OPTICAL MILLIMETER WAVES SIGNAL GENERATION USING STIMULATED BRILLOUIN SCATTERING APPROACH FOR RADIO OVER FIBRE SYSTEM

by

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LIST OF ABBREVIATIONS

BER	Bit Error Rate
BOF	Bessel Optical filter
BS	Base Station
CW	Continuous Wave
CS	Central Station
DSB	Double Side-Band
EDFA	Erbium Doped Fibre Amplifier
EAM	ElectroAbsorption Modulator
FP	Fabry-Perot
FWM	Four Wave Mixing
Ghz	Gigahertz
KLM	Kerr-lens mode-locking
LED	Light Emitting Diode
mm-waves	Millimeter waves
MZM	Mach-Zehnder Modulator
NRZ	Non-Return to Zero
PRBS	Pseudo Random Bit Sequence
RoF	Radio Over Fibre
RZ	Return to Zero
SSB	Single Side-Band
SBS	Stimulated Brillouin Scattering
SRS	Stimulated Raman Scattering
SPM	Self-Phase Modulation
XPM	Cross-Phase Modulation

LIST OF SYMBOLS

fc	The optical carrier frequency
f_{mm}	Generated frequency of millimeter waves
n	The refractive index of the core
n	Number of sideband
λ_p	Wavelength of the incident pump
V_A	Sound velocity inside the material

Generasi Isyarat Gelombang Milimeter Optik Mengunakan Pendekatan Penyerak Brillouin Untuk Sistem Gentian Melalui Radio

ABSTRAK

Gelombang milimeter adalah penting untuk mengatasi masalah kesesakan spekulasi pada jarak frekuensi rendah dan untuk mengiktiraf sistem prestasi gentian melalui radio (RoF) kerana jalur lebar yang besar, kos rendah dan pengecilan rendah. Dalam tesis ini, satu kaedah alternatif dicadangkan ialah Penyerakan Brillouin (SBS) dalam penjanaan signal (mm-waves) gelombang optik yang berdasarkan sistem (RoF). Pendekatan ini telah dibandingkan dengan modulasi intensiti optik iaitu Band Sisi-Berganda (DSB) dan Band Sisi-tunggal (SSB) bagi memastikan peningkatan dalam penjanaan isyarat. Kajian terdahulu mendedahkan bahawa kelemahan utama bagi prestasi sistem skim modulasi luaran adalah disebabkan penyebaran dan kesan pudar dalam penjanaan isyarat optik bersama menghasilkan Kadar Kesalahan Bit (BER) yang tinggi apabila melibatkan jarak gentian panjang. Sistem yang dicadangkan terdiri daripada stesen pusat (CS) dan stesen pengkalan (BS), dimana SBS berjaya dijana oleh perisian Optisystem dengan isyarat 40 Ghz (mm-waves) menggunakan laser gelombang berterusan dalam gentian optik melalui Mach Zehnder Modulator (MZM), dengan Penguat Gentian Erbium-Doped (EDFA) pam laser, pengedar optik, penapis optik dan photodiode. Beberapa kriteria prestasi yang telah diukur untuk penjanaan isyarat mm-waves untuk gelombang optik adalah berdasarkan kuasa yang diterima, kuasa input, penghantaran jarak jauh, kebarangkalian kesilapan dan rajah mata. Hasil simulasi didapati bahawa sistem DSB+SBS menunjukan prestasi yang paling bagus daripada kesemua skim, iaitu DSB+SBS adalah lebik baik berbanding SSB, iaitu menghantar isyarat ketara dengan jarak gentian pada 85-km dan 28% menambahbaik sebelum mencapai ambang sistem komunikasi optik iaitu 10^{-9}. Analisis purata kuasa yang diterima pada 50-km untuk DSB+SBS dan SSB+SBS adalah -16.94 dBm dan -15.71 dBm. Gambar rajah mata dan lengkung BER telah dinilai pada 50-km yang mana DSB+SBS mencapai BER yang paling rendah iaitu 10^{-77} berbanding SSB+SBS iaitu 10^{-60}, dan modulasi DSB menunujukan bacaan ralat kerana ia berupaya menjana signal pada jarak yang dekat. Selain itu, pengesahan hasil teoretikal dan simulasi juga telah dibentangkan. Oleh itu, teknik DSB+SBS mampu untuk menambaikan penjanaan signal mm-waves dengan kebarangkalian ralat yang rendah pada jarak yang jauh.

Optical Millimeter Waves Signal Generation using Stimulated Brillouin Scattering Approach for Radio Over Fibre System

ABSTRACT

Mm-waves are vital to overcome the issues of spectral congestion at low-frequency ranges and to acknowledge the performance of the Radio-over-Fibre (RoF) systems due to their large bandwidth, low cost and low attenuation. In this thesis, an alternative method is proposed, which used Stimulated Brillouin Scattering (SBS) in the generation of optical mm-waves signals based on the RoF system. The proposed approach is compared with optical intensity modulations, such as Double-Side Band (DSB) and Single-Side Band (SSB), to determine the enhancement in signal generation, Bit Error Rate, power received and eye diagram. Previous studies have confirm that the decrease on the performance of the external modulation scheme system is due to the dispersion and fading effect in optical signal generation with a high Bit Error Rate (BER) at long fibre distances, larger insertion loss and low frequency response. The proposed system consists of Central Station (CS) and Base Station (BS), where SBS is successfully generated by Optisystem software with 40 Ghz mm-waves signal by utilising a Continuous Wave (CW) laser in a single mode fibre (SMF) via Mach Zehnder Modulator (MZM) with Erbium-Doped Fibre Amplifier (EDFA), optical circulator, optical filter and photodiode. Several performance criteria measured for the signal generation of optical mm waves are based on received power, input power, transmission distance, error probability and eye diagram. The simulation results affirm that the DSB+SBS system exhibits the best performance amongst the schemes, in which DSB+SBS is superior compared with SSB, which significantly transmit the signal with fibre distance at 85-km and 28% improved before reaching the threshold of optical communication system of 10^{-9}. The average received power at 50-km for DSB+SBS and SSB+SBS are −16.94 dBm and −15.71 dBm, respectively. Further, the plot of eye diagram and BER curve is evaluated at 50-km distance where DSB+SBS manages to receive the lowest BER of 10^{-77} compared with the SSB+SBS of 10^{-60}, and DSB modulation shows an error floor because it generates signal at a low distance range. Moreover, the validation of theoretical and simulation result have also been presented. Thus, the DSB+SBS technique is capable of enhancing the generated optical mm-waves signals with low error probability at long distances.

CHAPTER 1 : INTRODUCTION

1.1 Research Background

The field of optical and wireless communication has a substantial progress in the past decades. The underlying driving force in this development is because of the expanding demand for broadband access and multimedia services. The current consumers demand for cost effective and reliable system of communication which can support their requirement anywhere and anytime instead of relying on the fundamental technology. Therefore, broadband radio connection has turned out to be predominant in the present systems of communication. In addition, there is an increase of new wireless subscribers and though there is limited radio spectrum which demand considerable capacities. To meet the rising demands, there should be migration of the overcrowded low-frequency spectrum to the high-frequency spectrum so that the radio frequency to mm-waves carriers contain the radio networks flexibility. These conditions result to the discussion on the accessibility of fibre-based wireless scheme through radio over fibre (RoF) technology.

Mm-waves can support high data bandwidth and have the potential as future data carriers. The research on photonic technologies has attracted considerable attention for the distribution of mm-waves from one central station to many base stations via optical fibre links to ease system complexity. Meanwhile, RoF is a hybrid system with a fibre optic link and free space radio path (Rashidi, Aljunid, Ghani , 2014). Few techniques for optical generation of mm-waves, such as direct modulation, external modulation and

nonlinear optic, have been presented in the past works. Moreover, RoF is a promising technique that provides broadband wireless access services in the upcoming optical-wireless networks, and optical mm-waves generation is a key technique used to realise low cost and high transmission performance in RoF systems (Bahrami, Ng, Ghassemlooy, & Qiao, 2011).

This study offers an alternative method for the technique mentioned above, that only applies the standard elements of optical telecommunications. Moreover, the suggested method depends on the production of the sidebands of a Continuous Wave (CW) laser resulting from optical modulator the nonlinear modulation, that depends on Stimulated Brillouin Scattering (SBS) in the optical fibre.

1.2 Problem Statement

The RoF system has attracted worldwide attention in delivering microwave and mm-waves signal and directly distributes radio waveforms from a Central Station (CS) to a Base Station (BS) through optical fibres. The rapidly increasing demand for high data rates in communication systems requires new frequency bands. In addition, the range of mm-waves has high potential because they can support high data bandwidth. Long-haul optics limits the development of RoF systems, and long haul refers to the transmission of visible light signals over optical fibre cables at long distances. Further, optical signal loss increases with the increase of transmission links. By contrast, the power density of the signal decreases when it propagates away from the transmitter, which makes detecting the waves difficult for a receiver.

Numerous studies have been carried out on the transmission and generation of optical mm-waves in the recent few years, for example external modulation, direct modulation, and optical heterodyne (Shams & Zhao, 2013); (Simonis & Purchase, 1990); (Kuri, Kitayama, & Member, 1999). However, these methods have several limitations such as low frequency response (direct modulation), larger insertion loss (external modulation), signal quality relies on two laser light waves (optical heterodyne).

For the technique of external intensity modulation, Optical Carrier Suppression (OCS), Single-Sideband (SSB), and Double-Sideband (DSB) are the method suitable for the production high-frequency scalability and responses even though they cannot stand the dominant impacts of dispersion in the transmission of radio frequency signals. For long distance of transmission, the produced DSB signal is inappropriate because of the fading effect, and OCS and SSB need a double arm Mach–Zehnder modulator (MZM) to control the optical source. Furthermore, the OCS mm-waves signal production (Al-shareefi, Hassan, Malek, Ngah, & Abbas, 2014) depends on the two parallel dual-drive MZMs. Though, there is need for a complex framework, and the produced mm-waves generate a high Bit Error Rate (BER) of 10^{-12} at 60-km distance of transmission.

In this study, an alternative technique is presented to enhance the signal generation in terms of BER, received power and distance delivery by utilising the SBS. Moreover, the SBS technique is experimentally demonstrated, and the performances of optical mm-waves signal generation based on optical intensity modulation scheme using SSB and DSB modulation are compared.

1.3 Objectives

The main goals of this research are as follows:

(i) To design the Double-Side Band (DSB) and Single-Side Band (SSB) modulation with Stimulated Brillouin Scattering (SBS) approach for optical generation of mm-waves signal utilize Optisystem software.

(ii) To investigate the suitability of the DSB+SBS and SSB+SBS method for optical generation of mm-waves signal by 40 GHz.

(iii) To evaluate the performance of propose DSB+SBS and SSB+SBS in terms of distance, optical power and error probability.

1.4 Scope of the Project

The purpose of this project is to enhance the design of current optical mm-waves signal generation based on SBS method where several limitations of the system are identified and can be improved. In this project, it involves the study of RoF system elements that cover in central station, base station, optical fibre links and optical modulation. On the other hand, RoF links require network operator to enhance the performance due to continuous bandwidth demand and the system should be cost effective. In particular, this project which mainly focus on non-linear optical fibre scattering of SBS where typical DSB modulation and SSB modulation are been compared to analyse system performance via simulation.

1.5 Research Contributions

- A new design of DSB and SSB modulation using SBS approach for optical generation of mm-waves signal with enhanced performance.

- An analysis of the proposed technique was demonstrated through comparison with the existing DSB and SSB modulation by 40 GHz mm-waves signal based on signal distance, effective received power, Bit Error Rate (BER) and eye diagram results via simulation platform.

1.6 Thesis Outline

The thesis discusses the optical mm-waves signal generation by SBS based on RoF communications. Chapter 1 describes background mm-waves and RoF systems including research overview, problem statements, objectives, and scope of work.

Chapter 2 considers the theoretical principle of the components utilize in proposed system which include optical source, optical link, optical modulation, optical amplifier and optical filter. Previous study on related topic has been thoroughly discuss in here as to deal and improve the performance of the RoF system operating at optical mm-waves signal.

Chapter 3 provides a detailed procedure of data analysis for the system such as system design and parameters. The operating complete design of proposed system has been compared utilize OptiSystem software simulation as to investigate the performance.

Chapter 4 presents and demonstrate a comparison results based on compile data analysis. The factor which contribute to enhance the system which is important parameter are examined and highlight. Besides that, the chapter is concluded with discussion of performance evaluation of the modulation scheme.

Finally, Chapter 5 draws the thesis conclusion, highlight the main contribution and provides range of ideas for possible future research work to improve the optical communication system.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

This chapter will define the RoF system characteristics and advantages, components used in the proposed system such as optical source, fibre transmission link, optical modulation and optical amplifier and receiver which includes for generating the signal in mm-waves. Apart from that, a fundamental study of SBS applied in generating mm-waves signals are discussed here in details. In addition, a technique for optical mm-waves signal generation is described at the end of this chapter.

The research scope which focuses on the nonlinear scattering in optical fibre and development of proposed SSB+SBS and DSB+SBS method for optical mm-waves signal generation for radio over fibre are illustrated as in Figure 2.1. The performance of proposed system has been compared with former modulation techniques which are SSB and DSB modulation. Thus, the evaluation optical mm-waves based on RoF performance in terms of distance delivery, power received, eye diagram and BER by tuning several parameters such as input power, fibre distances, optical power, optical amplifier, pulse generator, bit rate, optical modulation, optical filter are made for proposed technique that interpret using simulation which apply real parameter application scenario.

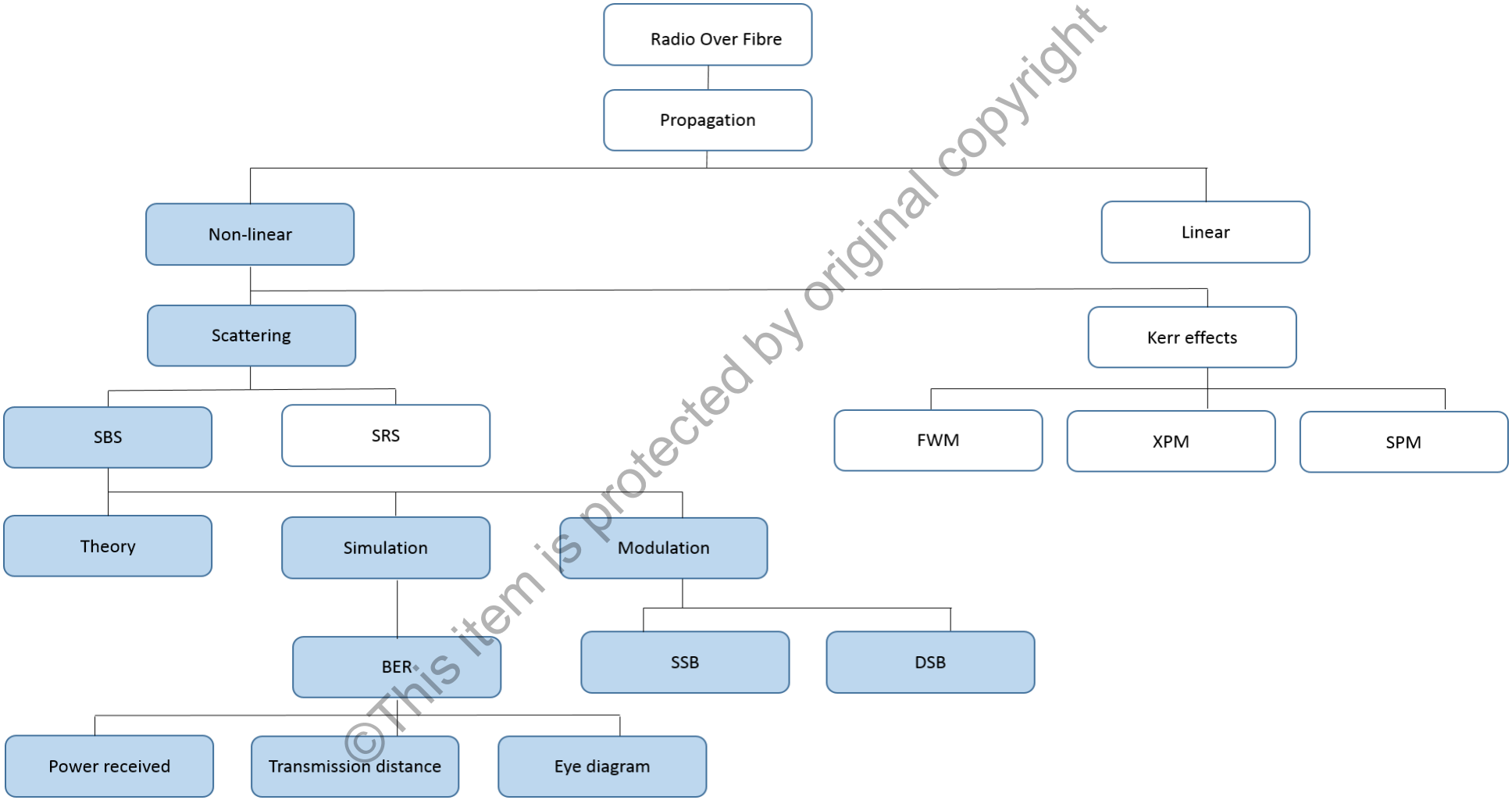

Figure 2.1 General scope model for the research work.

2.2 Radio over Fibre

One of the major access network solutions for future high-bandwidth wireless communication systems is based on optical fibre for the transmission of radio signals which is RoF. RoF is initially demonstrated for cell phone services or cordless in 1990 (Ogawa, Polifko, & Banba, 1992). In RoF, it uses highly linear optic fibre links to distribute RF signals between CS and BS. Meanwhile, the studies of RoF performance advancements have been done by researcher to examine the limitation and create new plan of it.

A RoF link shows in Figure 2.2 employs radio signals developed by laser lights which are then transported in an optical fibre medium. The radio frequency carrier signal is analogue in nature; therefore the laser modulation is also analogue. These signals are located at the CS and it is here that the majority of the activity like modulation, demodulation and routing occur. Additionally when frequency conversion occurs, it may result in furthermore modulation at the intermediate frequency or any other variant radio signal frequency. An analogue fibre optic link is composed of a bi-directional interface. This interface primarily contains a transmitter of an analogue laser and a receiver which is a photodiode situated at a remote antenna unit or BS. The remote antenna unit found at the radio processing unit paired with the analogue laser transmitter and the photodiode receiver. This implies that the central processing unit is connected with the remote antenna unit through one or more optical fibres.

There are many advantages that are inherent with using RoF communication technology. Besides being a cost-effective alternative for radio systems, other major advantages include resistance to electromagnetic interferences. The bandwidth of RoF is larger while attenuation is lower and the low-cost makes for a wide range of possibilities in application. To quote an example, wide-fidelity (Wi-Fi), radars and sensor networks (Rashidi, Aljunid, Anuar, Fadhil, & Ghani, 2014). In contrast to copper cables, optical fibres make for a lower installation cost and low maintenance costs and provide a higher capacity as well. Apart from transportation and mobility functions, RoF have the ability to carry out several other functions related to radio systems. Data modulation, signal processing and frequency conversion being some of these important operations.

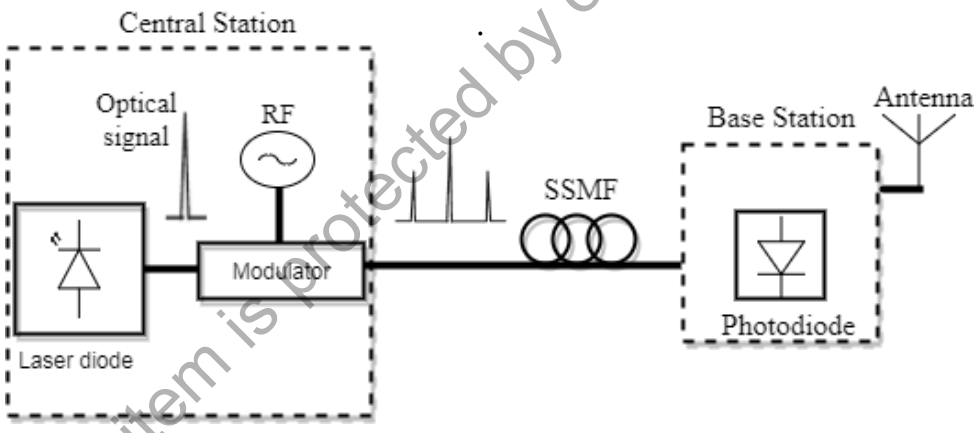

Figure 2.2 A generic schematic diagram of fibre-radio link for mm-waves signal generation.

2.3 Optical Kerr Effects

The terms linear and nonlinear, in optics, allude to intensity independent and intensity dependent phenomena respectively. The linear and nonlinear effects of the fibre influence the physical layer of the optical system. Any dielectric medium reacts nonlinearly to light affected by electromagnetic fields. Moreover, optical fibre react nonlinearly to light within the sight of electromagnetic fields. The change in the refractive index of the medium with optical intensity and inelastic scattering to nonlinear effects in optical fibre. The force reliance of the refractive index is in charge of the Kerr effect (Shoji, Hamaguchi, & Ogawa, 2002).

The Kerr effect is a nonlinear optical effect happening when intense light propagates in crystals and glasses. Its physical origin is a nonlinear polarization produced in the medium, which itself adjusts the engendering properties of the light.(Ramos, Member, Marti, Polo, & Member, 1998);(Wang, Chen, Zhang, & Zhou, 2015). Thus, the Kerr nonlinearity has three distinct effects which are Four-Wave Mixing (FWM), Cross-Phase Modulation (XPM) and Self-Phase Modulation (SPM).

(a) Four-Wave Mixing (FWM)

FWM procedure emerges because of the nonlinear reaction of bound electrons of a material to an applied optical field. The polarization initiated in the medium contains linear and the nonlinear terms. The extents of these terms are controlled by the nonlinear susceptibilities of different orders which FWM occurs because of third order nonlinear susceptibility (Wen, Wu, Li, Li, & Qiu, 2013).