunggal berbilang piawaian menggunakan konsep pensuisan telah dilaksanakan. Reka bentuk boleh memilih jalur frekuensi operasi dengan mengalihkan suis yang digunakan di rangkaian padanan masukan dan keluaran. Satu LNA berbilang piawaian dengan topologi Padanan Masukan dan Hingar Serentak dengan Kekangan Kuasa (PCSNIM) telah dilaksanakan bagi tujuan ini. LNA beroperasi pada frekuensi 0.9 , 1.8 dan 2.1 GHz. Oleh itu, reka bentuk piawai tanpa

wayar adalah bagi aplikasi GSM900 , DCS1800 dan W-CDMA. Reka bentuk ini telah dilaksanakan pada proses CMOS 0.13- $\mu\text{m}$  8-lapisan logam. LNA berbilang piawaiian mempamerkan nilai angka hingar (NF) serendah 1.72 dB pada 1.8 GHz dan 1.85 dB pada 2.1 GHz. Gandaan adalah dalam julat 10 ke 11 dB. Titik pintasan tertib ketiga (IIP3) adalah setinggi 0.2 dBm (pada 1.8 GHz), -1 dBm (pada 2.1 GHz) dan -2 dBm (pada 0.9 GHz). Manakala titik mampatan 1 dB pula adalah -12.2 dBm (pada 0.9 GHz), -11.5 dBm (pada 1.8 GHz) dan -11 dBm (pada 2.1 GHz). Jumlah penggunaan kuasa untuk reka bentuk ini adalah 7.42 mW dengan bekalan voltan sebanyak 1.2 V.

**A 0.13- $\mu\text{m}$  CMOS RECONFIGURABLE POWER CONSTRAINED SIMULTANEOUS NOISE AND INPUT MATCHING (PCSNIM) LOW NOISE AMPLIFIER (LNA) FOR MULTI-STANDARD 0.9, 1.8 AND 2.1 GHz MOBILE APPLICATION**

**ABSTRACT**

The wireless communication industry is experiencing tremendous growth. Previously, multi-standard receivers were designed using parallel architecture to accommodate multiple standards. However, for each path, the area consumption is high which increases cost of fabrication. Responding to the demand for a low-cost and high performance wireless front-end, many intensive researches on CMOS radio-frequency (RF) front-end circuits have been carried out. This project merges the parallel paths into a single path wireless receiver. The ultimate goal is to minimize the trade-off between high performance, smaller size and low-cost at low power consumption design. The target of this project is to design a multi-standard low noise amplifier (LNA) for three standards frequency bands. To demonstrate the effectiveness of the design technique, an LNA design is presented for multi-standard single path LNA with the switching concept. The design can select operating frequency band by switching the switches which are adopted at the input and output matching network. A multi-standard Power Constrained Simultaneous Noise and Input Matching (PCSNIM) topology was implemented. The multi-standard LNA is operated at 0.9, 1.8 and 2.1 GHz frequencies. The design covers wireless standards of GSM900, DCS1800 and W-CDMA applications. The design was implemented on 0.13- $\mu\text{m}$  8-metal CMOS process. The multi-standard LNA shows the noise figure (NF) as low as 1.72 dB at 1.8 GHz and 1.85 dB at 2.1 GHz. The gain is in the range 10 up to 11 dB. The third order intercept point ( $\text{IIP}_3$ ) is 0.2 dBm (at 1.8 GHz), -1 dBm (at 2.1

GHz) and -2 dBm (at 0.9 GHz) while  $IP_{1dB}$  compression point is -12.2 dBm (at 0.9 GHz), -11.5 dBm (at 1.8 GHz) and -11 dBm (at 2.1 GHz). The power consumption of the design is 7.42 mW with 1.2 V power supply.

# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

In the past decade, wireless communication systems have been evolving increasingly, growing rapidly and has high demand in market. The functionality of RF transceiver increase as RF designers pursue cost-effective multi-standard transceivers. Recent developments in wireless communication have new requirements on wireless transceivers. It is desirable to provide multi-band transceiver where wireless standards can operate simultaneously to extend its functionalities (Hashemi, 2002). Various communication standards have to be adopted to accommodate different needs depending on their data rate, bandwidth, operating range and carrier frequency. The key block of a multi-band multi-standard receiver is the low-noise amplifier (LNA). The easiest way is to employ several parallel passages to accommodate the different communication standard. There are different architectures that have been proposed to realize the goal. However, the requirement for a very large design area if the receiver is to be implemented on a single chip. The major drawback would also result in higher production cost. A block diagram of parallel architecture is shown in Figure 1.1.

The parallel architecture, shown in Figure 1.1, utilizes several single-band architectures that are placed in parallel. Each LNA is designed to receive one of the desired bands. The advantage of this architecture is low power consumption. However, for each path, the area consumption is high, which increases the cost of the chip for fab-

rication. One of the challenges for the parallel architecture design is to reduce the area.

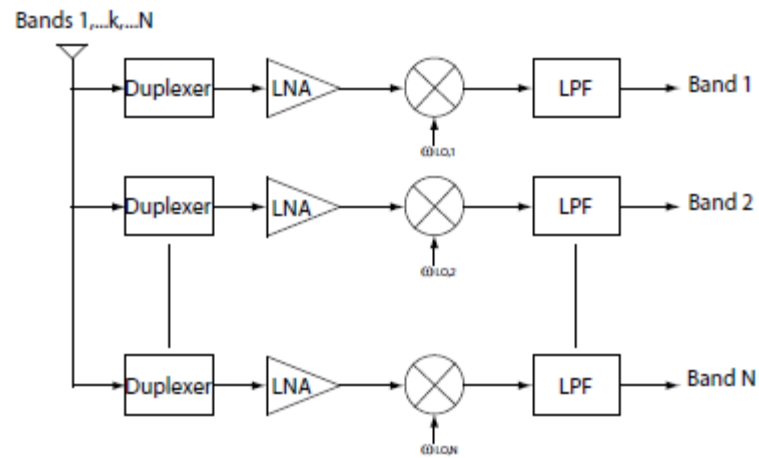


Figure 1.1: Block diagram of a multi-band receiver using parallel architecture. (El-Nozahi, 2010).

To overcome the large consumption problem, an architecture that should be more desirable with parallel architecture multi-standard receiver. This architecture can cover various standards with just one single LNA, compared to the previous architecture that uses one LNA for each single standard. Less number of devices leading to a system with less complexity, less area and most importantly, less power consumption.

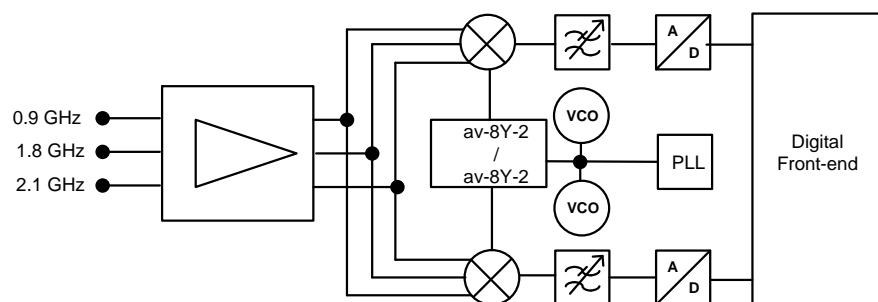


Figure 1.2: Block diagram of a multi-standard receiver with single LNA (Gustafsson, 2006)

## 1.2 Motivation

In a multiband LNA, the RF front-end has to cover a huge range of different carrier frequencies to incorporate all the standards. Some front-end needs either wideband LNA (Knapp, 2001), a narrowband LNA with multiple passbands or known also as concurrent LNA (Hashemi, 2002), concurrent with two stages design and wideband multimode (Aravint, 2015) or a tunable LNA (Andersson, 2002).

Concurrent LNAs with multiple passbands are only suitable where the passbands are well separated and not more than two. Tunable LNAs are very attractive but hard to design for a large tuning range (Andersson, 2005). The wideband LNA can receive multiple bands of interest, however, it requires higher consideration on the tradeoff between power, area and sensitivity. The high linearity requirement make it unattractive. Concurrent with two stages; common-gate (CG) and common source (CS) and wideband multimode can achieve good matching, gain and compression point but the NF is too high up to 8.5 dB (Aravint, 2015).

Tunable LNA which is also known as reconfigurable LNA, can dynamically change its configuration to achieve a different band. By tuning the switches ON/OFF, the LNA can alter between two operating frequencies bands. For this LNA architecture, the number of switchable or tunable components should be limited; otherwise, the performance of the LNA may be deteriorated because of the parasitic parameters introduced by CMOS switches. Furthermore, this topology is generally suitable for narrow band applications. Band selection of the LNA is realized by an inductor tuning circuit. Compared with concurrent LNAs, it can be continuously tuned and is preferred for applications with a large number of frequency bands.