Modeling of SMF Link for Optical Networks

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ABSTRACT
Innovations in optical fiber technology are revolutionizing world communications. The focus of this paper is the development of optical fibers that within 20 years displaced copper wire as the transmission medium of choice for most commercial applications in telecommunications systems and computer networks worldwide. High speed and ultra-high capacity of optical communications have emerged as the essential techniques for backbone global information transmission networks. As the bit rate of the transmission system gets higher and higher about 40 Gb/s to 100 Gb/s to several terabits, the modeling of proposed modulation techniques is very important so as to avoid costly practical demonstration. This paper thus describes the various losses associated with fiber and its simulation models and its analysis in OptSim. In this work we will be focusing on chromatic dispersion and fiber induced losses. Initially, it will be observing effects of this chromatic dispersion and fiber induced losses on optical communication and then providing a certain technique to minimize the same losses.

General Terms
Measurement, Performance, Optical models and its analysis, Design, Experimentation, Theory, Verification.

Keywords
SMF, DCF, CW laser, PRBS, EDFA, Optsim, Digital modulation schemes, NRZ, Linear MZ, Eye diagram, BER.

1. INTRODUCTION
The transmission rate can exceed 2 Gbps, nowadays around 6~8 Gbps and is the highest transmission medium in the world. Recently, in telecommunication field is laying fiber optic cables to provide data super highway to support personal video services. It is expected that the future communications network will consist of one optical fiber with coaxial cable as the backbone within the building [1]. The terminator erected around each three stories will provide a transmission bandwidth to each household at 20 Mbps. At this speed you can use it to watch movie, shopping, a real e-commerce world. Optical fiber can be used as a medium for telecommunication and networking because it is flexible and can be bundled as cables [2]. It is especially advantageous for long-distance communications, because light propagates through the fiber with little attenuation compared to electrical cables [6]. This allows long distances to be spanned with few repeaters. Additionally, the per-channel light signals propagating in the fiber have been modulated at rates as high as 111 Gigabits per second by NTT, although 10 or 40 Gb/s is typical in deployed systems. Each fiber can carry many independent channels, each using a different wavelength of light (wavelength-division multiplexing (WDM)). Fiber optic sensor: Fibers have many uses in remote sensing. In some applications, the sensor is itself an optical fiber. In other cases, fiber is used to connect a non-fiber optic sensor to a measurement system. Time delay can be determined using a device such as an optical time-domain reflectometer [8].
Ever since the ancient times, one of the principle interest of human beings has been to device a communication systems for sending messages from one distant place to another [4, 5]. The fundamental elements of any such communication system [10] are as shown in fig 1.

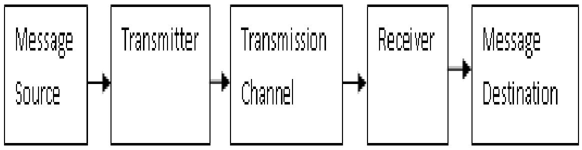


Fig 1: Fundamental elements of communication system

Optsim [11] is an advanced optical communication system simulation package designed for professional engineering and cutting-edge research of Wavelength Division Multiplexing (WDM), Dense Wavelength Division Multiplexing (DWDM), Time Division Multiplexing (TDM), optical Local Area Network (LAN), parallel optical bus, and other emerging optical systems in telecom, datacom, and other applications. It includes the most advanced component models and simulation algorithms, validated and used for research documented in numerous peer-reviewed professional publications, to guarantee the highest possible accuracy and real-world results. OptSim represents an optical communication system as an interconnected set of blocks, with each block representing a component or subsystem in the communication system. These can easily be selected in the component model parameter editing window. Simulation results that are produced by OptSim include signal waveform plots and eye diagrams at any point within the optical communication system, and bit error rate (BER) plots vs various parameters within the system such as the received optical power. Other simulation results are also available, including signal spectra, frequency chirp, power and dispersion maps, and more [3, 9].

2. MODELING OF OPTICAL FIBER LINK USING OPTSIM

2.1 Dispersion measurement

This example illustrates one of the simpler methods for measuring the average dispersion of a fiber. This method requires measuring the "electrical-to-electrical" transfer function of a link composed of a linear optical modulator, a fiber under test and a photodiode. The average dispersion is related to the first zero of the resulting transfer function. The following law expresses the resonance frequency *fu* corresponding to the u^{th} zeros of the transfer function:

$$f_u^2 L = \frac{C}{2D\lambda^2}\left(1 + 2u - \frac{2}{\pi}\arctan(\alpha)\right)$$

Where L is fiber length, D is the fiber dispersion and α is the modulator chirp. The model for the same is as shown in fig 2.

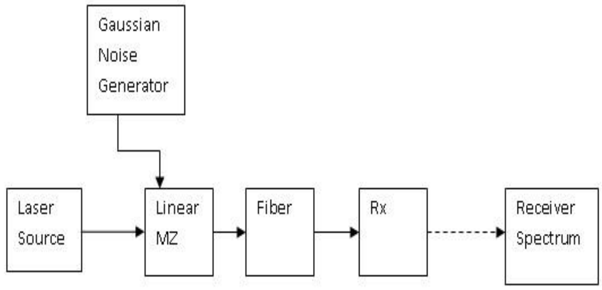


Fig 2: Model for Dispersion measurement

2.1.1 Chromatic dispersion

In fig 3 shows the block diagram for the chromatic dispersion. The model simulates a single-channel link. The three different lengths of the single mode fiber (70 km, 80 km and 115 km) accumulate different amount of chromatic dispersion. Since our main focus here is to see the effect of chromatic dispersion-induced penalties, fiber-loss, non-linearties and PMD (polarization mode dispersion) are ignored.

2.1.2 Dispersion compensating fiber (DCF)

The most common dispersion compensation technique used in long-haul links uses short lengths of DCFs followed by relatively longer lengths of transmission fibers in each span is shown in fig 4. This is also known as post-compensation of chromatic dispersion. The 20 km of DCF above in each span has negative dispersion slope. The net accumulated dispersion in each of the 20 spans is non-zero in order to help control nonlinearity-induced performance penalties. The amplifier in each span compensates for the fiber attenuation. The total length of the link is 2000 km.

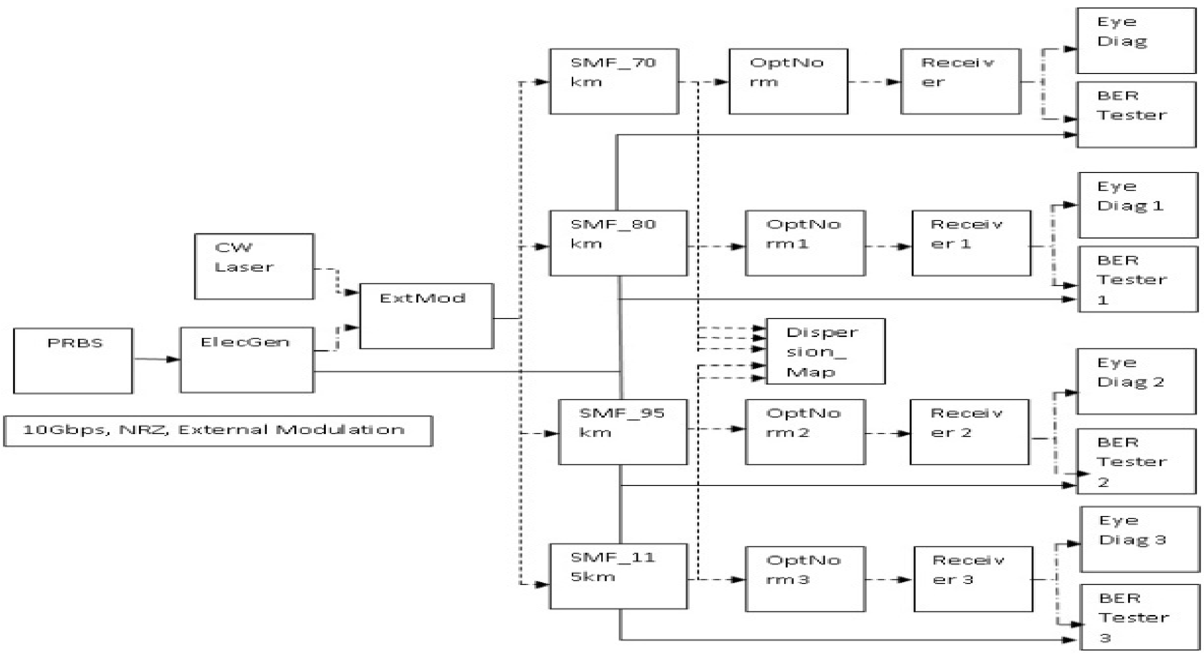


Fig 3 : Model for studying chromatic dispersion

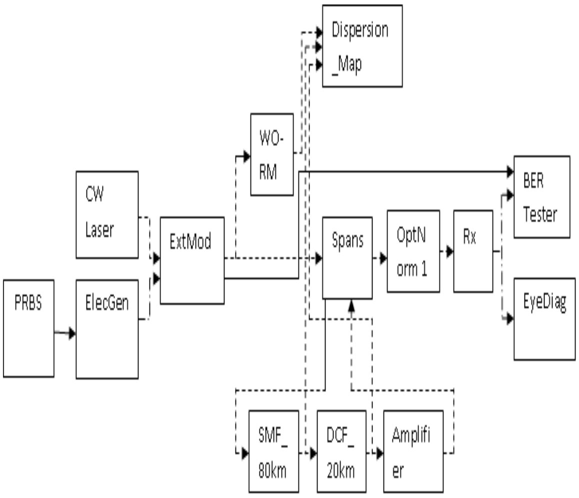
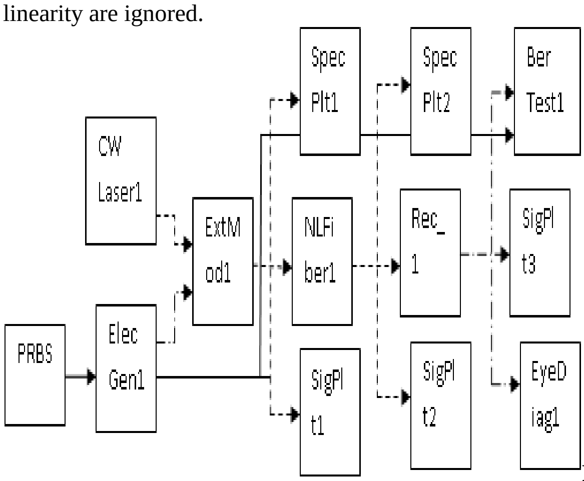


Fig 4 : Model for dispersion compensation

3. Fiber induced loss and compensation

3.1.1 Effects of fiber-induced loss

The model shown in fig 5 simulates a single-channel link. The transmitted power is kept constant while the bit-rate and the length of the fiber are varied. Since our main focus here is to see the effect of fiber-induced loss, dispersion and non-linearity are ignored.



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g 5 : Model for studying fiber induced losses

Fiber-induced signal loss puts limit on the transmission distance. The most common approaches for loss compensation are to use either (i) Lumped Amplification or (ii) Amplification scheme that makes use of distributed Raman amplification.

3.1.1.1 Lumped Amplification

The model for this scheme looks like as shown in figure 6. In the fig 6, the transmitter part comprises of the basic components like random generator, electric signal generator, the CW laser and the external modulator used to modulate the optical signal before being send to the span of fiber. The total length of the transmission distance more than 1600 km comprises of 20 spans each of which has 80 km of single mode fiber followed by a 10 m length of erbium-doped fiber.

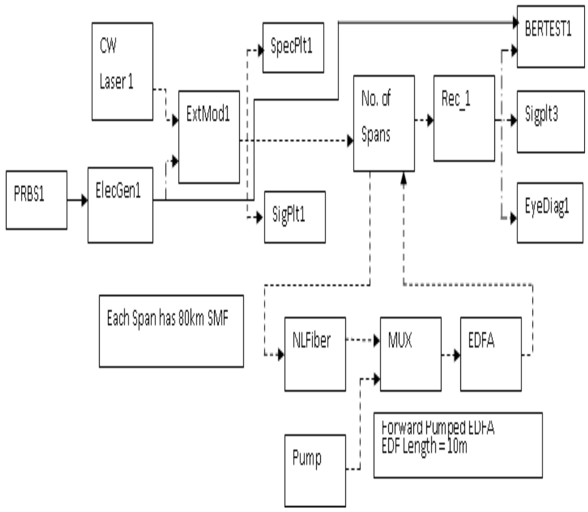
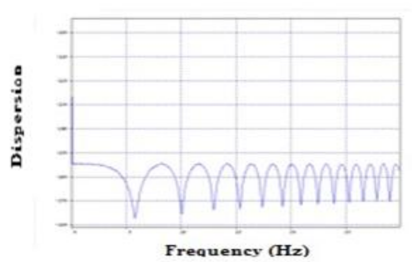


Fig 6 : Model for lumped amplification

In a single span of fiber, it have a 80 km of SMF and a forward pumped EDFA of 10 km. The signal from the SMF and a high signal generating pump is being fed to a multiplexer. The multiplexer combine's data channels with the pump signal. The erbium-doped fiber acts as an amplifier thereby compensating for the signal loss occurring in the 80 km span of the single mode fiber preceding it.

4. RESULT & DISCUSSION

Result 1: The result for dispersion measurement is as shown in fig 7. From the result, it is come to know that as the frequency increases the dispersion increases. As it is seen in fig 7 that at lower frequency the dispersion across the fiber is less but at higher frequency, dispersion also increases.



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g 7 : Result of dispersion measurement

Result 2: The result for chromatic dispersion as shown below in fig 8. It begin with discussion by first observing the effect's of chromatic dispersion over 70 km, then 80 km and then 115 km. The eye daigram as a part I shown in fig 8,9,10 and the BER result as a part II shown in fig 11,12,13.

Part I: Eye diagram

(a) 70 km

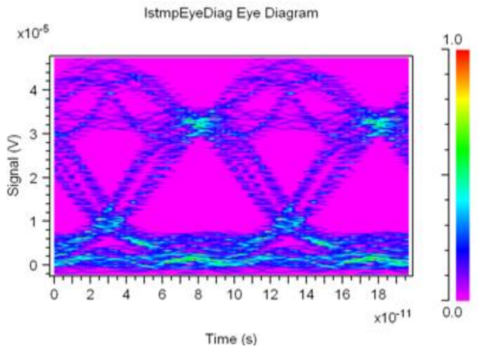


Fig 8 : Eye diagram at 70 km

The signal amplitude in volt vs time in sec for eye diagram as shown in fig 8 with eye opening at $3.5*10^{-5}$ V.

(b) 80km

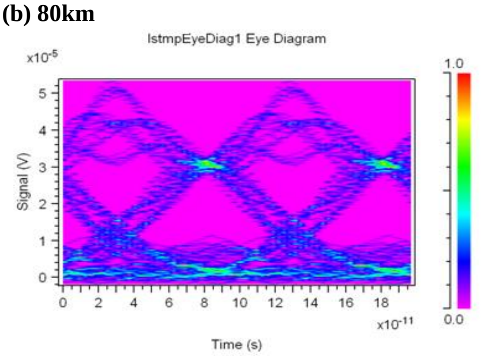


Fig 9 : Eye diagram at 80 km

As per the eye diagram as shown in fig 9, the eye opening has reduced to 2.8 * 10^{-5} V as compared to the previous eye diagram at 70 km is 3.5 * 10^{-5} V. This gives the result as the distance has slightly increased the chromatic dispersion taking place in the fiber and also increase leading to fiber induced losses.

(c) 115 km

The eye diagram shown in fig 10, the eye opening has reduced to $2.4*10^{-5}$ V, which is much more reduced as compared to the previous eye diagram 70 km and 80 km, which gives the result as the distance increases, more is the chromatic dispersion taking place in the fiber leading to fiber induced losses.

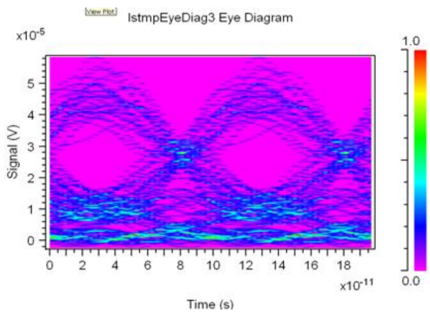


Fig 10 : Eye diagram at 115 km

Part II: Bit Error Rate (BER)

In digital transmission system, the number of bit errors is the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronization errors. The bit error rate or bit error ratio (BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval.

(a) 70 km

The BER result as shown in fig 11, it observe that BER of the transmission system with 70 km fiber is 5.7026 * 10^{-15}.

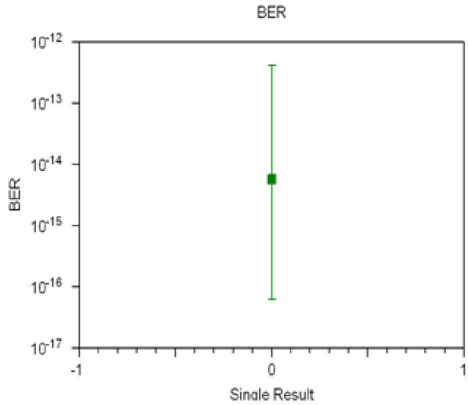


Fig 11 : BER at 70 km

(b) 80 km

The BER result shown in fig 12, it observe that the BER of the transmission system with 80 km fiber is increased to 3.7905 * $10^{-12.}$ as compared to the previous BER which is 5.7026 * 10^{-15} at 70 km. This gives the result as the distance has slightly increased the BER also increased.

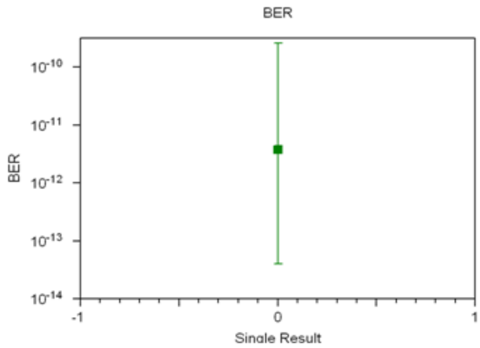
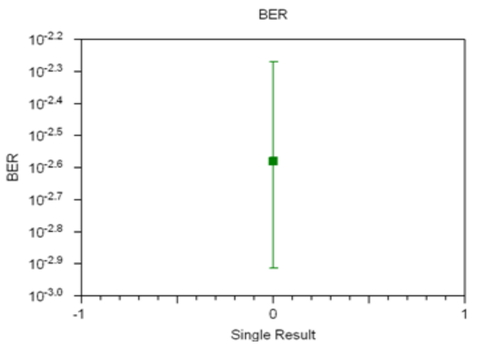


Fig 12 : BER at 80 km

(c) 115 km

The BER result as shown in fig 13, it observe that the BER of the transmission system with 115 km fiber is increased to 2.629 * 10^{-3} as compared to the previous BER, which is 5.7026 * 10^{-15} at 70 km, 3.7905 * 10^{-12} at 80 km. Thus we can conclude that with the increase in distance BER also increases. And also the chromatic dispersion increases which further gives fiber induced losses.



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g 13 : BER at 115 km

Result 3: The eye daigram for dispersion compensation is as shown in fig 14. In this eye diagram, the amplitude of the signal is $9*10^{-6}$ V, which is much more reduced as compared to the previous 70 km, 80 km and 115 km. From this, we come to know that after using this dispersion compensation technique the dispersion in the fiber is reduced..

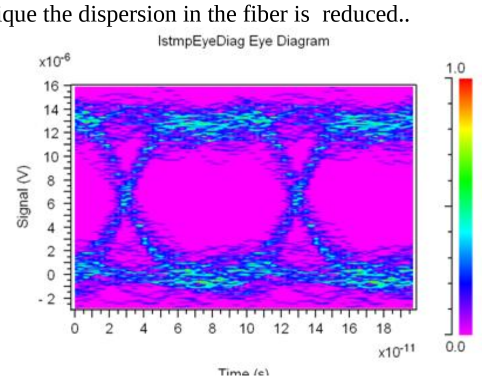
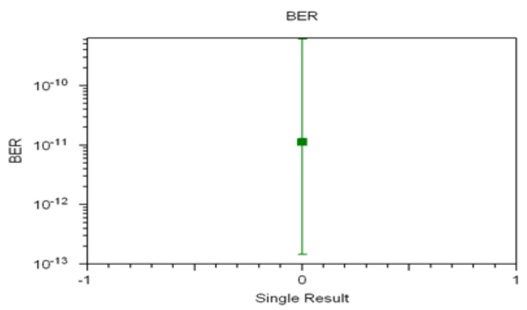


Fig 14 : Eye diagram after 2000 km of dispersion compensated transmission

From the BER result is shown in fig 15, it observe that the BER of the transmission system is $0.25 * 10^{-11}$. The BER for the system is shown in below fig 15.



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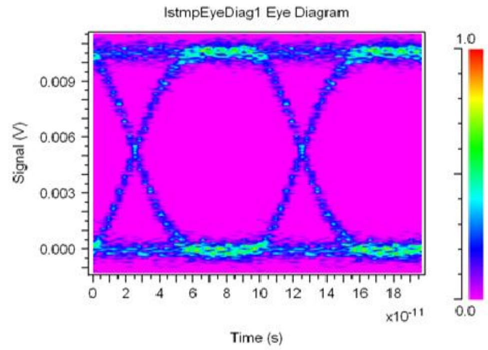
g 15 : BER after 2000 km of dispersion compen-sated transmission

Result 4: The amplitude of the eye diagram as shown in fig 16 is 0.010 V. From the BER result as shown in fig 17, it observe that the BER of the transmission system is 10^{-100}.



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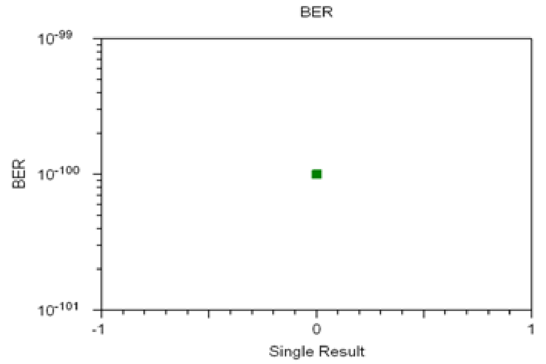
g 16 : Eye diagram for chromatic dispersion compensation



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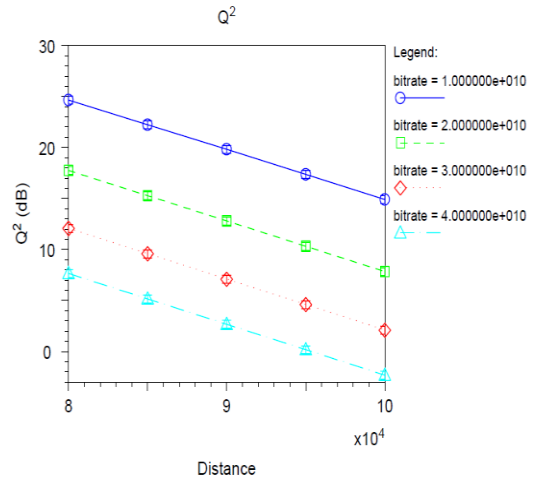
g 17: BER for self induced loss

As per the fig 18 (a) & (b) shown below illustrates what impact the fiber attenuation can have over the supportable data rates and distances. The length of the fiber and the bit-rates are changed to get about four to five readings. Then the BER versus the distance and the Q factor versus the distance graphs are plotted at the different bit rate readings as shown in fig 18 (a) & (b) respectively.



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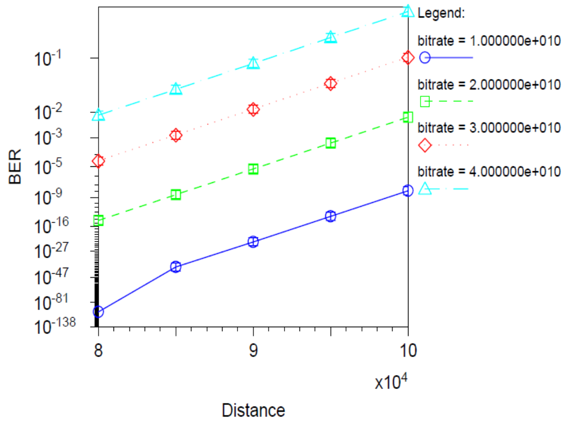
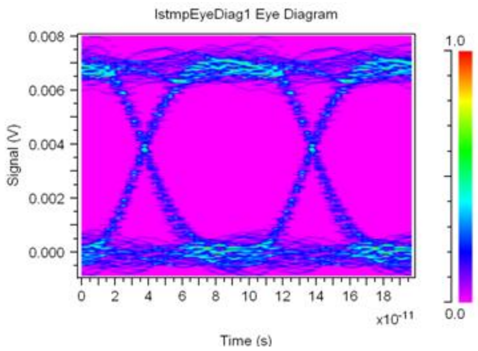
g 18 (a) : Q and BER plotted against the supp-ortable distance and the bit rate



Fi g 18 (b) : Q and BER plotted against the supportable distance and the bit rate

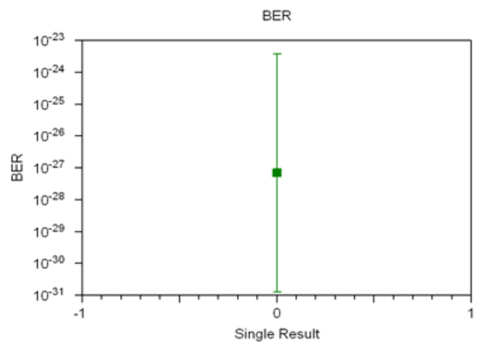
As seen from the above fig 18 (a) & (b), for a given transmission system, the receiver sensitivity, transmission power and the bit rate, the fiber loss can severely deteriorate the transmission signal.

Result 5: The below fig 19 shows the eye daigram of lumped amplification.The eye diagram with amplitude is 0.006 V which is less as compared to eye diagram amplitude value of the self induced losses.



Fi g 19: Receiver eye diagram after lumped amplification

From the BER result block shown in fig 20, we observe that the BER of the lumped amplification is 10^{-27}. The BER for the system is as shown fig 20.



: BER for lumped amplification

5. CONCLUSION

This paper described the architecture of the single mode fiber compatible transmission systems as well as some ideas for DCF compatible components. So, basically it is implemented single mode fiber transmission system which shows various ways to reduce the fiber induced losses as well as the dispersion losses. This paper shows a certain conclusions. The DCF helps compensating for chromatic dispersion thereby allowing transmission over longer distances. The compensation of fiber loss using lumped amplifier stages helps transmit over longer distances. Distributed amplification help overcome signal attenuation thereby allowing larger transmission distances, like in most designs, the choice of appropriate loss compensation scheme such as lumped, or distributed or both will depend on the trade-offs between the design objectives vis-à-vis cost, performance penalties, etc.

6. ACKNOWLEDGMENTS

Our thanks to RSoft team Mr Joshi and Mr Sujal Shah for their technical support for modeling of optical fiber link.

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