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PERFORMANCE ANALYSIS OF FSO CHANNEL BASED ON DIFFERENT AMPLIFIER CONFIGURATION

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Abstract

We inspected a DWDM-FSO system that has a 64*40gbps data stream. the analysis is monitored for NRZ line codes as a channel we use free-space optics length to establish a high speed optical wireless communication system within 1 Km length. in this system, we compare different types of configurable amplifier setups these setups smooth our high-speed data rate. We also change our receiver optics aperture which given us more reliable performance. The Free space optics system has to remark a different kind of attenuation problem this type of problem we are looking over in our proposed system to establish the best system. evaluating our proposed system we analyzed Bit error rate data, Quality factor data, eye diagram data. By comparing anyone can get a reliable system to the high capacity access network with more bandwidth cost-effective and good flexibility.

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List of Symbols

Hz	Hertz
THz	Terahertz
GHz	Gigahertz
f	Frequency
ω:	Angular frequency
λ	Wavelength
π	Pi
B	Byte
MB	Megabyte
s	Second
ps or s-1	Per second
MBps	Megabyte per second
GBps	Gigabyte per second
m	Meter
mm	Millimeter
cm	Centimeter
km	Kilometer
µm	Micrometer
nm	nanometer
m-1	Per Meter
ms-1	Meter per second
cm-1	Per Centimeter

g/cm3	Gram per centimeter cube
kJ/m	Kilo joule per meter
ps/THz/cm	Per second per terahertz per centimeter
dB/m	Decibel per meter
dB/cm	Decibel per centimeter
dB/km	Decibel per kilometer
%	Percentage
d	Diameter
r	Radius
w	Width
a	Major diameter of ellipse
b	Minor diameter of ellipse
η	Ellipticity
Λ Speed of light	Pitch
°C	Degree Celsius
η	Ellipticity
a	Major diameter of ellipse
b	Minor diameter of ellipse
W	Watt

List of Abbreviations

FSO	Free Space Optics
WDM	Wavelength Division Multiplexing
DWDM	Dense Wavelength Division Multiplexing
LED	Light Emitting Diode
TIR	Total Internal Reflection
PRE	Power Amplifier
AMP	Amplifier
SMF	Single Mode Fiber
NHMFL	National High Magnetic Field Laboratory
MOF	Micro-structured Optical Fiber
PM	Polarization Maintaining
0D	Zero-Dimensional
NRZ	Non-return to zero
RZ	Return To Zero
FSO	Free Space Channel
PCF	Photonic Crystal Fiber
3D	Three-Dimensional
MSF	Micro Steel Fiber
MCF	Multi-core Fiber
PGB	Photonic Bandgap
M-TIR	Modified Total Internal Reflection
COC	Cyclic Olefin Copolymers

TFE	Tetra-fluoro-Ethylene
PTFE	Polytetrafluoroethylene
MMA	Methyl Methacrylate
SOA	Semiconductor Optical Amplifiers
EDFA	Erbium Doped Fiber Amplifier
RA	Raman Amplifier
CAPEX	Capital Expenditure
UV	Ultraviolet
PC-PCF	Porous-Core Photonic Crystal Fiber
EML	Effective Material Loss
BER	Bit Error Rate
CL	Confinement Loss
TL	Total Loss
PF	Power Fraction
ESM	Endlessly Single Mode
GVD	Group Velocity Dispersion
FEM	Finite Element Method
PML	Perfectly Matched Layer
X-pol	X-polarization
Y-pol	Y-polarization
PS	Partially Slotted
FS	Fully Slotted
LFM	Localized-function Method

BPM	Beam Propagation Method
FDM	Frequency Division Multiplexing
PDIP	Plastic Dual Inline Package
PWM	Pulse Width Modulation
FDTD	Finite-difference Time-domain
BEM	Boundary Element Method
EWFD	Electromagnetic Wave, Frequency Domain
AFF	Air Filling Fraction
ENZ	Epsilon-Near-Zero
Rx Ap	Receiver Aperture
Tx Ap	Transponder Aperture

Chapter 1
Introduction

1.1 Introduction

Optical technology is a game-changer when it comes to features and advantages over ordinary electrical transmission. It features a large storage capacity and a rapid data rate. There are two parts to the optical transmission system: a transmitter and a multiplexer. Thanks to Opti-System, an all-in-one design and testing solution for modern optical networks, designing optical links at the transmission layer of modern optical networks has never been easier [1][2]. A significant urge to augment or perhaps replace the current RF regime has emerged in this era of the ever-increasing need for high-speed and uninterrupted connectivity. Free-space optical (FSO) communication systems feature a number of compelling qualities, including high data speeds, license-free spectrum, signal security, and cost-effectiveness. Communication via free-space optical means transmitting data by optical modulation over a free space medium (e.g., the atmosphere). An unlicensed frequency band in the visible or infrared spectrum is typically used to transmit the data. Government entities, therefore, do not require any operational expenditures. In contrast to optical fiber connections, Free Space Optical (FSO) communication is commonly used to gain an edge in terms of performance. Communication can take place using this media. It has a wide bandwidth, a high data rate limit, and a quick connection setup. The fundamental difference between FSO and fiber optic transmission is that the beam's energy is collimated and transmitted across the atmosphere to the destination, where a photodetector captures it. High-speed train It is also possible to slice a WDM-FSO system via supercontinuum synthesis. Various beam divergences, transmitter and receiver antenna diameters, and modulation formats are tested in the system. There are a number of additional optical amplifiers that we will look into in order to lessen the attenuation impact of the recommended design. Supplying high-speed data is the best practice. As a result, the system was built and tested at 10 Gbps[15]. When compared to current technologies, FSO offers a number of advantages. The primary advantage of the FSO system is that it is less expensive and less time consuming to set up than other systems. There are a few modifications needed to use optical equipment in an FSO system. Due to medium attenuation, the FSO communication system is a hot technology; yet, its features and application area make it desirable [7]. When power is lost, the transmission performance of the FSO system is hampered by its medium attenuation. However, additional attention and a pre-study of the medium may reveal what criteria to consider before implementing the system. WDM-based FSO systems are being developed to reduce the impact of attenuation. Analyses of performance before installation are performed using models based on this research. As a result of this, the system may be improved. Various techniques, such as OFDM-FSO WDM-FSO based systems, are a revolutionary way to increase system performance with high speed and long-distance capabilities. When these approaches are combined, new techniques are possible, and by reinforcing these techniques, system design may be improved. The flaws in FSO systems can be decreased to the absolute lowest level possible [9][21].

1.2 History of Free Space Optical Network and Optical Amplifier

As one of the most important wireless communication technologies, FSO has seen a dramatic increase in interest and progress over the past decade. Fiber-less and Laser Communication (Lasercom) are other terms for FSO technology. Wireless Optical Communication (WOC), Fiber-less and Laser Communication (Lasercom). FSO is seen as a strong contender in the broadband communication service market, with a unique demand for a point-to-point connection between transmitter and receiver in a clean air environment. FSO technologies are essentially the same as fiber optic transmissions. When it comes to FSO transmission, the difference is that the optical fiber will be used to carry the signal. To address the ever-increasing bandwidth demands, FSO provides a unique alternative. It's possible to use FSO systems in place of optical fiber cable when both lines are either unavailable or expensive (CAPEX) (CAPEX) (CAPEX). FSO technology has many advantages, including a large bandwidth, immunity to electromagnetic interference, no spectrum licensing, and a higher transmission rate [1][3][4]. A modulated narrow optical laser beam is used to send digital data from the FSO transmitter to the FSO receiver via free space atmosphere and then processed at the receiving station. The term "line of sight" refers to the ability of the transmitter and receiver to see each other at all times. Single-beam and multiple-beam FSO systems are subclassified. The system categories include both positive and bad aspects. As a single beam FSO system travels in open space, the beam is likely to be dispersed by air turbulence caused by large seized droplets or haze. Consequently, it's quite unlikely that the beam will reach the receiver under these conditions. In order to increase the chances of hitting the target, several beams can be used. The disadvantages of a single beam system are its simplicity and quick alignment between transmitter and receiver [10]. Multi-beam FSO uses a laser beam combination strategy to reduce the power consumption caused by air turbulence. 5G cellular backhaul networks can use FSO lines instead of fiber optic cables because they are less expensive and less intrusive. It is our goal to provide a backup for FSO backhaul networks with an additional millimeter-wavelength radio-frequency connection (RF). Switching between the primary FSO link and the secondary RF-FSO link is necessary; if air turbulence disrupts the direct link, the secondary link retains connectivity because the MMW RF link has complementary properties. As part of our analysis, we build basic mathematical equations for several performance measures, such as outage probability and average bit error rate (BER). Our results show that the FSO/RF-FSO architecture beats a single FSO link for outage probability and BER. Amplify, and Forward (AF) relays with an average power scaling are used to connect the mixed RF-FSO link. When considering the irradiance variations in FSO connections, we assume significant air turbulence, whereas we expect multipath Rayleigh fading when looking at the RF link. In order to prevent excessive switching, a single FSO threshold is initially set, followed by a second FSO threshold. 5G wireless networks are expected to rely heavily on free-space optical (FSO) communications [22]. Since FSO lines are easy to put up and maintain, they are a potential alternative to traditional fiber optic cables for backhaul communication. There is a disadvantage to using FSO because it requires a direct line of sight. In addition, air turbulence has a significant impact on propagation [13]. Some hybrid paradigms have been developed to combine the advantages of both radiofrequency (RF) and fiber-optic (FSO) links. Because of fog and scintillation, FSO lines, for example, have higher data rates than RF links but also suffer from air loss. On the other hand, the RF connection is ideal for FSO since it is weather-independent and can penetrate fog easily. In our suggested FSO/RF-FSO configuration, the primary FSO link is used when the LOS channel is clear. Otherwise, a backup RF-FSO link is established to ensure connectivity. With this technology, in the event of a primary FSO link failure in mountainous regions and industrial belts where dense fog, cloud or smog frequently engulfs an FSO transmission line, there is a backup link to deal with weather conditions. One of the most important technologies, free space optical communication (FSO), has a fast data rate, rapid expansion capacity, free licensing spectrum, and simple implementation. FSO transmission is carried out through the atmosphere. The effectiveness of the communication system diminishes because of air interference [15][16]. As a part of this study, a number of meteorological variables were examined to determine their impact on the performance of an FSO system. The received signal quality was evaluated according to various parameters, such as transmission range, power, and beam divergence in FSO - SISO and WDM - FSO systems. There must be a direct line of sight between the transmitter and the receiver for Free-Space Optical communication. An optical modulator is used on the transmitter side of the FSO system to modulate the data signal before it is sent to the receiver via the channel (free space) via the optical transmitter. The optical receiver on the FSO system's receiver side receives the provided signal [21][22]. The optical detector and low-pass filter detect and filter the incoming signal and approximate the broadcast data stream, respectively. Both external and internal factors influence FSO communication performance. Atmospheric conditions such as fog, rain, clouds, and so on can alter the environment's appearance. Power loss, beam difference, and internal parameters are all required features of the system [3].

1.3 Working principle of FSO Channel for Optical Fiber Communication

Wireless transmission of data through a modulated optical beam directed across open space without the need for fiber optics or other optical infrastructure is known as free space optical (FSO) communication [2][3]. When light (or smoke) signals were used to communicate information in prehistoric times, the core concept is still relevant today. Graham Bell's photophone invention may have been a precursor to current FSO systems. By manipulating the sun's rays, it sent audio signals. A new era of FSO systems has been ushered in by the development of lasers, which are light sources with enormous output power and coherence. For most of the 1970s and 1980s, FSO systems were primarily intended for secure long-distance (50–1000 km) communication between the earth and satellites or satellites and the earth. Over the past decade, a new market for FSO has emerged in the creation of high-bandwidth data lines and their integration over a spatially confined zone. Fiber optic networks, RF communication systems, and copper cable-based systems are the main competitors in this industry. " To put it another way, the optical carrier (1014–1015 Hz) allows for significantly faster transmission rates, compared to similar wireless radio frequency transmissions [5][6].

On the other hand, using an optical carrier necessitates an unobstructed line-of-sight between the emitter and detector, resulting in a significantly more concentrated beam propagation. This limits the deployment of most FSO systems to a range of a few hundred meters to several kilometers, which is perfect for spreading high-capacity networks over a regionally constrained area. Thus, FSO has a good shot of providing high-bandwidth Ethernet service to individual homes. FSO lines' ease of installation and adaptability are two of their main advantages over fiber networks. It makes them more cost-effective, streamlines maintenance, and allows for quick and cheap modifications [17][23].

WDM

Multiplexing optical carrier messages onto a single optical fiber using wavelength-division multiplexing (WDM) is essential in fiber-optic communications. A single fiber strand can be used for both bidirectional communication and capacity expansion. Multiplexers and demultiplexers are used in WDM systems, which are used to combine and decompose signals. In theory, an optical add-drop multiplexer might be built using the right kind of fiber to accomplish both goals at once. For decades, Etalons (Fabry–Pérot interferometers in thin-film-coated optical glass) have been used as optical filtering devices [8]. For the most part, WDM networks make use of 9-meter-diameter single-mode fiber optic connections. Also known as premises cable, 50 or 62.5 m multi-mode fibers can be used in some WDM variants. Conventional/coarse (CWDM) and dense (DWDM) wavelength division multiplexing systems are two types of WDM systems based on their wavelength patterns (DWDM)[37]. At 1,550 nm, silica fibers can transmit up to eight channels in the third transmission window (C-Band). In dense wavelength division multiplexing (DWDM), the same transmission window is used with fewer channels, but the channels are packed closer together. In a typical system, the channels might range from 40 at 100

GHz to 80 at 50 GHz, depending on the configuration. For example, ultra-dense WDM (often known as ultra-dense WDM) can be 12.5GHz spacing (sometimes called ultra-dense WDM). The usable wavelength range now includes the L band because of advances in amplification (such as Raman) [6][12].

DWDM

Dense Wavelength Division Multiplexing (DWDM) is a technique that enables numerous information streams to be transmitted on a single fiber concurrently. This provides a practical approach to extending the capacity of existing networks without more fiber. DWDM is the most often deployed technique for backbone lines [10]. The distance between information-bearing wavelengths is just 0.8 nm, and with increasing frequency, a separation of 0.4 nm may be reached. UDWDM (Ultra-Dense Wavelength Division Multiplex) systems are also available now. These systems use0.2 nm or even a 0.1 nm gap. However, decreasing spacing values increase the necessity for transmission route components, particularly the DFB (Distributed Feedback) lasers [23][31]. DWDM systems may transmit tens or hundreds of parallel optical lines. The normalized frequency of 193.1 THz characterizes DWDM. The wavelength cannot deviate from the normalized wavelength by more than 0.16 nm for optimum functioning [19].

Advantage of FSO Channel

1. Free space optics is a flexible network that delivers better speed than broadband.
2. Installation is straightforward, and it takes less than 30 minutes to install at standard locations.
3. It has a meagre initial investment.
4. It is a straightforward deployment system. There is no need for spectrum license or frequency coordination between users as required in previous radio and microwave systems [28].
5. It is a secure system because of the line of sight operation, and so no security system up-gradation is needed. A high data rate can be obtained, comparable to the optical fiber cable’s data rate [18][34]. Still, the error rate is meagre, and the extremely narrow laser beam enables an unlimited number of FSO links installed in a specific area.

6. Radiofrequency interference is immune.
7. Electromagnetic and radio-magnetic interference cannot affect the transmission in the FSO link.
8. FSO offers dense spatial reuse.
9. Low power usage per transmitted bit is the merit of the FSO system [8]
10. There is a relatively high bandwidth.
11. Transmission of the optical beam is done in the air. Hence, the message has a speed of light [10-15].

Limitation of FSO system

Using free-space optics is a no-brainer. Environmental concerns are inherent due to FSO's use of air as a transmission channel and the light flowing through it. More than 90 percent of all weather-related events occur in the troposphere [2]. Following is a summary of some of these restrictions:

A single beam can be swiftly obstructed by flying birds, trees, or tall objects when they are in the FSO system's line of sight (LOS)

Heating ducts, for example, can cause air packets to range in temperature, resulting in a shimmering effect. (b) FSO receivers may experience a "picture dance" due to signal amplitude oscillations caused by temperature changes. Using Light Pointe's unique multi-beam approach, scintillation may be addressed effectively [30].

C)Geometric losses or optical beam attenuation: These losses are induced by the beam's spreading and reduced signal power level as it moves from transmitter to receiver.

(d) Absorption: The water molecules floating in the Earth's atmosphere generate this. They would take the photon's energy and use it for themselves. The applied input signal may be magnified since there is no visual feedback system. In an FSO system, absorption directly impacts transmission availability because it reduces the ability of optical amplifiers to generate coherent output independently. Adding carbon dioxide to the air can also help to absorb signals [5].

Turbulence in the atmosphere is caused by meteorological conditions and the structure of the surrounding environment. Air masses of differing temperatures are mixed together due to wind and convection. An oscillation in air density results in a change in the refractive index of the air due to these fluctuations. Some of the more noticeable effects of the turbulence cell's size are discussed below [4]. There will be an essential role for the beam wander in turbulence cells with larger diameters than optical fiber ones. An example of beam wander is when a visual beam point quickly moves away from a fixed position. If the turbulence cell's diameter is smaller than the optical beam's, the optical beam's intensity fluctuation or scintillation is dominant. Turbulence can interfere with the transmission of an optical beam. A shift in the index of refraction alters the angle at which the beam is refracted. Optical beam propagation takes place as a result of this[23]35].

The most common cause of atmospheric attenuation is fog and haze. Dust and rain also have an impact on them. Wavelength-dependent air attenuation is widely acknowledged to be the case. This, however, is not the case at all. Depending on the wavelength, haze is present. 1550nm has lower attenuation than other wavelengths under foggy weather conditions. Fog-related attenuation is wavelength-independent.

Light dispersion and optical beams collide, resulting in scattering. Wavelength-dependent phenomena in which the optical beam's energy remains constant occur. It is possible to reduce the beam intensity across a longer distance by merely redistributing optical power in a specific direction [7][21].

Atmospheric Weather Conditions

The atmosphere serves as the transmission medium in an FSO link. A number of causes contribute to its decline. Attenuation is most frequently caused by changes in the local weather. The link's construction site features some unusual weather conditions. Information about prior attenuation can be gathered; the most prevalent weather conditions in temperate climates are fog and heavy snow. Weather variables such as heavy rain and haze considerably affect the availability of FSO lines in tropical locales [5]. Some of the current weather conditions are described in further detail below:

Optical radiation is much reduced when fog is present. Reflections and scattering of light are caused by the fog that blocks visibility. It is mostly a matter of increasing the transmitted power when fog scattering, also known as Mie scattering, occurs [42].

Nonselective scattering occurs as a result of rainfall-induced rain attenuation. This type of attenuation does not depend on the wavelength being used. Laser delivery could be affected if it's raining. Whether or not the FSO system is visible depends on the amount of rain that has fallen. A significant amount of water is created when it rains heavily. It is possible for them to alter the optical beam's qualities or impede its passage when absorbed, dispersed, and reflective [25][19].

Attenuation of the atmosphere occurs when particles of haze persist in the air over long periods of time. This means that attenuation levels are based on the current visibility [7][9]. There are two ways to collect data on attenuation when performing FSO system testing: It was done first by setting up and testing a temporary system at the location and then by using the Kim and Kruse model.

When compounds like carbon and glycerol burn, they emit smoke that may be seen from miles away. It impacts the visibility of the transmission medium [6].

A well-known difficulty in outside link communication is sandstorms. To begin with, soil texture determines how large wind particles will be; second, it also determines how fast wind must blow for the particles to be blown up.

Earth's atmosphere is not complete without cloud layers, which constitute a fundamental component of this layer. When water condenses or accumulates on top of the Earth's surface, it forms clouds. It has the ability to completely block portions of the optical beam sent from the Earth into orbit [27]. As a result of the cloud particles' diversity and inhomogeneity, it is difficult to quantify the attenuation.

G) Snow: The larger particles in snow contribute to the geometric dispersion because of their larger size. The snow particles disperse like Rayleigh scattering [5][9].

1.4 Optimization of Free Space Optics Parameters Using WDM System

The team's engineers devised a unidirectional WDM network. The data rate, power, link range and user count are all variables that must be adjusted depending on the weather conditions. For light, medium, and severe rain, the attenuation is 6.27, 9.64, and 19.28dB/km, respectively. Because it has the least amount of attenuation, the 1550 nm wavelength is ideal for rain and haze applications. For better system performance, the adjustment of parameters should be made clearer. This study does not account for geometric losses[21][34]. Aperture size, laser power, data rate, and Optical Amplifier Gain are all important, but the connection length is the least important.

Results show that a maximum data rate of 622Mbps is most suited to all forms of rain. Using a shorter link distance and a lower data rate, the FSO system might be more efficient during severe weather. Based on wavelength, power level, data rate, and link distance variables, these research are compared to one another. The more critical the attenuation, the shorter the distance between the two points of connection. As the data rate rises, the distance between the two devices becomes less. Depending on the size of the power, the link distance grows or decreases. Power output reduces attenuation's effectiveness. However, the amount of power that can be used is limited by numerous organizations that represent the principle of laser safety. As an example, when the Laser comes into direct contact with a person's eye at a specific wavelength and power level, the Laser can hurt them. An eye may be affected by a Laser, for example, when the eye comes into direct contact with the Laser at the wavelength and power permitted by IEC rules (International Electro technical Commission) [6-15].

1.4.1 Optical Amplifier

An optical amplifier seems to be a mechanism that amplifies an optical signal directly without converting it to an electrical form. The light itself is magnified. Optical amplifiers are frequently employed in three separate fiber transmission lines [1][3]. A fiber cable transfers data from one end to the other in an optical communication system consisting of a transmitter, a receiver, and a fiber cable. However, because a signal transmitted across a fiber cable has the most negligible attenuation compared to any other media, such as a coaxial cable, an additional device, an optical amplifier, is inserted between the transmitter and receiver sections to boost the signal level.

Long-distance communication, however, necessitates signal amplification throughout transmission over fiberoptic cable. It is critical to use amplifiers to reduce signal distortion as much as possible during signal transmission. An amplification unit is also essential when describing an optical communication system delivering data in light through the fiber cable. Numerous variables diminish the signal's quality as it travels from one end to the other. As a result, it is often difficult to extract the original information from that signal. If we utilize an electronic amplifier unit, we will require different devices to translate the optical signal to an electrical form and vice - versa. This procedure takes some time and reduces the data transfer rate [6][38]].

The emergence of optical amplifiers, on the other hand, has rendered this problem obsolete. As a result, optical amplifiers inside an optical communication system enable us to transmit a signal across a greater distance and quicker without attenuation. As we know, the optical amplifier utilizes stimulated emission, and for it to occur, population inversion must be induced, using the same technique as in the laser diode. Due to the lack of an optical feedback system, only the applied input signal may be enhanced because optical amplifier & laser diodes have a similar shape. Consequently, optical amplifiers' power to create coherence output through their own is restricted, and the accessibility of transmission in such an FSO system is directly regulated by absorption. Signal absorption may also be induced by carbon dioxide [13][22].

1.4.2 Power Amplifiers

Before transmitting the signal down the line, power amplifiers boost the signal's strength, extending the transmission distance before additional amplification is required. It's a power amplifier that amplifies the power of an optical signal at an optical transmitter's output before sending it down an optical fiber [1] [2]. Depending on the optical gain of the power amplifier and fibre losses, the transmission distance might be increased by 100 km or more. The highest output power of most DFB lasers used as optical sources, for example, is two mW. The optical signal can be boosted by using a power amplifier after the optical transmitter. Booster (power) amplifiers, such as optical couplers, splitters, WDM multiplexers, and external optical modulators, are used on the optical transmitter side to boost the transmitted power level or compensate for optical element losses between the laser and the optical fibers [29].

To put it another way, the booster amplifiers are used to amplify the transmitter's strength before it reaches the fiber link. Higher transmitter power might be used to travel further down the network. A laser diode or tunable laser source's output power is typically moderate, primarily when an external modulator is used. The high saturation output power of the booster is its main selling point [5][7].

Furthermore, the advocate should offer data signal amplification devoid of bit-pattern effects. It should enhance all signals uniformly across the spectrum in WDM systems. The majority of booster amplifiers are polarization sensitive [26].

Applications of Optical Amplifiers

- Typical applications of optical amplifiers are:
- An amplifier can boost a laser output's (average) power to higher levels (→ master oscillator power amplifier = MOPA).
- It can generate extremely high peak powers, particularly in ultra.
- Short pulses, if the stored energy is extracted within a short time.
- It can amplify weak signals before photodetection and thus reduce the detection noise unless the added amplifier noise is significant.
- In long fiber-optic links for optical fiber communications, the optical power level has to be raised between long fiber sections before the information is lost in the noise [22][5-10].

Parameters of an optical amplifier include:

- the maximum gain, specified as an amplification factor or in decibels (dB)
- the saturation power, which is related to the gain efficiency
- the saturated output power (for a given pump power)
- the power efficiency and pump power requirements
- the saturation energy
- the time of energy storage (upper-state lifetime)
- the gain bandwidth (and possibly smoothness of gain spectrum)
- the noise figure and possibly more detailed noise specifications
- the sensitivity to back-reflections
- the number of modes it can amplify (see above, multimode and single-mode amplifiers)[1-5]

1.4.3 Line Amplifiers

Line amplifiers are strategically placed along a longer transmission line to restore a signal's initial power level. As a result, the attenuation of the fibers is improved with a fiber–optic connection signal, an in-line optical amplifier functions [1][2]. The use of optical amplifiers as in-line amplifiers and the fiber link between the optical transmitter and receiver are depicted in the diagram below. An in-line optical amplifier's principal function in a WDM network compensates for signal losses caused by fiber attenuation, connection losses, and signal distribution.

In a typical application, a long-haul optical fiber communication connection can be replaced with a suitable in-line optical amplifier instead of an optoelectronic repeater (comprising a photodiode, timing and shaping circuits, and laser). In a long-haul fiber-optic communication network, a number of in-line optical amplifiers can be cascaded with the fiber link. This setup must ensure that the combined effects of ASE noise, dispersion, non-linearity, and stability do not affect system performance throughout the whole WDM bandwidth [7][26]. The optical signal strength should increase almost linearly with the length of the optical fiber link to compensate for the cumulative ASE noise level. The most critical performance criteria are saturation output power and noise because of the weak input signals. System performance will be improved by controlling small-signal performance and noise. The system length will be limited by the noise generated by amplifiers in series. The polarization dependency of the gain should be as modest as possible due to the unpredictable state of polarization inside a network [33]. Furthermore, the in-line amplifier must concurrently handle several wavelength channels. Furthermore, the data signal should be handled "transparently" by the in-line amplifier, which means that all modulation patterns at any data rate should be amplified without significant loss. In addition, because in-line amplifiers can be installed outside the central network offices, there is a growing desire for lower wall-plug power usage [[9].

1.4.4 Preamplifiers

Preamplifiers increase the signal strength at the optical receiver's input, increasing the receiver sensitivity (i.e., signal detection performance) (i.e., the receiver sensitivity). Each of the three situations calls for a different set of skills. Low noise is required for preamplifiers, whereas high gain is required for power amplifiers and line amplifiers. An optical amplifier can also be used in a variety of different ways in a network to compensate for network losses (such as in an optical switching node) (for example, within an optical switching node to compensate for losses in the switch fabric) [1][2]. What exactly we achieved when we directly use an optical amplifier before an optical receiver as a preamplifier, Due to a reduction in thermal noise, direct-detection optical receiver sensitivity has increased significantly. The fact that it can compensate for LAN distribution losses is an additional benefit. A preamplifier can operate much below saturation, but it does not have any control over feedback. As a result, a good preamplifier should have a high sensitivity, a high gain, and low noise. Because of the poor input signals, saturated output power and noise are the most important performance issues. Improved outcomes can be achieved by controlling the performance and noise of tiny signals [5][7][22]. Adding more amplifiers to a system will reduce its length because of their noise. In light of the network's stochastic state of polarization, it's best to keep the gain's polarization dependence to a minimum. In addition, the in-line amplifier must handle multiple wavelength channels simultaneously. This means that all modulation patterns at any data rate should be amplified without perceptible loss by the in-line amplifier, which is defined as handling the data signal "transparently". It's becoming increasingly important to reduce wall-plug power consumption since in-line amplifiers may be put outside of the central network offices [12].

1.4.5 SOA (Semiconductor Optical Amplifier)

A few of the many applications of a semiconductor optical amplifier include waveform conversion, signal regeneration, pulse shaping and power limitation (SOA). Because of its outstanding integration and high-volume manufacturing capabilities, it has become popular in activities that require high levels of space and power efficiency [1][3]. SOA has been utilized in a variety of optical networks, including long-haul, metro, and access. All of these form factors are available depending on the application and demand for SOA. An SOA is comparable to a semiconductor optical laser, except that it lacks feedback from reflection. In order to establish a transmission medium, an external current induces the electron to hop from one energy level to another [18]. When an incoming photon with a specific frequency interacts with the excited electron, it returns to a lower energy level. Using the same parameters as the incident photon, a new photon is formed with the same properties. Electrons in the active portion of the SOA are excited by an electrical pump current. When an optical signal passes through the active area, the electrons lose their energy in photons and return to the ground state. Signal amplification is achieved by using photons that have been stimulated and whose wavelength matches that of the original optical signal. The four essential features of an SOA include gain, gain bandwidth, saturation output power, and noise. dB stands for decibels, and it represents the gain factor used to boost the input signal (in dB). Soa current has an impact on optical gain. The optical signal is stronger when the gain is increased. The gain-bandwidth indicates the frequency range in which the amplification operates. An amplifier with a wide gain bandwidth is needed to boost signals of various wavelengths [9][11].

1.4.6 Erbium Doped Fiber Amplifier

An erbium-doped fiber amplifier (EDFA) is an optical repeater device that boosts the power of optical signals travelling through a fiber optic communications network [3][23]. For example, an optical fiber with erbium's rare earth element may absorb and create light at the same frequency[1][5]. The erbium-doped fiber (EDF) forms the foundation of EDFA technology. When erbium is exposed to a specific wavelength of light, it transitions into a long-lived intermediate state (980 nm or 1480 nm). The 1525-1565 nm wavelength range produces light when it decomposes. Light-pumped Erbium can either experience a short-lived, unstable condition before swiftly decaying into a quasi-stable state, or it can be instantly stimulated to a quasi-stable state by using light at 1480 nm wavelength. By emitting 1525-1565 nm radiation after reaching a quasi-stable state, it decomposes to the ground

Advantages of EDFA

- EDFA has high pump power utilization (>50%).
- EDFA directly and simultaneously amplifies a wide wavelength band (>80nm) in the 1550nm region, with a relatively flat gain [32].
- Gain-flattening optical filters can improve flatness.

- The gain is more than 50 dB
- EDFA features a low noise figure suitable for long haul applications.
- EDFA deployment is relatively easier to realize and more affordable than other signal amplification methods [8-12].

Why Different Amplifier Choose for FSO System

Amplifiers must be used in the network to ensure that the data stream is distortion-free during signal transmission. When talking about an optical communication system, where data is sent by light over a fiber line, an amplification unit is also required [3][30]. As the signal travels from one end to the other, several variables degrade its quality. As a result, recovering the original information from a signal might be difficult. A fiber cable transfers data from one end to the other in an optical communication system, consisting of a transmitter, receiver, and a fiber cable. A third component, an optical amplifier, is added between the transmitter and reception sections to raise the signal level [24].

Compared to other media, such as coaxial cable, a signal travelling via a fiber cable has low attenuation. On the other hand, long-distance communication needs signal amplification during fiber cable transmission. At 1500 nm wavelength, we know that typical fiber loss is 0.2 dB/km. Let's look at what happens when the optical impulses travel 100 kilometers down the fiber. By 20 decibels, the signals are muffled. As a result, they'll need to go up. Otherwise, the detected signal's signal-to-noise ratio is too low, and the bit-error rate (BER) is too high (a commonly acceptable BER value is 10-9). (A BER of 10-9 is usually suggested.) One alternative is to detect the weak signals and modulate a new laser (optical-to-electrical-to-optical conversions), which necessitates the use of high-speed (>10 GHz) electronic equipment. As a result, optical signal enhancement is the most effective signal enhancement method. The most efficient, dependable, and low-loss solution is fiber amplifier [12-17].

1.5 Objectives of Research

1. Investigation the different amplifier configurations for WDM system based FSO Link
2. Find out Q factor for Boost amplifier, Pre amplifier & In Line amplifier for WDM based FSO link
3. Find out Bit Error Rate (BER) for Boost amplifier, Pre amplifier & IN-Line amplifier

4. Find Out Q factor versus transponder aperture for different optical amplifier configurations in WDM system based on FSO link
5. Determine the performance comparison with existing work with respect to quality Factor & BER for different optical amplifier configurations

1.6 Advantages of Optical Amplifier for FSO System

Free Space Optics is a medium with high bandwidth with a maximum data rate. Demand for large data speed capacity has been increasing exponentially due to the massive spread of the internet. Electronic regeneration has become more expensive with the growing transmission rate and need for optical communication [1][14] [21].

- To transmit signal over a long distance and to compensate attenuation losses.
- Initially, this was accomplished with an optoelectronic module consisting of optical RX, Generator and equalizer, optical TX send data.
- Most of the optical fibers are used for stimulated emission.
- An optical amplifier is a laser without feedback.
- Optical gain is realized when the amplifier is pumped optically to achieve population inversion [22].
- Amplifiers are inserted at specific places to boost optical signals in a system where the signals are weak. This boost allows the signals to be successfully transmitted through the remaining cable length.
- The optical amplifier provides all types of nonlinear operation like cross-phase modulation; cross gain modulation can be conducted [2][5][17].

1.7 Thesis Outline

Chapter 1: Includes introduction, motivation and thesis outline.

Chapter 2: Outlines the previous works done in the field of RFID.

Chapter 3: Describes the methodology of the proposed model including the specific components and their description.

Chapter 4: Describes result and discussion.

Chapter 5: Concludes the paper stating the challenges were found and the future work of the project.

Chapter 2

Literature review

2.1 literature Review

[1] E. E. Elsayed, "Design and Analysis of 1.28 Terabit/s DWDM Transmission System for Free Space Optical Communication", Research Square, 2021.

RZ and NRZ line codes were examined as part of the DWDM-FSO communication system. He determined that NRZ line coding is superior to RZ in terms of efficiency. E. Ciaramella et al. built the first 1.28 Tbps (32-40 Gbps) FSO link. With the use of return-to-zero (RZ) and NRZ line codes, dense wavelength division multiplexing in a free-space optics link could be achieved.

Table 2.1: system parameter used in this paper

Component	Parameter	Value/unit
Free-space optics channel	Distance Attenuation Transmitter aperture diameter Receiver aperture diameter Beam divergence Wavelength Index refraction structure	1 km 25 dB/km 5 cm 20 cm 2 m/rad 193.1 THz 5e-015
EDFA	Gain	30dB
WDM transmitter	Initial frequency Frequency spacing Power Data rate Modulation type	193.1 THz 200 GHz 20 dBm 40 Gb/ps NRZ

For determining the association between BER and eye-opening during data decisions, statistical parameters of amplitude noise are obtained. BER is calculated using the figure of merit and the Q-factor. If there is no ISI distribution and the domain amplitude noise is Gaussian, the signal Q-factor is defined:

$$Q = \frac{v_1 - v_0}{\sigma_1 - \sigma_0} \text{ - - - - - - - - - - - - - - - - - - - (i)}$$

There is no ISI. Hence, these are the average values for v (t) amplitudes high and low. Additive white noise (RMS) is each Gaussian distribution's root mean square (RMS). This paper presents a study and simulation of 1.28 Tbps (32*40 Gbps) for a DWDM-FSO link using NRZ and RZ line coding is presented in this paper, with NRZ line coding is described as superior. According to simulation data, the bit error rate falls as the power and Q-factor increase. The author additionally makes use of wavelength division multiplexing in order to improve the open space optics channel.

[2] SAMIR AHMED AL-GAILANI. et al., "A Survey of Free Space Optics (FSO) Communication Systems, Links, and Networks", IEEE, 2020.

As part of the review, they gave essential ideas for all FSO systems, including single and multiple beam system designs. Rain and haze effect FSO signal transmission, according to the research. By combining a hybrid multi-beam FSO system with wavelength division multiplexing (WDM) technology, the author hopes to increase the scalability of an FSO network.

FSO TRANSCEIVER MODULE

The transmitter have four components

1. Laser modulator
2. Driver
3. Optical laser source
4. Transmitting telescope

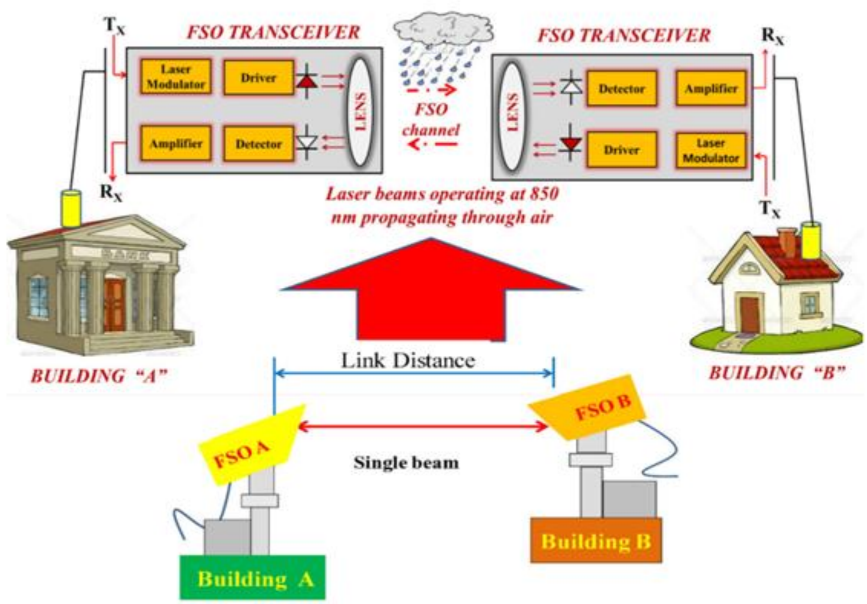


Fig 2.1: How beam transmit through free space channel

A FREE SPACE OPTICS SYSTEM'S BIT ERROR RATE (BER) A range of metrics, including the BER and Q-factor, may be used to evaluate the performance of an FSO system. The number of bit errors discovered in the receiver divided by the number of bits delivered by the transmitter is the bit error rate or BER. When noise (unwanted signals) is present on digital transmission, the receiver makes incorrect judgments, resulting in a high BER rating. Q is one of the essential quality factors influencing optical performance and characterizing BER as a quality factor.

The signals determine the quality of optical communication networks to noise ratio (SNR) and bit error rate (BER). The average determines the received scintillation intensity and receiver noise. The received optical power may be increased by averaging and increasing or decreasing the scintillation effect. LOSS OF POWER IN THE OPTIC SYSTEM Scattering, absorption, surface reflection, and overfull losses are examples of optical system losses in more detail. Geometrical loss is the phenomenon of an optical beam expanding and losing power as it travels from the transmitter to the receiver. The beamwidth, transmitter route length, and detector aperture area of optical transmitters, as shown in Fig. 2.2, determine the geometrical loss in any FSO connection. The transmitter's power, Pt, is broadcast across an area of (l) 2 /4, whereas the density of power flux at the detector is 4Pt/(l) 2, and the detected power is Pr = 4ArPt/(l) 2.

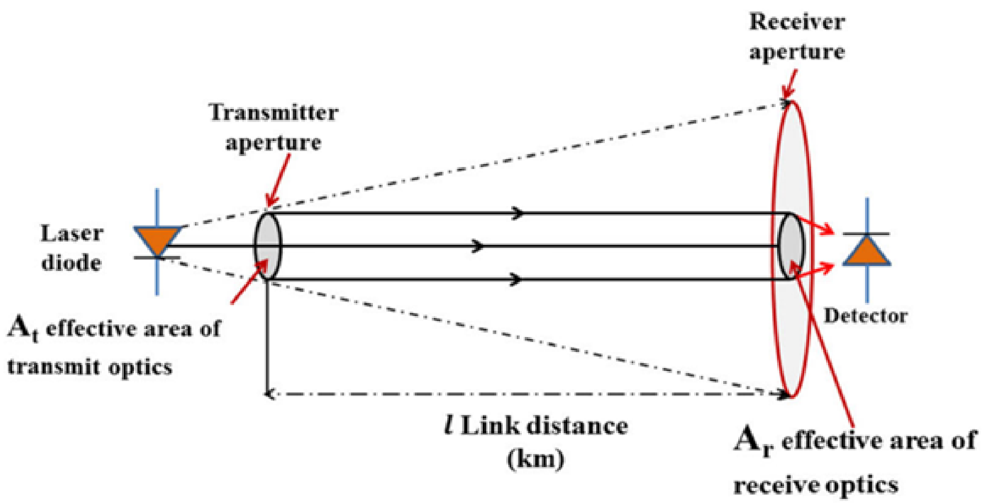


Fig 2.2: Spreading of the transmitted beam in free space between the transmitter and the receiver of an FSO system

FSO failed to account for the Fresnel zone: When radio waves leave the antenna, they spread out into the Fresnel Zone, which is where the visual line of sight is. Fresnel Zones are circular cross-sections between two wireless devices that must be free of any objects or impediments in order to prevent signal loss. CONNECTION TO THE FSO Transmission of data is accomplished by modulating a narrow optical laser beam that transmits digital data from the FSO transmitter to the FSO receiver in free space before processing at the receiving station. The line of sight refers to the ability of the transmitter and receiver at each networking site to see each other. As compared to microwave systems, IR beams propagate and increase linearly, which means that the line of sight limits are less stringent when it comes to IR systems. When modeling a free-space channel, the Fresnel zone is taken into consideration. As seen in Figure 2.2, appropriate and incorrect wireless antenna installation on towers are shown in various examples. In this Fresnel Zone, radio waves spread out after leaving the antenna and before they can be seen. An object or barrier can cause a Fresnel Zone to get jammed, decreasing signal strength. Accordingly, it has been found that the larger wavelength of a signal has a correspondingly wider frequency zone, which is an example of correct and incorrect tower antenna construction. For the sake of speeding up intricate calculations, the 5 GHz Fresnel Zone is considered to be approximately half the size of the 2.4 GHz Fresnel Zone.

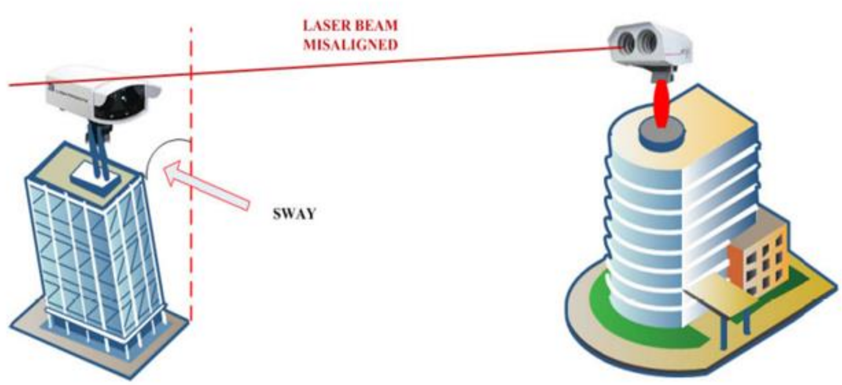


Fig 2.3: Building swaying effect towards an FSO system.

Externally oriented construction: Atmospheric conditions affect external parameters, resulting in losses. In the illustration, an FSO link's performance is mostly controlled by the climate and physical characteristics of the location where it is installed. Given All of these factors affect the performance of FSO connections by reducing or removing the ability to see the FSO transceiver through the glass of a window, the orientation of the transceiver to the building, and the solar interference. This section explains the atmospheric attenuation in tropical regions owing to rain and haze to better comprehend the situation.

ALIGNMENT DISAPPOINTMENT FSO systems work in a wireless medium with a narrow beam (Gaussian distribution) transmitter, which causes a lot of alignment loss. Using an FSO system, the alignment condition can be met when the detector's central point for Gaussian power distribution is in place. As demonstrated in Fig. 2.3, if the sensor and transmitter are not perfectly aligned, then loss occurs. This occurs since the detector cannot accurately gather light at the beam's edges, where intensity is relatively low. Misalignment in actual FSO systems is caused by building motion, particularly in skyscraper-mounted devices.

[3] Ahmed Abdulelah. et al., "Performance Enhancement In WDM – FSO System Using Semiconductor Optical Amplifier Under Different Rain Conditions", Turkish Journal of Computer and Mathematics Education, vol. 12102021, 7350-7354, 2021.

This article investigated the optimal performance for 2.5 Gbps data rate with 35 dB laser power level under three rain scenarios using different adjustable layouts of optical amplifiers in FSO. The outcomes of the proposed system are compared to those of the present system. The proposed solution appears to be more efficient in both performance and cost.

FSO is currently widely employed in various applications since it outperforms and outperforms other traditional systems while providing a slew of other benefits. However, because adverse weather conditions may harm its performance, efforts are undertaken to attain the highest possible degree of performance. Using optical amplifiers, as simulated, is one such way. Using optical amplifiers boosts the system's range as well as its SNR. The simulations show that System II provides better outcomes than System I, with a broader range and higher quality for the same power and other factors. Not only does the suggested solution improve system stability and performance, but it also lowers installation costs.

NRZ (non-return to zero) is used to describe when something does not return to its original state. The pulse stays active throughout the bit slot in the NRZ format, and its amplitude does not decrease to zero between two or more consecutive bits. As a result, the pulse width changes with the bit pattern. NRZ was used in fiber-optical communication in the early days or in commercial systems because:

1. It is not sensitive to laser phase noise.
2. It requires a relatively low electrical bandwidth for transmitters and receivers when compared to RZ,
3. It has the simplest transmitter and receiver configuration.
4. It is less expensive.

Unfortunately, the NRZ modulation standard is incompatible with significant data rates and long-range optical communication systems. When there are a lot of channels, NRZ modulation could be advantageous.

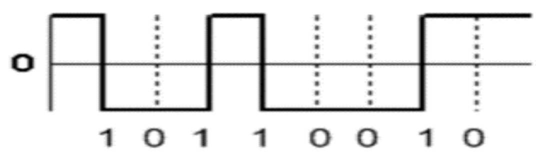


Figure 2.4: NRZ data format

[4] S. Payal Arora, "Reach Enhancement of Designed Free Space Optical Communication System Using Hybrid Optical Amplifier", DE GRUYTER, vol. 2019, 2019.

EDFA-EDFA hybrid optical amplifier (HOA) architecture has been proposed in this research to boost the reach and data rate of an FSO communication system. Regarding the transmission channel, log-normal statistical approximation of the weak turbulence, it has been determined that Q-factor, BER, and the Eye diagram are the performance measures. FSO communication system simulation findings show that the transmission range from 1,000 to 5,000 m may be effectively increased with a significant increase in Q-factor and BER. Using a modulated light signal to convey data over the air is nothing new. Despite the passage of time, this concept has remained constant. The transmitter sends out a tiny beam of light, which passes through the atmosphere and reaches the receiver. Point-to-point communication can be achieved using FSO, a LOS method that uses an optical signal as a carrier channel. You can use it to fix connection issues, and it can also be used to supplement microwave/radio frequency (RF) communications. It has a number of advantages, including quick deployment, the ability to extend the length of the optical fiber backbone network, high security, support for high bandwidth communications, and disaster recovery applications. There is no longer a requirement for physical fiber-optic cables or spectrum licenses to transmit multimedia data using FSO at speeds up to 10 Gbps and optical connection over the air. Using FSO communication channels is hampered by a number of internal and external challenges, including the following: This includes wavelength, divergence angle and transmission bandwidth, optical power on the transmitter side, aperture diameter, and receiver sensitivity. The system's environment is an example of an external factor. Attenuation, scintillation, and reduced visibility are all examples of atmospheric losses.

[5] A. Shaina Nagpal, "Performance Evaluation of Different Optical Amplifiers in Spectrum Sliced Free Space Optical Link", DE GRUYTER, vol. 2018, 2018.

This work presents a comprehensive performance analysis of homodyne-based coherent detection in Free-space optics (FSO) using a variety of optical amplifiers. The effect of scintillation is reduced when the FSO system uses homodyne detection. Optical amplifiers, including erbium-doped fibre amplifiers, semiconductor optical amplifiers, gain-controlled amplifiers, and black box amplifiers, can be used to improve the performance of the FSO system. The BER, Q-factor, and eye diagram may all be used to validate system improvements.

Table 2.2: System Parameter for this paper

Parameter	Value
Bandwidth	$1{,}280e^{9}$ Hz
Sample rate	$160e^{-9}$Hz
Sample mode Bit rate	20 Gbps
Coding	NRZ
Average power of CW laser	$0.05e^{-3}$ W
Modulator	Mach–Zehnder
Launch waist	$2e^{-2}$ m
Receiver aperture diameter	$10e^{-2}$ m
Wavelength	1,550 nm
Coupling coefficient	0.5
Modelling	Kolmogorov

Free space optics (FSO) is a capable and leading technology for delivering high-speed services in various environments, including mountainous terrain and inter-building networks. The spectrum sliced wavelength division multiplexed FSO system is effectively shown in this study. The wavelength division multiplexing (WDM) channels are spaced 75 GHz apart to increase system bandwidth efficiency. The nonlinearity known as self-phase modulation generates carrier spectrum widening for spectrum slicing. In addition, there is no need for several laser sources. However, to create n WDM channels in traditional WDM systems, n lasers are required. Three optical amplifiers are investigated in terms of Q-factor and bit error rate to improve the signal in this FSO system: erbium-doped fiber amplifier (EDFA), semiconductor optical amplifier (SOA), and Raman amplifier (BER). In the suggested SS-WDM-FSO system, the results showed that EDFA is the optimal amplifier.

[6] Miglani, R., Malhotra, J.S. Evaluation of link-compensated 32 × 40 Gbit/s DWDM free space optical (FSO) transmission. J Opt**47,** 467–474 (2018). https://doi.org/10.1007/s12596-018-0484-8

They illustrate in this work how fiber-based subsystems may complement optical multiplexing (DWDM) and FSO. The suggested approach, based on the findings, offers seamless communication as well as increased data throughput. We successfully showed a 32 9 40 Gbps DWDM-FSO connection operation across a 3 km distance, with an acceptable BER of 10-11 in the case of symmetrically compensated systems, using a typical reference channel width of 0.8 nms. When the connection length increases from 1 to 4 km, a minimal fluctuation in BER of the order of (less than) 10-4 is seen.

Table 2.3: System Parameter for this paper

Parameters	Description
Number of channels (*N*)	32/48/64
Channel spacing (DWDM)	0.8 nm
Source/detector	CW laser/APD
Transmitter aperture diameter	5 cm
FSO receiver aperture diameter	20 cm
Beam divergence	2 mrad
Bit rate	40 Gbps
Link attenuation	20 dB/km
Link turbulence	Gamma–Gamma model

They have successfully shown the operation of a 32-channel DWDM-FSO connection over 40 Gbps for moderately attenuated and turbulence-modelled (Gamma–Gamma) links. The findings are encouraging since compensation strategies (pre/post/symmetric) extend the effective coverage area, which would otherwise be limited to a maximum of 2 kilometers in the absence of compensation. At a link distance of 3 km, the pre-, post-, and symmetric adjusted DWDMFSO overcame link adversity to yield 10-7, 10-8, and 10-9 BER, respectively. Additionally, symmetric compensations were shown to be the most dependable system, as BER degradation with increased coverage range was extremely small, ranging from 10-13 to 10-9, although BER on pre- and post-compensated connections changed significantly.

[7] Thakur, A., Nagpal, S. & Gupta, A. A Performance Enhancement and High Speed Spectrum Sliced Free Space Optical System. Wireless Pers Commun **100,** 1775–1789 (2018). https://doi.org/10.1007/s11277-018-5674-9

Different line coding (return to zero, non-return to zero) and sophisticated modulation formats (compressed spectrum return to zero) are being researched for the system. Beam divergence, a significant degrading element in free-space communication, is also examined for the research. The diameters of the reception and transmitter antennas are necessary for FSO. Hence the performance of various diameters is investigated. The goal is to meet high-speed data needs. Thus the system was designed and proven at speeds ranging from 2.5 to 10 gigabits per second. Three optical amplifiers are investigated in terms of bit error rate and quality factor to improve the signal in this FSO system: erbium-doped fiber amplifier (EDFA), semiconductor optical amplifier (SOA), and Raman amplifier. In the studied SS-WDM-FSO system, the results demonstrated that EDFA is the optimal amplifier. The purpose of this dissertation is to investigate a 2.5 Gbps SS WDM FSO communication system based on Kerr nonlinearity self-phase modulation. The researchers examined clear skies, mild rain, haze, and fog. The most extended reported connection length in clear weather is more than 8 kilometers, while the shortest reported connection length in fog is 1.5 kilometers. Second, the system's performance was evaluated by varying the beam divergence angle, the aperture diameter of the transmitter/receiver antennas, and the modulation formats. By modifying these settings, we discovered that when CSRZ modulation is used, the SC-SS WDM technique outperforms alternative modulation formats. Signal quality improves when the beam divergence angle is set to a reasonable value, and the BER decreases. The larger aperture sizes of the transmitter and receiver antennas also help increase the system's performance. Finally, numerous optical amplifiers have been examined, including the EDFA, Raman, and SOA amplifiers and the CSRZ modulation technique. When several amplifiers' performance is compared, it is determined that the EDFA amplifier achieves the best results. When the EDFA amplifier is used, the system is capable of transmitting data at a rate of up to 10 Gbps across a distance of 10 km.

Table 2.4: Atmospheric weather condition along with value of attenuation

S. no.	Quantity	Values
1	Data rate	2.5–10 Gbps
2	Weather condition investigated	Clear weather, mild rain, medium rain, haze, fog
3	Power	30 dBm
4	Wavelength	1552.52 nm
5	No. of channels	4
6	Channel spacing	75 GHz
7	Diameter of transmitting antenna (in cm)	Varied from 5, 10, 15, 25
8	Diameter of receiving antenna (in cm)	Varied from 5, 10, 15, 25
9	Beam divergence (in mrad)	Varied from 0.25, 0.5, 0.75, 1
10	Effective aperture of HNLF	10 μm^2
11	HNLF attenuation	0.5 dB
12	Nonlinear index of refraction	2.6e−019 m^2/W
13	Link length	More than 5 km
14	Amplifier	EDFA, SOA, Raman
15	Line coding	NRZ, RZ, CSRZ

[8] Abdul Gafur &. Syed Zahidur Rashid, "Quality Optimization Based Trend Line for Hybrid Optical Amplifier Configurations in DWDM Transmission Systems", INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,, vol. 14, 5, 2019, 2019.

This article aims to improve signal quality in 128x10 channel DWDM transmission systems with 100GHz channel spacing. Amplified Spontaneous Emission (ASE) and nonlinearities are well-known flaws in long-distance optical fibre communications. Hybrid Optical Amplifiers can alleviate both of these issues (HOA).

The estimated signal quality is based on channel input power, minimum log Bit Error Rate (BER), and maximum eye-opening factor for three HOA setups. They also generated a trend line that may be used to forecast the performance of long-haul optical fibre communications in three distinct deployment scenarios for hybrid optical amplifiers. The H3 (EDFA-RAMAN & OA) configuration covers 128 channels with an optimal channel input power of -5dBm and 17.11dB signal quality.

Table 2.5: Comparison table for proposed & previous model

Factors	Ref. No. [15]	Ref. No. [16]	Ref. No. [17]	Ref. No. [18]	Ref. No. [19]	Ref. No. [20]	Ref. No. [21]	Ref. No. [22]	Current Investigation
Multiplexing Type	DWDM-OTDM	U-DWDM	WDM	DWDM	WDM	DWDM	DWDM	WDM	DWDM
Modulation Formats	Duobinary	NRZ	NRZ	RZ	DPSK	NRZ & RZ	-	NRZ	NRZ
Data Rate(Gbps)	40	-	10	12.5	40	10	-	42.7	10
Channel Input power(dBm)	-10 to 10	-13	10	0	-10	10	-	-2 and -4	-10 to 10
No of Channels	16	100	32 and 64	3	16	64	96	54	128
Channel spacing	0.2nm	0.19nm	20GHz	-	0.1THz	50GHz	0.8nm	100GHz	100GHz
Span length(km)	119	205	40-200	45.75	100	80-200	40	225	60
Dispersion (ps/nm/km)	16	5.5	2	-	16	2	-	-	16.75
Amplifier Type	Raman-EDFA	Raman-EDFA	Raman-EDFA	EDFA-Raman	Raman-EDFA	EDFA-EDFA-Raman	EDFA-TDFA	Raman-EDFA	Raman-EDFA
Q factor(dB)	18	8	11.5	11.801	18.71	18	9.8	16.1	19.68

This work covers the trend line analysis for several hybrid optical amplifier designs for DWDM systems. The H3 (EDFA-RAMAN-OA) combination delivers the best signal quality in channel input power, BER, and eye-opening factors. The H3 setup yields BER -

65.26 and an eye-opening aspect of 94.15, resulting in maximum signal quality of 17.11dB for 128 channels. This simulation study aids in the determination of the best channel input power and signal quality with the highest eye-opening factor and lowest log of BER. The findings of the trend line and eye diagrams and the performance curves are in agreement and provide solid evidence for our view.

[9] F. Ajibodu, Zacchaeus Adetona, "Performance Analysis of Erbium Doped Fiber Amplifier's and FWM Characteristics in a Passive Optical Network", International Journal of Optoelectronic Engineering 2016,, vol. 611-7, 2016.

The performance of the Erbium-Doped Fiber Amplifier (EDFA) was evaluated. Its characteristic was identified when the input power was changed in the 1550nm band using the OptiWave OptiSystem simulator. Additionally, it demonstrated EDFA's performance under dense wave division multiplexing (DWDM) by studying its qualities when four transmitters with wavelengths of 1560nm, 1550nm, 1541nm, and 1532nm were multiplexed across a fiber connection and amplified using an EDFA. A subsequent experiment in this study demonstrated the effect of strengthening Four-Wave Mixing (FWM) across a DWDM network and the effect of decreasing the Chromatic dispersion coefficient from 16.75ps/nm/km to 11.75ps/nm/km on the FWM generated. The results indicated that in order to get an excellent optical signal to noise ratio, the amplified spontaneous emission (ASE) characteristic of an EDFA must be as small as possible (OSNR). According to the eye diagram created, inter-symbol interference (ISI) was also reduced at 1541nm and 1532nm as a result of lower attenuation at these wavelengths. The effect of FWM increased when transmitter input power was increased, whereas the impact of FWM on the transmitted output wave was reduced as the chromatic dispersion coefficient was increased.

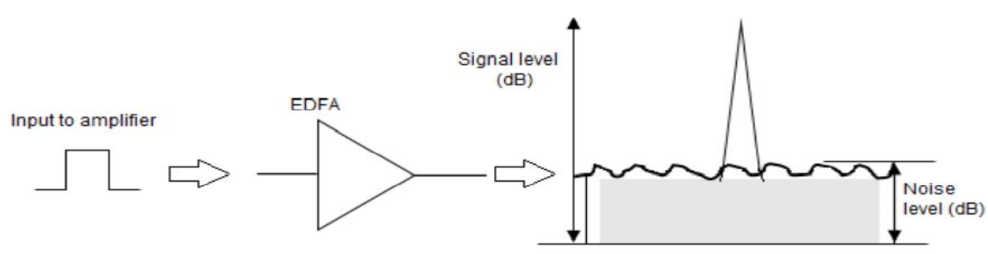


Figure 2.5 Single stage amplifier noise

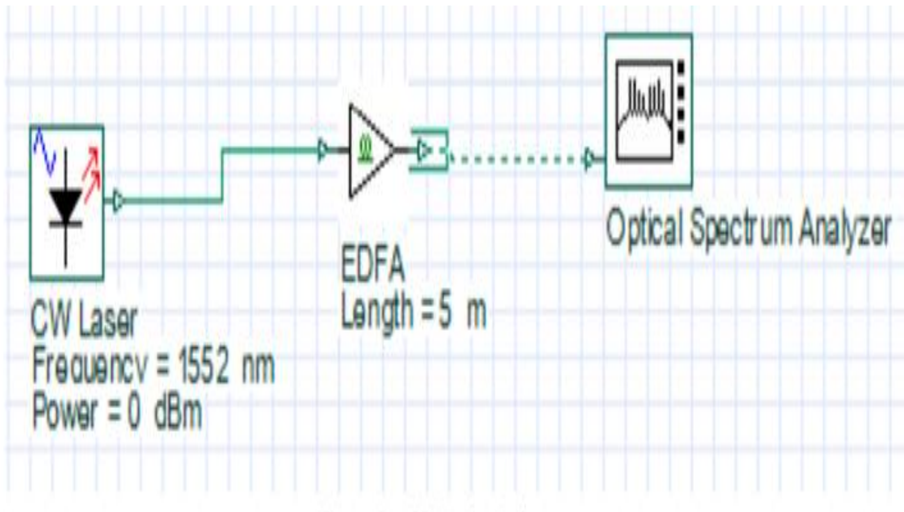


Figure 2.6: EDFA simulation Setup

Table 2.6: EFDA Characteristic

Input power (dBm)	Output power (dBm)	ASE (dB)	Gain (dB)	OSNR (dB)
-30	4.7	-29.2	34.7	33.9
-28	6.6	-29.4	34.6	36.0
-26	8.38	-29.6	34.4	37.98
-24	10.8	-29.9	34.8	40.7
-22	11.7	-30.4	33.7	42.1
-20	13	-31.1	33	44.1

Table 2.7: Amplified WDM network output

ave-lengths (nm)	Output power (dBm)	ASE (dB)	OSNR (dB)	Eye height (m)
1560	-16.06	-41.66	25.65	3.62619e-005
1550	-13.06	-38.49	25.43	6.90165e-005
1541	-9.10	-38.23	29.13	0.000183269
1532	-3.46	-27.58	24.12	0.000643659

Table 2.8: power at the input and output of the fiber.

Wavelength (nm)	Output power at fiber input(dBm)	Output power at fiber output(dBm)
(λ) 1550.52	9.4250	-11.61
(λ_1) 1550.12	9.9503	-11.10
(λ_2) 1549.72	9.9054	-10.59
(λ_3) 1549.32	9.9404	-11.05

Three conclusions may be drawn based on the study and statistics shown above. First, the EDFA experiment revealed that when an EDFA is used as an amplifier, the amplified spontaneous emission (ASE) characteristic of the EDFA must be taken into account, as it was discovered that as the ASE increased, the amplifier's gain decreased. Thus the signal to noise ratio (OSNR) decreased.

Second, the eye diagram shows that inter-symbol interference (ISI) was reduced at wavelengths of 1541nm and 1532nm. As revealed by the experiment results, this range will be acceptable for amplification in practical applications due to the low degree of interference.

[10] T. N. Victor jaya, "Performance Analysis of 48 Channels DWDM System using EDFA for Long Distance Communication", GRD Journals- Global Research and Development Journal for Engineering, vol. 2, no. 3, pp. ISSN: 2455-5703, 2017.

The performance of Dense Wavelength Division Multiplexing was computed and analyzed in this research. In addition, assess the optical pulse's quality factor and bitrate. The data was sent using several modes of optical fiber. Single-mode fiber (SMF) and dispersion compensation fibers (DCF) are employed in this application. The BER analyzer and the Optical Analyze explain the 48 channel DWDM with stated looping in this study. Optical Add/Drop Multiplexers (OADMs) are used in wavelength-division multiplexing systems for fiber optic signal routing and multiplexing. They are also utilized to carry data across vast distances. Two modulation techniques are available in this procedure. RZ and NRZ are two acronyms for "Research and Development Zone" and "National Research and The NRZ modulation approach can be employed in this project.

Table 2.9: Required parameters and Values

parameters	Value
Reference frequency	1450 nm
Frequency spacing	100GHz
Optical fiber length	90km
DCF length	30km
EDFA gain	20 db
Optical receiver cutoff frequency	0.75x Bit rate Hz

Simulated a 32-channel DWDM network running at 40 GB/s using NRZ modulation modes. A 32-channel WDM transmitter with a starting frequency of 1450nm and a frequency spacing of 100 GHz is used in the transmitter part. A transmission loop with a length of 90 km of SMF, 30 km of DCF, and two EDFAs was employed as an optical connection in this experiment. PIN photodetectors and BER testers are used in the receiver, a 32-channel WDM de-multiplexer. With the generic Optical fibre, a 32-channel multiplexer and DCF were employed. The gain of the optical amplifier was raised by 20 per cent. 100GHz then separates the wavelength in frequency. The signal is sent in an ideal mux using a WDM transmitter. After that, it was divided and sent through the control loop. Optical fibre transmits signals. Optical fibres of two different kinds are employed in this application. Dispersion compensation fibre and single-mode fibre are the two types of fibre. Then WDM did the Demux. Proceed to the photodiode after de muxing the wavelength. Optical receivers receive the signal from the WDM demux. The BER analyzer's output is shown. On the graph, the BER treatment is conducted. The output is high, and the quality factor value improves when the waves are dispersed equally. The Signal transmission rate is as high as the quality factor value increases. Before this method, The quality factor is now 2.345; it has increased by 11.4327 after changing the length of the optical cable. When data is transferred over a long distance, the quality factor improves.

[11] B. M.L. Meena, R.S. Meena, "DESIGN AND PERFORMANCE ANALYSIS OF SEMICONDUCTOR OPTICAL AMPLIFIER FOR 16×10Gbps DWDM TRANSMISSION SYSTEMS", ICTACT JOURNAL ON COMMUNICATION TECHNOLOGY, JUNE 2019, vol. 10, no. 02, pp. ISSN: 2229-6948, 2019.

We proposed a sixteen-channel dense wavelength division multiplexing (DWDM) optical transmission system (SOA) based on semiconductor optical amplifiers. SOA amplifiers compensate for signal attenuation during transmission in optical communication systems. To evaluate the performance of the DWDM system and overcome attenuation effects, pre-, post- (booster), and in-line SOA techniques are modelled, studied, and compared. The suggested system is constructed using the Optisystem7.0 simulator for a 10Gbps network employing a non-return-to-zero (NRZ) modulation format with a 14-kilometer dispersion compensation fiber (DCF) and a 70-kilometer single-mode fiber (SMF). The constructed system's performance is examined and compared in terms of eye shape (eye-diagram), Q-factor, and bit error rate by varying the input power (mw) parameter of a CW laser source (BER). It has been demonstrated that the in-line SOA amplifier functions admirably as an attenuation compensator for the optical transmission systems proposed.

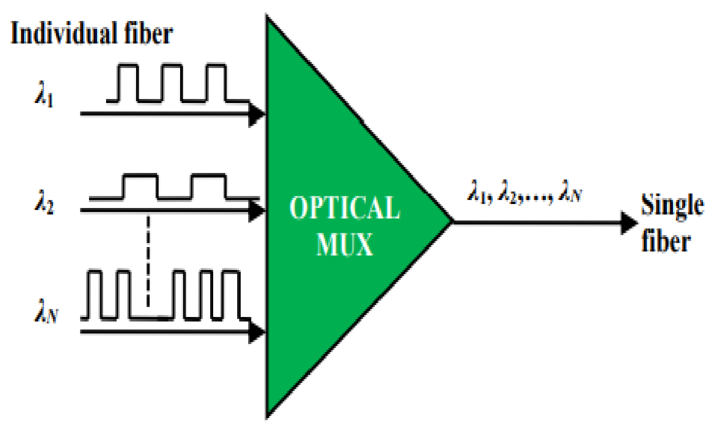


Figure 2.7: Basic building block of optical DWDM transmission

The performance of a developed 1610Gbps DWDM optical transmission system employing various semiconductor optical amplifiers was emphasised in the current study (pre-SOA, booster-SOA and Inline-SOA). Variable input power is used to explore the performance characteristics of a proposed 84km optical connection in terms of eye diagrams, bit error rate (BER), and Q-factor on each channel (mW). In addition, we use cost analysis to analyse the performance of each channel for SOA topologies, and we discover that the optimised In-line SOA amplifier architecture provides the highest performance (higher Q-factor and lower BER) compared to pre-and booster amplifiers.

Table 2.10: Simulation Parameter

Technique/ Parameters	**Proposed Work**	**[5]**	**[9]**	**[13]**	**[14]**
	In-line-SOA	**EDFA**	**SOA+EDFA**	**SOA**	**SOA**
Max Q-Factor (dB)	11.630	12.7412	25.91	10.346	8.2712
Min BER	1.210 e^{-031}	1.63383 e^{-037}	1.010 e^{-040}	4.844 e^{-015}	6.328 e^{-010}
Gain (dB)	-	5.2840	6.9470	36.5230	30.1430
Output Power (dBm)	11.13	13.450	13.80	21.36	19.20
SMF Length (km)	70	150	100	60	40
DCF/CFBG Length (km/mm)	14km	45mm	16km	20km	15km
Cost	Medium	Low	Medium	High	Medium

[12 R. Dharmendra Dhadhal, "Performance Analysis of 64 Channel DWDM System Using Single Mode Fiber at Different Power Levels and Frequency Spacing", ICMAICT 2020, vol. 1804012153, 2020.

The purpose of this article is to demonstrate how a 64-channel DWDM system with a data throughput of 10 Gbps can be used to enhance system quality across a 50-kilometer single-mode fiber at various power levels and frequency spacings (SMF). We used EDFA (Erbium Doped Amplifiers) to increase the gain of the battery and DCF to increase the system's efficiency and capacity. The Optisystem program's findings include modelling at various power levels and frequency spacing study of the BER, Q-factor, and eye height.

Table 2.11: Simulation Parameter

WDM transmitter frequency	190THz
Frequency spacing	100,90,70 GHz
Input power	-7,-3,3,7 dBm
Bit rate	10 Gb/sec
Modulation type Fiber length	NRZ 50km
Attenuation	0.2 dB/km
EDFA gain	10 dB
DCF length	15 km
Reference wavelength	1450 nm

This performance study of 64 channels works With the use of single-mode fibre; a single channel was replaced with 64 channels, yielding superior system quality at various frequency spacings and power levels. With a Q-factor of 12.4041 for varied frequency spacing at 100GHz frequency spacing at -10dBm input signal strength and 10.7893 for different power levels at three dBm input signal power, the DWDM system has outperformed the competition. The eye diagram depicts this finding. It has a higher quality factor and a lower bit error rate, indicating an improved estimate.

[13] Ebrahim E. Elsayed, "Performance evaluation and analysis of four waves mixing in DWDM optical communications", Research Square, 2021.

Optical nonlinearities cause a slew of common optical phenomena. These effects are fascinating, but they can be dangerous in optical communication. Nonlinear effects play a significant role in the Dense Wavelength Division Multiplexing (DWDM) technology. Component reliability, system availability, and system margin are advantages of using a DWDM system. Different channels are carried by DWDM. As a result of the increased power carried by fibre, nonlinear effects such as SPM, XPM, SRS, SBS, and FWM emerge. One of the most concerning problems is four-wave mixing (FWM). In DWDM systems with narrow channel spacing, the FWM produces crosstalk. Data may be switched between two wavelengths simultaneously via wavelength exchanging. Wavelength conversion, wavelength sampling, optical 3R, optical interconnects, and optical add-drop multiplexing are just a few examples of how these phenomena have been exploited in Wavelength Division Multiplexing (WDM) optical networks.

Table 2.12: FWM vs no of channel for the dispersion of 0ps

No of channels	Input frequency (THZ)	Input power (Mw)	FWM power (Mw)	OSNR (dBm)	Frequency at which Max. FWM occurs ((THz
1	192	1	0.0000	∞	No
2	192&192.2	1	0.0400	13.98	192.2
8	[192:0.2:193.4]	1	0.0510	12.92	193.0
16	[192 : 0.2 :195]	1	0.0511	12.91	195.0
32	[188:0.2:194.2]	1	0.0520	12.84	196.0
64	185:0.2:198.6	1	0.0560	12.51	203.4

In DWDM systems, FWM can cause interchannel crosstalk. It adds to the noise and reduces the efficiency of the system. The FWM effect can be decreased by utilising non-zero dispersion-shifted fibre, i.e. fibre with four ps/nm/km dispersion and irregular channel spacing. Because unequal channel spacing can minimise non-linearities [FWM & SRS] while also increasing OSNR, it may improve performance and lower BER.

[14] H. Ullah Manzoor, et el., "FWM Mitigation in DWDM Optical Networks", ICaTAS 2019, vol. 14472020012033, 2019.

This paper proposes three optical communication options for avoiding Four-Wave Mixing (FWM). Three solutions are used: low input power coupled with a high gain amplifier, OTDM and WDM technology, and alternate circular polarisation. The first approach reduces the input signal strength to -20 dBm and then increases it by 20 dB before demultiplexing. The second approach divides the input signal into four-time slots and then combines them with the aid of a power combiner. The third approach modifies the polarization of input pulses prior to multiplexing them into right and left-handed circular polarization. Optics are used to perform a vast array of simulations. The performance evaluation takes into account the Q-factor, the optical signal to noise ratio (OSNR), the received power, the bit error rate (BER), and the eye diagram.

Table 2.13: comparison between different techniques

Technique	Avg. OSNR (dB)	Avg. Recieved Power (dBm)	Avg. Q factor	Avg. RER
Low input power and high optical gain	20.14	-17.84	4.5	12×10^{-8}
WDM/OTDM	22.05	-15.8	4	3×10^{-6}
Circular polarizers	23	-25.27	5	7×10^{-7}

Three systems for eliminating FWM are presented and examined in this research. The first is low input power with a high gain optical amplifier, the second is a combination of DWDM and OTDM, and the third is an alternate circular polarization. The proposed approaches reduced FWM significantly, albeit at the expense of system quality. FWM may be considerably reduced by altering system settings. Based on OSNR, received power, and Q factor, using different circular polarizers to suppress FWM improves system performance.

[15] S. Mahdi Hamzah, et al, "Enhancement of the Performance of DWDM Free Space Optics (FSO) Communications Systems Under Different Weather Conditions", International Journal of Intelligent Engineering & Systems, vol. 13, 4, 2020, 2020.

The suggested system's primary goal is to reduce the attenuation when an optical signal is sent over free space and subjected to various weather conditions. The research is based on the use of the Optisystem simulation toolkit to simulate different weather attenuation circumstances in two distinct types of FSO systems. The first is DWDM SISO, while the second is Hybrid DWDM-MIMO, which is a proposed system. A comparison is made between the proposed method and the old system in various weather attenuation conditions in terms of the quality factor. The suggested system has shown encouraging results in terms of performance and signal quality. Compared to typical DWDM-SISO, the transmission path length of the proposed system during dense fog attenuation of 260 dB/km is increased by 30.43 per cent, and when heavy rain attenuation of 9.29 dB/km is increased by 55.55 per cent. Compared to typical DWDM-SISO, the transmission route length of the proposed system is increased by 26.19 per cent under heavy dry snow with an attenuation of 131.835

dB/km. SISO is an acronym for "Synergistic Information. Wireless communications ushered in a slew of technological advancements in data transmission and sharing. SISO is a technology used in classical radio communications. The SISO approach is based on only one antenna for transmission and one antenna for reception. Because of the influence of weather conditions and interruption due to barriers such as birds and insects, FSO systems using SISO technology are more vulnerable to atmospheric attenuation.

[16] Lema, Gebrehiwet Gebrekrstos. "Free space optics communication system design using iterative optimization" Journal of Optical Communications, vol. , no. , 2020, pp. 000010151520200007

Weather conditions that reduce signal strength have a significant impact on connection dependability. As a result, this work aims to employ iterative optimization on FSO communication to offset weather and geography impacts. By lowering the Bit Error Rate, the optimization enhances visible distance while still ensuring dependability (BER). The 10 Gbps data rate is incorporated into the wireless optical communication technology. In terms of visible distance, quality factor, BER, and Eye diagram under various atmospheric circumstances, the suggested wireless optical communication is compared to the literature. According to the simulation findings, the recommended work outperforms the competition.

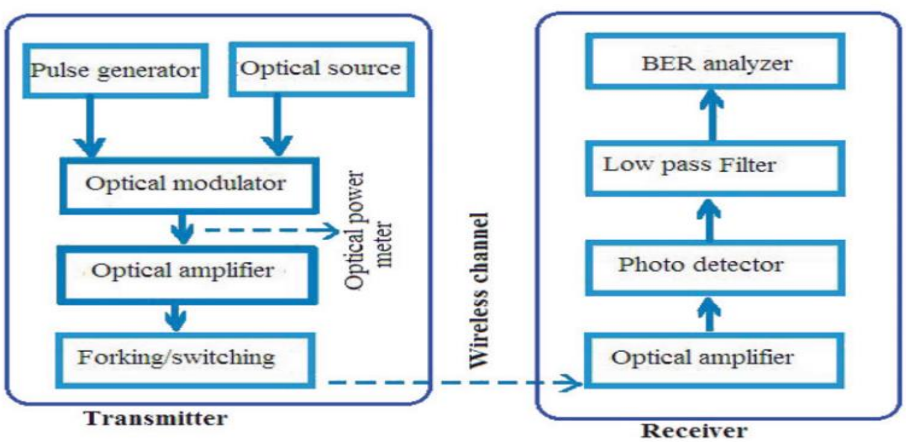


Figure 2.8: Transmitter and Receiver step for FSO

A hazy, misty, rainy, and foggy weather circumstances, the performance of the optimized optical connection design is assessed in terms of visibility distance, quality factor, BER, and Eye diagram. The performance evaluation was completed while the reliability and data rate was used to ensure the QoS. The visible distance is maximized by developing the optical link design and improving the optical amplifier length while keeping the BER data rate. Q-factor more than or equivalent to the latest researches. The greatest assured QoS visible distance for every given atmospheric condition is established, and the innovative suggested design allows for the adaptation of the meteorological state. In general, simulation findings indicate that at the sacrifice of minimal system complexity, improved visibility distance, Q factor, and lower BER may be attained.

[17] N. Harjeevan Singh, Prabhjot Singh, "Analyzing the FWM at Different Power Levels in the Fiber Optic DWDM System", DWDMProceedings of the Fifth International Conference on Communication and Electronics Systems (ICCES 2020), vol. 978-1-7281-5371-1, 2020

Dense wavelength division multiplexing (DWDM) is a technique for boosting the capacity of an optical fiber communication system. The term "dense" refers to the system's ability to combine wavelengths more closely than previous wavelength division multiplexing technologies allowed. DWDM enables the simultaneous transmission of multiple signals at various wavelengths over a single cable. DWDM generates nonlinear effects as the data rate increases and the channel spacing decreases. FWM is a nonlinear effect that has an effect on both the transmitted signal and the system's overall performance. This work investigates the effect of four-wave mixing on DWDM-based optical fiber communication efficiency at a range of power rates. This article was written using the modelling software OptiSystem7.0 to simulate the 16-channel dense multiplexing wavelength division (DWDM) technique. The optical spectrum analyzer, the bit error rate, and the quality factor are examined on the receiver side.

[18] N. Harjeevan Singh, Prabhjot Singh, "Mitigation of FWM in the Fiber Optic DWDM System by using Different Modulation Techniques and Optical Filters", Proceedings of the Fifth International Conference on Communication and Electronics Systems (ICCES 2020), vol. 978-1-7281-5371-1, 2020

High launching power and the smallest channel spacing are required to maximise the fibres' transmission capacity. As a result, DWDM (Dense Wavelength Division Multiplexing) is now widely used. However, nonlinear distortion such as Four-Wave Mixing lowers the transmitted signal and hence the overall system performance when the spacing and number of channels are reduced. Various modulation approaches and optical filters were studied in this research to reduce Four-Wave Mixing (FWM) in Dense wavelength division multiplexing.

Table 2.14: power of FWM product

Modulation techniques	**Modulation techniques**	**Modulation techniques**
Gaussian pulse generator	-72	-76
Raised-Cosine pulse generator	-64	-73
Inverted Rectangular Filter	The power of Four Wave Mixing products is not obtained.	The power of Four Wave Mixing products is not obtained.
Duo binary format	-75	-81

Optisystem 13 is used to produce all of the findings. We looked at the Gaussian pulse generator, Raised Cosine pulse generator, Inverted Rectangular filter, and Duobinary modulation format. To decrease FWM products, the circular polarizer is employed in various modulation approaches. The raised-cosine pulse generator has the maximum quality factor of around 18.3942, while the duobinary format has the lowest quality factor of about 4.29446, as seen by the circular polarizer. AS SHOWN IN THE TABLE, the FWM is decreased in duobinary format, with a value of -81 dBm. The inverted rectangular filter doesn't produce any FWM products. According to the results, the usage of circular polarizers can minimize the power of FWM goods.

[19] N. Desita D Fadhilah, Suherman, "Point to Point Communication Link Design by Using Optical DWDM Network", 2020 4th International Conference on Electrical, Telecommunication and Computer Engineering (ELTICOM), 2020.

From one place to another, To allow access networks to provide high-bandwidth traffic to backbone networks, Ethernet requires a high-bandwidth connection. Thanks to optical dense wavelength division multiplexing (DWDM), the demand was met. The system also requires an amplifier to amplify the received signal for long-distance point-to-point communication. This study discusses network architecture for long-range DWDM point-to-point links. Using a wavelength of 1555 nm, the OptiSystem v.17 is used to construct the 100-kilometre network link. The proposed connection comprises 40 channels and is capable of operating at 100 GHz bandwidth. However, while working with a bandwidth of 8 GHz, the best bit error rate and Q-Factor are reached.

Table 2.15: Specifications

Parameter	Design 1	Design 2	Design 3
Transmitter			
Outputs	40	40	40
Wavelength (nm)	1555	1555	1555
Space frequency (GHz)	100	100	100
Power (dBm)	-5	20	20
Extinction ratio (dB)	30	30	30
Line width (MHz)	0.1	0.1	0.1
Single mode fiber			
Wavelength (nm)	1555	1555	1555
Length (km)	100	100	100
Attenuation (dB/km)	0.2	0.3	0.3
Dispersion (ps/nm.km)	16	17	17
Dispersion slope (ps/nm.km)	0.076	0.075	0.075
Non linear	off	off	off
EDFA			
Mode	Gain control	Gain control	Gain control
Power (dBm)	14	40	40
Saturation (dBm)	10	10	10
Gain (dB)	10	40	40
Noise Figure (dB)	5	10	10
Demux			
Outputs	40	40	40
Wavelength (nm)	1555	1555	1555
Spacing freq. (GHz)	100	100	100
Bandwidth (GHz)	80	15	8
Insertion loss (dB)	0	0	0
Depth (dB)	100	100	100

A point-to-point optical DWDM design for a 100-kilometre link is discussed in this work. The optimum design uses a wavelength of 1555 nm, a fiber optic attenuation of 0.3 dB/km, and an operational bandwidth of 8 GHz. The greatest results may be reached with an average BER of 10-6 and a Q-factor of 4.6. Even though the first and second designs have greater bandwidths of 80 and 15 GHz, respectively, the BER and Q-factor are not met.

Chapter 3

System Model

3.1 WDM system with Boost amplifier, Preamplifier, Inline amplifier

The NRZ line codes were used to simulate the setup of a 2.56Tb/ps (64 40 Gbps) communication system via the FSO channel. This system was created with Optisystem version 7, a software platform for optical communication design and simulation. At the input, we employed a DWDM transmitter. The DWDM Transmitter is a single component that encapsulates numerous components, allowing users to pick different modulation formats and schemes for many channels. It's a transmitter array that supports a variety of modulation methods and types. The initial frequency is 193.1 THz, with a 100 GHz frequency gap. NRZ is a form of modulation. We've picked 64 channels, each with a bandwidth of 40 Gbps. The overall data rate at the multiplexer is 2.56 Tb/ps. The FSO component comes after the optimal multiplexer. It's a transmitter array that supports a variety of modulation methods and types. Free space optical links can be simulated with this component. The component is a transmitter telescope, free space, and receiver telescope subsystem. The parameter range defines the propagation distance between the transmitter and receiver telescope. The laser power attenuation is determined by two main factors: attenuation and geometrical loss.

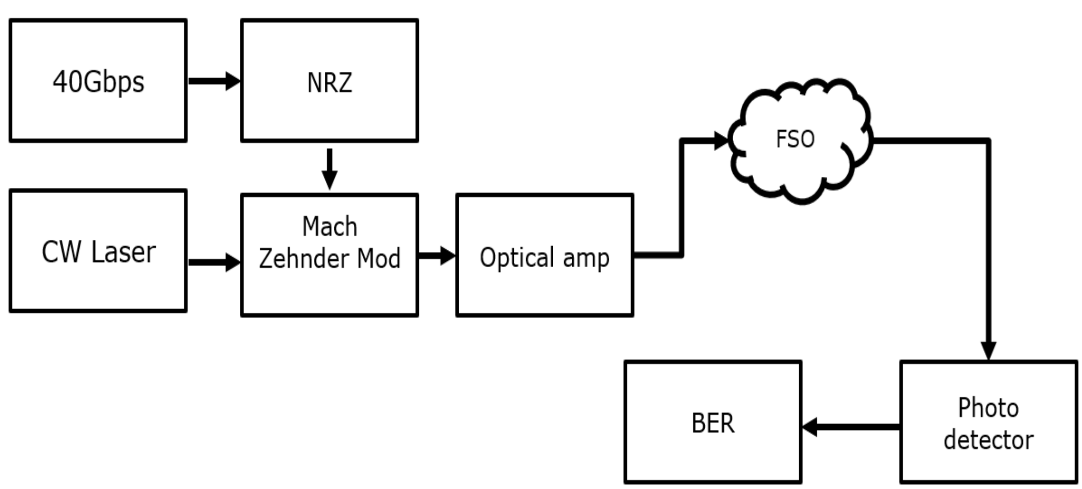


Figure 3.1: Proposed WDM system with Boost amplifier

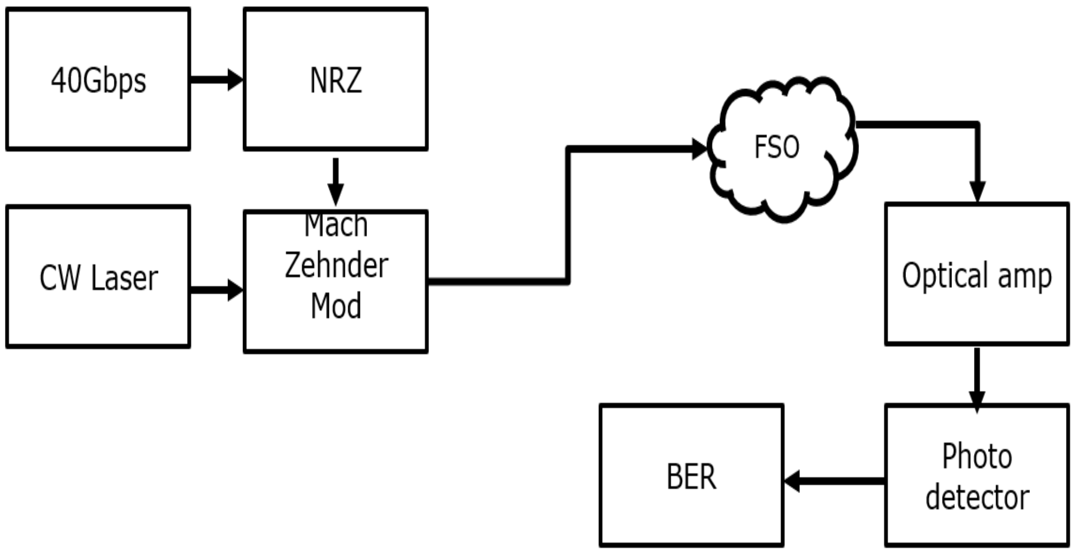


Figure 3.2: Proposed WDM system with Preamplifier

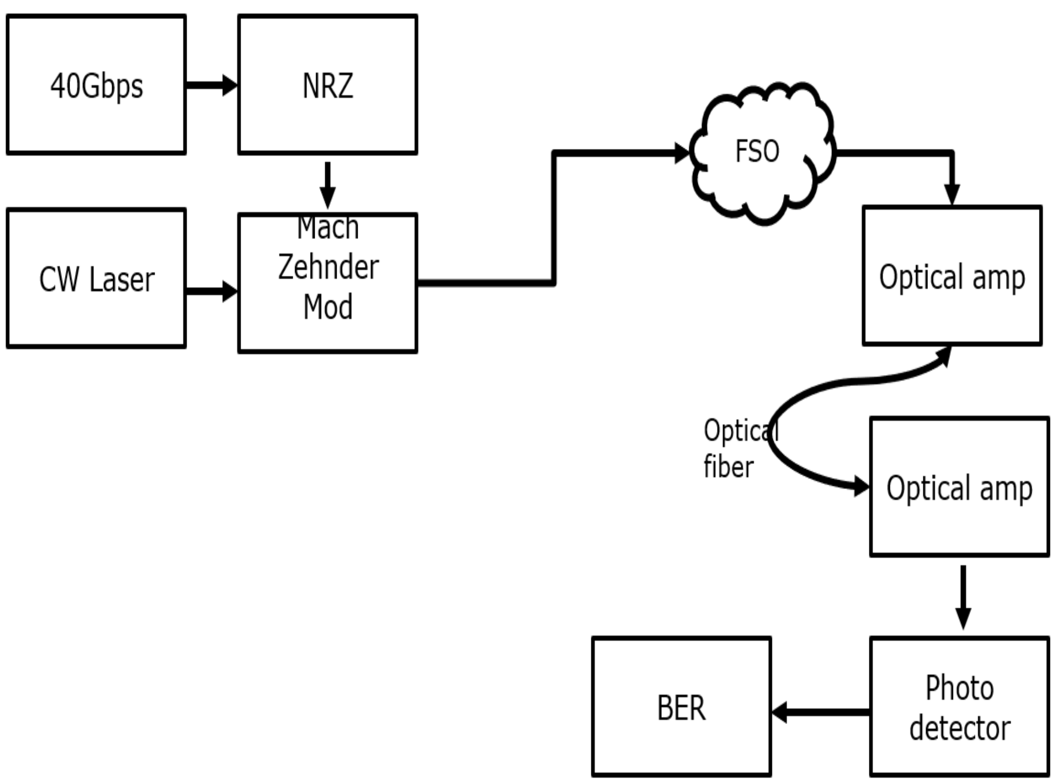


Figure 3.3: Proposed WDM system with Inline amplifier

Q-factor is used for determining BER. If the ISI distribution does not exist and the dominant amplitude noise has Gaussian distribution, the signal Q-factor is defined:

$$Q = \frac{V1-V.}{\sigma-\sigma.} \text{ ……..………………………………………………1}$$

- Here are the mean values for ν (t) amplitude high and low without ISI, whereas are the root mean square (RMS) of the additive white noise for each Gaussian distribution.

- The BER can be given as

$$\mathrm{BER} = \frac{1}{\mathrm{erfc}}\left(\frac{\mathrm{Q_{BER}}}{\sqrt{2}}\right) \text{ ………………………..………………………..2}$$

Q BER is the minimum required Q-factor for a given BER

- Analytical expression for FSO link detect Power Calculation

$$\mathrm{Pt}= \frac{[\pi(\mathrm{I}\theta)^{\wedge 2}]}{4} \text{ ……………………..…………3}$$

The detected power can be calculated

$$\mathrm{Pr} =\frac{4ArPt}{\pi[(\mathrm{I}\theta)]^{\wedge}2} \text{ ……………………………..……..4}$$

Pr is the received power

Pt is the power transmitted

θ is the transmitters beam width

Ar effective area of receive optic

l Link distance

This is the optic system (figure :3.4) simulation part for 32 channel wdm system which is previous model in this field where they use 100GHZ channel spacing also used NRZ & RZ line coding by using pre amplifier

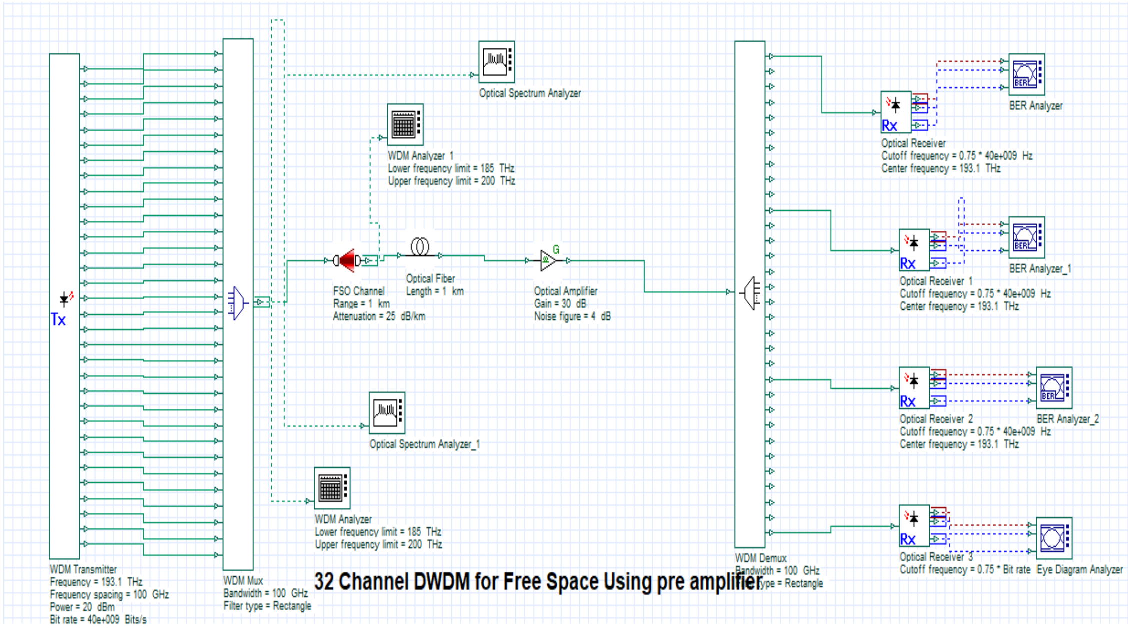


Figure 3.4: 32 channel WDM for Free Space Optic using pre amplifier for previous model

In (figure 3.4) 64channel dwdm system for fso by using NRZ line coding for boost optical amplifier also we use 100GHZ as a channel spacing .In figure 3.5 boost amplifier for 64channel dwdm system for fso. In figure 3.6 shows simulation design for in line amplifier for fso system.

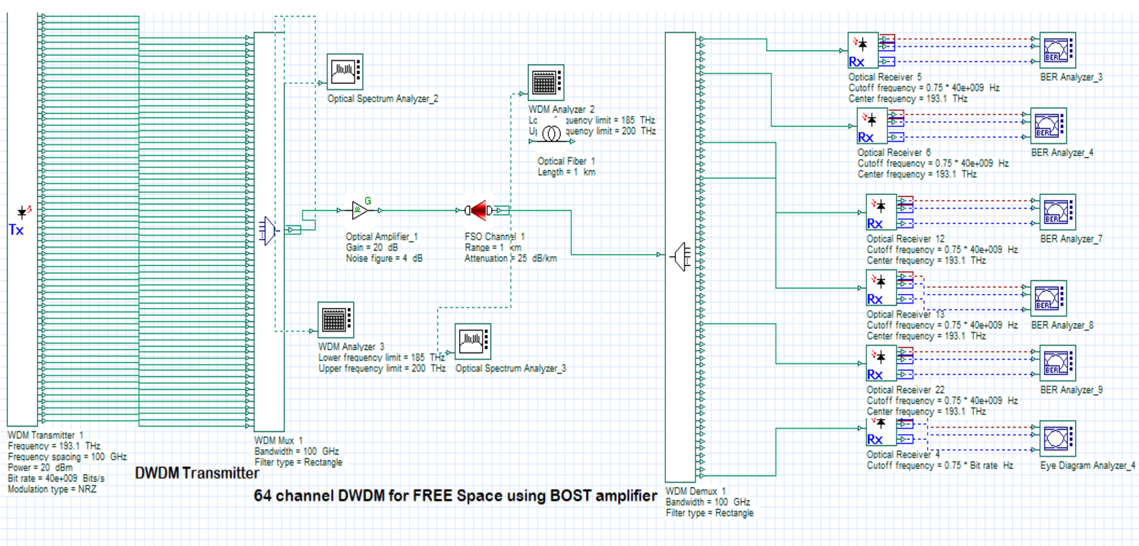


Figure 3.5: 64 channel WDM for Free Space Optic using Boost amplifier for proposed model

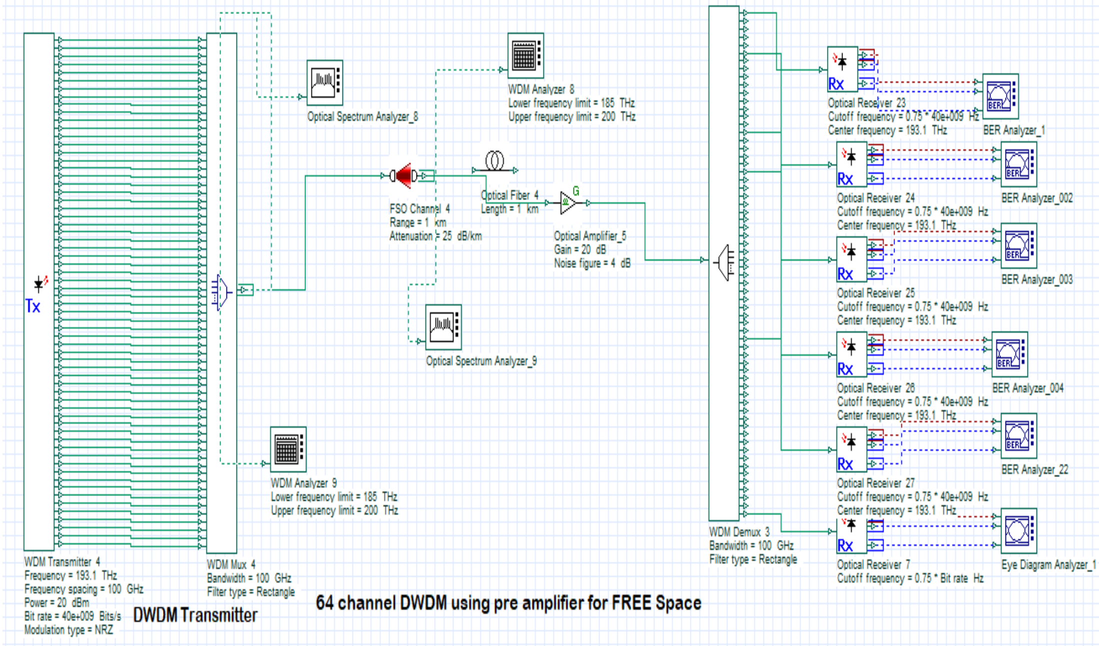


Figure 3.6: 64 channel WDM for Free Space Optic using Pre amplifier for proposed model

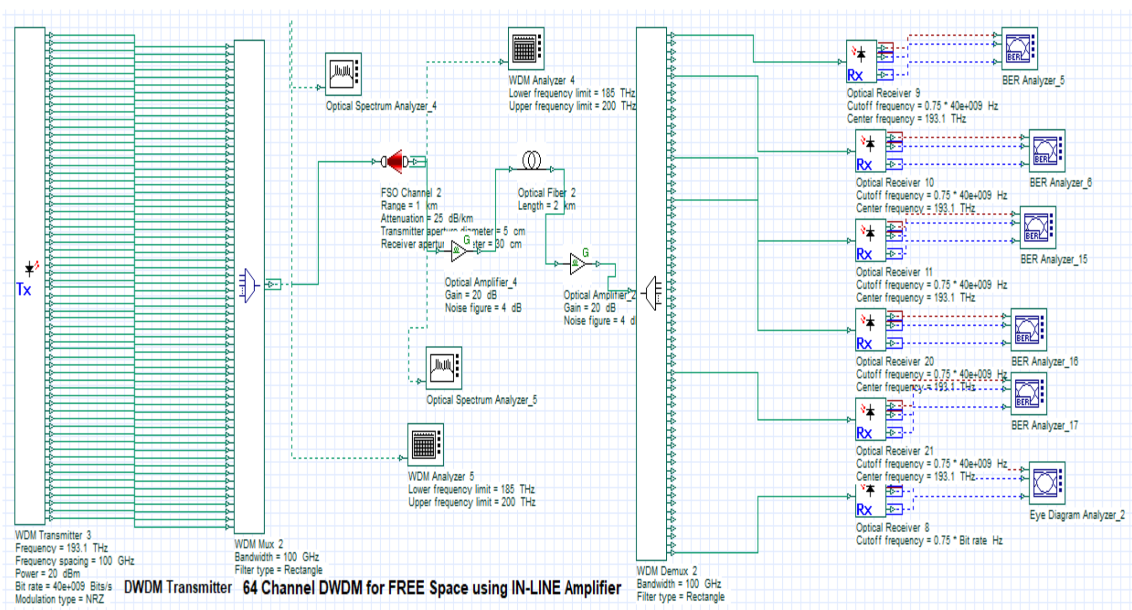


Figure 3.7: 64 channel WDM for Free Space Optic using In_Line amplifier for proposed model

Chapter 4

Result and Simulation

4.1 Proposed System performance analyzing using different amplifier

Analyses are made of the final WDM link design, which includes the optical signal before and after it is amplified by a variety of methods. The stability of the system in the wireless medium has been evaluated using channel modelling factors, including link range, transmitter aperture size, receiver aperture size, and beam divergence. As a result, the effect of the Q-factor on free space medium properties has been plotted and analyzed using several amplification approaches.

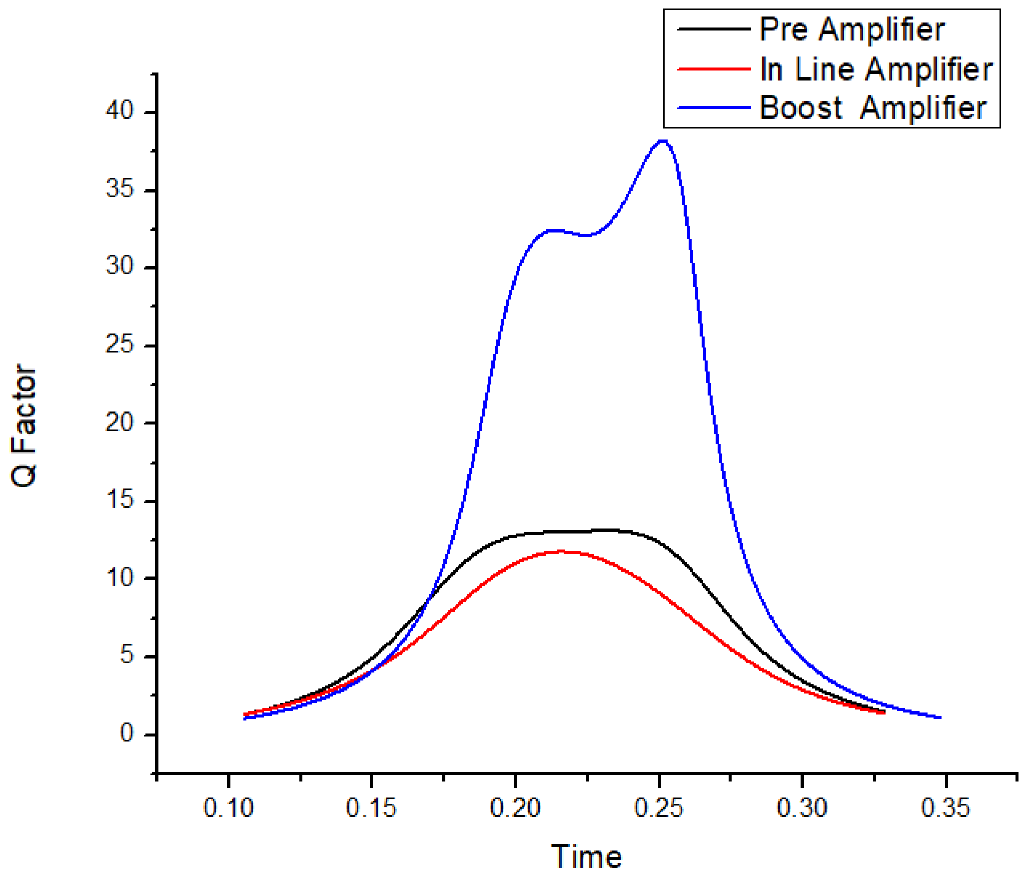


Figure 4.1: Proposed System performance for Q Factor using different amplifier

The figure 4.1 shows the maximum quality factor relation with time for different amplification technique. Where boost amplification technique shows the highest quality factor with respect to time & in line amplification shows the lower result.

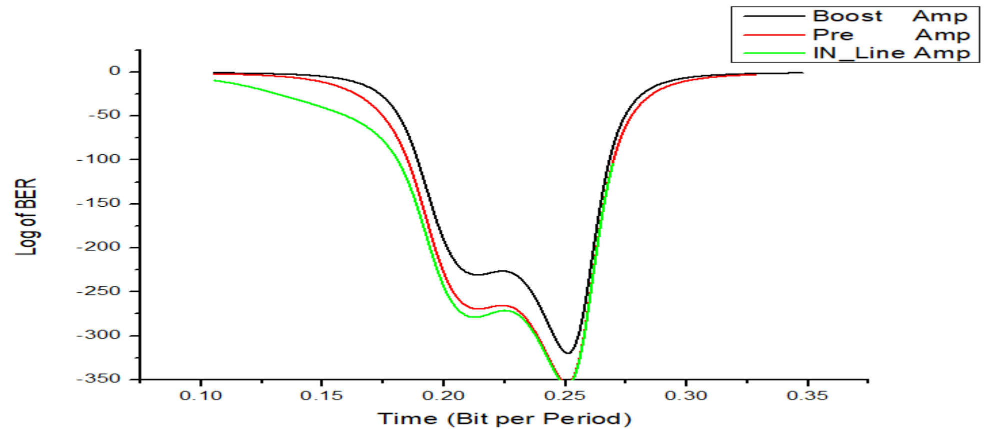


Figure 4.2: Proposed System performance in Bit Error Rate using different amplifier

The figure 4.2 shows the relation between log of BER and Time, where in line amplifier shows the lowest bit error rate. For Boost amplification setup it shows the highest rate. The figure 4.3 input spectrum for boost amplification setup and figure 4.4 shows the relation between power and wavelength for pre amplification setup. The figure 4.5 shows optical spectrum for the in line amplifier setup.

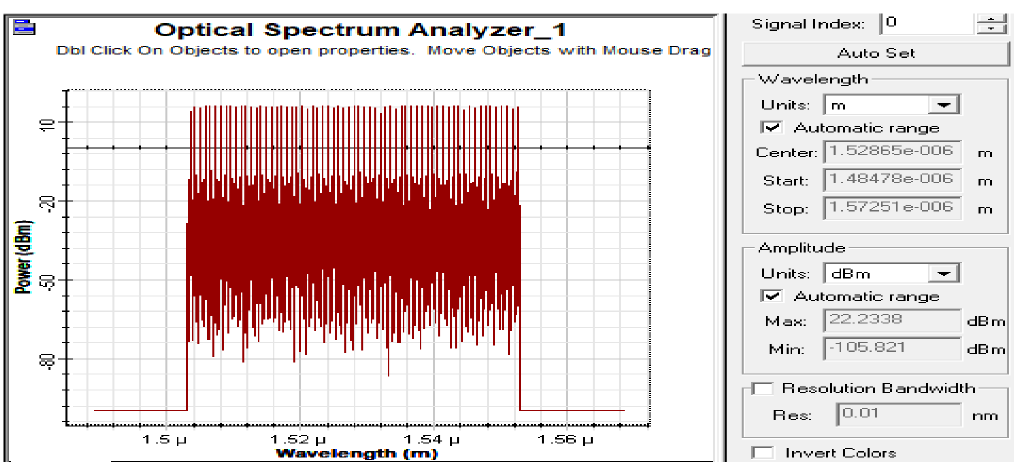


Figure 4.3: Input spectrum Analyser for Boost amplifier

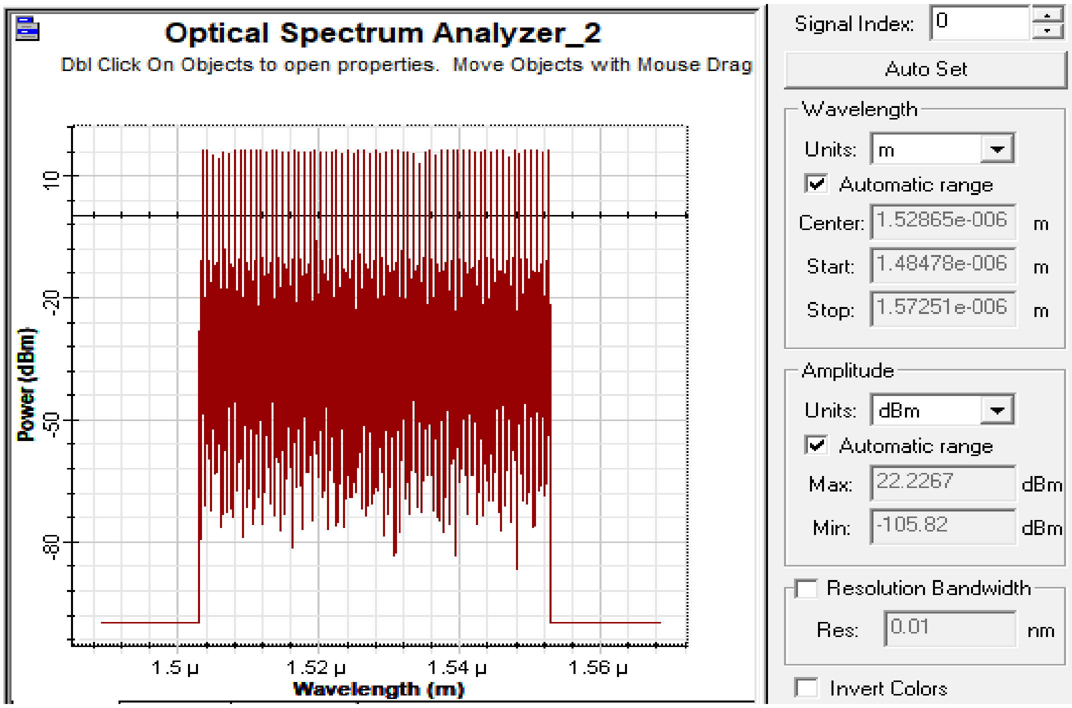


Figure 4.4: Input spectrum Analyser for Pre amplifier

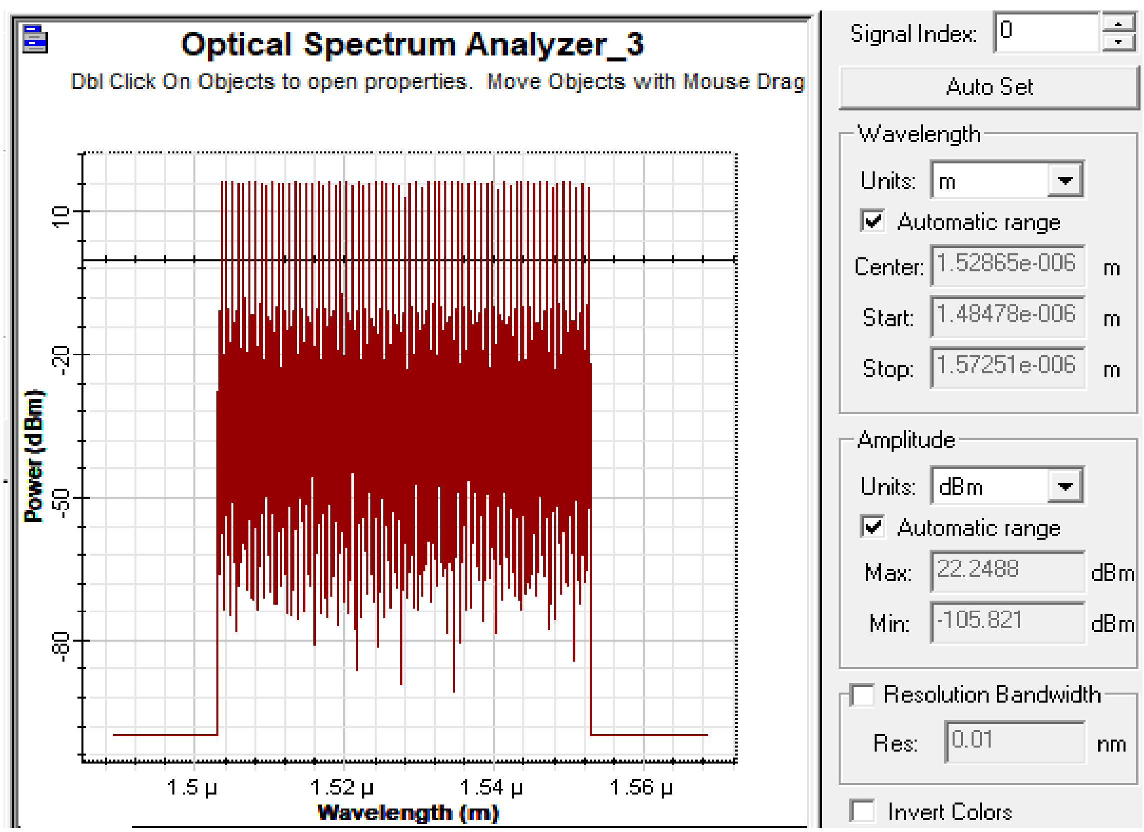


Figure 4.5: Input spectrum Analyser for IN-LINE amplifier

Figure 4.6 shows the relation between maximum quality factor and time for Boost amplification setup and previous model result where boost amplifier quality factor 38.22 which is higher the previous model

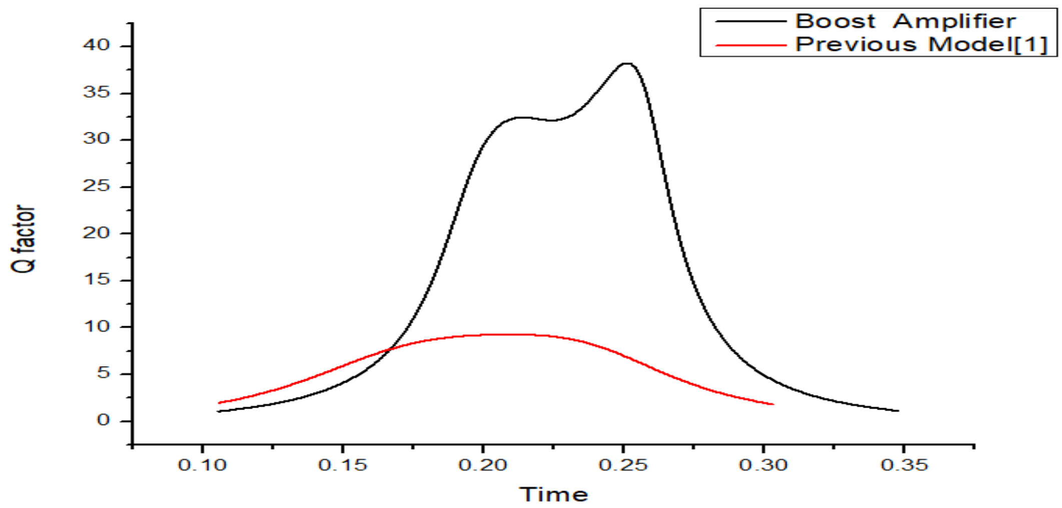


Figure 4.6: Maximum Q factor using Boost optical Amplifier vs previous model

Figure 4.7 shows the relation between maximum quality factor and time for pre amplification setup and previous work setup where pre amplifier quality factor 13.55 which is higher then previous model setup

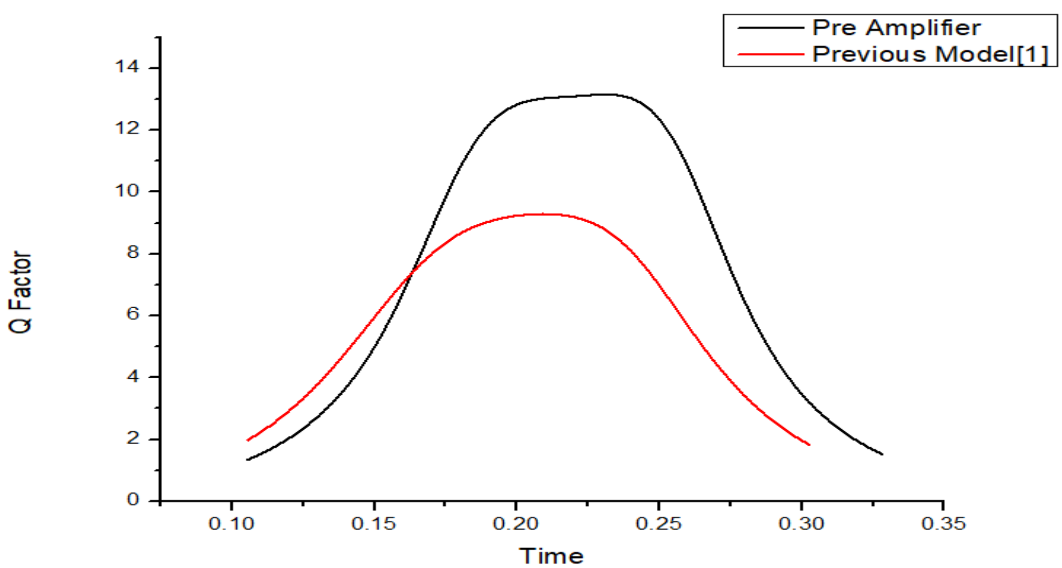


Figure 4.7: Maximum Q factor using Pre optical Amplifier vs previous model

Figure 4.8 shows the relation between maximum quality factor and time for In Line amplification setup and previous work setup where pre amplifier quality factor 11.22 which is closer to previous model setup but higher.

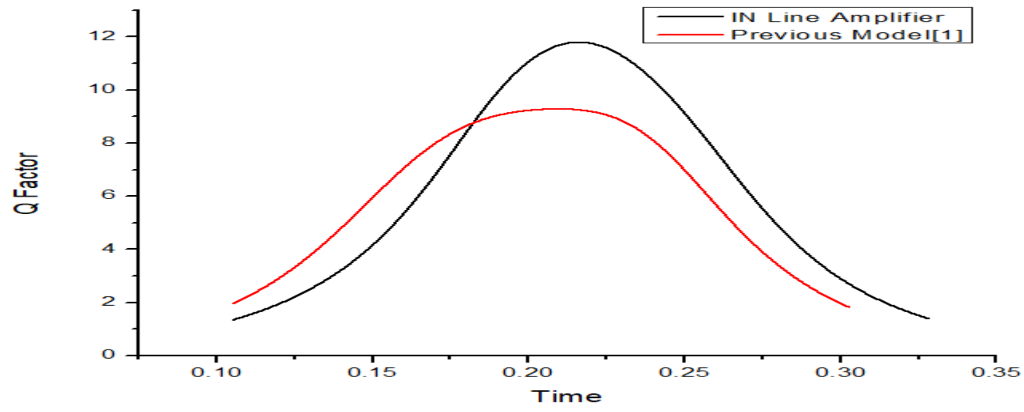


Figure 4.8: Maximum Q factor using IN –Line optical Amplifier vs previous model

The figure 4.9 shows the relation between log of BER & Time bit period for the previous model and boost amplification setup .Where our proposed boost amplification result shows the low bit error rate the previous model setup . Figure 4.10 shows the result between previous model & pre amplification setup .And figure 4.11 shows the previous model and in line amplification setup .Where our proposed amplification setup shows the good result.

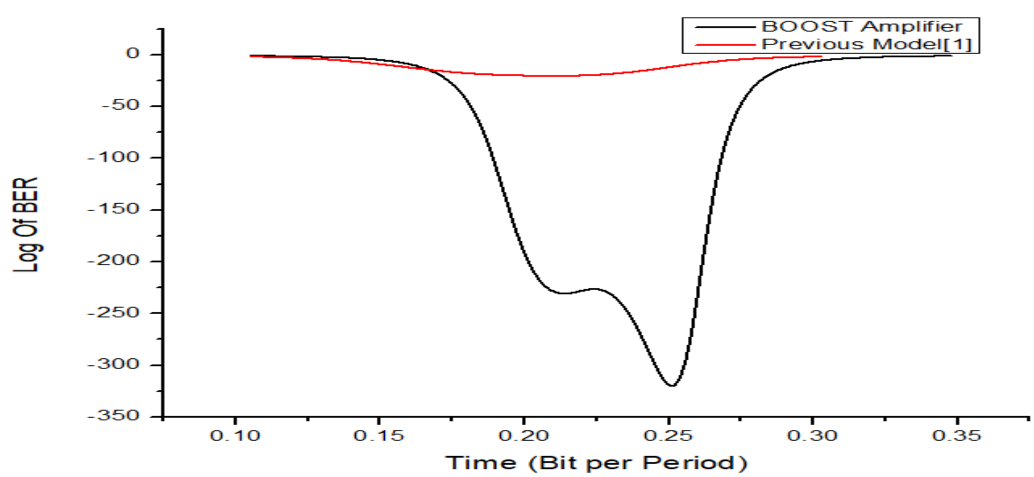


Figure 4.9: Bit Error Rate using Boost Amplifier vs previous model

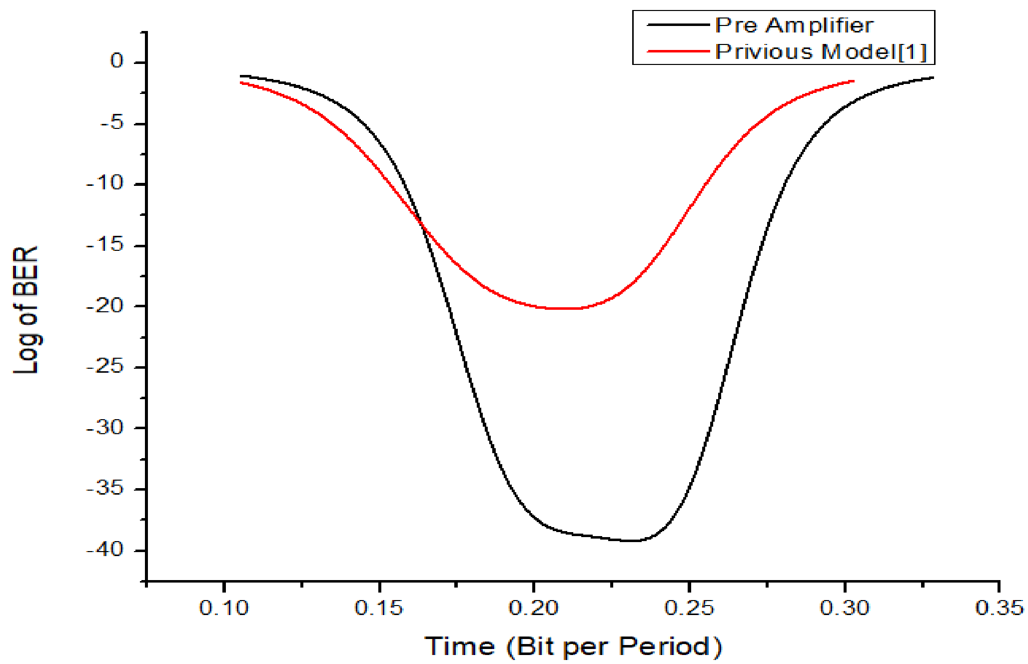


Figure 4.10: Bit Error Rate using Pre Amplifier vs previous model

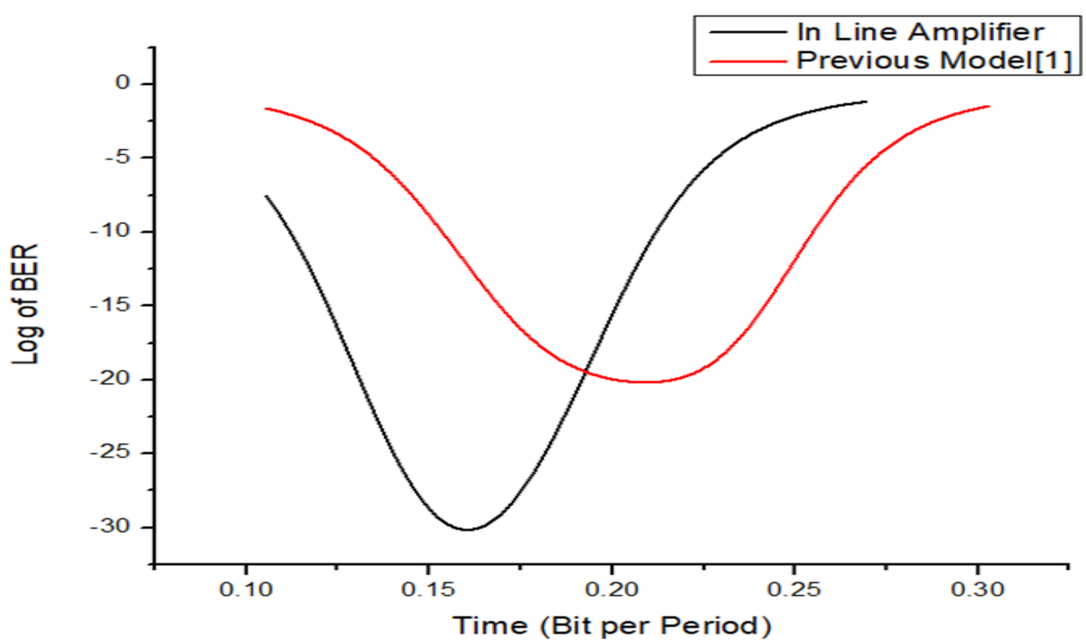
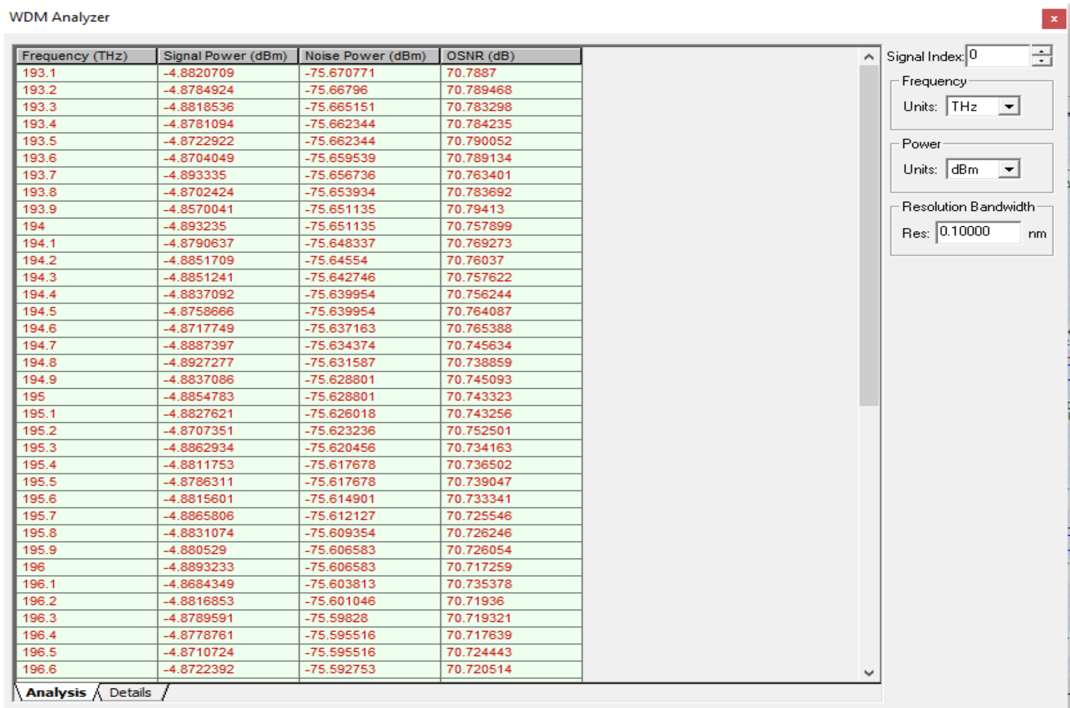


Figure 4.11: Bit Error Rate using In_Line Amplifier vs previous model

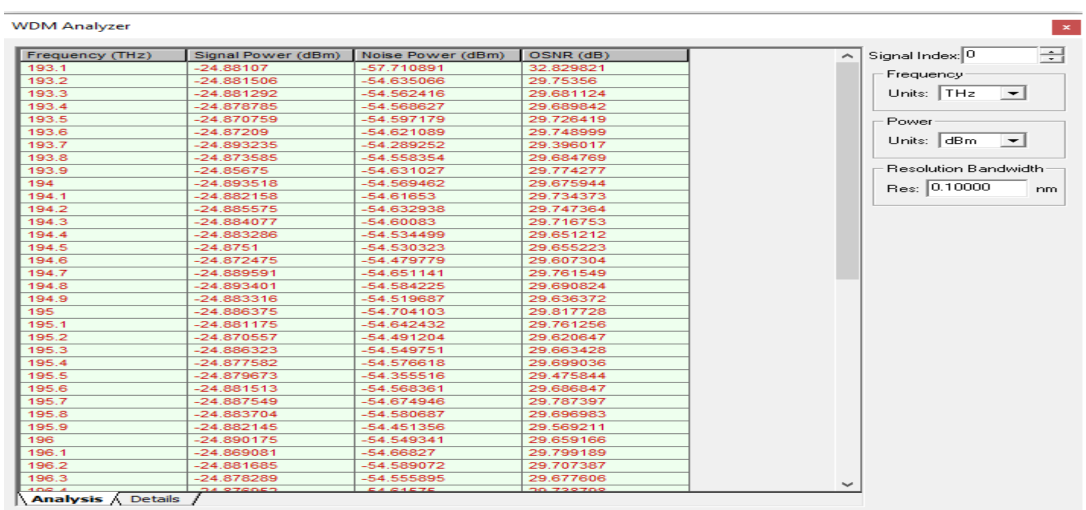
Figure 4.12 shows WDM Analyzer result where it shows the snr & osnr value for the boost amplifier ,figure 4.13 shows for pre amplification setup & figure

4.14 shows the in line amplification setup value for the wdm analyzer by which boost amplification setup it shows the balanced signal to noise ratio value.



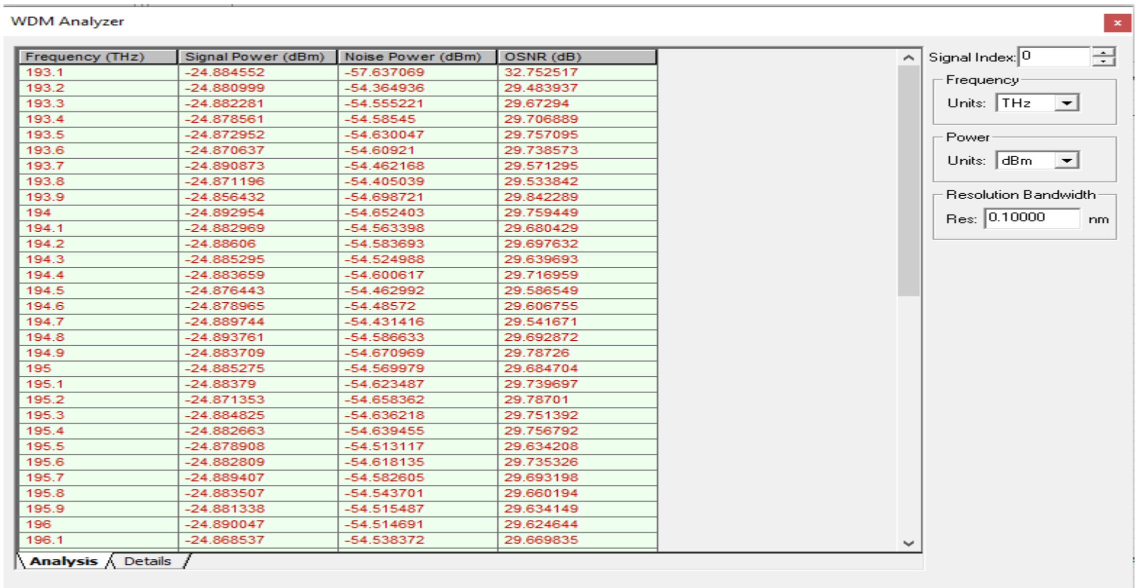
Frequency (THz)	Signal Power (dBm)	Noise Power (dBm)	OSNR (dB)
193.1	-4.8820709	-75.670771	70.7887
193.2	-4.8784924	-75.66796	70.789468
193.3	-4.8818536	-75.665151	70.783298
193.4	-4.8781094	-75.662344	70.784235
193.5	-4.8722922	-75.662344	70.790052
193.6	-4.8704049	-75.659539	70.789134
193.7	-4.893335	-75.656736	70.763401
193.8	-4.8702424	-75.653934	70.783692
193.9	-4.8570041	-75.651135	70.79413
194	-4.893235	-75.651135	70.757899
194.1	-4.8790637	-75.648337	70.769273
194.2	-4.8851709	-75.64554	70.76037
194.3	-4.8851241	-75.642746	70.757622
194.4	-4.8837092	-75.639954	70.756244
194.5	-4.8758666	-75.639954	70.764087
194.6	-4.8717749	-75.637163	70.765388
194.7	-4.8887397	-75.634374	70.745634
194.8	-4.8927277	-75.631587	70.738859
194.9	-4.8837086	-75.628801	70.745093
195	-4.8854783	-75.628801	70.743323
195.1	-4.8827621	-75.626018	70.743256
195.2	-4.8707351	-75.623236	70.752501
195.3	-4.8862934	-75.620456	70.734163
195.4	-4.8811753	-75.617678	70.736502
195.5	-4.8786311	-75.617678	70.739047
195.6	-4.8815601	-75.614901	70.733341
195.7	-4.8865806	-75.612127	70.725546
195.8	-4.8831074	-75.609354	70.726246
195.9	-4.880529	-75.606583	70.726054
196	-4.8893233	-75.606583	70.717259
196.1	-4.8684349	-75.603813	70.735378
196.2	-4.8816853	-75.601046	70.71936
196.3	-4.8789591	-75.59828	70.719321
196.4	-4.8778761	-75.595516	70.717639
196.5	-4.8710724	-75.595516	70.724443
196.6	-4.8722392	-75.592753	70.720514

Figure 4.12: Calculation results of the proposed system for DWDM-FSO link using boost amplifier



Frequency (THz)	Signal Power (dBm)	Noise Power (dBm)	OSNR (dB)
193.1	-24.88107	-57.710891	32.829821
193.2	-24.881506	-54.635066	29.75356
193.3	-24.881292	-54.562416	29.681124
193.4	-24.878785	-54.568627	29.689842
193.5	-24.870759	-54.597179	29.726419
193.6	-24.87209	-54.621089	29.748999
193.7	-24.893235	-54.289252	29.396017
193.8	-24.873585	-54.558354	29.684769
193.9	-24.85675	-54.631027	29.774277
194	-24.893518	-54.569462	29.675944
194.1	-24.882158	-54.61653	29.734373
194.2	-24.885575	-54.632938	29.747364
194.3	-24.884077	-54.60083	29.716753
194.4	-24.883286	-54.534499	29.651212
194.5	-24.8751	-54.530323	29.655223
194.6	-24.872475	-54.479779	29.607304
194.7	-24.889591	-54.651141	29.761549
194.8	-24.893401	-54.584225	29.690824
194.9	-24.883316	-54.519687	29.636372
195	-24.886375	-54.704103	29.817728
195.1	-24.881175	-54.642432	29.761256
195.2	-24.870557	-54.491204	29.620647
195.3	-24.886323	-54.549751	29.663428
195.4	-24.877582	-54.576618	29.699036
195.5	-24.879673	-54.355516	29.475844
195.6	-24.881513	-54.568361	29.686847
195.7	-24.887549	-54.674946	29.787397
195.8	-24.883704	-54.580687	29.696983
195.9	-24.882145	-54.451356	29.569211
196	-24.890175	-54.549341	29.659166
196.1	-24.869081	-54.66827	29.799189
196.2	-24.881685	-54.589072	29.707387
196.3	-24.878289	-54.555895	29.677606
[illegible]	[illegible]	[illegible]	[illegible]

Figure 4.13: Calculation results of the proposed system for DWDM-FSO link using pre amplifier



Frequency (THz)	Signal Power (dBm)	Noise Power (dBm)	OSNR (dB)
193.1	-24.884552	-57.637069	32.752517
193.2	-24.880999	-54.364936	29.483937
193.3	-24.882281	-54.555221	29.67294
193.4	-24.878561	-54.58545	29.706889
193.5	-24.872952	-54.630047	29.757095
193.6	-24.870637	-54.60921	29.738573
193.7	-24.890873	-54.462168	29.571295
193.8	-24.871196	-54.405039	29.533842
193.9	-24.856432	-54.698721	29.842289
194	-24.892954	-54.652403	29.759449
194.1	-24.882969	-54.563398	29.680429
194.2	-24.88606	-54.583693	29.697632
194.3	-24.885295	-54.524988	29.639693
194.4	-24.883659	-54.600617	29.716959
194.5	-24.876443	-54.462992	29.586549
194.6	-24.878965	-54.48572	29.606755
194.7	-24.889744	-54.431416	29.541671
194.8	-24.893761	-54.586633	29.692872
194.9	-24.883709	-54.670969	29.78726
195	-24.885275	-54.569979	29.684704
195.1	-24.88379	-54.623487	29.739697
195.2	-24.871353	-54.658362	29.78701
195.3	-24.884825	-54.636218	29.751392
195.4	-24.882663	-54.639455	29.756792
195.5	-24.878908	-54.513117	29.634208
195.6	-24.882809	-54.618135	29.735326
195.7	-24.889407	-54.582605	29.693198
195.8	-24.883507	-54.543701	29.660194
195.9	-24.881338	-54.515487	29.634149
196	-24.890047	-54.514691	29.624644
196.1	-24.868537	-54.538372	29.669835

Figure 4.14: Calculation results of the proposed system for DWDM-FSO link using In-Line amplifier

Figure 4.15 shows the relation between transmitter and receiver aperture for proposed in line proposed boost ,pre ,In line amplification setup where if transmitter aperture increased the quality factor decreasing . In figure 4.16 shows the relation between receiver aperture and transmitter aperture it shows when we increase antenna parameter that time the quality factor value increasing.

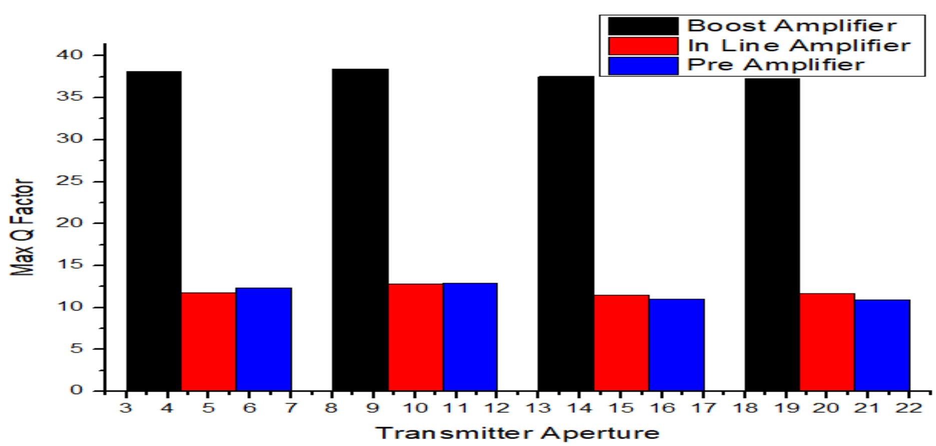


Figure 4.15: Maximum Q factor in relation to transmitter aperture diameter for different amplifier

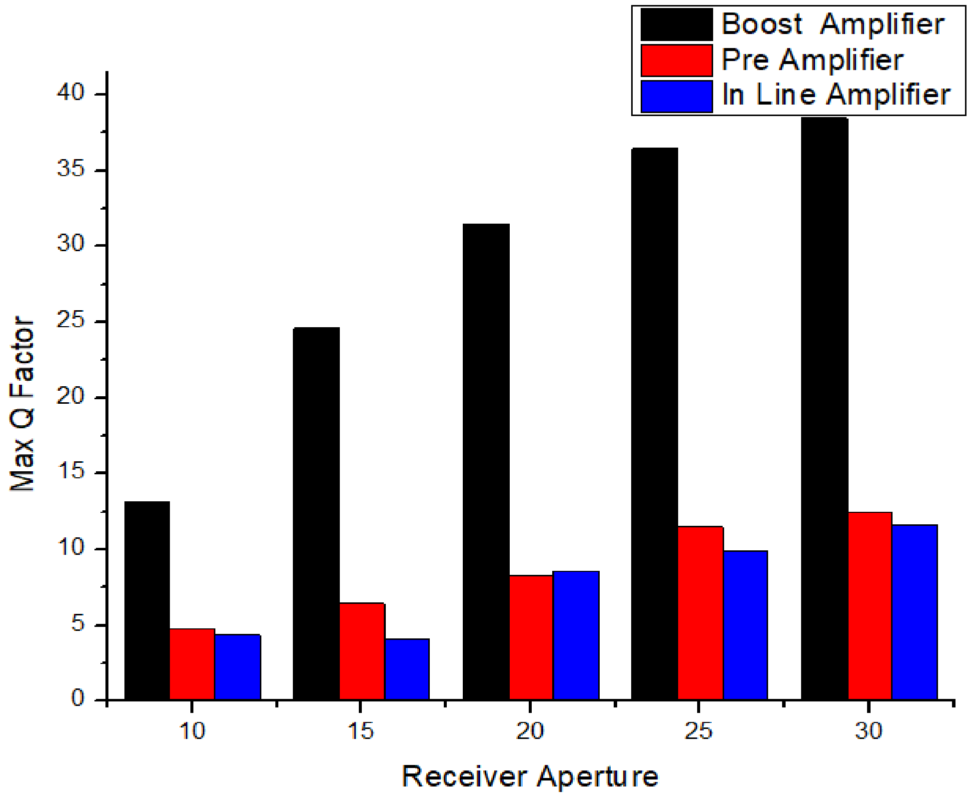


Figure 4.16: Maximum Q factor in relation to the receiver aperture diameter for different amplifier

Chapter 5

Conclusion and Future Work

In our previous chapter we studied about different types of amplifier setup with WDM system by using FSO system. In our result and simulations part basically we did our simulation and compare with our model paper for what we improve in our system. And then reached to an optimized design which provide high performance. Finally in this chapter we will conclude our thesis work by bring up a short conclusion of the research, achievements, limitations and future recommendation of the proposed design.

5.1 Conclusion

In this work, we presented a great design with different type of amplifier setup. Basically, we choose 3 type of setup such as preamplifier, boost amplifier, In line amplifier. This 3 types setup has their own characteristics. our system stability was checked with respect to link range, transmitter aperture size, receiver aperture and beam divergence. From Q factor result boost amplifier setup got highest quality factor with respect to Inline amplification and Inline amplifier from bit error rate result Inline amplifier shows lowest bet error rate result inline amplifier shows lower bit error rate . On the other side Boost amplification setup shows highest bit error rate. Our boost amplifier setup shows good quality factor with compare to previous model. Finally, we can say that our experimental setup has got good result compare to previous model

5.2 Achievement

In this section we will finalize our full achievement. In our system we increase our channel number also increase our data rate .A 2.56Tb/ps discovered in which 64 channel each of 40Gbps data stream are combined using wavelength division multiplexed .By moderating our transmitter and receiver aperture in the FSO system we get good quality factor and low bit error rate with respect to different amplifier configurable setup for best signal amplification to get best performance.

5.3 Limitation

Limitation of our proposed system are as follows

- Atmospheric Disturbances: A major impairment on FSO links is caused due to the atmospheric turbulence. It is the result of random variations in the refractive index caused due to inhomogeneities in temperature and pressure.
- Pointing Error: Apart from scintillation effects, the performance of the FSO link degrades because of the building sway, which introduces a pointing error (PE) between transmitter (Tx) and receiver (Rx), representing a particular problem in urban areas, where FSO equipment is placed on high-rise structures.
- Physical Obstructions: Since FSO is a line-of-sight communication, any obstruction in the path can interrupt or affect the communication.
- Geometric Losses: These losses are the form of optical beam attenuation that is caused due to the spreading of beam and results in the reduction of power level of signal as it travels from transmitter to receiver.
- Background Radiation: Last but not least, background radiation, also called background noise or ambient noise, can degrade the performance of FSO links. In fact, in addition to the useful signal, the receiver lens also collect some undesirable background radiations that may consist of direct sunlight, reflected sunlight, or scattered sunlight from hydrometeor or other objects.

References:

1) J.Abid, H., 2021. A New Suppression approach of FWM Crosstalk Effect in Optical Communication Link based on Polarization combiner Method. *IICESAT*.
2) Gafur, A., 2019. Quality Optimization Based Trend Line for Hybrid Optical Amplifier Configurations in DWDM Transmission Systems. *IJMOT*.
3) Elsayed, E., 2021. Design and Analysis of 1.28 Terabit/s DWDM Transmission System for Free Space Optical Communication.
4) kakar, V., 2015. Performance Analysis of 64-Channel DWDM System Using EDFA. *IJIRCST*.
5) Ajibodu, F., 2016. Performance Analysis of Erbium Doped Fiber Amplifier's and FWM Characteristics in a Passive Optical Network. *International Journal of Optoelectronic Engineering*.
6) Jaya, N., 2017. Performance Analysis of 48 Channels DWDM System using EDFA for Long Distance Communication. *ISSN*.
7) Ahuja, B., 2019. DESIGN AND PERFORMANCE ANALYSIS OF SEMICONDUCTOR OPTICAL AMPLIFIER FOR 16×10Gbps DWDM TRANSMISSION SYSTEMS. *ICTACT*.
8) Ahuja, B., 2019. DESIGN AND PERFORMANCE ANALYSIS OF SEMICONDUCTOR OPTICAL AMPLIFIER FOR 16×10Gbps DWDM TRANSMISSION SYSTEMS. *ICTACT*
9) Kogias, P., 2020. Modelling and performance analysis of DWDM passive optical network. *CIEES*,
10) Miglan, R., 2020. Gain analysis of high-speed DWDM link with different optical amplification configuration. 13.
11) Manzoo, T., 2019. FWM Mitigation in DWDM Optical Networks. *ICaTAS*.
12) B, B., 2018. Performance enhancement of the power penalty in DWDM FSO communication using DPPM and OOK modulation. *OQEL*, 50.
13) Murdas, I., 2020. Enhancement of the Performance of DWDM Free Space Optics (FSO) Communications Systems Under Different Weather Conditions. *INASS*.

14) Lema, G., 2020. Free space optics communication system design using iterative optimization. *ISSN*.

15) Sharma, N., 2020. Analyzing the FWM at Different Power Levels in the Fiber Optic DWDM System. *ICCES*.

16) Singh, H., 2020. Mitigation of FWM in the Fiber Optic DWDM System by using Different Modulation Techniques and Optical Filters. *ICCES*.

17) Mubarakah, N., 2020. Point to Point Communication Link Design by Using Optical DWDM Network. *(ELTICOM)*.

18) Danaryani1, S., 2018. FIRE DETECTION BASED ON IOT THROUGH FIBER TO THE HOME (FTTH). *MEI*, 17.

19) Safrianti, E., 2018. Broadband Network Fiber to the Home (FttH) Design for Improving Performance of Information and Telecommunication Network in Riau Universit. *(IJEEPSE)*.

20) Mouweffeq, B., 2018. Optical Code Division Multiple Access for a FTTH system. 10 (4).

21) Setiawan, S., 2018. IMPLEMENTASI JARINGAN FIBER TO THE HOME (FTTH) DENGAN TEKNOLOGI GIGABIT PASSIVE OPTICAL NETWORK (GPON). *SIMETRIS*, 9.

22) Purnomo, S., 2018. IBER TO THE HOME (FTTH) ACCESS NETWORK DESIGN USING GIGABIT PASSIVE OPTICAL NETWORK (GPON) TECHNOLOGY AT KALIDERES PERMAI RESIDENTIAL WEST JAKARTA. *ISSN*.

23) Siregar, V., 2018. PERANCANGAN JARINGAN AKSES FIBER TO THE HOME (FTTH) MENGGUNAKAN TEKNOLOGI 10-GIGABIT-CAPABLE PASSIVE OPTICAL NETWORK (XGPON) UNTUK PERUMAHAN BENDA BARU. *ISSN*.

24) Utama, A., 2018. PERANCANGAN JARINGAN AKSES FIBER TO THE HOME (FTTH) MENGGUNAKAN TEKNOLOGI 10-GIGABIT-PASSIVE OPTICAL NETWORK (XGPON) UNTUK PERUMAHAN BENDA BARU TANGERANG SELATAN. *ISSN*.

25) Bugaje, K., 2018. Enhancement of Gigabit Passive Optical Highspeed Network using Fiber-T. *(ICCCEEE)*.

26) Singh, A., 2018. Design and Performance Evaluation of Bidirectional WDM-PON using FTTH Architecture. *International Conference on Communication and Signal Processing,,*.

27) Rathore, S., 2017. Development of a Hybrid FSO/RF System During Link Misalignment. *International Conference on Networking and Network Applications*.

28) Sharma, S., 2019. Switching-Based Cooperative Decode-and-Forward Relaying for Hybrid FSO/RF Networks.

29) Kumar, K., 2014. Quantize and Encode Relaying through FSO and Hybrid FSO/RF Links. *IEEE Transactions on Vehicular Technology*.

30) Kumar, P., 2015. Kumar, K., 2014. Quantize and Encode Relaying through FSO and Hybrid FSO/RF Links. IEEE Transactions on Vehicular Technology,. *IEEE International Broadband and Photonics Conference, Bali*.

31) *SPIN*, 2020. Performance Analysis of FSO-SISO and FSO-WDM Systems under Different Atmospheric Conditions

32) Mohammad, A., 2014. Optimization of FSO System in Tropical Weather using Multiple Beams. *ICP*.

33) Al-Eryani, Y., 2018. Protocol Design and Performance Analysis of Multiuser Mixed RF and Hybrid FSO/RF Relaying With Buffers. *OPT. COMMUN. NETW.*

34) Kumar, K., 2014. Quantize and Encode Relaying through FSO and Hybrid FSO/RF Links. *IEEE Transactions on Vehicular Technology*.

35) Keshavarz, A., 2018. On Performance of Adaptive Subcarrier Intensity Modulation over Generalized FSO Links. *ICEE*.

36) Abadi, M., 2017. Hard Switching in Hybrid FSO/RF Link: Investigating Data Rate and Link Availability. *ICC*.

37) Bhanja, U., 2017. Performance Analysis of a SAC-OCDMA FSO Network. *ISPCC*.

38) Salhab, A., 2018. Two-Way Multiuser Mixed RF/FSO Relaying: Performance Analysis and Power Allocation. . *OPT. COMMUN. NETW.*

39) Borah, D., 2014. Boolean Satisfiability Solvers and Their Applications in Model Checking. *IEEE Transactions on Vehicular Technology*.

40) Fang, J., 2018. Polar-Coded MIMO FSO Communication System Over Gamma-Gamma Turbulence Channel With Spatially Correlated Fading. *OPT. COMMUN. NETW.*

41) Saber, M., 2018. On Performance of Adaptive Subcarrier Intensity Modulation over Generalized FSO Links. *ICEE*.

42) Ragheb, A., 2018. Broadly Tunable Self-injection Locked InAs/InP Quantum-dash Laser Based Fiber/FSO/Hybrid Fiber-FSO Communication at 1610 nm. *IEEE Photonics Journa*, 10.

43) Elsayed, E., 2021. *Design and Analysis of 1.28 Terabit/s DWDM Transmission System for Free Space Optical Communication*. [onli

44) ne] Research Gate. Available at: <https://www.researchsquare.com/article/rs-460317/v1> [Accessed 25 November 2021]..

45) Miglani, R., 2018. valuation of link-compensated 32 3 40 Gbit/s DWDM free space optical (FSO) transmission. *The Optical Society of India 2018*,.

46) ALdory, M., 2021. EDFA Gain Evaluation in WDM Transmitting System of the Free Space Optics FSO. *ASRJETS*,.

47) Mahajan, S., 2019. Analysis of Free Space Optical System Under 4-Channel Spectrum ALdory, M., 2021.

48) EDFA Gain Evaluation in WDM Transmitting System of the Free Space Optics FSO. *ASRJETS*,.Slicing Wavelength Division Multiplexing (SS-WDM). *ICAICR*,.

49) Sharma, L., 2019. Optimized FWM Parameters for FTTH Using DWDM Network. *ICCIKE*,.