

**NEW FREQUENCY QUADRUPLING TECHNIQUES
BASED ON CARRIER SUPPRESSION FOR
HIGH-QUALITY 60 GHz RADIO-OVER-FIBER
SYSTEMS**

NAEL AHMED MOHAMMED

UNIVERSITI MALAYSIA PERLIS

2014

© This item is protected by original copyright



UniMAP

**NEW FREQUENCY QUADRUPLING TECHNIQUES
BASED ON CARRIER SUPPRESSION FOR
HIGH-QUALITY 60 GHz RADIO-OVER-FIBER
SYSTEMS**

By

NAEL AHMED MOHAMMED

(1040810522)

A thesis submitted
In fulfillment of the requirements for the degree of
Doctor of Philosophy (Communication Engineering)

**School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS (UniMAP)
MALAYSIA**

2014

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

Author's full name : NAEL AHMED MOHAMMED
Date of birth : 12th September 1974
Title : NEW FREQUENCY-QUADRUPLING TECHNIQUES BASED ON CARRIER SUPPRESSION FOR HIGH-QUALITY 60 GHz RADIO-OVER-FIBER SYSTEMS
Academic Session : 2013/2014

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as :

- CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)
- RESTRICTED** (Contains restricted information as specified by the organization where research was done)
- OPEN ACCESS** I agree that my thesis is to be made immediately available as hard copy or on-line open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of _ years, if so requested above).

Certified by:

SIGNATURE

G1194940
(NEW IC NO. / PASSPORT NO.)

Date : _____

SIGNATURE OF SUPERVISOR

Professor Dr. Syed Idris Syed Hassan
NAME OF SUPERVISOR

Date : _____

Acknowledgements

Praise and thanks to Allah (SWT) who gave me the strength and courage to complete this project. My most special thanks to Prof. Dr. Syed Idris Syed Hassan, for supporting me through the doctoral process and for his academic advice. His guidance, ideas, encouragement, affable nature, kindness and support were greatly helpful. Even with his busy schedule, he spent considerable amount of time helping me through the different phases of this project. I would also like to thank my co-supervisor Assoc. Prof. Dr. Mohd. Fareq Abd. Malek for his kind support, and suggestions. Special acknowledgement to my co-supervisor Assoc. Prof. Razali Ngah from Universiti Teknologi Malaysia for his valuable suggestions, revision of this project and for the many interesting discussions. I would also like to thank my co-supervisor Prof. Dr. Syed Alwee Aljunid. A special acknowledgment must be given to my brothers and sisters for their motivation help and support during my academic period at UniMAP. I am indebted to them and words will never express the gratitude I owe to them.

I wish to thank my parents, my brothers and sister for their daily prayers, giving me the motivation and strength, and encouraging me to accomplish and achieve my goals.

Last but not least, sincere thanks and gratitude to my lovely wife Sura who inspired me by her, courage, support and patience throughout the period of my study.

Nael Ahmed Mohammed
University Malaysia Perlis (UniMAP)

TABLE OF CONTENTS

	PAGE
DECLARATION OF THESIS	i
ACKNOWLEDGEMENTS	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	viii
LIST OF FIGURES	ix
LIST OF ABBREVIATIONS	xiii
ABSTRAK	xvii
ABSTRACT	xix
CHAPTER 1: INTRODUCTION	
1.1 Research Background	1
1.2 Problem Statement	9
1.3 Research Objectives	10
1.4 Scope and Limitations of the Work	11
1.5 Methodology	12
1.6 Contributions	14
1.7 Thesis Outlines	14
CHAPTER 2: LITERATURE REVIEW	
2.1 Introduction	16
2.2 Electrical Approaches for MMW Wireless Signals Transportation	16

2.3	Optical Approaches for MMW Wireless Signals Transportation	17
2.4	Radio-over-Fiber Technology	20
2.4.1	Radio-over-Fiber System Configuration	21
2.4.2	External Intensity Modulation Techniques	24
2.4.3	Technical Issues to be Resolved in RoF systems	29
2.5	Optical Millimeter-Wave Signal Generation Techniques	31
2.5.1	Optical Heterodyne Detection Technique	31
2.5.1.1	Optical Phase-Locked Loop	34
2.5.1.2	Optical Injection Locking	35
2.5.2	Optical Frequency Up-conversion Techniques	36
2.5.2.1	Frequency-Doubling Technique	37
2.5.2.2	Frequency-Quadrupling Technique	42
2.5.2.3	Frequency-Sixupling Technique	50
2.6	Summary	53

CHAPTER 3: DEVELOPMENT OF NEW FREQUENCY-QUADRUPLING APPROACHES FOR HIGH-QUALITY 60 GHz OPTICAL MMW SIGNAL GENERATION

3.1	Introduction	55
3.2	Proposed Frequency-Quadrupling Approach Using Two Parallel DD-MZMs	56
3.2.1	Principle of DD-MZM Modulation	56
3.2.2	Principle of the Proposed OCS MMW Signal Generation Approach	61
3.2.3	Theoretical Analysis	65
3.2.4	Quality of the Generated OCS MMW and Electrical MMW Signals for	69

	B-T-B Case	
	3.2.4.1	Optical Sidebands Suppression Ratio 69
	3.2.4.2	Radio Frequency Spurious Suppression Ratio 71
	3.2.5	Transmission Performance of the Generated OCS MMW Signal over Optical Fiber 73
	3.2.6	Advantages of the Approach 77
3.3	Proposed Frequency-Quadrupling Approach Using One IDP-MZM 78	
	3.3.1	Principle of SD-MZM Modulation 78
	3.3.2	Principle of the Proposed Optical MMW Signal Generation Approach Based on one IDP-MZM 81
	3.3.3	Theoretical Analysis 85
	3.3.4	Quality of the Generated Optical MMW and Electrical MMW Signals for B-T-B Case 88
	3.3.4.1	Optical Sidebands Suppression Ratio 88
	3.3.4.2	Radio Frequency Spurious Suppression Ratio 89
	3.3.5	Transmission Performance of the Generated Optical MMW Signals Over Optical Fiber 89
	3.3.6	Advantages of the Approach 94
3.4	Summary 95	
CHAPTER 4: RESULTS AND DISCUSSION		
4.1	Introduction 97	
4.2	Evaluation and Simulation Results of the Proposed Frequency-Quadrupling Approach Using Two Parallel DD-MZMs 97	

4.2.1	Back-To-Back System	98
4.2.2	Effect of Phase Shifting	103
4.2.3	Effect of RF driving Voltage Deviation	104
4.2.4	Effect of Non-ideal MZM Extinction Ratio	105
4.2.5	Effect of RF Oscillator	107
4.2.6	Radio-over-Fiber system	108
4.2.7	Effect of Modulation Index	116
4.2.8	Bit-Error-Rate Variation as a Function of Fiber Length	118
4.3	Evaluation and Simulation Results of the Proposed Frequency-Quadrupling Approach Using One IDP-MZM	119
4.3.1	Back-To-Back System	119
4.3.2	Effect of Phase Shifting	127
4.3.3	Effect of RF driving Voltage Deviation	129
4.3.4	Effect of Non-ideal IDP-MZM Extinction Ratio	130
4.3.5	Effect of RF Oscillator	132
4.3.6	Effect of Modulation Index	133
4.3.7	Radio-over-Fiber System	135
4.4	Comparison of Approaches	141
4.5	Summary	143
 CHAPTER 5: CONCLUSIONS AND FUTURE WORKS		
5.1	Conclusions	145
5.2	Future Works	148

REFERENCES	150
APPENDIXES	161
Appendix A Derivation of Equation (3.14)	161
Appendix B Derivation of Equation (3.24)	163
Appendix C Integrated Dual-Parallel Mach–Zehnder Modulators MXIQ-LN-40 Parameters	165
Appendix D Derivation of Equation (3.39)	166
Appendix E Derivation of Equation (3.46)	168
Appendix F ITU-G.652 Non-Dispersion Shifted Fiber (NDSF) Standard	171
LIST OF PUBLICATIONS	173

LIST OF TABLES

NO.		PAGE
Table 1.1	Summary of Wireless Access Networks.	5
Table 1.2	Comparison of TDM-PON and WDM-PON Technologies.	7
Table 2.1	Comparison of MMW Signal-Transporting Approaches.	20
Table 2.2	Comparison of EIM Techniques.	29
Table 2.3	Comparison of MMW Generation Techniques.	53
Table 2.4	Survey of OFU Techniques to Generate MMW Signals.	54
Table 4.1	Comparison of Present Work With That of Earlier Works.	142

© This item is protected by original copyright

LIST OF FIGURES

NO.		PAGE
1.1	Wireless Access Technologies.	2
1.2	Architecture of TDM-PON.	8
1.3	Architecture of WDM-PON.	8
1.4	Classification of Optical MMW Generation Techniques	11
1.5	Research Methodology	12
2.1	Electrical Transportation System for MMW Wireless Signals.	17
2.2	Categories of MMW Wireless Signals Transmission Over Optical Fiber .	19
2.3	Basic RoF System.	22
2.4	Intensity Modulation of the Light Source by DIM and EIM.	23
2.5	Optical Output Power versus the Applied Voltage for MZM.	24
2.6	Principle Diagram of DD-MZM Modulation.	25
2.7	OHD Technique.	32
2.8	OPLL Technique.	34
2.9	OIL Technique.	35
2.10	Frequency-Doubling Technique by using DD-MZM.	37
2.11	Frequency-Doubling Technique by using SD-MZM.	39
2.12	Frequency- Doubling Technique by using an Optical PM.	40
2.13	Frequency-Quadrupling Technique by using a Single MZM.	42
2.14	Frequency-Quadrupling Technique by using a Cascaded MZMs With a ODL.	44
2.15	Frequency-Quadrupling Technique by using a Cascaded DD-MZMs.	46

2.16	Frequency-Quadrupling Technique by using Nested MZMs.	47
2.17	Frequency-Quadrupling Technique by using an IMZM with Four Optical PM Arms.	49
2.18	Frequency-Sixupling Technique by using Fiber Nonlinearity.	50
2.19	Frequency-Sixupling Technique by using Two Cascaded DD-MZMs Interleaved with GOBF.	52
3.1	Principle Diagram of Optical MMW Signal Generation by using DD-MZM.	57
3.2	Simulated Optical Spectrum of the Generated MMW signal with Different Modulation Techniques.	60
3.3	Principle of the Proposed OCS MMW Signal Generation Approach.	63
3.4	Flow Chart of the Proposed Frequency-Quadrupling Approach.	64
3.5	Bessel Function of the First Kind.	70
3.6	Diagram of the RoF System Based on the Proposed OCS MMW Signal Generation Approach.	74
3.7	Principle Diagram of Optical MMW Generation via SD-MZM.	79
3.8	Principle of the optical MMW Signal Generation Approach.	83
3.9	Flow Chart of the Proposed Frequency-Quadrupling Approach.	84
3.10	Diagram of the RoF System Based on the Proposed Optical MMW Signal Generation Approach.	93
4.1	Simulation Setup for the Designed B-T-B System Using “OptiSystem” Software.	99
4.2	Simulated 60 GHz MMW Signal Generated by the Proposed Approach when ER is Infinite .	101

4.3	Simulated 60 GHz MMW Signal Generated by the Proposed Approach When ER is 25 dB.	102
4.4	OSSR and RFSSRR versus Phase Shifting at 25 dB ER.	104
4.5	OSSR and RFSSRR versus RF Driving Voltage Deviation at 25 dB ER.	105
4.6	Effect of Non-Ideal MZM ER on OSSR and RFSSRR.	107
4.7	Effect of Oscillator RF on OSSR and RFSSRR at 25 dB ER.	104
4.8	Block Diagram of the designed RoF System.	109
4.9	Simulation Setup for the Designed RoF System Using “OptiSystem” Software.	110
4.10	Simulating Spectra at Different Locations Corresponding to (a) and (b) In Figure 4.8.	111
4.11	Simulated Electrical Eye Patterns of the Down-Converted 2.5 Gbps Baseband Signals Carried by the 60 GHz MMW Signal at Transmission Distance of: (a) 20, (b) 40, (c) 60, and (d) 70 km.	114
4.12	Simulated Eye Patterns at Transmission Distance of (a) 0, (b) 20, (c) 40, and (d) 70 km.	115
4.13	OSSR versus RF Oscillator with a Function of Modulation Index.	116
4.14	Q-factor versus Modulation Index.	117
4.15	BER versus Fiber Length.	118
4.16	Block Diagram of the Designed B-T-B System.	120
4.17	Simulation Setup for the Designed B-T-B System Using “OptiSystem” Software.	120
4.18	Simulated 60 GHz Signal When $\Delta\phi=135^\circ$ and ER is Infinite.	123

4.19	Simulated 60 GHz MMW Signal When $\Delta\phi=45^\circ$ and ER is Infinite.	124
4.20	Simulated 60 GHz MMW Signal When $\Delta\phi=45^\circ$ and ER is 30 dB.	125
4.21	Simulated 60 GHz MMW Signal When $\Delta\phi=135^\circ$ and ER is 30 dB.	126
4.22	OSSR against Phase Shift Deviation at 30 dB ER.	128
4.23	RFSSRR against Phase Shift Deviation at 30 dB ER.	128
4.24	OSSR against RF Driving Voltage Deviation at 30 dB ER.	129
4.25	RFSSRR against RF Driving Voltage Deviation at 30 dB ER.	130
4.26	Effect of Non-Ideal IDP-MZM ER on OSSR.	131
4.27	Effect of Non-Ideal IDP-MZM ER on RFSSRR.	132
4.28	Effect of RF Oscillator on OSSR and RFSSR at an IDP-MZM ER of 30 dB.	133
4.29	RFSSRR Versus. RF Oscillator with a Function of Modulation Index.	134
4.30	Q-factor versus RF Modulation Index	135
4.31	Simulation Setup for the designed RoF System.	136
4.32	Simulation Setup for the Designed RoF System Using “OptiSystem” Software.	137
4.33	Simulated Electrical Eye Patterns of Down-converted 2.5 Gbps Baseband Signals at Transmission Distance of (a) 20 (b) 40 (c) 60 and (d) 65 km.	140
4.34	Simulated Eye Patterns at Transmission Distance of (a) 0, (b) 20, (c) 40, and (d) 65 km.	141

LIST OF ABBREVIATIONS

1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
A/D	Analogue to Digital Convertor
AWG	Arrayed Waveguide Grating
BB	Base Band
BER	Bit-Error-Rate
BERT	Bit Error Rate Tester
BS	Base Station
B-T-B	Back-to-Back
CD	Chromatic Dispersion
CMOS	Complementary Metal–Oxide–Semiconductor
CO	Central Office
CS	Central Station
CW	Continuous Wave
dB	Decibel
dBm	Decibels, Milliwatt
D	Chromatic Dispersion Parameter
D/A	Digital to Analog Converter
DC	Direct Current
DD-MZM	Dual Drive Mach–Zehnder Modulator
DFB-LD	Distributed feedback laser diode

DIM	Direct Intensity Modulation
DR	Dynamic Range
EDFA	Erbium Doped Fiber Amplifier
EIM	External Intensity Modulation
E/O	Electrical To Optical
EPON	Ethernet Passive Optical Network
ER	Extinction Ratio
FBG	Fiber Bragg Grating
FTTH	Fiber To The Home
FTTP	Fiber To The Premise
FWM	Four Wave Mixing
Gbps	Gigabit per second
GHz	Gigahertz = 10^9 Hertz
GSM	Global System For Mobile Communications
HDTV	High Definition Television
IDP-MZM	Integrated Dual-Parallel MZM
IEEE	Institute of Electrical and Electronics Engineers
IF	Intermediate Frequency
IM	Intensity Modulation
IM-DD	Intensity Modulation and Direct Detection
ISI	Intersymbol Interference
LD	Laser Diode
LED	Light Emitting Diode
LiNO ₃	Lithium Niobate Oxide
LO	Local Oscillator

LOS	Line-of-Sight
LTE+	Advanced Long Term Evolution
MATBP	Maximum Transmission Bias Point
MITBP	Minimum Transmission Bias Point
MMI	Multimode Interference
MMW	Millimeter-Wave
MZI	Mach-Zehnder Interferometer
NDSF	Non Dispersion Shift Fiber
NF	Noise Figure
NLOS	Non-Line-of-Sight
OCS	Optical Carrier Suppression
ODSB	Optical Double Sideband
ODL	Optical Delay Line
O/E	Optical To Electrical
OFU	Optical Frequency Upconversion
OHD	Optical Heterodyne Detection
OIL	Optical Injection Locking
OLT	Optical Line Terminal
ONU	Optical Network Unit
OOK	On-Off Keying
OPLL	Optical Phase Locked Loop
OSSR	Optical Sidebands Suppression Ratio
OSSB	Optical Single Sideband
PD	Photo Diode
PIN	Positive Intrinsic Negative

PM	Phase Modulation
PON	Passive Optical Networks
PRBS	Pseudorandom Binary Sequence
QAM	Quadrature Amplitude Modulation
QBP	Quadrature Bias Point
RF	Radio Frequency
RIN	Relative Intensity Noise
RFSSRR	Radio Frequency Spurious Suppression Ratio
RoF	Radio Over Fiber
RS	Raman Scattering
SD-MZM	Single Drive Mach–Zehnder Modulator
SNR	Signal to Noise-Ratio
SMF	Single Mode Fiber
TDM	Time Division Multiplexing
UMTS	Universal Mobile Telecommunication System
WDM	Wavelength Division Multiplexing
WiMax	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network

Teknik Baru Frekuensi Empat Kali Ganda Berasaskan Penyekatan Pembawa Untuk Sistem Radio Atas Gantian 60ghz Berkualiti Tinggi

ABSTRAK

Gelombang millimeter (MMW) rangkaian tanpa wayar dalam jalur tanpa lesen 60GHz menjadi teknologi utama untuk membolehkan capaian pelbagai gigabit tanpa wayar dan penyediaan aplikasi yang memerlukan kualiti perkhidmatan (QoS) sensitif. Walau bagaimanapun, banyak kesukaran dalam sistem tanpa wayar 60 GHz yang perlu diselesaikan; yang paling utama adalah kehilangan laluan udara yang lebih tinggi. Ini bermakna lebih banyak stesen tapak (BSs) diperlukan untuk memberi liputan bagi kawasan yang luas. Teknologi radio melalui gantian optik (RoF)-merupakan integrasi antara sistem tanpa wayar dan optik, telah lama dicadangkan sebagai teknologi yang sesuai untuk menyelesaikan kesukaran ini. Disamping banyak kelebihan seperti kehilangan penghantaran yang rendah, kos yang rendah, lebar jalur yang besar dan imuniti kepada gangguan elektromagnetik. Teknik RoF membolehkan kerumitan beralih dari BSs ke pejabat pusat dengan peruntukan berpusat bagi pembawa MMW. Dalam sistem RoF, kos yang efektif dan penjanaan isyarat frekuensi tinggi yang berkualiti tinggi melalui pelaksanaan yang mudah merupakan teknologi utama dalam pelaksanaan system ini. Berbanding kaedah konvensional elektrik, kaedah optik adalah lebih digemari.

Dalam tesis ini, kami mencadangkan dua pendekatan baru bagi penjanaan dan penghantaran isyarat MMW 60 GHz termodulat optic menggunakan pengganda frekuensi ganda empat berasaskan kepada dua pemodulat *Mach-Zehnder* (DD-MZMs) selari dwi-pandu dan satu MZM (IDP-MZM) dwi-selari bersepadu. Hasil dari pendekatan yang dicadangkan, dua frekuensi ganda empat skim penjanaan MMW optik yang baru direka telah dicadangkan. Skim yang pertama menggunakan dua DD-MZM selari untuk menjana isyarat MMW optik beserta penyekatan pembawa (OCS) tanpa penapis optik, manakala skim yang kedua hanya menggunakan satu IDP-MZM untuk menghasilkan dwi nada isyarat MMW optik yang berkualiti tinggi. Analisis teori terperinci penjanaan isyarat MMW optik menggunakan pendekatan yang dicadangkan itu dijalankan dan ungkapan jelas bagi nisbah penindasan jalur sisi optik (OSSR), nisbah frekuensi radio penyekatan palsu (RFSSRR), dan arus MMW diberikan dan boleh digunakan untuk penilaian prestasi sistem ROF. Perisian simulasi, OptiSystem, digunakan untuk mensimulasikan skim penjanaan MMW optik frekuensi empat kali ganda. Kesefahaman yang baik antara teori dan simulasi diperolehi. Dengan menggunakan pendekatan pertama, keputusan simulasi menunjukkan bahawa isyarat MMW 60 GHz boleh dijana dari pengayun RF 15 GHz dengan OSSR sehingga 39.4 dB dan RFSSRR melebihi 35 dB tanpa mana-mana penapis optik atau elektrik apabila nisbah kepupusan daripada MZM ialah 25 dB. Manakala bagi pendekatan kedua, keputusan simulasi menunjukkan bahawa MMW 60 GHz boleh dijana daripada pengayun 15 GHz RF dengan OSSR dan RFSSRR yang melebihi 33.7 dB dan 33.4 dB tanpa penggunaan penapis optik atau elektrik apabila nisbah kepupusan MZM ialah 30 dB. Pengaruh beberapa nombor ukuran yang tidak ideal, seperti nisbah kepupusan tidak sempurna, voltan RF didorong tidak ideal dan peralihan fasa pada dicadangkan skim generasi MMW optik dikaji menerusi simulasi. Keputusan menunjukkan perubahan kecil dari nilai ideal tidak akan menyebabkan pemerosotan yang besar bagi isyarat MMW optik yang telah dijana. Akhir sekali, kami membina suatu sistem RoF menerusi simulasi, dan prestasi penghantaran oleh isyarat MMW yang dijanakan telah

dibentangkan. Corak mata masih jelas terbuka walaupun selepas gentian optik sepanjang 60 km.

© This item is protected by original copyright

New Frequency Quadrupling Techniques Based On Carrier Suppression For High-Quality 60 GHz Radio-over-Fiber Systems

ABSTRACT

Millimeter-wave (MMW) wireless networks in the 60 GHz unlicensed band have become a key technology for enabling multi-gigabit wireless access and provisioning of quality of service (QoS)-sensitive applications. However, numerous difficulties need to be solved in the 60 GHz wireless systems, the most important of which is the high air-link loss. This issue implies that many remote base stations (BSs) need to be deployed to cover a large area. Radio-over-fiber (RoF) technology, the integration of wireless and optical communication, has long been proposed as an ideal technology for solving these difficulties. Aside from numerous advantages, such as low propagation loss, low cost, large bandwidth, and immunity to electromagnetic interference, the RoF technology enables the shift of complexity from BSs to a central office by a centralized provision of the MMW carrier. In an RoF system, the high-quality generation of MMW signals with simple implementation is a key technique. Compared with the conventional electrical method, the optical method is preferable. In this thesis, we propose two new frequency-quadrupling approaches for the optical generation and downstream transmission of high-quality and data modulated 60 GHz signals on the basis of two parallel dual-drive Mach-Zehnder Modulators (DD-MZMs) and one integrated dual-parallel MZM (IDP-MZM). As a result of these proposed approaches, two newly designed optical MMW generation schemes are proposed. The first scheme uses two parallel DD-MZMs to generate a high-quality optical carrier suppression (OCS) MMW signal, whereas the second scheme uses only one IDP-MZM to generate a high-quality optical MMW signal without optical filter. A detailed theoretical analysis of the proposed frequency-quadrupling approaches is conducted. Moreover, explicit expressions of the optical sidebands suppression ratio (OSSR), radio frequency spurious suppression ratio (RFSSRR), and MMW current are given and can be utilized for the evaluation of the qualities of the generated optical and electrical MMW signals in back-to-back (B-T-B) transmission, as well as the transmission performance of the generated optical MMW signal over optical fiber. The simulation software, OptiSystem (version 9.0), is utilized to evaluate the performance of the proposed approaches. Good agreement is found between theory and simulation. By using the first approach, the simulation results show that a 60 GHz MMW signal can be generated from a 15 GHz RF oscillator with an OSSR of up to 39.4 dB and an RFSSRR exceeding 35 dB without optical or electrical filter when the extinction ratios of the two DD-MZMs are 25 dB. For the second approach, the simulation results show that the a 60 GHz MMW signal can be generated with an OSSR and an RFSSRR equal to 33.7 dB and 33.4 dB, respectively, without optical or electrical filter when the extinction ratio of the IDP-MZM is 30 dB. The influences of a number of non-ideal parameters, such as imperfect extinction ratio, RF driving voltage deviation, and phase shifting, on the performance of the proposed optical MMW generation schemes are examined through simulations. Results indicate that a slight deviation from the ideal values would not result in a significant degradation of the generated optical MMW signal. Finally, we build a RoF system through simulation, and the transmission performance of the generated optical MMW signals is presented. The eye pattern is clearly opened even when the optical MMW signal is transmitted over 60 km.

CHAPTER ONE

INTRODUCTION

1.1 Research Background

The demand for high-bandwidth access networks has been growing rapidly with no end in sight. Bandwidth-hungry applications such as high-definition (HD) telepresence and HD televisions (HDTVs) are now accessible and require considerable bandwidth. These applications force the need for a connection that can carry high bit rates inside buildings and homes.

Wireless access networks have become one of the most pervasive core technology enablers for diverse forms of communication and computing applications. The evolution of wireless technologies and the presence of inexpensive wireless equipments have transformed consumer behavior from low-bandwidth applications to rich-media content, including video streaming, rich-content downloading and interactive applications (Thapliya & Hu, 2013). Wireless technologies are technologies that require line-of-sight (LOS) and non-line-of-sight (NLOS) operations. The NLOS technologies provide advantages in terms of ease of deployment and wider network coverage. Wireless technologies support a variety of applications and vary according to range, speed, and bandwidth (Figure 1.1) (Kuran & Tugcu, 2007; Jia, 2008). Wireless fidelity (Wi-Fi) based on IEEE 802.11 standards is an NLOS technology developed in the last 10 years for short-range applications and hotspot connectivity within home and business local area networks (LANs). Wi-Fi has been classified into a number of standards, including IEEE 802.11a, 802.11b, and 802.11g. Wi-Fi offers theoretical data transmission rates of up to 54, 11, and 54 Mbps per channel for 802.11a/b/g, respectively, and a limited range of 100 m (Bhojar, Ghonge, & Gupta, 2013). The current version of IEEE 802.11n can support transmission

rates of 600 Mbps by employing multiple-input multiple-output techniques. However, at present theoretical data transmission rates of 54 Mbps capability limits the practical end user rate to approximately 1Mbps (Wells, 2009).

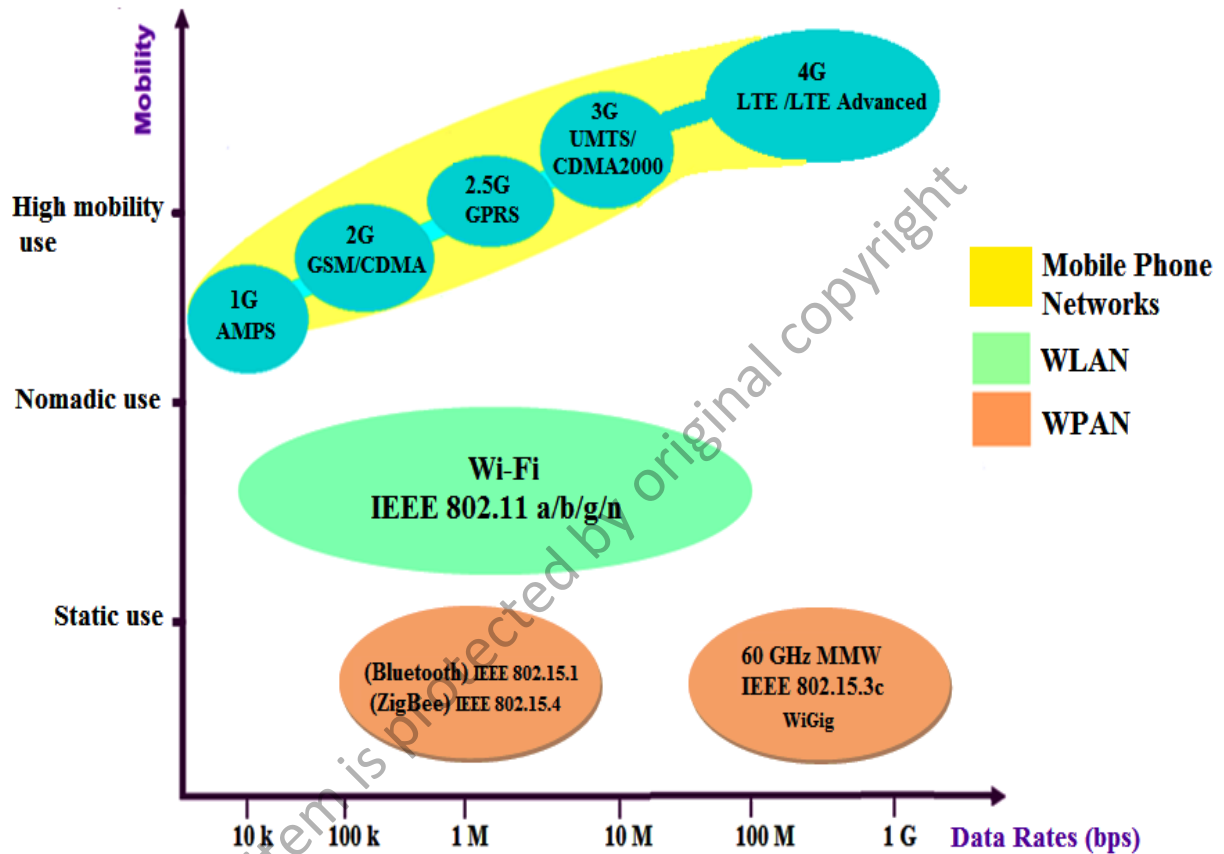


Figure 1.1: Wireless access technologies (Zhensheng Jia, 2008)

A wireless personal area network (WPAN) is a short-range wireless network for interconnecting devices, such as personal digital assistants (PDAs) and cell phones, centered around an individual person’s workspace (Callaway, et al., 2002). WPAN has been classified into two standards, including IEEE 802.15.1 (Bluetooth) and IEEE 802.15.4 (ZigBee). Bluetooth was the first low data-rate standard for WPAN networks. This standard enables wireless connectivity between mobile phones, computers, and electronic appliances with data rates of up to 3 Mbps. ZigBee is targeted for ultra-low

complexity, ultra-low cost, ultra-low power consumption, and low data-rate wireless connectivity. This standard can be used for wireless sensor networks (WSNs), industrial control, home, office/factory automation, and tracking. ZigBee can achieve data rates of 20 Kbps to 250 Kbps (J. S. Lee, Su, & Shen, 2007).

First-generation (1G) mobile phones had only voice facilities. These phones were then replaced by second-generation (2G) digital phones that added fax, data, and messaging services. These 2G phone systems differed from 1G phone systems in their use of digital transmission instead of analog transmission and the introduction of fast phone-to-network signaling (Harte & Bowler, 2003). Global System for Mobile Communications (GSM) is the most popular digital cellular network standard allocated in the radio spectrum around 900 and 1800 MHz. The initial GSM standard allowed only 13 Kbps for voice transmission and 9.6 Kbps for data transmission (Clark, 2000). General Packet Radio Service (GPRS) is an additional technology applied as an overlay on GSM networks to facilitate data rates of up to 170 Kbps and transfers large data files (Halonen, Romero, & Melero, 2002). Universal Mobile Telecommunication System (UMTS) is a third generation (3G) networking standard adopted globally as an upgrade to existing GSM mobile networks; this system added multimedia facilities to 2G phones. The basic UMTS system provides downlink speeds of 2 Mbps and uplink speeds of up to 384 Kbps (Walke, Seidenberg, & Althoff, 2003). Long Term Evolution (LTE) is the fourth generation (4G) of mobile phone technology and enables mobile data and voice communication with transmission speeds of up to 150 Mbps (Holma & Toskala, 2009). LTE is provided as a substitute to existing 2G and 3G technologies. The 6 GHz to 38 GHz point-to-point (P2P) licensed bands are commonly heavily congested and are used particularly for mobile backhauling. The maximum channel bandwidth in these frequencies is 56 MHz. Even with