**UNIVERSITI PUTRA MALAYSIA**

# *MITIGATION OF MACH ZEHNDER MODULATOR NONLINEARITY IN MILLIMETER WAVE RADIO OVER FIBER SYSTEM USING DIGITAL PREDISTORTION*

**SHANKAR DURAIKANNAN**

**FK 2017 116**

# MITIGATION OF MACH ZEHNDER MODULATOR NONLINEARITY IN MILLIMETER WAVE RADIO OVER FIBER SYSTEM USING DIGITAL PREDISTORTION



**By**

**SHANKAR DURAIKANNAN**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

**October 2017**

# DEDICATIONS

…to GOD Almighty.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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**October 2017**

**Chair: Assoc Prof Siti Barirah Binti Ahmad Anas, PhD**
**Faculty: Engineering**

In this era of multiscreen generation, with connected devices per person escalating dramatically, the transmission of uncompressed videos and tons of data over wireless networks have driven the wireless networks to migrate from lower radio frequency to higher mm wave frequency band. The standard 802.11ad recommends the usage of 7 GHz unlicensed frequency spectrum at 60 GHz. The spectrum with low multipath impairment, suffers a high channel attenuation that demands mixed architecture of radio and fiber for enhancement of coverage distance. Radio over Fiber (RoF) using Mach Zehnder Modulator (MZM) is the most widely adapted architecture for mm-wave generation. However, the architecture with low insertion loss, power consumption, and dispersion effects suffers the effect of MZM nonlinearity that significantly limits the performance of RoF system.

This thesis proposes an I/Q channel separated coherent optical OFDM transmission system at 60 GHz, that employs mm-wave generation by optical frequency up-conversion using cascaded dual drive MZM (DD-MZM) and dual parallel MZM (DP-MZM) architecture at the transmitter and with coherent optical detection at the remote antenna unit. The first stage DD-MZM generates a carrier suppressed odd harmonics of the input optical signal from the laser diode modulated by RF signal. The second stage DP-MZM followed by the Gaussian optical band pass filter (GOBPF) that passes the desired (fifth) harmonic of the optical signal at its output, generates I/Q channel separated OFDM baseband modulated optical signal. The coherent detection of the modulated optical signal received at the Remote Antenna Unit (RAU) produces the 60 GHz mm-wave that is transmitted wirelessly to the Mobile Unit (MU).

The theoretical and simulation analysis of the techniques for 16QAM/OFDM signal is performed. The simulation results in an Error Vector Magnitude (EVM) of 10 percent and 13 percent at 10km and 80 km respectively, a reduced power penalty of 2 dB/km at 80 km and enhanced data rate of 40 Gbps with only 10 GHz signal bandwidth that clearly indicates the accuracy of the technique in mm-wave radio signal generation and transmission over fiber. Further with I/Q channel separation, harmonic distortion due to intermediate frequency translation is reduced along with the reduced computational and circuit complexity. However, with coherent optical orthogonal frequency division multiplexing adopted to achieve multi-gigabit transmission the system becomes sensitive to nonlinear distortions induced by MZM.

Therefore, this thesis further analyses the modulator nonlinearity and proposes an adaptive digital pre-distortion (DPD) to mitigate the MZM modulator nonlinearity. The proposed adaptive digital pre-distortion is based on memory polynomial (MP) model with indirect learning architecture (ILA) where the predistorter is modeled as an inverse polynomial model of the nonlinear RoF system. The predistorter is the copy of the training filter that is connected as the post distorter to the nonlinear RoF system. The coefficient computation is performed using recursive prediction error method (RPEM) algorithm which shows a dominant spectral regrowth reduction and in-band distortion reduction with reduced complexity compared to the commonly used slow converging, least mean square algorithm. The RoF system with and without the DPD is simulated and the results demonstrate that the MZM nonlinearity is compensated using the proposed adaptive DPD and substantially improves the performance of the system in terms of Adjacent Channel Leakage Ratio (ACLR) and EVM. The ACLR is improved by 10 dB and the EVM is reduced from 13 percent to 0.06 percent at 80 km.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**MITIGATION OF MACH ZEHNDER MODULATOR NONLINEARITY IN MILLIMETER WAVE RADIO OVER FIBER SYSTEM USING DIGITAL PREDISTORTION**

Oleh

**SHANKAR DURAIKANNAN**

**Oktober 2017**

**Pengerusi: Prof Madya Siti Barirah Binti Ahmad Anas, PhD**
**Fakulti: Kejuruteraan**

Pada era multi paparan, perhubungan antara peranti semakin meningkat secara dramatik, transmisi video tidak mampat dan jutaan data melalui rangkaian tanpa wayar telah menyebabkan kecenderungan rangkaian tanpa wayar untuk beralih dari radio dengan frekuensi rendah kepada jalur frekuensi gelombang mm yang lebih tinggi. Piawaian 802.11ad mencadangkan penggunaan spektrum frekuensi 7 GHz yang tidak berlesen kepada frekuensi 60 GHz. Spektrum dengan herotan pelbagai arah yang rendah terpaksa berhadapan dengan pengecilan saluran yang tinggi yang memerlukan gandingan radio dan gentian untuk meningkatkan jarak liputan. Radio atas Gentian (RoF) menggunakan Mach Zehnder Modulator (MZM) merupakan senibina yang digunakan secara meluas untuk penjanaan gelombang mm. Walaubagaimanapun, senibina tersebut yang mempunyai kehilangan sisipan rendah, penggunaan kuasa dan kesan penyebaran menghadapi kesan ketaklurusan MZM yang mengehadkan prestasi sistem Radio atas Gentian (RoF).

Tesis in mencadangkan saluran 1/Q yang mengasingkan sistem transmisi asas OFDM pada frekuensi 60 GHz yang menggunakan penjanaan gelombang mm pada frekuensi optik dimana dwi-pemanduan MZM dan dua rekabentuk MZM yang selari digunakan pada pemancar dan dengan pengesanan optik koheren di Unit Antena Kawalanjauh. Pada peringkat pertama, DD-MZM menjana pembawa harmonik ganjil isyarat awal optik dan diod laser isyarat RF. Pada peringkat kedua, DP-MZM diikuti oleh jalur laluan penapis Gaussian (GOBPF), yang melalui harmonik kelima isyarat optik akhir, menjana saluran 1/Q yang mengasingkan OFDM iaitu jalur asas isyarat optik yang dimodulasi. Pengesanan koheren isyarat optik yang dimodulasi pada Unit Antenna Kawalanjauh (RAU) menghasilkan gelombang mm berjumlah 60 GHz yang dihantar secara tanpa wayar ke Unit Mobil (MU). Analysis secara teori dan

simulasi berkenaan dengan teknik untuk isyarat 16QAM/BB-OFDM dijalankan. Keputusan simulasi Magnitud Vektor Ralat (EVM) adalah 10 peratus pada 10km dan 13 peratus pada 80km.Ini menunjukkan pengurangan kuasa penalti pada 2 dB/km pada 80km dan peningkatan kadar data pada 40 Gbps dengan hanya isyarat jalur lebar 10 GHz. Ini jelas menunjukkan ketepatan teknik dalam penjanaan gelombang mm isyarat radio dan transmisi fiber. Dengan pengasingan saluran I/Q, kemerosotan harmonik yang disebabkan penterjemahan frekuensi pertengahan dikurangkan berserta pengurangan kekompleksan pengiraan dan litar. Walaubagaimanapun, dengan menggunakan optik frekuensi ortogon pemultipleksan pembahagian frekuensi untuk mencapai penghantaran multi-gigabit, sistem menjadi cenderung kepada herotan tak lurus yang disebabkan oleh MZM.

Justeru, tesis ini menganalisa ketaklurusan modulator dengan lebih mendalam dan mencadangkan penyelewengan pra-digital adaptif (DPD) untuk mengurangkan ketaklurusan modulator MZM. Teknik penyelewengan yang dicadangkan untuk adalah berdasarkan model memori polynomial (MP) yang menggunakan senibina cara pengarajaran secara tidak langsung (ILA) dimana ia dimodelkan secara model polynomial songsang untuk sistem yang tidak lurus. Predistorter ialah salinan penapis latihan yang dihubungkan sebagai post distorter kepada sistem RoF tidak lurus. Dua algoritma adaptif iaitu kuasa dua paling kurang yang tidak kompleks dan teknik algoritma ramalan ralat rekursif yang menunjukkan pengurangan pertumbuhan semula spektrum dominan dan penyelewengan dalam jalur digunakan. Sistem RoF disimulasi dengan dan tanpa DPD menunjukkan ketaklurusan MZM boleh diganti menggunakan adaptif DPD yang dicadangkan boleh meningkatkan prestasi sistem Nisbah Kebocoran Saluran Bersebelahan (ACLR) dan EVM secara langsung. Prestasi ACLR meningkat sebanyak 10 dB manakala EVM berkurang dari 13 peratus ke 0.15 peratus di 80 km.

# ACKNOWLEDGEMENTS

It is said “Plans are established by councils and with many advisor plans succeed and there is safety. Hearing to councils and receiving instructions from experienced advisors makes one wiser”. Nothing brightens life like the spirit of thanks giving. I take this thesis as an another opportunity to submit my humble thanks to my supervisors and committee members for their immeasurable support in completion of this thesis.

Firstly, my cordial thanks to my supervisor **Assoc. Prof Dr Siti Barirah Bt. Ahmad Anas** for accepting me as a PhD student and sincere gratitude for her patients, continuous support, motivation, critical comments, knowledge and advise throughout the whole period of study.

My special thanks to **Dr Pooria Varahram**, not only for his valuable knowledge, advice, encouragement and support but also for initiating and giving me this wonderful opportunity to work on this research.

My sincere thanks to **Prof Dr Borhanuddin B Mohd Ali** for accepting to be my supervisory committee member and deep sense of thanks to your excellent advices, reviews and critical comments.

My hearth felt thanks to **Dr Zuraidah Bt Zan** for accepting to be my supervisory committee member and sincere gratitude for your insightful discussions, significant improvement directions, comments and invaluable advice along the research.

My sincere thanks to **Prof Ir Dr Vinesh Thiruchelvam** not only for accepting to be my supervisory committee member but also for his continuous guidance and encouragement towards this research and other professional achievements.

I owe my thanks and gratitude to the most important people of my world, my family members, especially to my mom **Rajeswari,** beloved **Eva** and **Rachel** for their love, care, understanding and guidance in every step of my life.

Finally, but by no means the least, I thank all my friends and colleagues for their moral support.

**APPROVAL SHEETS**

I certify that a Thesis Examination Committee has met on **19/10/2017** to conduct the final examination of SHANKAR DURAIKANNAN on his thesis entitled "MITIGATION OF MACH ZEHNDER MODULATOR NONLINEARITY IN MILLIMETER WAVE RADIO OVER FIBER SYSTEM USING DIGITAL PREDISTORTION" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

**Prof. Madya Y. M. Dr. Raja Syamsul Azmir bin Raja Abdullah**
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

**Y. Bhg. Prof. Dr. Nor Kamariah bt Noordin**
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

**Prof. Madya Dr. Ahmad Shukri bin Muhammad Noor**
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

**Assoc Prof Dr Tahmina Ajmal**
Associate Professor
Department of Computer Science and Technology
University of Bedfordshire
United Kingdom
(External Examiner)

**NOR AINI AB. SHUKOR, PhD**
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 30 November 2017

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:


**Siti Barirah Binti Ahmad Anas PhD**
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

**Borhanuddin Mohd Ali PhD**
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

**Zuraidah Binti Zan, PhD**
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

**Vinesh Thiruchelvam, PhD**
Professor
Faculty of Computing, Engineering and Technology
Asia Pacific University of Technology and Innovation
(Member)

**ROBIAH BINTI YUNUS, PhD**
Professor and Dean
School of Graduate Studies
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| | |
|---|---|
| ACLR | Adjacent Channel Leakage Ratio |
| AM/PM | Amplitude Modulation-Phase Modulation |
| ASE | Amplified Spontaneous Emission |
| B2B | Back to Back |
| BBoF | Baseband over Fiber |
| BER | Bit Error Rate |
| CDMA | Coded Division Multiple Access |
| CNR | Carrier to Noise Ratio |
| CO-OFDM | Coherent Optical Orthogonal Frequency Division Multiplexing |
| CSO | Composite Second Order |
| CTB | Composite Triple Beat |
| DCMZM | Dual Cascade Mach Zehnder Modulator |
| DDMZM | Dual Drive Mach Zehnder Modulator |
| DLA | Direct Learning Architecture |
| DPD | Digital Predistortion |
| DPMZM | Dual Parallel Mach Zehnder Modulator |
| DSBSC | Double Sideband Suppressed Carrier |
| E/O | Electro Optical |
| EMP | Envelop Memory Polynomial |
| EVM | Error Vector Magnitude |
| ER | Extinction Ratio |
| FIR | Finite Impulse Response |
| GaAs | Gallium Arsenide |
| GMP | Generalized Memory Polynomial |
| GOBPF | Gaussian Optical Band Pass Filter |
| IFoF | Intermediate Frequency over Fiber |
| ILA | Indirect Learning Architecture |
| IoT | Internet of Things |
| I/Q | In-phase/Quadrature |
| $LiNbo_3$ | Lithium Niobate |
| LMS | Least Mean Square |
| LUT | Look-up Table |
| LS | Least Square |
| LTE-U | Long Term Evolution – Unlicensed |
| MIMO | Multiple Input Multiple Output |
| MP | Memory Polynomial |
| MU | Mobile Unit |
| MZM | Mach Zehnder Modulator |
| OFDMA | Orthogonal Frequency Division Multiple Access |
| OMP | Orthogonal Memory Polynomial |

| | |
|---|---|
| PA | Power Amplifier |
| QAM | Quadrature Amplitude Modulation |
| QPSK | Quadrature Phase Shift Keying |
| RF | Radio Frequency |
| RFoF | Radio Frequency over Fiber |
| RIN | Relative Intensity Noise |
| RLS | Recursive Least Square Algorithm |
| RoF | Radio over Fiber |
| RFoF | Radio Frequency over Fiber |
| RPEM | Recursive Prediction Error Method |
| SDR | Signal to Distortion Ratio |
| SNR | Signal to Noise Ratio |
| SNDR | Signal to Noise Distortion Ratio |
| SSB | Single Side Band |
| WLAN | Wireless Local Area Network |
| WMAN | Wireless Metropolitan Area Network |
| WPAN | Wireless Personal Area Network |
| WWAN | Wireless Wide Area Network |

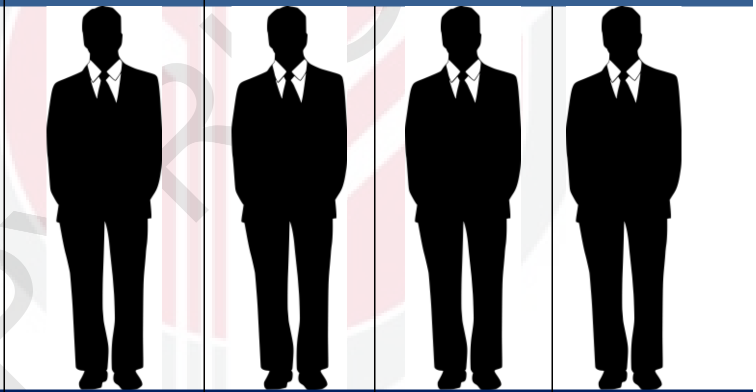
# CHAPTER 1

# INTRODUCTION

## 1.1. Research Background

In this era of multiscreen generation, with connected devices per person escalating dramatically as illustrated in Figure 1.1, it is predicted that there will be 50 billion connected devices on internet by 2020 [1][2].

| | | | | |
|---|---|---|---|---|
| **World Population** | 6.3 Billion | 6.8 Billion | 7.2 Billion | 7.6 Billion |
| **Connected Devices** | 500 Million | 12.5 Billion | 25 Billion | 50 Billion |
| **Connected Device Per Person** | 0.08 | 1.84 | 3.47 | 6.58 |
| | | **More Connected Device than Persons** | | |



| | | | | |
|---|---|---|---|---|
| **Year** | 2003 | 2010 | 2015 | 2020 |

**Figure 1.1: Global growth of connected devices [1]**

According to the statistics of CISCO Visual Network Index, the annual global internet traffic has passed 1 Zettabyte per year in 2016 and would be 2.3 Zettabyte per year by 2020[3]. The total internet traffic has tremendously leaped from 100 GB per day in 1992 to 20235 GB per second in 2015 and would be 61386 GB per second in 2020. The monthly traffic internet per capita has grown from 10 MB in 2000 to 7Gb in 2015 and expected to be 21 GB in 2020. The number of connected devices which was 4.9 billion in 2015 would be 50 billion by 2020. The global connected devices per capita would be 6.58 in

2020 which would be 4 times the world population. In a nutshell the statistics illustrated graphically in Figure 1.2, clearly indicates that the busy hour traffic increase rapidly than average traffic, smart phone traffic exceeds the personal computer traffic, traffic from mobile and wireless devices would account for two third of the total traffic of which two third would be content delivery like ultra-high definition videos.

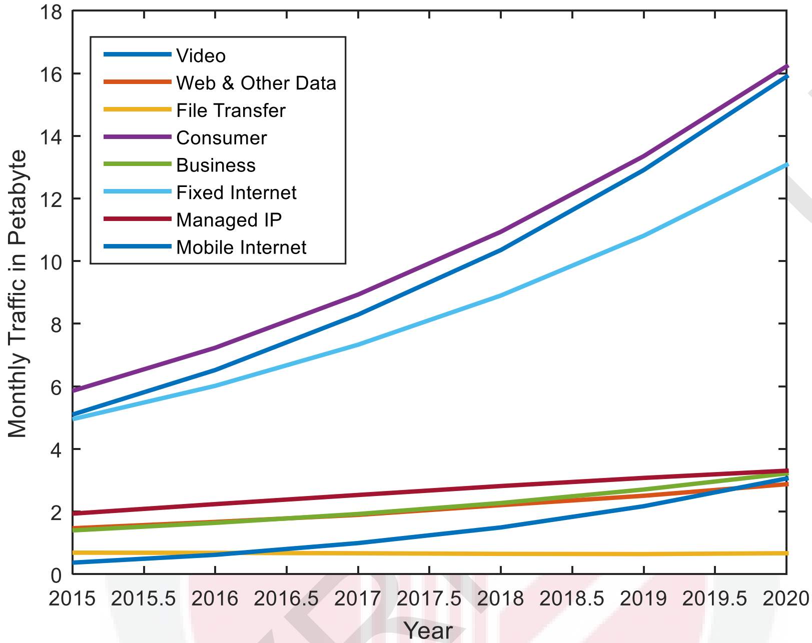



**Figure 1.2: Global monthly traffic in petabytes[3]**

Furthermore, Internet of Things (IoT) born between 2008 and 2009, claimed as network of networks, is looked as the next industrial and network revolution. IoT is directed to interconnect every possible living and non-living things commonly referred as ‘‘things’ and convert them as smart things such that they can communicate, be tracked, controlled, monitored and secured remotely through networks. The sky rocketing growth of IoT demands a connectivity significantly in terms of high data rate, low latency, extended coverage, low power, low deployment cost with support for massive number of high speed, bandwidth hungry devices at personal, local and wide area networks. Furthermore, the success of IoT completely relies on extending the multi-gigabit network at indoor and rural area.

Thus the demand in high traffic on wireless networks across first and last mile requires high speed multi-gigabit wireless networks. With this high demand in data rate the Wireless Local Area Network (WLAN) 802.11ad aims to use the unlicensed mm-wave frequency between 57 GHz and 64 GHz. The Wireless Wide Area Network (WWAN) like WiMax and Long Term Evolution-Unlicensed

(LTE-U) specifies mm-wave frequencies between 10 GHz and 66 GHz for first and last mile access.

The requirement of multi-gigabit data transmission speed at Wireless Personal Area Network (WPAN), Wireless Local Area Network (WLAN), Wireless Metropolitan Area Network (WMAN) and Wireless Wide Area Network (WWAN), in general at every point of the network, have fueled the use of extra high frequency bands commonly called as millimeter waves and the 60 GHz band mm-wave have been identified as a suitable candidate. The standard 802.11ad by WiGig consortium, recommends the usage of 60 GHz millimeter wave band to achieve the high data rate in Wireless Local Area Networks (WLAN) [4]. Similarly the IEEE 802.16 work group are to incorporate 60 GHz band for Wireless Metropolitan Area Networks[5]. The radio technologies at 60 GHz utilize the unlicensed 7 GHz frequency band extending from 57 GHz to 66 GHz. The channelization of 60 GHz band which is typically around 7 GHz, as listed in Table 1.1, with the central two channels available for 60 GHz applications around the world as shown in Figure 1.3. The specification supports 7Gbps transmission speed with OFDM and 4.6 Gbps over single carrier.

**Table 1.1: 57 – 66 GHz band channelization** [4]

| Channel Number | Low Frequency (GHz) | Center Frequency (GHz) | High Frequency (GHz) | Nyquist Bandwidth (MHz) | Roll-Off Factor |
|---|---|---|---|---|---|
| A1 | 57.240 | 58.320 | 59.400 | 1.728 | 0.25 |
| A2 | 59.400 | 60.480 | 61.560 | 1.728 | 0.25 |
| A3 | 61.560 | 62.640 | 63.720 | 1.728 | 0.25 |
| A4 | 63.720 | 64.800 | 65.880 | 1.728 | 0.25 |

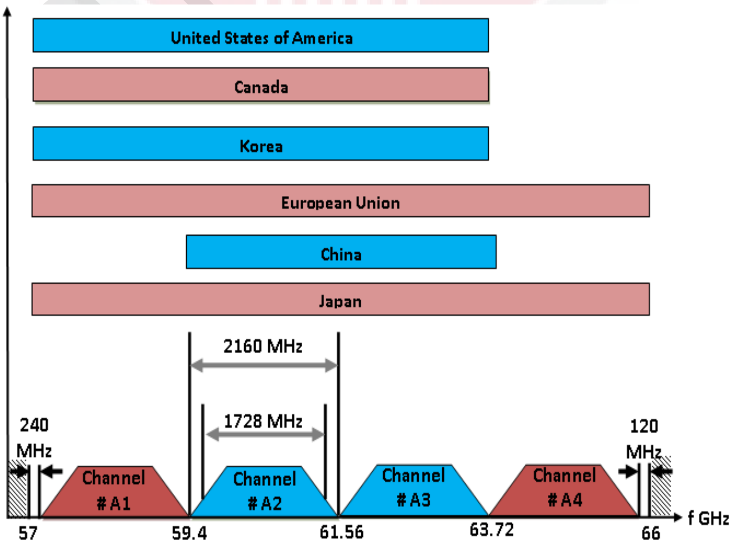



**Figure 1.3: Worldwide spectrum of 60 GHz band [4]**

The spectrum even though has an advantage of low multipath impairment; the coverage range is limited due to free space attenuation which limit the distance of coverage as shown in Figure 1.4. For instance, the free space attenuation of 60 GHz at 1 km is the same as 600 MHz free space attenuation at 10 km. Apart from free space attenuation the 60 GHz signal is attenuated by atmospheric gases such as oxygen and water vapor. Furthermore the 60 GHz spectrum is highly susceptible to rain attenuation which may exceed up to 40 dB/km [5][6].

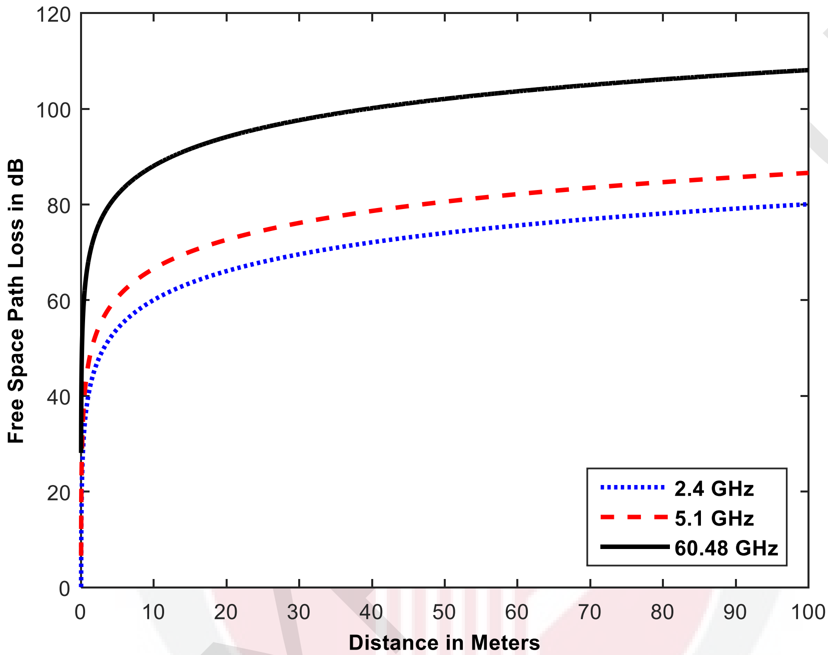



**Figure 1.4: Free space path loss of 2.4, 5 and 60 GHz RF signal[5][6]**

The spectrum also suffers from high penetration loss across the walls as demonstrated in Figure 1.5 limiting the coverage inside a room[4].

Therefore, to enhance the coverage distance and to mitigate the challenges faced by conventional electronics in generation of 60 GHz millimeter wave, a mixed architecture of Radio over Fiber (RoF) is adopted widely. The RoF architecture that uses Mach Zehnder Modulator (MZM) for mm-wave generation dominates several other techniques such as direct modulation and optical heterodyning. Several MZM based RoF architecture that mitigates the insertion loss, power consumption, and dispersion effects are proposed by researchers[7]. However, with data transmission formats such as Orthogonal Frequency Division Multiplexing (OFDM) and Code Division Multiple Access (CDMA), adopted to achieve multi-gigabit transmission the system becomes sensitive to nonlinear distortions induced by MZM. Digital Predistortion (DPD), a highly efficient, highly flexible low cost linearization technique [8] is adopted to mitigate the MZM nonlinearity in RoF and allows the use of MZM with high efficiency in system.

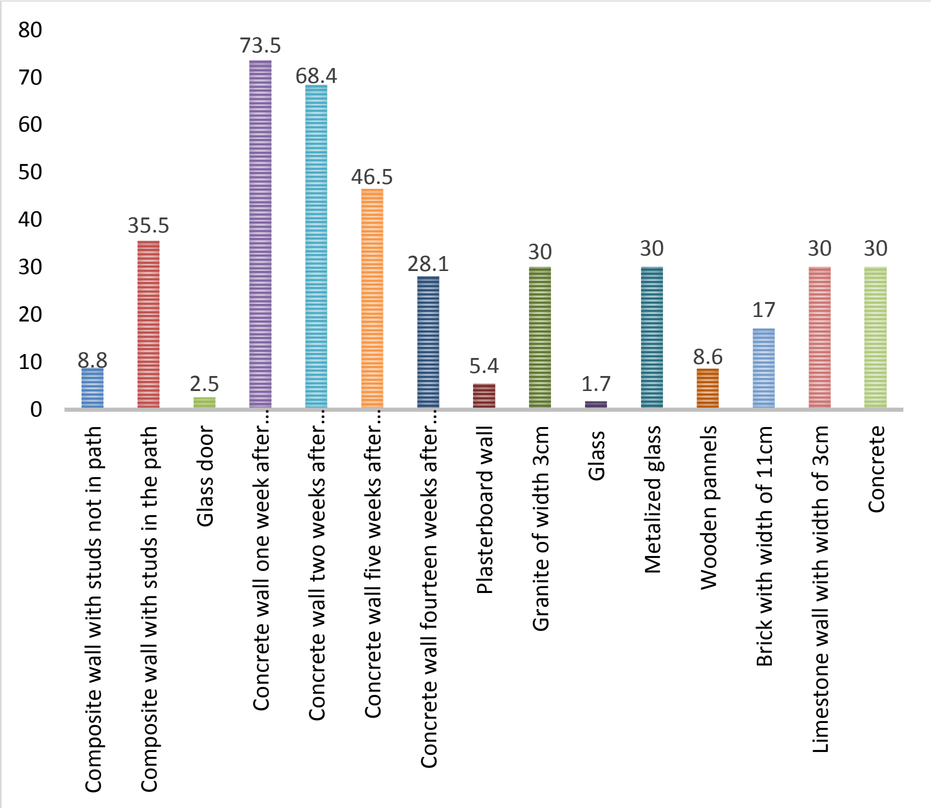



**Figure 1.5: Penetration loss(dB) of 60 GHz passing through standard wall of different materials [4]**

## 1.2. Research Problems

MZM is the heart of RoF system that translates the RF signal to optical signal. Several schemes of mm-wave generation using MZM, based on double sideband (DSB), single sideband (SSB) and double sideband with suppressed carrier (DSBSC) have been demonstrated for multi-gigabit optical up-conversion RoF system, among which DSBSC have the advantage of best receiver sensitivity, smaller bandwidth and low loss[9]. However, independent of the modulation adopted the MZM exhibits a nonlinear electro-optic (E/O) conversion response [9]–[13]. The significant problem dealt in this research is to mitigate the MZM nonlinearity in mm-wave RoF for multi-gigabit transmission using digital predistortion technique. The critical part of digital predistortion is realizing a non-linear model of MZM. Several behavioral model, that have been proposed for power amplifier linearization have been adopted for linearization of MZM nonlinearity. The fundamental model that is based on Volterra series, suffers high complexity in computing the Volterra kernels, with increase in nonlinearity and memory length of the device under test and therefore is limited to devices with low nonlinearity and fading memory [14]. Thereafter several algorithms based on Volterra model with reduced complexity is proposed namely Memory Polynomial (MP) model, Envelop Memory Polynomial (EMP) model, Orthogonal Memory Polynomial (OMP) model and Generalized Memory Polynomial (GMP) model. Further two box model such as Wiener, Hammerstein, augmented Hammerstein and three box model as the combination of Wiener and Hammerstein models are proposed [8], [14]–[19]. In this thesis an I/Q channel separated Coherent Optical Orthogonal Frequency Division Multiplexing (CO-OFDM) transmission system at 60 GHz that employs mm-wave generation by optical frequency up-conversion using cascaded Dual Drive MZM (DDMZM) and Dual Parallel (DPMZM) architecture is proposed. Furthermore, an adaptive predistortion with reduced number of coefficients and computational complexity for reduction of MZM nonlinearity is proposed. The proposed RoF system has shown better results compared to the other proposed techniques such as frequency quadrupling and frequency sextupling. As well the adaptive digital predistortion based on memory polynomial model has shown a significant improvement in the reduction of MZM nonlinearity of RoF system compared to other DPD proposed in literatures.

## 1.3. Research Aim and Objectives

The aim of the research is to model a mm-wave RoF system for multi-gigabit wireless transmission and to devise a predistortion technique for reduction of MZM nonlinearity in millimeter wave RoF system.

The specific objectives that pave way to achieve the aim are to;

- Design a robust millimeter wave radio over fiber system for multi-gigabit wireless transmission
- Analyze the dispersive and non-linear effects of MZM in RoF system at mm-wave frequency.
- Devise, analyze and optimize a digital predistortion technique for reduction of MZM non-linearity in the modeled mm-wave RoF system.

## 1.4. Scope and Limitations

The scope of the research is to mitigate the MZM nonlinearity in mm-wave RoF system using adaptive digital predistortion. The research is focused to mm-wave RoF system at 60GHz. Therefore, the research primarily concentrates on the following questions;

1. How to generate a 60 GHz mm-wave signal?

Several mm-wave generation techniques have been reported in literature that mitigates the insertion loss, power consumption, and dispersion effects. However, the effect of MZM nonlinearity is not considered in most of the design. This thesis proposes an I/Q channel separated coherent optical OFDM transmission system at 60 GHz, that employs mm-wave generation by optical frequency up-conversion using cascaded dual drive MZM and dual parallel MZM architecture at the transmitter and with coherent optical detection at the remote antenna unit. The proposed system suppresses unwanted harmonics with I/Q channel separation.

2. How to reduce the nonlinearity of MZM in the mm-wave RoF transmission system?

This thesis further analyses the modulator nonlinearity and proposes an adaptive DPD to mitigate the MZM modulator nonlinearity. The proposed adaptive digital pre-distortion is based on memory polynomial (MP) DPD model with indirect coefficient learning architecture. The coefficient learning is performed using the MP-DPD model combined with coefficient calculation subsystem that is based on recursive prediction error method algorithm.

Limitations: The mm-wave RoF system is simulated using Optisystem that mimics the real time system and is not analyzed with prototype. The RoF system performance in terms of EVM and BER is improved using a cascade architecture of DD and DP MZM which increase the cost of the system which implies a cost performance trade-off.

## 1.5. Scheme of Proposed Work

The research is carried out as theoretical and simulation modelling of two major parts of the mm-wave RoF system design, namely mm-wave RoF system and adaptive digital predistortion. The pathway to achieve the objective of the research is indicated in Figure 1.6. Focusing on the mitigation of MZM nonlinearity in mm-wave RoF system using DPD the research is carried out in two main domains of technology, namely the design of a robust mm-wave RoF system and the adaptive DPD that reduces the MZM nonlinearity in the designed mm-wave RoF system. An extensive literature review is carried out to investigate the existing techniques in RoF system design. MZM based RoF system identified as a dominant technique in mm-wave generation, a RoF system based on cascaded DD-MZM and DP-MZM is proposed and simulated using Optisystem.

Alongside with the RoF system, the existing DPD are investigated, and an adaptive digital predistortion technique is designed and simulated for the reduction of MZM nonlinearity in the proposed RoF system. The simulation results are further compared with other DPD techniques reported in literatures. The designed system is simulated for varied power and distance and evaluated based on the error vector magnitude (EVM), bit error rate (BER) and adjacent channel leakage ratio (ACLR).

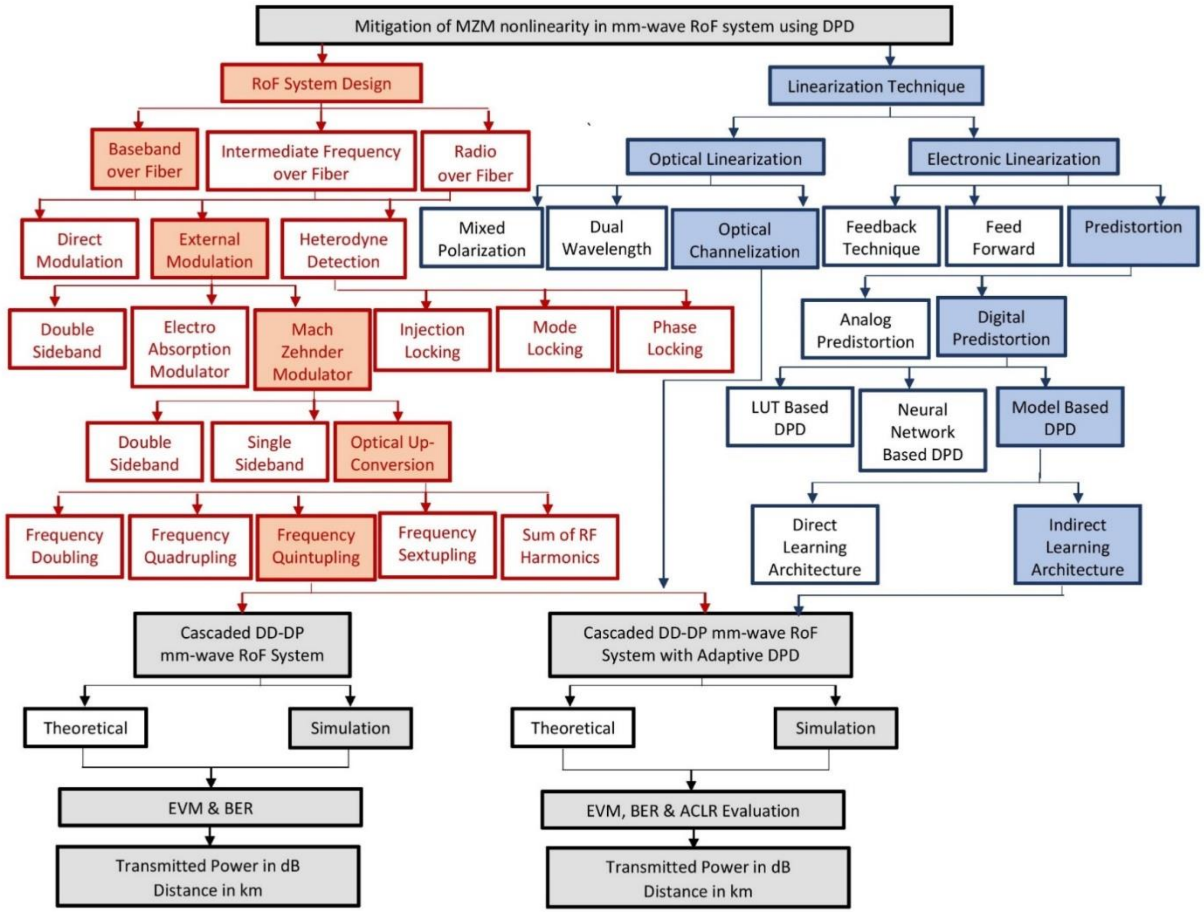



**Figure 1.6: Scheme of the proposed work**

## 1.6. Thesis Outline

The PhD thesis extends over several areas of 60 GHz mm-wave Radio over Fiber, specifically from problems statement that indicate the requirement of a digital predistortion for reduction of MZM nonlinearity to the simulation of adaptive digital predistortion linearizer.

Chapter 1 describes the motivation of work, problem statement and research objectives.

In Chapter 2 an extensive literature review of mm-wave RoF architectures is reported followed by review of the effect of MZM modulator linear dispersion and nonlinearity on the performance of mm-wave RoF transmission system. Furthermore, an elaborate review of digital predistortion techniques adopted for the reduction of MZM nonlinearity in RoF system is reported.

In Chapter 3 a new I/Q channel separated CO-OFDM transmission system at 60 GHz that employs mm-wave generation by optical frequency up-conversion using cascaded DD-DP MZM architecture is proposed. The system is simulated with Optisystem 12.

In Chapter 4 a new adaptive baseband digital predistortion is proposed. The proposed adaptive digital pre-distortion is based on memory polynomial DPD model with indirect learning architecture. The coefficient learning is performed using the MP-DPD model of the proposed RoF system combined with coefficient calculation subsystem based on recursive prediction error method (RPEM). Finally, the RoF system with DPD and without DPD is simulated using MATLAB and Simulink interfaced with Optisystem.

Chapter 5 summarizes the results highlighting the main contributions of the research and suggests scope for the future works.

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