THE UNIVERSITY OF WARWICK

TECHNIQUES FOR SIGNAL TO NOISE RATIO ADAPTATION IN INFARED OPTICAL WIRELESS FOR OPTIMISATION OF RECEIVER PERFORMANCE

MOHAMMAD FAIZ LIEW ABDULLAH

A thesis submitted in partial fulfilment of the requirements for the degree
of Doctor of Philosophy

The University Of Warwick
Division of Electrical & Electronic Engineering,
School Of Engineering,
December 2006

CONTENTS

Pages

List of Tables Pages

List of Figures Pages

GLOSSARY

AGC	Automatic gain control
BJT	Bipolar junction transistor
BTA	Bootstrapped transimpedance amplifier
CFA	Current feedback amplifier
EMI	Electro-magnetic interference
FET	Field effect transistor
FTTH	Fibre-to-the-home
IrDA	Infrared data association
LAN	Local Area Network
NF	Noise figure
QoS	Quality-of-service
SNR	Signal-to-noise ratio
VCR	Variable resistor
VFA	Voltage feedback amplifier
VFIR	Very Fast IR
VGA	Variable gain amplifier
USB	Universal serial bus

Acknowledgements

First of all I would like to thank God and the many people that had helped me to make this study and thesis possible. I am indebted to my supervisor, Prof Roger Green, for being my mentor for the last four years, for his keen guidance, encouragement and valuable comments throughout my research. I wish to thank my second supervisor, Dr. Mark Leeson for his valuable comments and suggestions throughout the research and thesis. I endeavour to pass on to future students that which I have experienced from them. I wish to express my gratitude to the Ministry of Science and Technology Malaysia and College University Technology Tun Hussein Onn for their financial support of this study.

I would also like to express my thanks to all the technical staff of the University of Warwick, Jonathan and Ian for their technical support.

I wish to thank my friends in the Communications and Signal Processing Research Group, my friends back in Malaysia and my friends who are venturing the same journey in other universities in United Kingdom for providing valuable support over the years.

Special gratitude to my loving wife, Anika Zafiah: for being a wonderful wife and for your tireless support of our family, even though you are striving for your PhD research studies at the same time. To you I wish you the very best of luck in your viva and I owe everything to you with compound interest. I wish to thank my parents, Gwi Peng for her support. A special thanks goes to my brother-in law, Akmal for his invaluable support. To our three loving children, Zu Arasy (6), Sadrina (5) and Syakib (3), who was born 4 months after we began our PhD studies, for constantly bringing joy, excitement and always testing our parenting skill. Finally this thesis is also dedicated to our "baby" who is going to be born at the end of March 2007.

DECLARATION

The work described in this thesis is entirely original and my own, except where otherwise indicated.

Parts of this work were presented at conferences, namely

"Optical Wireless Front-Ends", 2nd Malaysian Research Group Annual Conference, Manchester, Sept 2003.
(www.mrg-online.org/conference/02/mohdabdullah.htm)

"Optical Wireless Communication Front-Ends" High Frequency Postgraduate Student Colloquium, pp. 3-8, Manchester, 6-7 Sept 2004.

11/6/2007

Signed Date

ABSTRACT

The challenge of creating a new environment of links for wireless infrared and optical local area networks (LANs) is driving new innovations in the design of optical transceivers. This thesis is concerned with a systematic approach to the design of receivers for indoor optical wireless communication. In particular, it is concerned with how to offer bandwidth adjustment capability in a receiver according to the dynamic service quality of the incoming signals. Another part of the discussion of the thesis is how one can properly choose the front-end preamplifier and biasing circuitry for the photodetector. Also, comparison is made between different types of amplifier, and the methods of bandwidth enhancement.

The designs of six different techniques of integrating transimpedance amplifiers, with photodetectors to adapt an adjustable bandwidth control receiver are discussed. The proposed topologies provide an adjustable range of bandwidths for different frequency ranges, typically between 52Hz to 115MHz. The composite technique designs were used to incorporate into a system with an automatic gain control to study its effect, on an optical wireless receiver which had bandwidth adjustment and automatic gain adjustment. Theoretical analysis of noise performance for all the designed circuits is also presented. The theory and design of obstacles of indoor optical wireless receiver delivery, in addition to techniques for mitigating these effects, are discussed. This shows that infrared is a viable alternative to radio for certain applications.

Chapter 1

Introduction

1.1 Overview

Trends in the telecommunications and computer industries suggest that the network of the future will consist of a high capacity backbone network with short range communication links providing network access to portable communicators and portable computers. In this vision of the future, mobile users will have access to similar grade high-speed network services available to wired terminals. For this purpose, some parts of communication links need to be constructed wirelessly. This situation is illustrated in Fig. 1.1. During the last decade, therefore, wireless communication technology, such as optical local area networks (LANs) and wireless infrared (IR) communication systems has grown rapidly [1.1 – 1.5]. Optical LANs use fibre as the physical transmission medium for networks serving resources within a small geographic area, while wireless IR uses free space as a communication channel for short-range, localised networks. Optical wireless communications is becoming one of the cornerstones of today's revolution in information technology because of its benefits of high speed transmission and isolation from electromagnetic interference. With the drive towards portable and multimedia communications, we are faced with the challenge of bringing the capacity of our communications infrastructure directly to the user, providing seamless access to large quantities of information anywhere and at any time. To accomplish this however, will require mid-range or short-range wireless communication links with extremely high capacity. In an extreme case, for example, uncompressed high-definition video can require a data rate of in excess of 100 Mbit/s.

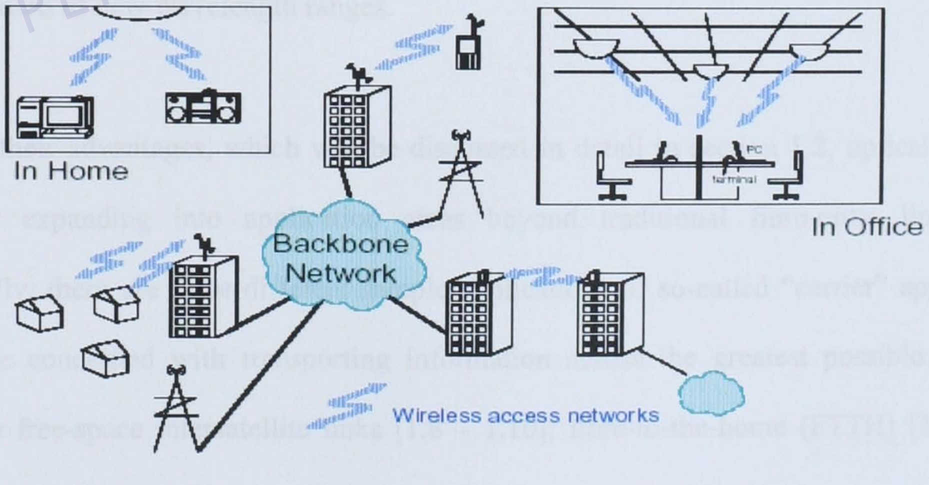

Figure 1.1 Wired backbone and wireless access network [1.1]

Light offers great advantages as a medium of communication. It enjoys unequalled channel bandwidth and is capable of data rates in the terabits per second range, whether traveling through free space or through optical fibre. This tremendous capacity is due to the nature of the photons that constitute an optical signal. Unlike electrons, photons react weakly to their environment and to one another as such optical signals neither generate nor are sensitive to electromagnetic interference (EMI), parasitic coupling and other problems faced by electrical signals [1.6]. In comparison, from IR to radio frequencies, the technology suffers from electro-magnetic interference (EMI) problems as the radio spectrum gets increasingly crowded. Now that personal communications and wireless computer networks are evolving rapidly, the available spectrum is considered to be a scarce resource. Simultaneously, there is an increase in the interference level caused by switched node power supplies and other high-frequency equipment. Particularly in hospitals and industrial environments, the applicability of radio systems is already seriously limited by these problems. Extensive frequency allocation regulations can only partly solve them. Eventually although EMI aspects will become an integral part of every system design, future applications require the exploration of new wavelength ranges.

Given their advantages, which will be discussed in detail in section 1.2, optical links are rapidly expanding into application areas beyond traditional fibre-optic links [1.7]. Basically, there are three different sample applications of so-called "carrier" applications that are concerned with transporting information across the greatest possible distance, namely free-space intersatellite links [1.8 – 1.10], fibre-to-the-home (FTTH) [1.11-1.12] and terrestrial free-space links for inter-building communications [1.13]. Current optical LANs, represented by the Gigabit Ethernet and ATM-PON network specifications, can be used to realise high data rate systems that find their application in parallel processing environments, newspaper and magazine production, and medical imaging networks [1.14]. The immunity of fibre optic LANs to electromagnetic radiation makes this technology an attractive choice for implementation in sensitive environments, such as in aircraft and vehicles [1.15-1.16]. Furthermore, broadband requirements to connect central office locations to customer premises benefit from the high bandwidths made feasible through the use of FTTH technology. Today, the limiting factor in the deployment of advanced optical LANs is the prohibitive cost of the transmitter and receiver [1.17]. However, novel integrated circuit design techniques are helping drive down the cost of implementation, in order for these LAN solutions to become more common. Finally, so called "optical wireless links" provide a communications solution for portable applications [1.18]. In particular, short range "point-and-shoot" systems in accordance with the infrared Data Association (IrDA) standard provide a simple solution for transferring information to and from portable devices, offering high data rates at low cost and with a small form factor that is not prone to mechanical wear [1.19].

The success of such short range systems is particularly showing how optical communication systems are likely to proliferate in the future, where IrDA wireless links have overshadowed both the Universal Serial Bus (USB) and IEEE 1394 FireWire to become the leading serial port alternative for connectivity [1.20]. A new technology has been proposed for indoor, short range wireless communication, called IrGate. IrGate core technology is based on a method of diffused-infrared (DIR) communication links, performing at high bit rates reaching up to 10Mbps [1.21]. IrDA is also extending its IR-PHY standard to 16Mbps, a new high speed extension called Very Fast IR (VFIR). VFIR is designed as an extension to the current 4Mbps FIR, where the much higher throughput enables wider applications beyond the current perception of a "wire replacement" [1.22]. Figure 1.2 and Figure 1.3 show the main features of the IrDA standards and the IR transmission speed, time and coverage area of the current implementations.

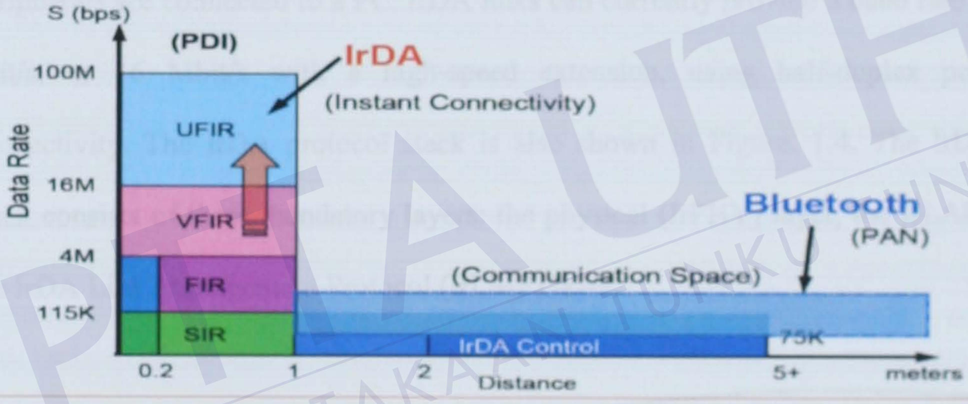

Figure 1.2 The main features of IrDA [1.23]

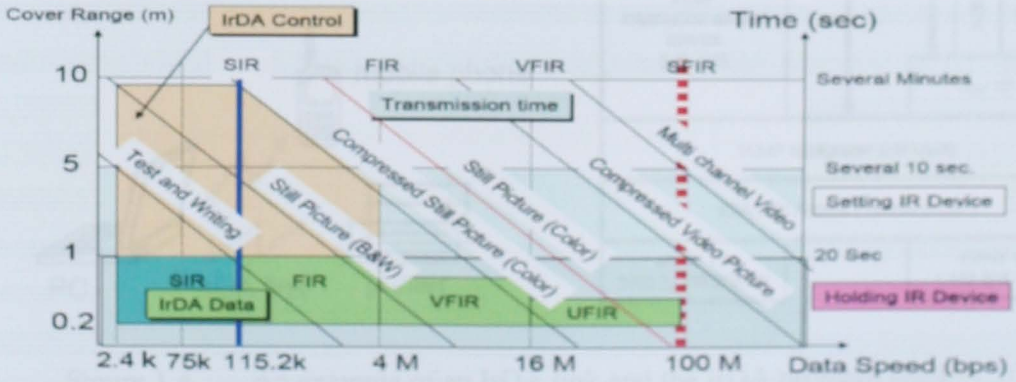

Figure 1.3 Infrared transmission speed, time and coverage area [1.23]

1.2 Wireless Infrared Medium – Advantages and Drawbacks

The infrared data association (IrDA) was established in 1993 as a collaboration between major industrial organisations in order to establish an open standard for infrared (IR) data communication [1.20] [1.24-1.28]. The resulting IrDA protocol aimed to provide a simple, low-cost, reliable means of IR communication between devices such as portable computers, desktop computers, printers, other peripherals and LANs using directed point-to-point connectivity. Figure 1.4 illustrates an example image of an IrDA link with which PC peripherals are connected to a PC. IrDA links can currently provide a baud rate up to 115.2 kbit/s, or 16 Mbit/s with a high-speed extension, using half-duplex point-to-point connectivity. The IrDA protocol stack is also shown in Figure. 1.4. The IrDA protocol stack consists of three mandatory layers: the physical (IrPHY) layer, the IrLAP layer, and the IrDA Link Management Protocol (IrLMP) layer.

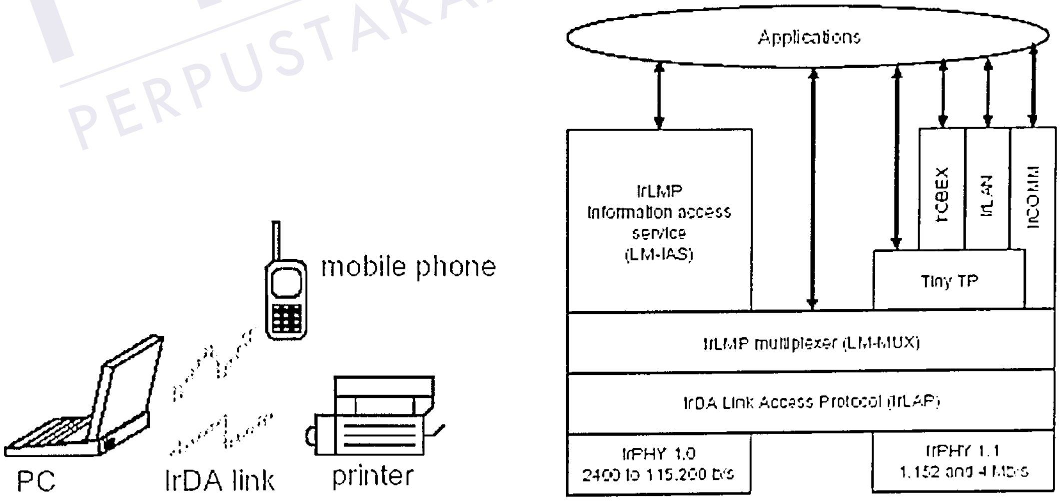

Figure 1.4 An example of an IrDA link and the IrDA protocol stack [1.20]

Therefore, one of the prime motivators for considering the use of an optical carrier in the wireless context is the demand for greater transmission bandwidths. As previously discussed, the radio frequency spectrum has already exceedingly become congested and frequency allocations of sufficient bandwidths are extremely hard to obtain [1.29]. As a medium for short-range wireless communication, IR radiation has several advantages over radio. The primary advantage is an abundance of unregulated bandwidth, with a range of more than 130THz. In addition, being similar in wavelength, part of the infrared spectrum shares many of the features of visible light; in particular, infrared radiation does not pass through walls or other opaque barriers, so that an infrared signal is confined to the room in which it originates. More importantly, it allows neighbouring rooms to use independent infrared links without interference. Furthermore, infrared links using intensity modulation and direct detection receivers do not suffer from multipath fading [1.30].

Nevertheless, IR does have some drawbacks as well, offering a limited range because the noise from ambient light is high, as shown in Figure 1.5 [1.30]. Also, the square-law nature of a direct-detection receiver doubles the effective path loss in dB when compared to a linear detector. Moreover, strict power limitations, due to eye and skin safety considerations, restrict the transmitter output power. IR is also susceptible to blocking, either from objects or personnel, resulting in loss of the communication link. The differences between radio and IR are summarised in Table 1.

References

[8.1] Nikolaus P. Schmitt, ”Wireless optical NLOS communication in aircraft cabin for in flight entertainment distribution” DTI-Workshop on Photonic Wireless Communication, 2005.

[8.2] J. J. F. Rijins, “54MHz switched capacitor video channel equalize” Electronics Letters, Vol. 29, No. 25, pp. 2181-2182, 1993.

[8.3] V. Peluso, P. Vancorenland, M. Steyaert and W. Sansen,”900mV differential class AB OTA for switched opamp applications” Electronics Letters, Vol. 33, No. 17, pp. 1455-1456, 1997.

[8.4] K. Phang, “CMOS optical preamplifier design using graphical circuit analysis”, Thesis, 2001.