Analysis of BER for optical transmission link using commercial fibers with and without dispersion compensation

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Abstract: In this paper, an optical transmission link at 10 Gb/s is experimented with Non -Return to -Zero (NRZ) modulated input source with the help of OptSim-software. The performance of the system has been measured in terms of BER for optical link developed using various types-of-fibers at reference loss and wavelength of 1550 nm along with dispersion and nonlinearities whose tolerances have been assessed up to 400 kms. Results have been obtained and compared by considering the impact of second and third order dispersion terms with and without dispersion compensation for different fibers. It has been observed that DS_Anomalous (DSA) fiber shows the best practical results with 10⁻¹⁰ BER value at 246 kms of transmission -distance without dispersion compensation and 340 kms with dispersion compensation.

Keywords: Fibers, Dispersion Compensating Fiber (DCF), Fiber non-linearities and BER.

1. Introduction:

The optical-fiber-systems have massive opportunities in terms of bandwidth up to 50 THz and low loss at 1550 nm central wavelength in communications. The large- bandwidth creates the possibilities of many signals transmission on single line for far distance locations practically. The various design issues and challenges of optical-system for WDM, fiber nonlinearities; dispersion etc. have been explained in [1–3]. To improve the performance of optical system, there can be a need of single-mode -fiber (SMF) along with dispersion shifted fiber to obtain better results. From the long past it has been acknowledged that light-wave communication systems are progressive towards longer transmission distances with big -data transmission capabilities [4]. For the deployment of systems to acquire these features, there is a need of high bit -rates and wavelength division multiplexing for the transmission of multiple signals with maximum power and tolerable receiver sensitivity. In an optical system inclusive -limitations is attenuation in fiber -link which is due to dispersion of signal pulses and nonlinear interaction between light- waves and fiber -medium [5–6]. These limitations may be observed in the performance of system in different signal impairments and fading. (Kuldeep Singh et al, 2017) demonstrated the system evaluation of a 1024 DWDM channels for BER, Eye diagrams and Q-factor with a channel spacing of 25 GHz on simulative model. A transmissible signal has been recovered with upright quality in S, C, L, U-optical bands optical spectra [7]. (Takayuki Kobayashi et al, 2019) explained the needs and applications of high speed networks for bulky data that may be utilized for futuristic IOT network [8]. (Kuldeep Singh et al, 2018) examined the impact of the signal- to crosstalk –ratio (SXR) on the performance of WDM system for radio-over-Fiber (ROF) applications [9].

In this paper, case study of various fiber types for BER values in optical transmission link carried at a central wavelength of 1550 nm along with fiber non-linearities and dispersion in OptSim simulator with dispersion compensation. After presentation of the scheme in section 1, the section 2 presents the system description. The results have been discussed in Sections 3 and Section 4 concludes the paper.
2. System Description

An optical communication system model employing various fibers as shown in fig. 1 has been simulated and analyzed and is set to verify the results with specified system parameters listed in table 1.

![Optical Transmission system under simulation](image)

Table 1. System design parameters

| Block       | Parameter                                | Value | Units      |
|-------------|------------------------------------------|-------|------------|
| Transmitter | Data rate                                | 10    | Gb/s       |
|             | Samples per bits                         | 31    |            |
|             | Random sequence generator size           | $2^7$-1|            |
|             | Laser source power                       | 6     | dBm        |
|             | Laser line width                         | 10    | FWHM       |
|             | Laser phase mode                         | Random|            |
|             | Laser Noise bandwidth (BW)               | Ideal | Hz         |
|             | Bessel filter’s poles                    | 5     |            |
|             | Bessel filter’s loss                     | -3    | dB         |
|             | Bessel filter’s bandwidth (BW)           | 10    | GHz        |
|             | MZ modulator offset voltage              | 2.5   | V          |
|             | MZ modulator extinction ratio            | Ideal |            |
|             | MZ modulator chirp factor                | 0     |            |
|             | MZ modulator average power reduction     | 3     | dB         |
|             | Amplifier small signal gain              | 35    | dB         |
| Receiver    | Band pass filter bandwidth (BW)          | 60    | GHz        |
|             | PIN diode quantum efficiency             | 0.7   |            |
|             | PIN diode dark current                   | 0.1   | nA         |
|             | Bessel filter’s poles                    | 5     |            |
|             | Bessel filter’s loss                     | -3    | dB         |
|             | Bessel filter’s bandwidth (BW)           | 8     | GHz        |
The basic standard properties and parameters of different SMFs used to carry out the analysis of optical transmission system are listed in tables 2, 3 and 4. The fibers declared in the tables have varied dispersion profiles spectra and are counterfeited to evaluate the BER values for optical link in two case studies with and without dispersion compensation. In each case, the fiber transmission length varied from zero to 400 kms for reference wavelength of 1550 nm. The dispersion in optical fibers leads to broadening of pulses and as a result the various spectral components of pulse travel at different group velocities; which results in group -velocity -dispersion (GVD). The optical fiber dispersive model is expressed in terms of standard components D, D’, β₂, β₃, and polarization mode (PM) dispersion. Where D is the standard dispersion parameter used to derive dispersion slope and offset values. β₂ and β₃ are second and third order dispersion parameters whose values for various fibers types are given in tables 3&4. Single -mode fibers with very low losses (~0.2 dB/km) are mainly used in DWDM telecommunication system for high -transmission capacity [3].

Most of the optical-fibers with standard and modified properties make them most appropriate for convinced applications. The uses of fibers in certain applications are selected up on the standard defined parameters like mode field diameter, effective mode area, dispersion parameters, dispersion slope, and nonlinearity coefficient, attenuation (α₀, α₁, and α₂) [10-11].

Fiber-optics technology is changing very fast. For updated knowledge in this field one has to follow the market leaders and their products with every timelines. World manufacturer for the optical-fiber cables are Alcatel-Lucent, Corning, Furukawa Electric Group, and Pirelli Telecom. Alcatel & Lucent optical -fibers are designed for a variety of applications e.g. telecom, media, entertainment and community access television up to range in metropolitan, and terrestrial long-haul and ultra-long-haul transmission worldwide [12-14]. The Corning LEAF Non-Zero Dispersion-Shifted fiber (NZDSF) is single mode fiber which is the industry leader in polarization mode dispersion (PMD) specifications everywhere [15]. Furukawa optical-fibers have the specialty for business development in FTTx, FTTH, Telecommunications [16]. Pirelli Telecom corporate provides complete solutions for the development of nationwide high-speed IP networks optical system for Submarine technology [17].

**Table 2. Standard Properties and Parameters of Different Fibers**

| Fiber Name        | Fiber nonlinearity coefficient [1/W/Km] | Raman Profile Reference frequency (THz) | Raman constant | First Raman time constant (fs) | Second Raman time constant (fs) |
|-------------------|----------------------------------------|----------------------------------------|----------------|-------------------------------|-------------------------------|
| DS_Normal (DSN)   | 1.842                                  | 299.79                                 | 0.18           | 12.2                          | 32                            |
| DS_Anomalous (DSA)| 1.842                                  | 299.79                                 | 0.18           | 12.2                          | 32                            |
| Alcatel SMF (ALS) | 1.240                                  | 299.79                                 | 0.18           | 12.2                          | 32                            |
| Alcatel Teralight (ALT)| 1.559                                  | 299.79                                 | 0.18           | 12.2                          | 32                            |
| Corning LEAF (CLEAF)| 1.407                                  | 206.04                                 | 0.22           | 12.1                          | 31.70                         |
| Corning SMF 28e (CSMF28E)| 1.192                                  | 299.79                                 | 0.18           | 12.2                          | 32                            |
| Corning SMF 28 (CSMF28)| 1.192                                  | 299.79                                 | 0.18           | 12.2                          | 32                            |
| Furukawa SM332 (FKSM332)| 1.172                                  | 299.79                                 | 0.18           | 12.2                          | 32                            |
| Lucent Truewave (LTW)| 1.843                                  | 206.04                                 | 0.20           | 12.1                          | 31.70                         |
| Pirelli FreeLight (PFL)| 1.408                                  | 299.79                                 | 0.18           | 12.2                          | 32                            |
| Pirelli Widelight (PWL)| 1.987                                  | 299.79                                 | 0.18           | 12.2                          | 32                            |
| Sumitomo Z Plus (STZP)| 1.032                                  | 299.79                                 | 0.18           | 12.2                          | 32                            |
| Sumitomo Z (STZ)| 1.419                                  | 299.79                                 | 0.18           | 12.2                          | 32                            |
3. Results & Discussion

A comparative case study has been developed of BER for an optical transmission link with several types of fibers along with a variable transmission distance of 0 to 400 kms for each case. The plotted results for BER versus fiber length with dispersion compensation, reference loss and dispersion wavelength has been presented.

Table 3. Standard Parameters of different Fibers

| Fiber Name                  | $\alpha_0$ (dB/km) | $\alpha_1$ (dB/km/THz) | $\alpha_2$ (dB/km/THz^2) | $D$ (ps/nm/km) | $D'$ (ps/nm^2/km) | $\beta_2$ (ps^2/km) | $\beta_3$ (ps^3/km) |
|-----------------------------|---------------------|-------------------------|--------------------------|----------------|-------------------|---------------------|---------------------|
| DS-Normal (DSN)            | 0.2                 | 0                       | 0                        | -2             | 0.07              | 2.551               | 0.110               |
| DS-Anomalous (DSA)         | 0.2                 | 0                       | 0                        | 2              | 0.07              | -2.551              | 0.118               |
| Dispersion Compensated Fiber (DCF) | 0.55                | 0                       | 0                        | -80            | 0.19              | 102.3               | 0.141               |
| Alcatel-SMF (ALS)          | 0.2                 | 0                       | 0                        | 16             | 0.086             | -20.407             | 0.173               |
| Alcatel Teralight (ALT)    | 0.205               | 0                       | 0                        | 8              | 0.058             | -10.204             | 0.111               |
| Corning-LEAF (CLEAF)       | 0.2                 | 0                       | 0                        | 4              | 0.108             | -5.102              | 0.184               |
| Corning SMF28e (CSMF28E)   | 0.206               | 0.001                   | 1.10 e-04                | 16             | 0.086             | -20.408             | 0.173               |
| Corning-SMF28 (CSMF28)     | 0.235               | 0.002                   | 9.95 e-05                | 16             | 0.086             | -20.407             | 0.173               |
| Furukawa SM332 (FKSM332)   | 0.211               | 0.012                   | 1.06 e-04                | 18             | 0.092             | -22.958             | 0.187               |
| Lucent-Truewave (LTW)      | 0.2                 | 0                       | 0                        | 4.5            | 0.045             | -5.740              | 0.083               |
| Pirelli-Free-light (PFL)   | 0.23                | 0                       | 0                        | 4.3            | 0.114             | -5.484              | 0.194               |
| Pirelli-Widelight (PWL)    | 0.24                | 0                       | 0                        | -6.85          | 0.157             | 8.737               | 0.241               |
| Sumitomo-Z-PLUS (STZP)     | 0.168               | 0                       | 0                        | 20.5           | 0.059             | -26.147             | 0.139               |
| Sumitomo-Z (STZ)           | 0.17                | 0                       | 0                        | 18.5           | 0.056             | -23.596             | 0.130               |

Table 4. Standard Parameters of different Fibers

| Fiber Name                  | Core Effective Area ($\times 10^{-12}$ m^2) | Nonlinear Refractive Index ($\times 10^{-20}$ m^2/W) | PM (ps/√km) |
|-----------------------------|-----------------------------------------------|-----------------------------------------------------|-------------|
| DS_Normal                   | 55                                            | 2.5                                                 | 0.1         |
| DS_Anomalous                | 55                                            | 2.5                                                 | 0.1         |
| Alcatel SMF                 | 81.7                                          | 2.5                                                 | 0.1         |
| Alcatel Teralight           | 65                                            | 2.5                                                 | 0.1         |
| Corning LEAF                | 72                                            | 2.5                                                 | 0.1         |
| Corning SMF28e              | 85                                            | 2.5                                                 | 0.1         |
| Corning SMF 28              | 85                                            | 2.5                                                 | 0.1         |
| Furukawa SM332              | 86.5                                          | 2.5                                                 | 0.5         |
| Lucent Truewave             | 55                                            | 2.5                                                 | 0.1         |
| Pirelli-Free-light          | 72                                            | 2.5                                                 | 0.1         |
| Pirelli-Widelight           | 51                                            | 2.5                                                 | 0.1         |
| Sumitomo Z Plus             | 110                                           | 2.8                                                 | 0.1         |
| Sumitomo Z                  | 80                                            | 2.8                                                 | 0.1         |
The comparison of optical communication system with ALS and ALT fibers has been shown in fig. 2 (a). The plotted results state that optical fiber link using ALT fiber has lesser system BER than ALS fiber and it is found that estimated BER is within $10^{-10}$ for the transmission distance of 279 kms in ALT and 234 kms in ALS. Fig. 2 (b) expresses the evaluation of system using CLEAF, CSMF28e and CSMF28 fibers relatively. The relative observations show that the BER versus length characteristics of optical system with CSMF28e_1550 fiber and CSMF28_1550 fiber look like each other. Moreover, the CLEAF fiber is the most suitable contender for submarine applications up to a transmission distance of 319 kms with dispersion compensation and up to a distance of 242 kms without dispersion compensation by keeping BER value stable at $10^{-10}$. Fig. 2 (c) shows a comparison between optical communication system using STZP and STZ fibers and the observations reveal that at distances approximately 210 kms the characteristics of system for two fibers overlap and past this transmission distance reference the performance of system with STZ fiber improves relative to STZP fiber. However, Sumitomo Z shows very bad performance without dispersion compensation and may only be able to use up to 97 kms. Further, STZP fiber depicts very good performance with dispersion compensation and gives BER $10^{-10}$ at a transmission distance of 234 kms. However, without dispersion compensation the optical link using STZP fiber has the transmission distance limits to value 78 kms only. Fig. 2 (d) illustrates the comparison between light system employing PFL and PWL fibers with dispersion compensation. The results illustrate that fiber family give almost equal performance up to fiber length of 279 kms. However, without dispersion compensation optical communication system using PFL fiber shows better performance and has BER of $10^{-10}$ at a transmission distance of 210 kms. Moreover, PWL demonstrates very good performance with compensation and depicts BER of $10^{-10}$ at a transmission distance of 234 kms, whereas without dispersion compensation it shows very poor performance and gives a BER of $10^{-10}$ at a transmission distance of merely 78 kms. Further, Fig. 2 (e) demonstrates the comparison between fiber links using DSA and DSN fibers with dispersion compensation. The plots show that DSA has better characteristics employing the link up to a fiber length of 340 kms. Moreover, without dispersion compensation the transmission distance is only 246 kms for a BER of $10^{-10}$. Whereas the link with DSN fiber shows a BER of $10^{-10}$ at a distance of 319 kms with dispersion compensation while without dispersion compensation transmission distance limits to 156 kms only. Fig. 2 (f) illustrates the comparison between optical communication system using FKSM and LTW fibers with dispersion compensation. The figure demonstrates that Lucent_Truewave fiber has better performance and has BER of $10^{-10}$ at a distance of 314 kms. Further, Furukawa_1550 fiber also shows very good performance with dispersion compensation and has BER of $10^{-10}$ at a distance of 240 kms. However, without dispersion compensation it shows a very poor system performance of merely 93 kms. The relative performance of optical communication system for variety of fibers with and without dispersion compensation at $10^{-10}$ BER is demonstrated in table 5.
### Table 5. Comparative Analysis of results

| Fiber Name | Transmission Length in kms for BER value of $10^{-10}$ (Without Dispersion compensation) | Transmission Length in kms for BER value of $10^{-10}$ (With compensation) |
|------------|------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| DSN        | 156                                                                                      | 319                                                                                      |
| DSA        | 246                                                                                      | 340                                                                                      |
| ALS        | 204                                                                                      | 234                                                                                      |
| ALT        | 242                                                                                      | 279                                                                                      |
| CLEAF      | 242                                                                                      | 319                                                                                      |
| CSMF28e    | 103                                                                                      | 240                                                                                      |
| Corning-SMF28 | 93                                                                                       | 240                                                                                      |
| FKSM332    | 133                                                                                      | 240                                                                                      |
| LTW        | 208                                                                                      | 314                                                                                      |
| PFL        | 155                                                                                      | 279                                                                                      |
| PWL        | 78                                                                                       | 278                                                                                      |
| STZP       | 97                                                                                       | 234                                                                                      |
| STZ        | 97                                                                                       | 239                                                                                      |

![Graph showing BER at optimal decision threshold](image)
4. Conclusions

The BER for optical communication system has been estimated by employing variety of fibers with and without dispersion compensation for the fiber transmission length varying from 0 to 400 kms. From the demonstrated case studies of optical system link with variety of fibers, it has been observed that for a target BER of $10^{-10}$ DSA fiber shows the finest system services up to a fiber length of 246 and 340 kms without and with dispersion compensation respectively. Further, it has been investigated that CLEAF and DSN may be used up to fiber length of 319 kms with dispersion compensation. Moreover, optical fiber communication system with dispersion compensation LTW fiber is suitable for transmission distance of 280 kms to achieve BER of $10^{-10}$. Further it has been investigated that all the PFL and PWL show equal performance and have BER of $10^{-10}$ at a distance of nearly 279 kms with dispersion compensation. In all the system links, it found that the characteristic of system expressively improves by compensating the dispersion. Further based upon the results reported in this paper it is concluded that for the optimistic system design a fiber selection with suitable properties is most significant to implement an optical communication system in order to keep BER of $10^{-10}$ for a suitable transmission distance with and without dispersion compensation.
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