DEVELOPMENT OF A NEW DUAL DIFFUSER MODULATION TECHNIQUE TO ALLEVIATE THE SCINTILLATION EFFECT IN FREE SPACE OPTICAL COMMUNICATION

By

ABDUL RAHMAN BIN KRAM
(1040810527)

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DECLARATION OF THESIS

| Author’s full name   | :   ABDUL RAHMAN BIN KRAM  |
| Date of birth       | :   8 MAY 1984              |
| Title               | :   DEVELOPMENT OF A NEW DUAL DIFFUSER MODULATION TECHNIQUE TO ALLEVIATE THE SCINTILLATION EFFECT IN FREE SPACE OPTICAL COMMUNICATION |
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Pembangunan Satu Teknik Baharu Dwi Peresap Pemodulatan Untuk
Mengurangkan Kesaran Pergolakan Atmosfera Dalam Komunikasi Ruang Bebas Optik

ABSTRAK

Tesis ini membentangkan pendekatan baharu untuk teknik modulasi dalam ruang bebas komunikasi optik disebabkan oleh pergolakan atmosfera. Teknik modulasi baharu adalah berdasarkan pengubahsuaian konvensional modulasi intensiti untuk mengesakan langsung hidup-padam memasukkan not (CIM/DD-OOK) yang mampu untuk mengoptimumkan kesan fasa peresap skrin, meningkatkan kuasa yang diterima dan meningkatkan tahap paras ambang isyarat. Pembatasan yang utama bagi CIM/DD-OOK ialah menderita dengan proses pengesanan ambang kerana berlakunya isyarat turun naik dan oleh kerana itu mengguna penyesuaian ambang untuk mendapatkan prestasi yang optimum yang mana memerlukan proses yang sangat kompleks. Menggunakan peresap boleh mengurangkan indeks sintilasi walau bagaimanapun ia boleh memerkaikan kuasa isyarat. Pembangunan teknik modulasi baharu terdiri daripada tiga bahagian utama. Bahagian yang pertama adalah membangunkan analisis saluran atmosfera Gaussian bagi menentukan hala tuju kajian penyelidikan. Bahagian kedua ialah pembangunan terbitan matematik di mana untuk menganalisis secara teori teknik modulasi baharu dengan teknik modulasi konvensional. Analisis prestasi akan menyiapkan kuasa isyarat, isyarat tahap ambang, isyarat kepada nisbah bising dan kadar ralat bit. Akhir sekali, bahagian ketiga adalah mengsimulasi teknik modulasi yang baharu dengan menggunakan perisian OptiSystem. Dengan ini boleh mengukur keupayaan DDM secara dekat hampir dalam keadaan FSO sebenar dan pada masa yang sama boleh mengesan dengan bahagian teori. Keputusannya menunjukkan bahawa untuk prestasi kuasa penerima pada hanya penerimaan BER $10^{-9}$ di bawah keadaan pergolakan yang kuat, teknik DDM dapat mengesakan kuasa yang lemah sehingga -$18$dBm. Sementara itu, bagi CIM/DD-OOK dengan dan tanpa peresap adalah pada -$14$dBm dan $0$dBm masing-masing dengan kuasa yang diterima diterima kira-kira $4$dBm dan $18$dBm atau bersamaan 66 peratus dan 99 peratus peningkatan . Dalam menganalisis kadar bit , kadar data penilaian adalah dari $622$Mbps sehingga $10$Gbps. Analisa menunjukkan bahawa apabila sistem FSO beroperasi di bawah keadaan pergolakan yang kuat dan jika kuasa menerima ditetapkan pada $10$dBm, dengan jelas teknik DDM menunjukkan prestasi unggul jika dibandingkan dengan teknik modulasi OOK konvensional. Pada $2.5$Gbps, magnitud BER untuk DDM teknik meningkat dengan 12 magnitud atau bersamaan peningkatan $100$ peratus dan CIM/DD-OOK dengan peresap hanya 2 magnitud dimana memberikan peningkatan $33$ peratus sahaja. Sementara itu, bagi keputusan analisis kuasa menerima DDM pada jarak $3$km perambatan dengan mempertimbangkan $0$dBm kuasa menghantar, panjang gelombang $1550$nm dan kekuatan peresap $l_c = 0.01$, kuasa yang diterima adalah -$4.59$dBm dan dibandingkan dengan konvensional OOK yang menggunakan peresap hanya -$7.6$dB yang sama dengan $3$dBm perbezaan atau kira-kira $100$ peratus peningkatan. Dari segi prestasi BER, DDM boleh meluaskan penyebaran jarak dengan peningkatan kira-kira $42$ peratus. Oleh itu perlaksanaan teknik modulasi DDM baharu adalah lebih baik daripada teknik modulasi keamatan konvensional untuk mengesakan langsung hidup-padam memasukkan not (CIM/DD-OOK) bagi mengatasi degradasi isyarat pudar disebabkan keadaan pergolakan yang kuat.
Development of A New Dual Diffuser Modulation Technique To Alleviate Atmospheric Turbulence Effect In Free Space Optic Communication

ABSTRACT

This thesis presents new approach for modulation technique in free space optical communication due to atmospheric turbulence. The new modulation technique is based on the modification conventional intensity modulation for direct detection on off keying (CIM/DD-OOK) which capable to optimize the phase screens diffuser effect, enhance power received and improve threshold signal level. The main limitation of the CIM/DD-OOK is suffering with the threshold detection for the occurrence of signal fluctuations and therefore the use of adaptive threshold for optimum performance of which requires a very complex process. The using of diffuser can reduced the scintillation index however it can attenuate the signal power. The development of new modulation technique consists of three major parts. The first part is developing the Gaussian atmospheric channel analysis to determine the direction of research study. The second part is the mathematical derivation development where to analyze theoretically the new modulation technique based on conventional modulation technique. The performance analysis will investigate the signal power, threshold signal level, signal to noise ratio and bit error rate. Lastly, the third part is simulating the new modulation technique by using the OptiSystem software. This can measured the capability of DDM in close in real FSO situation and at same time can validate with the theoretical part. The result shows that for the receiving power performance at acceptable BER $10^{-9}$ under strong turbulence condition, the DDM technique able to detect weak signal up to -18dBm. Meanwhile for CIM/DD-OOK with and without diffuser are at -14dBm and 0dBm respectively with different received power approximately 4dBm and 18dBm or equivalent to 66 percent and 99 percent improvement. In a bit rate analysis, the evaluation data rate from 622Mbps up to 10Gbps. Analysis shows that when the FSO system operate under strong turbulence effect and if the power receive is set fix at -10dBm, clearly the DDM technique shows the superior performance if compare to conventional OOK modulation technique. At 2.5Gbps, the magnitude of BER for DDM technique increase with 12 magnitudes or equivalent to 100 percent improvement and the CIM/DD-OOK with diffuser only 2 magnitudes which give the 33 percent improvement. Meanwhile for the analysis result of receiving power DDM at 3km distance propagation with consider 0dBm power transimit, wavelength 1550nm and diffuser strength at $l_c = 0.01$, the received power is -4.59dBm compare with conventional OOK that using diffuser only -7.6dBm which equal to 3dBm different or around 100 percent improvement. In term of BER performance, the DDM can further the distance propagation with approximately 42 percent improvement. Thus the new modulation DDM technique performs better than the conventional intensity modulation for direct detection on off keying (CIM/DD-OOK) to overcome the degradation of signal fading due to strong turbulence condition.
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<td>Avalanche Photodiode</td>
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<td>AWGN</td>
<td>Addictive White Gaussian Noise</td>
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<td>BER</td>
<td>Bit Error Rate</td>
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<td>CIM/DD-OOK</td>
<td>Conventional Intensity Modulation Direct Detection On-Off Keying</td>
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<td>CW</td>
<td>continuous wave laser</td>
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<td>DFB</td>
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<td>FCC</td>
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<td>FEC</td>
<td>Forward Error Control</td>
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<td>FP</td>
<td>Fabry–Perot</td>
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<td>FSO</td>
<td>Free Space Optic</td>
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<td>FWHM</td>
<td>Full-Width Half Maximum</td>
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<td>Gbps</td>
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<td>Synchronous Digital Hierarchy</td>
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<td>SNR</td>
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CHAPTER 1
INTRODUCTION

1.1 Background

The Free Space Optics (FSO) can be defined as an optical communication technology that uses light which usually uses a LASER source and propagate via free space to transmit data between two points (FSO, 2009). Alexander Graham Bell, who the first discovered it in the late nineteenth century with his experiment to convert voice sounds into telephone signals and transmitted them between receivers through free air space along a beam of light for a distance of some 600 feet (fSONA, 2009). In the year 1960’s, the scientists have successfully developed Light Amplification by Stimulated Emission of Radiation (LASER) technology which after that is used in the optical communication (FSO, 2003 & Johnson, 2002). This technology has the same characteristic with the fiber optic communications but only distinguished intern of medium propagation. The data of optic fiber communication are transmitted by modulated laser light in cable, while FSO data are transmitted in a narrow beam through the atmosphere. Light travels through air faster than it does through glass, so it is fair to classify FSO as optical communications at the speed of light. The stability and quality of the link is highly dependent on atmospheric factors such as fog, haze, scintillation and heat. Maximum range of terrestrial links is limited (less than 10 km). Nowadays, the FSO communication systems are increasingly being considered as an attractive option for the rapid provisioning of multi-gigabit per second links (Willebrand, 2002 & Nykolak, 2001 & Carbonneau, 1998).
Various applications can be applied in an FSO system today such as the last mile high bandwidth internet connectivity, the temporary high bandwidth data links, the mobile telephony backhaul (3G), satellite links as well as the various applications where the optical fibers cannot be used. There has been exponential growth in the use of FSO technology over the last few years, primarily for “last mile” applications, because FSO links provide the transmission capacity to overcome information bottlenecks (Dennis, 2002). This high data rate application can send voice, video conference and real-time image transmission, and also to achieve affordable communication for everyone, at any time and place (Hamed Al-Raweshidy, 2002). The communication capabilities allow not only human to human communication and contact, but also human to machine and machine to machine interactions. The communication will allow our visual, audio, and touch sense, to be contacted as a virtual 3-D presence (Govind, 2001).

1.2 Problem Statement and Motivation

The FSO communication is strongly influenced by the atmospheric channel effect which can cause the beam signal fading and wander. There are two main effects that can deterior the quality signal of FSO that are atmospheric attenuation and atmospheric turbulence as report in (D. Kedar, 2004 & X. Zhu, 2002& S. Karp, 1988& S. Bloom, 2003&D. Kedar, 2003). In the atmospheric attenuation will causes the signal scattering and absorption, need modification on an FSO system design to transmit higher power without exceeding the safety limits or has to reduce the propagation link (Isaac I, 2001& A. A. Farid 2007). Meanwhile for the atmospheric scintillation is caused by the atmospheric temperature inhomogeneity as presented in (Li, 2003&I. Kim, 1999). The scintillation effect will cause the signal fading due to constructive and
destructive interference of the optical beam traversing the atmosphere. Typical scintillation fade margins for short propagation link is around 2 to 5 dB which is less than the margins for atmospheric attenuation (I. I. Kim, 1997), making scintillation insignificant for short range FSO systems. Nevertheless if the range is exceeding more than 1 km the scintillation will impairs the FSO link availability and degrade the FSO performance significantly (X. Zhu, 2002& S. Bloom, 2003& I. Kim, 1999& S. Chan, 2006).

The OOK modulation technique is one simple modulation technique to be implemented and it has become the most popular for the commercially modulation technique available terrestrial FSO systems currently (H. Willebrand, 2002& X. Zhu, 2002& S. Bloom, 2003& J. T. Li, 2003). The major problem with OOK is suffering from the threshold signal level. The threshold level/point in the decision circuitry used to distinguish between bits zero and one is always fixed midway between the expected levels of data bits one and zero (I. B. Djordjevic, 2007). This will produce an optimum less error performance in non-fading channels. However when the presence of turbulence, the received signal level will fluctuate and at the same time the threshold detector has to track this fluctuation in order to determine the optimum decision point (H. Yamamoto & T. Ohtsuki, 2003). As a result this will need a great design challenge, as the channel noise and fading will have to be continually tracked for the OOK in FSO to perform optimally. If ignoring the signal fluctuation and just let the OOK FSO system operate with a fixed threshold level will cause the increment of detection error (E. J. Lee & V. W. S. Chan, 2004).

By using a phase screen diffuser which is mounted at the laser exit of transmitter, it can reduce the scintillation index and enhance the FSO performance. Nevertheless the use of the phase screen diffuser will attenuate the power transmit due to the expended of
beam divergence cause by the diffuser effect. Consequently more less power will be received at the receiver detector. The effect of diffuser also will become less effective when increase to strong turbulence. This condition will not give the advantage over FSO to improve the overall performance. Therefore the new DDM overcomes this limitation of CIM/DD-OOK where optimizes the diffuser effect, increases the power received and fix to zero threshold level signal to create robust modulation against atmospheric turbulence effect.

1.3 Research Objectives

The new DDM technique designed is because of the limitation CIM/DD-OOK in threshold detection process which cause the increasing of BER when experiencing scintillation effect. The use of diffuser can reduce the scintillation index but it limitation can weak the signal power. Therefore the DDM aim to improve threshold detection signal, enhance the signal power and increase the reduction of scintillation index. Therefore the main objectives of this research are stated below:

a) To develop a new modulation technique with optimize the diffuser effect, increase the power received and improve the threshold signal level

b) To develop a mathematical derivation for a new modulation technique

c) To analyze the theoretically and simulated performance of a new modulation technique
1.4 Scope of Work

Figure 1.1 shows the scope of research to develop the new modulation technique. This can be effectively guided the direction of research and can focus on the research contribution. Basically this research is under the terrestrial FSO and can divide into three main challenges that are effect of absorption and scattering (fog, aerosol, and smog), the effect of atmospheric turbulence and eye and skin safety. We focus on the atmospheric turbulence effects which focus on the scintillation effect that cause the FSO experiencing signal fading. In order to mitigate the scintillation effect five methods can be implemented. The first is adaptive optics where this approach does not require wavefront measurements which are difficult to obtain under strong scintillation conditions typical for many communication scenarios. It is based on the direct optimization of a performance quality metric such as the communication signal strength. The second is forward error control (FEC) which aims to manage the bound error variability within certain limits to improve the link reliability. The third is diversity technique which can be divided into two parts; a) spatial domain technique and b) temporal domain technique. The fourth method by using the modulation technique and lastly, employ the partially coherent beam (PCB) over the FSO system. A new modulation technique is based on the modulation technique with using partial coherent beam.
Figure 1.1: Scope of research

Terrestrial Free Space Optic

- Fog, Aerosols, Smog
- Atmospheric Turbulence
  - Coherence degradation
  - Beam spreading
  - Signal fading (scintillation)
  - Image dancing

- Eye and Skin Safety
- Modulation
- Adaptive Optic
- Partially Coherent Beam
- Diversity Technique
- Forward Error Control (FEC)

New Modulation Technique - Dual Diffuser Modulation (DDM)

Challenges

Effect

Mitigation Technique

Research Contribution
1.5 Thesis Organization

The remainder of this dissertation is organized as follows. Chapter 2 provides an overview of free space optic to concentrate the effect of atmospheric turbulence, atmospheric attenuation and eye and skin laser safety. This chapter is more focused on literature to mitigate the effect of atmospheric turbulence. There are five mainly effects due to turbulence which will be discuss briefly that are coherence degradation, beam spreading, image dancing, and signal fading. Literature on FSO strengths and issues will be also reviewed in this chapter. Other than that the fundamental of modulation and partially coherent beam will be highlighted in the case study. Chapter 3 discusses the methodology to implement the research. In this chapter will discuss briefly on the research methodology, designing parameters analysis and simulation analysis. This chapter also discuss the noise consideration in research and fundamental on partial coherent beam (PCB) which relate to diffuser part.

Chapter 4 can be divided into two main parts. The first part discusses the development of new modulation technique which will briefly highlight the elements of light source, inverter, phase screen diffuser, photodetector and subtractor. The second part is devoted to a thorough investigation into the new dual diffuser modulation (DDM) technique. The performance of new modulation will analyze interm of signal power, threshold detection, signal to noise ratio (SNR) and bit error rate (BER). It will be compared with the conventional intensity for direct detection on-off keying (CIM/DD-OOK). The mathematical model for DDM also covered. The Chapter 5 is more focus on the performance of the DDM technique in the presence of turbulence and concentrate under strong turbulence effect. The mathematical model with presence of
turbulence will be included to analyze the new modulation technique. The simulation result is discussed also in this chapter to compare and validates the theoretical results. Finally, a review of all investigated systems in this dissertation is conducted and the results obtained for the new modulation technique are also summarized in the Chapter 6. In addition, the contribution of the research will be highlight as well and also the future work are discussed in this chapter.
CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter delivers the review of contemporary research, theories and principles of FSO systems of study. It encircles the overview of terrestrial free space optical, the effect of atmospheric channel such as atmospheric attenuation, atmospheric turbulence and laser safety. In this chapter we also discuss in brief the mitigation methods to reduce turbulence induce fading effect. The overall of the background study can be described in Figure 2.1.

![Figure 2.1: Literature background of study](image-url)
2.2 Overview of Terrestrial Free Space Optic Communications (FSOC)

The terrestrial FSO communication is a line-of-sight (LOS) technology that transmits a modulated beam of visible or infrared light through the atmosphere for broadband communications. In a manner similar to fiber optic communication, FSO uses Light Emitting Diode (LED) or laser (Light Amplification by Stimulated Emission of Radiation) point source of data communication. The basis of FSO communication is illustrated in block diagram Figure 2.2.

![Basic FSO diagram](image_url)

**Figure 2.2: Basic FSO diagram (Weichel H., 1990)**

Basically the FSO communication can be divided into three main parts which consist of a transmitter, atmospheric channel and a receiver (O. Bouchet, 2005). The transmitter part has the primary duty of modulating the source data onto the optical carrier, which then propagates through the atmosphere to the receiver. The most widely used modulation type is the intensity modulation (IM), in which the source data is modulated onto the intensity of the optical radiation. In the atmospheric channel part consists of three main effects. Firstly is absorption, which occurs primarily in response to water particles and also contribute by gases, but quite a small effect when compared with