UNIVERSITI PUTRA MALAYSIA

DESIGN OF AN OPTICAL RECEIVER FOR THE FIBER TO THE HOME (FTTH) SWITCH

MOHD HANIF BIN YAACOB

FK 2002 94

DESIGN OF AN OPTICAL RECEIVER FOR THE FIBER TO THE HOME (FTTH) SWITCH

By

MOHD HANIF BIN YAACOB

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Partial Fulfillment of the Requirement for the Degree of Master of Science

August 2002

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in partial fulfillment of the requirement for the degree of Master of Science

DESIGN OF AN OPTICAL RECEIVER FOR THE FIBER TO THE HOME (FTTH) SWITCH

By

MOHD HANIF BIN YAACOB

August 2002

Chairman: **Associate Professor Borhanuddin Mohd Ali, Ph.D.**

Faculty: **Engineering**

Fiber to the home (FTTH) architecture provides the full set optical telecommunication services (narrowband and broadband) up to customer premises across the local access services. The main challenge to the realization of FTTH is the cost. However, as the installation cost of the optical fiber technology decreases, FTTH started to gain its reputation as the future communication infrastructure. Once implemented, FTTH architecture needs to maintain its reliability and connectivity. These responsibilities are given to FTTH switch; a network device in the FTTH network that provides very fast inter-connectivity and excellent backup features. One main component of the switch is the optical receiver to receive the optical signal from any locations, either from the central office or the premises and convert the signal to its electrical form to be processed by the switch. Therefore, the objective of the research is to design the optical receiver for the FTTH switch.

In this thesis, the intended bandwidth by the receiver is specified at 155 MHz. The other performance parameters concerned are signal to noise ratio (SNR) and sensitivity. The main components of the receiver are PIN photodetector, transimpedance

amplifier and post amplifier. PIN photodetector is used as the optical detector to convert the optical signal into its electrical form. Meanwhile, transimpedance amplifier is the photocurrent to voltage converter. The function of the post amplifier is to amplify the electrical signal. Besides that, additional circuit configuration and topology are applied to improve the performance of the receiver.

The optical receiver design was broken into a few modules. Each of them was developed step by step based on two approaches. They are software simulation and hardware implementation (experiment). The receiver performance was analysed based on the results produced by each approach.

The final results on the optical receiver system show that the performance standard (155 MHz bandwidth) was achieved by the simulation approach. However the experiment only manage to support the bandwidth around 126 MHz. The SNR and sensitivity measured from the experimental circuit also give a lower performance compared to the simulation.

Based on the experimental results, a few solutions are suggested to increase the optical receiver performance. Meanwhile, the application of the designed optical receiver in the other area is also investigated.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

REKABENTUK PENERIMA OPTIK UNTUK SUIS "FIBER KE RUMAH" (FTTH)

Oleh

MOHD HANIF BIN YAACOB

Ogos 2002

Pengerusi: **Profesor Madya Borhanuddin Mohd Ali, Ph.D.**

Fakulti: **Kejuruteraan**

Senibina fiber ke rumah (FTTH) menyediakan satu set lengkap perkhidmatan telekomunikasi optik (jalur sempit dan jalur luas) sehingga ke premis pelanggan melalui perkhidmatan capaian tempatan. Cabaran utama untuk menjalankan FTTH ialah kos. Walau bagaimanapun, disebabkan kos prasarana teknologi fiber optik semakin menurun, FTTH mulai mendapat tempat sebagai infrastruktur komunikasi masa hadapan. Apabila diimplementasi, senibina FTTH perlu mempertahankan kebolehpercayaan dan kesalinghubungannya. Tugas-tugas ini diserahkan kepada suis FTTH; satu peranti rangkaian di dalam rangkaian FTTH yang menyediakan kesalinghubungan yang pantas dan ciri sandaran yang cemerlang. Salah satu komponen suis ini ialah penerima optik yang menerima isyarat optik dari mana-mana lokasi, tidak kira dari pejabat pusat atau premis dan menukarkan isyarat optik tersebut kepada bentuk elektrik untuk diproses oleh suis. Oleh itu, objektif penyelidikan ini adalah untuk merekabentuk satu penerima optik untuk suis FTTH.

Di dalam tesis ini, lebar jalur yang diinginkan oleh penerima optik ditetapkan pada 155 MHz. Parameter prestasi lain yang diambil berat adalah nisbah isyarat ke

hingar (SNR) dan kepekaan. Komponen utama penerima adalah pengesan cahaya PIN, penguat antara-galangan dan penguat pasca. Pengesan cahaya PIN digunakan sebagai pengesan optik untuk menukarkan isyarat optik kepada bentuk elektrik. Sementara, penguat antara-galangan ialah penukar arus cahaya kepada volt. Fungsi penguat pasca pula adalah untuk menguatkan isyarat elektrik tersebut. Selain itu, konfigurasi litar dan topologi tambahan juga digunakan untuk meningkatkan prestasi penerima.

Rekabentuk penerima optik dipecahkan kepada beberapa modul. Setiap satu daripadanya dimajukan langkah demi langkah berdasarkan dua pendekatan. Pendekatan tersebut adalah simulasi perisian dan implementasi perkakasan (eksperimen). Prestasi penerima dianalisa berdasarkan keputusan yang dihasilkan oleh setiap pendekatan.

Keputusan akhir sistem penerima optik menunjukkan piawaian prestasi (lebarjalur 155 MHz) telah dicapai oleh pendekatan simulasi. Walau bagaimanapun, ekperimen hanya mampu menyokong lebarjalur sekitar 126 MHz. SNR dan kepekaan yang diukur dari litar eksperimen juga menunjukkan prestasi yang lemah berbanding simulasi.

Berdasarkan keputusan eksperimen, beberapa penyelesaian dicadangkan untuk meningkatkan prestasi penerima optik. Pada masa yang sama, aplikasi penerima optik yang dicipta di dalam bidang lain juga diteroka.

ACKNOWLEDGEMENTS

First of all, I would like to express my greatest gratitude to ALLAH the almighty, for his help and support during the course of life and moment of truth. Alhamdulillah.

I would like to thank both my supervisor and co-supervisor, Associate Professor Dr Borhanuddin Mohd Ali and Associate Professor Dr Mohamad Khazani Abdullah for their continual support, endless encouragement and patience towards completing the research. Without all that nothing would have been accomplished.

My special thanks go to other committee member Puan Ratna Kalos Zakiah and all my colleagues from Photonic Lab. Working with all of you is a good experience that could never be forgotten.

This gratitude also goes to all staffs of Computer and Communication Systems Engineering Department, especially Kak Aishah, Kak Sal, Abang Nor, my cool HOD, Puan Nor Kamariah and others. How lucky I am to have people like you around me to guide me like your little brother.

A huge appreciation to my beloved wife Zuraidah. Your unconditional love and continual support made me strong in completing the thesis. I love you so much.

Last but not least, I would like to thank my father, mother, and the rest of my family who keep encouraging and supporting me in whatever I do. Thank you very much. I love you all.

I certify that an Examination Committee met on 5th August 2002 to conduct the final examination of Mohd Hanif bin Yaacob on his Master of Science thesis entitled "Design of an Optical Receiver for the Fiber to the Home (FTTH) Switch" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

V. PRAKASH, Ph.D.
Department of Computer and Communication Systems,
Faculty of Engineering,
Universiti Putra Malaysia.
(Chairman)

BORHANUDDIN MOHD ALI, Ph.D.
Associate Professor,
Department of Computer and Communication Systems,
Faculty of Engineering,
Universiti Putra Malaysia.
(Member)

MOHAMAD KHAZANI ABDULLAH, Ph.D.
Associate Professor,
Department of Computer and Communication Systems,
Faculty of Engineering,
Universiti Putra Malaysia.
(Member)

RATNA KALOS ZAKIAH SAHBUDIN, M.Sc.
Department of Computer and Communication Systems,
Faculty of Engineering,
Universiti Putra Malaysia.
(Member)

SHAMSHER MOHAMAD RAMADILI, Ph.D.
Professor / Deputy Dean,
School of Graduate Studies,
Universiti Putra Malaysia

Date: 16 OCT 2002

The thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of Supervisory Committee are as follows:

BORHANUDDIN MOHD ALI, Ph.D.
Associate Professor,
Department of Computer and Communication Systems,
Faculty of Engineering,
Universiti Putra Malaysia.
(Chairman)

MOHAMAD KHAZANI ABDULLAH, Ph.D.
Associate Professor,
Department of Computer and Communication Systems,
Faculty of Engineering,
Universiti Putra Malaysia.
(Member)

RATNA KALOS ZAKIAH SAHBUDIN, M.Sc.
Department of Computer and Communication Systems,
Faculty of Engineering,
Universiti Putra Malaysia.
(Member)

AINI IDERIS, Ph.D.
Professor / Dean
School of Graduate Studies,
Universiti Putra Malaysia

Date:

DECLARATION

I hereby declare that the thesis is based on my original work except for the quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

MOHD HANIF BIN YAACOB

Date: 14/10/02

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	-	Alternating Current
APD	-	Avalanche Photodiode
ATM	-	Asynchronous Transfer Mode
BNC	-	Bayonet Neil-Concelman/British Naval Connector
DC	-	Direct Current
EMI	-	Electromagnetic Interference
ESD	-	Electrostatic Discharge
FDDI	-	Fiber Distributed Data Interface
FTTH	-	Fiber To The Home
GBWP	-	Gain Bandwidth Product
LSBW	-	Large Signal Bandwidth
NEB	-	Noise Equivalent Bandwidth
NEP	-	Noise Equivalent Power
OLT	-	Optical Line Termination
ONU	-	Optical Network Unit
OOK	-	On-Off Keying
Op amp	-	Operational Amplifier
PBX	-	Private Branch Exchange
PCB	-	Printed Circuit Board
PD	-	Photodiode
PIN	-	*p-n* junction with intrinsic region, *i*
PN	-	p-n junction
POTS	-	Plain Old Telephone Service
RJ11	-	Registered Jack 11

RJ45	-	Registered Jack 45
SMC	-	Simple Miller Compensation
SNR	-	Signal to Noise Ratio
STM-1	-	Synchronous Transfer Mode 1

LIST OF NOTATIONS

η	-	Quantum Efficiency
ω	-	Operating Frequency (Radian)
λ	-	Operating Wavelength
Av	-	Voltage Gain
B	-	Bandwidth
B_n	-	Noise Bandwidth
C_a	-	Amplifier Capacitance
C_d	-	Detector Capacitance
C_D	-	Detector Capacitance
C_{EL2075}	-	Elantec Amplifier Capacitance
C_f	-	Feedback Capacitor
$C_{in(CM)}$	-	Common Mode Input Capacitance
$C_{in(Diff)}$	-	Differental Input Capacitance
C_T	-	Total Capacitance
e	-	Electronic Charge ($1.6\text{x}10^{-19}$)
f	-	Varied Input Frequency
G	-	Open Loop Gain
h		Planck's Constant ($6.626\text{x}10^{-34}$)
H_{CL}	-	Closed Loop Transfer Function
i_a	-	Total Amplifier Noise
i_{amp}	-	Amplifier Input Leakage Current
I_d	-	Dark Current
i_D	-	Dark Current Noise
i_{dct}	-	Photodetector Current

i_f	-	Feedback Current
i_n	-	Total Noise
I_p	-	Output Photocurrent
i_s	-	Shot/Quantum Noise
i_t	-	Thermal Noise
K	-	Boltzmann's Constant
P_{ES}	-	Electrical Output Signal Power
P_N	-	Total Noise Power
P_o	-	Incident Optical Power
Q factor	-	Quality Factor
R	-	Responsivity
R_0	-	Output Resistance
R_a	-	Amplifier Input Resistance
R_b	-	Detector Bias Load
R_f		Feedback Resistor
R_L	-	Load Resistor
R_M	-	Nulling Resistor
R_T	-	Total Resistance
R_{TL}	-	Total Parallel Resistances (Bias And Amplifier Resistances)
T	-	Absolute Temperature
v		Velocity of light (2.998×10^8 ms^{-1})
V_{amp}	-	Amplifier Input Noise Voltage
V_{bias}	-	Bias Input Voltage
V_{in}	-	Input Voltage
V_{out}	-	Output Voltage
V_p	-	Peak Output Voltage

V_{p-p}	-	Peak-To-Peak Output Voltage
V_{rms}	-	Root Mean Square Output Voltage
Z	-	Impedance
Z_c	-	Capacitor Impedance

CHAPTER 1

INTRODUCTION

In this chapter, the background of fiber optics communications are given to provide the motivation that leads to the research area. It also provides the overview of the research area and its accomplishment.

1.1 Future Media in Telecommunication Network

The period of 21^{st} century promise a further shift in the telecommunication technology from the conventional electrical copper-based system to the increasingly popular optical fiber-based system. An important breakthrough in the making of the commercialised fiber optic cable by the scientists at Corning Glass Work in 1970 had lead to an optimistic future of optical fiber telecommunication system (Hecht, 1999). Since then, optical fibers gained its popularity and started to be used widely by the telecommunication companies especially as the backbone for the intercity communication network. The Internet had pushed further the popularity of the optical telecommunication. The explosive growth of the Internet has had a dramatic impact on the communication network. The popularity of networking together with the increase in demand for multimedia over the Internet are forcing the network to deliver more bandwidth to the users with more reliable and secure connections. The bandwidth will always be a scarce resource in the future, as new services will emerge and more and more people shift from using traditional communication equipment to Internetworking facilities (Rantanen, 1998). Optical fiber technology is without doubt the media that can fulfil all the demands.