UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electronic and Computer Engineering

RF RECEIVER DESIGN USING THE DIRECT CONVERSION APPROACH AT 5.8 GHz BAND BASED ON IEEE 802.11a STANDARD

Asreen Anuar bin Abd Aziz

Master of Science in Electronic Engineering

2014

RF RECEIVER DESIGN USING THE DIRECT CONVERSION APPROACH AT 5.8 GHz BAND BASED ON IEEE 802.11a STANDARD

ASREEN ANUAR BIN ABD. AZIZ

A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Electronic Engineering

Faculty of Electronic and Computer Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

DECLARATION

I declare that this thesis entitled “RF Receiver Design Using The Direct Conversion Approach at 5.8 GHz Based On IEEE 802.11a Standard” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	Asreen Anuar Bin Abd Aziz
Date	:	08 September 2014

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature	:………………..
Supervisor Name	: Prof. Madya Dr. Abdul Rani Bin Othman
Date	:………………………..

DEDICATION

To my beloved mother and father,

Pn. Wan Jah Binti Haji Mat Zain and En. Abd Aziz Bin Haji Saamah

To my brother and sisters,

Azrul Afenddy, Azlen Suryaniey and Aznen Anizam

To my lovely wife and daughter,

Rashidah Rashed and Atiyah Zahra'

To my mother and father-in-law

Muslipah and Rashid

To all my family members

To my supervisors and lecturers

Then last but not least to all my friends.

ABSTRACT

This thesis presents the development and analysis of a radio frequency (RF) front-end direct conversion receiver at 5.725 – 5.825 GHz where IEEE 802.11a standard is used as performance test. The RF receiver is designed based on the commercialized products (off-the-shelf) where it focuses on the system design tradeoff, rather than circuit design tradeoff. The RF receiver has been designed with the selected architecture where it is consist of low noise amplifier (LNA), radio frequency amplifier (RFA), power divider and two bandpass filters. The modeled RF receiver has been analyzed by using Advanced Design System (ADS) 2005A software for system characteristic and performance test. From the simulation, minimum sensitivity is -91 dBm at data rate 6 Mbps and -74 dBm at data rate 54 Mbps where it is comply with the IEEE 802.11a standard. The RF receiver prototype has been measured and this system produces has gain of 39 dB which is higher than the reviewed of 37.5 dB. The noise figure of this work is measured at 1.30 dB, which is better than the reviewed work at 4.6 dB. The nonlinearity characteristic such as power at 1dB compression point (P1dB) and third order intercept point (IP3) is observed. From the measurement, the RF receiver will drop 1 dB when input power (P_{in}) is injected above -27 dBm then it caused output power (P_{out}) start saturated. The third output intercept point (OIP3) and third input intercept point (IIP3) is at around 15 dBm and -24.50 dBm respectively. The RF receiver system characteristic such as sensitivity meet the standard requirement of IEEE 802.11a standard for wireless local area network (WLAN) bridge system.

ABSTRAK

Tesis ini melaporkan satu pembangunan dan analisis sebuah penerima frekuensi radio (RF) penukaran terus bahagian hadapan pada frekuensi 5.725 – 5.825 GHz di mana piawaian IEEE802.11a telah digunakan sebagai ujian prestasi. Penerima RF ini direkabentuk berdasarkan kepada produk komersial (daripada pasaran) di mana ia menumpukan pada pertukaran rekabentuk sistem, berbanding pertukaran rekabentuk litar. Penerima RF ini telah direkabentuk dengan seni bina yang terpilih di mana ia mengandungi satu penguat hingar rendah (LNA), satu penguat frekuensi radio (RFA), satu pembahagi kuasa dan dua penapis lulus jalur. Penerima RF ini telah dianalisis dengan menggunakan perisian Advanced Design System (ADS) 2005A untuk ciri-ciri sistem dan ujian prestasi. Daripada simulasi, sensitiviti minima adalah -91 dBm pada kadaran data 6 Mbps dan -74 dBm pada kadaran data 54 Mbps di mana ianya mematuhi piawaian IEEE802.11a. Prototaip penerima RF ini telah diukur dan sistem ini telah menghasilkan gandaan sebanyak 39 dB yang mana lebih tinggi berbanding dengan 37.5 dB nilai yang dikaji. Angka hingar bagi penyelidikan ini diukur pada 1.30 dB, yang mana ianya lebih baik berbanding dengan nilai 4.6 dB kerja yang dikaji. Sifat-sifat ketidaksejajaran seperti kuasa pada titik mampatan 1 dB (P1dB) dan titik pintasan tertib ketiga (IP3) diperhatikan. Daripada pengukuran, penerima RF akan jatuh 1 dB apabila kuasa masukan (P_{in}) dibekal lebih daripada -27 dBm kemudian ia menyebabkan kuasa keluaran (P_{out}) mula menjadi tepu. Keluaran titik pintasan tertib ketiga (OIP3) dan masukan titik pintasan tertib ketiga (IIP3) adalah masing-masing pada lingkungan 15 dBm dan -24.50 dBm. Ciri-ciri sistem penerima RF seperti sensitiviti mencapai piawaian keperluan IEEE802.11a untuk sistem perhubungan rangkaian tanpa wayar kawasan setempat (WLAN).

ACKNOWLEDGEMENT

First and foremost, I would like to take this opportunity to thank to my supervisor, Associate Professor Dr. Abdul Rani Bin Othman from the Faculty of Electronic and Computer Engineering Universiti Teknikal Malaysia Melaka (UTeM) for his constant support, motivation and encouragement throughout my research especially in completing this thesis. With his assist, we successful obtained RF front-end receiver which is designed and fabricated from Man & Tel, Korea.

I would also like to thank to my former supervisor Engr. Imran Bin Mohd Ibrahim from the Faculty of Electronics and Computer Engineering for his guidance and advice, my co-supervisor Mr. Noor Azwan Bin Shairi from the Faculty of Electronic and Computer Engineering for his a lots of support in thesis arrangement especially in technical part and also give motivation and inspiration to me. Special thanks also Minister of Science and Technology of Malaysia (MOSTI) and UTeM short term grant funding for the financial support throughout this project.

Particularly, I would like to thank Department of Telecommunication, Faculty of Electronic and Computer Engineering for providing postgraduate laboratory with complete facilities to easier my research works. Also thanks to technicians and and security guard for allowing me to use this lab wheather on the day and the night side to complete this research. I would like to thank to my friends and lecturers where always together in postgraduate laboratory that I unable to mention their name in supporting me in this research. Again, I want to thank to my co-supervisor Mr. Noor Azwan Bin Shairi for introducing and assisting me in measurement of the RF receiver prototype at Telekom Malaysia Research and Developement (TM R&D).

Also thanks to all family members especially my beloved mother, father, my lovely wife and daughter where I know they never stop praying for me so that I become success. Thank you all!!!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ACR	Adjacent Channel Rejection
ADS	Advanced Design System
ASP	Analog Signal Processing
BFP	Bandpass Filter
BiCMOS	Bipolar Complementary Metal Oxide Semiconductor
Balun	Balance Unbalance
CIMD	Carrier To Intermodulation Distortion
CMOS	Complementary Metal-Oxide Semiconductor
CWTS	China Wireless Telecommunication Standardization Group
DC	Direct Current
DCR	Direct Conversion Receiver
DECT	Digital European Telecommunication
DR	Dynamic Range
DSP	Digital Signal Processing
DUT	Device Under Test
EVM	Error Vector Magnitude
FCC	Federal Communications Commission
FET	Field Effect Transistor

G	Gain Factor
GaAs	Gallium Arsenide
GHz	Giga Hertz
GSM	Global System for Mobile Communications
HDTV	High Definition Television
HEMT	High Electron Mobility Transistor
IEEE	Institute of Electrical and Electronics Engineers
IF	Intermediate Frequency
IIP_3	Third Input Intercept Point
IL	Insertion Loss
IM3	Third Order Intermodulation
IMD	Intermodulation Distortion
IP3	Third Intercept Point
I/Q	In Phase/Quadrature
IR	Image Rejection
ISM	Industrial, Scientific and Medical
LC	Inductor Capacitor Network
LPF	Low Pass Filter
LNA	Low Noise Amplifier
LO	Local Oscillator
MAN	Metropolitan Area Network
Mbps	Mega Bit Per Second
MDS	Minimum Detectable Signal
MMIC	Monolithic Microwave Integrated Circuit
NF	Noise Figure

OFDM	Orthogonal Frequency Division Multiplexing
OIP_3	Third Output Intercept Point
PDA	Personal Digital Assistant
PER	Packet Error Rate
PSDU	Physical Sublayer Service Data Units
PWD	Power Divider
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RC	Resistor Capacitor Network
RF	Radio Frequency
RFA	Radio Frequency Amplifier
RFIC	Radio Frequency Integrated Circuit
RR_{3o}	Order Rejection Ratio
SDR	Software Defined Radio
SiGe	Silicon Germanium
SNR	Signal To Noise Ratio
TD-SCDMA	Time Division – Synchronous Code Division Multiple Access
TOI	Third Order Intercept Point
TRF	Tuned Radio Frequency
U-NII	Unlicensed National Information Infrastructure
VCO	Voltage Control Oscillator
VNA	Vector Network Analyzer
WiBro	Wireless Broadband
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

LIST OF PUBLICATIONS

1. Othman A.R, **Abd Aziz A**., Pongot K., Shairi A., Mohd Nor M.N, *" Design and Sensitivity Analysis of Direct Conversion RF Receiver for IEEE 802.11a WLAN System at 5.8 GHz Frequency"*, 2012 IEEE Student Conference on Research and Development SCORED 2012, Parkroyal Resort Hotel, Penang, Malaysia on 5 – 6 December 2012.

2. **A. A. Abd Aziz**, N. A. Shairi, I. M. Ibrahim, A. R. Othman, *"Direct Conversion RF Receiver Design and Sensitivity Analysis for WLAN Point to Point Communication at 5.8 GHz Band"* in Proceeding of 2009 IEEE International Conference on Antennas, Propagation and Systems (INAS 2009).

3. **A. A. Abd Aziz**, N. A. Shairi, I. M. Ibrahim, A. R. Othman, "*Design and Analyses of Direct Conversion RF Receiver for WLAN System Based On IEEE802.11a Standard*" in Malaysia Technical Universities Conference on Engineering and Technology (MUCEET 2009).

4. M. A. Othman, A. S. Jaafar, **A. A. Abd Aziz**, "*Simulation of a Broadband Amplifier for Broadband Applications*" in Seminar Pencapaian Penyelidikan UTeM (REACH 2008).

5. Othman, A.R.; Halim, M.H.C.; Aziz, M.Z.A.A.; Sahingan, S.A.; Selamat, M.F.; Aziz**,**. **A. A. Abd Aziz,**; *5-6GHz Front End Low Noise Amplifier* in 6th National Conference on Telecommunication Technologies 2008 and 2008 2nd Malaysia Conference on Photonics. NCTT-MCP 2008.

6. Othman, A.R, Halim, M.H.C.; Aziz, M.Z.A.A.; .Sahingan, S.A.; Selamat, M.F.; **Aziz, A.A.A**.; *Low Noise Amplifier for front end transceiver at 5.8 GHz* in International Conference on Electronic Design, 2008. ICED 2008.

7. **A. A. Abd Aziz**, A. R. Othman, I. M. Ibrahim, "*Simulation of Cascading LNA and RF Amplifier for Front-End Direct Conversion Receiver at 5.8 GHz*" In Asia Pacific Conference On Applied Electromagnetics Proceeding (APACE 2007).

8. Othman, A.R.; Ibrahim, I.M.; Samingan, M.; **Aziz, A.A.A** ; Selamat, M.; Halim, H.C.; Single stage RF amplifier at 5.8GHz ISM band with IEEE 802.11a standard in Asia-Pacific Conference on Applied Electromagnetics Proceeding (APACE 2007).

9. Othman, A.R.; Ibrahim, I.M.; Selamat, M.; Samingan, M.; **Aziz, A.A.A**; Halim, H.C.*;* 5.75 GHz microstrip bandpass filter for ISM band in Asia-Pacific Conference on Applied Electromagnetics Proceeding (APACE 2007).

CHAPTER 1

INTRODUCTION

1.0 Introduction

Wireless Local Area Network (WLAN) is seen as the technology that will enable the most convenient link between existing wired networks and portable computing. Communications equipments, such as laptop, computers and personal digital assistants (PDAs) at the office, hotel, company or campus level. Building company and campus wide data communications through the WLAN can reduce the need for wiring among several buildings (Qizheng Gu, 2005). In general, the application of the WLAN systems can be simply between two computers or between a computer and a wired network, all the way up to a complete network with many users and a great numbers of data paths.

The IEEE 802.11a standard defines a WLAN system based on the orthogonal frequency division multiplexing (OFDM) technology that splits an information signal across 52 separate subcarriers to provide a transmission of data rate up to 54 Mbps and throughput over 24.3 Mbps, and the operating frequency of the system is in license-free where it is called Unlicensed National Information Infrastructure (U-NII band) 5.15 to 5.35 GHz and 5.725 to 5.875 GHz bands. The high data rate WLANs like the 802.11a systems satisfy requirements of multimedia applications including streaming High Definition Television (HDTV) - quality video in the home, high-speed internet and file transfer.

1.1 Objectives

The objective of the research project is to develop a system level design, simulation and measurement, including analysis and verification of a front-end direct conversion receiver at 5.725 – 5.825 GHz. The direct conversion receiver requires system level analysis and verification in terms of system characteristic and performance. Therefore, the IEEE 802.11a standard is used as performance test. This frequency range can provide higher bandwith untill 100 MHz. The front-end receiver should meet this standard requirement and should operate satisfactorily for WLAN Bridge system.

1.2 Problem Statement

In designing and developing an RF receiver for WLAN communication system, the initial stage is determining what kind of architecture will be employed based on considerations of performance, cost, power consumption, and robust implementation. The selection of receiver architecture is playing the important rule to achieve the desired performance. From the literature surveys, there are various type of receiver has been developed nowadays. That is direct conversion receiver, superheterodyne receiver, tuned radio receiver, low IF receiver and band-pass sampling radio (Gu, 2005). But the architectures mostly discussed are superheterodyne architecture and direct conversion architecture. At present most RF receivers in wireless communication systems are using superheterodyne architecture. This architecture has the best performance if compared with the others, and therefore it has been the most popular architecture since it invented in 1918. To obtain a great cost saving and to take advantage of multimode operation without increasing extra parts, the direct conversion or homodyne architecture has now become a very popular radio architecture for wireless communication systems (Chang *et. al*., 2002a).

The performance of the RF receiver depends on the system design, circuit design, and working environment. The acceptable level of distortion or noise varies with the application (Chang *et. al.*, 2002b). Basically the system includes a couple of real RF components, such as amplifier, power divider, filters and local oscillator. Each of these components introduces different distortions such as thermal noise, phase noise, spurious frequencies and intermodulation distortion (Luzzatto *et. al.*, 2007). In a RF transceiver design, the distortions must be determined and reduced. This research work therefore aims to provide the best solution for the RF receiver design, so that, the best performance of WLAN Bridge system can be achieved. According to Razavi (1998a), the inefficient simulation technique in design tools is another challenge to RF designers in getting accurate simulation result.

This research work is to develop the RF front-end direct conversion receiver operating at 5.8 GHz band and be an alternative architecture compare to superheterodyne architecture. This band is allocated for the use of outdoor links (Razavi, 1998b). The system level analysis and verification are performed in terms of system characteristic and performance. The IEEE 802.11a standard is used for performance test such as sensitivity and adjacent channel rejection (ACR). Federal Communications Commission (FCC) approved IEEE 802.11a standard in September 1999 that uses the unlicensed 5 GHz U-NII bands. The IEEE 802.11a uses OFDM, a new coding scheme that provides a significantly higher data rates up to 54 Mbps. The required speeds defined in IEEE 802.11a are 6, 12 and 24 Mbps with optional speeds up to 54 Mbps. The communication distance for the system is at least 100 m.