UNIVERSITI PUTRA MALAYSIA

DESIGN AND ANALYSIS OF A DOUBLE CARRIER MODULATION/DIFFERENTIAL DETECTION TECHNIQUE FOR OPTICAL FIBER COMMUNICATIONS

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In the name of God, the Most Gracious, the Most Merciful

Dedication to

My beloved country Iraq

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

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Fiber optic long haul transmissions have been globally deployed at a staggering rate. All of the installed networks are using Intensity Modulation/Direct Detection (IM/DD). Although the IM/DD systems are proven and used widely, these networks are still subjected to many problems. The main problems associated with long haul transmission are; high dispersion and losses incurred by the fiber, and the inability of the receiver circuit to regenerate the transmitted bits. This is because of low signal power and inter-symbol interference, in addition to the masking noises. The recovery technique in the conventional receivers based on the IM/DD scheme uses an injected voltage level as a threshold into a decision circuit, which decides whether the incoming bit is a 0 or a 1. This scheme has two inherent problems; the

instability of the injected threshold voltage, and the complexity of a dynamic threshold processing. As the threshold voltage has its own noise and fluctuation, it adds to the deterioration of the signal, thus limits the systems performance. Meanwhile, due to the random nature of the incoming bits, coupled with the masking noises and jitters, the threshold voltage level cannot be set at a fixed value, and therefore a dynamic voltage threshold adjustment is required. The demand of high data rate and long transmission distance impose much difficulty, therefore new approaches and techniques have to be applied to improve the system and solve these problems. This led to the development of new techniques for the system performance improvement.

This thesis introduces a new transmission technique to improve the optical communication system performances. The new technique namely Double Carrier Modulation / Differential Detection (DCM/Diff.D) is presented. The system uses two carriers to send the data. One carrier carries the data, while the other carries the data inversion. A differential detection scheme based on the amplitude subtraction is used at the receiver end. The original signal A1 and its inversion A2 are detected by two photodetectors and produce two voltage signals V1 and V2. The voltage signal that is produced by the inversion data signal is subtracted from that of the original data signal. Note that no external DC voltage supply is required to be the reference threshold voltage as in conventional systems. V2 itself automatically serves as the threshold whose value is always reversal to that of the data, V1 (between mark and space levels). Thus the first problem associated with threshold fluctuation and noise is minimized. At the same time, the automatic decision making is provided because both V1 and V2 themselves change together dynamically depending on the received optical power levels at receivers 1 and 2 respectively. Therefore there is no need for complicated automatic threshold control schemes such as the eye-pattern scanning method. This suggests doubling the eye magnitude of the conventional system. Therefore, the new system suggests doubling the conventional distance. The new technique is presented by two models; one-fiber model and two-fiber model. A bit error rate (BER) of as good as 10^{-13} is achieved over 150 km distance for 2.5 Gbps data rate with 0dBm transmit power, while conventional systems perform good only for 70 km distance for the same system parameters

The study carried out through a computer simulation. The relationship in design parameters namely; distance, bit rate, bit format, filters bandwidth, photodiode type, and wavelength spacing, are well studied in view of their effects on the performance parameters namely; BER and eye-opening. It is shown here that DCM/Diff.D improves the system performance significantly.

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

REKA BENTUK DAN ANALISIS BAGI TEKNIK PEMODULATAN PEMBAWA BERGANDA /PENGESAN BERBEZA UNTUK KOMUNIKASI GENTIAN OPTIK

Oleh

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Penghantaran jarak jauh gentian optik telah digunakan secara global pada kadar yang menakjubkan. Kesemua rangkaian yang dipasang menggunakan pemodulatan keamatan/pengesahan terus(IM/DD). Walaupun sistem IM/IDD telah terbukti dan digunakan secara meluas, rangkaian ini masih menghadapi pelbagai masalah. Masalah utama berhubung penghantaran jarak jauh adalah penyerakan dan kehilangan yang tinggi disebabkan oleh gentian dan ketidakupayaan litar penerima untuk menjana semula bit-bit yang dihantar. Ini disebabkan oleh kuasa isyarat yang rendah dan gangguan antara simbol, disamping hingar topeng. Teknik pemulihan dalam penerima berdasarkan skim IM/DD yang sedia ada menggunakan tahap voltan suntikan sebagai ambang dalam litar keputusan, yang memutuskan sama ada bit yang masuk ialah 0 atau 1. Skim ini

mempunyai dua masalah sedia ada iaitu ketidakstabilan voltan ambang suntikan dan kompleksiti pemprosesan ambang dinamik. Voltan ambang mempunyai hingar dan turun-naik sendiri, yang menambah kepada kemerosotan isyarat dan menghadkan prestasi sistem. Pada masa yang sama, sifat rawak bit-bit masuk, terganding dengan hingar topeng dan getar menyebabkan tahap ambang voltan tidak dapat dikekalkan pada nilai tetap dan ini memerlukan pelarasan ambang voltan dinamik. Permintaan untuk kadar data yang tinggi dan penghantaran jarak jauh menimbulkan banyak kesulitan , oleh itu pendekatan dan teknik baru perlu digunakan untuk meningkatkan sistem tersebut dan menyelesaikan masalah-masalah ini. Ini membawa kepada pembangunan teknik-teknik baru untuk meningkatkan prestasi sistem.

Tesis ini memperkenalkan teknik penghantaran baru untuk meningkatkan prestasi sistem komunikasi optik. Teknik baru iaitu Pemodulatan Pembawa Berganda/Pengesahan Berbeza (DCM/Diff.D) dikemukakan. Sistem ini menggunakan dua pembawa untuk menghantar data. Satu pembawa membawa data manakala satu lagi membawa data songsangan. Skim pengesanan berbeza berdasarkan penolakan amplitud digunakan pada penerima. Isyarat asal A1 dan songsangannya A2 dikesan oleh fotopengesan dan menghasilkan dua isyarat voltan V1 dan V2. Isyarat voltan yang dihasilkan oleh isyarat songsangan data ditolak dari isyarat data asal. Bekalan voltan DC luar tidak diperlukan untuk dijadikan voltan ambang rujukan seperti dalam sistem sedia ada. V2 sendiri ialah ambang secara otomatik di mana nilainya sentiasa menyongsang daripada data V1 (antara tahap tanda dan ruang). Oleh itu, masalah pertama berhubung turun-naik dan hingar dapat dikurangkan.. Pada masa yang sama, pembuat keputusan secara otomatik disediakan kerana kedua-dua V1 dan V2 berubah bersama secara dinamik bergantung kepada tahap kuasa optik yang diterima oleh penerima 1 dan 2. Oleh itu, skim kawalan ambang secara otomatik yang rumit tidak diperlukan, seperti kaedah imbasan pola-mata. Ini mencadangkan penggandaan magnitud mata bagi sitem sedia ada. Oleh yang demikian, sistem baru mencadangkan penggandaan jarak sedia ada. Teknik baru ini dikemukakan dalam bentuk dua model, model satu gentian dan model dua gentian. Kadar Ralat Bit (BER) sebaik 10^{-13} dicapai bagi jarak 150 km untuk kadar data 2.5 Gbps dengan kuasa hantar 0dBm, manakala system sedia ada mempunyai prestasi yang baik hanya untuk jarak 70km bagi parameter-parameter sistem yang sama.

Kajian ini dijalankan dengan menggunakan simulasi komputer. Perhubungan antara parameter reka bentuk seperti jarak, kadar bit, format bit, lebar jalur penapis, jenis foto pengesan dan ruang panjang gelombang dikaji dengan mendalam dari sudut kesannya kepada parameter prestasi seperti BER dan bukaan mata. Ditunjukkan disini bahawa DCM/Diff.D meningkatkan prestasi sistem dengan berkesan.

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INTRODUCTION

1.1 Background

Communication systems have appeared in many forms over the years. The principal motivations behind each new system were either to improve the transmission fidelity, to increase the data rate so that more information could be sent, or to increase the transmission distance between relay stations together with the system reliability. Meanwhile the massive increase in the availability of inexpensive, high-speed personal computers has led to the deployment of large-scale distribution computing networks with the capability of serving a large number of users, which requires high-speed digital communication channels. At the present time, fiber optic communication systems (FOCS) are the strongest candidate for achieving the communication speed required on many applications like a high-definition image transmission including medical images as well as magnetic resonant images (MRIs), video cables transmitting high-definition TV with a huge number of channels, three-dimensional images for robotics and next generation surveillance and tracking systems.

Moreover, since the amount of information that can be transmitted is directly related to the frequency range over which the carrier wave operates, increasing the carrier frequency theoretically increases the available transmission bandwidth, which is desirable for communication systems. Light carriers operate at the top of the frequency spectrum which adds one more advantage of using light carriers.

The ensuing development of optical fiber transmission systems had grown from the combination of semiconductor technology, and optical waveguide technology upon which the fiber is based. The result was a transmission link that had certain inherent advantages over conventional copper wire systems in telecommunication applications, such as live telephone, and TV channels.

An especially important feature of optical fiber relates to its dielectric nature. This provides optical waveguides with immunity to electro-magnetic interference, such as inductive pickup from signal carrying wires and lighting, and freedom from electromagnetic pulses (EMP) effects. Furthermore there is no need to worry about ground loops. Fiber-to-fiber cross talk is very low, and a high degree of data security is afforded since the optical signal is well confined within the waveguide.

Early recognition of all these advantages in the early 1970s, created a flurry of activity in all the areas related to fiber optic transmission systems. This resulted in significant technological advances in optical sources, fibers, and photodetectors and other enabling technologies. By 1980 this activity had led to the development and world wide installation of practically and economically feasible optical fiber communication systems.

The ultimate goal of any digital communication system design is to be able to recover the original transmitted bits at the receiver. The design of such system involves many interrelated parameters among which are the fiber, source, photodetector operation characteristics, and the overall transmitting-receiving techniques and protocols used.

1.2 Motivation and Problem Statement

Long haul transmission system requirements needed in analyzing links are; the maximum (or possible) transmission distance, the data rate or channel bandwidth and the bit error rate (BER). Based on these requirements, optical communication systems are designed to ensure that the desired performance level can be maintained over the expected system lifetime without over-specifying the component characteristics. For long distance, different techniques are used to achieve best system performances. So far, conventional intensity modulation direct detection (IM/DD) systems, operating with a single optical channel, at 155 Mbps, 622 Mbps, and 2.5 Gbps bit rate and beyond, are presented over links of 50-80 km repeaters distance (Peter K Cheo, 1990).

Factors affecting conventional systems over long distances are the dispersion and the attenuation. These are directly related to the link distance. Another is the receiver noise. These are the main factors that limit the system performance. In long haul transmission, the very weak received random bits are contaminated with the masking noises and jitters. Receiver noises add an extra shot noise to the small incoming bits opening. All that results in difficulty to recover the bit sequence at the decision circuit. This presents the first problem associated with long haul conventional systems. The second problem arises from the decision circuit itself. Here, the injected threshold (voltage or current), which has an inherent fluctuation, and the controllability of this threshold to make it dynamically with the incoming bits level, are the two sub-problems associated in the decision circuit. Also the noises linked with the threshold control circuit are another issue that affects the decision making. Nevertheless, so many techniques are used to control the decision circuit threshold automatically. These techniques impose more complexity to the receiver circuit in addition to the sacrificed time to make such controllability. Therefore a system which overcomes such problems is desirable. Researchers are seeking to develop systems with less inherent problems. In this thesis we introduce a novel technique namely Double Carrier Modulation/Differential Detection (DCM/Diff.D), which overcomes problems associated with fluctuation of threshold that exists in conventional systems. The technique which is based on a differential detection scheme enhances significantly the system performances.

1.3 Methodology

The novelty of the idea of DCM/Diff.D led to many design configurations. This technique can be used in many applications to enhance the system performance. Basically, the design of a DCM/Diff.D system is done using simulation software. Here the performance of the circuit and the variation of the device parameters can be verified in an earlier stage to determine whether the theory was valid or otherwise. Suitable devices and parameters values can be easily identified. Also the flexibility of the design using software allows extensive study on the design. From this study, an optimum