FOUR WAVE MIXING NONLINEARITY EFFECT IN WAVELENGTH DIVISION MULTIPLEXING RADIO OVER FIBER SYSTEM

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DEDICATION

To my beloved late mother, may her soul rest in Paradise.

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ABSTRACT

The integration of wireless and optical networks is a potential solution for the increasing capacity and mobility as well as decreasing costs in the access networks. Optical networks are fast, robust and error free, however, there are nonlinearity obstacles preventing them from being perfect media. The performance of wavelength division multiplexing (WDM) in radio over fiber (RoF) systems is found to be strongly influenced by nonlinearity characteristics in side the fiber. The effect of four wave mixing (FWM) as one of the influential factors in the WDM for RoF has been studied here using Optisystem and Matlab. From the results obtained, it is found that the FWM effects have become significant at high optical power levels and have become even more significant when the capacity of the optical transmission line is increased, which has been done by either increasing the channel bit rate, and decreasing the channel spacing, or by the combination of both process. It is found that when the channel spacing is 0.1 nm, 0.2 nm and 0.5 nm the FWM power is respectively, becomes about -59 dBm, -61 dBm and -79 dBm. This result confirms that the fiber nonlinearities play decisive role in the WDM for RoF system. The simulation results obtained here are in reasonable agreement as compared with other numerical simulation results obtained, elsewhere, using different simulation tools.

ABSTRAK

Integrasi talian tanpa wayar dan rangkaian optik menjadi potensi kepada penyelesaian untuk peningkatan kapasiti dan mobiliti dan seterusnya mengurangkan kos capaian rangkaian. Rangkaian optik adalah pantas, berkesan, dan tidak mempunyai masalah. Namun begitu halangan '*nonlinearity*' menghalangnya menjadi media yang sempurna. Prestasi jarak gelombang pembahagi pemultipleksan (WDM) dalam radio melalui fiber (RoF) sistem amatlah dipengaruhi oleh ciri-ciri '*nonlinearity*' didalam fiber. Kesan '*four wave mixing*' (FWM) yang menjadi salah satu faktor berpengaruh dalam WDM untuk RoF telah dikaji menggunakan Optisystem dan Matlab. Keputusan yang diperolehi mendapati bahawa kesan FWM menjadi penting pada optik kuasa aras tinggi dan sangat penting apabila kapasiti talian penghantaraan optik bertambah, sama ada dengan meningkatkan kadar bit saluran, mengurangkan penjarakan saluran, ataupun kedua-duanya sekali. Ianya didapati bahawa apabila penjarakan saluran adalah 0.1 nm, 0.2 nm, dan 0.5 nm kuasa FWM masing-masing adalah lebih kurang –59 dBm, -61 dBm, dan –79 dBm. Keputusan ini mengesahkan bahawa '*fiber nonlinearities*' memainkan peranan utama dalam WDM untuk sistem RoF. Keputusan simulasi berangka yang diperolehi juga bersamaan dengan keputusan model analisis yang diperolehi melalui Matlab.

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LIST OF ABBREVIATIONS

RoF	-	Radio over Fiber
SPM	-	Self Phase Modulation
XPM	-	Cross Phase Modulation
FWM	-	Four Wave Mixing
SRS	-	Stimulated Raman Scattering
SBS	-	Stimulated Brillouin Scattering
WDM	-	Wavelength Division Multiplexing
DWDM	-	Dense Wavelength Division Multiplexing
SMF	-	Single Mode Fiber
nm	-	nanometer
E/O	-	Electrical-To-Optical Converter
O/E	-	Optical - To Electrical- Converter
RF	-	Radio Frequency
IF	-	Intermediate Frequency
CW	-	Continuous Wave
RAU	-	Radio Antenna Unit
THz	-	Teri hertz
OTDM	-	Optical Time Division Multiplexing
SCM	-	Sub-Carrier Multiplexing
EMI	-	ElectroMagnetic Interference
IM-DD	-	Intensity Modulation and Direct Detection
OFM	-	Optical Frequency Multiplication
GSM	-	Global System for Mobile communication
MVDS	-	Multipoint Video Distribution Service
MBS	-	Mobile Broadband System

GHz	-	Gigahertz
RHD	-	Remote Heterodyne Detection
TDM	-	Time Division Multiplexing
OADM	-	Optical Add-Drop Multiplexer
LED	-	Light Emitting Diode
GVD	-	Group velocity dispersion
ITU	-	International Telecommunication Union
MUX	-	Multiplexer
NDSF	-	Non Dispersion Shifted Fiber
PMD	-	Polarization Mode Dispersion
NRZ	-	Non-Return to zero

LIST OF SYMBOLS

A	-	Pulse amplitude
A_{eff}	-	Effective area of optical fiber
c	-	Speed of light
c_o	-	Speed of light in vacuum
D	-	Dispersion parameter
d_{ijk}	-	Degeneracy factor
$\mathbf{E}$	-	Electric field, vector
E	-	Electric field, scalar
f	-	Frequency
I	-	Intensity
L	-	Length
L_{eff}	-	Effective length
n	-	Refractive index
n_o	-	Wavelength dependent refractive index
n_2	-	Nonlinear refractive index
n_2/A_{eff}	-	Nonlinear coefficient
$\mathbf{P}$	-	Total polarization, vector
P	-	Power
p_i	-	Input power
r	-	Radius
t	-	Time
z	-	Distance
α	-	Attenuation constant [1/m]
α_{dB}	-	Attenuation constant [db/km]
β_i	-	Propagation constant of the mode i
γ	-	Nonlinear parameter

ε_o	-	Vacuum permittivity
λ	-	Wavelength
λ_o	-	Center wavelength
τ	-	Normalized time constant
ω_i	-	Angular frequency
$\chi^{(j)}$	-	j^{th} order susceptibility

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In the past, dating back to the beginning of the human civilization, communication was done through signals, voice or primitive forms of writing and gradually developed to use signaling lamps, flags, and other semaphore tools.

As time passed by, the need for communication through distances, to pass information from one place to another, became necessary and the invention of telegraphy brought the world into the electrical-communication. The major revolution that affected the world however was the invention of the telephone in 1876. This event has drastically transformed the development of communication technology. Today's long distance communication has the ability to transmit and receive a large amount of information in a short period of time.

Since the development of the first-generation of optical fiber communication systems in the early 80's [4], the optical fiber communication technology has developed fast to achieve larger transmission capacity and longer transmission distance, to satisfy the increased demand of computer network. Since the demand on the increasing system and network capacity is expected, more bandwidth is needed because of the high data rates application, such as video conference and real-time image transmission, and also to achieve affordable communication for everyone, at anytime and place [1]. The communication capabilities allow not only human to human communication and contact, but also human to machine and machine to machine interaction. The communication will allow our visual, audio, and touch sense, to be contacted as a virtual 3-D presence [3].

To keep up with the capacity increasing requirement, new devices and technologies with high bandwidth are greatly needed by using both electronic and optical technologies together to produce a new term Radio over Fiber (RoF). The progress made so far has been impressive, where information rate at 1 terabits/s can be handled by a single fiber [5].

RoF is a technology used to distribute RF signals over analog optical links. In such RoF systems, broadband microwave data signals are modulated onto an optical carrier at a central location, and then transported to remote sites using optical fiber. The base-stations then transmit the RF signals over small areas using microwave antennas and. Such a technology is expected to play an important role in present and future wireless networks since it provides an end user with a truly broadband access to the network while guaranteeing the increasing requirement for mobility. In addition, since it enables the generation of millimeter-wave signals with excellent properties, and makes effective use of the broad bandwidth and low transmission loss characteristics of optical fibers, it is a very attractive, cost-effective and flexible system configuration.

1.2 Problem Background

Normally light waves or photons transmitted through RoF have little interaction with each other, and are not changed by their passage through the fiber (except for absorption and scattering). However, there are exceptions arising from the interactions between light waves and the material transmitting them, which can affect optical signals in RoF. These processes generally are called nonlinear effects because their strength typically depends on the square (or some higher power) of intensity rather than simply on the amount of light present. This means that nonlinear such as self phase modulation (SPM), cross phase modulation (XPM), four wave mixing (FWM), stimulated raman scattering (SRS), and stimulated brillouin scattering effects (SBS) are weak at low powers, but can become much stronger when light reaches high intensities [7]. This can occur either when the power is increased, or when it is concentrated in a small area-such as the core of an optical fiber. Nonlinear optical devices have become common in RoF applications, such as to convert the output of lasers to shorter wavelengths by doubling the frequency. The nonlinearities in RoF are small, but they accumulate as light passes through many kilometers of fiber. Nonlinear effects are comparatively small in optical fibers transmitting a single optical channel. They become much larger when wavelength-division multiplexing (WDM) packs many channels into a single fiber [9].

WDM puts many closely spaced wavelengths into the same fiber where they can interact with one another. It also multiplies the total power in the fiber. A single-channel system may carry powers of 3 milliwatts near the transmitter. DWDM multiplies the total power by the number of channels, so a 40-channel system carries 120 mW. That's a total of 2 mW per square micrometer-or 200,000 watts per square centimeter [11]. Several nonlinear effects are potentially important in RoF, although some have produce more troublesome than others. Some occur in systems carrying only a single optical channel, but others can occur only in multichannel systems.

1.3 Problem Statement

The rapid development of the wireless communication networks has increased the need of the optical signal processing. The link lengths have grown to thousands of kilometers without need to convert optical signals back and forth to electric form, and the transmission speeds of terabits per second are feasible today [5]. This ever-growing demand for the high speed communication has forced to use higher bit rates as well as transmission powers.

Nonlinear effects on communication have become significant at high optical power levels and have become even more important since the development of erbium-doped fiber amplifier (EFDA) and DWDM systems. By increasing the capacity of the optical transmission line, which can be done by increasing channel bit rate, decreasing channel spacing or the combination of both, the fiber nonlinearities come to play even more decisive role.

The origin of the nonlinearities is the refractive index of the optical fiber, which is varies with the intensity of the optical signal. This intensity-dependent component of the refractive index includes several nonlinear effects, such as SPM, XPM, FWM, SRS, and SBS, and becomes significant when high powers are used. Although the individual power in each channel may be below the level needed to produce nonlinearities, the total power summed over all channels can quickly become significant. The combination of high total optical power and large number of channels at closely spaced wavelengths is a source for many kinds of nonlinear interactions.

Form the above-mentioned reasons, this study is aimed to gain insight into nonlinear effect caused specifically by FWM in the WDM for RoF system and measure the coefficient behind these nonlinear effects. Nonlinear coefficient of the RoF may become an important parameter, when new optical long-haul transmission lines and networks are being deployed.

1.4 Objective of the Project

The main objective of this project is to evaluate the FWM in WDM for RoF technology, in order to calculate the impairments associated with long-distance high-bit rate optical fiber communication systems. In order to achieve the objective, optisystem and matlab programming software will be used respectively in the numerical simulation and the analytical modelling will be verified through comparison with optisystem simulation.

1.5 Scope of the Project

To study the efficiency of the FWM in WDM for RoF optical network, two approaches were followed in this project. The first approach is the numerical simulation using Optisystem software which almost replicates a real system. The second aproach is the analytical modeling, which is simple and faster to analyze its performance. MATLAB programming is used to implement the analytical model. To verify the analytical system, a comparison is made with the Optisystem software. Since Routing and wavelength assignment algorithm (RWA) needs to set up the path immediately to reduce network delays, the analytical model developed in this project can be used to calculate the impairments fast enough so that the routing decisions can be made efficiently, to achieve optimal systems.

1.6 Organization of the Project

Chapter 1 provides the introduction to this project where brief background of the study problem and to the statement of the problem. Followed by the objective, and the scope of the study. Chapter 2 reviews the literature, which includes introduction to the RoF, the benefits, and applications of the Radio over Fiber Technology in both satellite and mobile radio communications. In addition various types of RoF Multiplexing Techniques, such as Sub carrier multiplexing and wavelength division multiplexing, have also bee covered. Chapter 3 provides information about the fiber characteristics, and the non linear effects such as SPM, FWM, SBS, SRS, and XPM.

Chapter 4 describes the methodological processes by showing detailed diagram of the methods implemented as well as highlighting briefly the steps those have been followed to achieve the objective of this project. Chapter 5 presents the results derived from the methods explained where some analyses and simulations were done based on the FWM effects. Finally the conclusions of the study, as well as some suggestions for future work were summed up in Chapter 6.