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A Power Loss Reduction Development for a Distributed Fiber Optic Communication Network

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ABSTRACT

The big issue in today's telecommunications is the crowded information communication pushed to this study that has analyzed a thorough comparison of non-return to zero and return to zero modulation strategies installing and testing each along with optical amplifier alone once and optical amplifier with polarization mode dispersion emulator in hybrid. It recorded maximum quality factor, minimum bit error rate, and optical received power analyzing the range of working wavelengths (1310–1550 nm) between the E and S bands. When it comes to improving optical transmission, the Non-Return to Zero NRZ modulation technique outperforms the Return to Zero RZ modulation approach in that it has received an optical power of 12.76 mW, a quality factor of 11.81, and bit error rate nearly zero, the quality factor and bit error rate chosen considering the strength of optical received power enhancement.

Keywords: Fiber Optic Digital Communication, Loss Relieving, Optical Amplifiers, PMD-Emulator, Hybrid Amplifiers, Quality Factor.

1 Introduction

A key component of the telecommunications infrastructure is fiber optics. Its high transfer speed capabilities and low decreasing characteristics make it ideal for sending large amounts of data. Figure 1 illustrates how an optical fiber communication system works. The transmitting side consists of an optical source and a modulator, which modulates the data from the source before it is transmitted through the transmitting medium (optical fiber). The receiving side is made up of a detector and a demodulator, which is located at the desired location [1]. Unfortunately, signal attenuation and other losses that occur throughout signal transmission through fiber optics lower the operation of the system for optical communication. Attenuation in fibers may happen for several causes, involving splicing, scattering, dispersion, absorption, bending, and connections links variations in temperatures can also play a role. Considerably to improve their performance, further study and development of the primary components of Optical Fibers are required [2]. Although numerous studies have been conducted to repair these attenuations and losses in various ways, the destination still requires a suitable signal to operate the connection more effectively. The optical amplifier has enabled numerous improvements in optical networks [3]. The goal of current research and development activities is to make conveyed data more visible and to minimize data loss. The modification of the communication system's loss reduction has always been a crucial task for the power supply of the communication system to improve their economical operation, as the power of the communication network system loss makes up a sizeable portion of the entire power system. Although there are many study sources for loss mitigation techniques at the moment, their primarily concentrate thinking theoretically development on various loss mitigation techniques. The majority of earlier research has been on computing power [4]. In this study, a workable method of loss reduction for the communication system is proposed to address the system quality, power, and bit error issues of unclear received information. NRZ modulation and RZ modulation were suggested, it could enhance several crucial targets of the communication system efficiently and lower the power loss of the communication network system in comparison to other modulation techniques. This approach is founded on the combined employing optical amplifier first and PMD-E after him in a cascade manner, as the results of testing with a vice versa connection did not yield satisfactory results. We measured the maximum Q-factor, minimum BER, and optical received power at various operating wavelengths. We contrasted the outcomes in the current communication system, the results demonstrated that employing NRZ modulation with OA+PMD-E is the preferred method of connection in the communication system, which recorded a maximum Q-factor of 542.9, a minimum BER of nearly zero, and a received optical power of 12760 µW. Which produced better readings in comparison to using OA alone with NRZ Modulation gave 1280 µW, with a maximum Q-factor of 542.9, a minimum BER of zero, OA+PMD-E RZ modulation, 4590 µW with a maximum Q-factor of 1150, a minimum BER of nearly zero, and using OA alone with RZ modulation received optical power of 4590 µW, a maximum Q-factor of 14.55, minimum BER of zero, we took these readings at the system operating wavelength of 1400 nm.

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The study demonstrates that the best augmentation of the readings is achieved when utilizing NRZ modulation and OA+PMD-E. Through the use of eye diagrams, the enhancement of the communication system was also investigated and illustrated.

2 Related Work

A fiber-optic attenuator with several wavelengths and digital control employing a digital micromirror device (DMD) in both dimensions, was first created by Nabeel A. Riza and Sarun in 1999. An eleven-bit resolution and a 26-dB dynamic range were demonstrated via an example attenuator using four experimental wavelengths: 1546.92, 1548.52, 1550.12, and 1551.72 nm.

The suggested attenuator of the median coherent visible crosstalk per wavelength channel was restricted to 238 dB due to the additional noise resulting from the improper separation of the reduction module and optical oscillator [5]. In 2003, Shlomi Arnon created a bit-error probability (BEP) model that takes into consideration the tilt and tension peak log fluctuations of the two structures (i.e., signal strength fade), when the turbulent coherence's diameter, d0, is less than the receiving apertures, d0. It is thought that the receiver is aware of both the current state of signal fading and its peripheral statistics [6]. 40Gb/s signals are used to propagation across DWDM optically amplified communications systems across 320 km standard SMF and 328 km dispersion compensating modules employing RZ, NRZ, CS-RZ amplitude, and differential phase shift keying modulation was documented by L. N. Binh and T. L. Huynh in 2007. It has been established that the mutual effects of 10G and 40G co-transmission are minimal [7]. Simranjit Singh and R. S. Kaler looked into post-, pre-, and symmetrical power compensation techniques in 2012 were discovered that using RAMAN-EDFA as a post-power adjustment method resulted in the least bit error rate (10–40) and highest output power (12 dBm) at a signal input power of -15 dBm at the fiber cable [8]. Using the Mobile Telecommunications Network (MTN) Fiber Optic backbone project as a test bed, Alexander. N. Ndife, et. al. conducted experimental characterization in 2015. According to the results, there was essentially no attenuation or dispersion during amplification in an erbium-doped fiber amplifier (EDFA) at 1550 nm. The research work showed a 23% enhancement over earlier works [9]. Yoshiaki Tamura, et al. conducted research in 2018, For the lowest transmission loss ever, they employed a Silica-core optical fiber free of Ge, achieving 0.1419 dB/km at 1560 nm and 0.1424 dB/km at 1550 nm. It was an increase of 4 dB/km over the previous record, which was achieved in 2015 [10]. The optical technique was used in 2020 by Ifeoma Asianuba and Christian Nwabueze to correct for mechanically induced anomalies (micro bends) or external pressure on the optical communication line. A 10% decrease in the micro-bend losses was realized based on the results. The refractive index of the fiber clad was raised in further efforts to minimize losses until it exceeded that of the core. This meant that channel losses caused by microbends were rising rather than decreasing. Their research has particular relevance since it will help determine the precise marginal refractive index value needed to maximize throughput while ensuring efficiency [11]. In passive optical networks, Aadel M. Alatwi and Ahmed Nabih demonstrated the performance effectiveness of hybrid continuous-phase frequency shift keying (CPFSK)/optical quadrature-phase shift keying (OQPSK) modulation transmission schemes in 2021. Based on hybrid suggested modulation transmission approaches, differences in the maximum Q factor and minimum BER for different bits and symbols were carefully examined regarding modulation frequency and fiber length. Based on hybrid modulation approaches for CPFSK/OQPSK of 32 bits/symbol and a modulation frequency of 500GHz across a fiber length of 30km, the maximum Q Factor, minimum BER, maximum signal power, and minimum noise power variations were achieved [12]. In a work published in 2021 by Elham Khoobjou et al., a new construction was introduced using Photonic crystal fibers (PCF) using metallic nanoparticles to minimize dispersion and optical loss. According to simulation studies, at wavelengths between 1.3 and 1.65 m, the loss is 7e4 dB/cm and the dispersion is less than 0.3 PS/nm/km. When compared to other relevant research, the light loss and dispersion are decreased [13]. Demissie Gelmecha, et al. released a study in 2022. Their work's objective is to use space-division multiplexing (SDM)to increase the capacity of fiber optic communication (FOC) networks. During this process, the capacity improved by about 14.75 pb/s/fiber, after which this started to decline, featuring a broadcast range of 250 kilometers, the usable wavelength of the C + L band. The signal-to-noise ratio in FOC is 35 dB when using single-mode fiber (SMF) and multicore fiber (MCF) [14]. A study on the lowering of optical fiber loss was published in 2022 by Elechi P., et al. To reduce signal dispersion and attenuation caused by the optical fiber bends, and to ascertain the amount of loss, they employed the Marcuse technique and carried out folding studies on both single-mode and multimode fiber optics. It was done to compare the outcomes of the different degrees of bending [15].

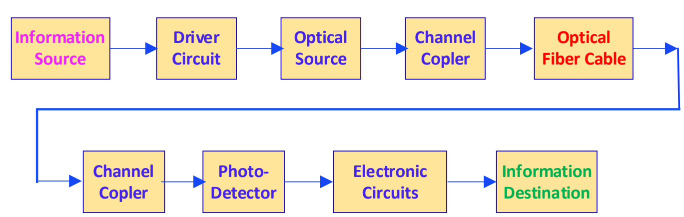

Figure 1: System of Optical Fiber Connectivity.

3 Optical Fiber Attenuation

Loss or attenuation is the most important aspect of transmission. The total fiber transmission system duration appears to be limited by the number of lost signals [16]. The optical fiber communication industry's method of data transfer aids in the transmission of extremely high data at the speed of light. Losses are connected to the optical fiber line, though. This issue sometimes referred to as attenuations, prevents the full input signals from being transmitted [17]. Loss of optical boost, also known as absorption, happens when light travels through a fiber optic. The optical output power proportion (Po) to optical power input (Pi), which can be the definition of signal attenuation in dB, could be expressed as [18]:

Attenuation, $\alpha = -(10/L) \log 10[power\ out/\ power\ in]$ dB.......1

L is measured in kilometers, while loss is measured in decibels per kilometer. Extrinsic or intrinsic losses cause attenuation in optical fiber cables. Extrinsic losses are caused by things like the mode of splicing, bending, and insertion losses, whereas intrinsic losses are caused by things like absorption, scattering, and dispersion losses [17]. The damaged analog and digital information transmitted via laser fibers is due to dispersion. When fiber optic transmission is employed, transmitted light pulses spread as they travel along the channel due to intrinsic dispersion mechanisms in the fiber, requiring some kind of digital modulation as an essential element. Intermodally (modal) diffusion, which just occurs in modal (chromatic) dispersion, and multimode fibers which occur in all types of fibers (single mode and multimode), can be classified as the two main types of dispersion. These two types can also be divided into two subtypes: waveguide dispersion and material [16]. The only source of birefringence that remains is the layers of internal strain within the waveguide, which needs to be monitored and may be impacted by its declaration circumstances. The finite difference Beam Propagation Method (BPM) technique was used to determine bending losses. Comparable to low waveguides, the minimum bending radii are as follows: At 1300 nm, a bending radius of 30 mm and an input-output lateral distance of 125 m results in a 0.04 dB loss. A 15 mm radius causes the loss to rise to 0.12 dB. Using tapered waveguides and elliptically linked bends makes it simple to reduce loss [19]. Power loss results from the transmitting light in optical fibers bending and radiating outward away from the core [17]. Two examples of intrinsic losses in a Plastic Optical Fiber (POF) are material absorption and Rayleigh scattering; attenuation is dependent on the fiber type and operating wavelength. Compared to multimode fibers, single-mode fibers (SMF) exhibit less attenuation. The attenuation decreases with increasing operating wavelength [20]. Extrinsic losses include the absorption caused by both metallic and organic impurities, as well as the dispersion exacerbated by abrasives, air pockets, microfractures, and other formational defective flaws during POF. Moreover, there are radiation losses that are caused by changes in the fiber geometry, both microscopic and macroscopic. Radiation losses occur when the POF bends at a particular angle [18]. Impurities in the glass cause fiber optic cable to absorb light and project it in the opposite direction. Distortion depends on wavelength; it must be provided for the specific wavelength being used [21].

Modality diffusion directly depends on data rate, which is just an issue using multiple-mode links. With an increase in data rate, the signal's maximum travel distance accurately lowers before modality dispersion making it difficult to distinguish between a "1" and a "0". Even though modal dispersion does not affect single-mode fiber, other dispersion effects still limit the distance possible with relation to data rate and induce pulse spreading. One of the most prominent examples of this is called chromatic dispersal, in which a wider range of some transmitter types can lead to differing traverse lengths over various components to a burst of light. Asymmetry of chromatic rarely becomes a problem before Gigabit speeds [21]. Due to the two distinct group delays (DGD) primary states of polarization (PSPs), which are brought on by random birefringence in fibers and devices, polarization mode dispersion (PMD) is considered a significant restriction transmission method for communicating far away via expansion rates of data, greater than 10-Gbits/s/channel [22]. There is no ideal loss-free splice, despite being small and frequently negligible. Refusal to include splices results in several inaccuracies in loss computations. With single-mode cable, the typical splice loss is less than 0.01 dB [21]. There isn't a 100% loss-free connector, much like with splices. It is significant to remember that connectors of any quality might become unclean. A fiber light wave can be obscured by dirt and dust, resulting in significant losses. Connector loss typically falls within the range of 0.15 (LC) to 0.5 (dB) (ST-II). The worst-case case would be to use a loss of 0.5 dB per connection, assuming the connector has been coated and cleaned. It appears necessary to remember that every fiber segment will always have a minimum of two connectors. A few dB of loss are frequently added as a design margin. Including a loss of 2 to 3 dB can account for aging fiber, poor splices, heat, moisture, and other factors while maintaining a stable structure. After the fiber has been placed, precise measurements must be taken to determine damages. The total of all worst-case parameters inside a fiber section is used to calculate maximum signal loss [21].

Since fibers bend easily, bend losses are a typical issue in waveguides, particularly in optical fiber. Light from core modes (directed modes) is connected to cladding modes when optical fibers are bent, increasing dispersion losses. These losses often rise rapidly once a critical bend radius is reached [17].

The incident light ray tilts within the interface surrounding cladding and the core varies if a fiber is bent. The criterion of total reflection, as illustrated in Figure 2, is not met, some beams are released from the fiber as a result, and an overflow of attenuation is visible. Bending loss is divided into macro bend loss and micro bend loss based on the bend radius of curvature [18]. The bending effects cause fibers to experience higher losses. Micro bends are frequently overlooked bends in the core-cladding interface, while macro bends are massive curves of the cable and fiber. Those more recent failures were referred to as the winding and cables losses, correspondingly [23]. Mode field diameter and cutoff wavelength are used to measure macro bending, which is induced by the curve of the whole fiber axis, which creates the "MAC number," an experimental parameter that measures the mode field diameter from over cutoff wavelength [24]:

$$MAC = \frac{mode\ field\ diameter}{cutoff\ wavelength} \quad \text{..2}$$

$$\lambda_c = \frac{\pi d \sqrt{n_1^2 - n_2^2}}{2.405} \quad \text{...3}$$

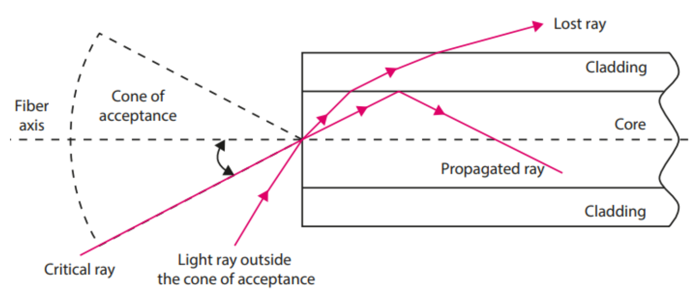

Figure 2: Explanation of bending loss.

Lowering the field's modal diameter and raising the core-cladding refractive index difference (relative to the cutoff wavelength) both result in reduced macro bending loss because the smaller the

MAC number, the less macro bending loss there will be. Longer wavelengths are less likely to cause loss bends. Figure 2 illustrates the macro bending-induced attenuation at a threshold wavelength, where it is comparatively small at short wavelengths [24]. Micro bending is the term for tiny, tiny bent in the plane of the fiber which occur any time throughout production, cable installation, or service. They develop as a result of environmental factors, mainly temperature changes. Little surface defects brought about by microbending have the potential to lead to radiation loss by coupling adjacent modes Figure 3. When a fiber experiences significant stooping over a certain level from the curve (the curve) is big about the diameter of the fiber, such as when the fiber is rolled on a wrap, macro bending occurs. Some of the light enters through the fiber's core and is attenuated by the cladding because of the huge bending curve, which creates an extremely acute direction that allows the light to reflect into it.

The majority of macro bend production occurs during the installation of POF.

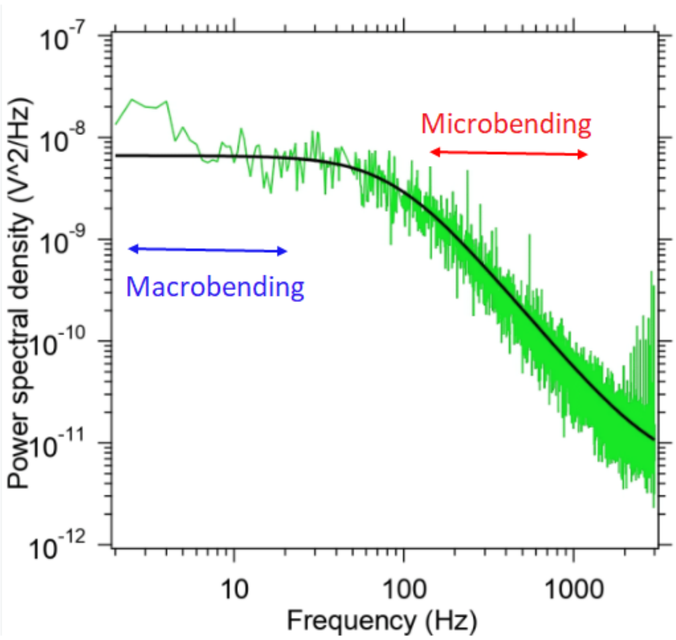

Figure 3: A graph showing pitch Power Spectral Density (PSD) shown in green to a 3 µm birefringent component trapped within the sampling tube[25].

The losses are essentially nonexistent when the curvature is minimal. In a conventional PMMA step-index POF, the study discovered that radiation power losses grow exponentially for a whole turn like the bend radius reduces [18]. Depending on the fiber requirement and the micro-bend Gaussian shape, Petermann-'s approach provides an approximation of the micro-bending loss; specification and the micro-bend Gaussian geometry is given [24]:

$$\alpha = \frac{q}{m}\left[\frac{A^2B^3}{(B^2+\sigma^2)^{\frac{5}{2}}} + \frac{\sigma^2 B}{2(B^2+\sigma^2)^{\frac{3}{2}}}\right] exp\left[\frac{-A^2}{B^2+\sigma^2}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Where:

Q = Constant, k = Wave number, σ = Standard deviation parameter, A = Average half width at 1/e amplitude.

The variable q is defined as the square of the amplitude of the modest, Gaussian-like oscillations in the radius of the core as indicated by Y2 and the combination of an experimentally determined constant. As a result, we can write Q like [24]:

$$Q = 13.644\, Y^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

The parameter m defines the product of the square of the patch size w and the period (time interval between the Gaussian nodes) between the Gaussian oscillations or micro bends along the fiber line.

Petermann's equation to simulate the micro bending loss anomaly:

$$\alpha = \frac{13.644\, Y^2}{Lw^2}\left[\frac{A^2B^3 2(B^2+\sigma^2)^{\frac{3}{2}} + \sigma^2 B(B^2+\sigma^2)^{\frac{5}{2}}}{(B^2+\sigma^2)^{\frac{5}{2}}\, 2(B^2+\sigma^2)^{\frac{3}{2}}}\right] exp\left[\frac{-A^2}{B^2+\sigma^2}\right] \quad \ldots\ldots\ldots 6$$

L = time between the Gaussian nodes.

w = Patch size

$$B = \frac{kn\, w^2}{\sqrt{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

k = wave number, provided by the expression:

$$k = \frac{2\pi}{\lambda} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 8$$

n = core's reflection index.

The method used for simulating this decrease in micro-bending through optimization of the Peterman model links the anomaly of micro-bending which is known to be caused externally to the internal parameters that reflect the presence of these micro-bends [24]. Moreover, it is quite simple to prevent optical interference between fibers; as a result, crosstalk is not noticeable even when several fibers are connected, unlike communication utilizing electrical conductors.

Researchers have developed Marcuse's approach to lessen the loss and dispersion of the signal caused by optical fibers, bent. They also conducted bending experiments to determine the loss across single-mode and multi-mode optical fibers [17].

Relative refractive indexes can range from greater than one to exactly one. While so switch between substance 1 having (n1) refractive index to substance 1 having a refractive index of (n2), the result will be as shown. Then, you can determine the refractive index related to 1 n2 through the division of the refractive index of substance 2 (n2) from the refractive index of substance 1, or via the division of the sine of an incident angle (1) by the sine of the scattered angles (2), or by dividing the velocity of light in materials 1 (C1) by the velocity of light in materials 2, among other methods. in Figure 4 [17].

Material 1 = glass
Material 2 = air

$$1n_2 = \frac{c1}{c2} = \frac{n2}{n1} = \frac{\sin\theta 1}{\sin\theta 2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 10$$

4 Critical Angle

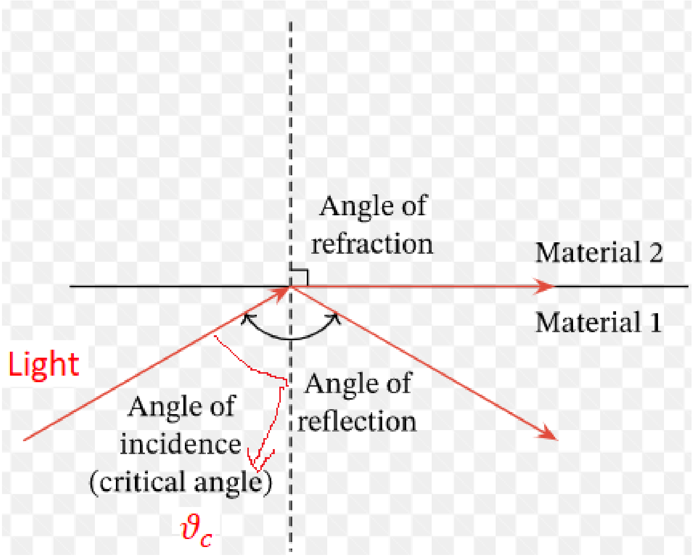

Figure 4: Light at critical angle, Incident light totally reflected.

when a light ray passes through an optically less dense medium, like air before arriving at its destination, The light beam passes through both materials' joints. The angle of incidence is known as the critical angle (ϑ_c) when the angle of refraction approaches 90 degrees Figure 4 [17], [16].

$$S\frac{\sin\theta 1}{\sin\theta 2}=\frac{n2}{n1} \quad \text{.....11}$$

$$S\frac{\sin\theta c}{\sin 90}=\frac{n2}{n1} \quad \text{.....12}$$

$$S\frac{\sin\theta c}{1}=\frac{n2}{n1} \quad \text{.....13}$$

$$\sin\theta c=\frac{n2}{n1} \quad \text{.....14}$$

If air is the second substance, then $n_2 = 1$ and so on. [17]

$$\sin\theta c=\frac{1}{n1} \quad \text{.....15}$$

Whenever the incident angle is greater than the critical angle, total internal reflection which is depicted in Figure 4 occurs at the line dividing the two materials [17].

Step Index Fine glass makes up the core of optical fibers, which is a glass's exterior layer with a lower refractive index than its inner layer. This indicates that all light reflected at the central cladding interface will be from an angle-shone light entering the core. After passing through several reflections throughout the fiber's length, the light eventually emerges at the opposite end Figure 5.

$$n'=n_{material}.e^{\frac{x}{R}}=n_{material}(1+\frac{x}{R}) \quad \text{.....16}$$

In comparison to the unstressed condition, the refractive index (n′) of the stressed bent fiber understanding along the fiber's inner half toward the bend's center, and tension along its outer half Figure 6. It is possible to say this:

$$n_{material}=n\left[1-\frac{n^2x}{2R}[P_{12}-v(P_{11}+P_{12})]\right] \quad \text{.....17}$$

Where v is Poisson's ratio and P_{11} and P_{12} are elements of the photo-elastic tensor [17].

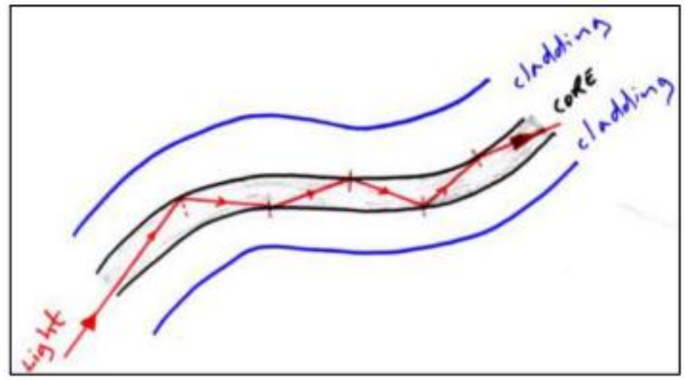

Figure 5: Step index optical fiber or Macro bending schematic in an optical fiber [17].

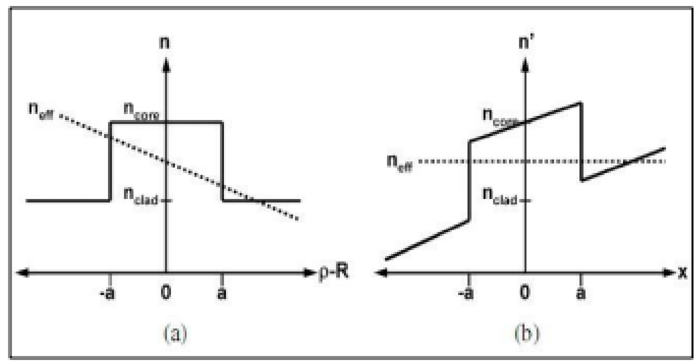

Figure 6: A bent fiber's index of refraction distribution under no tension following the contoured diagram, and its equal linear fiber [17].

SMF's output optical power is provided by [23].

$$P_o(Z)=P_i\,.10^{\alpha_T\cdot\frac{z}{10}dB} \quad \text{.....18}$$

And provides the attenuation coefficient (α bend) [23].

$$\alpha_{bend}=c_1e^{-c_2r_b} \quad \text{.....19}$$

where (c1) and (c2) were dependable, and (rb) is the fiber bend's radius of curvature. Up until the radius reaches a certain size specified, the losses are virtually nil [23]:

$$r_{critical}\approx\frac{3n_2\lambda}{4\pi(NA)^3} \quad \text{.....20}$$

According to this relationship, the fiber needs to have a high Numerical Aperture NA and operate at a short wavelength [23].

Gas has a lower refraction index than core glass, so an optical fiber can still work without the cladding. However, the cladding is useful because it protects the core and lessens light leakage and crosstalk. The core should be narrowed to lessen multimode dispersions, which happen when light enters the optical fiber at slightly different angles, passes through the fiber at different rates, and broadens out [17].

The goal of this study is to look into ways to reduce attenuation and signal transmission losses over a fiber optic connection. Using optical amplifiers and the PMD-E connection in a series approach power losses brought on by signal transmission over the 50 km long fiber are reduced in an optical fiber communication system.

5 Operating Wavelength

The International Telecommunication Union's (ITU) Table 1 lists the bands that are assigned to long- and intermediate-distance optical fiber communications, denoted by the letters O, E, S, C, L, and U band are the more often used bands since they attenuate the least across the length of the fiber. O-band and C-band are the more often used bands since they attenuate the least across the length of the fiber. The lowest attenuation occurs between 1.310 µm and 1.550 µm in wavelength. For these selected bands attenuation is less than 0.6 dB per kilometer, and the laser source manufacturers have created a variety of laser sources [16].

Table 1: ITU band regulations.

Name	ITU Band	Wavelength λ (µm)
Original band	O-band	1.260 to 1.360
Extended band	E-band	1.360 to 1.460
Short band	S-band	1.460 to 1.530
Conventional band	C-band	1.530 to 1.565
Long band	L-band	1.565 to 1.625
Ultra Long band	U-band	1.625 to 1.675

Wavelength: 780–850 nm Free Space Optics (FSO) activities are ideally suited for these wavelengths. Reliable, affordable, advanced transmitters and detector parts were easily accessible at 850 nm. Typically, network and transmission equipment use the wavelength. A 1520–1600 Hz range wavelength can be operated with advanced vertical-cavity surface-emitting laser (VCSEL) technologies and highly sensitive silicon (Si) avalanche photodiode (APD) detector technology. This wavelength range is appropriate for transmission in open areas. Nonetheless, their parts were typically expensive. In comparison to operational Si APD detection devices at 850 nanometers, the detectors offer a lower sensitivity and a lower receiving extensive zone. Finally, in the identical eye protection category, 1520-1600 nm may transfer 50–65 times more power than 780–850 nm can [26].

Fiber optic communication is mostly used in the wavelength range where optical fibers have a relatively small transmission loss [18]. This low-loss wavelength range lies between 1260 and 1650 nm. Creating wideband optical amplifiers can also be achieved by combining many light amplifications operating in parallel or series, each of which covers a different spectrum region [27]. A comparable arrangement which was discovered to enhance Efficiency with the structure's capability is a hybrid optical amplifier (HOA) [28].

6 Optical Amplification

For prospective use in optical communication systems, the optical amplification of an important signal is of particular interest. To such an implementation of amplification, nonlinear optical phenomena have gotten a lot of attention during the earlier several lifetimes. Taking advantage of four-photon mixing, stimulated Brillouin scattering, or stimulated Raman scattering can all lead to optical amplification in optical fibers [29].

The semiconductor optical amplifier (SOA) has shown excellent promise for application in developing optical communication networks. It has a variety of functional uses, including optical switching and wavelength conversion, in addition to its use as a general gain element. Transparent optical networks need these operations, where the optical pulses are not processed into electricity impulses [30].

The efficiency of a single-mode fiber transmission system can be affected by major losses such as colored scuttle, polarity modes scuttle, abnormalities, and fiber degradation. The transmission network's design for fiber attenuation and distances greater than 100 km must be adjusted since their combined impacts could cause the signal to decline to the point where data cannot be retrieved at the destination. Optic amplifiers mitigate this damaging problem, but because dispersive effects can accumulate over large distances, they exacerbate the dispersion problem. Optical phase conjugator, fiber Bragg grating, and dispersion-compensation fiber can all be used in reality to control the dispersion issue. Chromatic dispersion can be eliminated by using dispersion management [31]. Although SOAs are small, they may be integrated with other components on the same chip thanks to the utilization of semiconductor materials. Since SOAs may additionally magnify the signal being processed through electrical pumping, they could be used to manage optical signals without generating insertion losses [32]. The transmission distance is limited by fiber attenuation. For loss compensation, the two most used methods are (i) amplified using lumps, (ii) Spreading Amplification.

Lumped amplification: The transmission system uses an optical amplifier to account for loss. The Stimulated Raman Effect provides the foundation for distributed amplification [31], Distributed Raman amplifiers are becoming more popular in long-distance communication with huge data rate systems due to their poor Noise Figure (NF) performance converters can greatly improve network accessibility and scalability by rerouting light data traffic rather than first converting it to electrical signals. The common methods for converting wavelengths are four-wave mixing (FWM), cross-gain modulation (XGM), and cross-phase modulation (XPM) [32].

The Raman amplification exhibits great adjustability since stimulated Raman scattering permits a phase shift from the motor to the signal at 13 THz. This provides more flexibility in choosing the Raman gain fiber and pump wavelengths [33]. Historically, amplifying takes place within an enclosure amplifier unit that is placed which is necessary. Erbium Doped Fiber Amplifiers (EDFA) and Semiconductor Optical Amplifiers are two examples of these lumped amplifiers. whereas, Raman amplification can occur anytime a fiber—including the transmission fiber itself. It enables distributed Raman amplification (DRA), a method that entails pumping distributive fiber to increase the amount of information passing through the fiber [32]. Since high PMD fibers are difficult to obtain in the lab, simulators must be used to replicate the characteristics of the fiber used in ancient transmission connections. The temperature can be used by a PMD emulator to create variable birefringence, although installed cables need active PMD compensators [22].

In contrast to single optical amplifiers, hybrid amplifiers amplify differently [34]. PMD-Emulator enhances the useful message's energy to the energy of its errors, such as the ability to measure impairments (noise power and distortion power). This demonstrates excellent detection evaluation [35].

7 Methodology

We created the optical fiber communication system depicted in Figures 7 and 8, with their optical communication system block diagrams likewise shown in b branches, under Table 2's primary simulation parameters. The simulation tool "OPTISYSTEM 15" was used to model the SMF optical fiber communication system's design. The RZ and NRZ pulse generators that we tested are connected to an MZM, and the user-defined bit sequence generator is connected to them. Before the prepared signal is transferred to the transmission medium, an optical fiber with a length of 50 km, the MZM alters the signal sequence that is sent to it with the laser signal. A dependable forecasting approach that can handle the numerous parts and assemblies used in this kind of system is now necessary due to the growing interest in the use of fiber optic data lines for commercial, military/defense, and educational purposes. Unfortunately, there were a number of attenuations that occurred during information transmission in the optical fiber connection, which decreased system performance and caused communication system degradation and unidentified information signal at the receiver end. The attenuation measurement will differ depending on the type of cable and wavelength being utilized. A design issue is the core issue with communications. The combination of communication links is typically referred to as a data link because the information is restricted to being a series of bits. The input data signal generally refers to the disturbance that the transmitter introduces into the transmission medium. The output data signal is the disturbance that results at the receiver. The main issue with communications in the context of our topic is creating a data link that is suitable for connecting a specific source-user pair. We created the system employing a hybrid connection of an optical amplifier in cascade with a PMD-E to improve the communication system and provide a more dependable received information stream.

Table 2. The communication system properties.

Parameter	Value
Input Power	5 dBm
Input frequency	193.1 THz
Input Wavelength λ (µm)	1.553 = C band
Bit rate	5 G bit/sec
Optical Fiber Cable Length	50 Km
	SMF
Attenuation	2.61 dB
Modulation Type	RZ and NRZ
Operating Wavelength λ (nm)	1310 to 1552 = E band and S band

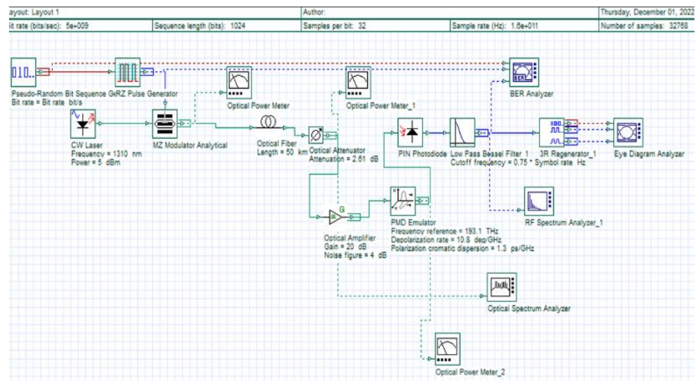

Figure 7. a: Optical Fiber Communication Circuit Design Using RZ-Modulation and Optical Amplifier + PMD-E.

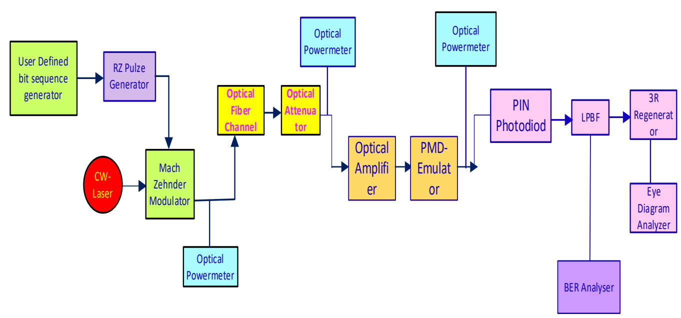

Figure 7. b: Block diagram of RZ-Modulation and Optical Amplifier +PMD-E in the System for Communication through Optical Fiber Design.

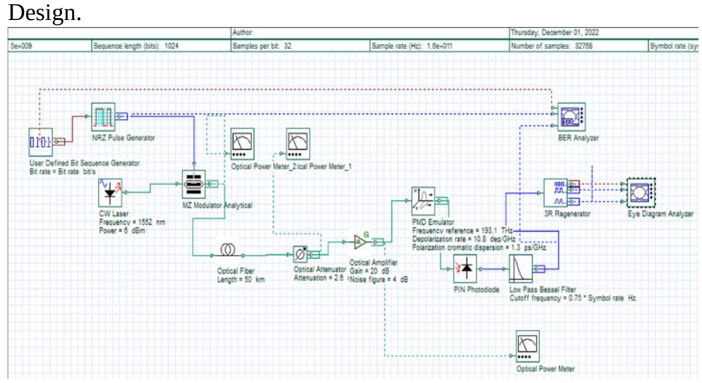

Figure 8. a: Circuit Layout for Fiber Optic Communications Using NRZ-Modulation and Optical Amplifier + PMD-E.

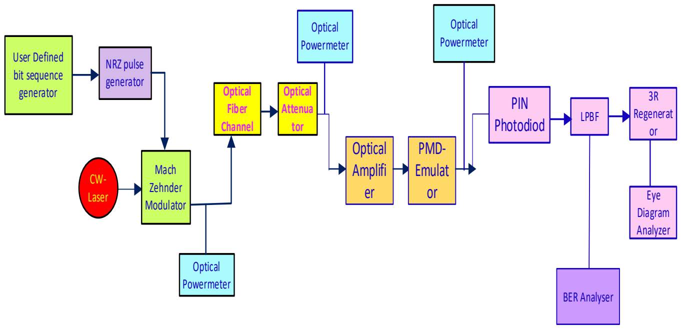

Figure 8. b: Block diagram of NRZ-Modulation and Optical Amplifier +PMD-E in the Optical Fiber Communication System Design.

4 Results and Discussion

During transmission distances longer than 50 km, this research tested RZ and NRZ Modulations to distinguish the better type, an optical amplifier, and PMD-E connection is used to analyze and lessen the impact of attenuation in the optical network. Q factor, Bit error rate (BER) and received power are used to assess system efficiency. In "Optisystem 15," extensive simulation sets are run to research and assess the optimal ways to achieve outcomes in fiber optic communication systems. The objective aims to transmit the largest amount of data over the greatest distance with a minimum of signal attenuation. while selecting a transmission wavelength. Absorption is one way that a signal might be attenuated. Little amounts of water vapor or trace metals that are included in the glass can absorb light signals and cause them to be lost. The greatest amounts of absorption occur at particular wavelengths.

A chart showing the attenuation for the full fiber route can also be used to quote attenuation in dB/km. Attenuation is measured in dB. The lowest attenuation occurs between 1.310 µm and 1.550 µm in wavelength. A wave's attenuation rate is directly related to its length. Less attenuation occurs as the wavelength grows, but as the signal attenuation rises, the transmission loss rises.

This study looked at the optical fiber communication system that created at working wavelengths of (1310, 1350, 1400, 1450, 1500, and 1552) nm. This research's goals included obtaining the most optical power, improving the system's quality factor, and reducing BER. this research used NRZ modulation and RZ modulation techniques, and with each modulation test the research examined optical amplifiers in the communication system and contrasted the outcomes with the use of an optical amplifier and PMD-E connected in series, exactly as it is written as the order, because, contrary to expectations, the connection of optical amplifier + PMD-E produced superior outcomes.

The optical power readings didn't change with the use of RZ-Modulation and an optical amplifier alone Figure 9, or the RZ-Modulation with the use of OA+PMD-E Figure 10. Which gave measurements ranging from (4.5 mW to 4.59 mW), with the largest optical power being 4.590 mW at the operating wavelength of 1552 nm. Using NRZ modulation with the use of OA+PMD-E enhances the optical received power to 12.76 mW Figure 13 from 4.47 mW with the use of an optical amplifier alone Figure 12, at 1552 nm operating wavelength. Which means that by combining an optical amplifier and PMD-E in the optical fiber communication system, this study achieved improved optical power results with NRZ modulation, but the optical received power does not change by applying the OA+PMD-E technique.

Figure 11 displays the Q-Factor results for each amplification technique using RZ-Modulation. As can be seen, using an optical amplifier alone results in a system with a higher Q-Factor if an operating wavelength of 1400 nm is taken as a sample example, the study got 1150.47 for using RZ modulation and 542.9 using NRZ modulation, while using an optical amplifier plus PMD-E results in a system with a lower Q-Factor if looked at an operating wavelength of 1400 nm, the research read a QF of 4.99 for RZ modulation and 6.54 for NRZ modulation. System quality factor falls with the use of hybrid amplification in general in any system but NRZ modulation technique gave better QF to the communication system for enhancing maximum received optical power if the study used OA+ PMD-E in the system to enhance the communication between users in the telecommunication system. If the research concentrates the Q-Factor results with NRZ-Modulation giving results according to different operating wavelengths in the system shown in Figure 14 also employing an optical amplifier delivers greater quality factor to the communication system than optical amplifier + PMD-E; they gave 542.9 at 1400 nm operating wavelength and 26.36 at 1350 nm as maximum Q-factor, respectively.

Using RZ-Modulation and an optical amplifier alone produced the best system quality and BER performance because it has zero BER at all operating wavelengths, as shown in Table 3. However, using NRZ-Modulation in combination with an optical amplifier and PMD-E, Figure 19 produced better BER readings because it only has a small amount of BER at 1552 nm wavelength. For each working wavelength, the other methods provided the communication system with low BER measurements. The system's smallest BER reading is nearly zero at 1552 nm operating wavelength when the RZ-Modulator and optical amplifier + PMD-E method is used, Figure 17, while it is nearly zero at 1310 nm operating wavelength when the NRZ-Modulator and optical amplifier alone are used in Figure 18.

Our investigational findings demonstrate us that NRZ-Modulation outperforms RZ-Modulation in terms of communication system performance and that the optical amplifier + PMD-E method combination improves receiver performance.

Table 3: Minimum BER readings according to the wavelengths used.

Operating Wavelength	**BER**			
	RZ		NRZ	
	Optical Amplifier alone	Optical Amplifier + PMD-E	Optical Amplifier alone	Optical Amplifier + PMD-E
1310	0	8.41E-32	0	0

1350	0	1.82E-15	0	0
1400	0	3.70E-07	0	0
1450	0	1.66E-08	0	0
1500	0	1.85E-16	0	0
1552	0	2.78E-50	0	0

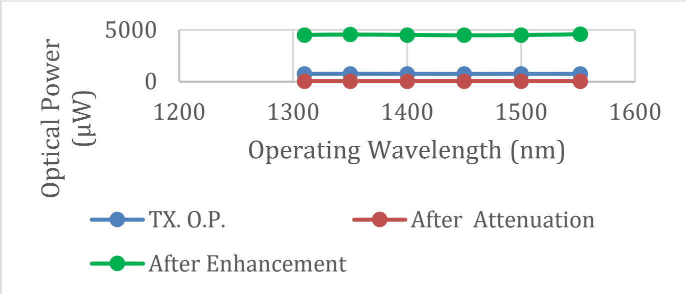

Figure 9: Optical Received Power Versus Operating Wavelength Using RZ-Modulation and Optical Amplifier Alone.

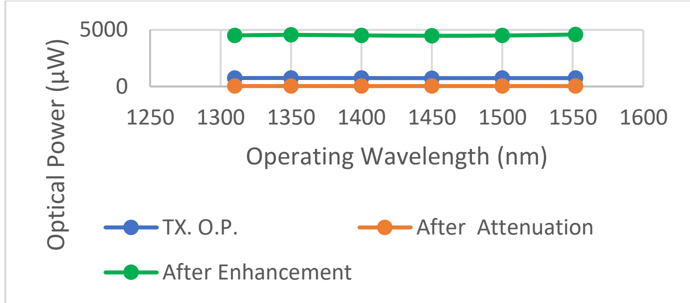

Figure10: Optical Received Power Versus Operating Wavelength Using RZ-Modulation and Optical Amplifier + PMD-E.

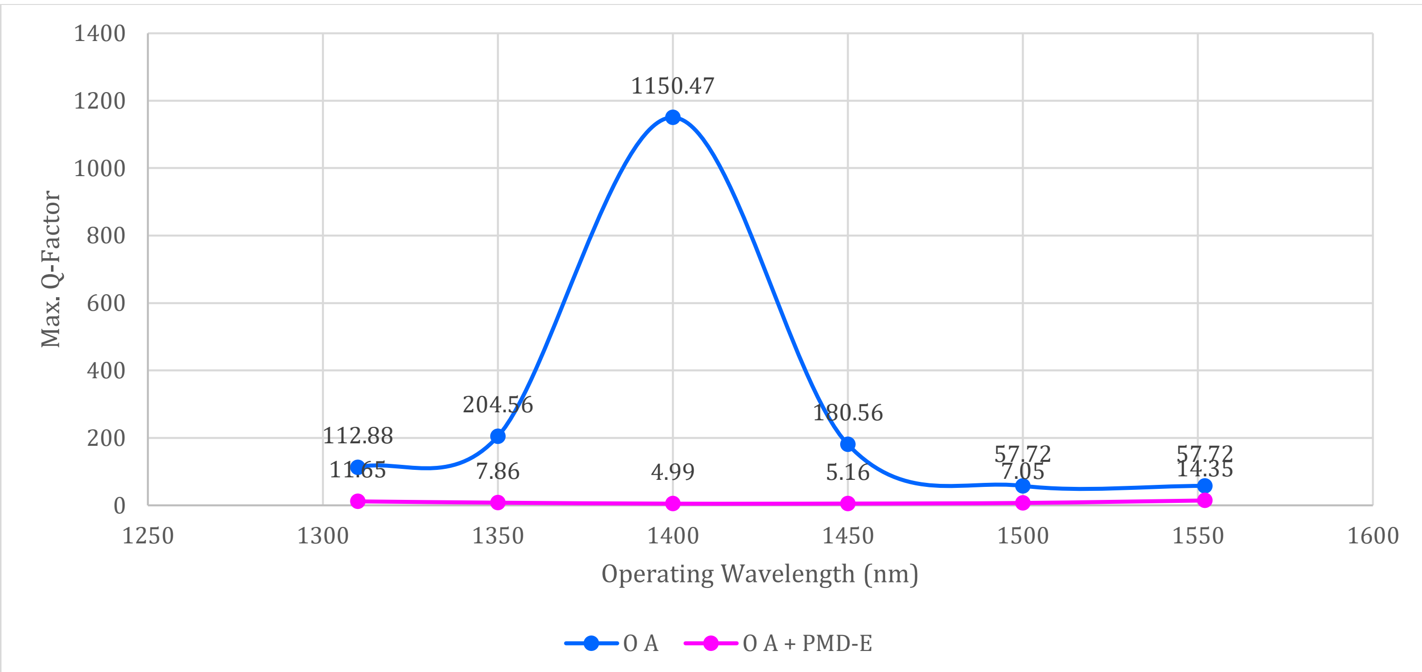

Figure 11: Maximum Q-Factor of Each Amplification Technique using RZ-Modulation.

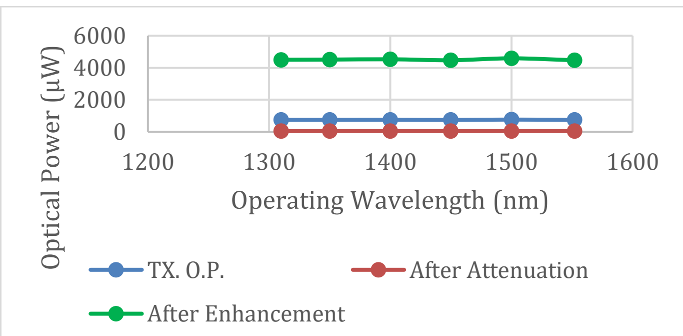

Figure 12: Optical Received Power Versus Operating Wavelength Using NRZ-Modulation and Optical Amplifier Alone.

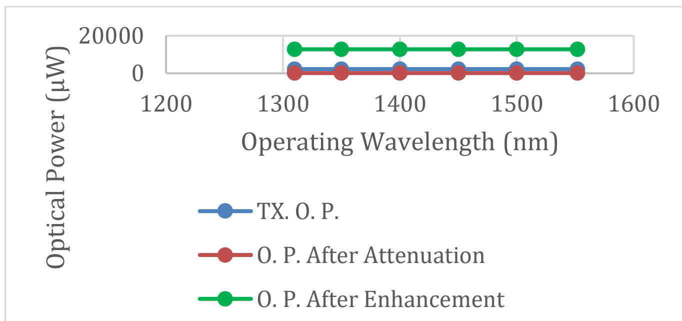

Figure 13: Optical Received Power Versus Operating Wavelength Using NRZ-Modulation and Optical Amplifier + PMD-E.

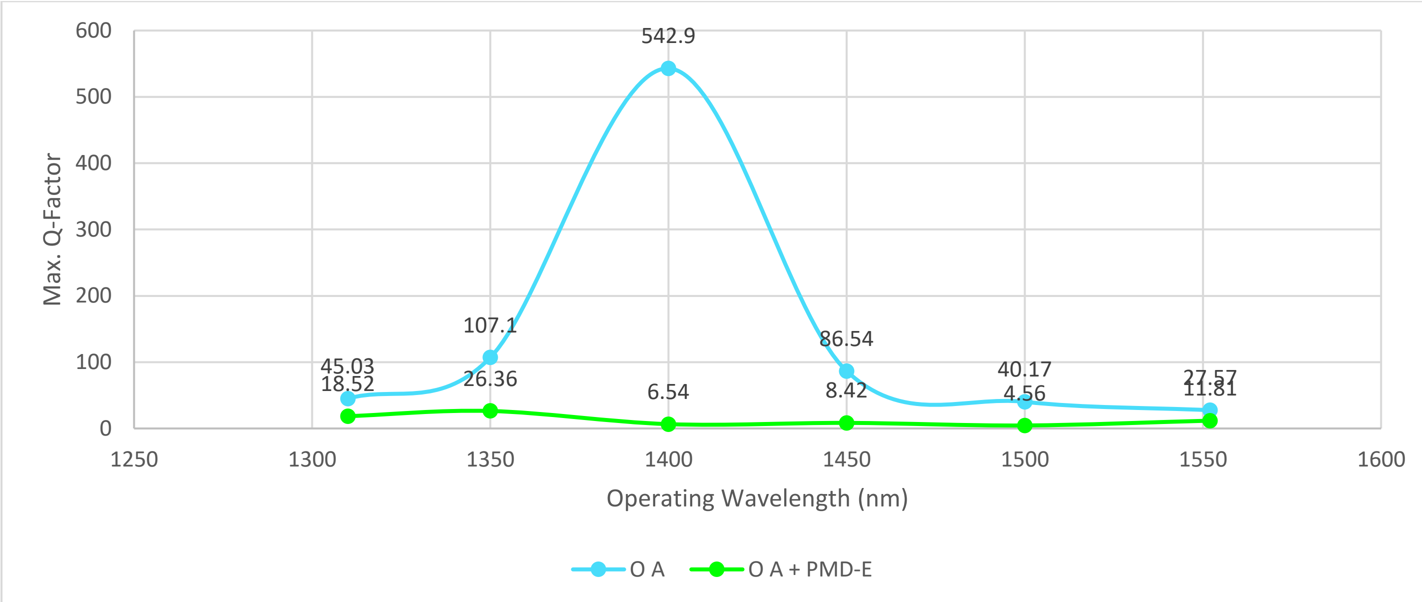

Figure 14: Maximum Q-Factor of Each Amplification Technique using NRZ-Modulation.

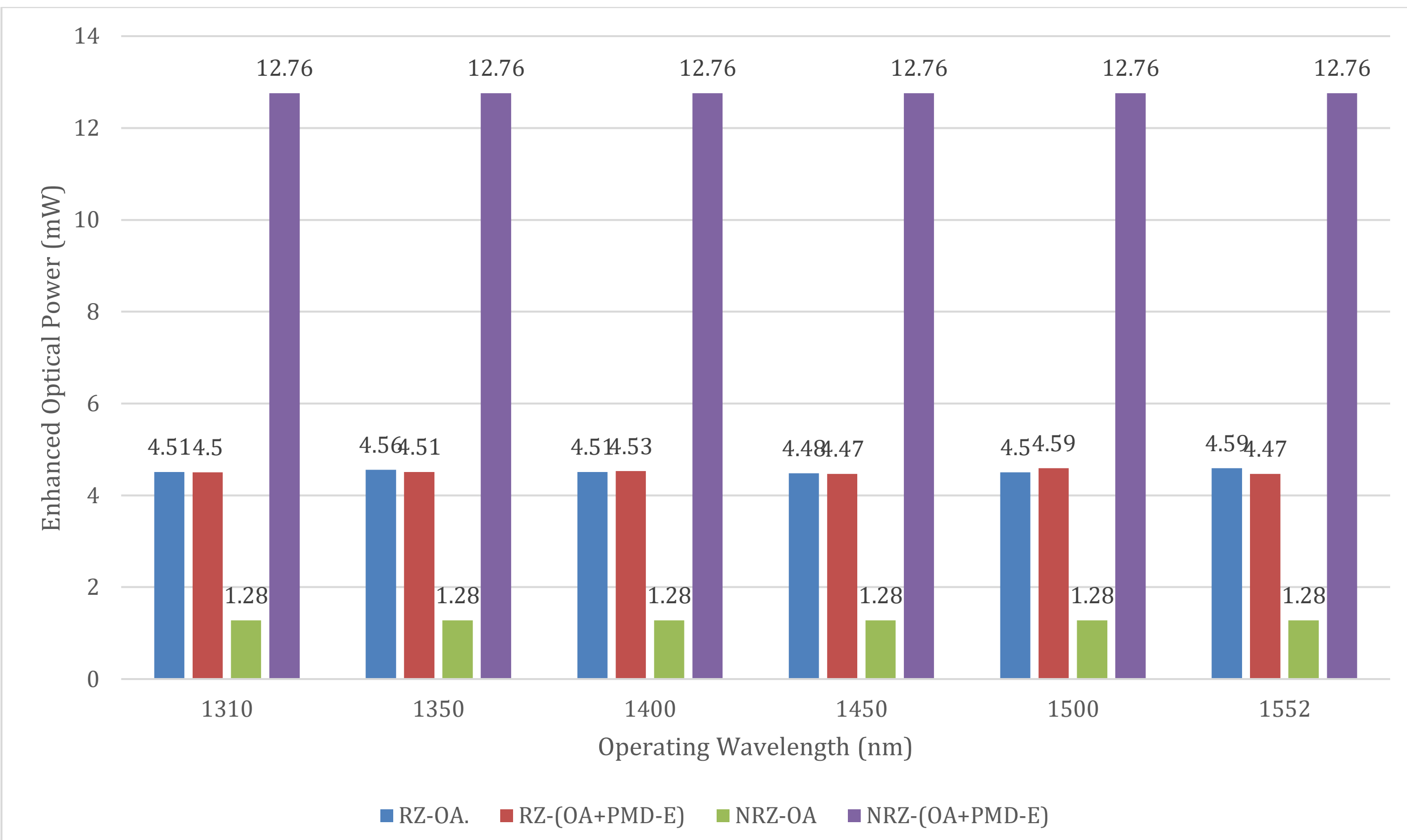

Figure 15: Enhanced Optical Received Power Versus Operating wavelength Showing All Arrangement Techniques.

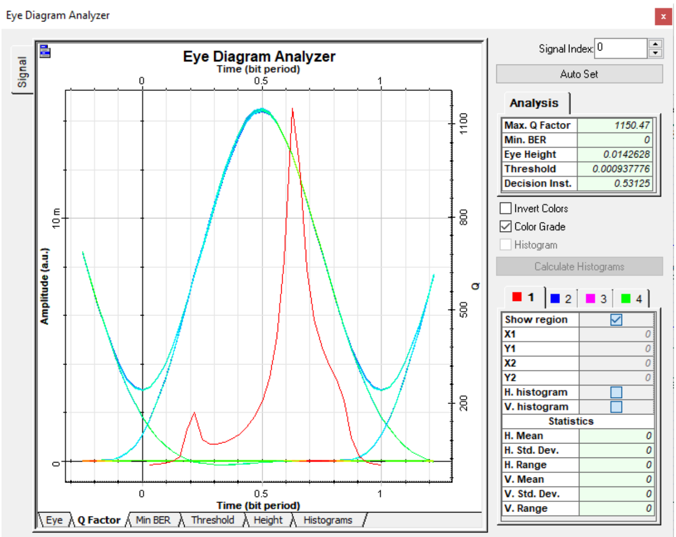

Figure 16: Eye Diagram Case RZ-Modulation and OA Alone.

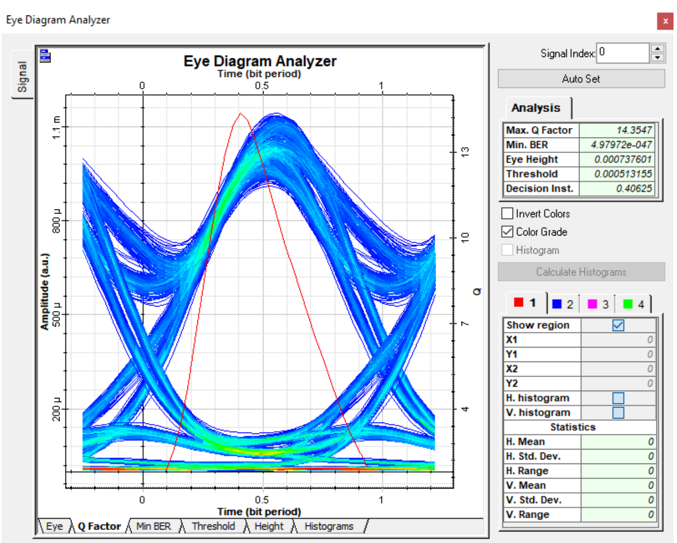

Figure 17: Eye Diagram Case RZ-Modulation and OA+PMD-E.

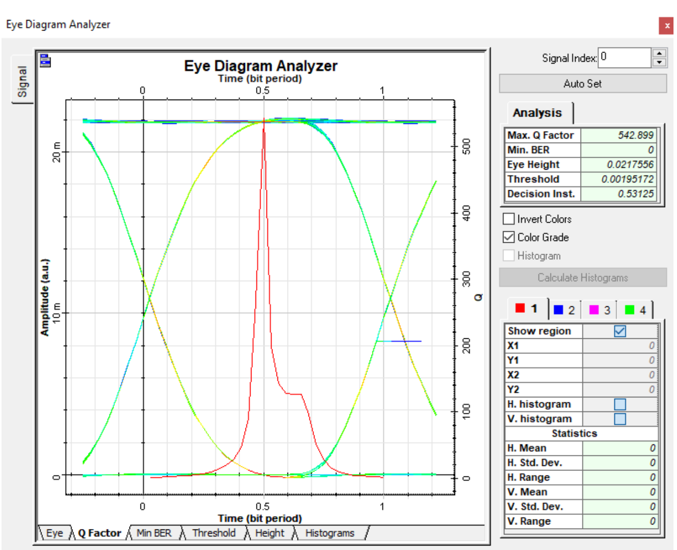

Figure 18: Eye Diagram Case NRZ-Modulation and OA Alone.

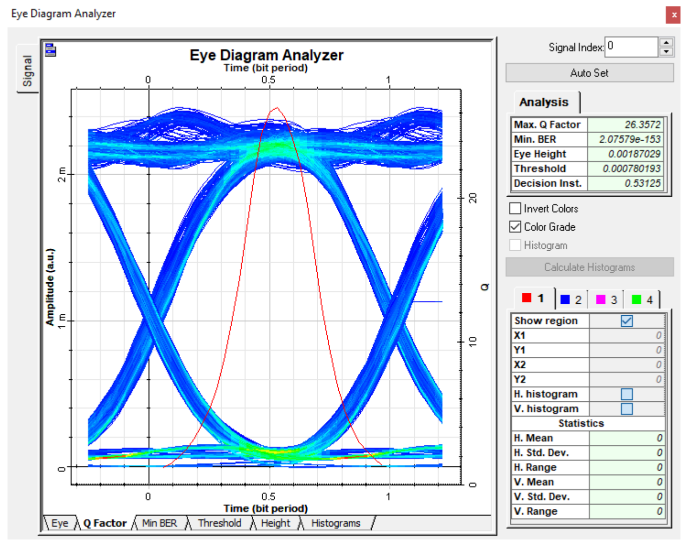

Figure 19: Eye Diagram Case NRZ-Modulation and OA+PMD-E.

Conclusion

In this article, we investigated the power losses brought on the signal transmission through a 50 Km single-mode fiber SMF. We employed optical amplifier alone and optical amplifier + PMD-E in series connection approach to analyze RZ-Modulation and NRZ-Modulation kinds because they attenuate the communication system less than other modulation types. We compared how well each of them performed after reading the data. We looked into and studied how the communication system performed when running at (1310, 1350, 1400, 1450, 1500, and 1552) nm wavelengths. According to the experimental results, the communication system produced superior results when NRZ-Modulation, an optical amplifier and PMD-E were used. In comparison to using the NRZ-Modulator an optical amplifier alone (Figure 9), and RZ-Modulator with optical amplifier + PMD-E (Figure 10) techniques, it gave an enhanced received optical power of 12.76 mW, enhancing an optical power of 0.1235 mW, while they gave the results of 1.28 mW, for a transmitted optical power of 2.25 mW, and attenuated optical following attenuations, the power ratios were 4.59 mW for 40.73 µW and 4.59 mW for 40.56 µW respectively (Figure 15) for all-optical amplifier arrangement techniques.

Also, NRZ-Modulation with an optical amplifier and PMD-E boosted a significant amount of attenuated optical power [P(transmitted) = 2.25 mW, the power before enhancement = 0.1235 mW, that the attenuated optical power becomes 2.1265 µW]. It is possible that after using PMD-E, the Q factor decreases. According to the results, the communication system's quality factor was 1150.47 when RZ-Modulation and an optical amplifier alone reduced to a maximum Q-factor reading of 14.35 after OA + PMD-E were used at operating wavelengths of 1400 nm and 1552 nm, respectively. When NRZ-Modulator and an optical amplifier alone were used, the system's quality factor was 542.9 and it was reduced to a maximum Q-Factor reading of 26.36 when PMD-E was used with the OA., at operating wavelengths of 1400 nm, and 1350 nm, respectively.

The use of NRZ-Modulation and OA techniques to achieve zero-bit error rates improves the communication system's BER readings as well. However, RZ-Modulator and optical amplifier use alone also produced excellent results for the system's bit error rate when compared to other types of techniques used, as shown in the eye diagram figure 18 and 16 respectively.

The output optical power, the quality factor, the signal's quality with a low noise value, and the transmitter's length or propagation time were all improved in this study. The result is that the system design demonstrated an improvement in the receiver's signal detection.

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List of Abbreviations

HM	Hybrid Modulation
OFC	Optical Fiber Communication
RZ	Return to Zero
NRZ	Non-Return to Zero
OA	Optical Amplifier
PMD-E	Polarization Mod Dispersion-Emulator
HA	Hybrid Amplification
Q-F	Quality-Factor
BER	Bit Error Rate
A	Attenuation
L	Distance (Km)
P_o	Optical Output Power
P_i	Optical Input Power
MAC	Macro bending
Q	Constant
K	Wave Number
N	Reflective Index of the Core
Σ	Standard deviation
A	Average half width at 1/e amplitude
Q	Sequence of the amplitude of the modest
Y2	Gaussian-like oscillations of core
L	Time between the Gaussian nodes
W	Patch size
N	Cor's reflection index
n_1	Reflection index of the first substance
n_2	Reflection index of the second substance
Θ_c	Critical angle
C_1	Velocity of light in material 1
C_2	Velocity of light in material 2
V	Poison's ratio
P_{11} and P_{12}	Elements of the photo-elastic tensor
Rb	Fiber bends radios
NA	Numerical Aperture