INVESTIGATIONS ON INTER-SATELLITE OPTICAL WIRELESS COMMUNICATION

A Dissertation Submitted in Partial Fulfillment of the Requirement for the Award of the Degree of

MASTER OF ENGINEERING

In Wireless Communication

Submitted By

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DECLARATION

I, Ravneet Kaur hereby declare that the work presented in this thesis entitled "Investigations on Inter-satellite Optical Wireless Communication" in partial fulfillment of the requirement for the award of degree of Master of Engineering in Wireless Communication submitted at Electronics and Communication Engineering Department, Thapar University, Patiala is an authentic record of work carried out under the supervision of Dr. Hardeep Singh (Assistant Professor, ECED, Thapar University) from 2015 to 2017. The matter presented in this dissertation has not been submitted either in part or full to any other university or institute for the award of any other degree.

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It is certified that the above statement made by the candidate is correct to the best of my knowledge and belief.

Date: 13-07-2017

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ABSTRACT

The lightwave communication systems are capable of transmitting the signals at very high speeds. Distances up to thousands of kilometers are covered using LASERS and LED's as light sources. Inter-satellite link (ISL) has great significance for the global coverage with high rate switching and processing abilities. This concept extents lightwave communication technology into the space technology and the Inter-satellite Optical Wireless Communication. Inter-satellite optical wireless communication link exploits the intermixed features of two most powerful communication technologies Wireless and Optics to transmit data between two points using lasers. This technology is useful where fiber optic cable is impractical. Investigations have been carried out of the system for different linearly polarized modes such as LP_{00}, LP_{01} and LP_{02} with return-to-zero (RZ), non-return-to-zero (NRZ) and compressed-spectrum-return-to-zero (CSRZ) modulation formats at varied data rates in terms of Q-factor and eye diagram. A comparison of the three modulation formats is formulated. As the performance of IsOWC is extremely affected by system data rate because Q-factor decreases with increase in the data rate. So results are taken at varied data rates of 5-50 Gbps. The projected setup is simulated for three diverse modulation formats RZ, NRZ and CSRZ using LP_{nm} modes with input power of 0 dBm and transmission distance of 1000 km at operating wavelength of 1550 nm. It has been observed that for any LP_{nm} mode Q-factor increases with increase in Tx/Rx aperture diameter. Results demonstrate successful transmission of LP modes through IsOWC link.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

IsOWC	*Inter-satellite Optical Wireless Communication*
ISL	*Inter-satellite Link*
OWC	*Optical Wireless Communication*
APD	*Avalanche Photo Diode*
TT&C	*Telemetry, Tracking and Communication*
LED	*Light Emitting Diode*
ILD	*Injected Laser Diode*
RF	*Radio Frequency*
LP	*Linearly Polarized*
FSK-CM	*Frequency-Shift Keying Coherence Multiplexing*
RZ	*Return-to-Zero*
NRZ	*Non-Return-to-Zero*
CSRZ	*Compressed-Spectrum-Return-to-Zero*
BLSIL	*Broadband Laser Inter-satellite Link*
LOS	*Line of Sight*
BER	*Bit Error Rate*
GNSS	*Global Navigation Satellite System*
RF	*Radio Frequency*
QPSK	*Quadrature Phase Shift Keying*
QAM	*Quadrature Amplitude Modulation*
WDM	*Wavelength Division Multiplexing*

CHAPTER 1

INTRODUCTION

An enormous development and progress is witnessed in information and communication technologies from recent years. Lightwave communication systems aree beneficial in transmitting signals at very high speeds. Thousands of kilometers of distances are covered due to these high speed systems at speed of light. LASERS and LEDS's as light sources are being used in these communications systems for high speed operation [1]. This concept emerges the opportunity of using lightwave communication or optical wireless communication technology into the space technology. So the Inter-satellite Optical Wireless Communication (IsOWC) is established [2]. The inter-satellite link(ISL) have significant part for globally covering the area with high rate switching and processing abilities. High-capacity inter-satellite communication enables more effective and more consistent operation of satellite systems in future. Crosslinks can attain connectivity between the opposite side terminals of earth without a need for high cost intermediate ground relay stations.

In June 2015, it has been seen that there are 17,142 satellites that orbits around the Earth and are growing every year in a large amount. Simultaneously, Optical Wireless Communication (OWC) technology has progressed in years. These manmade satellites are developed for the convenience and ease of mankind [3]. The benefits included are research, communication, weather forecasting and military purposes.

The optical wireless communication is utmost widespread due to the following advantages:

1. License is not compulsory.
2. Radio frequency interfaces are resisted.
3. Safety measurements.
4. Greater bandwidth. (Several Gbps).
5. It is tough tapping or jamming the signal because of the narrow beam angle.
6. Wireless Optical Communication prevents polluting the atmosphere with electromagnetic radiation.
7. Communication is made faster.
8. Size and weight of antenna is small.

9. Efficient power.
10. Precision is high.

These reasons are very important in a satellite communication system as they decrease the loads and resulting in reduction of cost [4], [5].

1.1 INTER-SATELLITE OPTICAL WIRELESS COMMUNICATION (IsOWC)

From last few centuries, government organizations, corporations, academies, and individuals in numerous places have done incredible technical evolution in optical wireless communication. Intersatellite Optical Wireless Communication refers to the data signals that are transmitted through the transmitter to the receiver through vacuum that is the free space between the satellites. This kind of communication between two satellites is referred as Inter-satellite Optical Wireless Communication (IsOWC) [6]. Therefore, IsOWC links the satellites in the similar or in dissimilar orbits. In IsOWC, source of light is LASER. Light travels at speed of $3*10^8$ m/s. Signals between the satellites can be sent with minimal delay. The space being, vacuum, distortion and attenuation are also minimized. An evolutionary space network can be formed from satellites serving as both backbone and user-access nodes connected via high-speed ISLs. In optical communication between two satellites, information is modulated with a carrier signal before transmitting. This is a light signal from laser diode. It is then transmitted through free space. On the receiver side a receiver with a photo detector detects the light signal. The photo detectors generally used are Avalanche Photo Diode (APD) or PIN Diode. The light signal is detected and is converted back to its original electric signal [7]. An evolutionary space network can be formed from satellites serving as both backbone and user-access nodes connected via high-speed ISLs. The Figure 1.1 shows the optical communication between two satellites. Figure 1.2 shows how the inter-satellite laser links covers a large area of the Earth’s surface.

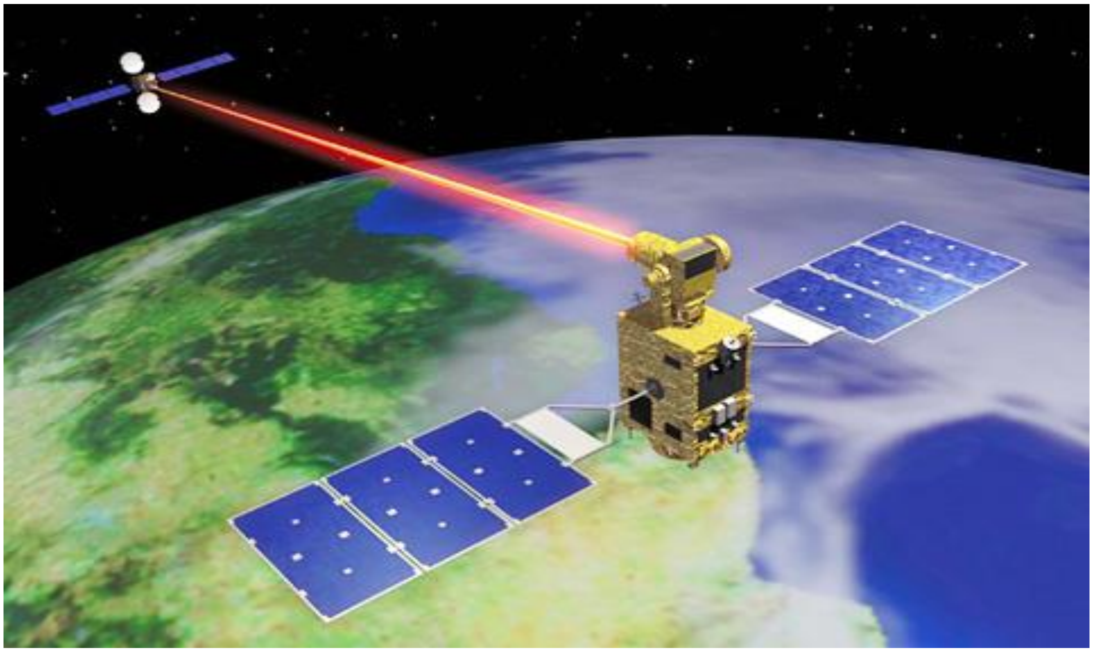


Figure 1.1 Inter-satellite Optical communication [30]

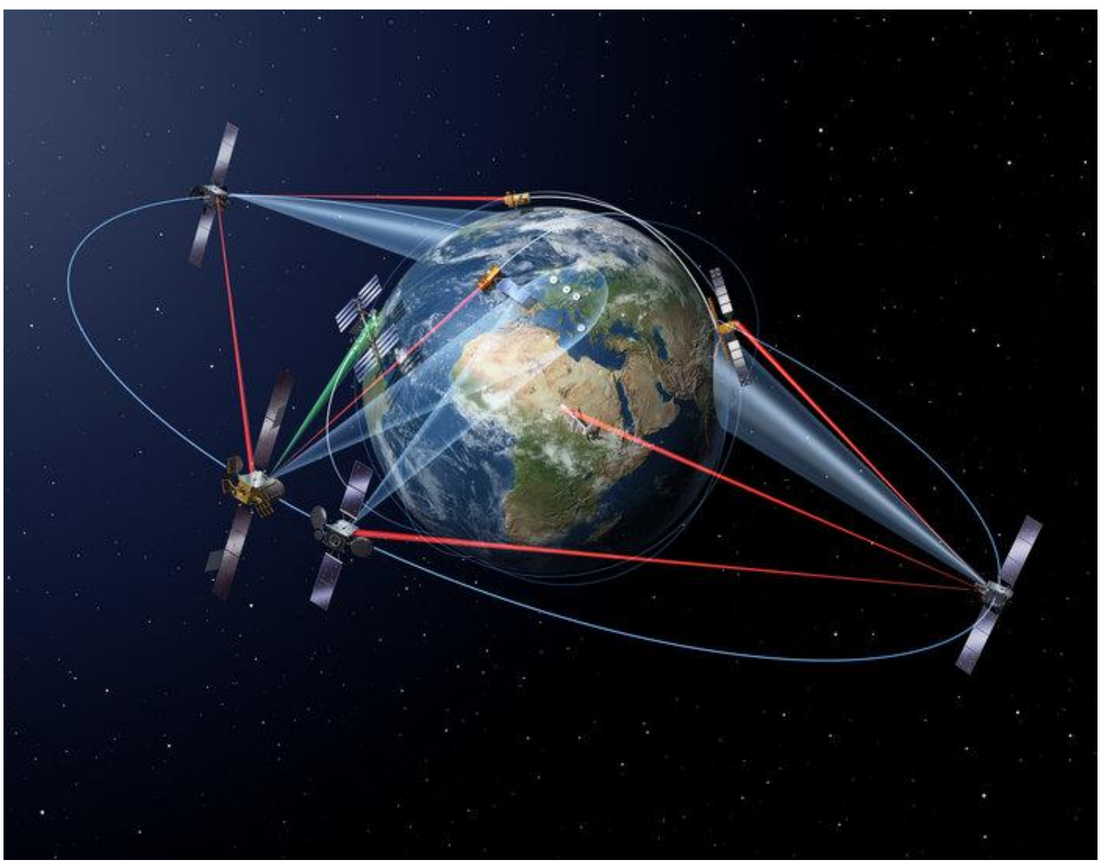


Figure 1.2 Inter-satellite laser links around the Earth [30]

In Inter-satellite Wireless Optical Communication (IsOWC) the signals between two satellites are transmitted through optical communication [8]. The medium used for transmitting the signal between the satellites is the free space between them. The Figure 1.3 represents the basic block diagram of Inter-satellite Wireless Optical Communication (IsOWC).

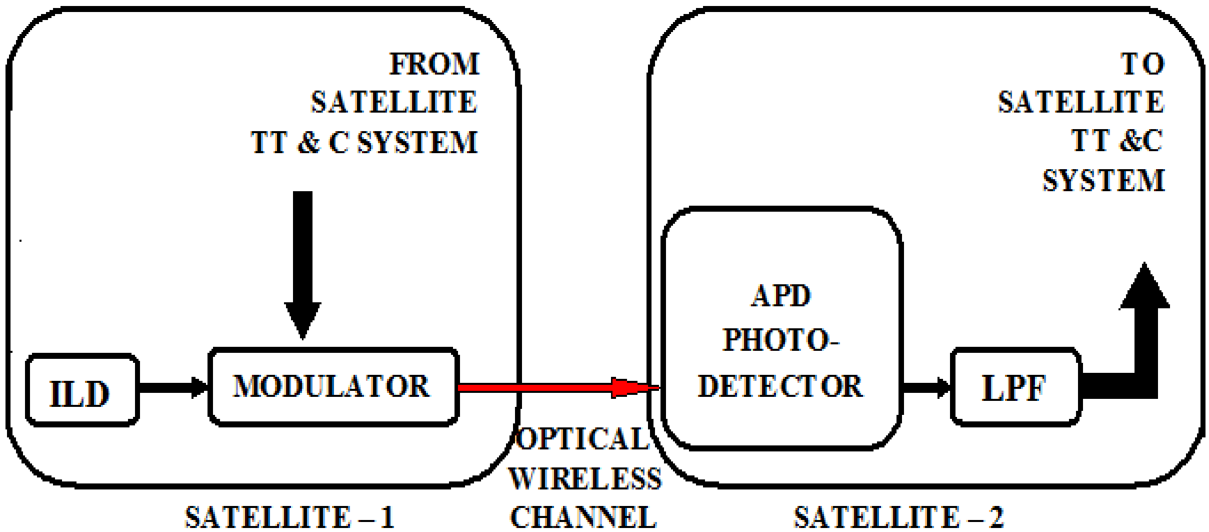


Figure 1.3 IsOWC basic system block diagram for simplex communication [30]

1.1.1 Transmitter

The transmitting satellite consists of LASER which is used a source for generating light, satellite telemetry, tracking and communication system and an optical modulator. The IsOWC transmitter receives information from the satellite's Telemetry, Tracking and Communication (TT&C) system [9]. The information which is generally transmitted by a satellite is same as the location of the satellite and tracking of attitude, picture capturing the data that is usually transmitted by a satellite are such as the satellite location and attitude tracking for isolated detecting satellite and speech data intended for handset system conveying satellite. The most substantial component in the system is light source as communication is done by transmitting light. Two types of optical light sources are used in optical communication, i.e., Light-emitting diode (LED) and injected laser diode (ILD). Formation of these devices is done by semiconductor materials with the interaction of positive and negative charges semiconductor yielding photons or light energy. Emission of light from ILD monochromatic, coherent and has inordinate vivacity making it appropriate for covering large distance for transmitting in free space [10], [11]. The main difference between laser and LED is that light emitted by laser travels considerably futher than the light produced by the LED. Therefore, ILD is preferred for IsOWC system.

TT&C system generates the electrical and laser generates the optical signals which are both modulated by an optical modulator before it is ready to transmit into space. The strength of the input light signal is varied corresponding to the electrical signal. It is accomplished by varying the factors like refractive index, reflection factor and transmission factor of the optical modulator which is constructed from fiber waveguide. Figure 1.4 demonstrates the modulation procedure of an optical modulator [12], [13]. The light pulses from the optical modulator are transmitted to the receiving satellite through the transmission medium.

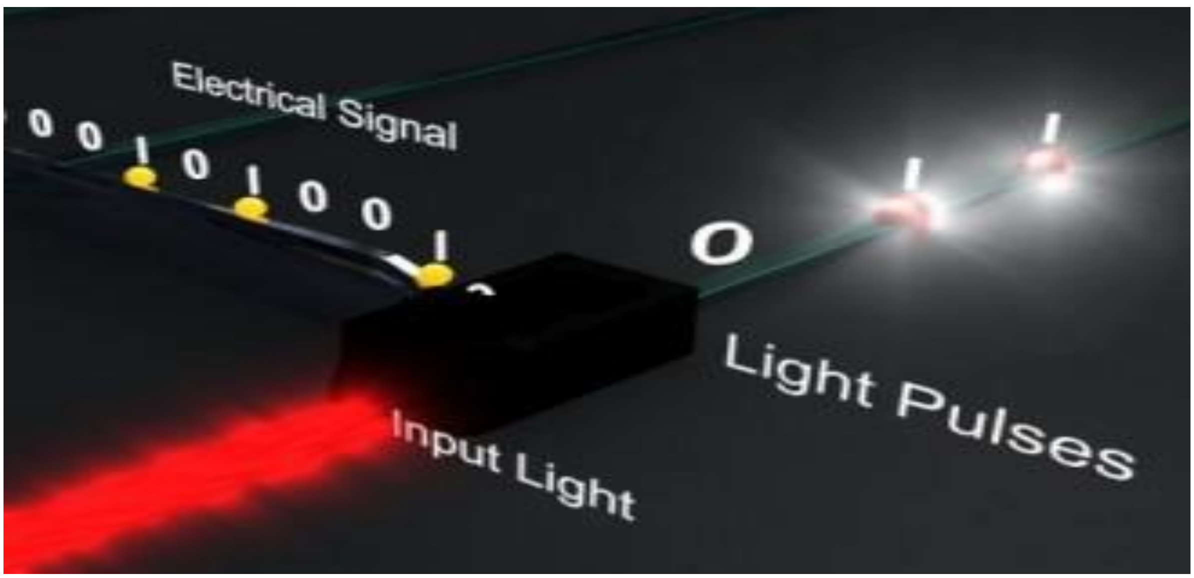


Figure 1.4 Optical modulation processes where input light is varied according to electrical signal to produce light pulses [37]

1.1.2 Propagation Medium

Considering the circumstance of IsOWC system, optical wireless channel is regarded as the transmission medium. OWC channel is vaccum which is free from losses like atmospheric losses contrary to free space optics which is introduced to several losses owing to weather and atmospheric attenuation [14], [17]. Taking the ideal case, transmitting distance is the sole cause signal attenuation. At the transmitter and the receiver side, use of optical antennas or optical lenses is made. The optical antenna permits wider divergence of light beam recognition. An optical antenna is in fact a lens or a telescope that is positioned before and after the transmitting medium as displayed in Figure 1.5.

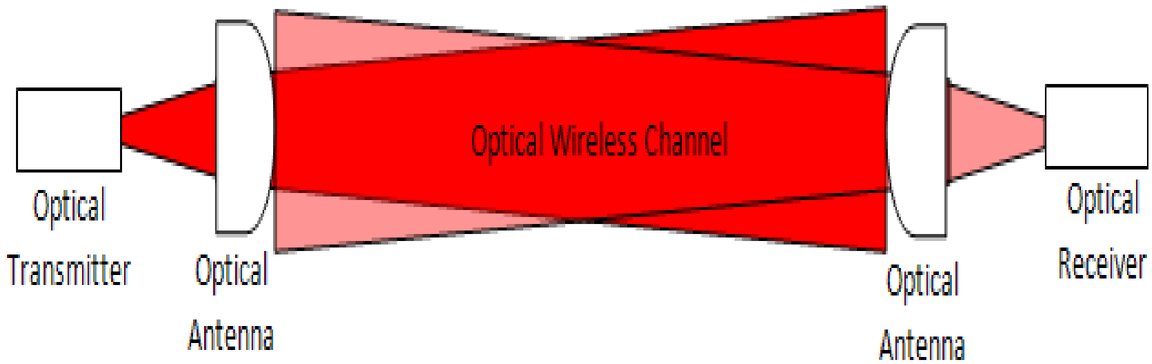


Figure 1.5 Optical antennas at transmitter and receiver side [37]

1.1.3 Receiver

The signal on the receiver side of the IsOWC, includes a photodiode and a low pass filter. The detection of the received signal is done by a photodiode which converts it into an electrical signal [18]. Photodiode comprises of positive and negative charged semiconductor connection, linked in reverse bias just like in an optical light source [19], [20]. The construction for APD photo-detector is shown in Figure 1.6.

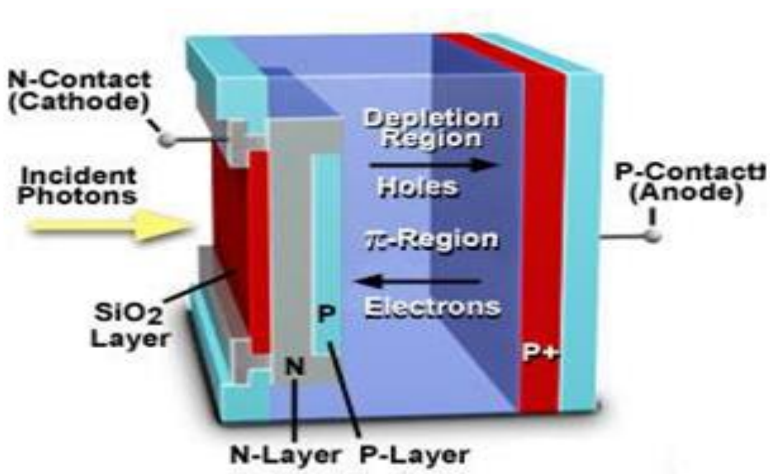


Figure 1.6 APD Photo-detector construction [37]

An electrical signal is generated when photons strike the junction. APD is used because of its distinctive feature of having very large amplification of low or weak light signals in free space optical transmission of data [21]. Amplification or avalanche occurrence in APD photo detector take place during introduction of charged electrons in excessive high electric field region and strike with neutral semiconductor atoms, hence creating additional carriers in huge quantity. PIN Diode can also be used in place of APD.

1.2 OVERVIEW OF SATELLITE

A satellite is an entity orbiting in space around another body. Like Earth has Moon as a satellite and Sun has Earth as a satellite. There are in two categories of satellites in general: (a) Natural satellites (b) Manmade satellites. The natural satellite rotates around orbits of a planet. Earth's natural satellite is Moon [22], [24]. Other planets have several natural satellites. The satellites which are guided in free space by humans are called as man-made satellites. The satellite is referred to as the space segment which composes of the three distinct components: the fuel system, the satellite and telemetry controls, and the transponder. The component dealing with the transmission of the signal is referred to as the transponder comprising of the receiving antenna for gathering the ground place signals, a wide-ranging receiver, multiplexing input and a frequency converter utilized for readdressing the signals with the help of a large powered amplifier for downlink [25]. Primary part of the satellite is reflecting the electrical signals.

1.2.1 Orbital Aspects of Satellite Communication

Orbit is referred to as the path around which a satellite or a planet revolves. As the planets follow a governed motion around the sun, the satellites orbiting around the earth follows the same motion. They all follow a law of motion [26]. Generally, the form is ellipse of satellite orbit with the location of the planet between the two foci of the ellipse. Satellite orbits are classified according to their height of orbit.

(a) Low Earth Orbit (LEO): The satellites which orbit above the surface of the earth at an altitude of 500 to 1500 km are referred to as LEO. The LEO satellites are generally circular in shape. The LEO satellites do not remain at a fixed location comparative to earth's surface [27], [28]. LEO satellites normally take 2 to 4 hours for rotating around the earth.

(b) Medium Earth Orbit (MEO) / Intermediate Circular Orbit (ICO): The satellites which orbits above the surface of earth from 5000 to 25000 km are referred to as Medium Earth Orbit/ICO. In terms of functionality, MEO satellites and LEO satellites are alike. MEO satellites are alike LEO satellites in terms of functions. They cover larger area in comparison to LEO satellites. MEO satellites usually have 4 to 12 hours of orbiting periods [29].

(c) Geosynchronous Earth Orbit (GEO): The revolving speed of objects in GEO stationery orbits have the same speed at which earth rotates. The GEO satellites have a fixed location comparative to surface of earth [30], [32]. The satellite is in equatorial circular orbit with a height of 35,786 km. The time of orbit of GEO satellites is 24 hours. Entire area of the world is covered by three satellites in GEO positioned 120^o spaced out over equator for the purpose of communication. Figure 1.7 illustrates the satellites orbiting around the Earth.

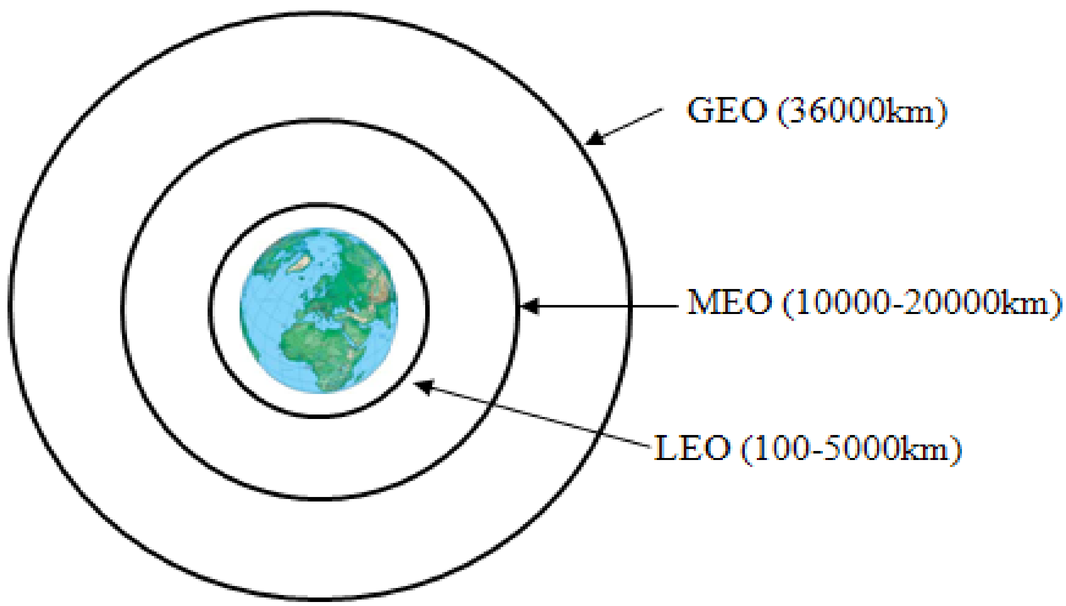


Figure 1.7 Earth satellite communication orbits [30]

(d) Molniya Orbit: The Molniya orbit is used by Russia past many years. The satellite in a Molniya orbit remains in a stationary location comparative to the earth. Molniya satellite orbits in elliptical form. Molniya orbit satellites have an average period of eight hours. When three Molniya satellites are in a series, they can perform as a GEO satellite.

(e) High Attitude Platforms (HAPs): The HAPs is among the latest concept in satellite communication. A blimp about 20 km above the surface of the earth is used as a satellite. Considering coverage area, HAPs have comparatively small coverage area but in matters of signal strength, they have relatively strong signal strength.

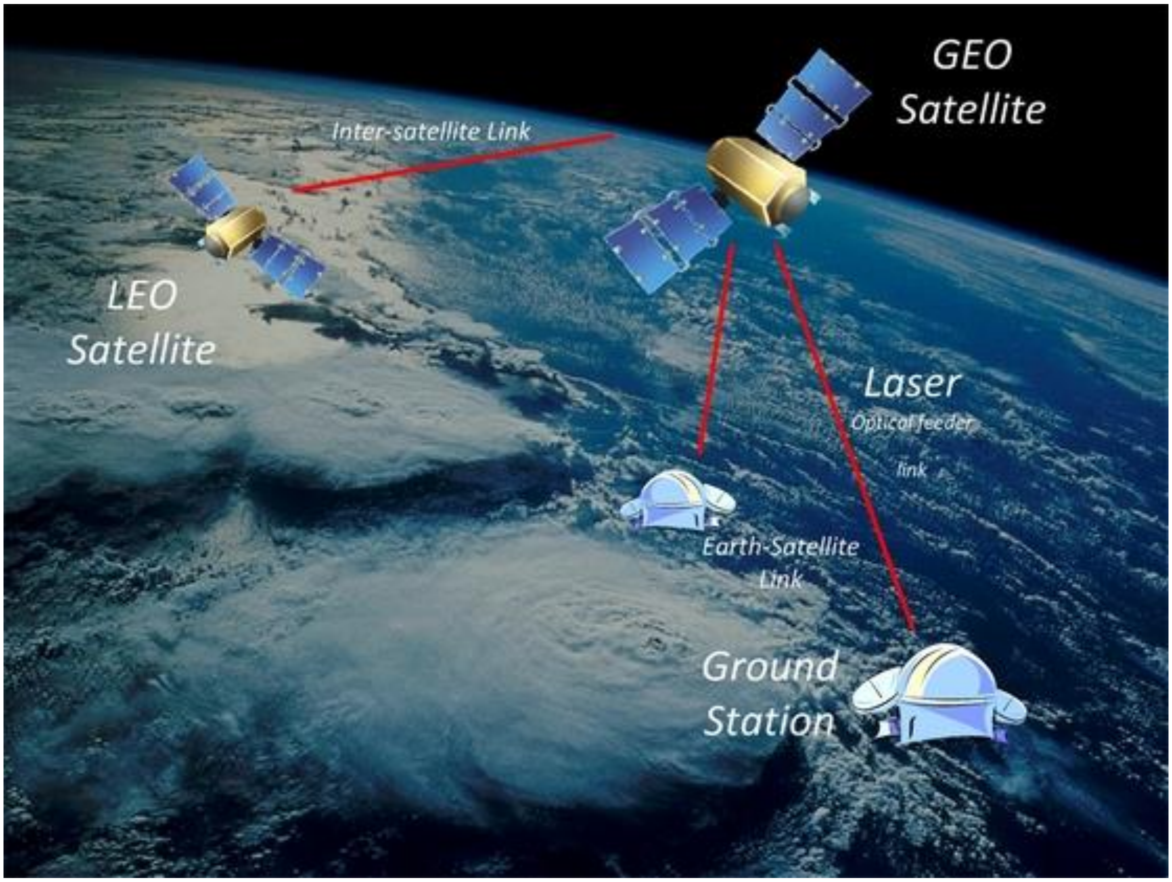


Figure 1.8 Inter-satellite links [30]

1.3 APPLICATIONS OF IsOWC LINK

The light wave system is utilized in numerous forms associated with satellite communication. The variety of uses of Inter-satellite Wireless Optical Communication (IsOWC) can be generally subdivided as:

- Broadband/Internet links
- Deep Space Optical Communications

- Satellite launch support

The IsOWC have other application areas also that include satellite aircraft, deep space, under water and terrestrial communications [33], [35].

1.4 ADVANTAGES OF IsOWC LINKS OVER TRADITIONAL RF OR MICROWAVE LINKS

The conventional ways of wireless communication were completed by Radio Frequency (RF) or Microwave links. In the past years, the inter-satellite optical wireless communication has become famous become due to the following benefits:

1) High Data Rates: It is possible to improve fast inter-satellite links with the help of light as carrier frequency [36]. Data rates up to numerous Gbps are effortlessly accomplished in optical inter-satellite communication.
2) Unlicensed Spectrum: In optical inter-satellite communication requirement of license of spectrum or frequency coordination is not needed for other users as in radio and microwave systems. Interference is not a chief concern from or to systems and also, point-to-point laser signal is tremendously hard to interrupt, making it very secure and safe.
3) Smaller Wavelength: The wavelength of light is about 1000 times smaller than microwaves. Hence, there is a larger difference in the signal wavelength of optical inter-satellite communication over RF/Microwave communication system. In other words, the RF/Microwave wavelength is much longer as compared to LASER light wavelength. Therefore, variation from RF/Microwave to light waves signifies the decrease of the beamwidth of the signal of the order of magnitude [37]. Intensity on the receiver side is increased due to the reduced beamwidth and crosstalk between closer operating links is also reduced.
4) Huge Bandwidth: In a particular communication system, the amount of data which is transported is directly related with modulated carrier bandwidth. Bandwidth of about 2000 THz can be used by by means of optical carrier of high frequencies. Hence, assured increase in capacity of information is offered by optical inter-satellite communication in comparision to communications systems that are based on radio frequency. The reason

behind this being, optical carrier frequency (including infrared, visible and ultra violet frequencies) much superior on the electromagnetic spectrum than radio/microwave frequency. The bandwidth of the frequency that is functional in RF/Microwave range is moderately low.

5) Reducing Antenna Size: The size requirement of the transmitter and receiver antenna is very large and also bulky if RF/Microwave system is to be active. But in optical inter-satellite communication, the antenna size gets reduced to centimeters only, as its carrier frequency is very large, therefore, decreasing the heaviness of the satellite and also reducing power requirement for the communication system [38], [40]. The cost of the satellite is also greatly reduced by decreasing the size and height of payloads of the satellite.
6) Narrow Beam Size: The optical radiation is recognized for its particularly narrow beam and a typical laser beam has a diffraction restricted divergence between 0.01 to 0.1μrad. This demonstrates that transmitting power is focused with a narrow range giving an optical inter-satellite link providing ample isolation from its probable interferers. It is also very tough jamming or tapping the signal with a narrow beam angle ensuring more safety.
7) The other advantages include immunity to the radio frequency interfaces, faster communication, power efficiency, high precision and above all wireless optical communication doesn't pollute the environment with electromagnetic radiations. All the details specified are dynamic in an optical inter-satellite communication system since it can decrease the payloads and therefore decreasing the cost.

1.5 FUNDAMENTAL CONCEPTS OF LP MODES FOR OWC/IsOWC

A lightwave is a form of electromagnetic wave travelling over the vacuum of exterior space. Light waves are created by energetic electric charges. The electromagnetic wave is in the form of transverse wave that has both an electric and a magnetic constituent [42]. In electromagnetic wave travels the vibrations occurs in more than one plane of vibration. The vibrations occur in a single plane in polarized light waves. Un-polarized light is converted into polarized light which is referred to as polarization. Moreover, light intensity profiles broadcast through any medium sustaining the transverse field shape. Consequently, the formed light waves are referred to as Linearly Polarized (LP) modes of light. Light radiated by the sun, by a spotlight in the room, or by a candle flame is un-polarized light. These light waves are formed by electric charges which vibrate in different directions, therefore creating an electromagnetic wave that vibrates in different directions [43], [44]. It is probable to convert un-polarized light into polarized light.

Considering electromagnetic view, different categories of modes (transverse and hybrid) depending upon the angle between electric field vector and axis of transmission medium are there. In other words, the natural modes can entirely be transverse (TE and TM) or have longitudinal elements [45]. Grouping together all different modes into a single series is known as Linearly Polarized (LP) modes. These LP modes can be obtained,

- By changing refractive index of core.
- By changing core size.
- By changing the wavelength of wave.
- By setting a specific Eigen value.

Here, in this proposed work it is not possible to obtain LP modes by means of first two parameters, as modes of light are transmitted through OWC channel, not through optical fiber cable. So, LP modes will be obtained by either changing the wavelength of wave or by setting a specific Eigen value.

1.5.1 Electromagnetic Modes

The Light propagates through any medium in the form of electromagnetic waves as is shown in Figure 1.9.

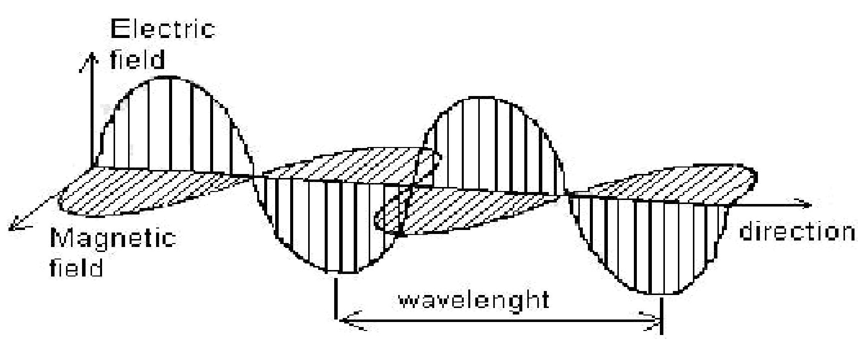


Figure 1.9 Electromagnetic wave [37]

Few Electromagnetic modes of light are shown in Figure 1.10. It is observed from figure that,

- HE_{11} mode has an electric field which is always directed upwards with maximum amplitude at the axis and it decreases as we move radially outwards [46]. The HE_{11} mode is the lowest order mode.

- The TE_{01} and TM_{01} modes have circularly symmetric electric fields. These fields have a maximum electric field at the center and it decreases as we move radially outwards.

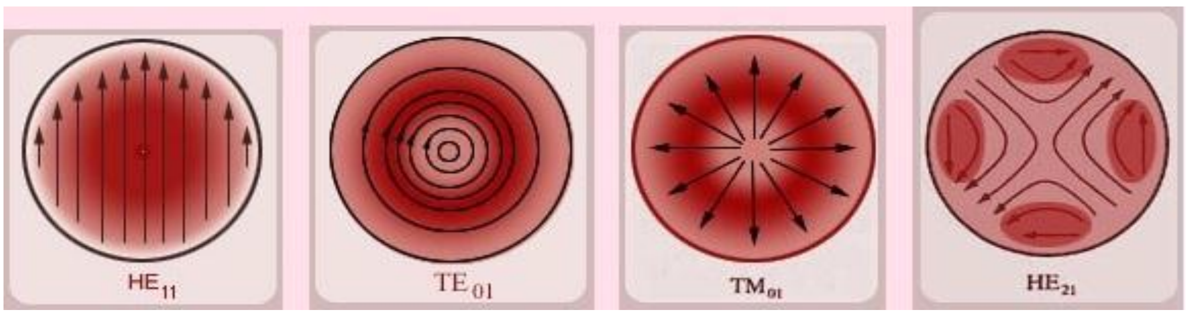


Figure 1.10 Few Electromagnetic modes in optical domain [37]

1.5.1.1 Nomenclature and Indices of EM Modes

To identify the field pattern from the two subscripts written along with the mode, consider the ordered pair (ν, m). The value of 'ν' indicates the behaviour of the field in the azimuthal plane, i.e. the variation of the field with respect to Φ. In other words, it indicates the number of complete cycle variations in the Φ plane. The subscript 'm' dictates the number of zero-crossings, maxima and minima in the azimuthal plane [44], [47]. The number of zero-crossing is one less than the index 'm'. From Figure 1.8, it is clear that for the hybrid mode HE_{11} there is one complete cycle variation in the azimuthal plane for both Er and Eϕ components of the field and the field intensity has no zero crossings in the azimuthal plane though they are decreasing in nature. This can be seen from the Figure 1.11.

Similar observations can be made for the modes TE_{01}, TM_{01} and HE_{21}, and the field variations can be predicted from the knowledge of the two indices of the mode. For TE_{01} or TM_{01} modes, the fields are circularly symmetric about the axis of the transmission medium and have no zero crossings in the azimuth plane. This can be verified from the field pattern shown in the Figure 1.10.

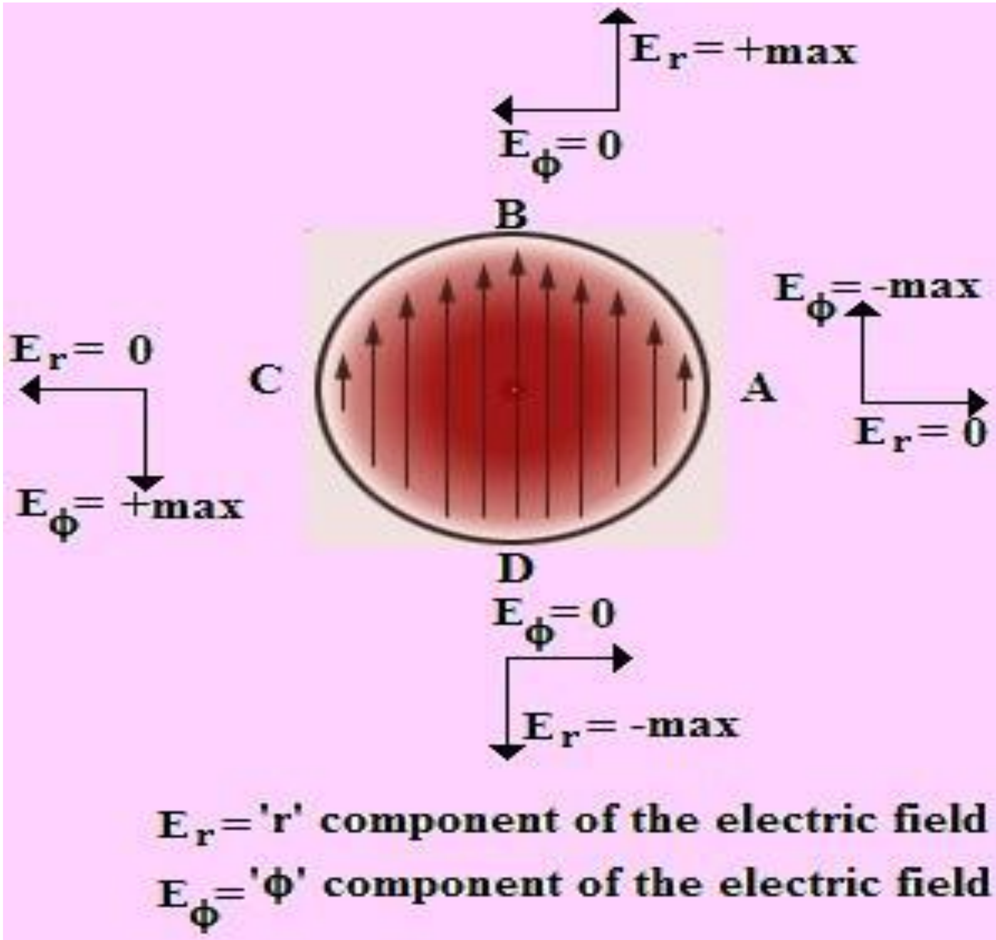


Figure 1.11 Variation of the field components [37]

1.5.2 Linearly Polarized (LP) Modes

It is clear from above discussion that the electromagnetic fields are almost transverse in nature and also they are linearly polarized. This means that the field patterns shown in Figure 1.10 no longer remain so as far as direction is concerned [42]. That is, the fields do show the same intensity variation patterns but they all are now polarized linearly with the same linearity, i.e. all the fields have same polarization orientations. These polarizations may be either vertical or horizontal as shown in the Figure 1.12 below:

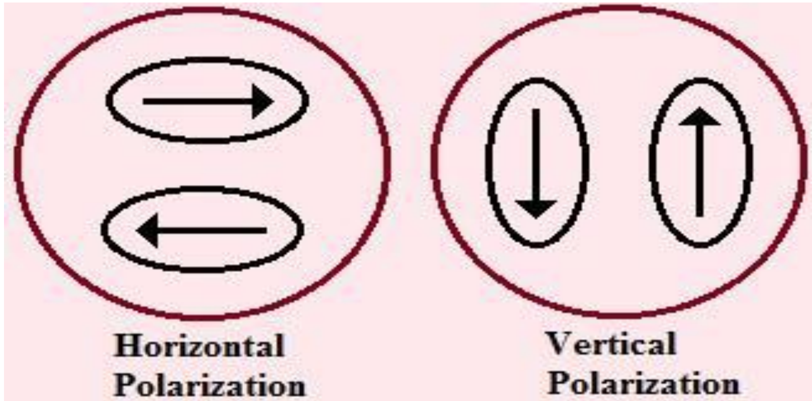


Figure 1.12 Polarizations of the linearly polarized modes [37]

It is observed from the b-V diagram, shown in Figure 1.13, that all the clusters of the modes higher than HE_{11} degenerate to form linearly polarized modes. For example, the cluster TE_{01}, TM_{01} and HE_{21} degenerate to form one single linearly polarized mode. The dominant mode HE_{11} is already a linearly polarized mode as can be seen from Figure 1.8. In almost all practical optical transmissions, one would not find light propagating in the form of TE, TM or HE modes. Light propagates in the form of linearly polarized modes which are briefly called as LP modes. The TE, TM and HE modes thus remain only to academic investigations, because in practice light transmitted through any medium is almost linearly polarized.

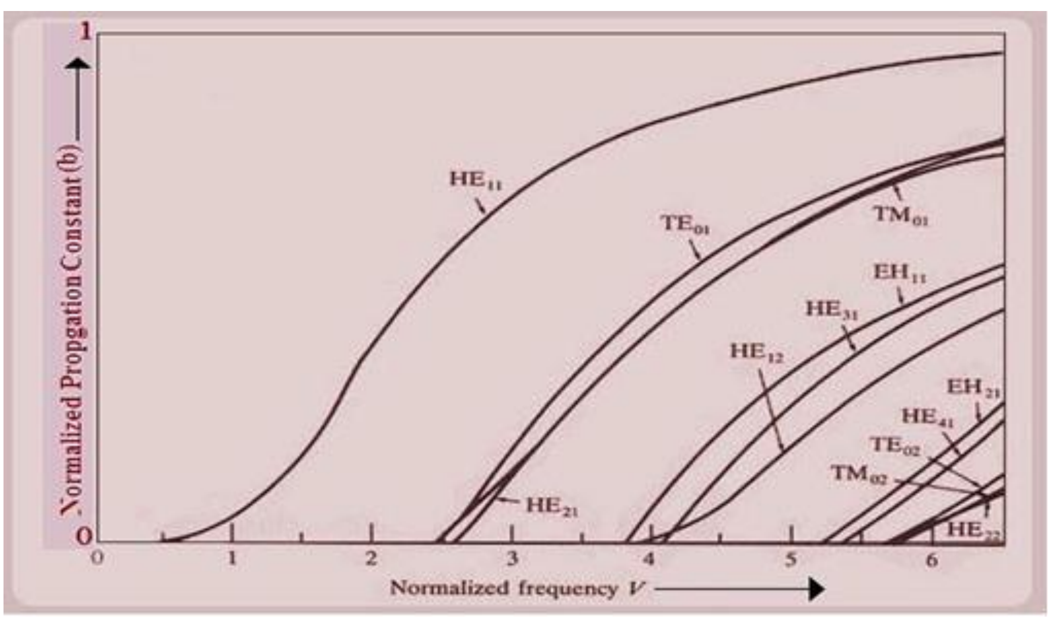


Figure 1.13 b-V diagram [37]

1.5.2.1 Nomenclature and Indices of LP modes

To understand the nomenclature and indices of the LP modes, consider the HE_{11} mode in practical fibers which is referred to as the LP_{01} mode. Note that the first index of the LP mode signifies the variation of light intensity in the azimuthal plane i.e. with respect to ϕ. In case of HE modes the first index showed the field variations in the azimuthal plane and hence had the value 1 for the lowest order mode. But in case of LP modes this index turns into 0 because once the direction of the field has been ascertained, the field intensity is constant at all ϕ for a given value of ‘r’. The second index of the LP modes indicates the number of zero crossings in the light intensity pattern. The number of zero crossings is one less than the index. Hence LP_{01} mode has (1-1=0) no zero crossings in the intensity pattern, though the intensity decreases radially outwards [49]. Similarly, TE_{0m}, TM_{0m} and HE_{2m} modes degenerate into LP_{1m} modes. In LP_{1m} modes there would be one cycle variation in the light intensity in the azimuthal plane and the number of zero crossings would be (m-1). Thus under the weakly guiding approximation, the dominant mode of propagation is the LP_{01} mode. The next mode that propagates is the LP_{11} mode and in such a way all the consequent modes propagate.

1.5.2.2 Basic Modes LP_{01} and LP_{11}

Consider the two LP modes, i.e. LP_{01} and LP_{11} modes. These two modes are very important for long distance optical communication. LP_{01} mode propagates inevitably like the HE_{11} mode and the LP_{11} mode is used for dispersion compensation.

LP_{11}: The LP_{11} mode is created by degeneration of the three modes-TE_{01}, TM_{01} and HE_{21}. So as to have a qualitative glimpse as to how this mode is formed by the degeneration of the above three modes consider the Figure 1.14 below that shows the different possible forms of creation of LP_{11}:

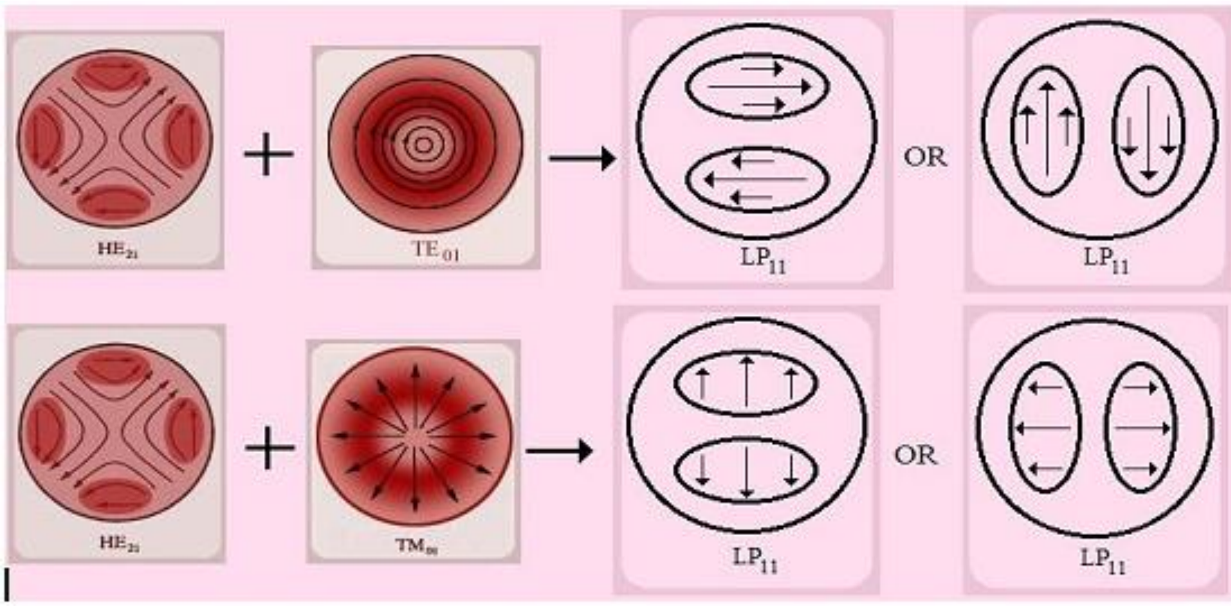


Figure 1.14 Formation of LP_{11} mode from the TE_{01}, TM_{01} and HE_{21} modes [37]

As the figure suggests, there are four possible field patterns for the LP_{11} mode [44]. Thus when somebody speaks of LP_{11} mode it inherently meant four possible field patterns having polarizations and intensity patterns given by Figure 1.14. Thus if light of arbitrary polarization when launched into an optical fiber has an excitation mode of LP_{11}, the light propagating inside the fiber is in fact a combination of the four possible patterns of the LP_{11} mode propagating simultaneously inside the optical fiber.

LP_{01}: Similar possibilities exist for the LP_{01} mode too. The only difference comes due to the circularly symmetric nature of the intensity pattern due to which any angular rotation of the pattern about the axis makes no difference in the intensity pattern but only has a change in the orientation of the polarization. Therefore there are two possible orientations of polarization as shown in the Figure 1.15.

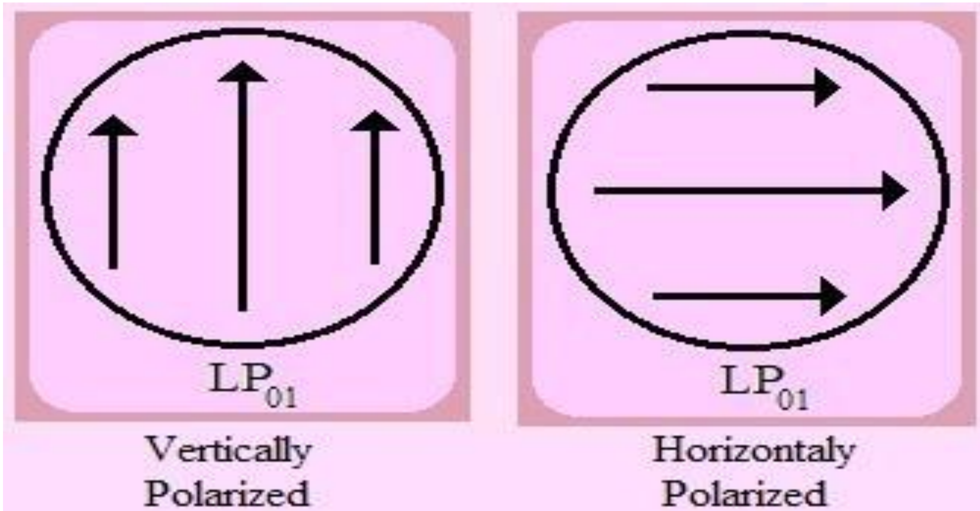


Figure 1.15: Possible field orientations of LP_{01} mode [37]

1.5.3 LP Mode Number

All modes with the mode group number *G* must fulfil the following equation:

$$G = m+2n+1$$

The mode having same group number will have the same phase constant and group delay. Table 1.1 gives some of LP modes groups.

G	Modes
1	LP_{00}
2	LP_{10}
3	LP_{01}
4	LP_{11a} LP_{11b}
5	LP_{02} LP_{21a} LP_{01b}
6	LP_{12a} LP_{12b} LP_{31a} LP_{31b}
7	LP_{03} LP_{22a} LP_{22b} LP_{41a} LP_{41b}
8	LP_{13a} LP_{13b} LP_{32a} LP_{32b} LP_{51a} LP_{51b}
9	LP_{04} LP_{23a} LP_{23b} LP_{42a} LP_{42b} LP_{61a} LP_{61b}

Table 1.1 Primary LP Mode Groups [37]

From the Table 1.1 the amount of modes per group increases with increasing mode group number G, so that even with a high number of modes the number of groups remains relatively small.

CHAPTER 2

LITERATURE REVIEW

For evaluating the advancement and level of research work done till date, in the area of titled work, an extensive literature has been studied. This section comprises of the work done by several researchers in the fields of inter-satellite optical wireless communication. By reviewing the research papers, we gain knowledge of the work that has been accomplished Researched papers are described below:

V.W.S Chan (2003) [4] analysis the creation of an optical satellite network with fast speed space optical crosslink is now achievable with combined space terrestrial network. He explores the construction insinuations of the discovery of such drastic technology constructing block. Improvements in satellite network working and value improvements along with altering properties on space scheme design and data network user applications.

G. Kats and S. Arnon (2004) [5] discuss that space between the satellites when networked together delivers a high data rate midst the satellites. He further states that coherence multiplexing strikes a good method for satellite networking because of being capable of managing the asynchronous behavior of communication stream traffic and dynamic variations dwelling in satellite constellation. Optical radiation produces very narrow beam divergence angle when working for inter-satellite links making it a complex task. There are two reasons for vibrating of the point produced by stochastic essential mechanisms i.e., the noise generated due to electro optic tracker is traced and production of vibrations due to inner satellite mechanical mechanisms and external surroundings. Measured representations of estimated signal-to-noise ratio and the estimated rate of bit-error of optical communication satellite networks as purposes of the system's considerations, the quantity of satellites, and the vibration amplitude for frequency-shift keying coherence multiplexing (FSK-CM) on which harmful consequence of both the sum of satellites and the optical terminal vibration on the system's presentation is calculated.

M. Guelman *et al.* (2004) [6] examined that due to the intrinsic characteristics of laser free-space link like less weight, power efficient, highly précised etc., making it striking for applicant for micro-satellite expansion missions. Investigations done on two ways laser link implementing simultaneous variety of estimated functions among development of spacecraft completed on the framework of Broadband Laser Inter-Satellite Link (BLSIL), a combined Israeli-German investigation scheme. An exceptional method of pointing control system for an inter-satellite laser communication and ranging link is presented where the same laser is used both as a beacon and as a transmitter. The beamwidth is controlled for exploiting the traffic capacity link for narrowing the attainment phase. The pointing control must be high-speed and accurate to uphold the links among the satellites. A two-level scheme switch is projected where the low level lower switches gimbals of optical of the electro-optical transceiver and the higher level is a fast closed loop that simultaneously controls the beamwidth and direction. Primary directing attainment undertakes exchanging the location-related material among the satellites for creating the primary line of sight (LOS).

Vincent W.S. Chan (2006) [8] studies that with the growing and developing optical communications, technology is prepared for operational utilization. The cost is still a problem as they are very expensive for serious considerations. Costs can be decreased by two kinds of developments, the first one considering the enhancement of physical link communications effectiveness by a degree with the help of photon-calculating vacuum receiving channel, structure complication, mass, and space scheme power and the second is by using coherent systems in links where clear-air turbulence impairs communication efficiency, and in numerous admittance claims wherever coherent behavior could decrease the amount of interference, substantial decrease in the cost of system.

F.J. Ghosna *et al.* (2010) [11] explore that it is now probable using different applications like speech, audiovisual, multimedia etc., due to the swift and substantial development of communications links amid the satellites. Numerous researches have been done for decreasing the power ingestion and growing the transmitting reliability. The distinct coding schemes used are: multiple pulse position modulation (MPPM); digital pulse position modulation (DPPM); Dicode pulse position modulation (Dicode PPM). The coding schemes are contrasted considering the weight of error and effective coding taking into consideration the PCM error rate which is influenced by wrong alarm and eliminating faults for MPPM, DPPM and Dicode PPM coding 3 bits of PCM. These coding schemes are compared taking into account sensitivity and efficient bandwidth.

Bernhard Epple (2010) [13] studies that for the understanding of high-bandwidth optical wireless communications is a striking technology. Characteristics of the optical signal and the characteristics of the fiber channel or radio frequency wireless channels are diverse from each for broadcasting through the free space. A channel which can be simply used by protocol designers is essential for estimating fading mitigations procedures. The goal is to develop a simple methodology for demonstrating the receiving power subtleties of the surrounding free-space optical channel. The projected ideal contains an arbitrary amount generator with a low-pass filter, easier for implementation. The establishment of channel is done on the basis of received measuring power from the nautical mobile link, a ground mobile link, and a downlink for satellite.

Zoran Sodnik *et al.* (2010) [15] describe the accomplishments in optical inter-satellite communication on the basis of progresses that began in Europe (European Space Agency) that happened 30 years ago. In the year 2001, establishment of world's first optical inter-satellite link was made which verified that optical communication mastered in free space efficiently. The establishment happened between the SPOT-4 and Advanced Relay and Technology Mission Satellite (ARTEMIS) satellites. Further in the year 2006, Japanese Space Agency (JAXA), an optical bidirectional link was initiated among its Optical Inter-Orbit Communications Engineering Test Satellite and ARTEMIS. Later in the year 2008, the German Space Agency (DLR) created established an inter-satellite link, linking the near-field infrared testing and TerraSAR-X satellites which are founded on the laser communication technology of second generation.

X. Liu (2011) [17] studies that the transmitter sways in azimuth and elevation axis in optical inter-satellite communications are continually imagined as not related. The investigation is extended to the case of correlation. This research demonstrates the immediate signal-to-noise ratio trailng the log-square-Hoyt distribution. Based upon the foundation of this ideal the outage probability can be decreased to a minimum level by a specifying transmitter power and suitably adjusting the transmitter gain.

Wanqing Xie *et al.* (2011) [19] discuss that the working of inter-satellite laser communication scheme could be influenced by optical antenna distortions. On the basis of wavelet analysis a deformation model is presented for the complexity of the external universe atmosphere. Mathematical investigations present the rebuilding error of a localized asymmetrical distortion by wavelet achieving 10^{-12} level that is much better than Zernike polynomials to some extent. Based on the model correlation between the diversified antenna distortions and the consequences on received strength of signal are acquired. The of misrepresentation on the signal received increases with the feature of the model, reducing along with the shifting factor of the model tending to increase due to with irregular instabilities with linearly growing with wavelet model coefficient.

Yuqiang Yang *et al.* (2011) [20] analyses that the system performance of inter-satellite optical communication can be worse due to local deformations in the transmitter lens of optical system. By taking into consideration the combined effect of local deformations and pointing errors the Bit error rate (BER) for on-off keying system is examined, without taking into account the noise factor of the detector. BER diverges frequently by distinguishing factors of resident distortion. Peak-to-valley worth is resolute which is utilized for estimating the machine lens accuracy. Contributions to lasercom system design are investigated.

B. Patnaik and P. K. Sahu (2012*)* [24] proposed an ultra-high bit-rate inter-satellite optical wireless communication (IsOWC) system. The system simulates with up to 400 Gbps bit rate. The projected is a line-of-sight setup which utilizes coherent optical quadrature phase-shift keying (QPSK) modulation method. The method is examined in terms of *Q*-factor, bit-error rate, eye opening etc. The distance covered is witnessed with an input power level of 30 dBm for a bit-rate of 400, 160 and 100 Gbps are 4767, 7542 and 9532 km, respectively. The utmost bit rate inter-satellite link at diverse orbits like low-Earth orbit, medium-Earth orbit and geostationary Earth track are investigated.

Zihang Zhu *et al.* (2013) [27] represents an identical logical statement of signal-to-noise ratio (SNR) for inter-satellite microwave photonics links having a lower biased Mach-Zehnder modulator and utilization of an optical booster amplifier and a preamplifier that are resultant from Bessel expansion and Graf's addition theorem. Restricted clatter is altered from current noise to the signal-amplifier extemporaneous production defeating noise arising due to optical preamplifier and power of the signal seemly grows in comparison with noise power due to optical preamplifier. Therefore, the SNR of the system can be enhanced with optical booster amplifier and an optical preamplifier contrasted with the SNR of optical booster amplifier. A gain of 20 dB for the pre-amplifier gain and 3 dB for noise figure, rise of around 19.7 dB in optimum SNR is achievable. Also, the product of optical booster and preamplifier constraints on the optimal DC bias shifting phase and SNR is examined.

Xianbin Li *et al.* (2014) [28] investigated that the global navigation satellite system (GNSS) could be improved ominously by presenting inter-satellite ranging (ISR). A serious problem is conserving energy for ISR because of restrictions on satellite battery resources. The power allotment in ISR navigation constellation is investigated. Due to high précised space time orientation of GNSS, the transmitter of the satellite can identify the channel dynamic variables of ISR by modes of the navigation. The optimum power allotted can be computed for quality of service (QoS) of ISR before the ranging is entrenched. The dynamic variables process is investigated and a closed form expression is derived for the optimum power allotment. Also, the actual GPS orbit date is used for calculating this procedure. Conceptually, the outcomes show that total energy ingestion can be decreased remarkably.

Zihang Zhu *et al.* (2015) [31] examined the working of optical inter-satellite communications with the help of microwave photonics tools engaging intensity modulation with direct detection (IMDD) and phase modulation (PM) with interferometric detection. The notional model taking into account the saturation expansion and amplifier impulsive production noise of optical booster amplifier and optical preamplifier is fabricated for both designs. Comparison of the working of PM with interferometric detection in contrast with optimum influenced IMDD in expressions of radio frequency (RF) gain, RF noise figure and compression dynamic range (CDR). The mathematical outcomes demonstration that the PM through interferometric recognition can attain improved RF gain, RF noise figure and CDR than the optimum biased IMDD link because th power output of laser is lesser than 14.34, 12.45 and 4.2 dBm, respectively.

Jie Wu and Yu Jian Cheng (2015) [32] discussed the wideband high-gain high-efficiency hybrid integrated plate array antenna for inter-satellite links. This antenna comprises of micro strip patches, substrate integrated waveguide (SIW) and waveguide power partitions. For exhilarating the micro strip sub-array with wideband features, a novel serving assembly is projected. Comparison of the radiation effectiveness of SIW arrays is done. Optimization of the hybrid SIW-waveguide feeding topology is made for high efficiency, low cost and compact formation at the same time. Fabrication of the array antenna is done by typical multi-layer PCB procedure and milling technology. Measured results demonstrate about 14.6% of reflection coefficient bandwidth ($|S_{11}|$<;-10 dB) in the frequency band of 57-66 GHz. Fluctuations in the same band is lower than in the gain is lower than 3 dB. The 1 dB gain bandwidth is 8.1% within the frequency band of 59-64 GHz. The maximum gain is 39.2 dBi at 59 GHz with the efficiency of 41%.

Yuechen Wang, Rui Li and R. Zhao (2015) [33] examined the Inter-satellite links (ISLs) for improving the GNSS's positioning precision and integrity for better consideration. For making certain the accurate position and stability on the basis of ISL a satellite and ground joint positioning mode is investigated by constraining the position error by caliber set. For computing variables and attaining Signal-in-space (SIS) integrity, error ellipsoid is applied for checking the precise mode and performances of monitoring, mixed constellation of Beidou system in support of the analysis is prompted and the impact of high-low ISLs is explored. Results confirm that initiated monitoring technique satisfies the integrity risk of 10^{-5}/h and SIS integrity monitoring is attained.

Yinyin Tang, Yueke Wang and J. Chen (2015) [34] states that a direct sequence spread spectrum (DSSS) signal is frequently used in inter-satellite link (ISL) in navigation constellation but attainment is a deamnding task due to large-scale relative movement between satellites. A signal search (carrier frequency and code phase) is executed by using two-dimensional partitioned fast Fourier transforms (FFTs) restricted by the processor memory. The steadiness of the carrier is ruined by the circular shift. To resolve this problem non-coherent integration is carried out. Due to square loss the attainment responsiveness is decreased. The flow of conventional noncoherent integration procedure and the coherent integration procedure is compensated. Numerical results show enhancement of the sensivity of attaining the weak signals and saving 60% calculating cost.

Jinhui Huang *et al.* (2016) [39] examined that the Inter-satellite link (ISL) will have a significant part in future age of global navigation satellite system (GNSS). Variations in the distance are huge resulting in power loss alteration of upto 20 dB. No progress in terms of spectral efficiency is present till date. An effectual utilization of the adaptive modulation and coding (AMC) scheme for ISLs in the GNSS is investigated. A methodology is proposed for the convenience of estimation of signal-to-noise ratio of the ISLs in GNSS. The process of AMC is conceded according to different algorithms i.e., target bit error rate (BER) algorithm that is functional on the base of inter-satellite distance retained by the BER underneath a target edge and secondly, the throughput algorithm on the basis of inter-satellite distance.. When the distance is short then in that series the results prove that AMC attains about 6 times that of fixed MCS under the assumption of the same transmission power.

Radhika Radhakrishnan *et al.* (2016) [40] states that, an entire new session of navigation tasks, communications, remote sensing is aided by small satellite systems. They also enable research in scientific era for civilian and military purpose both. Small satellites are useful by forming clusters in many scientific missions like mapping of gravity, keeping tracks of forest fires, discovering water resources, etc. they are helpful in many ways. This enables an improved understanding of the environment of Earth and effectively providing an economical admittance of multi-satellite solution. Better spatial and temporal resolution of the aim is provided by these clusters. Upcoming space undertakings are intended to turn into high complexity and work at a large distance from Earth supporting numerous operations with minimum human interactions. As the level of autonomy is growing, it has become a stage for isolated communication networks for providing communication among spacecraft. They will need a way to organize and preserve vibrant routes, accomplish intermediate nodes, and reconfigure itself for attaining objectives of missions. Therefore, inter-satellite communication is an important feature once satellites hover in formation. The implementation is based the open system interconnection (OSI) model. The design parameters are valid to the three layers of the OSI model, i.e., physical, data link, and network layer. Comprehensive framework also represents useful variables for attaining satellite communications for numerous minor satellite tasks.

Pablo G. Madoery *et al.* (2016) [42] examined that the Earth surveillance satellite constellations are ascending as a new prototype having significant benefits in contrast with traditional systems. The perception of Segmented Architecture is for transforming these cluters into a dispersed and associated arrangement for exploitig resource sharing. Numerous technical encounters are executed like packetized space networking communications. Because of the restricted accessibility of transmission of data, these can be demonstrated as delay and disruption tolerant networks (DTN). The author proposed a specific case study of numerous flight-formation satellites envisioned for the reflection of the Earth. Both the accessibility of Earth-to-space links and their obliging combination of inter-satellite links are taken into considearation. Diverse routing schemes such as Contact Graph Routing (CGR) and its extension Multi-Graph CGR (MG-CGR) are examined and matched.

Hemani Kaushal and Georges Kaddum (2017) [46] discussed that free space optical (FSO) communication improved drastically because of its exceptional features: greater bandwidth, spectrum free from license, great amount of data, rapid deploy ability, fewer power and mass necessities. In spite of inordinate potential of FSO communication, restriction in working is there due adversative effects (viz., absorption, scattering, and turbulence) of the atmospheric channel. Atmospheric turbulence is a huge challenge among the three leading to severe deprivation in the performance of bit error rate making the communication link viable. Various problems are faced by FSO communication system for ground-to-satellite/satellite-to-ground and inter-satellite links. For high link accessibility and consistency numerous performance mitigation methods are represented. A major problem is posed to the working of the system due to much impairment for ground-to-satellite/satellite-to-ground and inter-satellite links. For combating the adversative effects of environment numerous methods for physical and other layers is provided. It also exclusively represents a newly established method which used orbital angular momentum for operating the high capacity benefit of optical carrier in case of space-based and near-Earth optical communication links. Facts on using optical backhaul links based on space for providing high volume and lower value backhaul solutions.

Xiaohua Jia *et al.* (2017) [49] presented a satellite system attracting a huge amount of consideration from educational and industrial in past few years. Numerous satellites are launched which are used in predicting the weather, monitoring the environment and target surveillance. Downloading the data is one of the significant tasks which are composed in space to the ground servers via earth stations (ESs). Satellites move at great speed along their own orbits having restricted contact time with ESs therefore they may not be capable of downloading all the data they have to the ground on time. A cooperative system that permits satellites to divest data amongst themselves by means of inter-satellite links (ISLs) before interacting with the ES so that satellites carries the accurate quantity of data in accordance to the span of their interaction time with the ES and the output of downloading the data at the ES is maximized. An iterative optimization procedure is formed that mutually schedules data divest amid the satellites and downloading the data from satellites to the ES. Many simulations have been carried out for estimating the efficiency of the projected technique. The results prove that the data downloading throughput is increased considerably by using ISL. Throughput can even reach close to 100% of the size of the ES.

Tianya Song *et al.* (2017) [50] studied the consequence of pointing errors on the average bit error probability (ABEP) of an inter-satellite laser communication link. The expression in form of closed-form in terms of the Marcum Q -function is computed for instant channel gain. This expression delivers excessive potential in additional presentation investigation and system optimization. Additional simplifications of these limits are achieved and invertible ABEP expressions are assumed. It is easy to gain diversity by using the invertible ABEP expressions linking to the ratio of the correspondent beam radius to the pointing error displacement standard jitter at the receiver.

CHAPTER 3

IMPLEMENTATION AND ANALYSIS OF LP MODES OVER IsOWC LINK USING DIFFERENT PULSE SHAPES

In order to fulfill the objectives mentioned in previous chapters, initially, the model for inter-satellite communication system is prepared.

Inter-satellite optical wireless communication link utilizes the intermixed features of two most powerful communication technologies Wireless and Optics to transmit data between two points using lasers [32]. This technology is useful where fiber optic cable is impractical. In this chapter, a system performance has been investigated for different linearly polarized modes such as LP_{00}, LP_{01} and LP_{02} with return-to-zero (RZ), non-return-to-zero (NRZ) and compressed-spectrum-return-to-zero (CSRZ) modulation formats at varied data rates in terms of Q-factor and eye diagram. Simulation investigation results show that out of all above mentioned scenarios the NRZ modulation scheme performs best. Then the system performance of optimal modulation format-NRZ has been analyzed with varied aperture diameters and input powers for three linearly polarized modes LP_{00}, LP_{01} and LP_{02}. This proposed linearly polarized system analysis illustrates that all linearly polarized modes transverse with same Q-factor and BER over IsOWC channel.

3.1 INTRODUCTION

Over the past couple decades, wireless communications acquired massive popularity, contributing appealing options for several private and administrative communication purposes because of its inherit features such as flexibility, value efficiency, and mobility. The transmission methods for wireless communications which are brought into consideration till now are: *Radio Frequency (RF) and Optical Communications.* But due to its numerous advantages over traditional RF wireless communications, such as large bandwidth, ultra-high data rate, license free, higher immunity to interference, narrower beam width, light weight, low power, low loss and hence low cost, there is a briskly increasing importance in Optical Communications [35]. The Optical Wireless Communication (OWC) has distinct application areas that include satellite networks, aircraft, deep space under water and terrestrial communications. The key technology for realizing such applications by OWC system is the use of lasers as signal carriers. Earlier if we wanted to transmit distinct signals then different wavelength lasers (i.e. no. of lasers) were required, due to which cost of system increases to very large extent. In addition, system complexity increases. One solution to this problem will be use of tunable lasers. Definitely, system complexity reduces to large extent but cost of tunable laser is very high. So this method is not considered effective and efficient. Another solution to the reported problem will be the use of Linearly Polarized (LP) modes concept. As with the use of this concept, it has become possible to transmit distinct signals with same laser (i.e. only one laser will be required). Hence, cost and complexity both reduces at the same time [45]. So, with this proposed work now it has become possible to transmit various distinct signals by single laser, just by altering the mode of transmitted signal. In this chapter, the concept of signal transmission by generating different LP modes through OWC/IsOWC link is presented.

3.1.1 Linear Polarized Modes

Light propagates in the form of Linearly Polarized modes called LP modes. They are used so as to enhance the capacity of IsOWC link. Basically, they are the light intensity profiles (patterns) that propagate through any transmission medium (here IsOWC) maintaining their respective transversal field shapes [25]. Each mode corresponds to a light beam travelling with different angles. They can be obtained by changing the refractive index of core, changing the core size, changing the wavelength or setting the specific eigen value.

The LP modes are normally designated by the factors, the azimuthal mode number, n and the radial mode number, m. For a specific mode, '2*n'* relates to the amount of peak intensity in the azimuthal route and '*m'* corresponding to the intensity over 360 degrees in the radial direction [31]. Figure 3.1 shows the intensity distributions of some LP_{nm} modes.

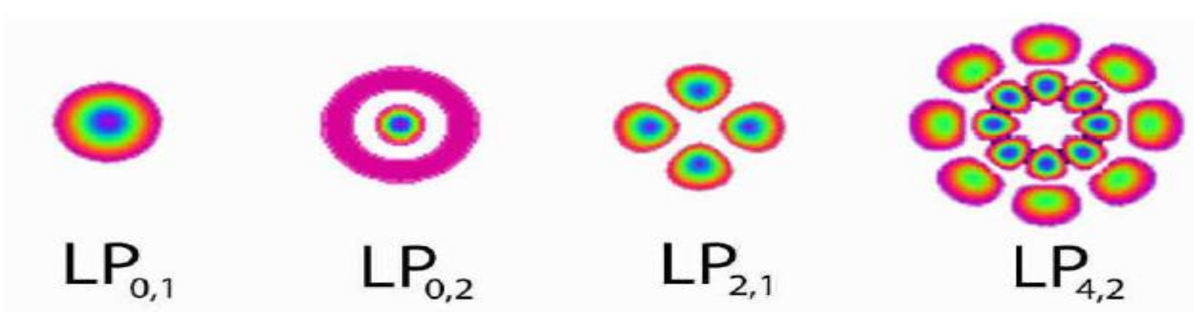


Figure 3.1 LP mode intensity distributions [37]

In this chapter, an attempt has been made to optimize the IsOWC link by incorporating LP_{nm} modes for different modulation formats.

3.2 MODEL DESCRIPTION

This chapter models optical wireless communication system for three different modulation formats RZ, NRZ and CSRZ to obtain different LP mode profiles. This is obtained with the help of single Spatial Continuous Wave Laser (SCWL) at transmitter side or combination of Transverse Mode Generator and CW laser. The SCWL is "ready-to-use" component that encapsulate an optical source and a transverse mode generator. The transverse mode generator has the ability to include transverse mode profiles in the optical signals.

3.2.1 Principle of RZ for LP modes

Figure 3.2(a) shows the block schematic of RZ and Figure 3.2(b) shows actual simulation arrangement for RZ modulation format. The signal is created by passing the RZ signal to the MZ-Modulator. The other input to the MZ-Modulator is from SCWL which is responsible for generation of different LP modes.

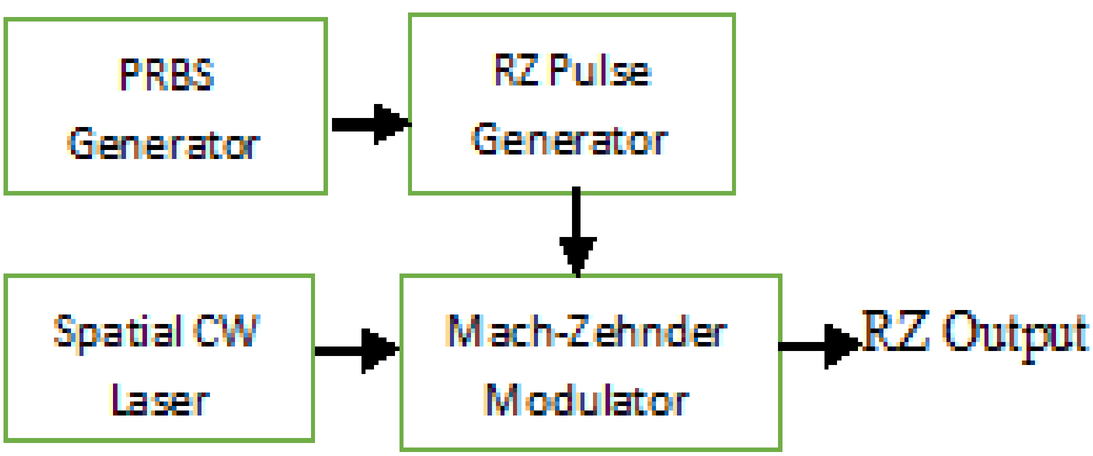


Figure 3 .2(a) Block schematic for RZ modulation format

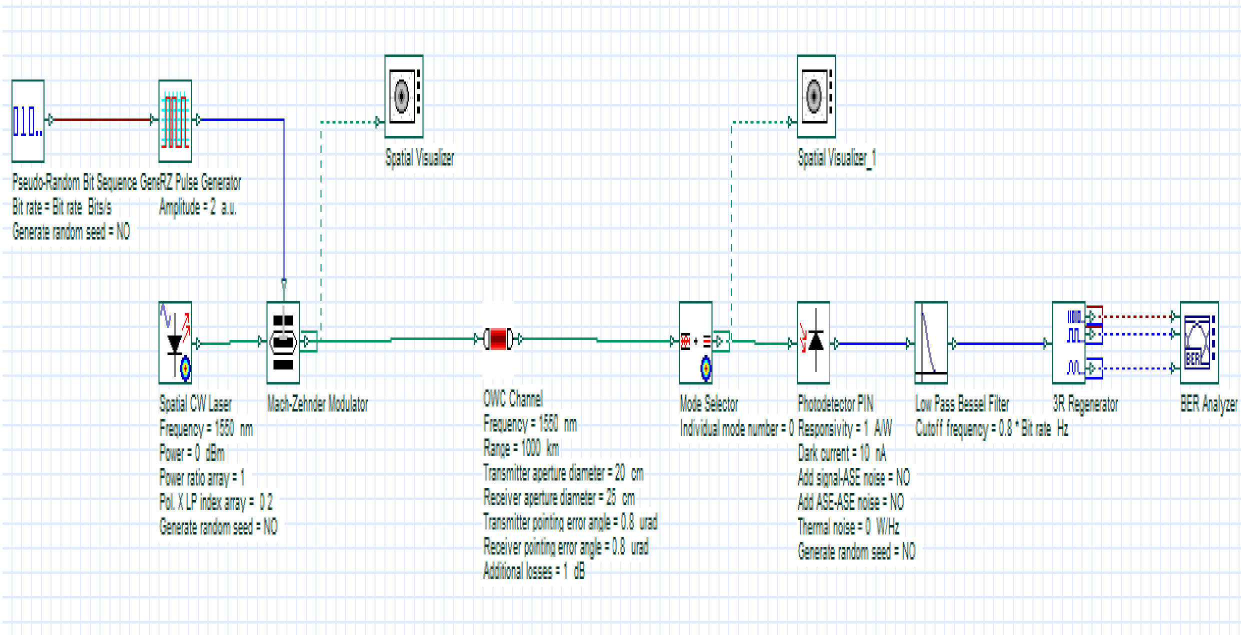


Figure 3.2(b): Simulation setup for RZ modulation format.

3.2.2 Principle of NRZ for LP modes

Figure 3.3(a) shows the block schematic of NRZ modulation format and Figure 3.3(b) shows actual simulation setup for NRZ modulation format. This signal is produced by passing the NRZ signal to the MZ-Modulator. The other input to the MZ-Modulator is from SCWL which is responsible for generation of different LP modes.

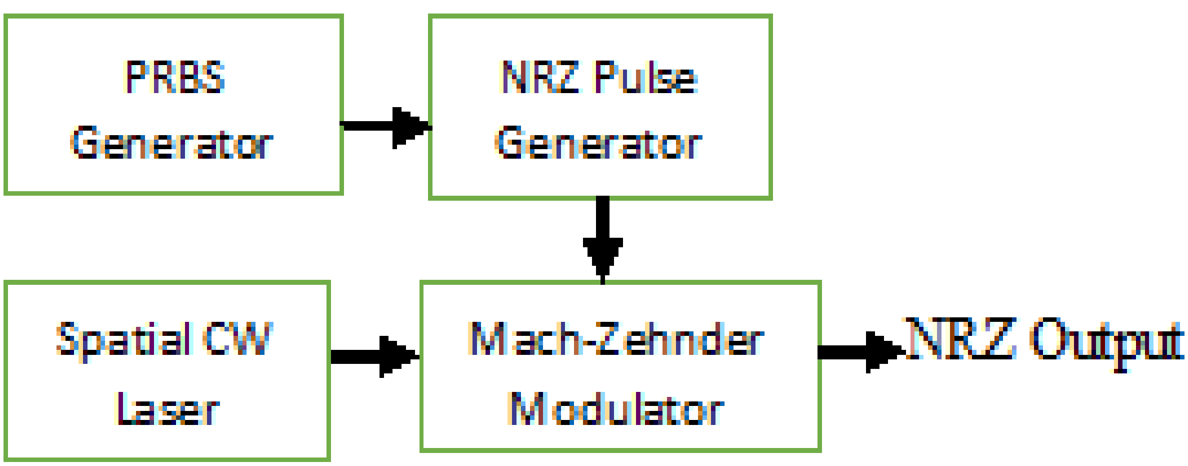


Figure 3.3(a) NRZ modulation format

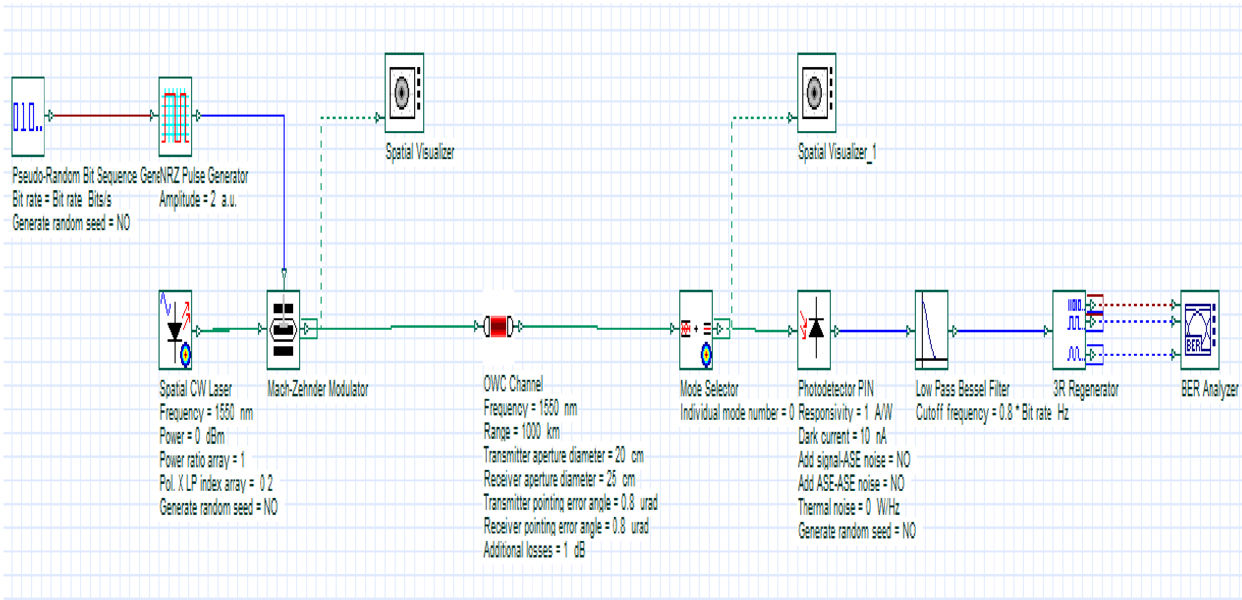


Figure 3.3(b) Simulation set up for NRZ modulation format

3.2.3 Principle of CSRZ for LP modes

Figure 3.4(a) shows the block schematic of CSRZ modulation format and Figure 3.4(b) shows actual simulation setup for CSRZ modulation format. This signal is produced by passing the NRZ signal to the MZ-Modulator and then applying to the phase modulator which is derived by a sine wave generator at the frequency equal to half the data rate. Thus a phase shift of π, between any two adjacent bits is introduced. As a consequence of it, the central peak at the carrier frequency is repressed so as to obtain CSRZ output. Here also SCWL is used to obtain different LP mode profiles.

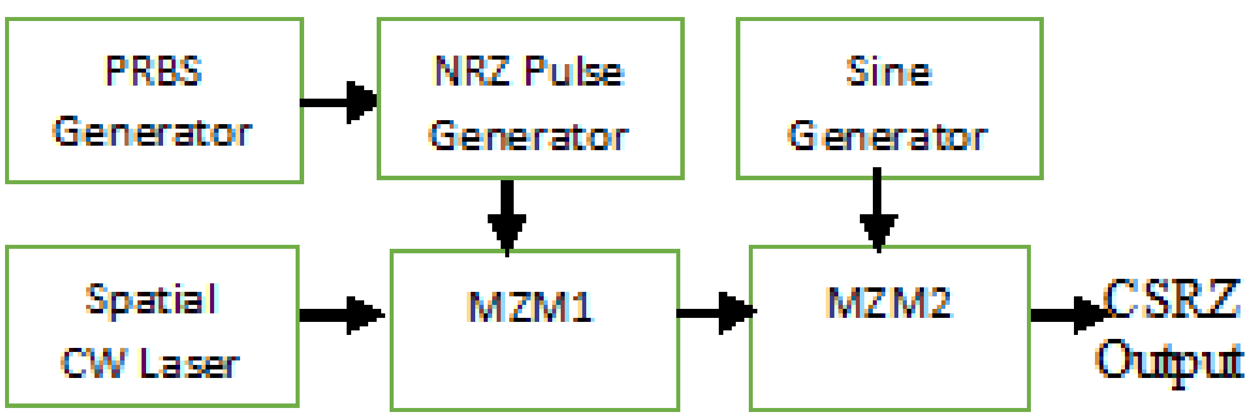


Figure 3.4(a) CSRZ modulation format

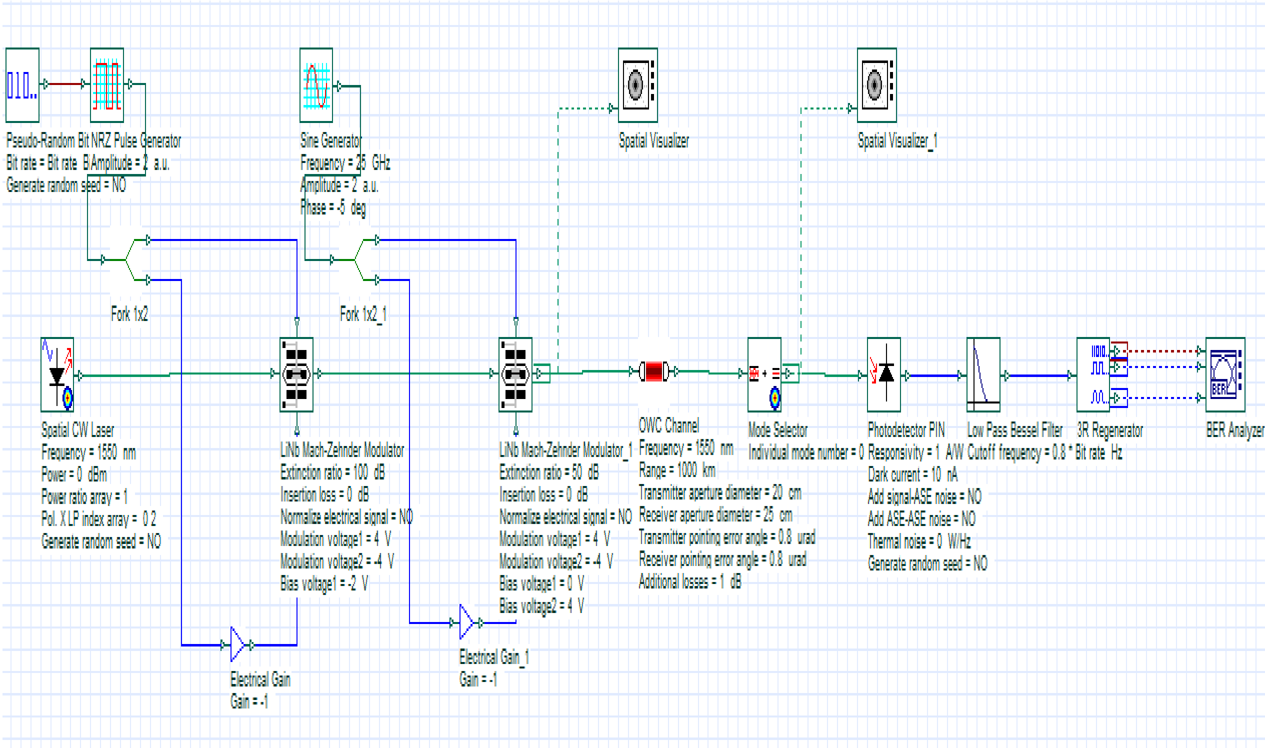


Figure 3.4(b) Simulation set up for CSRZ modulation format

The block schematic of modeled system for generating LP modes consisting of three chief communication parts those are transmitter, OWC/IsOWC propagating channel and receiver as shown in Figure 3.5. The generated optical signal is moderated by the arriving data stream with the support of a generally utilized optical modulator which is MZ-Modulator. The space among transmitting and receiving sides will be considered as propagating medium for transmitted light. Then at receiver side the received light ray will be detected by the combination of mode selector and photodiode followed by a low pass filter. The mode selector has ability to pick out the respective transverse mode profiles from the optical signals. Single Spatial PIN detector can also be used in place of combination. Simulation parameters for modeled system are shown in Table 3.1.

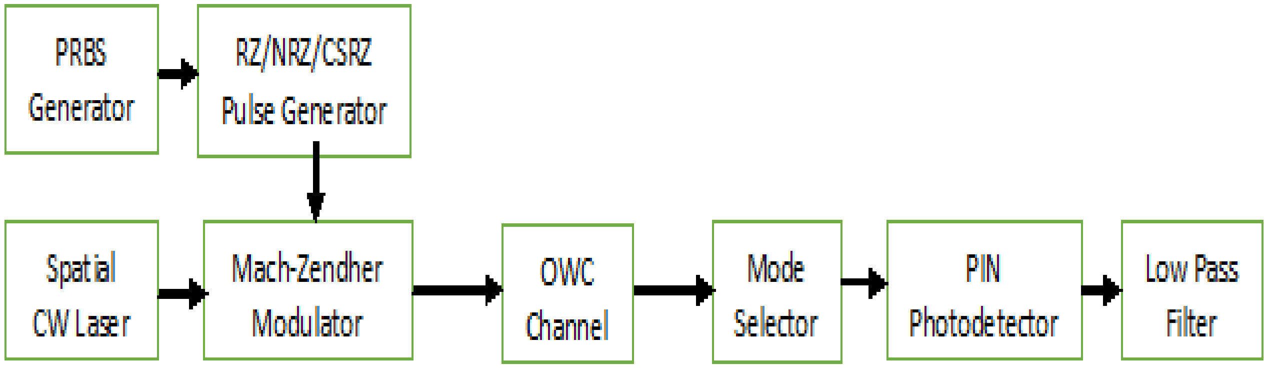


Figure 3.5 Schematic of system model of LP modes

Simulation Parameters	**Value**
Pulse Generator Amplitude	2 a.u.
Input Power	0 dBm
Wavelength	1550 nm
Extinction Ratio RZ/NRZ	30 dB
Extinction Ratio CSRZ MZ_1/MZ_2	100/50 dB
Insertion Losses	0 dB
Tx Aperture Diameter	20 cm
Rx Aperture Diameter	25 cm
Tx/Rx Pointing Angle	0.8 µrad
Additional Losses	1 dB
Responsivity	1 A/W
Add ASE Noise	No
Thermal Noise	0 W/Hz
Cut-off Frequency	0.8*Bit Rate
Generate Random Seed	No

Table 3.1 Simulation Parameters of System

3.3 PROPOSED METHODLOGY

Research Methodology is taken into consideration for implementing the project, defined as under:

Firstly, designing and simulation of the IsOWC model is taken into consideration. The execution is led by using Optiwave's Optisystem software. Initially the stoftware study is done for better understanding of the software. The optisystem software is effortless to use, flexible, powerful and fast. The optisystem permits operators for designing, testing and simulating the following:

1. System plan for WDM/TDM or CATV.
2. Ring resign for SONET/SDH.
3. Transmitter, channel, amplifier and receiver design.
4. Designing of dispersion map.
5. Estimation of BER and arrangement consequences with dissimilar receiver models.
6. Amplified system BER and link economical designs.

Numerous mechanisms are included in optisystem library enabling to have factors which can be evaluated from genuine devices. New components could be introduced on the basis of sub-sytems and libraries which are defined by users or operating co-simulation with tools as such MATLAB or SPICE.

For predicting the performance of the operating system, optisystem estimates parameters such as BER and Q factor with the help of mathematical investigation or semi-analytical methods for systems restricted by Inter-symbol Interference and noise. Advanced visualization tools produce OSA spectrum, signal chirp, eye diagrams, polarization state, constellation diagrams and much more. WDM analyzing tools consisting of power, gain, noise figure and OSNR per channel are also included. For saving the data constituent ports can be made certain and assign monitors after the simulation ends. This enables data processing without a need to recalculate. A random number of visualizers can be attached to the monitor simultaneously.

To study the working of the system we consider the system strategy in optisystem software with factors like bit rate, distance between links and power. The BER analyzer visulizer is used for investigation, whereby the system BER, Q-factor, and eye diagrams will be attained. The graphs are plotted between Q-factor and various parameters such as aperture diameters, transmitted power and bit rates.

3.3.1 Research Objectives

The present study has been taken up with a view to deal with following objectives:

1) Study the various concepts and theories related to Inter-satellite Optical Wireless Communication (IsOWC), Linearly Polarized (LP) Modes.

2) Implementation and comparative analysis of different modulation formats over IsOWC System using LP Modes.

CHAPTER 4

RESULTS AND DISSCUSIONS

In this chapter the results attained from simulation setup of the modulation formats RZ, NRZ and CSRZ is presented.

4.1 RESULTS

The intended setup is simulated for three diverse modulation formats RZ, NRZ and CSRZ using LP_{nm} modes with input power of 0 dBm and transmission distance of 1000 km at operating wavelength of 1550 nm. Results illustrate successful transmission of LP modes through IsOWC link.

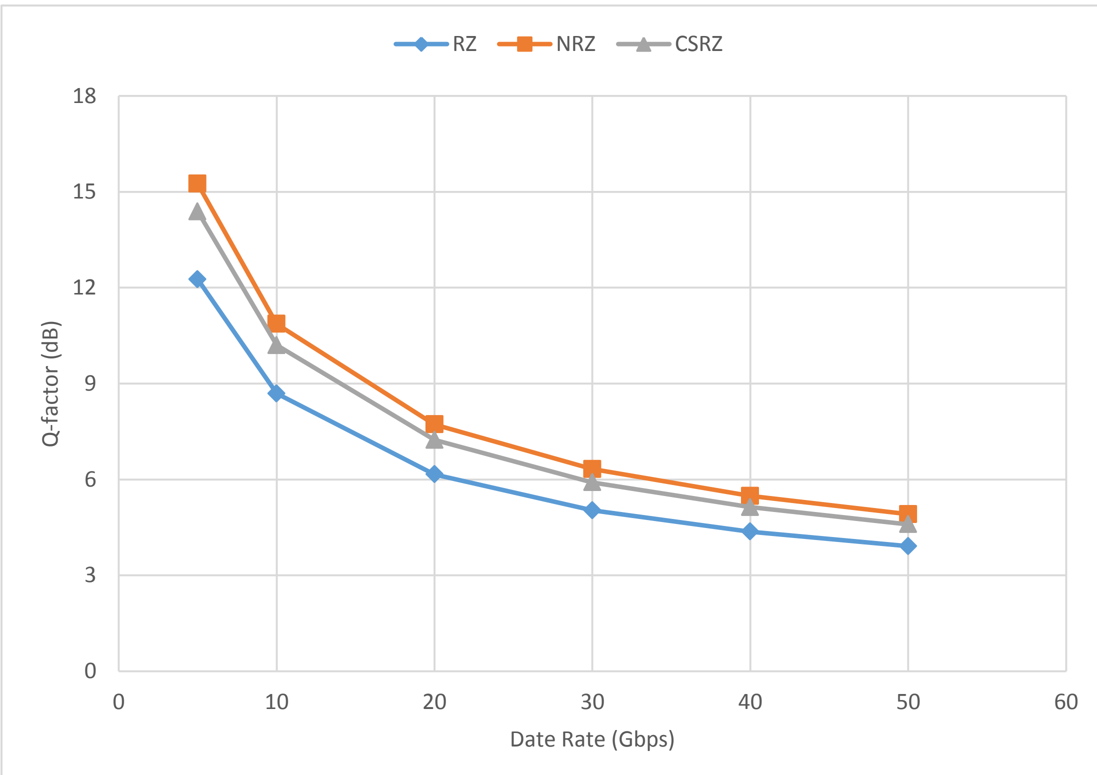


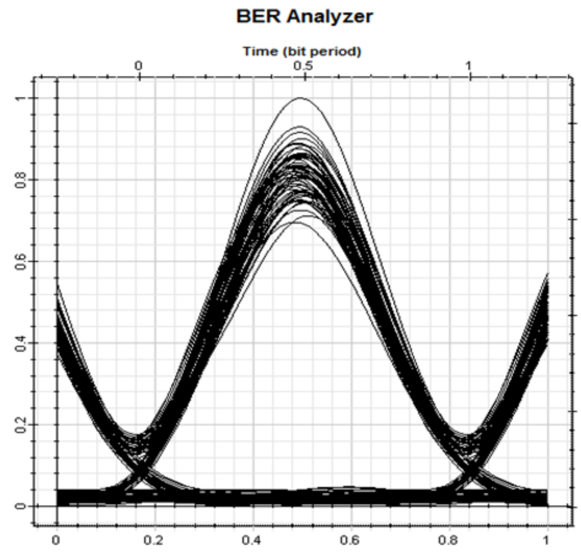
Figure 4.1 Evaluation of Q-factor w.r.t. data rate for various modulation formats for any LP_{nm} mode

Figure 4.1 represents comparison of RZ, NRZ and CSRZ modulation formats in terms of Q-factor at different data rates for three LP_{nm} modes LP_{00}, LP_{01}, LP_{02}. As the performance of IsOWC is highly affected by system data rate because Q-factor decreases with increase in the data rate. So results are taken at varied data rates of 5-50 Gbps. It has been observed that for any LP_{nm} mode, Q-factor for RZ, NRZ and CSRZ lies between 3.91211–12.2616 dB, 4.90982–15.2493 dB, and 4.59429–14.3872 dB respectively with acceptable BER. Hence, for any $LP_{n,m}$ mode NRZ modulation format performs best.

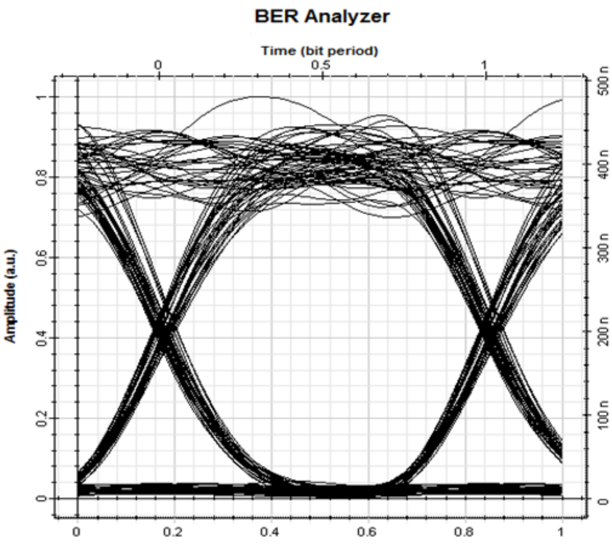
Data Rate (Gbps)	**Q-factor for RZ (dB)**	**Q-factor for NRZ (dB)**	**Q-factor for CSRZ (dB)**
5	12.2616	15.2493	14.3872
10	8.68558	10.8668	10.2004
20	6.15646	7.7225	7.23324
30	5.03315	6.32228	5.90608
40	4.36797	5.48244	5.13064
50	3.91211	4.90982	4.59429

Table 4.1 Q-factor w.r.t. Data Rate for Various Modulation Formats for any LP_{nm} Mode

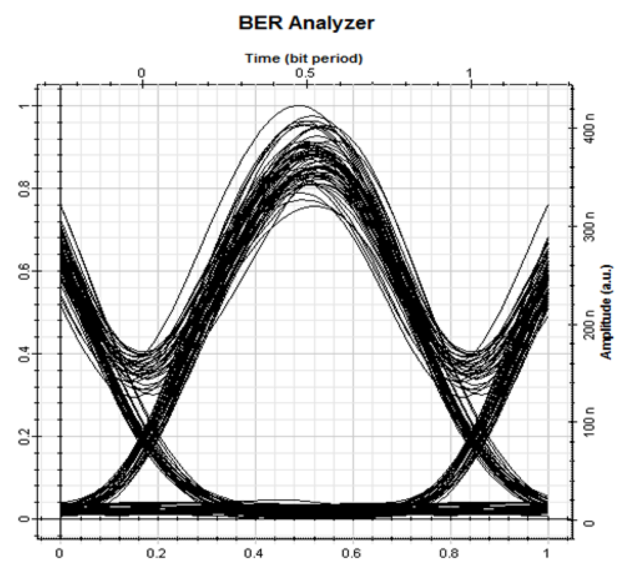
Figures 4.2 and 4.3 depicts eye diagrams for 5 Gbps and 50 Gbps respectively modeled IsOWC system using concept of LP modes for RZ, NRZ and CSRZ modulation formats. These eye diagrams are taken for LP_{02} mode but it has been observed from the analysis that all other modes gave similar results at similar simulation parameters. After investigation it is analyzed that eye diagram for CSRZ gives better results than RZ. Furthermore, investigations also show that eye diagrams of NRZ gives better results than RZ and CSRZ both. So we conclude that NRZ performs the best. Therefore, NRZ modulation format will be used for the rest of the analysis as it gives the best performance over other two formats. Further we examine the NRZ modulation format at different transmitter aperture diameter and varied input powers.



(a)

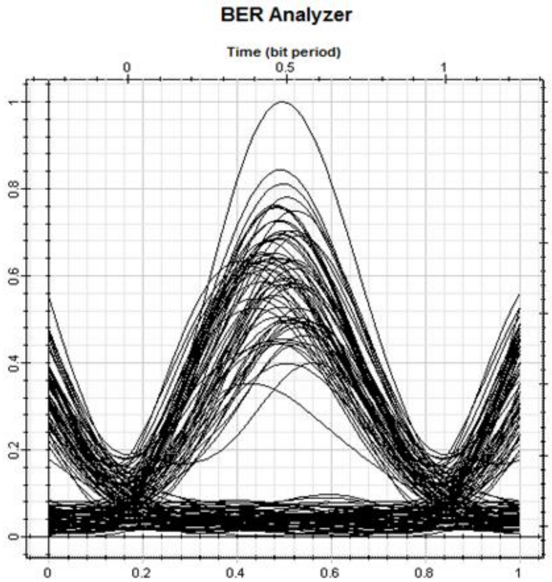


(b)

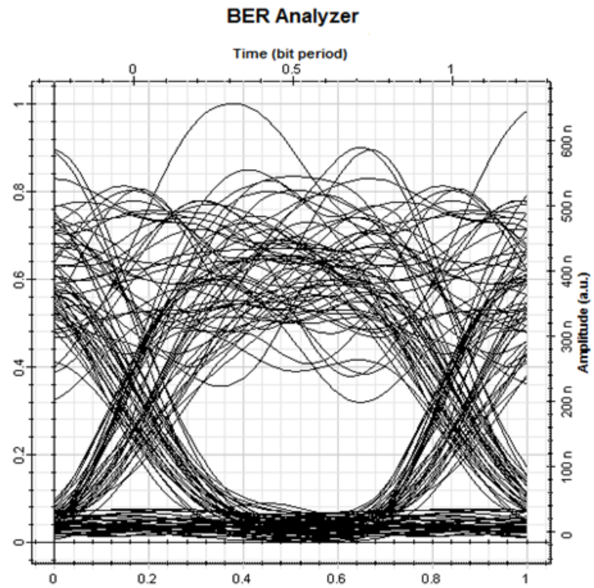


(c)

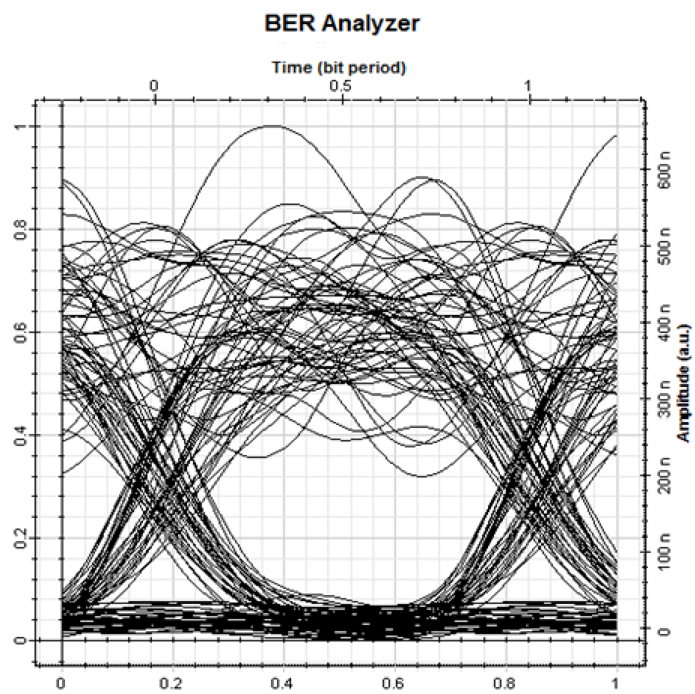
Figure 4.2 Eye diagrams for LP modeled 5 Gbps IsOWC system using (a) RZ; (b) NRZ; (c) CSRZ



(a)



(b)



(c)

Figure 4.3 Eye diagrams for LP modelled 50 Gbps IsOWC system using (a) RZ; (b) NRZ; (c) CSRZ

Figure 4.4 depicts the measurement of Q-factor at different Tx/Rx aperture diameters for three LP_{nm} modes LP_{00}, LP_{01} and LP_{02}. It is to be noted here that aperture diameter of receiver is to be kept 1 cm larger than transmitter so as to compensate the effect produced due to divergence of light beam. It has been observed that for any LP_{nm} mode Q-factor increases with increase in Tx/Rx aperture diameter.

Figure 4.4 Evaluation of Q-factor w.r.t different Tx/Rx aperture diameters for any LP_{nm} mode in case of NRZ modulation format

Tx/Rx Aperture Diameter (cm)	Q-factor for NRZ (dB)
5	0
10	2.38807
15	6.8464
20	12.8437
25	19.5359
30	26.4856

Table 4.2 Q-Factor w.r.t Different Tx/Rx Aperture Diameters for any LP_{nm} Mode in Case of NRZ Modulation Format

Figure 4.5 depicts the measurement of Q-factor at different input powers for three LP_{nm} modes LP_{00}, LP_{01}, LP_{02}. It has been observed that for any LP_{nm} mode Q-factor increases with increase in laser input power. Moreover, it is observed that system performs quiet well at low powers also.

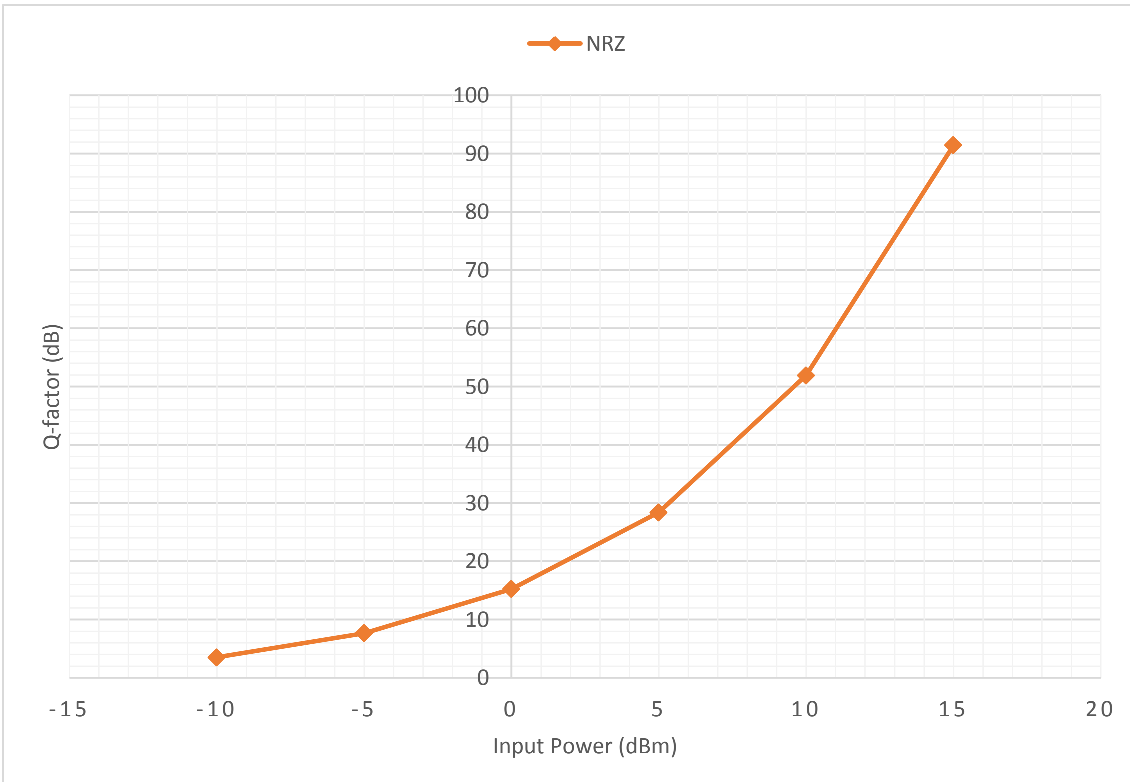


Figure 4.5: Evaluation of Q-factor w.r.t different input powers for any LP_{nm} mode in case of NRZ modulation format

Input Power (dBm)	Q-factor for NRZ (dB)
-10	3.50431
-5	7.6538
0	15.2493
5	28.4165

10	51.9306
15	91.4493

Table 4.3 Q-factor w.r.t Different Input Powers for any LP_{nm} Mode in Case of NRZ Modulation Format

4.2 DISCUSSIONS

In this chapter, the simulation investigation of OWC/IsOWC system for different modulation formats such as RZ, NRZ, and CSRZ is presented by means of different LP_{nm} modes LP_{00}, LP_{01}, LP_{02} at varied data rates of 5-50 Gbps, low input power of 0 dBm and transmitting distance of 1000 km at 1550 nm wavelength.

From Table 4.1, it has been observed that for any LP_{nm} mode, Q-factor for RZ lies between 3.91211–12.2616 dB, Q-factor for NRZ lies between 4.90982–15.2493 dB and Q-factor for CSRZ lies between 4.59429–14.3872 dB with acceptable BER.

Figures 4.2 and 4.3 depicts eye diagrams for 5 Gbps and 50 Gbps modelled IsOWC system using concept of LP modes for RZ, NRZ and CSRZ modulation formats. Eye diagrams are taken for LP_{02} mode but investigations show that all other modes gave similar results at similar simulation parameters. Eye diagram for CSRZ is better than RZ. But, eye diagram for NRZ gives better performance over RZ and CSRZ both. Therefore, NRZ performs best and is used for further investigation.

Figure 4.4 depicts the measurement of Q-factor at different Tx/Rx aperture diameters for three LP_{nm} modes LP_{00}, LP_{01} and LP_{02}. It has been observed that for any LP_{nm} mode Q-factor increases with increase in Tx/Rx aperture diameter.

Figure 4.5 depicts the measurement of Q-factor at different input powers for three LP_{nm} modes LP_{00}, LP_{01}, LP_{02}. It has been observed that for any LP_{nm} mode Q-factor increases with increase in laser input power. System also performs well at low powers.

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

This chapter delivers the summary of the research work done in thesis. Firstly, conclusion has been made from the results obtained and then recommendations for the future researches have been discussed.

5.1 CONCLUSIONS

The conclusions obtained based on the experiment observations and investigations are as follows:

In this chapter, the simulation investigation of OWC/IsOWC system for different modulation formats such as RZ, NRZ, and CSRZ is presented using different LP_{nm} modes LP_{00}, LP_{01}, LP_{02} at varied data rates of 5-50 Gbps, low input power of 0 dBm and transmission distance of 1000 km at 1550 nm wavelength. Simulation investigation results shows that NRZ performs best with Q-factor of 15.2493 dB at data rate of 5 Gbps and 4.90982 dB at 50 Gbps for all LP modes. Hence, it is concluded that all the LP modes transverse with same Q-factor and BER. Spatial visualizer results illustrate successful transmission performance of LP modes through OWC/IsOWC link.

5.2 FUTURE SCOPE

In the upcoming time, the current work may be expanded on the following lines:

1. Performance of higher order modes using multi-input multi-output IsOWC system can be studied.
2. Same setup can be studied for various bandwidth efficient techniques such as Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude modulation (QAM), etc in which data rate will be very high as work is done on bits per symbol basis.
3. Work can be done on capacity enhancement using Wavelength Division Multiplexing (WDM) technique.
4. Proposed work investigated from simulatory set-ups can be verified mathematically as well as experimentally.

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