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Performance Investigation of VCSEL based High Speed Optical Networks

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ABSTRACT

In this paper, a Vertical Cavity Surface Emitting Laser (VCSEL) based high speed optical network has been established. VCSEL's operating at 1550nm has been a very promising source used in optical networks because of their technologically attractive properties and broad range of applications. We have established the link for data transmission at the bit rate of 20Gbps with 10km fiber length at 1550nm wavelength and an operating temperature range of 30°C to 85°C. We have further studied the change in performance parameters of the model by comparing two models i.e. one by employing Erbium Doped Fiber Amplifier (EDFA) and Semiconductor Optical Amplifier (SOA)both (Hybrid Model) and the other one by employing EDFA only. With our proposed system, we have achieved maximum Q-factor of 23.68 and BER<10-12.

KEYWORDS

VCSEL; SOA; EDFA; Radio over Fiber (RoF); Optical Fibers

1. INTRODUCTION

Vertical Cavity Surface Emitting Laser (VCSEL) is a semiconductor laser diode which emits the laser beam perpendicularly from the top of the surface, which can be simply defined as a variation of DBR (Distributed Bragg Reflector) Laser. VCSEL is basically used for faster and larger distance data transmission. The main advantage that makes a VCSEL more productive than other lasers [1] is that it has low temperature dependency [2-4] and high Q-factor. VCSEL's are a potential candidate to be used in advanced generation optical networks such as RoF, FTTH, FSO, etc. [5-8]. It is very essential to establish a system with least bit error rate (BER) and highest quality factor (Q-factor) out of VCSEL to transmit signals at high speed and larger distance [9]. To attain superior output, various types of fiber amplifiers like EDFA and SOA are employed with VCSEL based system. The key advantage of using fiber amplifier with VCSEL based system is that it amplifies the optical signal as it is without any need to transform the respective optical signal to an electrical signal and, it is an exceptional device that is used to carry out the larger distance optical communication now a days. Fiber amplifiers such as EDFA and SOA are also integrated in the designed VCSEL model. Erbium Doped Fiber Amplifier (EDFA) is a type of Optical Fiber Amplifier (OFA) with the interior (core) of an optical fiber [29-30] consisting of Erbium ions. It provides with the advantages like higher gain and lower noise. Semiconductor Optical Amplifier (SOA) is a semiconductor element. It is of compact in size and its cost is also less as compared to an EDFA that makes it more economically productive and useful. VCSEL put forward many distinctive benefits at non-identical wavelengths. Some studies reported control of self-heating [10], sensing and the indemnifying of the temperature [11], error free operation at higher bit rates of 25 Gbps [12-13] to 50 Gbps [14]. If someone desires to grow a large number of lasers on a single chip, then it may not be possible with semiconductor laser of Edge Emitting type but with the help of VCSEL, it is possible and the main benefit of using a large number of lasers on a single chip is that it makes it compatible for high density data interconnects in computer chips [24-28]. As the dominating application areas of VCSELs, optical interconnects are employed, where emphasis is mainly on fiber-coupling properties, modulation effects of large signal and high-speed optical data transmission over various types of fiber [21]. Multi-mode cascade VCSELs are of very high interest for optical based links, analog type of systems, and applications which involves use of high-power [22]. VCSEL demand has grown rapidly along with huge requirements for 5G internet, 3D sensing, LiDAR, high-speed photodetectors [23]. Some studies reported that red coloured VCSEL (683nm) [15] is commonly used for delivering high power at the output as compared to the other VCSEL based system where the temperature performance of the system stays comparatively low [16]. Contrastingly, infrared VCSEL (1550nm) administers good temperature range performance and comparatively less power at the output [17]. We have established a system for high-speed data transmission over 10km fiber length for attaining good Q-factor and better performance at room temperature with a bit rate of 20Gb/s. In this paper, we have compared the improvement in q-factor and eye diagram performance when the system is incorporated with:

i) a hybrid connection of EDFA & SOA
ii) EDFA only

Eye diagram is also a good criterion to observe the quality of the detected signal [18]. All these investigations have been carried out on 1550nm wavelength [19-20] and an operating temperature range of 30°C to 85°C.

2. VCSEL PARAMETERS

The software that has been used to design, simulate, and analyse the model is "Opti-System". VCSEL of 1550nm wavelength have been used whose parameters are entered in Table 1.

Table 1: Values for VCSEL parameters

Parameters	Values taken
Input current (max.)	40mA
Bias current	14mA
Modulation peak current	12mA
Injection efficiency	01
Thermal impedance	2600C/W

3. SIMULATION SETUP

The VCSEL based model is designed to transmit the data at bit rate of 20 Gbps with 10 km Fiber length at 1550nm wavelength and an operating temperature range of 30°C to 85°C by employing EDFA and SOA Fiber amplifiers (i.e., Hybrid Network).

Our proposed model is consisting of basically three sections, namely, Transmission Section: Channel Section and Receiver Section. Figure 1(a) represents the simplified block diagram of the designed model that consists of both EDFA and SOA and Figure 1(b) represents the block diagram for the model that contains EDFA only.

In Transmission section, VCSEL is being utilised as a transmission device that is joined with Bias Generator that acts as a DC source which helps in reducing the non-linear effect from the Laser. The properties of the generator are modified to get better results. VCSEL of 1550nm wavelength is used. Further, we have connected Pseudo Random Bit Sequence (PRBS) to produce digital data and further this PRBS relates to a pulse generator of Non-Return Zero (NRZ) type. The modulator named Mach-Zehnder modulator is connected in the system. The prime role of this modulator is to combine the electrical signal with the feed in (input) signal that is coming from the VCSEL to generate output signal of optical type which is further forwarded to the receiver section over a link of an optical fiber.

In Channel Section, optical fiber of length 10km having dispersion value of 16.75ps/nm/km and attenuation value of 0.25dB/m. Then, optical amplifier is employed which amplifies the optical signal as it is without a need to convert SOA amplifiers are used at 1550nm wavelength the respective optical signal to an electrical signal. In the system without optical amplifier, we have found small temperature range of operation with drastic fall of Q-factor. Hybrid connection of EDFA and three to compensate the losses and achieve better results.

In Receiver Section, an optical receiver has been employed in which the photo detector that has been selected is of APD type and the filter selected is low pass Bessel filter. Here, the optical signal detection is done by the APD photo detector and further t is sent to the low pass filter which then passes the low frequency signals and discards the higher ones. This optical Receiver is connected to BER Analyser which is used to note down the results at the output.

The analysis has been carried out for 1550nm which is a standard wavelength for transmission but introducing more than one VCSEL to generate multiple wavelengths will degrade the Q-value and increase the bit error rate and range of the designed link will also be reduced.

A standard SMF is used to investigate the performance of VCSEL in optical network. The SMF considered here provides most relevant and practical values of dispersion and attenuation which will further yield results that are useful for industrial applications. Hence, only SMF has been investigated and rest of the fibers are not selected for analysis.

The values of gain of amplifier and the noise figure are 20 dB and 5 dB respectively.

Table 2: Simulation Parameters

Parameters	Values
Wavelength	1550nm
Bit Rate	20 Gbps
Fiber Length	10 km
EDFA length	5 m
SOA length	50e-006 m
SOA width	3e-006 m
Extinction Ratio	6 dB
Dispersion	16.75 ps/nm/km
Attenuation	0.2 dB/km
Photo detector type	APD
Filter type	Low pass Bessel Filter

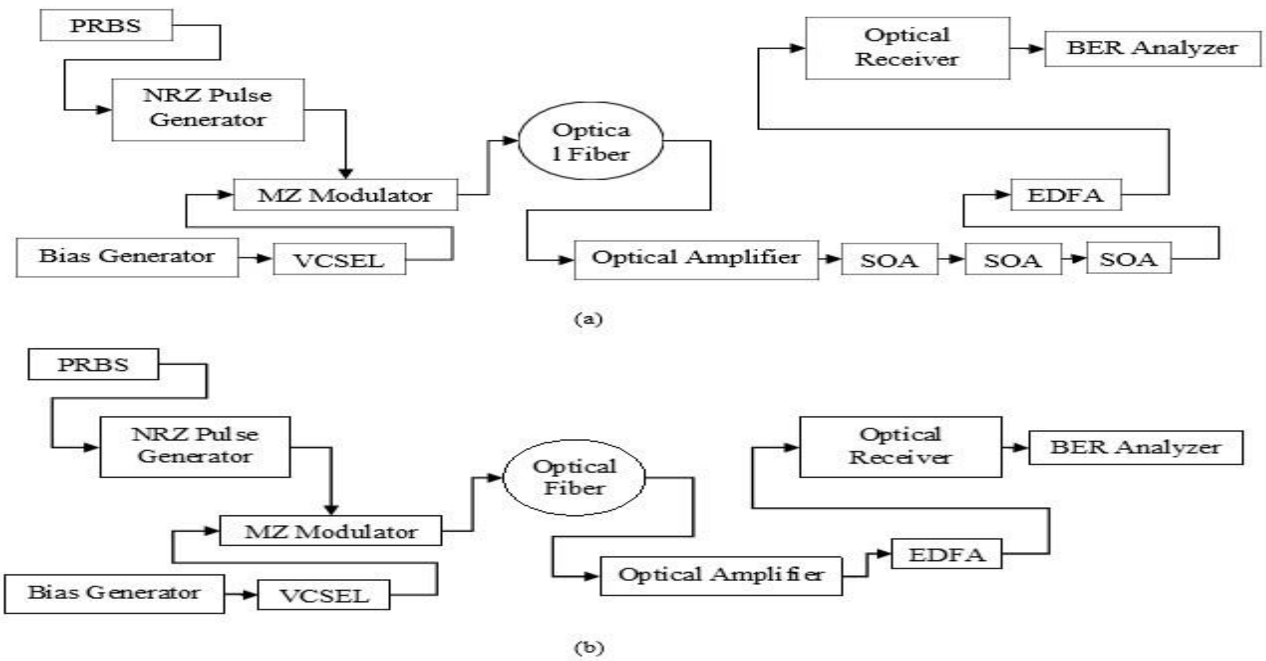

Fig. 1: Block Diagram for the system incorporated with: (a) EDFA and SOA (b) EDFA only.

4. RESULTS AND DISCUSSION

The model shown has been simulated and the different outputs are observed. The output is taken from two. models: one by connecting both EDFA and SOA fiber amplifiers in the system and the other by using EDFA only as shown and both the results are compared. The quality factor against the variation in fiber length, temperature of VCSEL and bit rate is observed. Table 2 shows the parameters that have been considered through simulation. The values of gain of amplifier and the noise figure are 20 dB and 5 dB respectively.

Figure 2 shows the variation of quality factor against bit rate for the model incorporated with EDFA and SOA both and Figure 3 shows the variation of quality factor against bit rate for the model incorporated with EDFA only.

As it can be seen from the figure 2 above, by connecting both EDFA and SOA fiber amplifiers in the model, we have achieved finer quality factor (23.68) at the bit rate of 20 Gbps with the temperature of Laser fixed to 35°C and the fiber length at 10km. The length of EDFA is taken as 5m, SOA is taken as 50µm and the wavelength at which the outputs are achieved is of 1550nm.

Whereas, on the other hand, when the model consists of EDFA only, there we noted down a gradual decrease in the quality factor (6.11) at 20 Gbps with temperature of the laser at 30°C and fiber length of 10km as shown in figure 3.

Table 3: MZM Parameters

Parameters	Values
Extinction Ratio	25 dB
Offset Voltage	5 V
Half Voltage	8 V
Excess Loss	3 dB

So, from this we concluded that by incorporating SOA with EDFA in the model, we can improve the quality factor performance against bit rate to a great extent.

We have also analysed our model's Q-factor performance at an operational temperature range of 30°C to 85°C at 1550nm wavelength. This investigation has been carried out with incorporating EDFA and SOA both and by incorporating EDFA only.

At 1550nm with EDFA and SOA incorporated in the system, we have got better quality factor (23.68) at 20 Gbps bit rate and 10km fiber length as shown in figure

4.

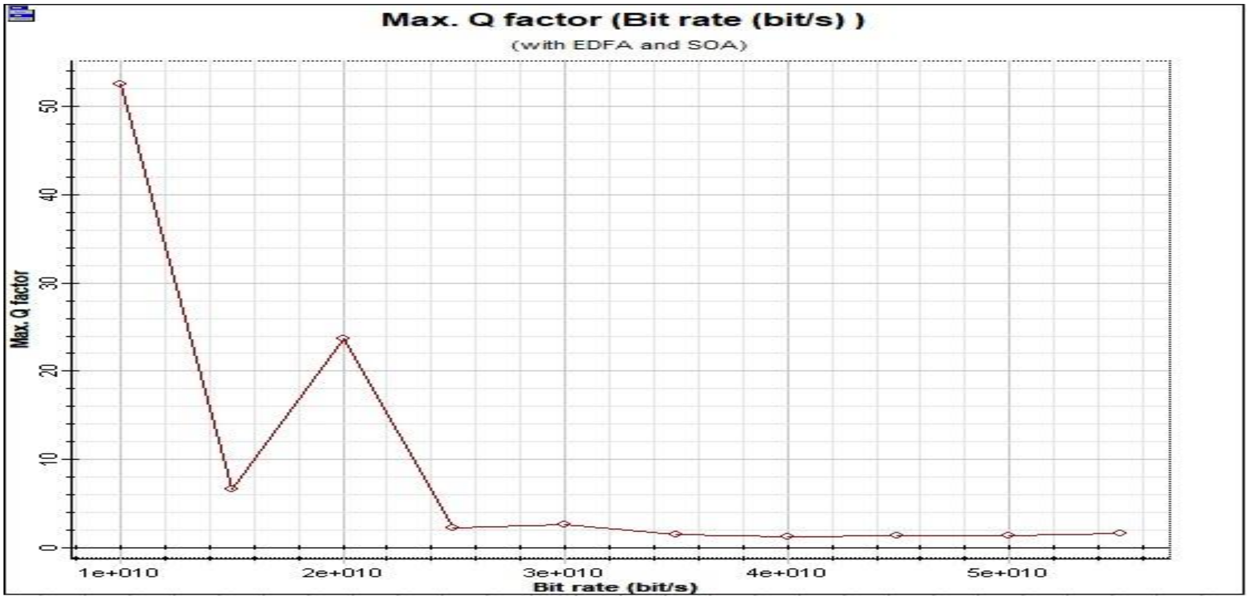

Fig. 2: Q-factor vs bit rate with EDFA and SOA

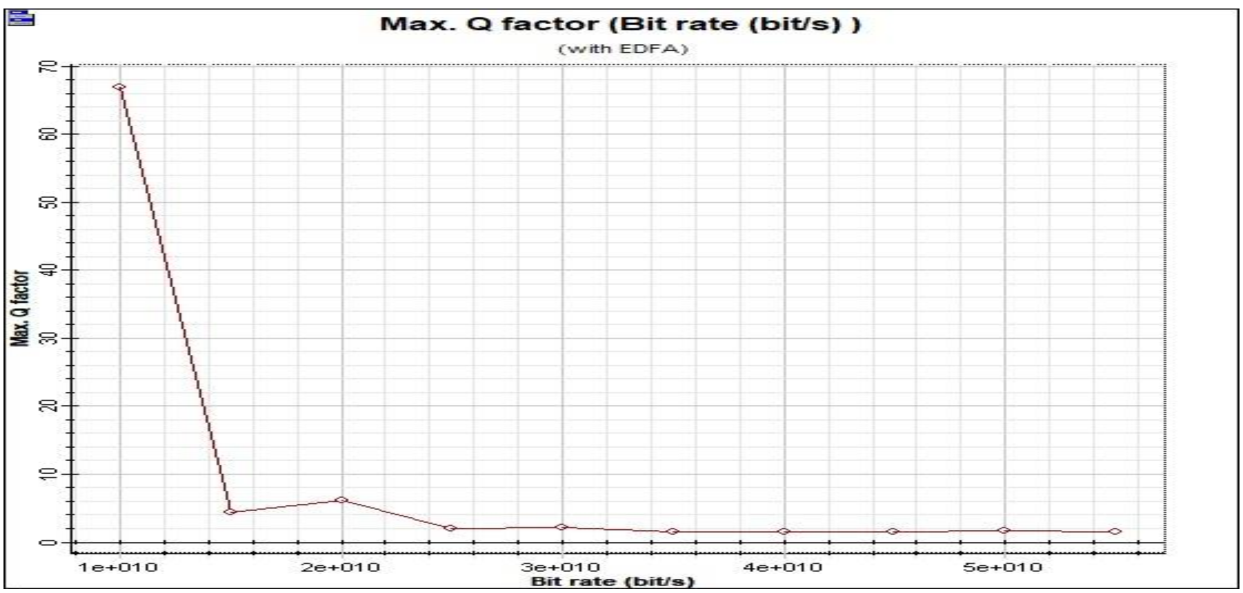

Fig. 3: Q-factor vs bit rate with EDFA

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with EDFA in the model, we can improve the quality investigation has been carried out with incorporating EDFA and SOA both and by incorporating EDFA only.

At 1550nm with EDFA and SOA incorporated in the system, we have got better quality factor (23.68) at 20

Gbps bit rate and 10km fiber length as shown in figure 4.

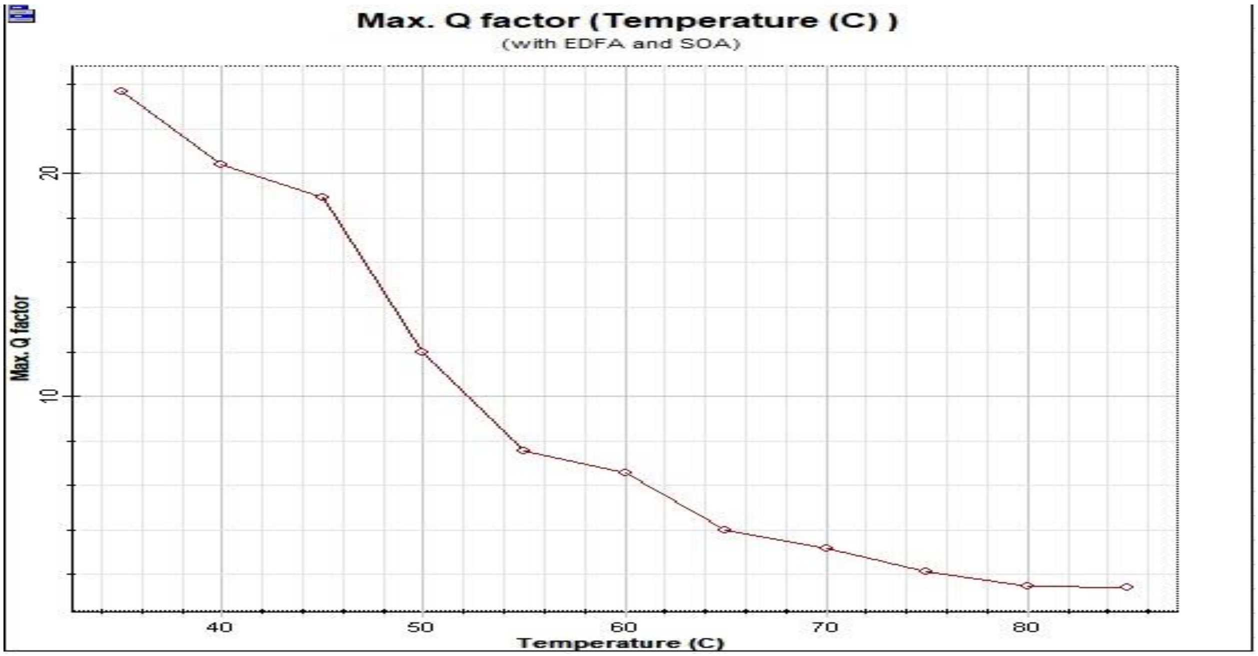

Fig. 4: Q-factor vs temperature with EDFA and SOA

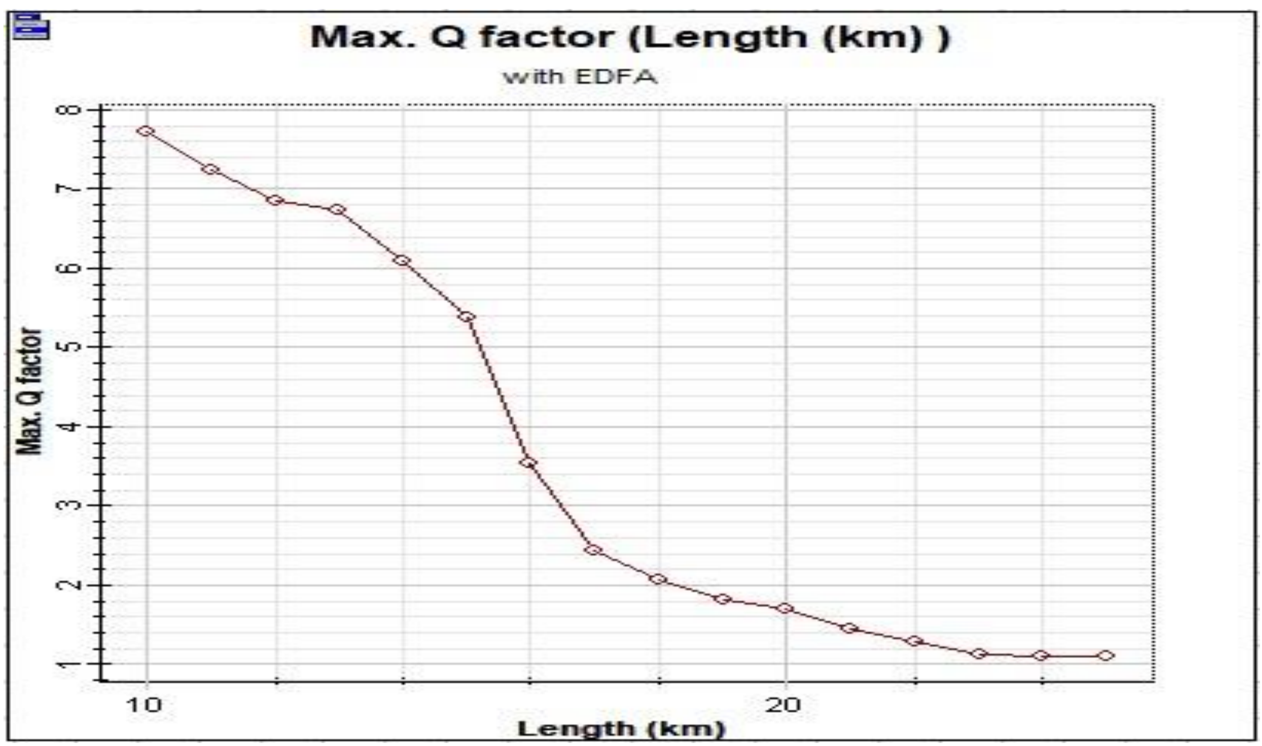

Fig. 5: Q-factor vs temperature with EDFA

On the other hand, in the system where SOA is not present and only EDFA is present, we have found a drastic fall in quality factor performance (7.72) against temperature at 1550nm wavelength and length of the fiber to be taken as 10km and bit rate of 20 Gbps as depicted in figure 5.
So, we concluded that we get better quality factor performance with the rise in temperature when our model is incorporated with EDFA and SOA both as compared to the system where only EDFA is incorporated.
When our model is employed with EDFA and SOA both at 1550nm wavelength with temperature of VCSEL fixed at 40°C, we have achieved finer quality factor performance at 20 Gbps bit rate up to 13km fiber length and it gradually decreases as length is further increased as shown in figure 6.

Fig. 6: Q-factor vs length with EDFA and SOA

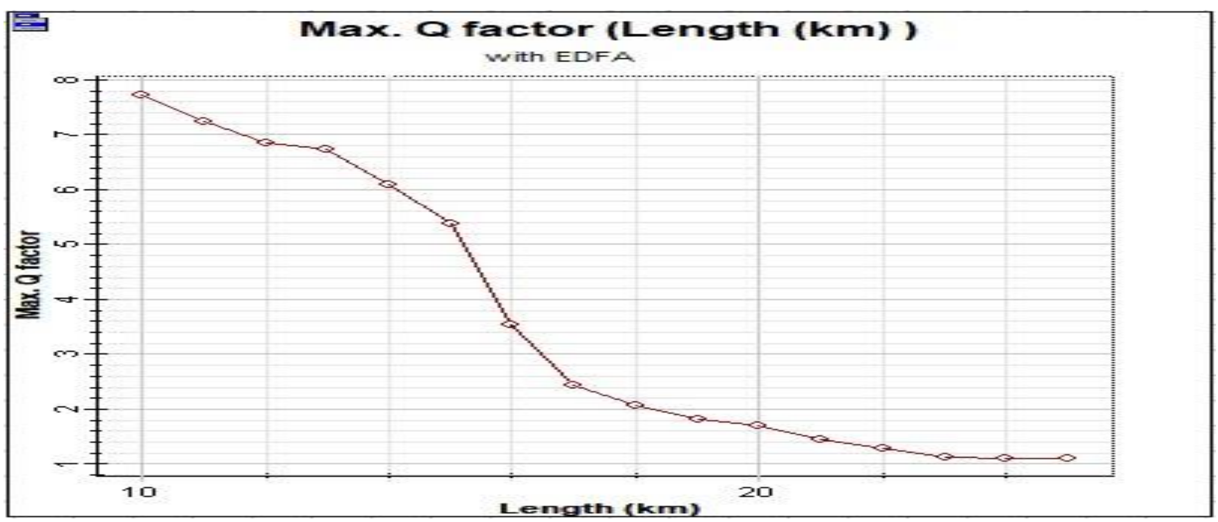

Fig. 7: Q-factor vs length with EDFA

On the other hand, at 1550nm wavelength, when only EDFA is connected in the system with temperature of VCSEL fixed at 35°C, we have seen a fall in the quality factor performance as compared to the system where both EDFA and SOA are incorporated as shown in the figure 7.

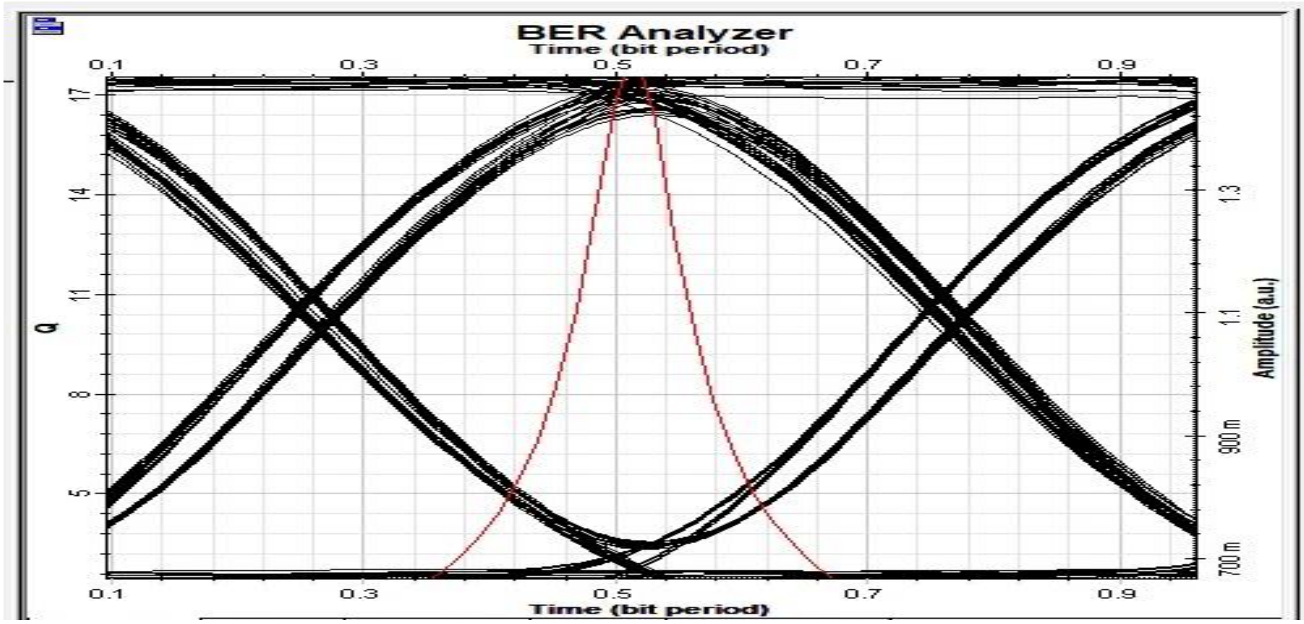

Fig. 8: Eye Diagram with EDFA and SOA

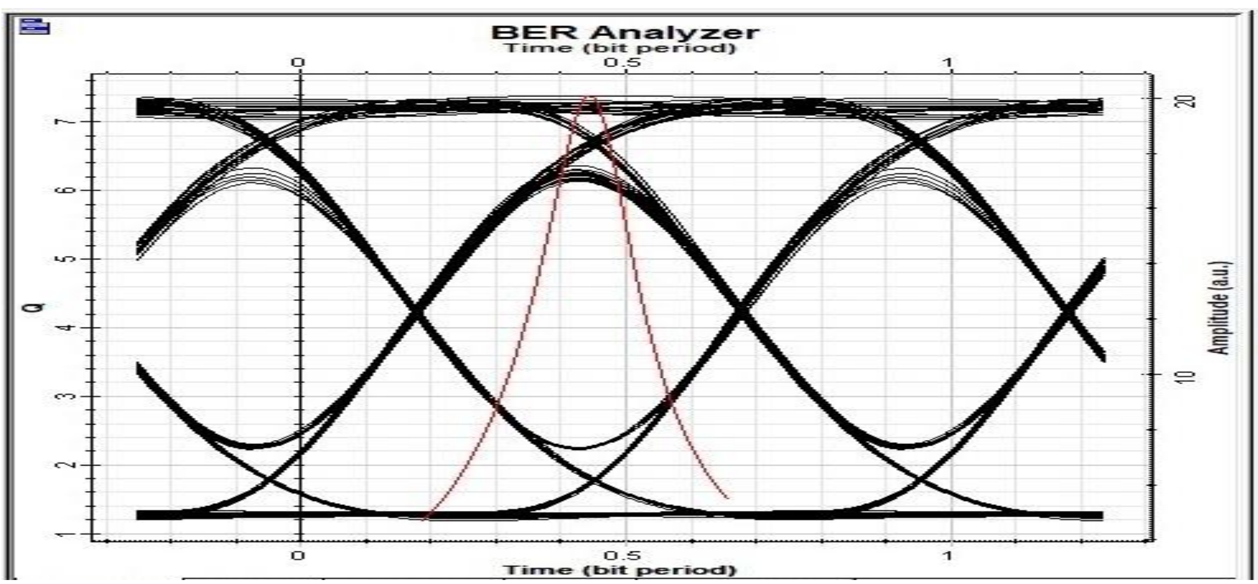

Fig. 9: Eye Diagram with EDFA

From the perspective of the q-factor performance against length of fiber, we concluded that by incorporating both EDFA and SOA in the model, we get quality factor of 23.68 which is clearly better than the other system which is incorporated with EDFA only.

The comparison for the previous work that have been carried out and our proposed network has been depicted in the table 4 below.

Table 4: Improvement Observed

Author	Year of publication	Outcome
Mohammad Tanvir Hannan et.al.	2017, ICAEE, Dhaka, Bangladesh	Transmission of VCSEL signal at 15 Gbps with Q-factor of 52.7 at 863nm wavelength.
Shen, Chih-Chiang, Tsung-Chi Hsu, Yen-Wei Yeh, Chieh-Yu Kang, Yun-Ting Lu, Hon-Way Lin, Hsien-Yao Tseng et al.	2019	Design, modelling, and fabrication of high speed VCSEL with data rate upto 50 Gb/s.
Proposed Network	2023	Transmission of VCSEL signal at 20 Gbps with Q-factor of 23.68 at 1550nm wavelength.

Further, we have analysed the eye diagram for the model.

Figure 8 represents the eye diagram analysis of the obtained signal with the bit rate of 20 Gbps, EDFA length is 5m, length of fiber is 10km and temperature of the VCSEL is fixed at 30°C.

It can be observed from the eye diagram that eye opening is much better for the system that is incorporated with both EDFA and SOA fiber amplifiers as compared to the system that consists of EDFA only.

Figure 9 above shows the eye diagram when the bit rate is 20 Gbps, temperature of the VCSEL is 30°C, EDFA length is 5m and length of fiber is 10km for the system that consists of EDFA only. It is observed that the eye diagram obtained for the hybrid model has bigger eye opening and thus its performance is enhanced.

From the results obtained through simulation of the model, it is analysed that by incorporating both EDFA and SOA in the model, the quality factor performance of the model is improved over a particular fiber length, temperature, EDFA length and 20 Gbps bit rate. Eye Diagram of the signal states that the signal quality obtained from the hybrid connection of EDFA and SOA is much better as compared to the one obtained when the system is employed with EDFA only.

5. CONCLUSION

We have achieved a system with data transmission speed of 20 Gbps at room temperature by incorporating both EDFA and SOA at 1550nm wavelength and fiber length of 10km. Also, we conclude that maximum quality factor of 23.68 is obtained for error free transmission by incorporating both EDFA and SOA at 20 Gbps at 1550nm wavelength and fiber length of 10km. Further, we concluded that quality factor performance is improved when both EDFA and SOA is connected in the system. Also, the Eye diagram obtained concludes that due to the presence of SOA amplifier in the model, the proper eye opening is obtained with maximum quality factor. So, finally, we concluded that the performance of our model is improved due to the presence of SOA amplifier and hence better results are obtained at the output. The use of VCSELs has increased in the last decade, spreading its applications into various areas. The main reason for such an increase in their use is their small size, ability to be fabricated in 2D arrays, their integration ability with the other components, and also, they are easy to test, and manufacturing process is also easier as compared to the other lasers available in the market. They are also used in more niche application areas for example optical clocks and as solid-state laser pumps. Seeing their drastic use and growth, their areas of application are expected to grow more in the coming years.

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