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

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 Gentian 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 gentian 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 perlaksanaan yang mudah merupaka teknologi utama dalam perlaksanaan 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.

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 MWW 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 (Bhoyar, 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).

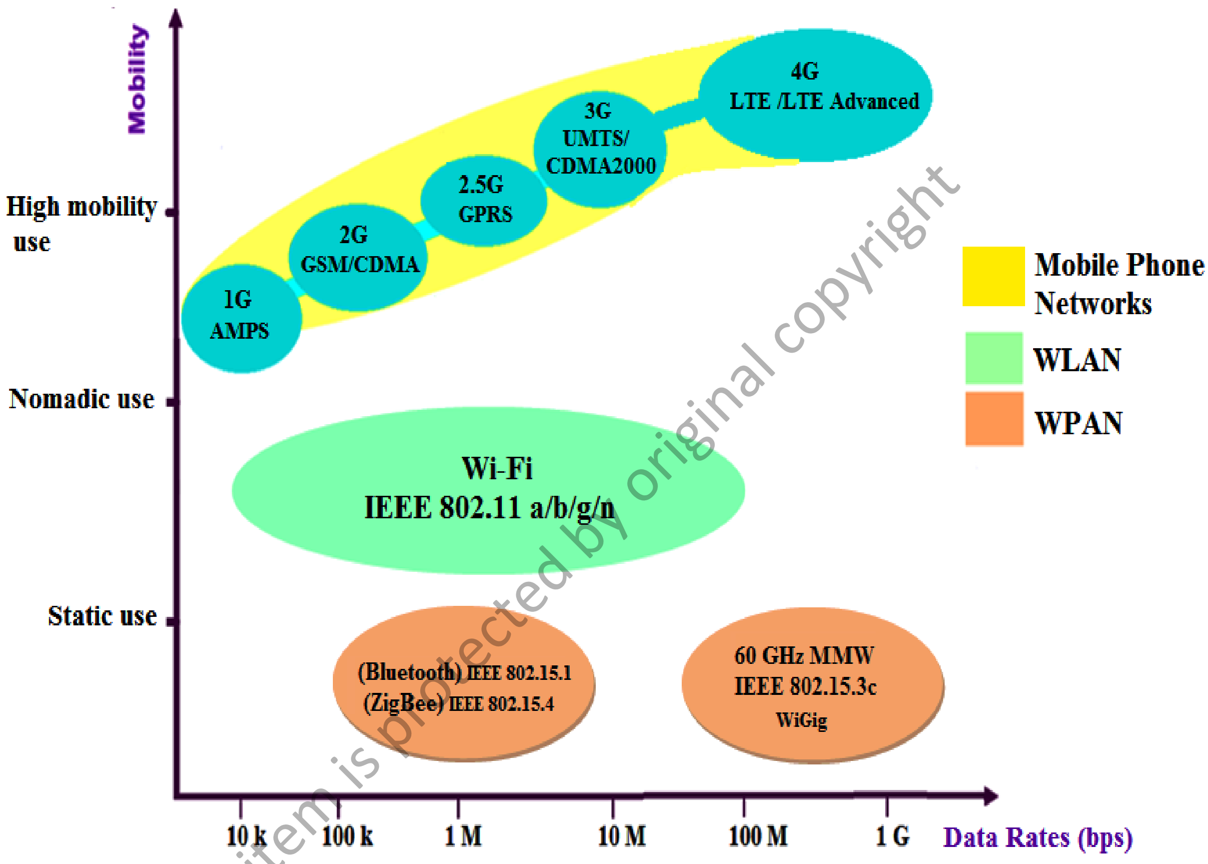

Figure 1.1: Wireless access technologies (Zhensheng Jia, 2008)

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

256-QAM, which is the highest practical modulation in common use, the transmission capacity is still restricted to 400 Mbps (Demian, 2012).

A solution to the shortage of access bandwidth and spectral congestion is seen in the development of wireless systems operating at the unlicensed 60 GHz millimeter-wave (MMW) band. The 60 GHz MMW band offers the following key benefits:

1. Unlicensed operations: the “unlicensed” spectrum allows operators to reduce their cost by avoiding costly spectrum licensing fees from a telecoms regulator (Mikkonen, Corrado, Evci, & Progler, 1998).
2. Huge bandwidths: the Federal Communications Commission offers 7 GHz of continuous bandwidth between 57 and 64 GHz to achieve a multi-gigabit data rate with efficient and low power consumption (Ng'Oma & Sauer, 2009).
3. Highly secure operations resulting from short transmission distances because of oxygen absorption loss of 60 GHz signals (15 dB/km) and narrow antenna beam width (Marcus & Pattan, 2005).
4. Coexistence with other wireless/mobile communication standards, such as Wi-Fi, 3G/4G cellular systems, Bluetooth, and ultra wideband systems because of large frequency availability (Huang & Wang, 2011).
5. Reduced inter-symbol interference caused by multi-path fading (Gunnarsson, et al., 2005).
6. Cost reduction by complementary metal–oxide–semiconductor (CMOS) technology, which allows high integration levels and mass production (Reynolds, et al., 2007).
7. Next-generation WLAN exploits the 60 GHz spectrum through the development of the IEEE 802.11ad and wireless gigabit alliance (WiGig) standards.