Analysis of lightwave system using negative dispersion fiber and high speed optical telemetry

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Abstract— **High bandwidth and fast packet processing is the need for this fast-moving communication environment. Users are in consistent need of higher data transfer with minimum delay. This research paper focuses on the simulative analysis of high data rates using optical telemetry implemented using low negative dispersion optical fiber. Low powered optical signal will be analyzed for longer transmission channels having adequate frequency magnitudes. Subsequent high-efficiency network will be realized and will be compared using similar telemetry on the lightwave system. Simple light signals will be transmitted with the help of continuous wave laser generator and then these originated signals will be merged with pulse and sequence generators for fancy output. This combined signal will be transmitted through MetroCor optical fiber and an EDFA will be present at the receiver side to provide the gain for proper analysis of the received signals. To avoid any loss in the light signal, MetroCor optical fiber will be implemented which itself is a low negative dispersion optical fiber. This fiber will replace the SMF-28 in the optical network and as a result, the need for DCB's will be eliminated. Results based on 65 Gbps data rate having transmitting power of 0 dBm will be analyzed for high-speed communication networks.**

Keywords— **Simple Mode Fiber (SMF), Optical Access Network (OAN), Bit Error Rate (BER), Non-Return to Zero (NRZ), Pseudo Random Bit Sequence Generator (PRBS), Erbium-Doped Fiber Amplifier (EDFA), Optical Signal to Power Ratio (OSNR).**

I. INTRODUCTION

Optical Access Network (OAN) [1] is the practical term for the lightwave systems when implemented on ground levels beyond the analytical phase of the communication. A traditional copper wire-based system is grappling hard to stay in the competition of communicating networks in terms of speed, data rate, power and reliability. Some of the drawbacks of these wires are the electromagnetic induction (when operating at higher power levels), lower bandwidth, smaller immunity levels to the losses and also high consumption of input power levels [2]. Optical networks are able to find a place in the rack to rack interconnected networks in this era of globalization.

The lightwave system comprises of the three sections i.e. the transmitter, the channel and the receiver section. Optical fiber transmissions are the backbone of any network in this era of digitization and it is expanding with course of time. For higher bit rate transmission, the power of CW laser has to be increased but if power is increased then optical non-linear ambiguities [3] will be introduced in the network such as Self Phase Modulation (SPM), Cross Phase Modulation (XPM), Four-Wave Mixing (FWM), Stimulated Brillouin Scattering (SBS), Stimulated Raman Scattering (SRS), etc. In case of lower optical transmission power there are fiber linearities and in signals higher than the predefined threshold transmission power, the errors are referred as fiber non-linearities. Where SPM is the change in properties of the transmitted light signal when it travels from varying refractive indexes, XPM occurs when two signals of similar characteristics travel along the same channel, FWM is the generation of another unwanted wavelength when two or more than two optical signals are present in the single channel having nearby parameters, where SBS and SRS deal with the photons of the optical fiber. On the other side when the information is to be sent to smaller distances the power can be reduced from the predefined threshold value but this phenomenon is also not feasible without the optical linearities such as polarization dependent losses like Polarization Mode Dispersion (PMD), filter concatenation, amplifier noise [4], attenuation, etc. In shorter distances, the amplifier is implied at the intermediate communicating network nodes of the lightwave system and when the same optical signal undergoes continuously amplification then minor losses are visible. Scattering, dispersion, reduction in transmitted power at the channel side are some of the few negativities which degrades the quality factor of the overall communication system and raises the BER (Bit Error Rate). The objective of this paper is to minimize the fiber non-linearities while having adequate power as well as frequency levels and to find out an optimized transmission distance that can handle the higher transmission data from source to the receiver side.

II. OPTICAL ARCHITECTURE

Power and frequency of CW laser are constant throughout the research work which stands at 0 dBm and 187 THz respectively whereas the frequency of low pass bessel filter also remains unchanged i.e. 35.5 GHz. The order and mark probability of Pseudo Random Bit Sequence Generator (PRBS) is 6 and 0.5 respectively, whereas the rise time and fall time for Non-Return to Zero (NRZ) pulse generator is 0.05 per bit and the amplitude is 1 a.u. Mach zehnder modulator controls the amplitude and phase of the light signal and the extension ratio for this modulator is 100 dB whereas the symmetry factor stood at -1. Parameters of MetroCor optical cable are also prefixed which are 5.8 ps/nm/km (time per wavelength per distance) for the dispersion and 0.12 ps/nm^2/km for the dispersion slope, whereas the reference wavelength taken is 1550 nm. Erbium-Doped Optical Fiber Amplifier (EDFA) has the fixed values for gain (35 dB) and noise figure (0 dB). Whereas the responsivity and dark current of the photodetector PIN are 1 A/W and 10 nA respectively. 35.5 GHz is the value of the cut off frequency of the low pass bessel filter. Optical power meter visualizer, BER analyzer and oscilloscope visualizer have been incorporated at different nodes for the proper analysis of the signals.

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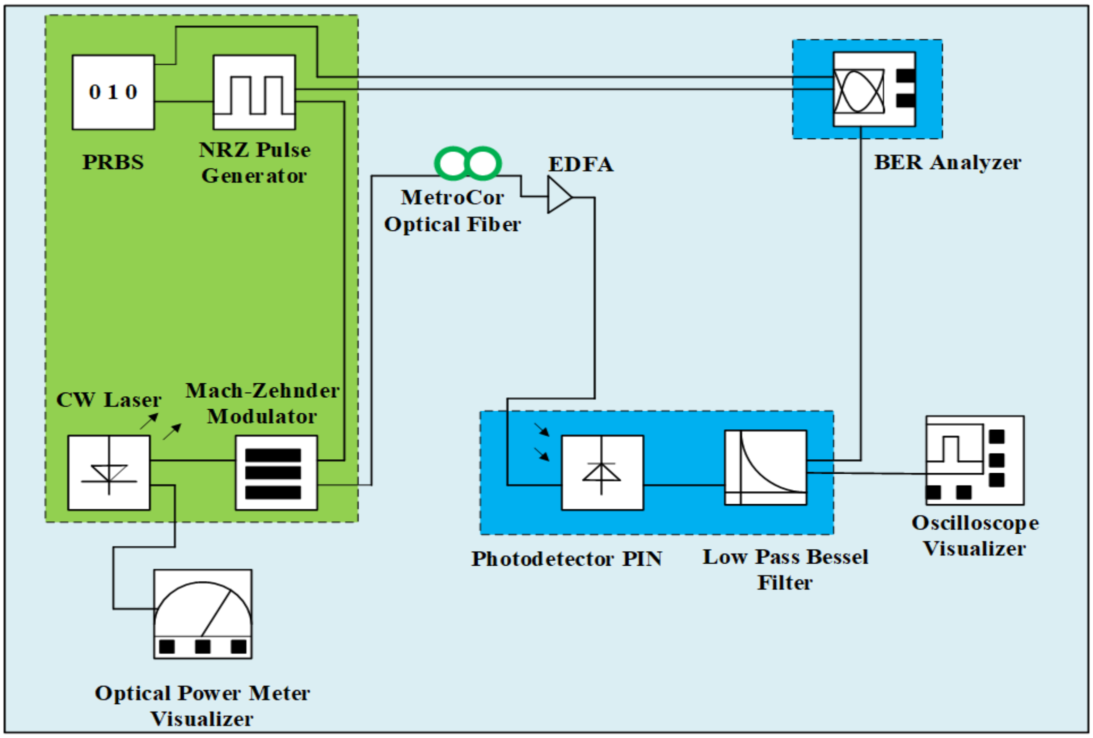


Fig 1. Simulation setup of the optical telemetry. Transmitter section is in green whereas the receiver part is in blue background.

Pseudo-Random Bit Sequence device (PRBS) generates a binary sequence of numbers with a predefined algorithm. The PRBS works on the analog behavior to fulfill the task of information conversion. Non-Return to Zero generator has more power than return to zero generator and also have parallel synchronization signals. Continuous Wave (CW) laser generates optical signals to be forwarded to mach-zender modulator. The optical signal produced is having frequency and power of 187 THz and 0 dBm respectively. An optical power visualizer is used to have a controlled generation of the light signal.

This light signal is then fed to the MetroCor Optical fiber. Where MetroCor optical fiber is the low negative dispersion fiber cable that does not need the DCB's therefore, reduces the installation cost of the system whereas the SMF-28 [5] cannot remove the dispersion at its own and need some external phenomenon to eradicate the BER. There are three dispersion compensation techniques such as pre, post and symmetric compensations and according to the need of application anyone of these techniques can be implemented. Where pre-compensation involves the eradication of non-linearities before the transmission, post-compensation method does this after the signal reaches the destination side and the symmetric compensation technique employs a mixture of different dispersion compensating methods.

EDFA is providing ideal gain [6] of 35 dB to the incoming signal with a noise figure of 0 dB. A photodetector PIN diode is implemented at the receiver side which creates a corresponding current when light signals make a contact with the diode. Then, this signal is fed to the low pass bessel filter having a cutoff frequency of 35.5 GHz. This filter allows only lower order signals to pass and drops all other higher voltage signals. An oscilloscope visualizer and BER analyzer is used at the receiver part in order to have a clear view of the received signal. These end devices help in the in-depth analysis of the received signal and provide sufficient statistics for further examination of the captured light wave.

III. RESULTS AND DISCUSSION

The performance of the optical network having SMF-28 fiber as the communication channel has been improved [7] by many sequential procedures, these methods are obtained with the help of optimization techniques. Firstly, the SMF-28 is replaced with the low negative dispersion optical fiber named as MetroCor fiber, then removal of DCB is done, furthermore by increasing the cut off frequency of low pass bessel filter to 35.5 GHz and finally by reducing the frequency of CW laser from 193.1 THz to 187 THz. These optimization techniques aided in the gain of high overall efficiency of the optical telemetry and it involves lesser investment in terms of physical hardware.

The central point of the research work is to find out an optimum value that holds the capacity to transmit 65 Gbps of data rate at reduced power (0 dBm) with optimum frequency (187 THz). To achieve the desired output statistics, the transmission distance has been varied from 500 to 100 km, data rate from 80 to 50 Gbps and power from -10 to 10 dBm. As quality factor (efficiency) and BER (losses) are inversely proportional to each other i.e. if efficiency elevates then the losses gradually drop [8]. A number of iterations have been performed but for better understanding and easy implementation, optimized values are discussed.

500 km of transmission distance yields quality factor of 11.1775 and BER of 2.60e-029, 400 km gives efficiency and losses of 13.449 and 1.55e-041 respectively whereas 300 km has relatively similar productivity of 14.0879 and BER of 2.21e-045. 17.5992 gain and 1.22e-069 of loss is observed in 200 km fiber cable and 100 km witness an increase in quality factor i.e. 23.9681 and has corresponding BER of 2.95e-127.

35 Gbps of data rate produces quality factor and BER of 54.05 and 0 respectively. Whereas the gain reduces to 19.8303 at 50 Gbps and losses are 6.36e-088. The quality factor reduces at an increased data rate of 65 Gbps which is 14.0879 and depletion is 2.21e-045. Whereas 80 Gbps data rate has efficiency and BER of 7.73846 and 4.93e-015 respectively. Where 15 Gbps increase in data transmission rate i.e. 95 Gbps has a lower gain of 4.12 and adequate errors of 1.80e-005.

Power is fluctuated from -10 to 10 dBm and -10 dBm witness productivity of 15.182 and errors of 2.19e-052 whereas -5 dBm has efficiency and losses of 14.9823 and 4.64e-051 respectively. 0 dBm receives effectiveness of 14.0879 and BER of 2.21e-045. In addition to these values, 5 dBm of power earns gain of 10.8825 and dissipation of 6.89e-028. Discussing the final iteration, 10 dBm of transmission power has quality factor and BER of 3.70 and 9.68e-005 respectively.

- *Principle Calculation.*

To evaluate the performance of the receiver side Q factor is considered. Where the Q factor or the quality factor is the direct function of OSNR. It is calculated by dividing the difference in mean values of two signals by the sum of noise deviations of the same signals. The OSNR ratio will increase with the elevation in the bit rate. Moreover, as the BER increases the Q factor is depleted simultaneously. The eye diagrams will depict the output signal at the receiver side. Greater the height of the eye diagram lesser will be the losses and the signal will have corresponding higher Q factor. Q factor and bit error rate could be calculated from the following principle formulas and the numerical statistics, as well as the charts, will be shown and discussed thereafter:

$$Q = \frac{|\mu_1 - \mu_0|}{\sigma_1 + \sigma_0} \tag{9}$$

$$\text{BER} = \frac{1}{2}\, erfc\left(\frac{Q}{\sqrt{2}}\right) \tag{10}$$

When the predefined threshold value is made constant to the desired values, then the BER becomes:

$$\text{BER} = \frac{1}{2}\, erfc\left(\frac{Q}{\sqrt{2}}\right) \cong \frac{1}{Q\sqrt{2\,\pi}}\, e^{-\frac{Q^2}{2}} \tag{10}$$

Where $\mu_{1,\,0}$ and $\sigma_{1,\,0}$ are the mean values and the standard deviations of the spaces in the voltage at the output side. Whereas erfc (x) represents the error function in the transmitted signal.

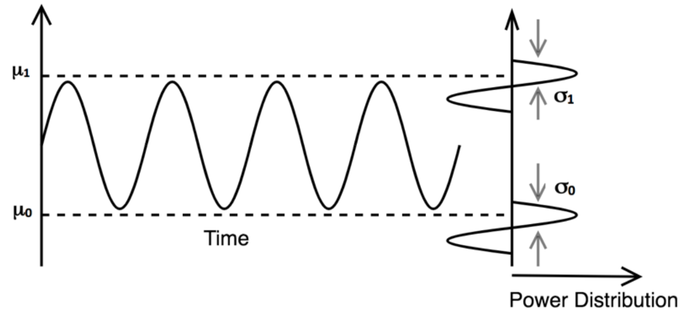


Fig 2. Mean values and standard deviation of the signal with respect to time and power distribution.

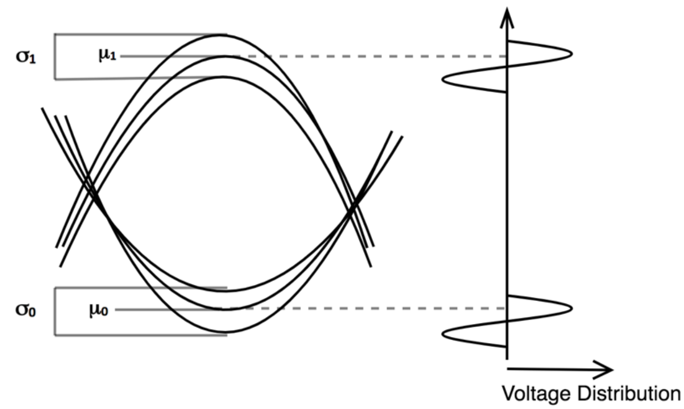


Fig 3. Mean values and standard deviation of the eye diagram having voltage distribution as measure of power.

- *Corresponding charts having comparison of various optical telemetry parameters.*

Table 1. Results of varying transmission distance with constant data rate (65 GBPS) and power (0 dBm).

Transmission Distance (km)	Quality Factor	BER
500	11.1775	2.60466e-029
400	13.449	1.55719e-041
300	14.0879	2.21309e-045
200	17.5992	1.22673e-069
100	23.9681	2.9523e-127

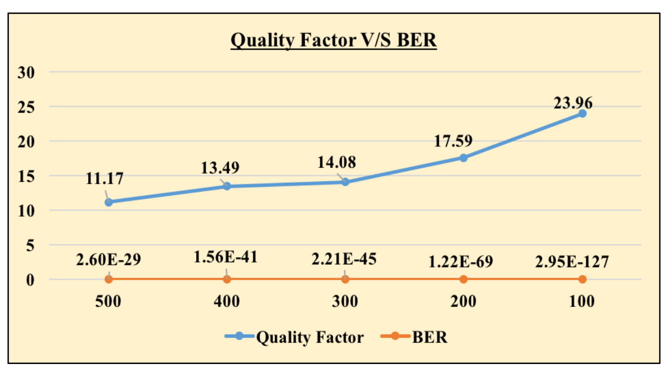


Chart 1. Quality Factor V/S BER for constant data (65 GBPS) and power (0 dBm). With the reduction in BER, the quality factor is improved.

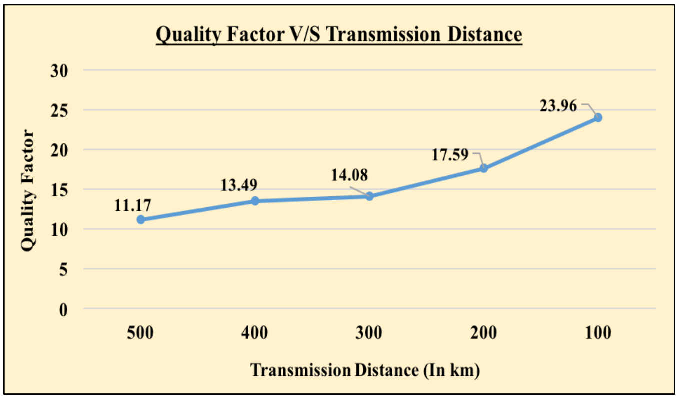


Chart 2. Quality Factor V/S Transmission Distance for constant data (65 GBPS) and power (0 dBm). Quality factor is improved with reduction in the transmission distance.

Table 2. Results of bit rate alterations with constant transmission distance (300 km) and power (0 dBm).

Bit Rate (Gbps)	Quality Factor	BER
95	4.12245	1.803e-005
80	7.73846	4.93349e-015
65	14.0879	2.21309e-045
50	19.8303	6.36436e-088
35	54.05	0

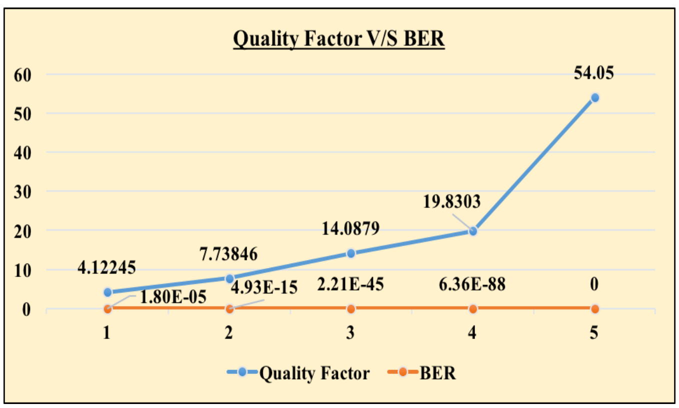


Chart 3. Quality Factor V/S BER with consistent transmission distance (300 km) and power (0 dBm). Efficiency improves with lower BER.

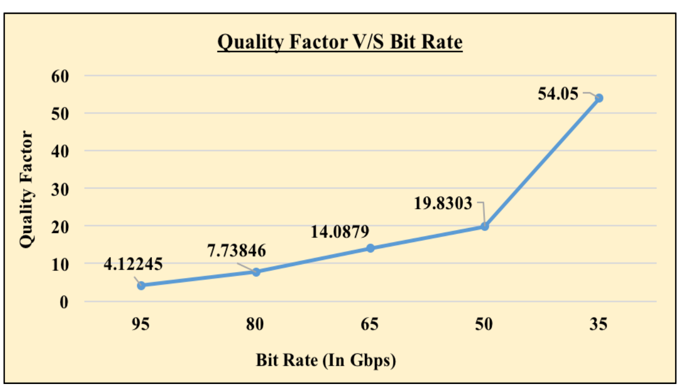


Chart 4. Quality Factor V/S Bit Rate with consistent transmission distance (300 km) and power (0 dBm). With higher data rates there is depletion in productivity.

Table 3. Results of power fluctuations with constant transmission distance (300 km) and data rate (65 GBPS).

Power (dBm)	Quality Factor	BER
-10	15.182	2.1964e-052
-5	14.9823	4.64412e-051
0	14.0879	2.21309e-045
5	10.8825	6.89899e-028
10	3.70359	9.68246e-005

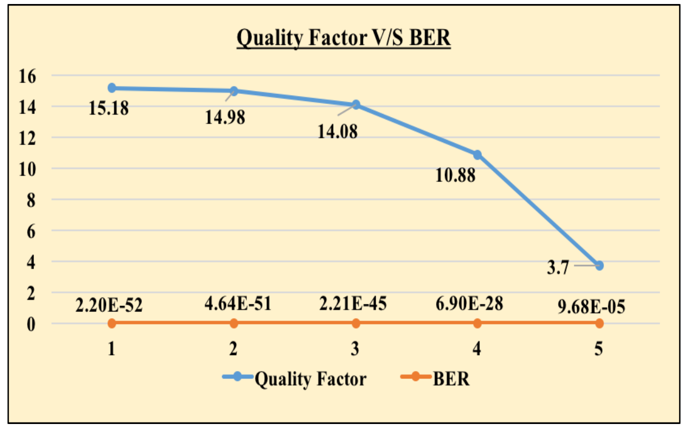


Chart 5. Quality Factor V/S BER for steady transmission distance (300 km) and data rate (65 GBPS). Reduction in quality factor with gain in BER is observed.

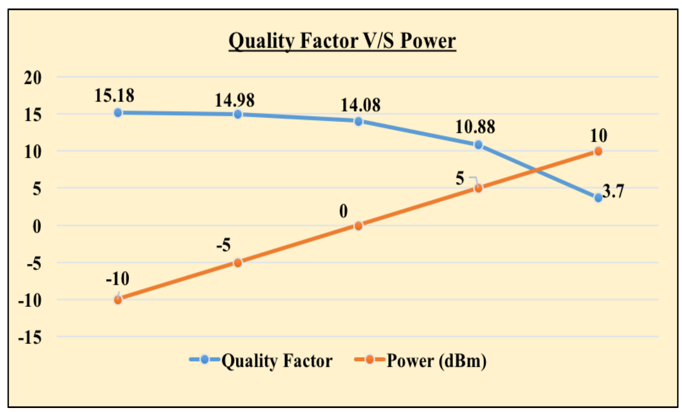
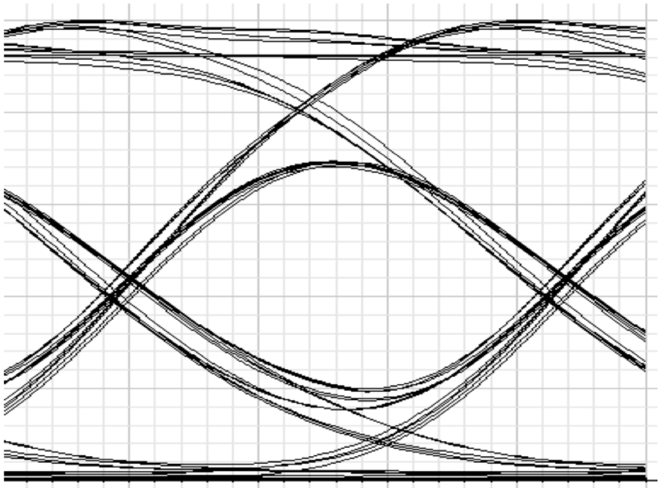


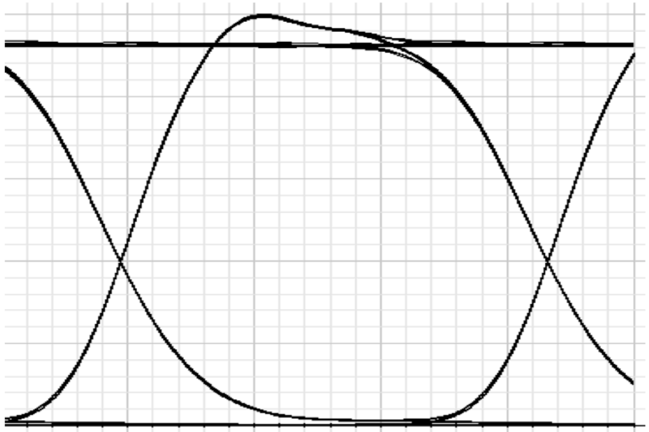
Chart 6. Quality Factor V/S Power transmission for steady distance (300 km) and data rate (65 GBPS). With expansion in transmitting power the quality factor is depleted.

The overall result points out that in order to have a sufficient value of quality factor with which the transmitted information should reach the destination without any major loss in data, the length of the transmission optical fiber should be adequate to handle the data rate while having a minimum bit error rate. If the requirement is to transmit higher data, then the power has to be raised and there will be some losses in the received signal which could be avoided while having the dispersion compensation banks. However, if the prerequisite is to have a smaller amount of information at the receiver side then the signal power could be lowered which will yield to higher quality factor and reduced losses in the transmitted data.

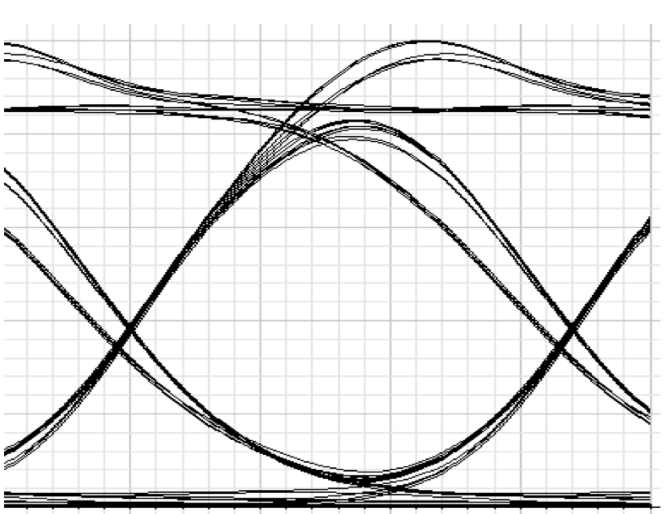
- *Corresponding eye diagrams for MetroCor Fiber.*



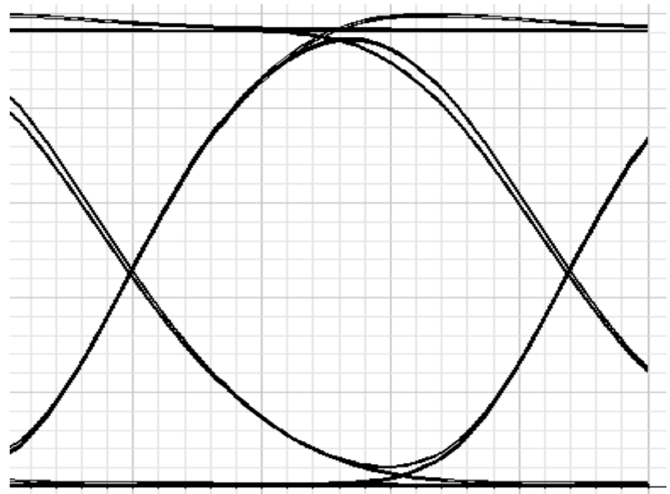
(i.) MetroCor length 300 km, signal power of 0 dBm produces quality factor 4.122 and BER 1.803e-0050 when data rate is 95 Gbps



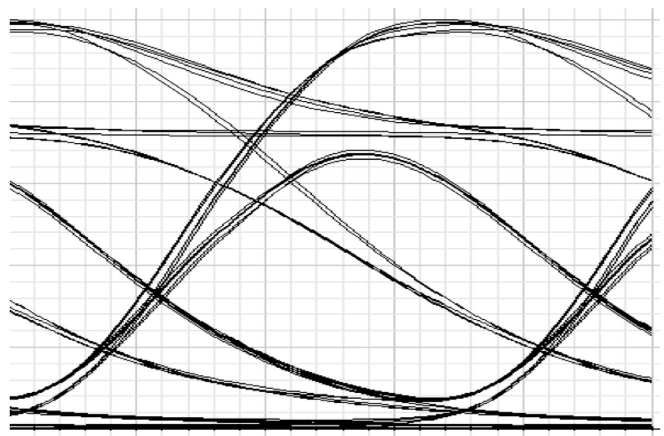
(ii.) MetroCor length 300 km, signal power of 0 dBm, quality factor 54.05 and BER 0 when data rate is 35 Gbps. This is the most desired implementation as there is highest Q-Factor and minimum errors.



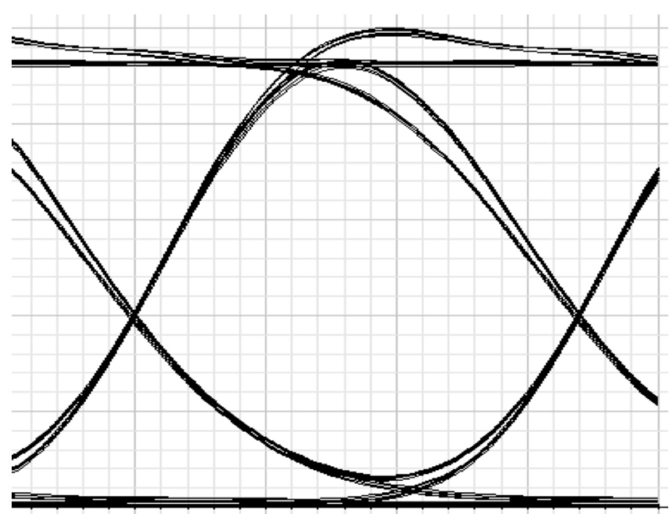
(iii.) MetroCor length 500 km, signal power 0 dBm gives quality factor 11.1775 and BER 2.60466e-029 when data rate is 65 Gbps.



(iv.) MetroCor length 100 km, power 0 dBm, quality factor 23.9681 and BER 2.9523e-127 when data rate is 65 Gbps.

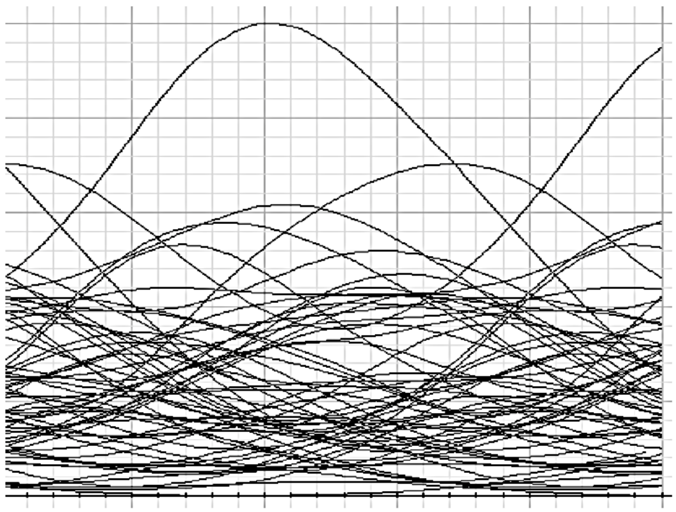


(v.) MetroCor length 300 km, signal power -10 dBm, quality factor 15.182 and BER 2.1964e-052 when data rate is 65 Gbps.



(vi.) MetroCor length 300 km, signal power 10 dBm, quality factor 3.70359 and BER 9.68246e-005 when data rate is 65 Gbps.

- *Corresponding eye diagram for SMF-28 Fiber*.



(vii.) SMF-28 length 300 km, signal power 0 dBm, quality factor 0 and BER 1 when bit rate is 65 Gbps.

This is the jitter scenario when SMF-28 optical fiber is used. It is clear from the eye diagrams that when MetroCor optical fiber is implemented and realized then there is a significant gain in the efficiency. However, SMF-28 is not able to produce any working results which are sufficient for the successful data transmission [11] from the sender to the destination side of the network.

IV. CONCLUSION

It has been observed that with increase in the MetroCor fiber distance, the quality factor declines and while expanding the data rate the BER and power alterations have a mean effect on the lightwave system. In the case of negative dispersion optical fiber, the highest quality factor and least BER for varying data rate is witnessed at 30 Gbps i.e 54 and 0 respectively. Power variations have the favorable results in case of 0 dBm i.e. efficiency of 14 and 2.21309e-045 of errors were realized. Whereas alteration in transmission distance gives an appropriate gain of 23 and losses of 2.9523e-127 at 100 km. On the other hand, SMF-28 optical cable has 0 efficiency and maximum errors i.e. 1 when operated at 300 km transmission distance while using 10 dBm transmission power of the CW laser. It has been concluded that MetroCor optical fiber when implemented at 300 km of distance with 0 dBm (1mW) power can yield practical results to transmit 65 Gbps of data with minimum errors.

V. FUTURE WORK

The demand for high data rates will rise with the expansion in the networking requirements. Users require more bandwidth to download and upload their information over the network. Browsing necessities such as uninterrupted video streaming and speedier internet access are gaining popularity in this era of global networking. The data has to be increased while having adequate power [12] of the CW laser. The frequency of low pass bessel filter along with the EDFA gain has to be altered in order to have more simulations and iterations with divergent optical network values [13]. Self optimized optical fibers could be used in future networks which could fetch more quality factor providing higher gain and lesser losses on the same transmission distance as that of the MetroCor. Traffic management methods could also be implemented having up-to-date hardware devices.

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