ADAPTIVE CONTROL OF FEED-FORWARD LINEARIZATION FOR LASER NONLINEARITY COMPENSATION SYSTEM

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Dedicated to…

My beloved Family and Friends

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ABSTRACT

Radio over Fiber technology (RoF) is a promising solution to the next generation wireless access network because of its ability to transmit high capacity data and to be cost effective. However, RoF systems are analog systems which are sensitive to noise and distortions. The RoF links need to have good linearity in order to avoid nonlinear distortions. The primary limitation on the performance of the optical transceiver in RoF links is the nonlinearity of the laser source in the transmitter. The laser source nonlinearities generate intermodulation distortion products which can severely degrade the performance of the RoF links. Hence, various linearization schemes are proposed to compensate the nonlinearity of the laser source, such as feedback, predistortion, and feed-forward. Among the linearization technique, feed-forward linearization is considered as the most effective due to its ability to provide broadband distortion reduction at high frequencies, and reduction in all order of distortions regardless of the laser nonlinear characteristics. However, feed-forward linearization is a relatively sensitive scheme, where its performance is highly influenced by changing operating conditions. Hence, the feed-forward linearization system needs to be incorporated with adaptive properties in order to achieve optimization in linearization for more practical implementations. In this thesis, a laser transmitter feed-forward linearization system has been modeled in the commercial software OptiSystem 9.0. The laser transmitter feed-forward linearization system is integrated with the proposed adaptive control system developed in MATLAB through Visual Basic scripting. The results of the co-simulations have achieved significant reductions of over 20 dBm in the third-order intermodulation distortion products for operating frequencies from 5.1 to 5.8 GHz.

ABSTRAK

Teknologi isyarat radio melalui gentian (RoF) merupakan satu penyelesaian yang menjanjikan kepada rangkaian capaian wayarles untuk generasi akan datang. Ini kerana dijangkakan ia mampu untuk menghantar data yang berkapasiti tinggi dan juga keberkesanan dari segi kos pelaksanaan. Walau bagaimanapun, semua sistem RoF ialah analog dan mereka bersifat sensitif terhadap herotan dan hingar. Pautan RoF memerlukan kelinearan yang baik untuk mengelakkan herotan tak linear. Penghalang utama kepada prestasi penghantar-terima optik dalam pautan RoF ialah ketaklinearan sumber laser di pemancar. Ketaklinearan sumber laser menjana keluaran herotan saling modulatan yang boleh merendahkan prestasi pautan RoF dengan tinggi. Oleh itu, pelbagai jenis skim pelinearan telah diwujudkan untuk memampas ketaklinearan sumber laser; antaranya termasuklah teknik suap balik, praherotan, dan suap depan. Antara teknik-teknik pelinearan tersebut, pelinearan suap depan dianggap teknik yang paling efektif oleh sebab keupayaannya untuk membawa pengurangan herotan jalur lebar pada frekuensi tinggi dan pengurangan herotan dari semua tertib tanpa mengira ciri tak linear laser. Akan tetapi, pelinearan suap depan merupakan satu kaedah yang agak sensitif dan prestasinya sangat terpengaruh oleh perubahan keadaan operasi. Oleh itu, sistem pelinearan suap depan perlu dibangunkan dengan sifat ubah suai untuk mencapai pengoptimuman dalam pelinearan bagi pelaksanaan yang lebih praktik. Pada tesis ini satu sistem pelinearan suap depan pemancar laser telah direkabentuk menggunakan perisian simulasi komersial OptiSystem 9.0. Sistem pelinearan suap depan pemancar laser tersebut digabungkan dengan satu sistem kawalan ubah suai yang dibina menggunakan MATLAB melalui penskripan Visual Basic. Hasil simulasi bersama tersebut telah mencapai pengurangan ketara yang melebihi 20 dBm terhadap keluaran herotan saling modulatan tertib ketiga untuk frekuensi operasi antara 5.1 ke 5.8 GHz.

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LIST OF SYMBOLS

g	-	Optical Gain Coefficient
I_a	-	Applied Modulation Current
I_0	-	Laser Bias Current
I_{th}	-	Laser Threshold Current
$i(t)$	-	Time Varying Modulation Current
m	-	Optical Modulation Depth
N	-	Carrier Density
N_0	-	Carrier Density for Transparency
O_C	-	Peak Photon Density for Optical Carrier
P	-	Optical Power
P_0	-	Average Optical Power
Q	-	Photon Density
Q_0	-	Steady State Photon Density
$q(t)$	-	Time Varying Photon Density
V'	-	Volume of Active Region times Electron Charge
β	-	Probability of Spontaneous Emission into Lasing Mode
Γ	-	Optical Confinement Factor
ε	-	gain compression parameter
τ_n	-	Recombination Lifetime of Carriers
τ_p	-	Photon Lifetime

LIST OF ABBREVIATIONS

AM	-	Amplitude Modulation
BS	-	Base Station
CATV	-	Community-antenna Television
CS	-	Central Control Station
DFB	-	Distribution Feedback
DR	-	Dynamic Range
EMI	-	Electromagnetic Interference
EVM	-	Error Vector Magnitude
FFT	-	Fast Fourier Transform
ITS	-	Intelligent Transportation System
IMD	-	Intermodulation Distortion
IMD2	-	Second order Intermodulation Distortion
IMD3	-	Third order Intermodulation Distortion
LD	-	Laser Diode
LO	-	Local Oscillator
MU	-	Mobile Unit
NF	-	Noise Figure
PD	-	Photo Diode
QAM	-	Quadrature Amplitude Modulation
QD	-	Quadrature Detector
QPSK	-	Quadrature Phase-shift Keying
RF	-	Radio Frequency
RIN	-	Relative Intensity Noise
RoF	-	Radio over Fiber
RVC	-	Road Vehicle Communication
SCM	-	Subcarrier Multiplexing

SFDR	-	Spurious Free dynamic Range
SMF	-	Single Mode Fiber
SNR	-	Signal to Noise Ratio
VB	-	Visual Basic
VSA	-	Vector Spectrum Analyzer
WiMAX	-	Worldwide Interoperability for Microwave Access
WLAN	-	Wireless Local Area Network
WTU	-	Wireless Terminal Unit

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Wireless communications is entering a new phase where multimedia services are getting increasing demand and new wireless subscribers are signing up at increasing rate. As a result, the system will need to offer high data transmission capacities while the radio spectrum is limited. Therefore, the next generation wireless access systems will be operated in upper millimeter wave frequency band, in order to get higher bandwidth and avoid spectral congestion in lower frequency bands. The high operating frequencies require smaller radio cells and also larger number of base stations (BS) per network area. Higher carrier frequencies also lead to increased cost of radio front-ends in BSs [1]. Hence, the idea of transmitting millimeter wave signal using optical fiber, known as Radio over Fiber (RoF) is introduced.

RoF technology, known as the integration of high capacity of optical networks and the flexibility of radio networks, is a promising solution for providing broadband wireless access services and increasing mobility [2]. However, RoF links suffers from performance degradation due to optical transmitter nonlinearity that generates distortion of harmonic and intermodulation in modulating RF signal. The nonlinear distortions generate new signals with new frequencies. This type of distortions is of concern because those signals can cause interference between channels and degrade the signal qualities.

Several techniques have been used to improve the linearity of the transmitter, such as feed-forward, feedback, and predistortion. Feed-forward linearization is seen as the most efficient compared to other techniques. This is because feed-forward linearization offers a number of advantages such as broadband distortion reduction at high frequencies, and reduction in all orders of distortions without the need of knowing the nonlinear characteristics of the lasers [3]. Even though feed-forward linearization is a relatively complicated and sensitive scheme, it is a promising linearization solution in view of the demand for high channel capacity lightwave systems [4].

A number of researches such as [5], [6], and [7] have been done on feed-forward linearization of laser transmitter, and significant reduction on distortions has been achieved. However, the parameter adjustment systems of their proposed design need to be improved for practical implementation in the RoF network. Hence, this project proposes a feed-forward linearization system equipped with an adaptive control system for practical implementation.

1.2 Problem Statement

Radio over fiber links suffers from performance degradation due to nonlinear distortions generated by optical transmitter. Several distortion-compensation techniques have been considered, and feed-forward linearization is seen as the most effective since it suppresses 3rd order intermodulation distortion (IMD) and higher order products, and also reduces laser relative intensity noise (RIN) over a large bandwidth. However, feed-forward is a complicated and sensitive scheme, the gains and phase shifts parameters of the amplifiers, attenuators, and phase shifters in the system has to be adjusted properly to optimize the error cancellation of the system. The magnitude and phase adjustments are also bound to be disrupted by any sort of drift and process variations such as temperature effect and laser aging. In order to make the practical implementation of this technique possible, an adaptive controller is needed to constantly monitor the system output and automatically readjust the system parameters to response to any process variations. Hence, in this project, a novel application of feed-forward linearization technique improved by an adaptive control system is developed for RoF application.

1.3 Objectives

The objectives of this study are:

1. To design and develop an adaptive controller for magnitude and phase matching adjustment in laser transmitter feed-forward linearization system.
2. To analyze and evaluate the performance of the developed controller by interfacing it to the proposed RoF feed-forward transmitter system.

1.4 Scopes of Project

The scopes of this study are:

1. Study on the laser transmitter nonlinearities and feed-forward linearization technique.
2. Model the laser nonlinearities using Volterra series analysis, and considering on the control algorithm.
3. Design an adaptive controller for the laser transmitter feed-forward linearization system.
4. Develop and test the adaptive control system using MATLAB.
5. Interface the controller model in MATLAB with the designed feed-forward linearization system for RoF laser transmitter in OptiSystem 9.0.

1.5 Research Methodology

The flow for this research study is briefly shown in the flow chart in Figure 1.1.

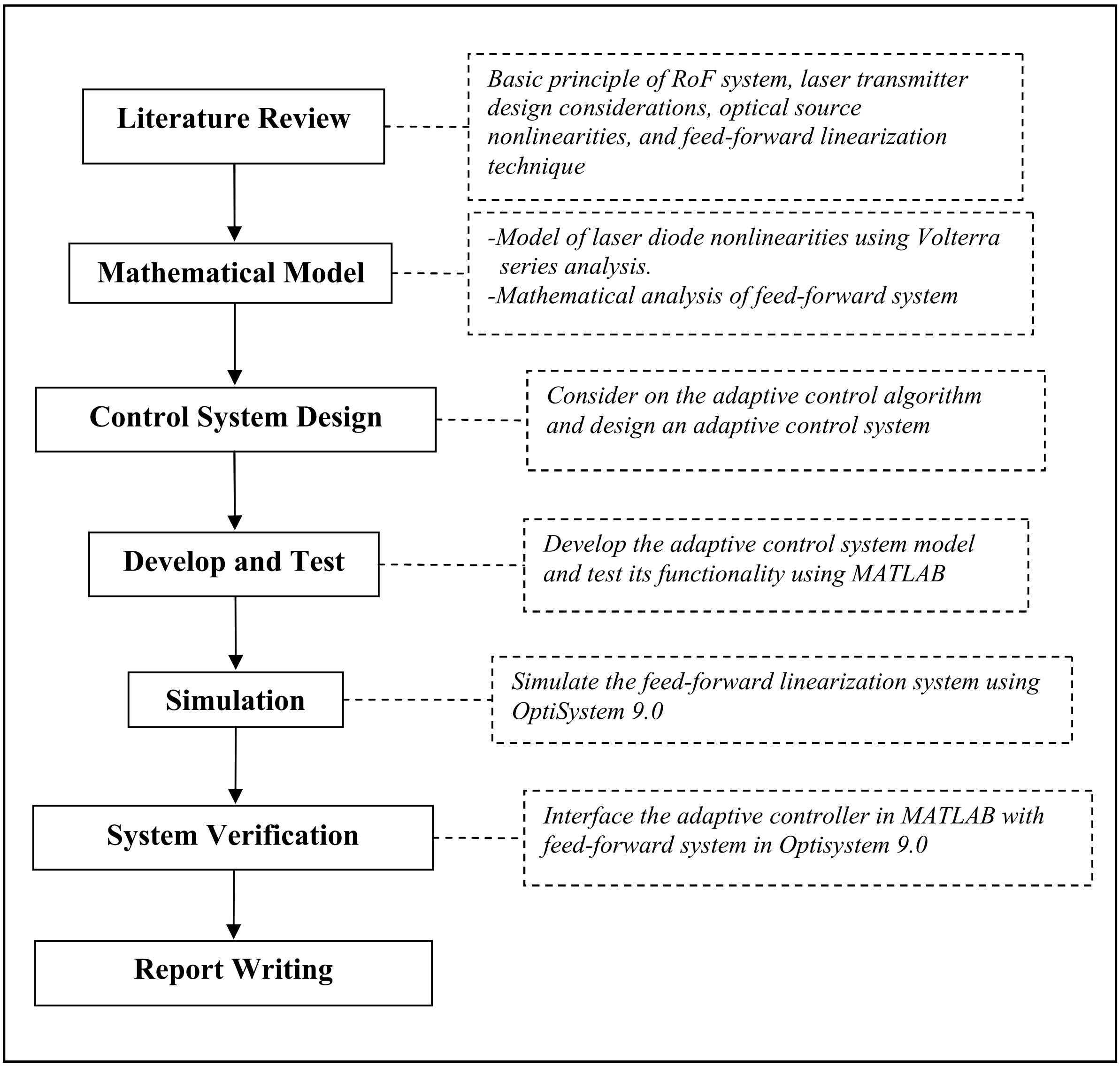

Figure. 1.1 Project flow chart

The project begins with the literature study and understanding of the basic principle of Radio over Fiber (RoF) system. Then, the laser transmitter design consideration for analog communication system is studied. Next, the optical source nonlinearities and the selected correction technique, feed-forward linearization are studied.

After that, the mathematical model of the laser diode nonlinearities is developed using Volterra series analysis. Mathematical analysis is also done on the whole feed-forward system.

The adaptive control algorithm for the loop adjustment parameters in the system is studied and considered. Then, an adaptive controller for the developed feed-forward linearization system is designed. The adaptive control system is developed and tested in MATLAB, where the developed mathematical model for the feed-forward system is the model to be optimized.

Next, the feed-forward linearization system is modeled and simulated using OptiSystem 9.0. After that, the developed adaptive controller model in MATLAB is interfaced with the feed-forward system modeled in Optisystem 9.0 for verification.

Finally, report writing and publications are done.

1.6 Thesis Outline

This thesis consists of six chapters and it is organized as follows:

Chapter 1 discusses on the research background, problem statement, objective, scope of project, research methodology, and the thesis outline.

In Chapter 2, the discussions are on the relevant literature review of this project. The Radio over Fiber technology, laser transmitter design considerations, nonlinear distortions, linearization schemes, and the reported works on feed-forward linearization technique are all presented.

Chapter 3 mainly focuses on the mathematical modeling of laser diode. The chapter starts with the system design, and then goes on with the mathematical modeling, where the Volterra series analysis is applied on the simplified laser rate equations.

Chapter 4 discusses on the modeling of adaptive feed-forward linearization system. The architecture of the adaptive feed-forward system, mathematical analysis of the feed-forward loops, and the optimization algorithm applied in the adaptive controller is discussed in details. The later section in the chapter presents a simplified adaptive feed-forward model and its optimization results.

Chapter 5 includes the model and simulation of the laser transmitter feed-forward linearization system in OptiSystem 9.0. The system integration of the adaptive controller in MATLAB and the feed-forward linearization in OptiSystem to become an adaptive feed-forward linearization system is also presented. Lastly, simulation results analysis and comparisons are included.

Finally, chapter 6 is on the conclusion and summary of the research. Recommendation for future works is also suggested.

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