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Performance Analysis of Dense Wavelength Division Multiplexing System Based on Free Space Optics Communication

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PERFORMANCE ANALYSIS OF DENSE WAVELENGTH DIVISION MULTIPLEXING SYSTEM BASED ON FREE SPACE OPTICAL COMMUNICATIONS

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DECLARATION OF CANDIDATE

"We declare that this project is the result of our possess unique inquire about which all sources utilized were appropriately acknowledged and cited within the reference segment. This work was never been submitted some time recently for any other scholastic certification or title. Any help gotten all through the investigate and planning of this proposal has been acknowledged, in spite of the fact that it is as it were counseling in nature.”

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ABSTRACT

This study reported the performance evaluation of various distributors and exchange elements configurations in the optical fiber communication system. With the increasing demand for high-speed data transfer, Dense Wavelength Division Multiplexing (DWDM) technology has become an attractive solution for optical communication systems. This paper presents the performance analysis of a DWDM-FSO-based on Free space optical communication system. The system consists of multiple channels, each transmitting data at a different wavelength, which are combined into a single optical fiber using a multiplexer. A demultiplexer separates the channels at the receiving end, and each channel's data is recovered separately. We analyze the performance of the system by measuring its bit error rate (BER) and Q-Factor (Quality Factor) under different channel. We also examine how varying the channel number affects the system's performance. Our results demonstrate that the proposed system can achieve high data rates and excellent performance with low BER and high Q-Factor (Quality Factor), making it a promising compressional evaluation for high-speed optical communication systems.

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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

LIST OF ABBREVIATIONS

WDM	Wavelength Division Multiplexing
DWDM	Dense Wavelength Division Multiplexing
PRE	Power Amplifier
SMF	Single Mode Fiber
MOF	Micro-structured Optical Fiber
PM	Polarization Maintaining
0D	Zero-Dimensional
NRZ	Non-return to zero
RZ	Return To Zero
FSO	Free Space Optical Communication
3D	Three-Dimensional
MSF	Micro Steel Fiber
MCF	Multi-core Fiber
M-TIR	Modified Total Internal Reflection
EDFA	Erbium Doped Fiber Amplifier
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
PWM	Pulse Width Modulation
FDTD	Finite-difference Time-domain
BEM	Boundary Element Method
EWFD	Electromagnetic Wave, Frequency Domain
Rx Ap	Receiver Aperture
Tx Ap	Transponder Aperture

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

With regard to its attributes and functionality above wired communication transfer of data, optical technologies is truly innovative. It provides rapid data rates and a large amount of storage. The transmitter and multiplexer make up the optical transmission system. With OptiSystem, it has never been simpler to construct optical links at the transmission layer of modern optical network thanks to a fully - featured development and evaluation technology. [1, 2]. Wavelengths ranging from 1300 to 1600 nm allow optical signals to travel apart without interfering with one another. Multiple wavelengths can be distributed over through the use of WDM networks (Wavelength Division Multiplexing), one fiber. Every input is created by a separate light source with a distinct wavelength. Step-by- step, WDM evolved into DWDM-FSO thanks to the development of the EDFA (Erbium-Doped Fiber Amplifier). Implementing Without the creation of EDFAs, DWDM-FSO would not have been feasible. Due to their near-wavelength operation, these amplifiers can be used with optical fibers operating within the same window of wavelengths as for 1550 nm. DWDM-FSO implementation in an optical communication network requires specific optical modules and components, such as a demultiplexer, multiplexers, EDFAs, and low-chirp integrated lasers. Multiple light sources are coupled to the transmitting fiber using an optical multiplexer. At either the target node, optical demultiplexers are designed to extract the various waves before individual signals can be visually identified. For incorrect signals to not reach the receiving channel, the demultiplexer needs to function inside a narrow spectrum window with clear wavelength cut-offs. No more than 30 dB of crosstalk is allowed. A few of DWDM-FSO's features are wavelength switching, capacity enhancement, transparency, and routing. In the telecommunications sector, demand for optical fiber technology is rising daily together with the large higher data transmission rate, bandwidth, & reasonably priced, reliable associates for optical fiber communication that have just become accessible. [3] Nowadays, DWDM-FSO technology is being used to increase the data transmission and efficient use of accepted manuscripts in optical fiber networks [4, 5]. In an era where high-speed, continuous connectivity is becoming increasingly necessary, there is a strong desire to enhance or even replace the current radio frequency regime. The high data rates without a license range, signals safety as well as affordability of FSO (Free Space Optical) communication systems are among their many appealing features. Through optical modulation, data is transmitted over a free-space medium (such as the atmosphere) to communicate via free-space optical means. Transmission of the data usually occurs over an unlicensed visible or infrared frequency band. For this reason, operating expenses are not needed for government organizations. To achieve a performance advantage, free-space optical communication is frequently utilized as opposed to optical fiber connections. With this medium, communication is possible. It can establish a connection quickly, has a large bandwidth, and has a high data limit.

The energy of the beam has been properly collimated & carried through a environment mostly to desired outcome, in which it is detected by a photodetector. This is the primary distinction between fiber optic transmission and FSO. elevated train a WDM-FSO system can also be sliced using supercontinuum synthesis. The system is tested with different beam divergences, modulation formats, and receiver and transmitter antenna diameters. We will investigate several other optical amplifiers to reduce the impact of attenuation caused by the suggested design. Providing fast data is the optimal approach. As a result, the technology was implemented and assessed at 10 Gb/s. [6]. There are several benefits that FSO has over existing technologies. The FSO system's main benefit over other systems is that it requires less money and less time to set up. The use of optical devices in an FSO structure requires a few adjustments. The FSO system of communication is a warm technology because of its medium attenuation, but its benefits and use area make it important [7].

1.2 THE OPTICAL COMMUNICATION SYSTEM'S HISTORY

Since ancient times, Technology has benefitted immensely from optical fiber communication. Integrating signaling arms and reflectors, to developing optical fibers and laser technologies, optical connections have been able to transfer enormous volumes of data quickly over great distances. Utilizing LED’s (Light-Emitting Diodes) and IR (Infrared Light), the very first digital optical system for communication was created in the middle of the 1960s to send digital messages between electronic equipment across short distances. This paved the way for optical communication to be widely used in the telecom sector. Long-distance light signal transmission was made possible with the advent of optical fibers in the early-1970's. Considering the advancement of optical communication systems, which are devices for the long-distance transmission of light signals. The very first fibers used to have a large performance degradation and were composed of glass, were replaced with low-loss optical fibers with a wide bandwidth, thanks to research done in the 1980s. Additionally, by significantly increasing the optical signal power, high-power lasers allowed adopting fiberoptic cables to send signals over large regions [8, 9]. Today, numerous companies that rely significantly on optical communication include telecommunications, health care, space exploration, and information technology. An objective of optical networks is to transfer data across large distances with little loss of signal and disturbance. Due to its lower signal attenuation, single-mode optical fibre cable has emerged as the industry standard for lengthy optical fiber communication and fast speed of signal transmission over long distances. Optical communication systems now offer greater bandwidth and capacity thanks to advancements in optical components such as wavelength-division multiplexers (WDM), optical amplifiers, or switches. WDM and optical switches allow several signals to be transmitted simultaneously via a single fiber, whereas light amplifiers as well as such as EDFA's (ERBIUM DOPED FIBER AMPLIFIERS), enhance the fiber's internal optical signals. With the invention of digital optical systems for communication, fiber optics, lasers, and sophisticated optical components, optical communication equipment has advanced significantly since antiquity. It has significantly changed how we receive and communicate information, and its significance is only anticipated to increase going forward. The efficiency of optical communications will continue to be enhanced by never-ending study of the subject, which will likewise inspire new developments [10-12].

1.3 FREE SPACE OPTICAL COMMUNICATION

The optical communication technology called free-space optical communication, or FSO, uses light traveling through free space to wirelessly transfer data for computer networking or telecommunication. "Free space" can refer to the vacuum, outer space, air, or any similar concept.

This is in contrast to the use of solids like optical transmission lines or fiber cables. The technology is helpful in situations where it is not feasible to make physical connections as a result of high costs or other factors [13]. The line-of-sight technological advancement approach creates optical connections by using light to connect two points. Fiber-optic connectivity is made possible by the simultaneous transmission of high-speed data, voice, and video through the air [14].

Data travels at the speed of light. Because of its many benefits and applications, free-space optical communication, or FSO, has grown significantly in popularity over the past 20 years when combined with radio frequency communication. Higher bandwidth and lower BER requirements have made free-space communication (FSO) a must-have technology. As a response to the rise of radio frequency (RF) communications, frequency spread optimization (FSO) is the next frontier for network-centric connectivity due to its favorable adoption in terms of bandwidth, spectrum, and security concerns [15, 16].

1.3.1 HISTORY

Alexander Graham Bell invented the "phone-phone" in the late nineteenth century. A number of scientists developed laser theory and technology in 1960. NASA began experimenting with laser communications among Goddard Space Flight Center's headquarters and Gemini-7 in the middle of the 1960s. United States military research in the 1980s. In space-free optics for satellite communication, Germany, France, and Japan achieved notable discoveries [13].

1.3.2 USES

Anti-aircraft defense units, computer networking, and military communication systems are only a few of the uses for free-space optical communication (FSO). Additionally, it facilitates real-time data sharing and control between offshore platforms and onshore facilities in the oil and gas sector. FSO can be used by healthcare facilities for telemedicine and medical imaging applications, as well as high-speed data transmission.

1.3.3 Works , Advantages & Disadvantages

Connectivity between FSO-based optical wireless units is the foundation of it. Each having a light transceiver to enable full duplex operation [13].

- **Advantage:** Free Space Optics (FSO) communication has advantages of high bandwidth, immunity to electromagnetic interference, and low latency, but also has disadvantages such as limited range and sensitivity to atmospheric conditions. Installation is easier and fast. Moreover, maintenance time is short.

- **Disadvantage:** Free-space optical communication (FSO) has several disadvantages: FSO is sensitive to weather conditions like fog, rain, and turbulence, which can disrupt the optical signal. FSO has a restricted range, making it unsuitable for long-distance communication.

1.3.4 Principal Difficulties with the FSO Communication System

Link availability is one of the main issues with FSO deployment, and it is heavily reliant on the equipment and infrastructure design's dependability. Although FSO holds great potential for next-generation entry applications, its widespread deployment is susceptible to atmospheric variations in availability because weather attenuation negatively impacts the performance of the FSO link. It causes the power of the received signal to decrease, which may hinder receiver- side functionality. When extreme PAT accuracy is required to establish a connection with mobile terminals via FSO, it presents an additional challenge [17].

During their propagation through the earth's atmosphere, laser beams must interact with particles and gas molecules. Losses in atmospheric channels are primarily caused by scattering and absorption. Either absorbing or scattering contribute to the atmospheric attenuation brought on by fog. An attenuation of more than 350 dB/km is expected in dense fog conditions. Rain does not have the same effect as fog. The size of the raindrops is greater than the FSO communication wavelength. In light rain, there is an attenuation loss of 2.5 mm/hr, and in heavy rain, there is a loss of 25 mm/hr. Snow particles range in size from fog to raindrops. Snow attenuates lighter than rain but less than fog. The range of attenuation is 30–350 dB/km [18].

1.3.5 FSO Communication System Application

FSO is a communication system where free space acts as medium between transceivers and they should be in LOS for successful transmission of optical signal. Medium can be air, outer space, or vacuum. This system can be used for communication purpose in hours and in lesser economy. For much improved electromagnetic interference (EMI) behavior, FSO makes use of lights rather than microwaves. The FSO is extremely tough to intercept now that the security has been improved. Today, the FSO communication connection is being utilized for a wide variety of services in a variety of locations. Examples of some of the most advantageous applications in which FSO plays an essential role are listed below:

- Citywide LAN-to-LAN connections, such as those in the Metropolitan Area Network.
- Campus LAN-to-LAN connections at FE or GE speeds
- To get over a road that is not owned by the sender or recipient, or to cross other barriers. Rapid high-bandwidth network access service delivery to optical fiber networks. Temporary network setup (for special occasions or other uses).
- Like enhancements or substitutes for current wireless technology. Quickly reestablish a high- speed connection (disaster recovery).
- For spacecraft-to-spacecraft communications, encompassing satellite constellation components.

1.4 Recent work of Free Space Optical Communication

Combining the best features of both optical communication methods, Dense Wavelength Division Multiplexing-Free Space Optical (DWDM-FSO) is a hybrid technology. For high-speed data transfer over extended distances, it is a viable option [19].

I discovered a study published recently with the title “Performance analysis of 320 Gbps DWDM-FSO System under the influence of various atmospheric conditions.” The study suggests a hybrid fiber + FSO system with 32 channels and 320 Gbps through the use of a hybrid dense wavelength division multiplexing scheme and cost-effective on-off key modulation. The 100 GHz channel spacing separates the 10 GB of data carried by each channel. Taking into account conditions of a clear sky, light fog, heavy fog, and dense fog, the impact of variation in climatic turbulence is investigated for both the non-return to zero and back to zero systems [20].

1.5 DWDM (Dense Wavelength Division Multiplexing)

Within optical networks for communication, one kind of wavelength division multiplexing (WDM) technique is called dense wavelength division multiplexing, or DWDM. Multiple information streams can be transmitted simultaneously over a single cable thanks to the method called DWDM (Dense Wavelength Division Multiplexing). This presents a feasible way to boost existing networks' capacity without laying new threads. The most popular method for integrity lines is DWDM. Its large channel support (up to 160 channels or more) and extremely narrow channel spacing (between 0.8 and 1.6 nm) make it's a productive & affordable method applicable to high-bandwidth operations. Needs as tiny as 0.1 nm as well as 0.2 nm are used in these systems. On the other hand, additional transmission path components—particularly Distributed Feedback (DFB) lasers seem to be required as spacing values decrease. DWDM systems can transmit data via dozens and perhaps hundreds of comparable optical fibers. That would be 193.1 THz, the normalized frequency, is defining characteristic of DWDM. The wavelength cannot differ by more than 0.16 nm from the normalization wavelength in order to function at its best. DWDM systems multiplex various streams of data on a single optical fiber, enabling massive data transmission over long distances. On the same fiber, information flows are transmitted at various wavelengths without interfering with one another. With the use of this technology, optical networks can function at much faster speeds, increasing their effectiveness and cutting expenses.

The optical communication systems have been transformed by DWDM technology, which has had a big impact on the telecom sector. This makes it suitable for use in applications such as storage facilities, broadband backbone networks, and long-haul or submarine communication systems, as it has made large-scale transmission of data over great distances possible. To compensate for signal losses, the optical amplifier boosts the light signal, has become one of DWDM systems' most crucial components. The EDFA (Erbium-Doped Fiber Amplifier), It is the most commonly utilized optical amplifier in DWDM systems because of its substantial gain and low noise while still being capable of interacting with regular single-mode fiber [21–24].

1.6 How many types of DWDM

In optical communications, a technique called DWDM (Dense Wavelength Division Multiplexing) can be implemented to transmit several signals using an individual optical cable at the same time. DWDM comes in a variety of forms with varying features and functionalities. It's crucial to remember that there might be more particular implementations and variations than the broad categories listed here.

1.6.1 CWDM (Coarse Wavelength Division Multiplexing)

A simpler version of DWDM that uses wider wavelength separations between channels is called CWDM. With a channel separation of 20 nm, it usually operates in the wavelength range of 1270 nm to 1610 nm. The shorter distances and tiny networks with fewer channels are good candidates for CWDM. Additionally, CWDM uses wider wavelength spacing, which helps bring down costs.

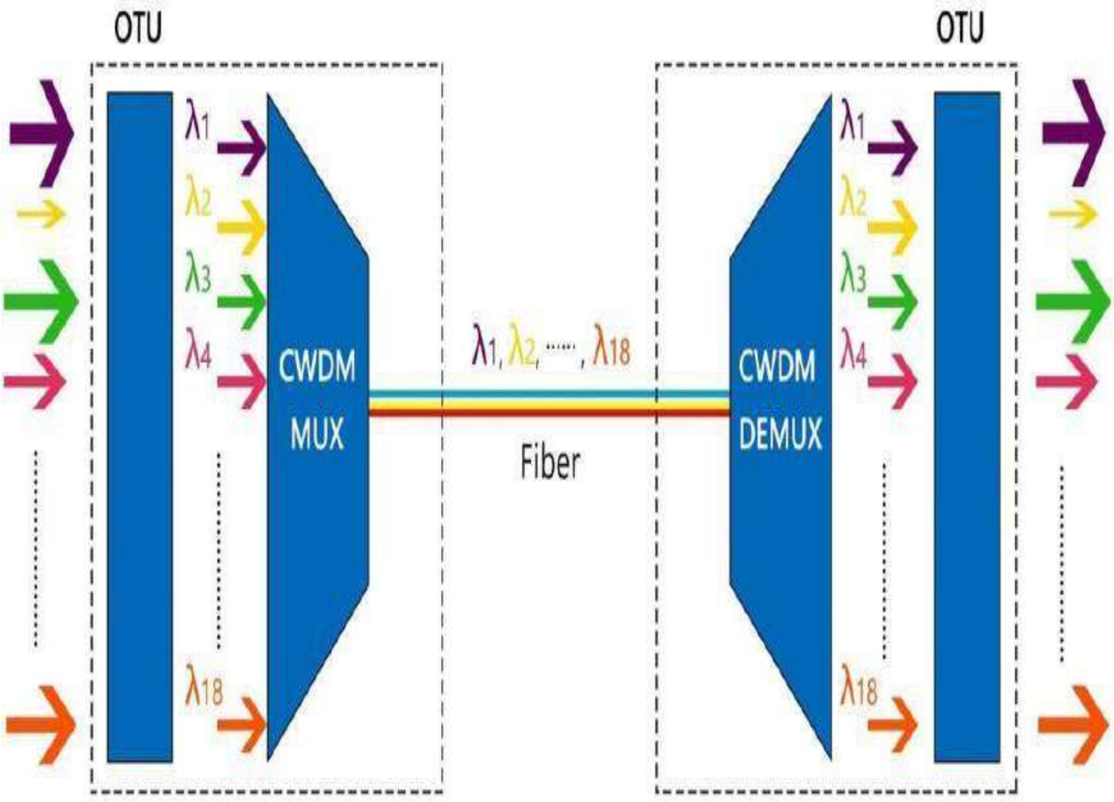


Figure 1.1 Block Figure of CWDM [25]

1.6.2 Long Wavelength Division Multiplexing (LWDM)

Operating in a broad wavelength range, usually around 1550 nm, LWDM is another form of DWDM. When it comes to transmitting a limited amount of data over shorter distances, it provides a more affordable option than conventional DWDM.

1.6.3 Ultra-Dense Wavelength Division Multiplexing (UDWDM)

Using a smaller channel spacing, UDWDM, an improved version of DWDM, enables more channels to be carried over a single fiber. In order to transmit more than eighty channels across a single fiber, UDWDM usually uses channels with a spacing of approximately 6.25 GHz or less.

1.6.4 Coherent Wavelength Division Multiplexing (Coherent WDM)

By utilizing complex modulation or detection schemes, such as coherent detection, coherent WDM is a technique for improving the spectral efficacy and transmitting capacity of DWDM systems. Transmitting data over a single fiber at different wavelengths allows for longer lengths of transmission and higher data rates.

1.6.5 HDWDM (Hybrid Dense Wavelength Division Multiplexing)

HDWDM combines DWDM & CWDM techniques to provide a combination of both with increased channels throughput. Sending both broadly dispersed (CWDM) and closely dispersed (DWDM) lines over a single fiber provides adaptability and versatility.

1.6.6 CDC-DWDM (Colorless, Directionless, and Contention less)

Advanced technology like CDC-DWDM improves the efficiency and flexibility of optical networks. It permits colorless additions and deletions of any wavelength at any network node, directionless bidirectional transmission on any wavelength, and interference-free wavelength access for disputants. CDC DWDM enables optical networks that are dynamic and reconfigurable.

1.6.7 Gridless DWDM

A more flexible method that allows the use of arbitrary channel spacings is gridless DWDM in contrast to fixed channel grids. Through channel spacing optimization based on network requirements, it maximizes spectral efficiency and allows for more effective utilization of the available light spectrum.

1.7 WDM

Optical carrier messages must be multiplexed onto one fiber using wavelength-division multiplexing (WDM). A single fiber strand can enhance capacity and communicate bidirectionally. Signals are multiplexed and demultiplexed in WDM systems. As an optically add-drop combination that uses the appropriate wavelength may perform both. Etalons, or Fabry-Pérot telescopes made of thin-film-coated refractive windshields, were regularly used to sift sunlight for ages [8]. WDM networks use 9-meter single-mode fiber optic cables. Some WDM uses premises cable, 50 or 62.5 m multi-mode fibers. There are two types of wavelength division multiplexing systems based on the frequency sequence [9].

Silica fibers may broadcast eight C-Band channels at 1,550 nm in the third window. Dense wavelength division multiplexing (DWDM) uses a comparable transmitting frame but has fewer channels than usual and closer separation. In fiber optic transmission, wavelength division multiplexing (WDM) sends data across one medium using numerous light wavelengths. This technology multiplexes optical carrier messages on one optical cable utilizing distinct laser wavelengths or colors. Each wavelength sends a non-overlapping signal. The operation of WDM technology is shown in the Figure below.

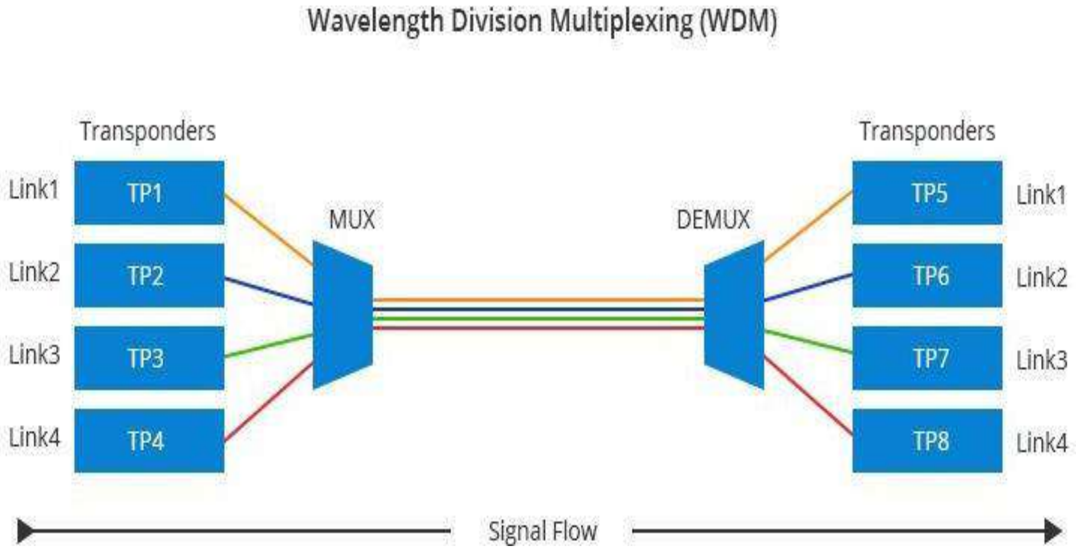


Figure 1.2 Block Figure of WDM [26]

1.7.1 Benefits of Adopting WDM Technology

Wavelength Division Multiplexing improves networking and communication. Transmission of several signals across a fiber optic cable enhances capacity and lowers infrastructure building costs. To address increased data needs, WDM can readily scale capacity by adding wavelengths. Many services can satisfy consumer expectations by supporting several traffic kinds on the same network. WDM's redundancy enables communication even if channels fail. Global networks need long-distance transmission with little signal degradation. Energy-efficient WDM reduces operational expenses and environmental impact, while wavelength-level security safeguards data. WDM's bandwidth, scalability, flexibility, reliability, security, and energy efficiency make it ideal for contemporary optical communication networks.

Ultra long Distance Transmission:

In WDM systems, EDFAs (Erbium-Doped Fiber Amplifiers) are frequently used to increase the optical signal's intensity for long-distance transmission.

Transparent Transmission:

There is no correlation between the wavelengths of light since each wavelength possesses its own unique set of chemical and physical characteristics. This is due to the fact that light includes a number of distinct characteristics. The fact that light may be sent in a transparent way across all channels without producing interference for the transmission is made possible as a consequence of this. When it comes to ensuring the dependability of the WDM system, it is feasible that the use of optoelectronic devices would be of beneficial assistance. Consideration ought to be given to this particular proposition.

Saving Both Fiber Resources & Expenses:

A pair of fibers is needed for each SDH system in a single-wavelength system, but a single pair of fibers is needed for every multiplexing system, regardless of the total number of SDH subsystems. As a result, fiber exhaust will not occur. WDM helps to maximize overall network investments in addition to maximizing fiber utilization. [26]

1.8 The designation of various optical communication channels

The many types of optical communication are referred to by a variety of distinct labels, which are listed below for your convenience:

1.8.1 SMF (Single-Mode Fiber)

That communication route that is utilized most frequently in optical networks is single-mode fiber. Single-mode light transmission is supported, enabling high rates of data and long-distance communication. Long-distance and high-capacity applications frequently use it.

1.8.2 Multimode Fiber (MMF)

The simultaneous transmission of multiple light modes is made possible by multimode fiber. In places like data centers and local area networks (LANs), it is usually utilized for shorter distances. Greater numbers of light rays are able to travel through multimode fibers due to their larger core diameters compared to single-mode fibers.

1.8.3 Free-Space Optical (FSO) Communication

Using laser or infrared beams, FSO communication entails sending data over open spaces. They are commonly utilized for point-to-point communication when conventional connections are not an option or when high-speed transmission is required.

1.8.4 Coaxial Cable

An example of a guided medium for transmission, coaxial cable consists of a core conductor surrounded by a dielectric substance. Optical communication is used in certain contexts, particularly in cable TV (CATV) networks, but it is more commonly associated with electrical talks.

1.8.5 Waveguides

Electromagnetic waves, including optical communications, can be contained and directed using structures called waveguides. Many different materials, such as silicon, polymer-based materials, and gallium arsenide, can be used to make them. They have several applications in interconnected optoelectronic electronics, optical devices with integrated circuits (PICs), and semiconductor photonics as well.

1.8.7 Optical Satellite Communication

The transmission of light signals via spacecraft to and from other spacecraft or even to ground stations is known as optical satellite communication. Applications like mapping, Earth observation, and deep space communication can benefit from its high rates of data as well as low-latency communication links.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

In this paper, they demonstrate how fiber-based subsystems can be used in conjunction with FSO and optical multiplexing (DWDM). The recommendations based on the results provide more data throughput and smoother communication. Using a common reference channel width of 0.8 nms, we successfully demonstrated a 32, 9, and 40 Gbps DWDM-FSO link operation over a distance of 3 km with an accepted BER of 10–11 in the context of symmetrically compensated systems. A little variation in BER on the order of (less than) 10-4 is observed when the connection length grows from 1 to 4 km [27].

TABLE I. PARAMETERS FOR THIS PAPER

Parameters	Description
Number of channels (N)/	32/48/64
Channel spacing (DWDM-FSO)	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

For links which are both turbulence-modeled and mildly attenuated (Gamma-Gamma), they have successfully shown how a 32 channel DWDM-FSO link functioning over 40 Gbps may work. The results are positive considering that the efficient covering the region, that normally, restricted without compensation, up to a limit of two kilometers, is extended by compensating schemes (pre/post/symmetric). The pre-, post-, and symmetrical optimized DWDM-FSO overcame link adversities to deliver 10-7, 10-8, and 10-9 BER, respectively, at a link distance of 3 km. Furthermore, symmetric compensations were demonstrated to be the most reliable system, as BER on pre- and post-compensated links changed dramatically, while BER loss with an expanded range was incredibly modest, ranging from 10–13 to 10–9. For DWDM-FSO-based optical communication systems, security is also essential. Recent research has demonstrated that combining photonic QKD with DWDM-FSO systems is feasible, along with photonic QKD being highlighted as a practical method for security protocols. Photonic QKD may be integrated into DWDM-FSO networks to improve the safety of optical communication networks. It has the ability to generate a safe key for use in encrypting and decrypting data. A technique that has been developed for secure communication is photonic quantum key distribution (QKD). Quantum key distribution (QKD) generates an encrypted key appropriate for application in telecommunication cryptography. According to recent research, QKD and DWDM, or systems, may be linked to provide extremely safe and effective communication [28].

The advantages, difficulties, uses, and functions of free space optics (FSO) in developing networks are covered in this research. Additionally, the authors examine how well FSO communication systems function while employing four dense wavelength division multiplexing (DWDM) channels. The many factors that impact connection performance are thoroughly discussed in the study, including attenuation, transmitter power, bit error rate, data rate, and distance under various weather scenarios. To demonstrate which of the two additional bands—the C and L—performs better, the authors also provide an objective evaluation of the functioning of the suggested system in each. The results are presented in the format of Q-factor and bit error rate charts at the end of the publication [29].

By demonstrating how the same data bandwidth of a 64-channel DWDM system may achieve 10 Gbps by adjusting intensities and spacing between frequencies (SMF), the purpose of this article is to demonstrate how this can be utilised to improve the stability of the system during use of a 50 km SMF (Single Mode Fibre). With the help of EDFA (Erbium-Doped Fibre Amplifiers), we were able to boost the gain of the battery, and with the help of DCF, we were able to boost both the capacity and efficiency of the system. The experimental frequency spacing evaluation of the Q-factor, eye height by eye diagram, and BER (Bit Error Rate) along with Bit Error Rate Analyzer, as well as simulation at various power levels, are some of the consequences that the Optisystem software system has produced. Simulations produced by a number of different power levels are among the other outputs.

TABLE II. PARAMETERS FOR THIS PAPAER

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

WDM transmitter frequency 190THz Frequency spacing 100,90,70 GHz Input power -7,- 3,3,7 dBm Bit rate 10 Gb/sec Modulation type NRZ Fiber length 50km Attenuation 0.2 dB/km EDFA gain 10 dB DCF length 15 km Reference wavelength 1450 nm. This 64-channel performance analysis is functional. Single-mode fiber allowed as an alternative to using 64 channels instead of one, resulting in enhanced system reliability within different power levels & frequency spacings. The DWDM system has surpassed the competition for which the Q-factor stands at 12.4041 various at a signal strength of -10dBm and a frequency spacing of 100GHz, 10.7893 at varying relative strengths of the input signals at 3 dBm. This result is illustrated in the eye Figure. Its bit error rate is lower and its quality factor is larger, suggesting a better approximation [30].

Optical signal attenuation reduction during free-space transmission & imposed with different environmental factors are such main objective of the proposed technology. The research is based on simulating various attenuation of the environmental conditions along with 2 different kinds upon Free space optical implementations the Optisystem simulation toolbox. A DWDM SISO is the initial one, and hybrid DWDM-MIMO is the second concept. Regarding the quality factor, an exam conducted contrasting the existing system coupled with suggested alternative under a range of weather damping scenarios. When it comes to the areas of functionality and signal reliability, it has been suggested that demonstrated promising outcomes. When the distance traveled during transmission for that has been suggested is compared to a standard DWDM-SISO, it increases by 30.43 percent under heavy fog attenuation of 260 dB/km and by 55.55 percent with severe rain attenuation of 9.29 dB/km.

Under heavy dry snow conditions, the communication route length of the suggested system is 26.19 percent longer than that of standard DWDM-SISO, resulting in 131.835 db/km is the attenuation. The abbreviation SISO stands as "Synergistic Information." Numerous technological developments during data transfer and exchange have been made possible via wireless communications. A technique used in traditional radio communications is called SISO. A single antenna is used for both transmission and reception in the SISO method. SISO-based FSO systems are more susceptible to air attenuation due to weather-related factors and interference from obstacles like insects and birds [31]. We successfully demonstrated Dense Wavelength Division Multiplexing (DWDM) over a free-space optical (FSO) communication system with 8 channels at 40 GB/s. With a 1.8GHz filter bandwidth and a 0.8nm (100GHz) channel spacing, each channel is transmitting at a data rate of 5 GB/s downstream. High-data-rate transmission with an extremely low bit error rate (BER) is possible with DWDM over FSO communication systems. The system's greatest reach, in the absence of a compensatory plan, is 4000 meters. The simulation work reveals that at 4000 meters, the minimum bit error rate (BER) for the Return-to-Zero (RZ) modulation format at distinct channels 1, 4, and 8 is $2.32e{-}17$, $1.70e{-}16$, and $9.51e{-}15$, respectively. When both the data rate and the distance increase to 10 GB/s and 5000 m, there is a sharp rise in BER [32].

The purpose of this research was to evaluate the best performance for a data rate of 2.5 Gbps with a laser power level of 35 dB under three distinct rain conditions utilizing different customizable topologies of optical amplifiers in FSO. A comparison is made between the results of the current system and those of the system that is being suggested. It would appear that the approach that has been presented is more effective in terms of both performance and cost. In light of the fact that it excels and outperforms other traditional systems while also delivering a multitude of other benefits, FSO is presently being utilized in a broad variety of applications worldwide. On the other hand, because the performance of the system might be negatively impacted by unfavorable weather conditions, efforts are being made to achieve the best possible degree of performance. Utilizing optical amplifiers in a simulated form is one example of such a method. The use of optical amplifiers increases both the system's range and its signal-to-noise ratio (SNR). Based on the simulations, it is evident that System II yields superior results compared to System I. System II offers a wider range of output and a greater quality for the same amount of electricity and other elements. The solution that was offered not only enhances the performance and reliability of the system, but it also reduces the expenses associated with its installation. Nonetheless, efforts are made to achieve the best level of performance because unfavorable weather conditions could impair its function. One such method is the use of simulated optical amplifiers. By using optical amplifiers, the SNR and range of the system are increased. According to the simulations, System II produces results that are higher quality and more varied than System I for the same power and other parameters. The suggested fix not only reduces installation costs but also enhances system performance and stability [33].

Reducing attenuation when an optical signal is delivered across free space and exposed to different weather conditions is the main objective of the proposed technology. The research is focused on simulating various weather attenuation conditions in two different kinds of FSO systems using the Optisystem simulation toolbox. The first is called DWDM SISO, while the second is a planned system called Hybrid DWDM-MIMO. Regarding the quality factor, a comparison is done between the existing system and the suggested alternative under various weather attenuation scenarios. In terms of performance and signal quality, the recommended system has produced positive results. The transmission channel length of the proposed system is enhanced by 30.43 percent when dense fog attenuation of 260 dB/km and by 55.55 percent when severe rain attenuation of 9.29 dB/km occurs, in comparison to normal DWDM-SISO. Under conditions of heavy dry snow and attenuation of 131.835dB/km, the transmission route length of the proposed system is extended by 26.19 percent in comparison to normal DWDM-SISO. The abbreviation SISO stands for "Synergistic Information." Numerous technical developments in data transfer and exchange have been made possible via wireless communications. A technique used in traditional radio communications is called SISO. A single antenna is used for both transmission and reception in the SISO method. SISO-based FSO systems are more susceptible to air attenuation due to weather-related factors and interference from obstacles like insects and birds [34].

As a result of the widespread use of optical fiber communication, there has been an increase in the demand for capabilities that enable transmission across long distances and at high bandwidths. DWDM network systems are being utilized by firms that supply telecommunication services as a reaction to the need. These systems are capable of satisfying the demand, despite the fact that this method is typically expensive for customers. Control-wave division multiplexing, often known as CWDM, is a network technology that has been proposed as a potential alternative that might provide a more economical solution for high bandwidth transmission. In a four-channel Convolutional Wavelength Division Multiplexing (CWDM) system, the proposed research explores how effective it is to broadcast various bandwidths for each channel. The software used for this investigation is called Opti System. The performance of the system is tested as part of the research by assessing the extinction ratio as well as the distance between the transmitter and the receiver up to a fiber span of one hundred kilometers. This evaluation is carried out in order to determine how optimal the system is. The major focus of this investigation is on applications that need shorter distances and where cost is a key concern. These are the applications that are being considered. These findings may be employed to improve the design and performance of CWDM systems by throwing light on the strengths and drawbacks of these systems. This study was conducted to investigate the capabilities of CWDM systems. The adoption of Coherent Wavelength Division Multiplexing (CWDM) technology offers a cost-effective solution for companies in the telecommunications industry to meet the rising need for high bandwidth transmission. In addition to this, it provides customers with a selection of options that are more reasonably priced. Through the modeling of Four Channels Continuous Wave Division Multiplexing (CWDM), it has been demonstrated that this technology has the potential to provide a solution that is both cost-effective and efficient for the transmission of high-speed data across extensive distances. A number of factors, including the Min Q factor, the threshold, the BER, and the eye height, have been shown to be affected by the length of the fiber, as evidenced by the findings. Based on the data, it can be concluded that longer fibers result in lower values for respective metrics. CWDM continues to be a desired option for corporate networks, interconnects in data centers, and telephone networks, despite the limits that have been mentioned. Typical DWDM systems require two fibers and can be more expensive and difficult than this option, which is suggested due to its vast bandwidth and affordable cost. This approach is recommended because of its high bandwidth. It is possible that we will be able to anticipate more improvements in the performance of the continual Wavelength Division Multiplexing (CWDM) technology as it continues to undergo the process of continual advancement. The potential uses of this technology within the field of optical networking will be expanded as a result of this. while taken as a whole, the findings of this study help to highlight how important it is to take into consideration the effects of fiber length while constructing and implementing transmission wavelength division multiplexing (CWDM) systems. As a result of this research, it is intended that academics and engineers who work in the field of optical networking would gain useful insights, and that it will also motivate more research into the creation and enhancement of CWDM technology [35].

In the field of optics, nonlinearities are the cause of a wide range of phenomena that may be observed in optical fibers. Even while these events are intriguing in and of themselves, there is a possibility that they might compromise the efficiency of optical communication. DWDM, which is an acronym that stands for dense wavelength division multiplexing, is a technique that lays a large emphasis on the nonlinear effects. DWDM systems provide a number of different components, including system margin, system availability, and component dependability. It is possible for a DWDM system to carry many channels at the same time. The consequence of this is an increase in the power level that is carried by the fiber, which in turn leads to the creation of nonlinear effects such as SPM, XPM, SRS, SBS, and Four waves mixing (FWM). FWM is one of the most difficult difficulties that we are currently dealing with. It is possible for the FWM to generate crosstalk inside a DWDM system given that the channel spacing is very close together. By use of the technique known as wavelength swapping, it is feasible to exchange data across two different wavelengths at the same time. These phenomena have been exploited in a broad number of applications within DWDM optical networks. Some of these applications include, include, but aren't restricted to, optic add-drop multiplication, optic 3R, frequency transformation, and frequency sample. Multi-wavelength modulation (FWM) has a tendency to result in inter-channel crosstalk in DWDM systems. The performance of the system suffers as a consequence of this, as well as an increase in the amount of excess noise. It is feasible to decrease the influence of FWM by adopting fiber with a dispersion of 4 ps/nm/km, which is sometimes referred to as none zero dispersion shifted fiber.

Additionally, it is possible to do so by applying uneven spacing among channels. An uneven channel spacing may simultaneously decrease non linearities [FWM and SRS], which may result in higher performance and a lower bit error rate (BER) as a consequence of greater optical signal-to-noise ratio (OSNR). If this is the case, then the channel spacing may be considered unequal [36].

This research is being conducted with the intention of presenting a four-channel WDM system that we have developed and recommended for usage in situations when the weather is clear. The Q Factor, the Bit Error Rate (BER), and eye-opening are examples of metrics that are applied in order to evaluate the performance of the system. With a data rate of twenty gigabits per second (Gbps) across four channels, the system runs at the O, E, L, and U bands. In the beginning, the performance of the system was not enough while it was operating at higher data rates with 10 Gbps and 20 Gbps. This made it difficult for the system to function properly. An improvement has been made to the bandwidth parameter in order to enhance the performance of the existing WDM system across a distance of 150 kilometers. Through the employment of the optimization strategy, it has been shown that the performance of the system may be enhanced by employing the bandwidth range of 40 GHz to 100 GHz. This was identified through the utilization of the optimization technique. It is possible for the Q factor to achieve an exceptional value when it is functioning within this bandwidth range. The WDM-FSO system that has been created has the ability to give an efficient solution to the issues that occur in the last mile, as well as to fulfill the ever-increasing demand for channel capacity and spectrum while good weather conditions are present. This is because the system has the potential to deliver both of these benefits inside the same system. The performance of the system that has been given is limited by the variable atmospheric conditions that include fog, haze, rain, snow, and other phenomena that are comparable to these. It is possible to increase the performance of the system regardless of the weather conditions by making use of a range of optical amplifiers that are appropriate for FSO communication. This may be accomplished through the exploitation of optical equipment.

The Free Space Optics (FSO) technology is a promising technology that has demonstrated its substantial value as a redundancy for existing fiber optic long haul networks and in metropolitan area networks due to its ability to provide redundant connections. On the other hand, the FSO is affected by the various atmospheric conditions because it uses air as an unguided medium when it transmits light. Because of this, the performance of the item is impacted in some way. Both the maximum data rate and the maximum range are significantly influenced by it, and this influence is significant enough to be considered significant. The objective of the researchers is to enhance the functionality of the FSO system by employing a wide range of alternative multiplexing and modulation schemes. When the weather is clear, a long-range wavelength division multiplexed (WDM) frequency selective optical (FSO) system is available for use. It is possible to achieve a channel capacity of 10 Gbps using this technology, which is equivalent to 2.5 Gbps and four channels [37].

This study has provided a description of an architecture for a DWDM ROADM that is not only efficient but also cost-effective. That of a WSS-based ROADM is significantly higher than the implementation maximum cost value of this architecture, which is an order of magnitude lower value. Ultimately, the purpose of this design is to satisfy the requirements for the convergence of metro–access networks in the future. In addition to that, a spectrum characterisation of a single-stage DWDM ROADM that is efficient in terms of cost has been developed. Following the completion of this characterization, a general insertion loss model for a ROADM with N stages that is both cost-effective and efficient has been proposed. A comprehensive analysis of the throughput of the network has been carried out in order to demonstrate that the performance of DWDM ROADM is cost-effective in the context of a metro ring network scenario. To determine the most cost-effective design of the DWDM ROADMs of the network, an iterative approach has been presented. The goal of this procedure is to determine the optimal design. As a reaction to the issue that was mentioned before, this approach was developed. When utilizing this strategy, the traffic that is assigned constitutes eighty percent of the total traffic that is carried by a network that use WSS-based ROADMs with FS granularity. This is because the allotted traffic is given priority over other traffic. The fact that 125 GHz is the tradeoff answer for a variety of DWDM channel widths is something that we have demonstrated as well. It has been determined that this frequency corresponds to the effective band of the single-stage cost-efficient ROADM that has been implemented here.

In order to meet the projected rise in the volume of Internet data traffic that will be brought about by the expansion of cloud services, 5G-based services, and social networks, the underlying networks will need to undergo architectural alterations. These modifications will be necessary in order to take into account the anticipated increase. The supply of extremely dynamic connectivity options will be made possible as a result of this step. It is required to create solutions for flexible network subsystems that are both cost-effective and energy-efficient in order to provide future networks that are sustainable. This is necessary in order to provide future networks. The goal of this research is to develop a reconfigurable optical add/drop multiplexer (ROADM) architecture that is not only capable of permitting optical metro–access network convergence but also has the ability to reduce costs. DWDM, which stands for dense wavelength division multiplexing, is the foundation of the design. An evaluation of the cost-effective DWDM ROADM capabilities has also been carried out within the framework of an ultra-dense wavelength multiplexing (u-DWDM) ring network scenario. In particular, the throughput that may be achieved by the network has been taken into consideration [38].

For the purpose of getting to the point In order to enable access networks to deliver data with a high bit rate to backbone networks, it is essential for an Ethernet link to have a connection that has a high information transfer rate. This is also important for the link to have a high information transfer rate. The requirement has been successfully accomplished by the utilization of this particular instance of DWDM, which is an acronym that stands for optical dense wavelength division multiplex. It is also necessary for the system to be outfitted with an amplifier in order to improve the quality of the signal that is received for a point-to-point connection that is established across a long distance. This study's purpose is to give a network architecture that can be of aid in the attempt of creating a long-range point-to-point DWDM connection. This will be accomplished by providing a network architecture that can be of assistance in this endeavor. The application of the OptiSystem version 17 is being done in the process of creating the network link that is 100 kilometers long. Within this particular variant, a wavelength of 1555 nm is utilized.

The hyperlink that was constructed has the capability to operate at a bandwidth of one hundred gigahertz, and it has forty channels that are included in its functionality. When the system is operating at a bandwidth of 8 GHz, on the other hand, the bits error rate and Q-factor are at their highest possible values. This is in contrast to the situation in which the system is operating at any other bandwidth. The scope of this study involves the description of a point-to-point optical DWDM system that is capable of delivering a connection that is one hundred kilometers long. The optimal design makes use of a wavelength of 1555 nm in order to accomplish a maximum attenuation fiber optic of 0.3 dB/km and an operational bandwidth of 8 GHz. This is the optimum design. With a bit error rate (BER) of 10-6 and a Q-factor of 4.6 on average, it is possible to reach the highest possible level of performance that is practicable. The bit error rate (BER) and the Q-factor are not satisfied with the designs, despite the fact that the first and second designs have a greater bandwidth of 80 GHz and 15 GHz, respectively. This is due to the fact that the designs are not optimized to the appropriate degree [39].

This article provides a definition of the relationship between the error parameters in networks that are constructed on optical transmission lines and the optical wireless connections. It is reasonable to anticipate that the transmission error will be subject to significant demands because of the enormous volume of data that is communicated as a result of the connection of a large number of tributary signals. The purpose of this article is to define techniques of measurement, evaluate individual error parameters, and explain the relationship between these three things. In backbone networks, optical fibers are the predominant medium, and DWDM wavelength multiplexing is the means by which future development is being carried out. The objective of the optical hierarchy is to establish a standard platform that can be utilized by many kinds of networks in order to provide support for enhanced service components. Within the scope of this essay, we have endeavored to provide an explanation for the link that exists between the various error parameters in optical wireless networks and nodes, which ultimately results in the electronic signal being converted from the optical signal. The article provides an explanation of the connection that exists between the Q-factor and the bit error rate. It is possible to use Q-factor for the monitoring of DWDM systems because of its speed measuring capabilities, its independence from the digital signal structure, and its ability to accommodate a broad range of transmission speeds [40].

An evaluation of the performance of a silicon photo-multiplier (SiPM) based PET scanner that was built for completely simultaneous pre-clinical PET/MR research was carried out by our team. LYSO crystals measure 1.3 millimeters by 1.3 millimeters by 10 millimeters, and the PET scanner has an interior diameter of 20 centimeters. The field of view (FOV) of the axial PET is 30.2 millimeters. SiPMs have been included into the PET detector modules, which have been engineered to be MR-compatible. This allows the modules to be placed directly into a Philips Achieve 3T MR scanner. When single slice rebinning (SSRB) and 2D filtered back-projection (FBP) are used for reconstruction, the spatial resolution of the system is just under 2.3 mm full width at half maximum (FWHM) in the trans axial direction. When resolution modeling is used, the FWHM is 1.3 mm. This system's spatial resolution is measured using a point source in a background that is not active. When a point source is located in the middle of the field of view, the sensitivity of the system is 0.6%. There is no indication that the genuine coincidence count rate will reach a saturation point at 30 MBq. At this time, the random fraction is 8.2%, and the scatter fraction for an item of rat size is around 23%. Imagery of phantoms that is devoid of artifacts has been achieved by the utilization of FBP and iterative reconstructions. owing to the constraints of the first-generation detector readout ASIC that is utilized in the system, the performance is now restricted. This is owing to the fact that only one of the three axial ring locations is packed with detectors. According to the description, the performance of the system is enough for doing simultaneous PET-MR imaging of significant organs within the mouse as well as animals large enough to be considered rats. This is illustrated by dynamic PET and MR data that were obtained concurrently from a mouse that had been implanted with a dual-labeled PET/MR probe [41].

High launching power and the smallest possible channel spacing are both necessary in order to achieve the goal of increasing the transmission capacity of the fibers. Therefore, in the present day, a cutting-edge technique known as DWDM (Dense Wavelength Division Multiplexing) is being implemented. On the other hand, in order to decrease the spacing and to increase the number of channels, there is a nonlinear distortion known as Four-Wave Mixing. This distortion cuts down on the signal that is broadcast, which in turn lowers the overall performance of the system. A number of different modulation strategies and optical filters have been taken into consideration in this article in order to reduce the effects of Four-Wave Mixing (FWM) in Dense Wavelength Division Multiplexing. Moreover, a circular polarizer is utilized in the optical DWDM system in order to reduce the impact of FWM significantly. investigations of simulation have been carried out using the DWDM system running at a data rate of 1 Gbps, and the program OPTISYSTEM 13 has been utilized for these investigations. When determining the output of the system, the quality factor and power of FWM goods are taken into consideration.

Through the use of OPTISYSTEM 13, each and every result was attained. The Duobinary modulation format, the Inverted Rectangular filter, the Raised Cosine pulse generator, and the Gaussian pulse generator have all been investigated with regard to their respective functions. In order to lessen the amount of FWM products, several modulation approaches make use of the circular polarizer. Through the use of the circular polarizer, it becomes evident that the raised-cosine pulse generator possesses the best quality factor, which is around 18.3942, while the duobinary format possesses the lowest quality factor, which is approximately 4.29446. The chart makes it quite obvious that the FWM is decreased in duobinary format, and the value that it is reduced to is -81 dBm. It has been observed that the inverted rectangular filter does not produce any FWM products. The findings make it abundantly evident that the utilization of circular polarizers has the potential to lessen the power output of FWM devices [42].

As a feasible wireless alternative to fiber optic cable that provides high bandwidth, FSO has developed over the course of the past many years. When compared to fiber, FSO provides a number of benefits, the most prominent of which are the short amount of time necessary for its deployment and the huge cost reductions it delivers. In addition, FSO offers a number of advantages. It is reasonable to anticipate that the accessibility of connections as a function of distance will be considered for any FSO system. This is because weather airports are weather airports. One of the drawbacks of FSO in compared to fiber is that the laser power attenuation that occurs as a result of the weather is difficult to anticipate and can be unpredictable. 1. a.This investigation is primarily concerned with the implementation of the FSO optic access model, and the analysis and assessment of this model is the major focus of the investigation. An analysis of their performance is also included in this article, with a special emphasis placed on BER. This investigation is presented in great depth. The results of the simulation indicate that there is a high degree of concordance between the behavior that was anticipated and the behavior that was observed in the region of intermediate turbulence. These results are located somewhere in the center of the weak and strong turbulence theories. An investigation of the bit error rate (BER) and signal-to-noise ratios for various degrees of turbulence has revealed that aperture averaging has the potential to considerably increase the performance of the connection, particularly as the turbulence becomes more severe.

This was determined through the observation that aperture averaging has the ability to improve the performance of the connection. The information that has been supplied is beneficial when it comes to directing receiver layout as it pertains to FSO communication systems. Through the exploitation of free space optical (FSO) technology, it is possible to get access to the fiber optic network in a manner that is both effective and efficient in terms of cost. Not only does FSO technology provide connections of high quality, but it also delivers the most cost-effective transmission capacity in the market. FSO systems are a wholly protocol independent broadband gateway that complement old network obligations and act in harmony with any protocol. In spite of this, they are not dependent on any single protocol, which allows them to save a significant amount of money in initial investments. The cost of procuring and establishing an FSO link is much lower when examined in comparison to the cost of building fiber cable. Also, the cost of microwave and radio frequency wireless systems that are similar to one another is around half of what it would be. Unlike radio frequency (RF) wireless technology, FSO does not require the purchase of expensive spectrum licenses or the fulfillment of additional regulatory criteria. This is the case with the exception of RF wireless technology. The purpose of this research is to explore the efficiency of optical access networks that are constructed using FSO components as fundamental building blocks. In addition to this, there is a comprehensive examination of the performance, with a specific focus on the bit error rate (BER) [43].

Free Space Optics (FSO) is a promising technology that has shown its great worth as a redundancy for existing fiber optic long haul networks and in metropolitan area networks owing to its capacity to provide redundant connections. This has been shown by the fact that FSO has demonstrated its substantial value. Due to the fact that it employs air as an unguided medium, the FSO, on the other hand, is susceptible to the varied variables that are present in the atmosphere. Because of this, the performance of the item is impacted in some way. Both the maximum data rate and the maximum range are significantly influenced by it, and this influence is significant enough to be considered significant. The objective of the researchers is to enhance the functionality of the FSO system by employing a wide range of alternative multiplexing and modulation schemes. The long-range wavelength division multiplexed (WDM) FSO system that is now available provides a channel capacity of 10 Gbps, which is equivalent to 2.5 Gbps multiplied by four channels. This capability is accessible for use in situations where the weather is clear.

This research is being conducted with the intention of presenting a four-channel WDM system that we have developed and recommended for usage in situations when the weather is clear. The Q Factor, the Bit Error Rate (BER), and eye-opening are examples of metrics that are applied in order to evaluate the performance of the system. With a data rate of twenty gigabits per second (Gbps) across four channels, the system runs at the O, E, L, and U bands. In the beginning, the performance of the system was not enough while it was operating at higher data rates with 10 Gbps and 20 Gbps. This made it difficult for the system to function properly. An improvement has been made to the bandwidth parameter in order to enhance the performance of the existing WDM system across a distance of 150 kilometers. Through the employment of the optimization strategy, it has been shown that the performance of the system may be enhanced by employing the bandwidth range of 40 GHz to 100 GHz. This was identified through the utilization of the optimization technique. It is possible for the Q factor to achieve an exceptional value when it is functioning within this bandwidth range. The WDM-FSO system that has been created has the ability to give an efficient solution to the issues that occur in the last mile, as well as to fulfill the ever-increasing demand for channel capacity and spectrum while good weather conditions are present. This is because the system has the potential to deliver both of these benefits inside the same system. The performance of the system that has been given is limited by the variable atmospheric conditions that include fog, haze, rain, snow, and other phenomena that are comparable to these. It is possible to increase the performance of the system during harsh weather conditions by utilizing a range of optical amplifiers that are suitable for FSO communication. This may be accomplished with the help of [44].

The goals of this thesis are to investigate the performance of a terrestrial free-space optical communication (FSO) system that is based on the On-Off keying (OOK) and Pulse Position Modulation (PPM) methods in the presence of air turbulence and aiming error. Specifically, the research will focus on how well the system performs in these conditions.

As the foundation for the investigation, the bit error rate (BER) is utilized in the process of carrying out the performance analysis. There are a number of factors that contribute to the attenuation of optical signals as they pass through the atmospheric channel. These factors include airborne particles, fog, atmospheric gases, and precipitation. The scattering and absorption processes are responsible for this attenuation. For the purpose of demonstrating the impact of air turbulence on an FSO system, both analytical and experimental verification are presented. In both the situation of a single hop (characterized by OOK modulation) and the case of several hops (characterized by PPM modulation), this is carried out. There is a substantial relationship between the turbulence that is present in the environment and the quality of a laser beam that is capable of passing through the atmosphere across enormous distances. Turbulence, which is created by the propagation of light over turbulent eddies of varying sizes and refractive indices, is the source of both beam wander and intensity scintillation. Turbulence is the cause of both of these phenomena. It is possible that the operation of target identification and FSO communications systems may be significantly hampered as a consequence of this potential. The circumstances under which this thesis conducts its examination of background interference (BER) include weak air turbulence, which is also known as log-normally distributed, and transmission using single hop and multi-hop, which is established on amplify-and-forward relays. Both of these conditions are established on log-normally distributed transmission. We present an instance of the combined probability density function for the FSO system that consists of many hops. The performance of the bit error rate (BER) is examined while the modulation order is constantly being changed.

In addition, the performance is investigated by employing many hops, and the power penalty and total transmission distance are also approximated as the curves that are produced as a consequence of this thesis for a fixed bit error rate (BER). In conclusion, the data that were revealed through numerical analysis indicate that the multiple hop transmission in conjunction with PPM is a superior choice to the OOK-based single hop when it comes to reaching the required Bit Error Rate (BER) in the presence of weak turbulence and pointing error. In order to assess the performance of a multiple-hop FSO connection in terms of its Bit Error Rate (BER) in the presence of modest air turbulence and pointing errors, an analytical approach is provided. This method makes use of Log distribution that is normal. When taking into account a higher PPM order of modulation, the data suggest that a greater number of hops may be applied to provide a better degree of performance than using no hop at all. This is in contrast to the situation in which no hop is utilized at all. Furthermore, the maximum permissible distance that was mentioned in this study as well as other data may be employed for the goal of establishing a multiple-hop FSO link. This is feasible because of the fact that this study was conducted [45].

Free Space Optics (FSO) is a popular choice for high-speed wireless communication because it transfers data faster, has fewer regulatory restrictions, and is exceptionally secure over long distances. Being a new technology also helps its appeal. Weather conditions vary, hence FSO optical band capacity and availability are critical. Even in bad weather, optical bands C, S, and O with FSO communications increase network flexibility and wireless coverage. This is true without FSO communications. This study examined the performance of a hybrid four-channel FSO-WDM system with a channel spacing of 100 GHz or 0.8 nm at various data rates and in adverse weather. The system's performance was evaluated up to three kilometers with an attenuation of 0.25 dB per kilometer. The O band performed best up to 25 gigabits per second, but the system did not improve with data rate. Kim model BER studies under various weather circumstances showed that the O band outperformed the S and C bands throughout the investigation. Eye diagrams showed that the O band performed better than the other two bands despite the bad conditions. The research found that FSO might be used for high-speed wireless communication, particularly in the O band. This article examines four hybrid WDM-FSO channels for O-, S-, and C-band optical bands. Analyzed wavelengths are 1308, 1505, and 1552 km/s. With a variety of optical wavelengths, data may be sent at varying rates. The data transport rate has risen to 50 gigabits per second to monitor bit error rate (BER) and eye diagrams, up from 5 gigabits per second spanning several optical bands. We evaluate performance with FSO connection lengths up to three kilometers. Many attenuation methods can imitate turbulent weather. We got better results using optical band O at 1308 nm. The hybrid model in this system produces better output than the FSO system (Figures 2 and 4). All bands were limited to 30 gigabits per second per channel by the hybrid system. FSO lines are indicated for high-capacity communication in densely populated metropolitan areas with line-of-sight transmission. Customizable backhaul optical systems are available. For a high-capacity, low-cost national communication link, this hybrid system may be the best solution for FSO throughput. This is especially true for wireless sensor network throughput [46].

CHAPTER 3
SYSTEM MODEL

3.1 A Brief Overview of the Opti system

Numerous different optical fiber communication systems may be designed and simulated using the Opti Systems software, including wavelength division multiplexing (WDM) networks, optical fiber sensors, passive optical networks, and more. This further highlights the versatility of the software as presented in the proposed thesis.

To build and simulate intricate optical communication systems, Opti Systems software offers a vast library of parts, including optical fibers, amplifiers, modulators, sensors, and filters.

The software allows for simulations of the behavior of the system under different operating conditions, such as different noise profiles and input power levels, and it provides a range of operation indicators and output data for analysis of the outcomes.

Utilizing OptiSystem for the suggested thesis has several benefits, one of which is that the program can simulate the suggested DWDM-based optical communication system more realistically and accurately. Numerous variables that can impact system performance, including chromatic dispersion, polarization mode dispersion, and the non-linear implications of high laser power, can be taken into account by OptiSystem.

By adjusting the coding schemes, such as forward error correction, the performance of the system may also be simulated with the assistance of the OptiSystem application. This can be done in order to model the system's performance. By doing research on these characteristics and the manner in which they impact the operation of the system, one may be able to obtain a more thorough knowledge of the benefits and drawbacks of the system that is being suggested. A more realistic and accurate modelling of the DWDM-based optical communication network, an in-depth investigation of metrics used to measure the system's efficiency, and an enhanced comprehension of aspects that make up the system's shortcomings and room for development are some of the benefits that can be gained from utilising OptiSystems software in the proposed thesis. These are just some of the benefits that can be gained. In general, there are a lot of benefits that may be obtained via the utilization of this programme.

3.2 Continuous-Wave (CW) Laser

A CW (Continuous-Wave) laser is a vital instrument for many different applications where a consistent, dependable source of high-grade light is needed. These lasers work by keeping the laser cavity's energy state constant, which causes a steady stream of photons to be released. There is a large variety of materials that may be used to construct CW lasers, including semiconductors, gases, and solid-state crystals. Additionally, CW lasers can be built in a wide variety of sizes and configurations. Gas lasers are frequently used in low-power scientific applications because to their great efficiency and high power output. However, solid-state CW lasers produce a beam of better quality, making them the obvious victor in this category. CW lasers have a number of benefits, one of the most important being their excellent beam quality, which enables them to perform drilling, welding, and cutting jobs with an amazing degree of precision. This is not the case with pulsed lasers, which generate a greater amount of heat energy and light bursts of high intensity, both of which have the potential to cause damage to the workpiece you are working on. One further advantage of CW lasers is that they are extremely dependable. Due to the fact that their energy level remains constant, continuous-wave (CW) lasers often have longer lifespans and require less maintenance than pulsed lasers that are used. As a result of this, they are ideal for applications that need continuous operation, such as the production operations in industrial settings or the treatments in medical settings. When compared to pulsed lasers, continuous-wave lasers consume far less energy. Because these lights consume less energy for each watt of light that they generate, their use over a longer period of time results in a more cost-effective financial investment. CW lasers are suitable for applications such as laser cooling experiments and spectroscopy, which require a stable and reliable light source. This is because CW lasers emit a continuous beam of light, which means that they are suitable for these kinds of applications. The operation of a continuous-wave (CW) laser requires both laser pumping and continuous light output in order to function properly. In addition to the high-frequency single-resonator mode, there are a number of other emission modes. With a wavelength of 1153 nanometers, helium-neon lasers were the first lasers to function continuously. Shortly after that, it was discovered that a variant had an emission wavelength of 632.8 nm, which is the norm at the moment. As a consequence of the development of gas lasers, different solid-state lasers (including semiconductor lasers), and dye lasers, a great number of other types of lasers that are capable of operating constantly have been created. A representation of the OptiSystem CW laser indicator may be seen in (3.1).

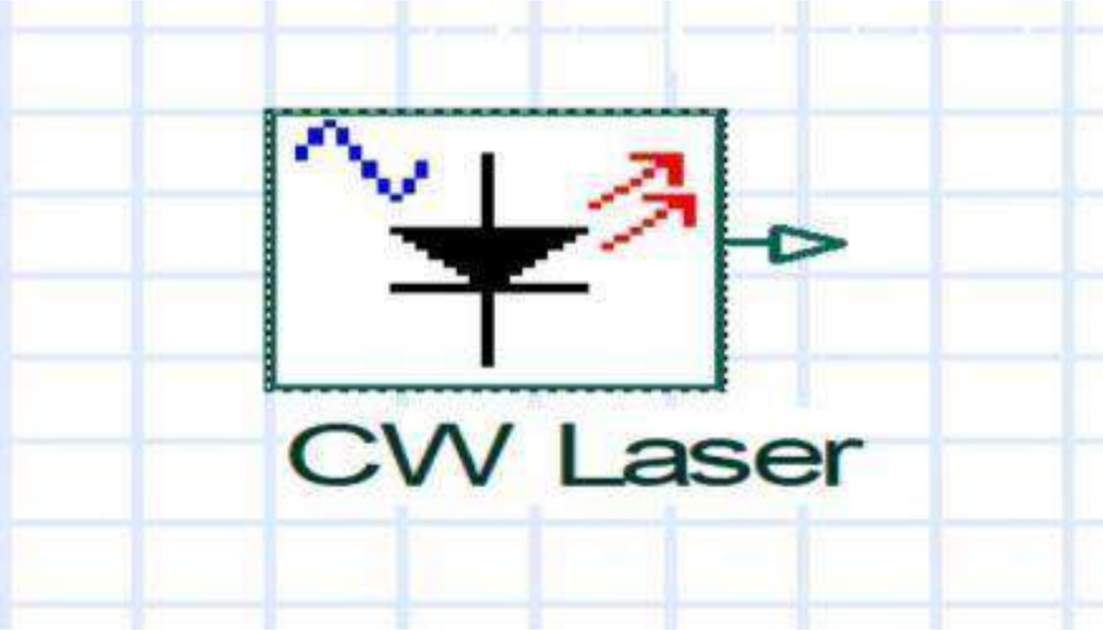


Figure 3.1 Optsystem integrated CW Laser

While pulsed transport operation is straightforward, continuous-wave operation can be difficult to achieve for numerous lasers in low-gain laser transitions. Sometimes, only fiber lasers can be used for continuous wave operation because of their much higher gain efficiency than bulk lasers. Certain purportedly self-terminating laser shifts are not suitable for continuous-wave operation. A continuous-wave laser's output power is roughly constant over longer time intervals, but it may fluctuate significantly due to various laser noise sources and beating mode (in the event that single-frequency functioning is not achieved).

3.3 PRBS Generator

The word PRBS stands as Pseudo-Random Binary Sequence, which is an unpredictable binary sequence, produced by an established algorithm, and exhibits statistical behavior similar to that of a truly random sequence. PBS is applied in cryptography, simulation, time-of-flight spectroscopy, and comparison methods, in addition to telecommunications. A digital circuit known as a PRBS (Pseudo-Random Binary Sequence) generator generates the sequence of binary digits that are deterministic yet meant as if it were a randomized order. This same produced sequence was designed to appear completely arbitrary, devoid of any obvious or readily anticipated pattern.

The sequence's extraordinarily extended duration size, because of this, it challenging in order to spot a certain phenomenon, contributes to its randomness. A PRBS generator's versatility makes it useful for many applications. in optical communication systems. For instance, they are widely employed in both the lab and the field in order to verify the functionality of optical receivers. A stressful scenario over the recipient's capability to correctly record on top of decoding impending bit can be provided by the generator, which generates high-speed data packets with varying degrees of randomness. Additionally, PRBS generators are frequently used in optical communication system optimization and simulation. This entails evaluating and assessing its optical connection's in addition to relevant element's performance in the varieties of operational scenarios. To verify robustness and dependability, testing under various environmental circumstances, such as fluctuating humidity or temperature, may be necessary.

The efficiency of the optical connection can be assessed to predict the way it would react in actual operating conditions by modifying the PRBS generator's parameters and adding simulated impairments, like noise or attenuation. The creation of encryption keys is a significant additional use for PRBS power plants in optical systems for communication. Encryption keys in a safe system of communication must be genuinely random and unpredictable in order to guarantee appropriate security. Randomness and high speed of generation are achieved when using PRBS generators as the key supply for encryption keys, making them hard to crack and unpredictable.

PRBS generators are a vital component of optical communication systems since they are important for the validation of efficiency, testing, and maybe even simulation, as well as the creation of keys. As communication systems continue to progress and demand better levels of data security and quicker speeds, PRBS generators will play an increasingly significant role in optical networks. This is because PRBS generators are able to accelerate data transmissions. Using Pseudo-Random Binary Sequence (PRBS) generators in light system communications has a number of advantages, one of the most important of which is the possibility to provide a stimulant that is both controlled and repeated for the purpose of evaluating various configuration settings. The efficiency of the optical connection can be assessed to predict the way it would react in actual operating conditions by modifying the PRBS generator's parameters and adding simulated impairments, like noise or attenuation.

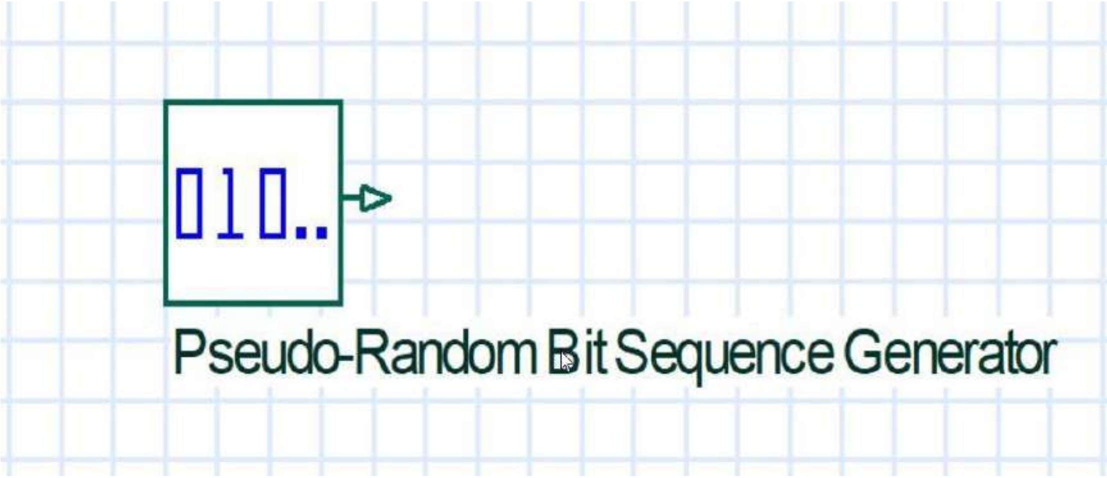


Figure 3.2 PRBS in OptiSystem

3.4 NRZ Pulse Generator

Connected electronic components that generates type of binary wave with a voltage level that stays constant in between the pulse's peak and low points & abruptly changes between them is known as a (NRZ) pulse generator. This produces a waveform with a sequence of rectangular pulses that have two different voltage levels. Applications including data transmission, digital signal processing, testing, and measurement frequently use NRZ pulse generators.

Non-Return-To-Zero (NRZ) pulse generators comprise that are essential for forming blocks among electronic means of communication in data communication applications. In order to transmit binary data via a channel of communication, they convert the data into a series of electrical pulses. The digital signal being transmitted is represented by electrical pulses, where a high voltage level denotes a "1" and a low voltage level denotes a "0." For the pulse generator, to ensure dependable and effective digital signal transmission, speed and accuracy are critical.

NRZ pulse generators are used in electronic signal processing to produce signals digitally needed for measuring and testing digital circuits which they all are able to be used to test the operation of digital networks under various conditions by simulating digital signals. NRZ pulse generators, in particular, are frequently used for testing and design of high-speed digital components, such as those found in computer processors & networks for rapid data transmission. Depending on the requirements of a particular application, the properties of the NRZ pulse engine, like its modulation frequency, amplitude, and pulse length, can be altered to meet those requirements.

Pulse generators utilized in signal processing applications might need more exact regulation of the pulse duration and amplitude, whereas those deployed in systems for high-speed data transmission might have to run greater frequencies to handle data rates that are faster. An essential part of many digital systems is NRZ pulse generators. They are a vital tool in contemporary technology because of their capacity to produce exact electrical pulses, which is crucial for digital signal processing, testing, and communication applications.

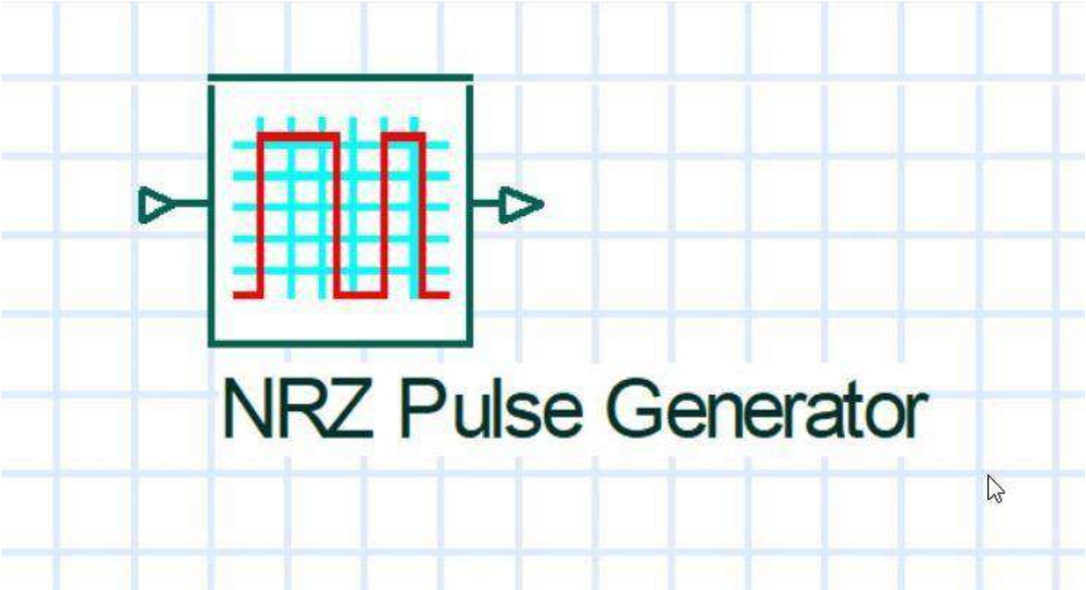


Figure 3.3 (Non-Return-To-Zero) NRZ Pulse Generator in OptiSystem

3.5 MZ Modulator

Analytical models could be used to simulate the performance of Mach-Zehnder modulators (MZMs) and optimize the way they work in an OptiSystem. MZMs are important components of optical communication systems. A software program called OptiSystem is used to simulate, analyze, and model optical communication networks. As soon as the two arms are recombined, this amplitude modulation is created from of the phase difference of the two waves.

Various techniques, including the matrix method, modified transfer matrix method, and transfer function theory, can be employed to develop analytical representations of MZMs in OptiSystem. It is possible to modify the properties of the NRZ pulse generator, such as its frequency, amplitude, and pulse length, in order to fulfill the needs of a specific application. Depending on the needs of the application, certain alterations could be done in compliance with those criteria.

MZM parameters in OptiSystem, such as length as well as switching voltage, can be changed in order to optimize the modulator's efficiency in accordance with the particular needs of the communication network. The impact of various controlling parameters, such as phase shift and insertion loss, on the device's performance can also be examined using the simulation. By using the mathematical representations of MZMs in OptiSystem, one can gain knowledge about the relationship between input and output signals and optimize devices in communication systems. Using this method also makes it possible to experiment with various design parameters in order to maximize the optical communication system's overall performance.

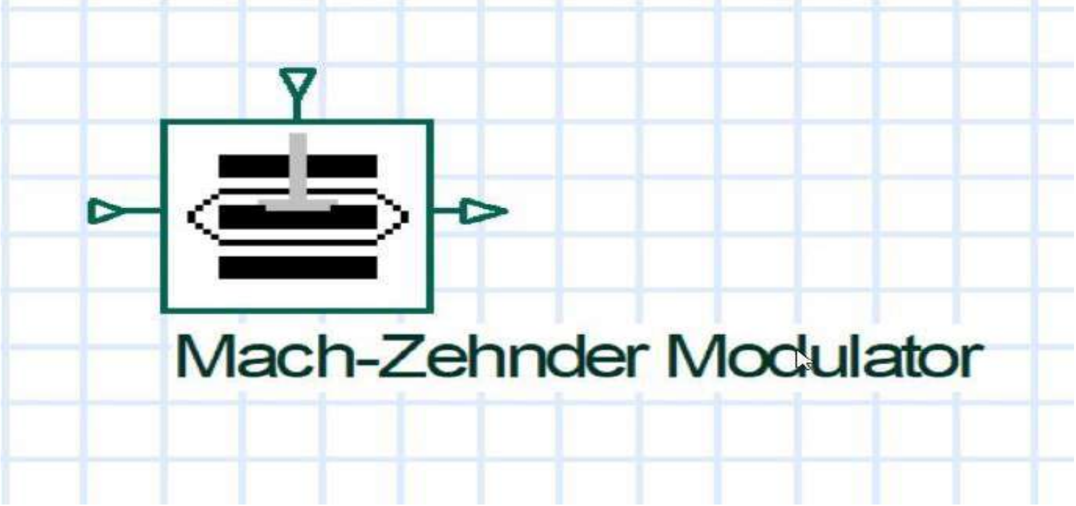


Figure 3.4 MZ Modulator in OptiSystem

3.6 WDM (Wavelength Division Multiplexing) MUX

In optical networks, this device is used to integrate signals of different wavelengths onto a single cable which is called an optical wavelength division multiplexing (WDM) MUX. WDM MUX device design, optimization, and performance assessment under various operating conditions can all be done with simulations in OptiSystem. A series of filters and couplers are used by the WDM (Wavelength Division Multiplexing) MUX in the OptiSystem to combine numerous light impulses of different wavelength scales. Different wavelengths can be combined on a single fiber thanks to the filters' ability to reflect those wavelengths. With OptiSystem, various filter classes and coupling schemes can be used to model various WDM MUX configurations. WDM MUX device performance, including bandwidth, absorption loss, and crosstalk, can be assessed using simulations in OptiSystem. Simulation tools can also be used to analyze the effects of many design variables, things like channel spacing, bandwidth, & filter type. Not only can WDM MUX equipment performance be analyzed using OptiSystem simulations but also to assess the general efficiency of WDM communication systems.

WDM MUX device design and optimization, as well as WDM communications network efficacy assessment, are made easier with the help of OptiSystem simulations. Using simulation tools, designers can determine how different design parameters impact a system's performance and optimize it for particular requirements and operating conditions. In order to support a variety of uses, including data storage facilities, communications, and supercomputers, this helps to maintain the stable and efficient functionality of wireless networks. Figure 3. 9 in a WDM system displays a figure of a WDM mux.

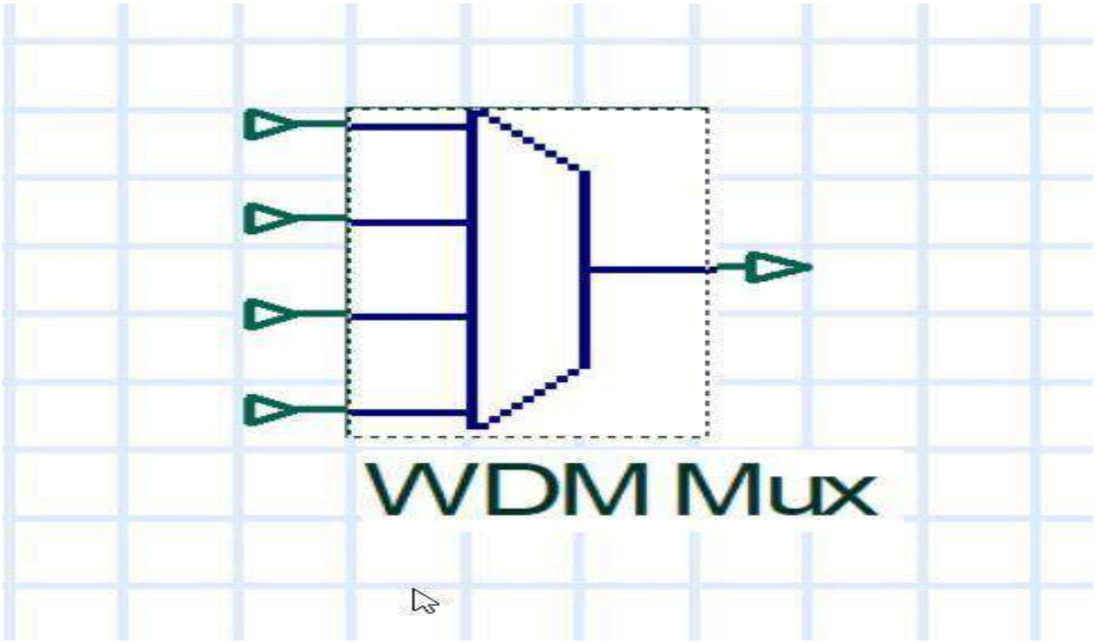


Figure 3.5 WDM (Wavelength Division Multiplexing) MUX in Optisystem

3.7 DWDM-DWMUX

For optical communications, a DWDM-DEMUX is a piece of equipment that divides multiple optical signals transmitted over a single fiber into various wavelengths of light. Simulations in OptiSystem are useful to develop and optimize DEMUX systems, as well as assess how well they perform in various operating environments. Utilizing an array of filters and connectors, the DEMUX of OptiSystem divides optical signals of various wavelengths. The filters are placed in series and send multiple signals with various wavelengths over a single optical fiber. To be more specific, they let a certain wavelength to pass through them successfully.

DEMUX device performance can be assessed through simulations in OptiSystem. Analyzing the bandwidth, absorption loss, and crosstalk is part of this. It also entails investigating how various design elements, like channel spacing, bandwidth, and filter type, affect the device's functionality. To enhance the overall performance of DWDM systems for communication, OptiSystem also offers instruments for assessing the influence of various system parameters. This may entail examining the effects of noise, dispersion, and attenuation on optical signals.

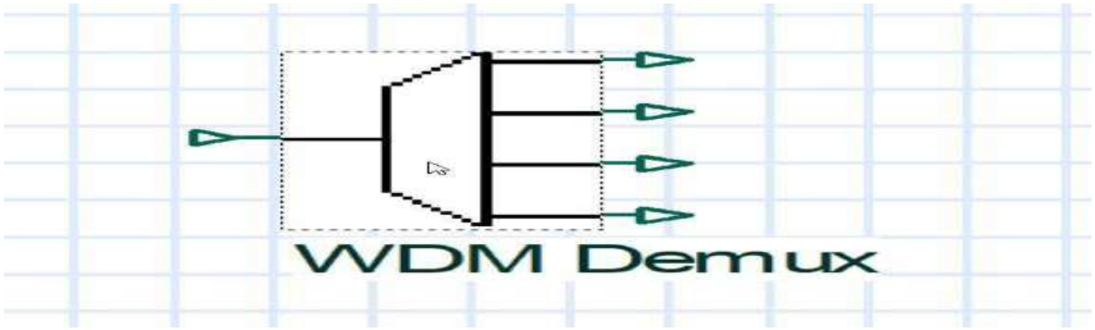


Figure 3.6 DWDM Demux in Optisystem

3.8 FSO

Using laser or infrared beams, FSO communication entails sending data over open spaces. When rapid connectivity is needed or telephone lines are impractical, they are often used for points-to-point transmission.

Figure 3.7 FSO Channel

3.9 3R Regenerator

In optical communications, a 3R regenerator is a crucial part that restores optical signals to their initial state prior to long-distance transmission. Models in OptiSystem are able to analyze 3R regenerators and assess how well they perform in various operating scenarios. A transmission device that sends the signal at the initial level and a receiver that receives the optical signal are the usual components of a 3R regenerator.

The data signal is reshaped to its original quality by the receiver, which also regenerates the time signal and extracts the data indicated from the optical signal. That resynchronized signal is then transmitted again by the transmitter. The operation of the 3R regenerator, including its effects on jitter, battery life, latency, or the signal-to-noise ratio (SNR), is able to be modeled in OptiSystem through simulations. The efficacy of various regenerator designs and variations, based on the number of types or kinds of amplifiers utilized, may also be assessed using the simulation.

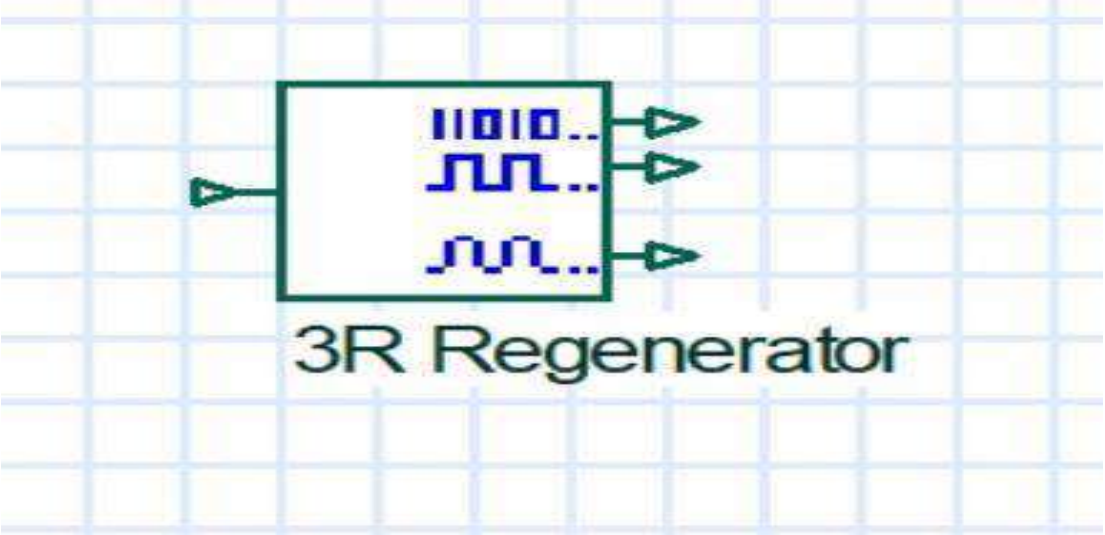


Figure 3.8 3R Regenerator

3.10 PIN Photodiode

Among the various types of detectors, the PIN photodiode is one that is employed relatively commonly. For the goal of detecting light signals that occur along optical channels, this specific detector is one which is employed. There are several significant characteristics of this detector, but one of the most notable is its ability to detect light signals. More information on this detector's primary function, which is the detection of light signals, will be provided in the following paragraphs. The simulation software that is supplied with OptiSystem may be used to model the activity of the PIN photodiode, which is something that can be done. Through the utilization of this software, it is possible to modify the performance of the PIN photodiode for certain applications, which is an additional benefit. The architecture of the PIN photodiode that is employed by OptiSystem provides a description of the responsiveness of the device. This description is helpful in understanding the device's capabilities. In addition, the dark current and quantum efficiency of the device are included in this description. To ensure that you have a comprehensive grasp of the apparatus, it is imperative that you be familiar with the material that is presented here. There are many different approaches that may be utilized in order to assess the performance of the photodiode. One of these approaches is the simulation of a broad variety of features. Changes in the input optical power, wavelength, and polarization are all examples of these features. It is also possible to do an investigation into the functional capabilities that the photodiode possesses, which is something that can be done.

In addition, the OptiSystem provides a broad variety of analytical tools that can be applied to assist in the evaluation of the performance of the PIN photodiode as well as the optimization of its design. These tools may be utilized to help in both of these areas. In either of these two procedures, these instruments might be deployed to provide assistance. The optimization of the design is something that can be accomplished with the aid of these technologies, which may be utilized. The objective of these devices is to evaluate the signal-to-noise ratio (SNR) of the detector, investigate the frequency response of the photodiode, and establish an estimate of the extent to which the functioning of the device is influenced by variations in temperature. It is necessary to make use of particular gadgets in order to achieve the goal of information collection. Furthermore, the simulation tools that are made accessible by OptiSystem may be utilized to study the ways in which the performance of the photodiode is influenced by a range of design elements. This is something that can be performed by making use of the tools that are available to the user. This purpose may be done in a number of ways, one of which is by conducting an investigation of the processes that are employed in the design of the photodiode. This is something that can be accomplished in a number of different ways, one of which is by taking use of the simulation capabilities that OptiSystem provides. It is possible to make modifications to the active area, thickness, and loading concentration of the photodiode in order to enhance the responsiveness, bandwidth, and other critical elements of the device.

These modifications may be made. It is possible to make these modifications. There is the possibility of carrying out these modifications. Implementation of modifications of this type is not completely out of the question. The deployment of these enhancements is a different possibility that should be taken into account.

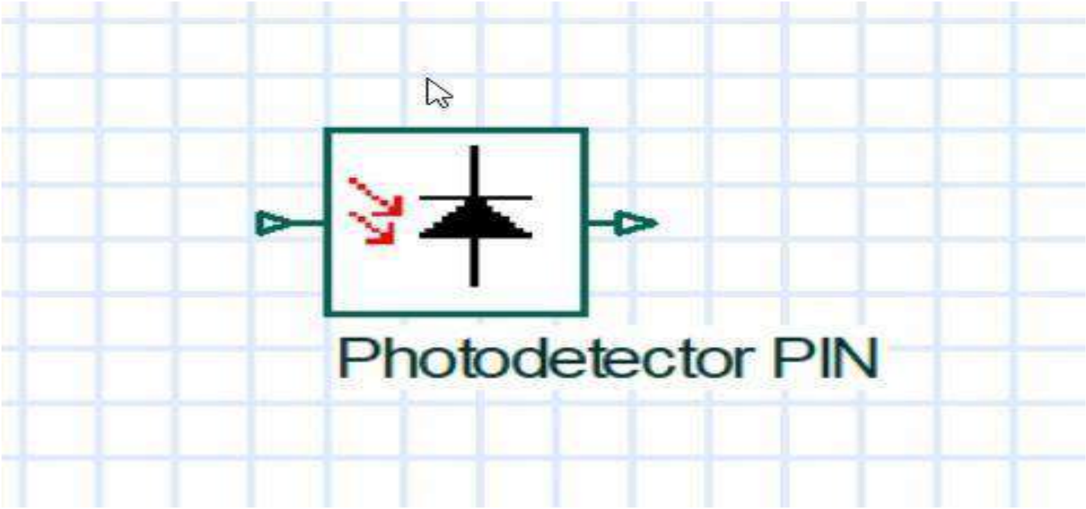


Figure 3.9 PIN Photodiode in OptiSystem

3.11 Bit Error Rate (BER) ANALYZER

The performance of optical network communication systems may be assessed using a BER analyzer. OptiSystem uses a BER analyzer to compare received and transmitted data error rates to evaluate optical communication networks.

An identifiable bit sequence is created at the transmitter and compared to the receiver's bit sequence by the OptiSystem BER analyzer to calculate bit error rate. The analyzer can measure bit error rate (BER) for ASK, FSK, PSK, and QAM modulation formats and encoding methods including interleaving and FEC.

In the end, the BER analyzer helps maintain reliable and effective communication networks for high-speed computers, data centres, and telecommunications.

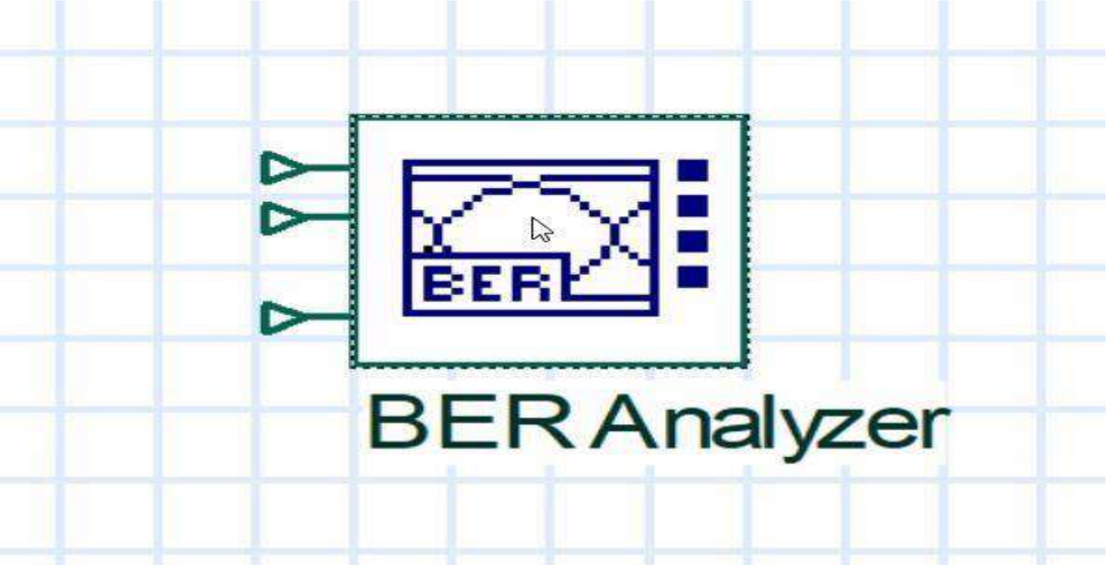


Figure 3.10 BER Analyzer in Optisystem

3.12 Proposed System in Optisystem using 4 Channel

This is the optisystem Fig. 3.11 simulation section for the 4-channel DWDM-FSO system, which is the earlier model in this sector that used a pseudo-random bit sequence generator with a bit rate of 10 GBits/s for the model's design. Following that is the NRZ Pulse Generator, which is connected to the MZ Modulator Analytical, and, lastly, the CW Laser at frequencies of193.1 THz .

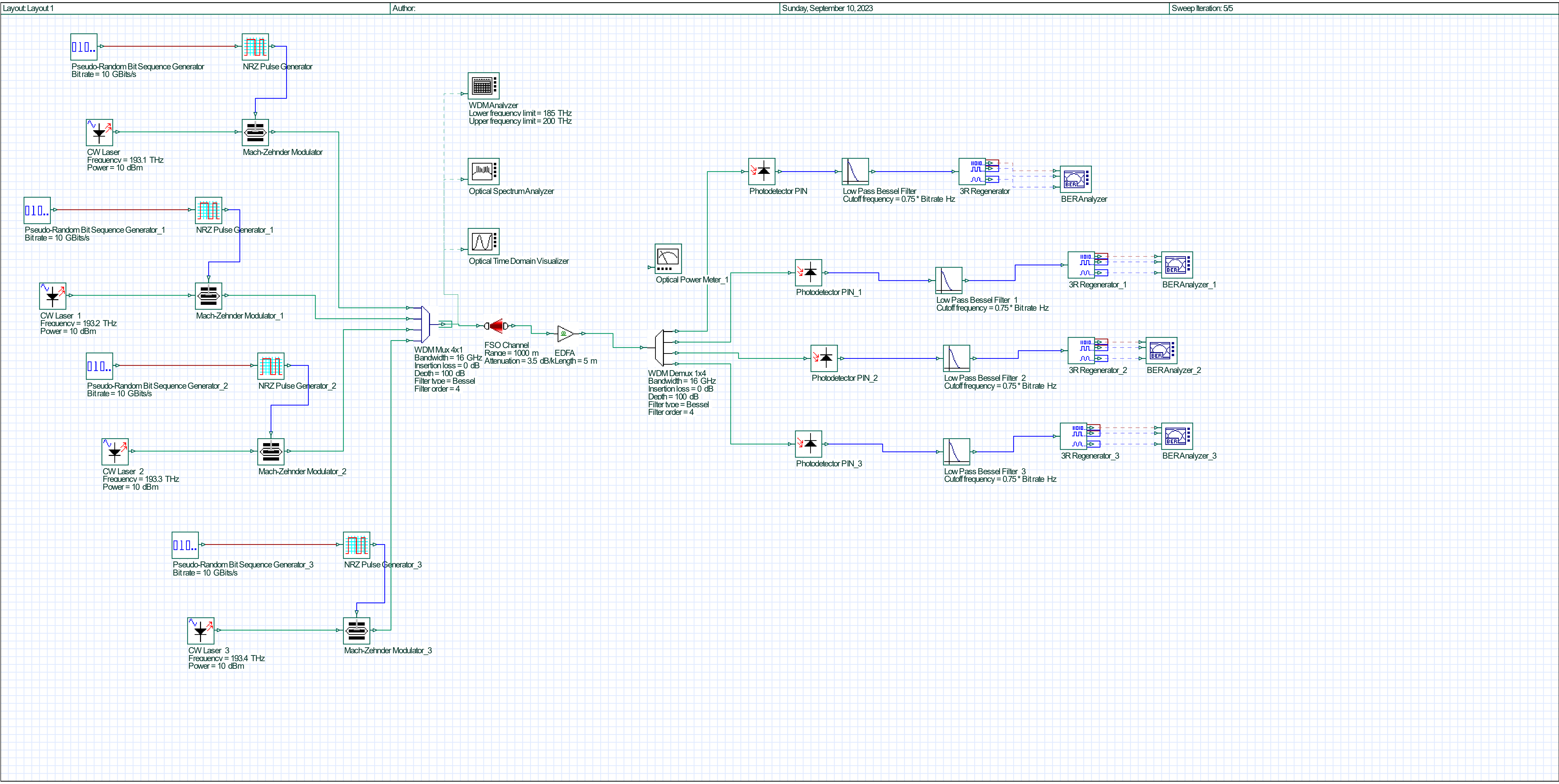


Figure 3.11 4 channel DWDM-FSO system Using Optisystem

3.13 Proposed System in Optisystem using 8 Channel

This is the optisystem Fig. 3.12 simulation section for the 8-channel DWDM-FSO system, which is the earlier model in this sector that used a pseudo-random bit sequence generator with a bit rate of 10GBits/s for the model's design. Following that is the NRZ Pulse Generator, which is connected to the MZ Modulator Analytical, and, lastly, the CW Laser at frequencies of193.1 THz .

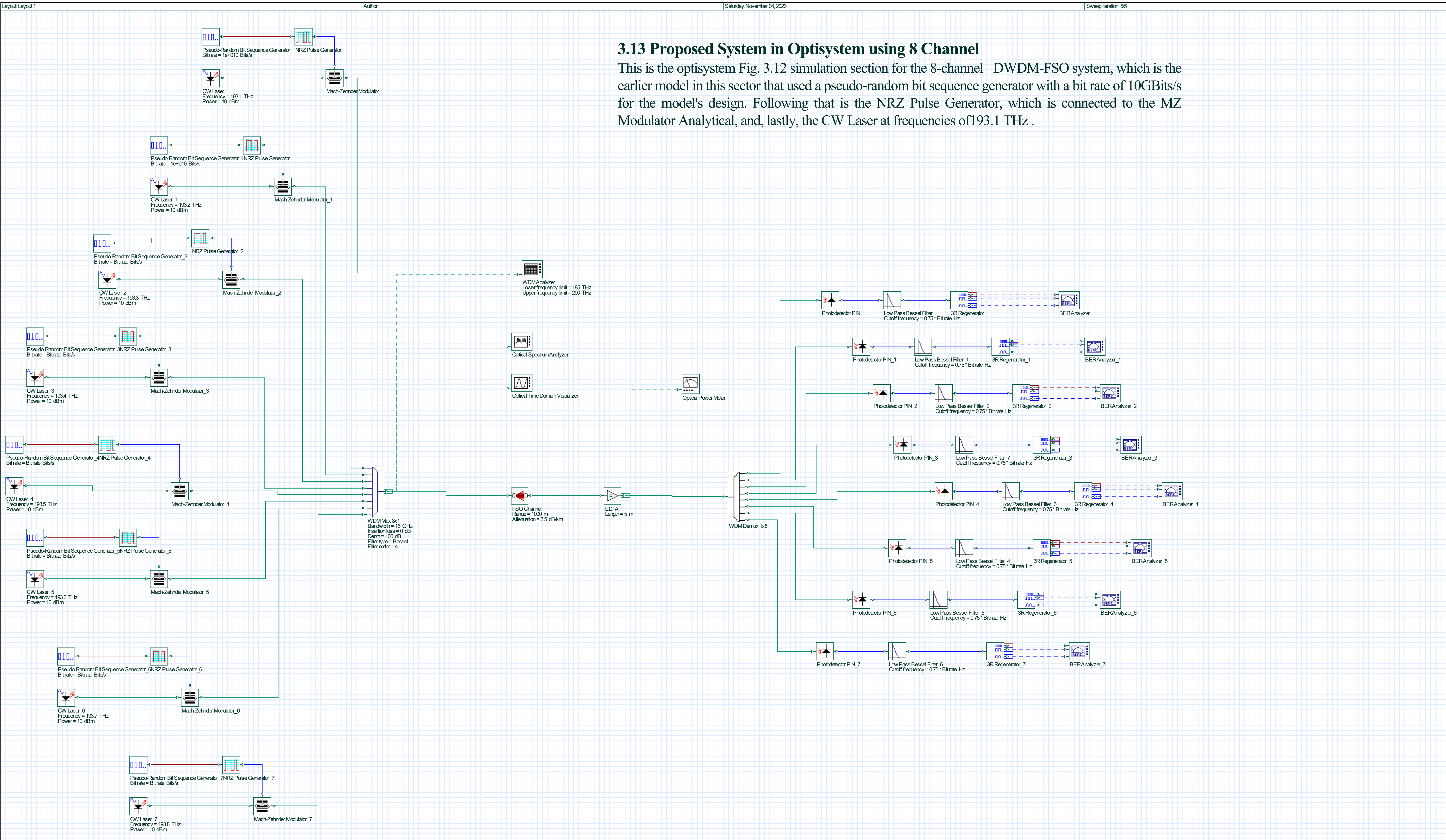


Figure 3.12 8-channel DWDM-FSO system Using Optisystem

3.14 Proposed System in Optisystem using 16 Channel

This is the optisystem Fig. 3.13 simulation section for the 16-channel DWDM-FSO system, which is the earlier model in this sector that used a pseudo-random bit sequence generator with a bit rate of 10GBits/s for the model's design. Following that is the NRZ Pulse Generator, which is connected to the MZ Modulator Analytical, and, lastly, the CW Laser at frequencies of193.1 THz .

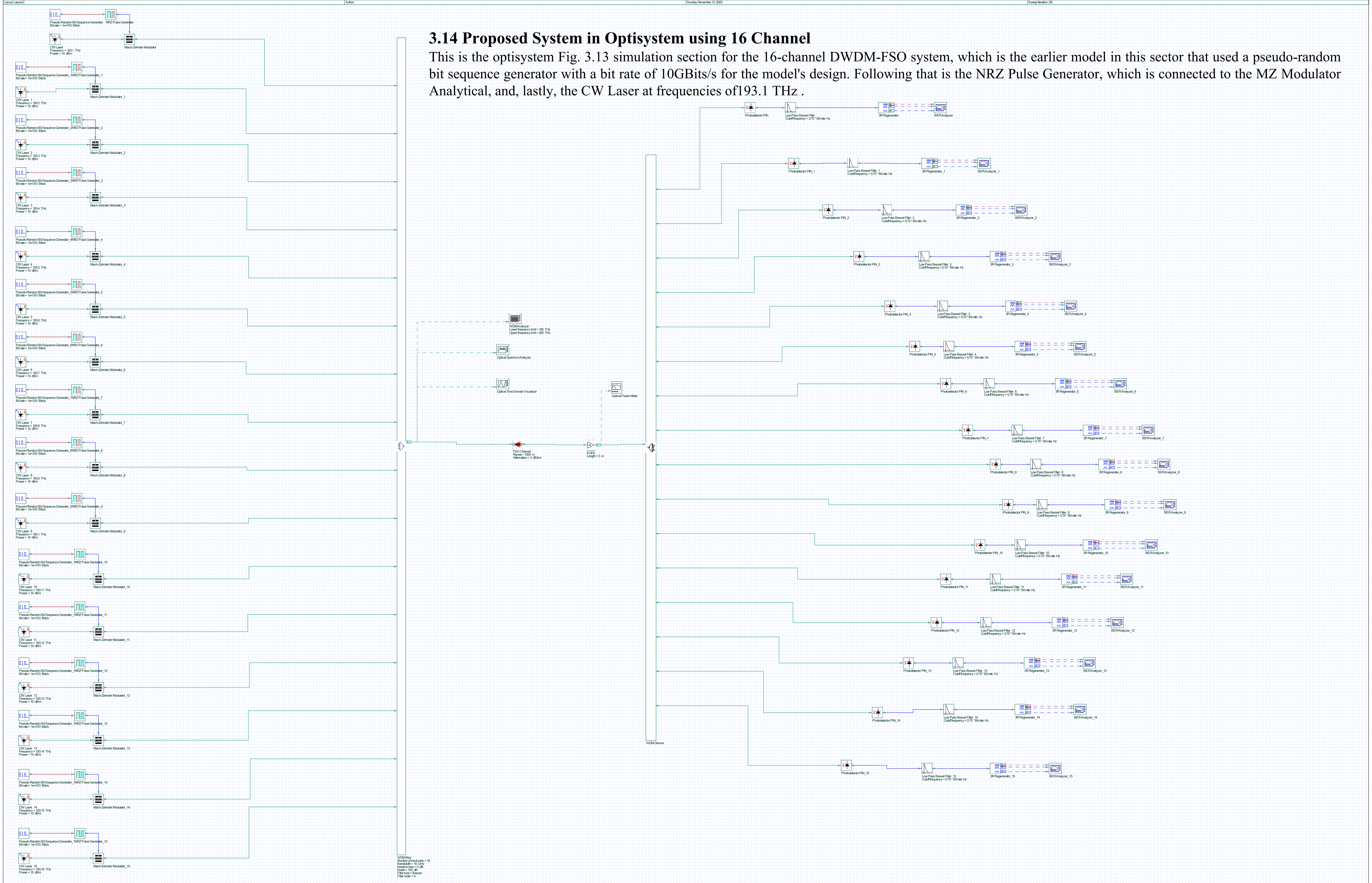


Figure 3.13 16-channel DWDM-FSO system Using Optisystem

CHAPTER 4

RESULT ANALYSIS

4.1 Analyzing the operation of the system via several channels

Identifying the channels that now the process creates through, defining metrics, putting up monitoring, collecting data, benchmarked across channels, locating obstacles and efficiency improvements, and prioritizing improvements are all part of analyzing system performance using various communication channels. Through the examination of performance data from every channel, trends and differences can be did find, enabling focused adjustments to boost the system's potency, efficiency, and user experience. In order to maximize system performance and assures that influence product are met or beyond across all channels, this analysis enable users in making well-informed judgements.

Authors use the BER tester upon its terminal voltage portion including the design to examine 4, 8, and 16-channel DWDM-FSO optical communication in the systems theorists. For a decent design, the BER output should be low and the Q factor should be high

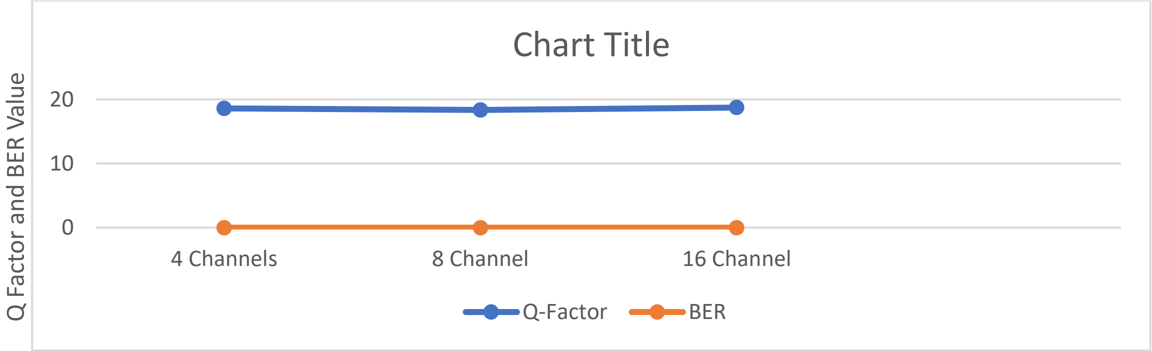


Figure 4.1 Q-Factor and BER comparisons across different channels to determine system performance

Here, Start figuring 4. 1 displays the Q factor and BER calculated values for the 3 separate channels.

In DWDM-FSO interaction, the Q factor and Bit Error Rate (BER) can be calculated by monitoring the gotten optical power, calculating the Q factor with the received power and noise parameters, comparing the received and transmitted data to determine the BER, analyzing the results, finding quality issues, optimizing the scheme, and constantly measuring and evaluating the system. Through this study, enterprises are able to assess the reliability and correctness of the transmitted signals, which in turn helps them enhance system performance and guarantee data transfer in DWDM-FSO communication. In order to perform Q factor analysis in DWDM-FSO OptiSystem, one must first create a DWDM-FSO system within the program, configure its parameters, generate optical signals with desired properties, send them through the system, and then decode them to determine the Q factor. Issues including signal-to-noise ratio, receiver sensitivity, and signal-to-power ratio are taken into account while determining the Q factor. User insights into DWDM-FSO signal performance and quality can be obtained using OptiSystem's Q factor analysis, which in turn allows for parameterization and entire system improvement.

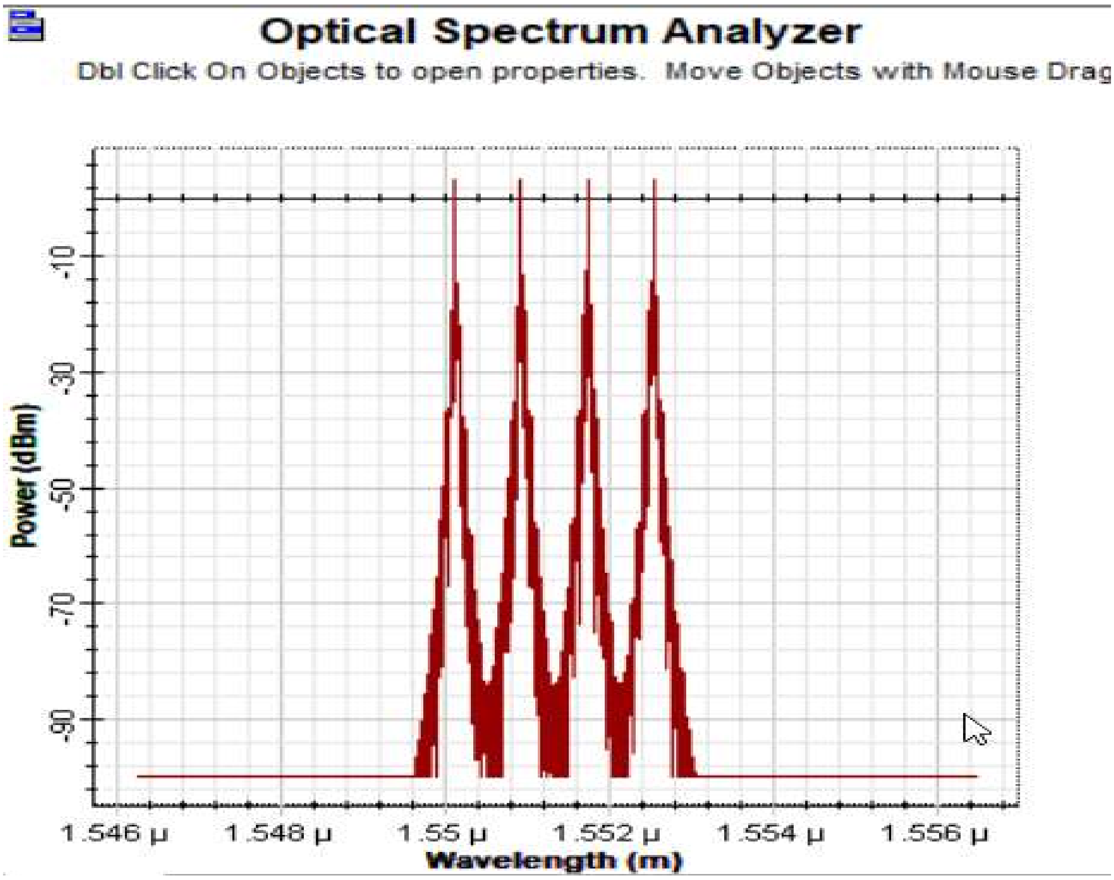


Figure 4.2 Spectrum analyzer with Four-Channel

Its results of the receiver section for the 4-channel optisystem are presented in Figure 4.2. In order to learn more about the 4-channel DWDM-FSO network power allocation and modulation scheme, it is feasible to use an optical spectrum analyzer set to 193.1 THz to examine the optical spectrum. Signal deterioration can be attributed to fractional differential equations like four-wave blending or inter modulation; the OSA can provide light on their presence. Optimizing system characteristics and ensuring higher level of security can be done to assess its consequences.

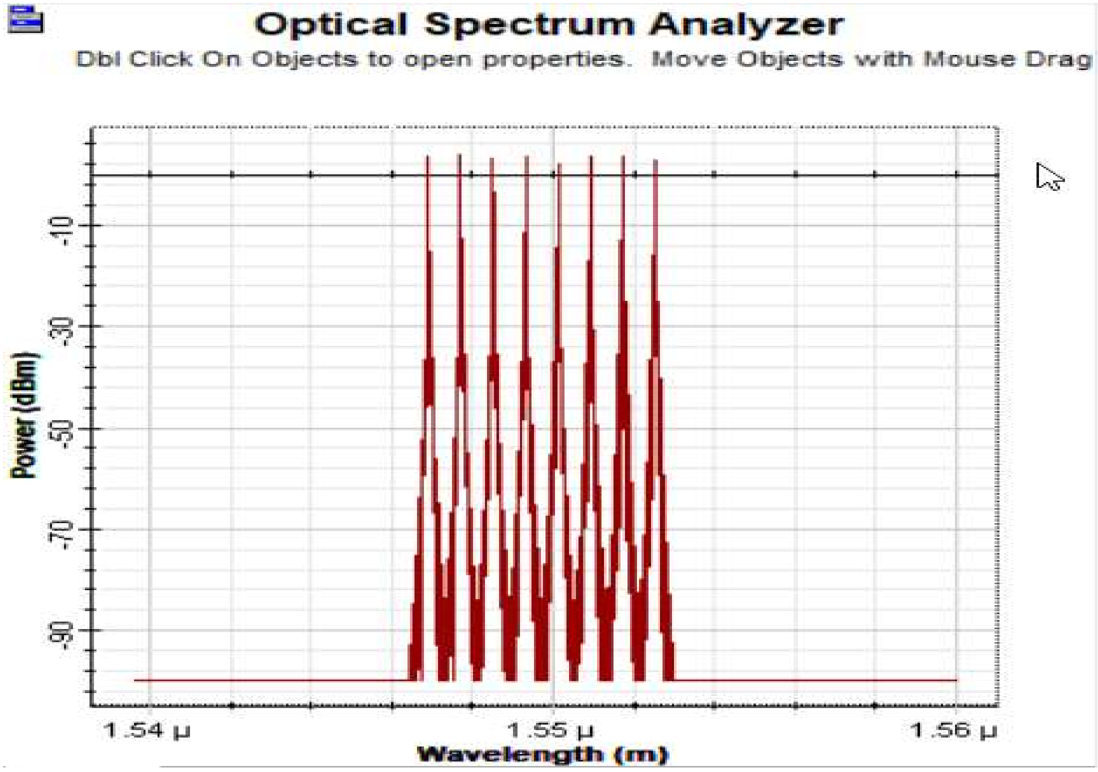


Figure 4.3 Spectrum analyzer over 8 channel

In figure 4.4, the OSA diagram that corresponds to the sixteen DWDM-FSO optical channels of communication is displayed for your perusal. Using the same Spectrum Analyzer (OSA), it was proved that all sixteen channels of the DWDM-FSO system had constant power levels. This was evidence that the signal transmission was dependable. The study was carried out using a frequency of 193.1 THz throughout the operation and a distance of ten kilometres for the fibre optic connection. As a consequence of the precise route loss, there was a minimal amount of disruption brought about by units that were situated in close proximity to one another. The good signal-to-noise ratio (SNR) gave evidence of clarity that was not only risk-free but also of a high quality. When it came to the communication with resonance, it was determined that there were no problems that occurred. Due to the fact that it made the most effective use of the photons that were hit upon it, that platform was able to make full use of the frequency potential that it possessed. Taking into consideration the fact that the optical fibre was ten kilometres in length, it was also concluded that the consequences of scattering were acceptable with regard to the situation. In accordance with the findings of the OSA study, the 16-channel DWDM-FSO system demonstrated remarkable performance when operating at 193.1 THz with the 10km optical fibre. Since this is the case, optical communication is guaranteed to be both speedy and dependable.

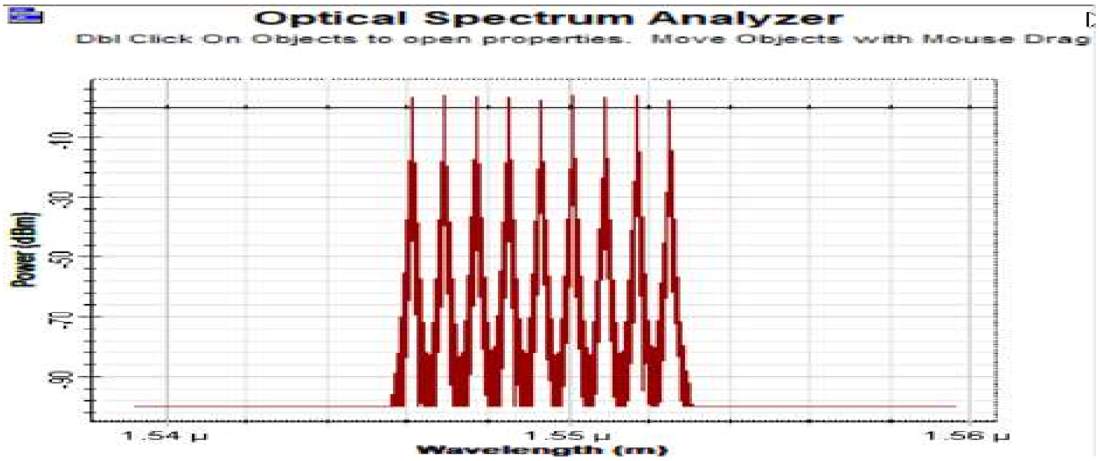


Figure 4.4 Spectrum analyzer over 16 channels

For the sixteen DWDM-FSO optical channels of communication, the OSA figure is displayed in Figure 4.4. With a 10 kilometer fiber optic distance as well as an operation frequency of 193.1 THz, this same Spectrum Analyzer (OSA) showed that all 16 channels of the DWDM-FSO system had constant power levels, suggesting that the signal transmission was robust. There was very little disruption from neighboring units because of the exact path loss. Safe and good quality clarity was shown by the favorable SNR. Communication was confirmed to be free of disturbance with resonance. By making optimal use of the incident photons, that platform was able to totally use its frequency potency. Also, those scatter implications found manageable given that 10-kilometer length of optical fiber. The 16-channel DWDM-FSO system ran well with the 10km optical fiber at 193.1 THz, according to the OSA study, which guarantees rapid and dependable optical communication.

4.2 Q Factor Analysis

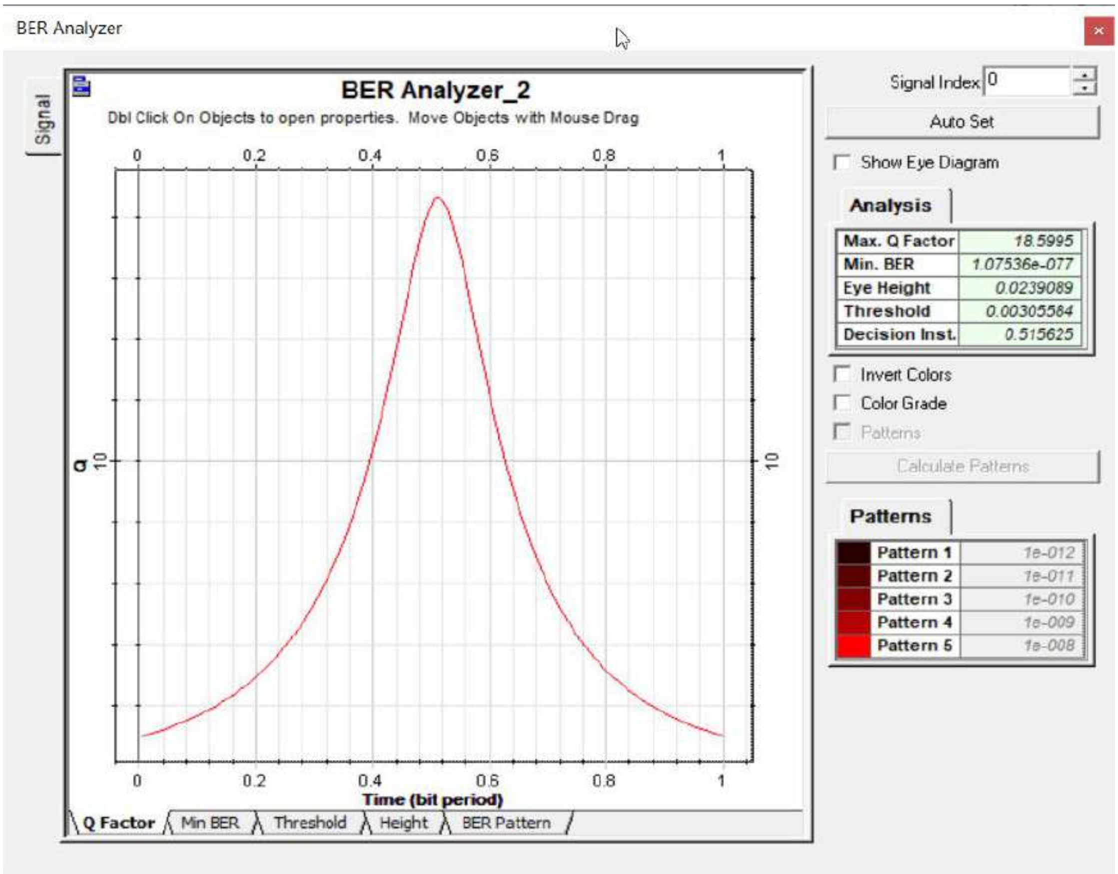
As a consequence, we can learn a vast portion and efficiency of 4, 8, and 16-channel DWDM-FSO optical communication architectures from of the reviews of the Q factors, BER, and OSA analyses.

Increasing the number of channels results in a higher Q factor, according to the Q factor study. Signals strength and errors risk during transmitting data are both improved with a larger Q factor. Thus, as best signal fidelity is shown by the maximum Q factor, which is displayed by the 16-channel DWDM-FSO architecture.

According to the BER research, the BER drops as the count of channel increment. This means that data dependability has increased and errors efficiency has been enhanced. Amongst some of the systems, the 16-channel DWDM-FSO network has the most robust data transmission with the least BER.

Another piece of evidence supporting the functionality comes from the Optical Spectrum Analyzer study. For every design, the OSA reveals stable power levels, accurate channel spacing, and good SNR. There is very little interference and crosstalk, thus the data transfer is clean and dependable. Sustainable optical networking is supported by the spectral signatures, which show optimal process usage with least frequency variation.

Better compared signal quality, reliable data transfer, and especially suited use are shown by the maximum Q factor, minimal BER, and good spectrum effectiveness of the 16-channel DWDM-FSO architecture. On the other hand, applications requiring fewer channels will find the 4-and 8-channel systems to be enough.



Signal Index 0

☐ Show Eye Diagram

Max. Q Factor	18.5995
Min. BER	1.07536e-077
Eye Height	0.0239089
Threshold	0.00305584
Decision Inst.	0.515625

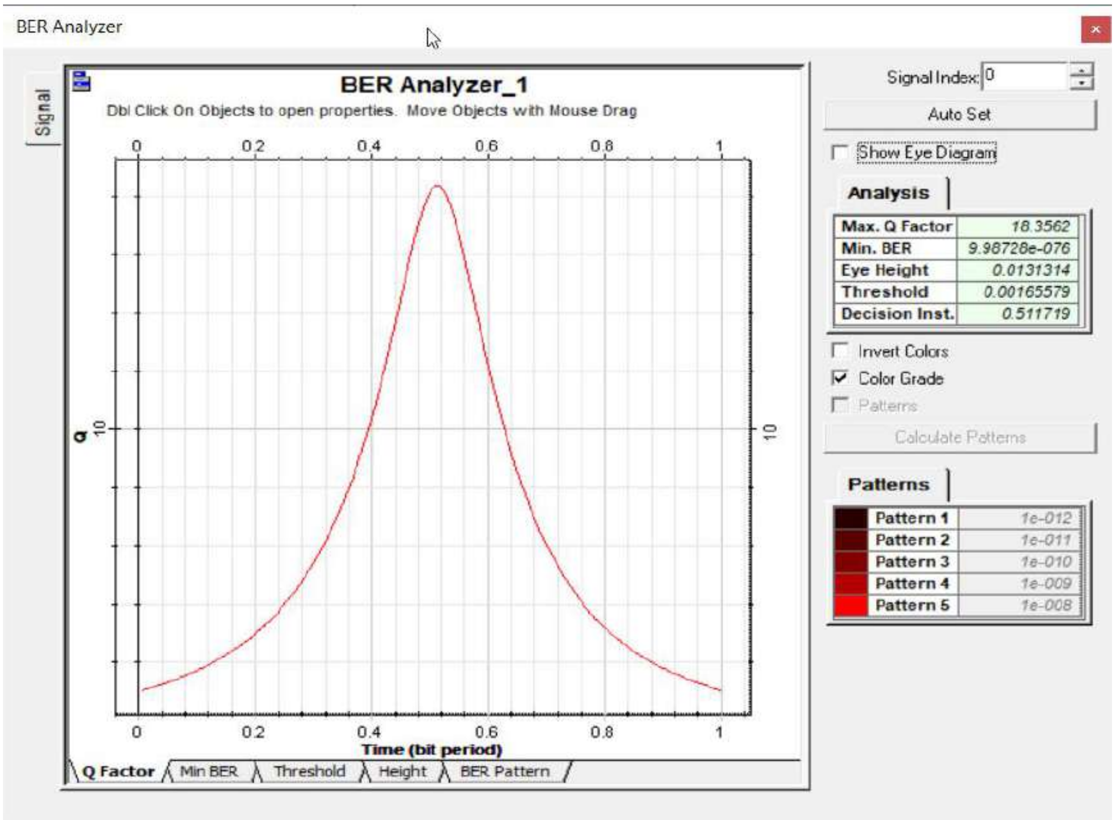
☐ Invert Colors
☐ Color Grade
☐ Patterns

■	Pattern 1	1e-012
■	Pattern 2	1e-011
■	Pattern 3	1e-010
■	Pattern 4	1e-009
🟥	Pattern 5	1e-008

Figure 4.5 The Q-Factor for Four Channels

Figure above shows the Q factor for the 4-channel DWDM-FSO in optisystem.

By comparing the Q factors of the three methods, we can see how they interact with one another.



Signal Index: 0

☐ Show Eye Diagram

Analysis

Max. Q Factor	18.3562
Min. BER	9.98728e-076
Eye Height	0.0131314
Threshold	0.00165579
Decision Inst.	0.511719

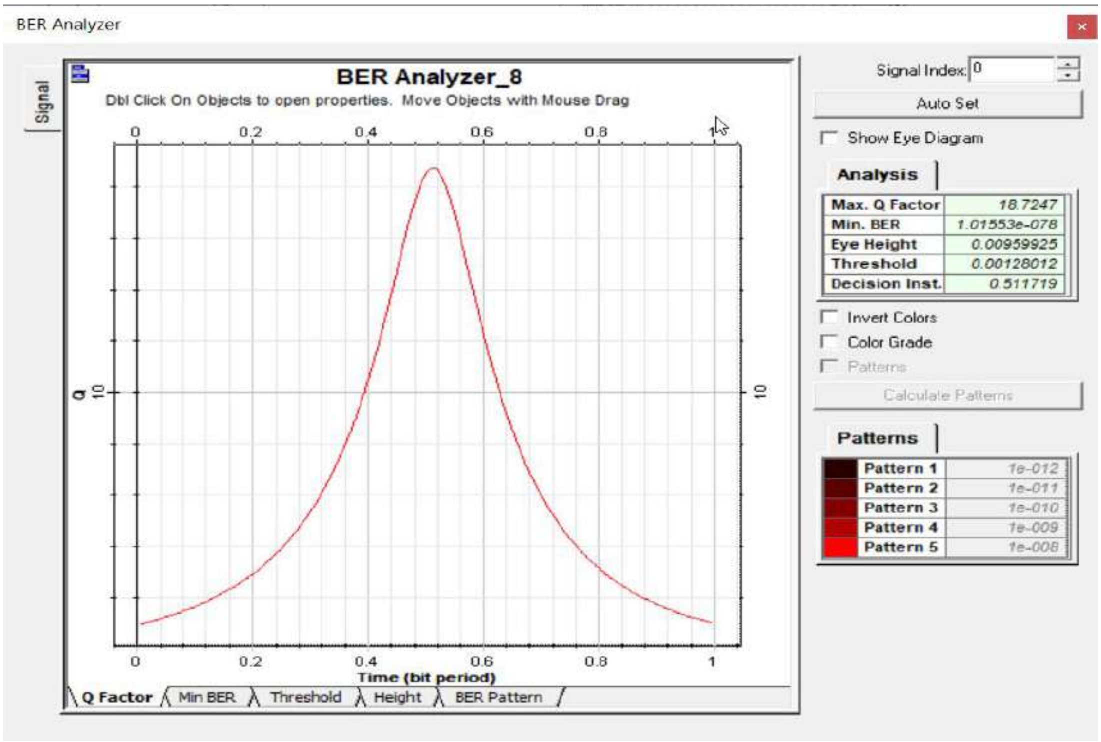
☐ Invert Colors
☑ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Figure 4.6 The Q-Factor for Eight Channels

To determine estimated Q factor across an 8-channel DWDM-FSO (Dense Wavelength Division Multiplexing) network, one must first configure the network also with parameters that are required for every channels, then send messages throughout the framework and assess their strength. It is possible to determine the Q factor to every network by taking into account parameters like received signal strength, SNR, and network limitations like dispersion and attenuation coefficient. Insights into the 8-channel DWDM-FSO project's speed and reliability are provided only by study, which helps protocols and procedures and ensure secure and economical propagation over spectral lines. The platform's demands, this same infrastructure's capabilities, and the requirements for future scalability determine whether 4, 8, or 16 channels are used in DWDM-FSO communication systems. For smaller networks with less demanding bandwidth needs, a 4-channel system is more economical, while medium-sized networks benefit from the improved capacity and flexibility of an 8-channel system. Networks on a grand scale necessitating substantial bandwidth might benefit from a 16-channel system's increased capacity and scalability. Considerations like budget, complexity of the network, bandwidth requirements (both present and future), and available resources should all go into the decision-making process.



Signal Index: 0

☐ Show Eye Diagram

Analysis

Max. Q Factor	18.7247
Min. BER	1.01553e-078
Eye Height	0.00959925
Threshold	0.00128012
Decision Inst.	0.511719

☐ Invert Colors

☐ Color Grade

☐ Patterns

Patterns

■	Pattern 1	1e-012
■	Pattern 2	1e-011
■	Pattern 3	1e-010
■	Pattern 4	1e-009
■	Pattern 5	1e-008

Figure 4.7 The Q-Factor for Sixteen Channels

In Figure 4.7, we can see the intended 16-channel DWDM-FSO in Opti system with its throughput Q factor. As part of a Q factor study, the signals integrity of any one of the sixteen channels in a dense wavelength division multiplexing system is taken into consideration. Source credibility, SNR, limitations (such as scatter and attenuation coefficient), and other evaluation criteria are all considered by the Q factor. Starting with setting the network with each channel's unique frequency, data rate, signal processing scheme, operating frequency, and propagation correction is the first step in doing Q correlation matrix for a 16-channel DWDM-FSO network.

After that, you need to address obstacles facing similar fibers dispersal and attenuation coefficient when you transmit the transmitted signal throughout the network, keeping in mind couplings across the channel. By doing so, we guarantee that the DWDM-FSO network's transmitted signal is comprehensively simulated. Examine the incoming data on every channels thereafter. Determine the SNR (signal-to-noise ratio) by measuring the transmitted signal while taking into account the network properties and deficiencies. Determine the Q factor for every channel by combining the power level with the SNR (signal-to-noise ratio). In most cases, the Q factor is found by dividing the averaged transmit power by the root-mean-square noise level, which is represented by the equation Q = 20log10(Avg. received power / RMS noise). By carrying out that whole assessment for every channel, possible problems may be identified and the efficiency of every channel can be assessed. It may be necessary to optimize and troubleshoot networks with low Q factors if they show signs of poor signal efficiency and increased errors. By analyzing the data, we can fine-tune the DWDM-FSO system's settings, boost the signal's strength, and guarantee effective and dependable communications over all sixteen channel.

TABLE III. CALCULATIONS OF THE Q FACTOR FOR VARIOUS CHANNEL

Number of Channels	**Q-Factor (dB)**
4	18.6157 dB
8	18.3562 dB
16	18.7247 dB

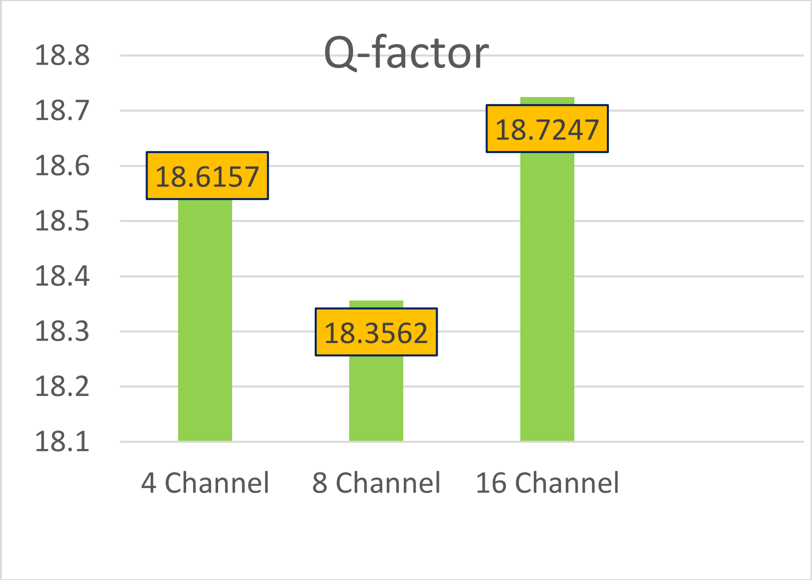
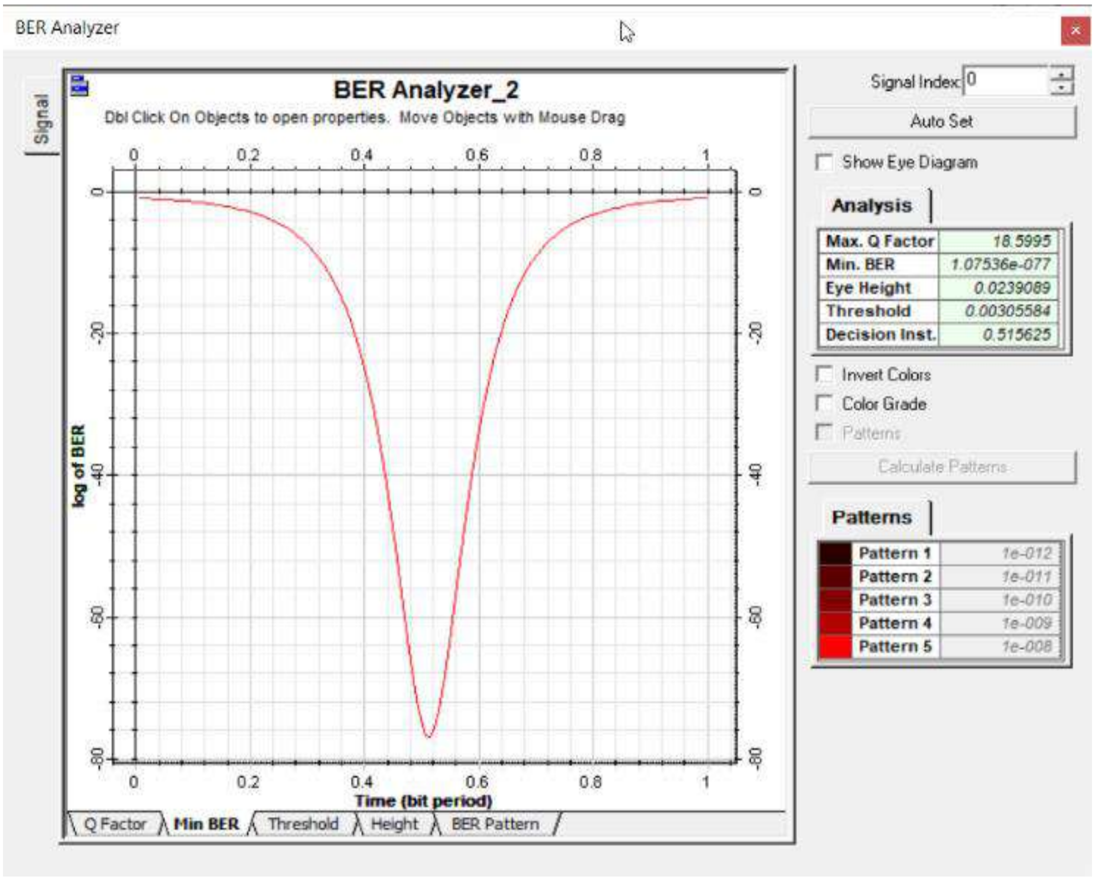


Figure 4.8 Quantitative assessment using 4, 8, and 16 channel shown as a bar graph

4.3 Outlining the Bit Error Rate

Individuals can see the Bit Error Rate (BER) for the 4 channels in optisystem configuration in **Figure 4.9**. A schematic representation depicting the four-channel BER result is seen in the figs. This BER is a measure of the precision and integrity of the information transferred across all the four channels in a four-channel DWDM-FSO-

FSO network. The first step is to train the algorithm according to the detailed specifications of every channel, which include its power rating, signal processing type, baud rate, and wavelengths. The data are subsequently routed across the infrastructure while taking limitations like distortion and scatter into consideration. Bit errors for each channel are detected and counted by comparing the received data with the original broadcast data. The bit error rate (BER) is determined by dividing the total number of transmitted bits by the number of bit errors. By looking at the bit error rate (BER) for every channel, we can evaluate the quality of data transmission and find the channels that are making more mistakes, so we can fix them. The 4-channel DWDM-FSO system's dependable and precise data transmission is guaranteed by this research.



Signal Index: 0

☐ Show Eye Diagram

Analysis

Max. Q Factor	18.5995
Min. BER	1.07536e-077
Eye Height	0.0239089
Threshold	0.00305584
Decision Inst.	0.515625

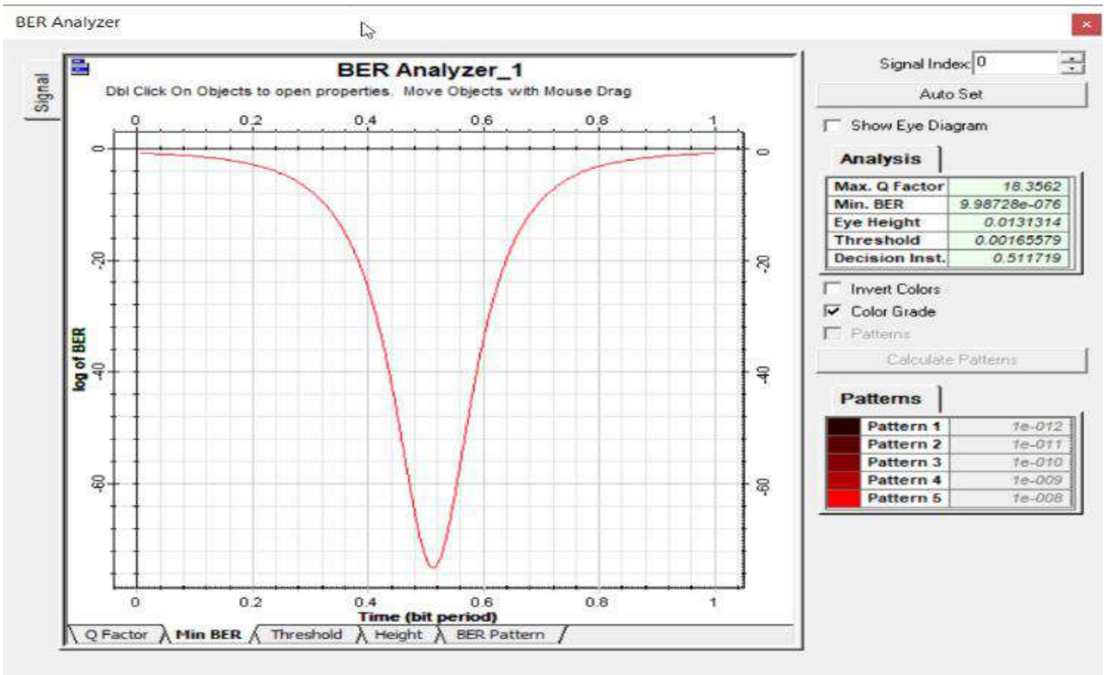
☐ Invert Colors
☐ Color Grade
☐ Patterns

Patterns

■	Pattern 1	1e-012
■	Pattern 2	1e-011
■	Pattern 3	1e-010
■	Pattern 4	1e-009
■	Pattern 5	1e-008

Figure 4.9 Bit Error Rate for Four Channel Environments

This BER value for the 8-channel DWDM-FSO communication network is displayed in **Figure 4.10,** which is derived from the DWDM-FSO demux output's BER analyzer. In an 8-channel DWDM-FSO communication system, the standards of quality for every channel can be evaluated independently using BER evaluation. By identifying channels with higher error rates that could need optimization or troubleshoot, this analysis contributes to the dependable and exact transfer of data over all 8 channels.



Signal Index: 0

☐ Show Eye Diagram

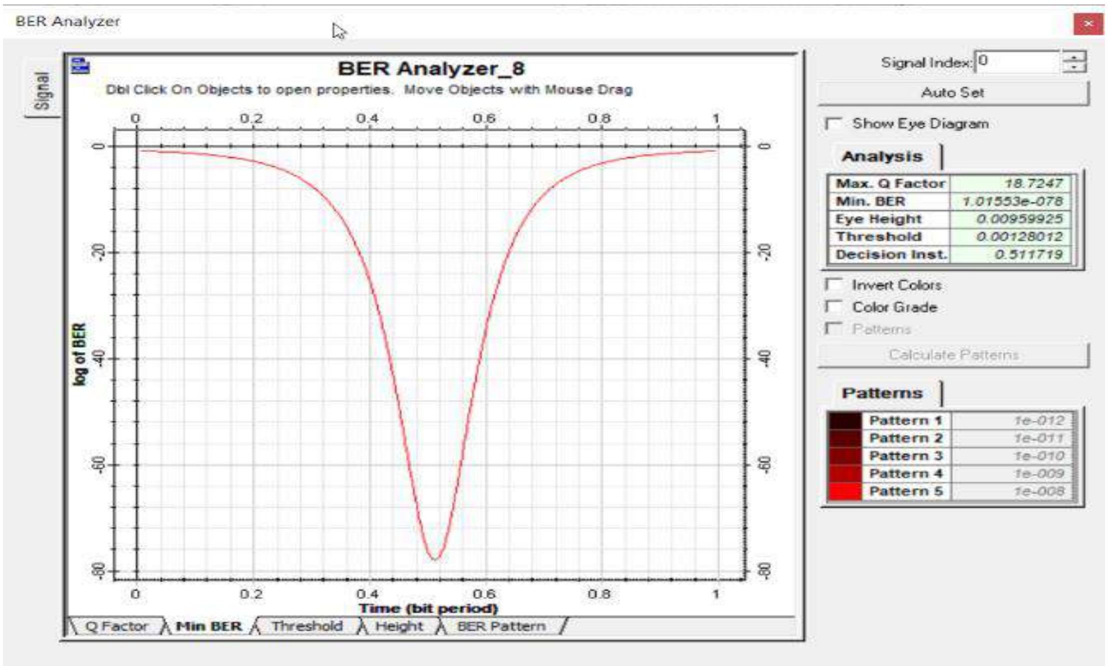
Max. Q Factor	18.3562
Min. BER	9.98728e-076
Eye Height	0.0131314
Threshold	0.00165579
Decision Inst.	0.511719

☐ Invert Colors
☑ Color Grade
☐ Patterns

■	Pattern 1	1e-012
■	Pattern 2	1e-011
■	Pattern 3	1e-010
■	Pattern 4	1e-009
■	Pattern 5	1e-008

Figure 4.10 Bit Error Rate for Eight Channel Environments

Estimated BER value for 16 channels for DWDM-FSO optical fiber communication is visualized in **Figure 4.11**. In a 16 channel DWDM-FSO optical network, the productivity and quality from each channel can be evaluated independently by executing BER assessment for every channel. By identifying channels with higher error rates that could need optimization or troubleshoot, this accuracy to the dependable and correct transfer of data over all 16 channels.



Signal Index: 0

☐ Show Eye Diagram

Max. Q Factor	18.7247
Min. BER	1.01553e-078
Eye Height	0.00959925
Threshold	0.00128012
Decision Inst.	0.511719

☐ Invert Colors
☐ Color Grade
☐ Patterns

■	Pattern 1	1e-012
■	Pattern 2	1e-011
■	Pattern 3	1e-010
■	Pattern 4	1e-009
■	Pattern 5	1e-008

Figure 4.11 Bit Error Rate for Sixteen Channel Environments

According to the data presented in the table and bar diagram below, the Bit Error Rate (BER) varies under various channels.

TABLE IV. DIFFERENTIAL CHANNEL BIT ERROR RATE

Number of Channel	Bit Error Rate
4	7.93876e-078
8	9.98728e-076
16	3.3309e-076

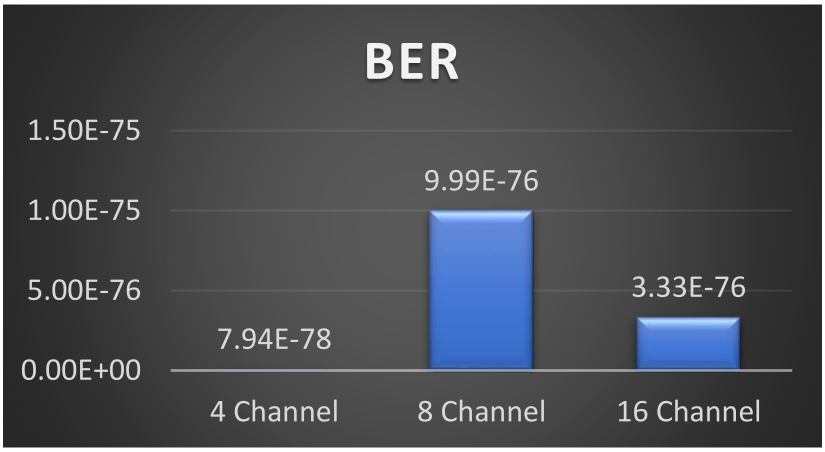
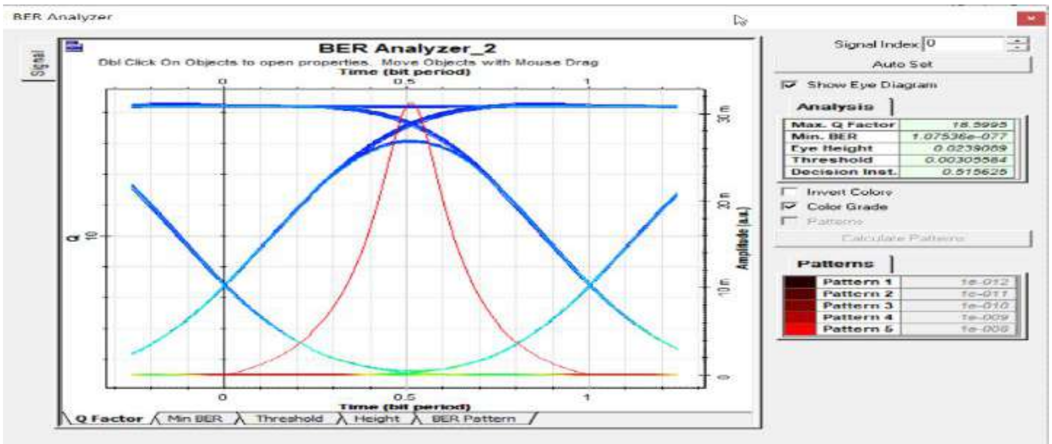


Figure 4.12 Bar chart shows the BER for the channels 4, 8, and 16

4.4 Analysis of Eye Figures

This eye Figure for the four channels of DWDM-FSO optical fiber communication is represented in **Figure 4.13**



Signal Index: 0

☑ Show Eye Diagram

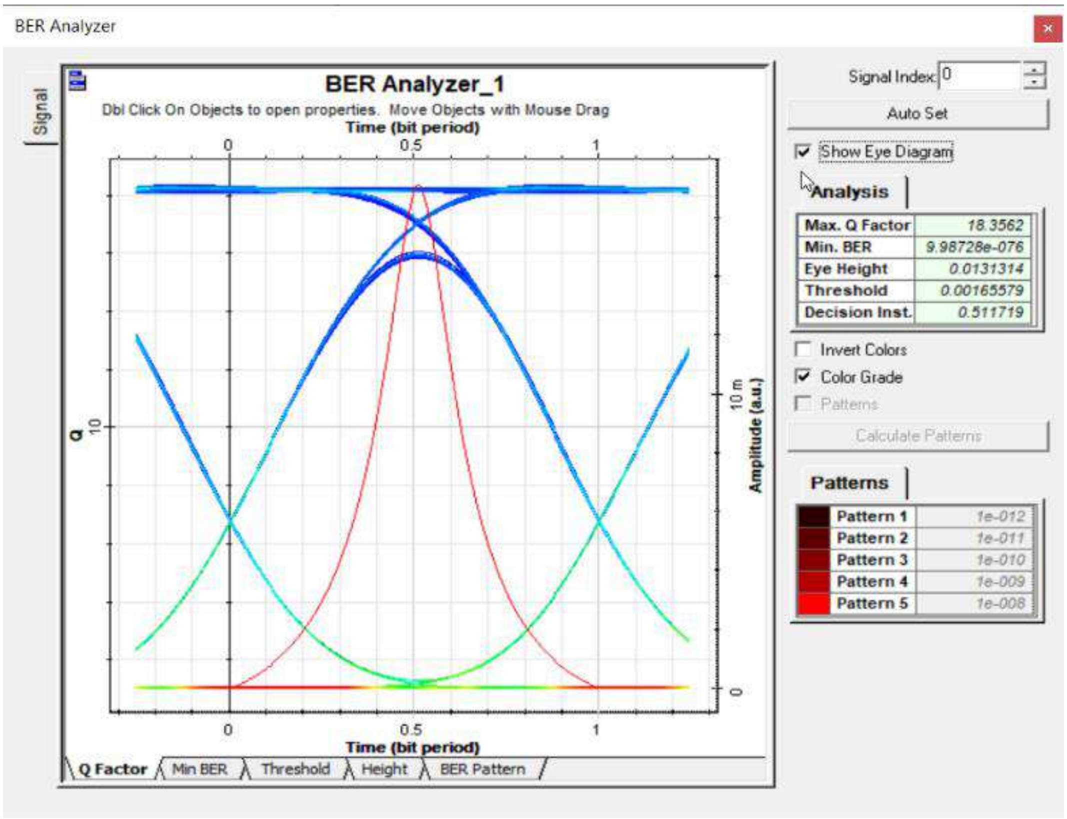
Analysis	
Max. Q Factor	18.5995
Min. BER	1.07536e-077
Eye Height	0.0239069
Threshold	0.00305584
Decision Inst.	0.515625

☐ Invert Colors
☑ Color Grade
☐ Patterns

Patterns	
Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Figure 4.13 4 channel Eye Figure

This same eye Figures upon the 8 channels throughout the 8 channel DWDM-FSO communication network can be inspected regularly in order to evaluate the transmission's fundamental performance and reliability, spot any anomalies or errors, and adjust the control parameters as necessary.



Signal Index: 0

☑ Show Eye Diagram

Analysis

Max. Q Factor	18.3562
Min. BER	9.98728e-076
Eye Height	0.0131314
Threshold	0.00165579
Decision Inst.	0.511719

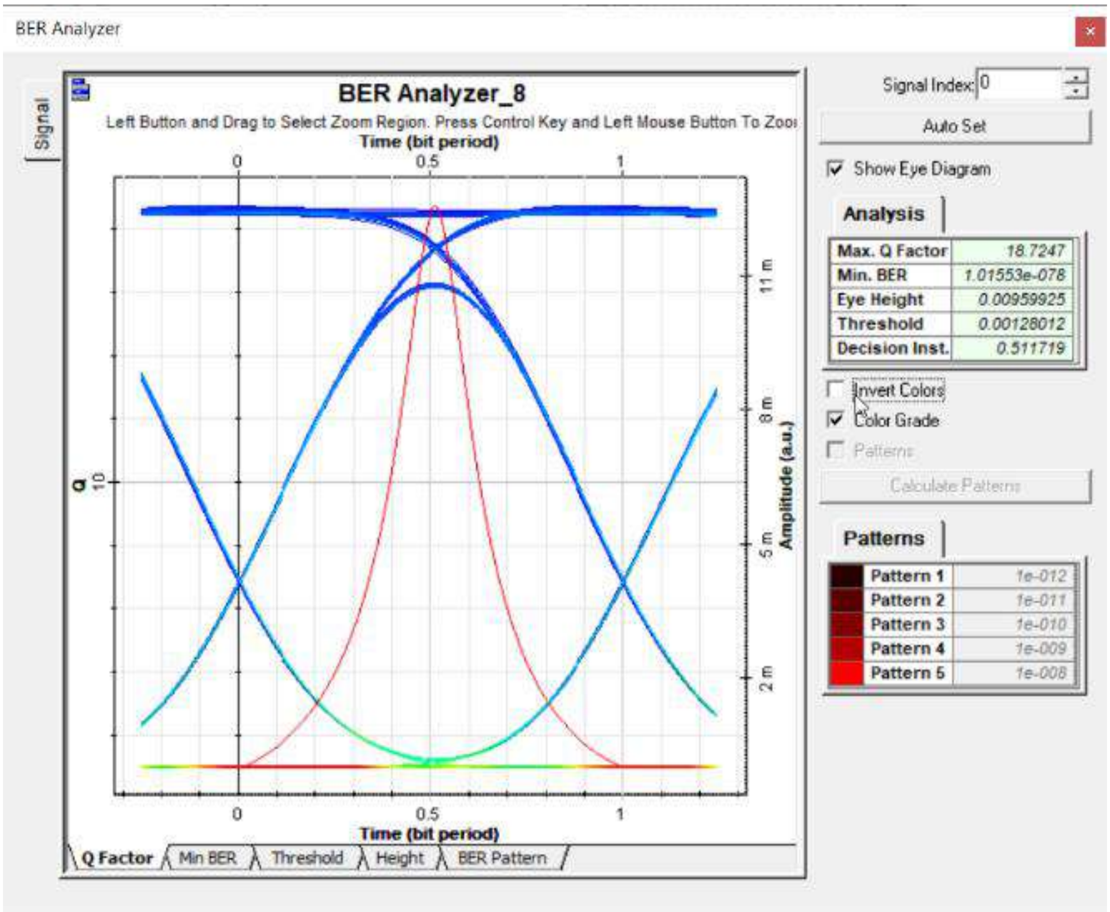
☐ Invert Colors
☑ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Figure 4.14 8-channel Eye Figure

Specifically with regard to the sixteen, eight, and four-channel DWDM-FSO networking technologies, this eye diagram result evaluation gives essential information on the reliability and believability of the same operations. A transparent and clean image is typically suggestive of increased spectral efficiency and maybe a lower risk of errors. This is because transparent and clear graphics are easier to see. The eye diagram for the four-channel DWDM-FSO system contains four separate eyes that are clearly defined. These eyes are present in the diagram. The reliability of transmission and the excellent quality of the signal are represented by these eyes. It can be seen in the eye diagram of the 8-channel DWDM-FSO system that there are eight distinct eyes. This implies that the signal consistency has been enhanced, and that there is less disruption to the coordination that is involved. In the eye diagram of the 16-channel DWDM-FSO system, there are sixteen eyes that are open and distinct, which shows that the signalling quality is superb and that the data transmission is proper.



Signal Index: 0

☑ Show Eye Diagram

Max. Q Factor	18.7247
Min. BER	1.01553e-078
Eye Height	0.00959925
Threshold	0.00128012
Decision Inst.	0.511719

☐ Invert Colors
☑ Color Grade
☐ Patterns

■	Pattern 1	1e-012
■	Pattern 2	1e-011
■	Pattern 3	1e-010
■	Pattern 4	1e-009
🟥	Pattern 5	1e-008

Figure 4.15 16-channel Eye Figure

TABLE V. AN EYE FIGURE FOR VARIOUS CHANNELS

Number of the channel	Eye Figure
4	0.00752659
8	0.00742377
16	0.00749419

The table that has been supplied gives numerical values that are related with the eye diagrams for various channel configurations in a DWDM-FSO optical fibre communication system. These configurations include four, eight, and sixteen channels. These numbers are representative of a certain parameter that is directly connected to the eye diagram of each channel. According to the description that is included with the table, the eye diagrams are extremely important when it comes to determining the fundamental performance and dependability of the gearbox for the vehicle.

Here is a summary and interpretation of the data table:

Summary:

- The table presents eye Figure values for DWDM-FSO optical fiber communication systems with different channel configurations (4, 8, and 16 channels) and the numerical values in the table represent a parameter associated with the eye Figures, which may indicate signal quality, error rates, or another metric.
- The accompanying explanation emphasizes the importance of regularly inspecting eye Figures for evaluating fundamental performance, identifying anomalies or errors, and adjusting control parameters.
- The description highlights that a clear, transparent graphic in the eye Figure often indicates better spectral efficiency and a potentially reduced chance of errors.
- Specific observations for each channel configuration are mentioned:

In conclusion, the table provides numerical values associated with eye Figures for different DWDM-FSO channel configurations, and the explanation underscores the significance of these Figures in assessing and maintaining the reliability and performance of the communication system.

4.5 Assessing and Comparison with Previous Research Work

In the realm of communication channels, the presented data reveals a diverse landscape of Q factors and Bit Error Rates (BERs), each offering unique insights. Paper [35], employing MIMO (ES) technology, boasts an impressive Q factor of 12.46. However, the exceptionally high BER of 6.36e36 raises concerns about its error correction capabilities. Conversely, Paper [34], utilizing Free-Space Optics (FSO), strikes a balance with a moderate Q factor of 5.98571 and a significantly lower BER of 1.07456e-9, showcasing its efficient data transmission. Meanwhile, Paper [37], featuring a channel type of 32, demonstrates a commendable Q factor of 10.6843 and an impressively low BER of 4.51354e-027, highlighting reliability in high-channel scenarios.

A Q factor of 9.41972 and a BER of 1.53428e-021 are presented in the paper [33], which makes use of Channel Type 2. Paper [36] demonstrates a Q factor of 6.3046 and a BER of 1.10093e-010. This measurement was obtained using Channel Type 4. Both papers exhibit strong performance, with Paper [33] putting an emphasis on a balance and Paper [36] succeeding in low BER with their respective papers. Turning to the

"Current Project," channel types 16, 8, and 4 showcase consistently high Q factors (18.4163, 18.6157, 18.3562) while revealing divergent BERs (3.3309e-076, 7.93876e-078, 9.98728e-076). This nuanced data underscores the need for a tailored approach, considering both signal quality and data integrity based on specific project requirements and technological preferences.

TABLE VI. ASSESSING AND COMPARISON PREVIOUS RESEARCH WORK

Article	**Types of Channels**	**Q Factor (dB)**	**Bit Error Rate (BER)**
[34]	2	9.41972 dB	1.53428e-021
[35]	FSO (ES)	5.98571 dB	1.07456e-9
[36]	MIMO (ES)	12.46 dB	6.36e36
[37]	4	6.3046 dB	1.10093e-010
[38]	32	10.6843 dB	4.51354e-027
[39]	4	6.44 dB	5.96e-11
Current Project	16	18.4163 dB	3.3309e-076
Current Project	4	18.3562 dB	9.98728e-076
Current Project	8	18.6157 dB	7.93876e-078

CHAPTER 5
CONCLUSION

In the prior chapter, we explored several configurations using DWDM-FSO systems that utilized various channel schemes. To evaluate potential system modifications, we performed simulations and compared the outcomes to our model paper in the findings and simulations section. have achieved a well-performing, ideal design. In this chapter, we will conclude our thesis work by summarizing the results, achievements, and possible future prospects for the proposed design.

5.1 Conclusion

Authors showcased an excellent design utilizing multiple channel throughout this effort. Typically, we go with one of three configurations, the most common of which is sixteen channels. There are some nice things about each of these three arrangements. The reliability of our model is evaluated with respect to connection range, receiver aperture, beams deviation, transmitters diameter size, and aperture.

Based on the Q factor, the 16-channel configuration has the best quality factor, while the 16-channel layout has the lowest bit error rates when compared to the 4-channel and 16-channel arrangements, respectively. And yet, the bit error rate is greatest for 4-channel. It shows good quality when compared to the previous model with our 16-channel setup. At last, we may say that our experimental setup outperformed the prior model.

5.2 Achievement

In the next section, we are going to talk about all that we have accomplished up to this point in time already. Our method has a number of benefits, one of the most significant of which is that it results in an increase in the data throughput as well as the number of networks. Through the employment of pin photodiode wavelength division multiplexing, all sixteen channels were combined in order to achieve a wavelength of 193.1 THZ. This was accomplished in order to complete the aforementioned endeavor. Bringing together the channels was the method that was utilized to accomplish this. Both a low bit error rate (7.93876e-078) and an extraordinary quality factor (18.6157) are discoveries that we make when we study a number of alternative channel designs in an effort to identify the most efficient and effective technique to boost and efficiency. Both of these results are a result of our investigation.

5.3 Limitation

The current analysis recognizes a number of the suggested system's fundamental shortcomings. The following outlines these limits for thorough comprehension and critical assessment.

5.3.1 Budget

Comparatively tiny enterprises and organizations may find it challenging to afford the comparatively high initial cost of setting up a DWDM-FSO based optical communications network particularly in comparison to those other communications technologies.

5.3.2 Fragility

Degradation to the delicate fiber optics might compromise the program's dependability and effectiveness. To keep the network running well, regular monitoring is important.

5.3.3 Complexity

Technological mastery is considered for the development and installation of multi-channel optical fiber communication depending on DWDM-FSO, which makes successful management and operation of such systems challenging for non-experts.

5.3.4 Distance Limitations

This same maximum range that communication networks based on DWDM-FSO can transmit data is constrained. Variables including attenuate, dispersion, and non-linear effects may diminish the signals strength and impact communication range.

5.3.5 Security

However, despite the fact that optical communication systems that are centred on DWDM-FSO provide a mode of data transfer that is considerably more secure than earlier technical advancements, these networks are still susceptible to security breaches that might potentially reveal personal information. On the other hand, in order to provide evidence in support of their claim, the authors took advantage of the free trial period that Optisystem 16 offered for a period of one month. In terms of the foundation of the project, this attempt might perhaps gain from the addition of extra comparison data in order to get a result that is more statistically significant.

5.4 Future Work

Throughout our thesis, authors looked into a Q factor of 18.6157. This occurrence might be the basis for future study on higher data rates or perhaps a thesis. An enhanced amplification is another option for achieving the highest Q-factor with a lower BER. enhancing the general functioning of the system and finding ways to lessen the effect of these characteristics might be the subject of future research. Research into novel methods or approaches to increase the transmission distance across large distances without reducing the signal quality should be prioritized in light of the distance limits of optical communication systems based on DWDM-FSO. To improve the performance of a system and dependability, researchers should look at sophisticated ways to process signals and modulation patterns which can boost the network bandwidth while decreasing signal distortion.

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