



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

**By**

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# **Pembangunan Satu Teknik Baharu Dwi Peresap Pemodulatan Untuk Mengurangkan Kesan 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 mengesan 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 melemahkan 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 menyiasat kuasa isyarat, isyarat tahap ambang, isyarat kepada nisbah bising dan kadar ralat bit. Akhir sekali, bahagian ketiga adalah mensimulasi 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 mengesahkan 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 mengesan isyarat yang lemah sehingga -18dBm. Sementara itu, bagi CIM/DD-OOK dengan dan tanpa peresap adalah pada -14dBm dan 0dBm masing-masing dengan kuasa yang berbeza diterima kira-kira 4dBm dan 18dBm atau bersamaan 66 peratus dan 99 peratus peningkatan. Dalam menganalisis kadar bit, kadar data penilaian adalah dari 622Mbps sehingga 10Gbps. Analisa menunjukkan bahawa apabila sistem FSO beroperasi di bawah kesan pergolakan yang kuat dan jika kuasa menerima ditetapkan pada -10dBm, dengan jelas teknik DDM menunjukkan prestasi unggul jika dibandingkan dengan teknik modulasi OOK konvensional. Pada 2.5Gbps, 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 3km perambatan dengan mempertimbangkan 0dBm kuasa menghantar, panjang gelombang 1550nm dan kekuatan peresap  $l_c = 0.01$ , kuasa yang diterima adalah -4.59dBm dan dibandingkan dengan konvensional OOK yang menggunakan peresap hanya -7.6dB yang sama dengan 3dBm perbezaan atau kira-kira 100 peratus peningkatan. Dari segi prestasi BER, DDM boleh meluaskan penyebaran jarak dengan peningkatan kira-kira 42 peratus. Oleh itu perlaksanakan teknik modulasi DDM baharu adalah lebih baik daripada teknik modulasi konvensional untuk mengesan 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 transmit, 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.

## LIST OF ABBREVIATION

APD	Avalanche Photodiode
AWGN	Addictive White Gaussian Noise
BER	Bit Error Rate
CIM/DD-OOK	Conventional Intensity Modulation Direct Detection On Off Keying
CW	continuous wave laser
DDM	Dual Diffuser Modulation
DFB	Distributed-Feedback Lasers
FCC	Federal Communication Commission
FEC	Forward Error Control
FP	Fabry-Perot
FSO	Free Space Optic
FWHM	Full Width Half Maximum
Gbps	giga bit per second
LED	Light-Emitting Diodes
Mbps	mega bit per second
PCB+OOK	Partially Coherent Beam On Off Keying
PDF	Probability Density Function
SDH	Synchronous Digital Hierarchy
SNR	Signal to Noise Ratio
VCSEL	Vertical-cavity Surface-Emitting Laser

# 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 interm 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 deteriorate the quality signal of FSO that are atmospheric attenuation and atmospheric turbulence as reported in (D. Kedar, 2004 & X. Zhu, 2002 & S. Karp, 1988 & S. Bloom, 2003 & D. Kedar, 2003). In the atmospheric attenuation will cause 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 impair 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.

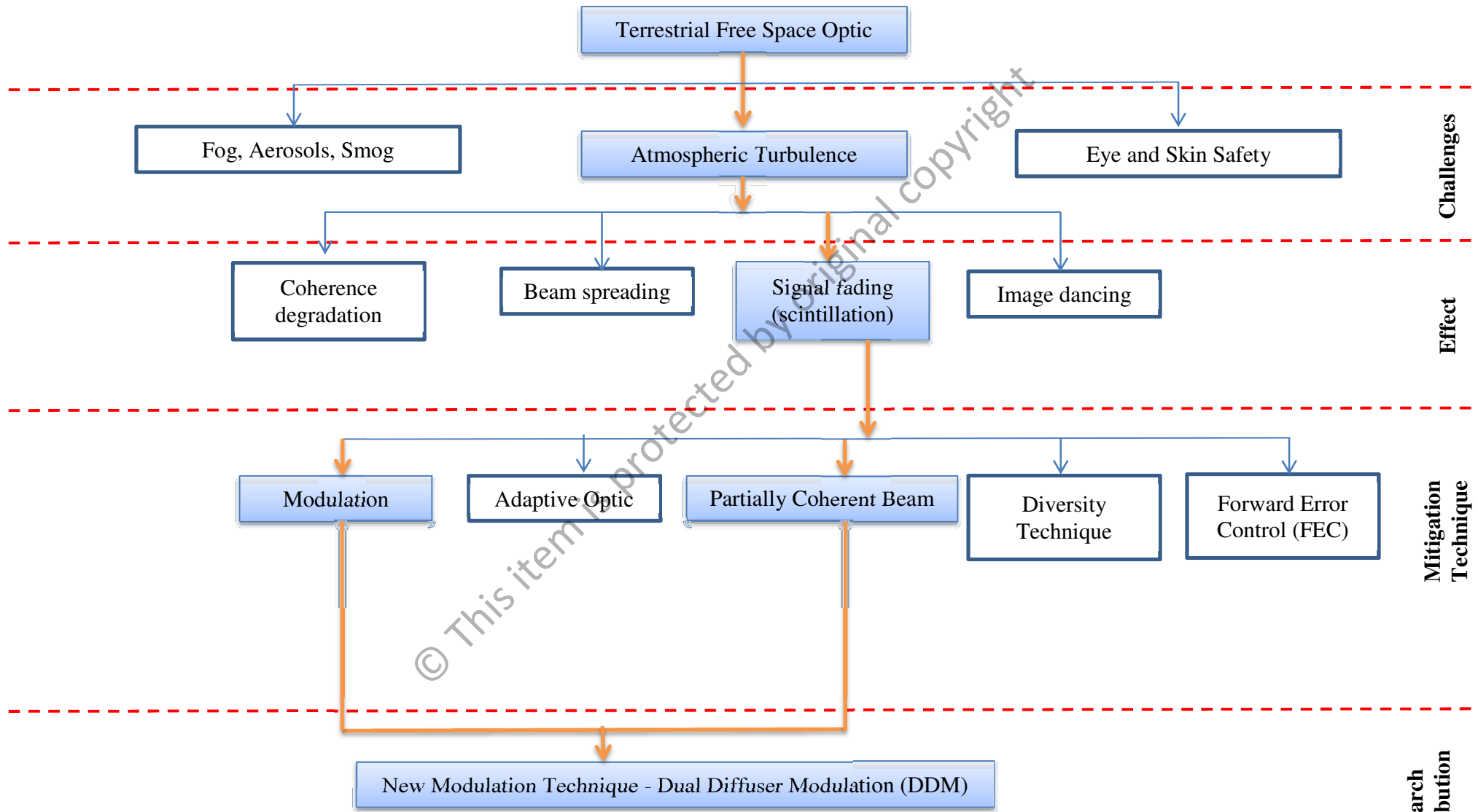


Figure 1.1: Scope of research

## 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 main effects due to turbulence which will be discussed 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 in terms 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.

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## 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.

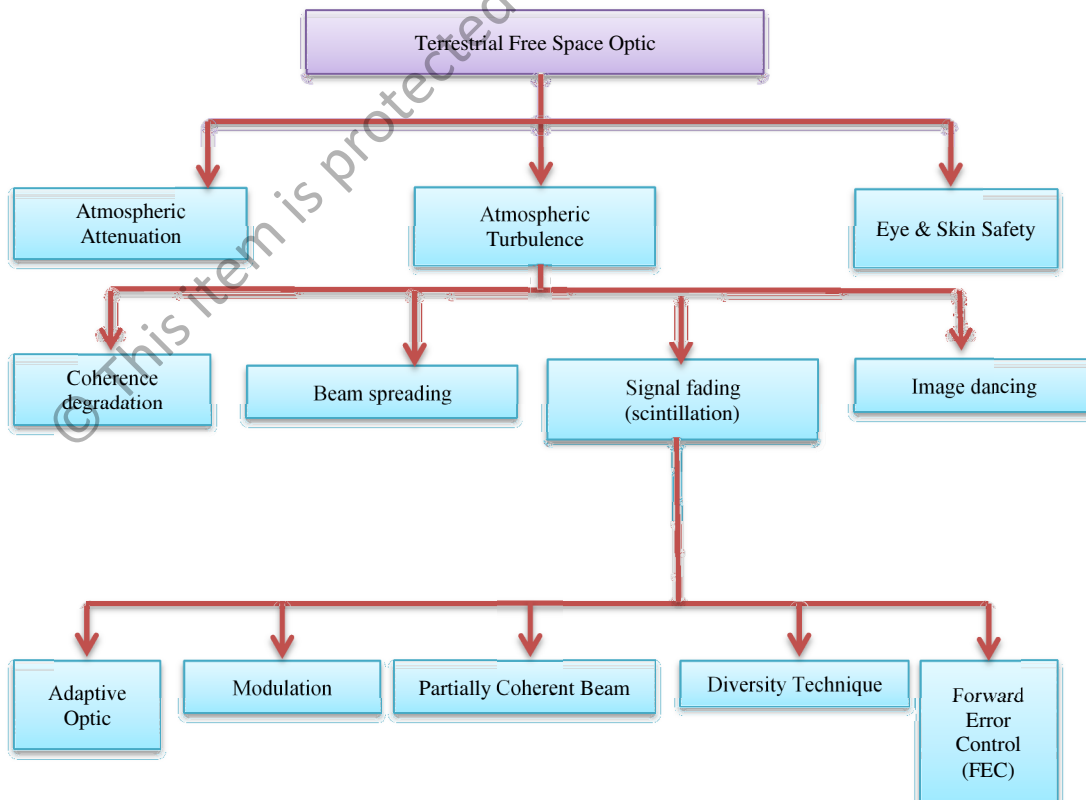


Figure 2.1: Literature background of study

## 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 a Light Emitting Diode (LED) or laser (Light Amplification by Stimulated Emission of Radiation) as a point source of data communication. The basis of FSO communication is illustrated in the block diagram in Figure 2.2.

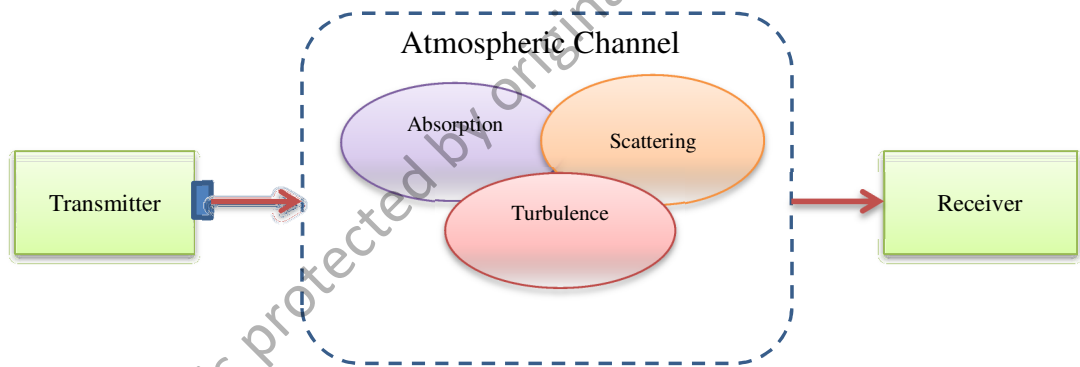


Figure 2.2: Basic FSO diagram (Weichel H., 1990)

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. 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

water absorption (B. Bova & S. Rudnicki, 2001). This effect causes a decrease in the power density of the FSO beam and directly affects the availability of a system. However, the use of appropriate power, based on atmospheric conditions, and use of spatial diversity helps maintain the required level of network availability (Z. Kolka, 2007). Secondly is scattering which occur when the wavelength collides with the scattered. The scattering will not cause the loss of energy but only a directional redistribution of energy will may have significant reduction in beam intensity for longer distances (Earl J. McCartney, 1997; E.B. Zyambo, 2001). Lastly is a turbulence effect where occur when radiation strikes the Earth from the Sun. Some of the radiation is absorbed by the Earth's surface and yielding heating up the Earth surface air mass. This mass of warmer and lighter air will mix turbulently with the surrounding cooler air mass which causes the fluctuation over signal transmission (N. Araki & H. Yashima, 2005).

Terms of advantages of FSO technology communication over fiber communication, the FSO is not requiring the licensing from the Federal Communications Commission (FCC). Unlike the RF communication need the licensing for frequency allocation due to RF use the frequency that less than 300 GHz (Lumenlink, 2003). Apart from that the FSO can support the bandwidth up to 2.5Gbps if compare to RF limited to 622Mbps. The further study has successfully tested 160Gbps in laboratories and speed could potentially be able to reach Terabit range (Rockwell, 2001). The FSO also has an attractive alternative to the excessively high cost of digging the street to lay the fiber and requiring permission from authorities for installation. This technology transmission only needs a place on a roof or behind a window to set up a transceiver. The duration of installation can be made over within a few hours or one day (Sona, 2001).