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Thesis Title

Performance Evaluation of Different QAM Modulation Schemes in a VCSEL Based Single Mode Optical Link

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Declaration

This report on the basis of our thesis paper and its enhancement of studies throughout our thesis work is submitted to follow the terms and condition of the department of electronics and communications engineering .This report is the requirement for the successive competition of M.Sc in Telecommunication Engineering.

We state that the report along with its literature that has been demonstrated in this report papers, is our own work with the masterly guidance and fruitful assistance of our supervisor for the finalization of our report successfully.

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Approval

This Thesis report "**Performance Evaluation of Different QAM Modulation Schemes in a VCSEL Based Single Mode Optical Link**" submitted by Alok Paul, ID: 2017-1-98-005 and Dipta Haldar, ID: 2017-2-98-003 to department of Electronics and Communications Engineering, East West University has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of Master of Science in Telecommunication Engineering and approved as to its style and contents.

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Abstract

Vertical Cavity Surface Emitting Laser (VCSEL) is first demonstrated by K.Iga in 1979. Since then it creates a new era for high speed optical communication system. The most important feature of this optical device is that it can emit light vertically from its substrate surface rather than emitting from its side edge. This special feature of VCSEL provides capability of high speed data transmission very efficiently. That is why today in applications for long range and short range high speed optical communication VCSELs have replaced edge-emitting lasers. VCSELs are now widely used in analog broadband signal transmission, absorption spectroscopy, laser printers, biological tissue analysis, optical fiber data transmission and so many applications. From the beginning of VCSELs introduction, temperature variation always remains dominant contributor to performance degradation and instable output. As VCSEL is a rapid growing field for optical communication, it has to copewith very high temperature, which makes the design of VCSEL based system more complicated and challenging. As increasing temperature reduces a major portion of output power of VCSEL, meeting up the temperature variation issue is prime need for VCSEL based optical communication system. In this thesis, we analyzed and comparedthe temperature dependence, power consumption, BER and Q factor ofM-QAM modulation schemes at 1550nm wavelength for VCSEL based optical link. We further analyzed the performance of VCSEL by designing a long range data transmission system. It is found that at bias current of 2mA the working temperature range extends up to 125^0C for 1550 nm. And at a bias current of 12mA, theminimum power dissipation is found to be 1.96mW at room temperature for 1550nm VCSEL based optical data transmission system at 10Gbps.

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LIST OF ABBREVIATION	
VCSEL	Vertical Cavity Surface Emitting Laser
BER	Bit Error Rate
LASER	Light Amplification by Stimulated Emission of Radiation
LED	Light Emitting Diode
EEL	Edge Emitting Laser
OSNR	Optical Signal to Noise Ratio
CW	Continuous Wave
DBR	Distributed Bragg Reflector
QAM	Quadrature Amplitude Modulation
EDFA	Erbium Doped Fiber Amplifier
SOA	Semiconductor Optical Amplifier
MZ	Mach-Zehnder Modulator
APD	Avalanche Photo Diode

Chapter 1

Introduction

1.1 Optical Communication

Optical communication is a communication system where light is used to carry the signal to the remote end, instead of electrical current. A modulator/demodulator, a transmitter/beneficiary, a light flag and a straightforward channel are the building pieces of the optical correspondences framework. Due to its various preferences over electrical transmission, optical strands have to a great extent supplanted copper wire interchanges in center systems in the created world. The principle advantages of optical correspondence incorporate high transfer speed, uncommonly low misfortune, awesome transmission run and no electromagnetic obstruction. The cons of optic correspondence incorporate the high cost of link, transmitter/beneficiary and other help hardware, and the aptitude and mastery required amid link establishment and interconnection [1].

1.1 Components of optical Communication system

1.1.1 Transmitter

Transmitter is a vital component which converts and transmits an electronic signal into a light signal. Transmitters are basically semiconductor devices, such as light-emitting diodes (LEDs) and laser diodes.

1.1.2 Receivers

Receiver is basically a photo-detector, which converts light into electricity using the photoelectric effect. The photo detector is also a semiconductor-based photodiode.

1.1.3 Optical Fiber

Optical fiber refers to the medium and the technology associated with the transmission of information as light pulses along a glass or plastic strand or fiber. A fiber optic cable can contain a varying number of these glass fibers from a few up to a couple hundred. Surrounding the glass fiber core is another glass layer called cladding. A layer known as a buffer tube protects the cladding, and a jacket layer acts as the final protective layer for the individual strand.

1.2 Light Source used in optical communication

Because of gigabit transmission of information, the fiber optic correspondence is a prevalent framework. This kind of correspondence is utilized to transmit voice, video, telemetry and information over long separations and neighborhood or PC arrange. A fiber Optic Communication System utilizes light wave innovation to transmit the information over a fiber by changing electronic signs into light.

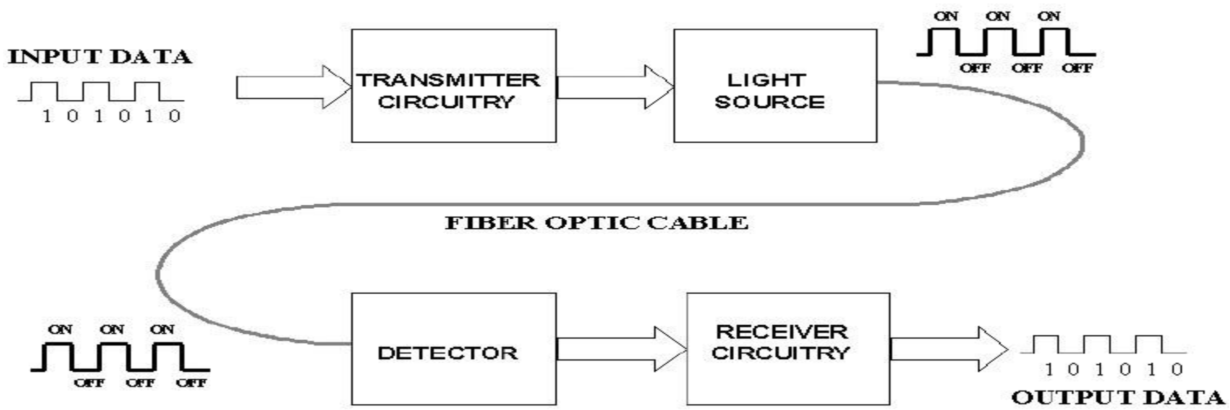

Fig 1.1: Block diagram of optical communication

1.2.1 LED (Light Emitting Diodes)

Light-emanating diode is a P-N semiconductor diode in which the recombination of electrons and openings yields a photon. At the point when the diode is electrically one-sided the forward way, it emanates mixed up limit range light. At the point when a voltage is connected to the leads of the LED, the electrons recombine with the openings inside the gadget and discharge vitality as photons. This impact is called as electroencephalogram. It is the change of electrical vitality into light. The shade of the light is chosen by the vitality band hole of the material. The utilization of LED is beneficial as it expands less power and creates less warmth. LEDs last longer than radiant lights. LEDs could turn into the up and coming era of lighting and utilized anyplace like in sign lights, PC segments, medicinal gadgets, watches, instrument boards, switches, fiber-optic correspondence, buyer hardware, family unit apparatuses, and so on [2-3].

1.2.2 Laser Diode

The prerequisites of the sources incorporate power, speed, otherworldly line width, clamor, toughness, cost, temperature, et cetera. Two parts are utilized as light sources: light discharging diodes (LED's) and laser diodes. The light producing diodes are utilized for short separations and low information rate applications because of their low data transmission and power capacities. Two such LEDs structures incorporate Surface and Edge Emitting Systems. The surface discharging diodes are straightforward in plan and are dependable, however because of its more extensive line width and regulation recurrence confinement edge radiating diode are for the most part utilized. Edge discharging diodes have high power and smaller line width capacities. For longer separations and high information rate transmission, Laser Diodes are favored because of its powerful, rapid and smaller phantom line width qualities [4].

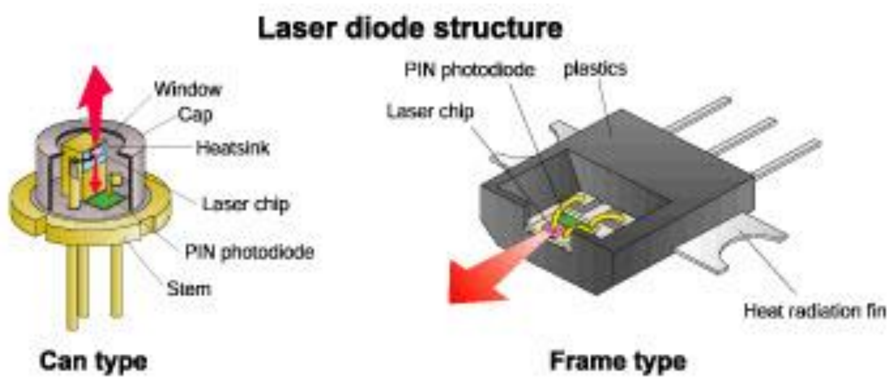

Fig 1.2: Laser diode structure

Table 1.1 LED versus LASER

Characteristic	**LED**	**LASER**
Output power	Lower	Higher
Spectral width	Wider	Narrower
Numerical aperture	Larger	Smaller
Speed	Slower	Faster
Cost	Less	More
Ease of operation	Easier	More difficult

1.2.2.1 Edge emitting laser

Semiconductor lasers can be grouped into two classes

1. **Edge-emitting lasers (also called in-plane lasers):** Where the laser light propagates in a direction along the wafer surface of the semiconductor chip and is reflected or coupled out at a cleaved edge.

2. **Surface-emitting lasers:** Where the light propagates in the direction perpendicular to the semiconductor wafer surface.

Edge-transmitting lasers are the first and still broadly utilized type of semiconductor lasers. Their resonator length is regularly between a couple of hundred micrometers and a couple of millimeters. This is adequate for achieving a high pick up, so that an edge-emanating laser may lase regardless of the possibility that the resonator misfortunes are genuinely high, e.g. at the point when the end confronts (edges) are not covered and there is just the Fresnel impression of the semiconductor/air interfaces. Inside the edge-radiating laser structure, the laser shaft is guided in a waveguide structure. Ordinarily, one uses a twofold hetero structure, which confines the created bearers to a restricted area and in the meantime fills in as a waveguide for the optical field. This game plan prompts a low edge pump control and a high effectiveness. Contingent upon the waveguide properties, especially its transverse measurements, it is conceivable either to acquire a yield with high shaft quality yet constrained yield control (around many mill watts), or (with an expansive zone laser diode) a yield with high yield control (several watts or even > 100 W) yet with poor pillar quality [5].

Semiconductor lasers can be assembled into two classes: Edge-producing lasers, where the laser light is proliferating parallel to the wafer surface of the semiconductor chip and is reflected or coupled out at a cut edge. Surface-radiating lasers, where the light engenders toward the path opposite to the semiconductor wafer surface. (a) Surface radiating , (b) Edge-producing.

1.2.2.2 Vertical-cavity surface-emitting laser

The vertical-hole surface-transmitting laser, or VCSEL, is a sort of semiconductor laser diode with laser shaft emanation opposite from the top surface, in spite of regular edge-producing semiconductor lasers (additionally in-plane lasers) which discharge from surfaces framed by separating the individual chip out of a wafer. VCSEL applications incorporate fiber optic interchanges, exactness detecting, PC mice and laser printers [6].

1.2.2.2.1 Structure of VCSEL

The laser resonator comprises of two appropriated Bragg reflector (DBR) mirrors parallel to the wafer surface with a dynamic district comprising of at least one quantum wells for the laser light era in the middle. The planar DBR-mirrors comprise of layers with exchanging high and low refractive files. Each layer has a thickness of a fourth of the laser wavelength in the material, yielding power reflectivities over 99%. High reflectivity mirrors are required in VCSELs to adjust the short pivotal length of the pickup area

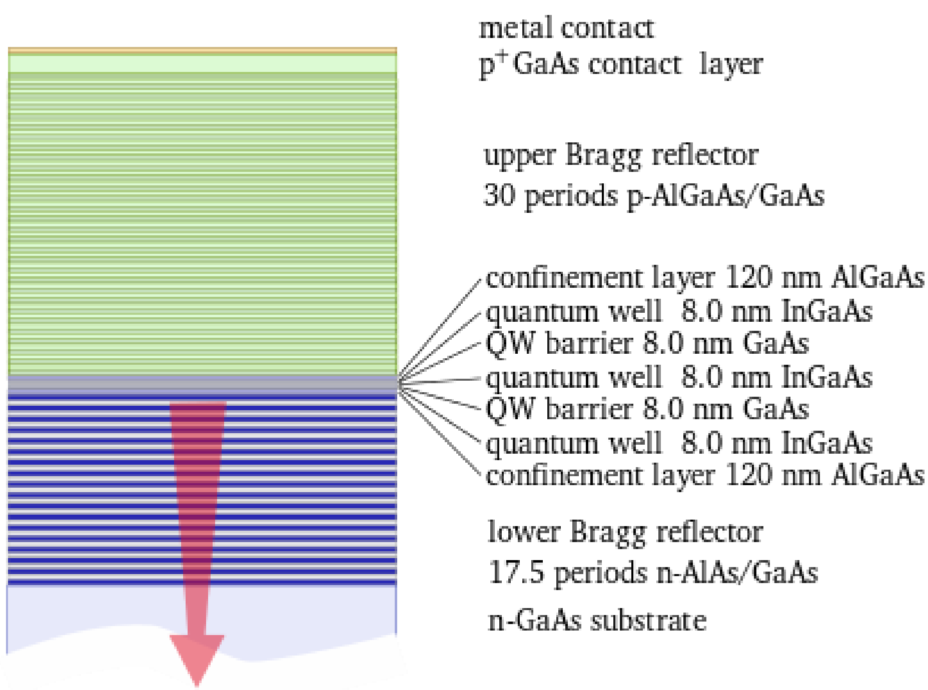

Fig 1.3: A realistic VCSEL device structure. This is a bottom-emitting multiple-quantum-well VCSEL.

In like manner VCSELs the upper and lower mirrors are doped as p-sort and n-sort materials, shaping a diode intersection. In more intricate structures, the p-sort and n-sort districts might be installed between the mirrors, requiring a more mind boggling semiconductor procedure to reach to the dynamic area, yet dispensing with electrical power misfortune in the DBR structure. In research center examination of VCSELs utilizing new material frameworks, the dynamic area might be pumped by an outside light source with a shorter wavelength, typically another laser.

This permits a VCSEL to be exhibited without the extra issue of accomplishing great electrical execution; however such gadgets are not down to earth for generally applications. VCSELs for wavelengths from 650 nm to 1300 nm are normally in view of gallium arsenide (GaAs) wafers with DBRs framed from GaAs and aluminum gallium arsenide (AlxGa(1-x)As). The GaAs–AlGaAs framework is favored for developing VCSELs on the grounds that the cross section steady of the material does not differ firmly as the arrangement is changed, allowing various "grid coordinated" epitaxial layers to be developed on a GaAs substrate. In any case, the refractive list of AlGaAs varies generally emphatically as the Al portion is expanded, limiting the quantity of layers required to frame a proficient Bragg reflect contrasted with other hopeful material frameworks. Moreover, at high aluminum fixations, an oxide can be shaped from AlGaAs, and this oxide can be utilized to confine the current in a VCSEL, empowering low limit streams[7-8].

1.2.2.2.2 Characteristics

Since VCSELs emanate from the top surface of the chip, they can be tried on-wafer, before they are cut into singular gadgets. This decreases the manufacture cost of the gadgets. It likewise enables VCSELs to be fabricated in one-dimensional, as well as in two-dimensional clusters.

1. The bigger yield gap of VCSELs, contrasted with most edge-transmitting lasers, delivers a lower disparity point of the yield bar, and makes conceivable high coupling proficiency with optical strands [9].

2. The high reflectivity mirrors, contrasted with most edge-transmitting lasers, lessen the edge current of VCSELs, bringing about low power utilization. In any case, up 'til now, VCSELs have bring down outflow control contrasted with edge-discharging lasers. The low limit current additionally allows high characteristic balance data transmissions in VCSELs [10-11].

3. The wavelength of VCSELs might be tuned, inside the pick-up band of the dynamic district, by altering the thickness of the reflector layers.

4. While early VCSELs discharged in different longitudinal modes or in fiber modes, single-mode VCSELs are currently normal.

1.2.2.2.3 Challenges of Vertical-cavity surface-emitting laser

Future elite PCs require optical interconnects with collected Extra-Byte/s information transport. Thickly stuffed varieties of vertical-cavity surface-producing lasers (VCSELs) may introduce the main attainable specialized arrangement. The fast properties of semiconductor lasers, be that as it may, are firmly influenced by their working temperature. Warm crosstalk winds up plainly predominant when thickly stuffed varieties of fast VCSELs are required. In this paper, we infer the greatest data transfer capacity of future VCSEL-based optical interconnects from the impact of gadget warming happening in fast VCSEL clusters. Moreover, we appraise the adaptability of this innovation and address the difficulties. From our figurings we get, that VCSEL clusters are versatile from a data transmission thickness of 100 Gbps/mm^2 with the present gadgets up to a mechanical breaking point of 15 Tbps/mm^2.

1.3 Fiber Optic Sensors

The fiber optic sensors additionally called as optical fiber sensors utilize optical fiber or detecting component. These sensors are utilized to detect a few amounts like temperature, weight, vibrations, relocations, pivots or centralization of substance species. Filaments have such a large number of employments in the field of remote detecting since they require no electrical power at the remote area and they have little size. Fiber optic sensors are preeminent for heartless conditions, including commotion, high vibration, and extraordinary warmth, wet and precarious situations. These sensors can without much of a stretch fit in little ranges and can be situated accurately wherever adaptable filaments are required. The wavelength move can be computed utilizing a gadget, optical recurrence area reflectometry. The time-postponement of the fiber optic sensors can be chosen utilizing a gadget, for example, an optical time-area Reflect meter.

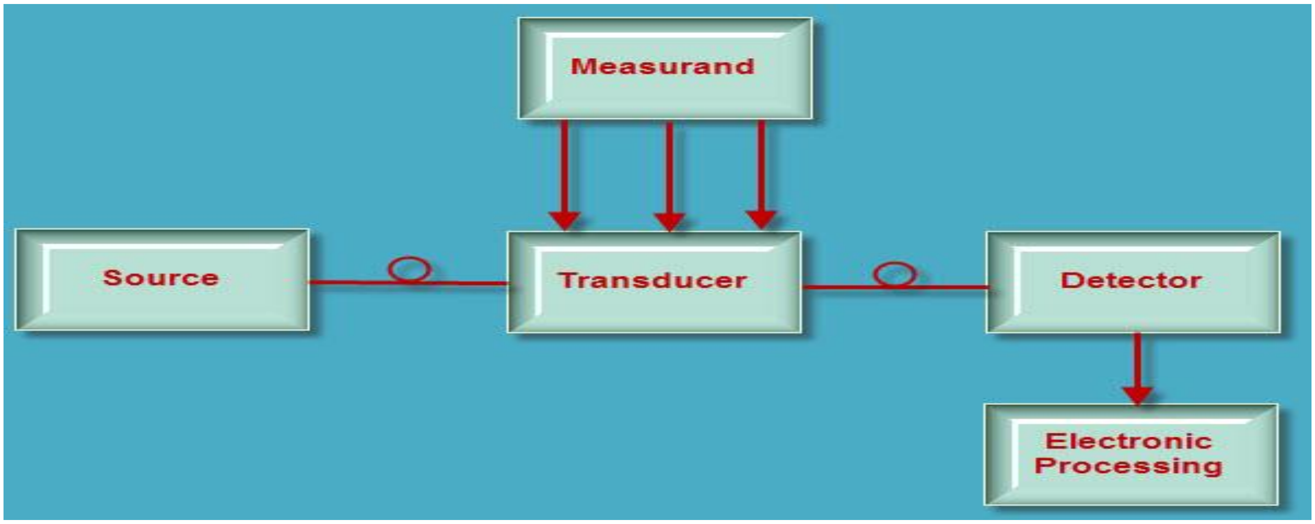

Fig 1.4: Basic optical fiber sensor

1.3.1 Application of Fiber optic Sensors

Fiber optic sensors are utilized as a part of a changed scope of uses, for example, In this manner, a diagram of fiber optic sensors and applications has been talked about. There are many preferences of utilizing fiber optic sensors for long separation correspondence that incorporate little in estimate, light in weight, conservativeness, high affectability, wide data transfer capacity, and so on. Every one of these qualities makes the best utilization of fiber optic as a sensor. Aside from this, for any assistance with respect to this subject or sensor based venture thoughts, you can get in touch with us by remarking in the remark area underneath. Measurement of physical properties, for example, temperature, displacement, velocity, strain in structures of any size or any shape. In continuous, observing the physical structure of wellbeing. Buildings and scaffolds, tunnels, dams, legacy structures. Night vision camera, electronic security frameworks, Partial release discovery and measuring wheel heaps of vehicles.

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Chapter 2

Literature Review

2.1 History of VCSEL

The first ideas of the Vertical Cavity Surface Emitting Laser (VCSEL) were conceived in the late 1970s at the Tokyo Institute of Technology by Kenichi Iga and his colleagues. The device was first suggested in 1977 and in order to operate they indicated that VCSEL should have a very small cavity volume,high optical gain and mirrors with a very high reflectively. At this time one of the major difficulties was acquiring a high gain using bulk materials and acquiring mirrors that would satisfy the needed reflectively. Its first realization of VCSEL was achieved in 1979 where a 1300-nm wavelength GaInAsP-InP material was used for the active region[12].The operating temperature for the first device was at 77K [13]. VCSELs (also called "micro lasers") have been around in various forms since the late 1970s. However in 1991 there was a major development in construction techniques reported and in 1996 the first commercial devices became available. In 1998 four manufacturers have low priced VCSELs on the market. In the near future it could be seen that VCSELs replacing LEDs completely for the LAN communications environment.

2.2 Recent works

Recently numerous numbers of researches are going on VCSEL and its performance improvements. One of the main challenges for VCSEL based system is to make it high temperature sustainable besides that it should emit high power which can be used in long distance error free optical data transmission system. And also the choice of wavelength in which VCSEL will perform draws a lot of interest among the researchers recent past.

S.Spiga et al. suggested that VCSEL emitting in the 1550 nm wavelength allows longer transmission distance compared with 1330nm and 850nm for lower fiber distortion and attenuation [14]. Numan Kifayat et al. reported that 1300nm and 1550nm VCSEL based optical link can transmit data over 50km for 3Gbps and 100km for 2.5Gbps [15]. N. Nishiyama et al. demonstrated that 10Gbps 1550nm VCSEL based system can perform 10km error free transmission at 85^0C and 40km transmission at room temperature [16].S.Spiga et al. in another investigation reported error free data transmission over long distances like 10km for 30Gbps,25km for 25Gbps [17].

VCSEL based system with single mode fiber draws special interest for access network systems as it provides good linearity and low distortion with a very low cost. Main challenge of the long distance transmission is transmitting error free data with higher SNR and lower BER[18-19]. HIGH operating temperature sustainable VCSEL is another challenge for error free optical data transmission over long distance[20]. Daniel M. Kuchta et al. reported NRZ modulated 850 nm VCSEL transmitting operating error free to 90^0C [21]. P.Moser et al. reported error free 46Gbps operation of oxide-confined 980 nm VCSELs at 85^0C [22]. Calvert et al. reported the continuous wave operation of 670nm single mode devices to a heat sink temperature of 80^0C [23].

There exists a growing interest in development of the high performance optical links at different data rated. Recent investigations are achieved error free optical data transmission at 20 Gbps [24],22Gbps for 1550nm and 40Gbps [25]. Some studies investigated error fredata transmission using multimode fiber and achieved 64 Gbps at 850nm up to 57m [26] and 57Gbps [27]. Danial M.Kuchta et al. reported 50Gbps [28],55Gbps [29],56Gbps [30],71Gbps [31] for 850nm by using single mode fiber with NRZ modulated VCSEL. All of these works are done practically by the help of equalization and by using different mode confinement approaches.

High power red laser sources are used in many applications such as cosmetics,cancer photodynamic therapy and DNA sequencing in the medical field,laser-based RGB projection display and bar-code scanning to name a few [32]. K.Johnson et al. suggested red VCSELs lasing up to 115^0C for smaller aperture single mode devices and to nearly 100^0C for multimode VCSELs. Single mode devices have produced 1mW of output power up to 60^0C and multimode devices provide up to 1.5mW of power at 80^0C. 2mW of output power at room temperature at 719nm wavelength [33]. P.Sundgren et al. reported high performance VCSEL which produced 1mW output power for 1300nm [34]. Jean Francois et al reported CW power of 0.2mW was obtained at 652 nm and 50^0C. Sale etal.has demonstrated CW lasing at 666 nm to 80^0C. Additionally, a 20^0C output power of 0.6mW at 650nm has been demonstrated at the Tyndall National Institute [35].

Some studies reported temperature sensing and compensation for VCSEL driver ICs [36],self-heating control [37], thermal effect of gain guided VCSEL [38],modeling temperature effects and spatial holes burning [39] to make it more efficient as a transmitter.

All the above mentioned works are done for making the high performance VCSEL transmitter for error free optical data transmission system.

Chapter 3

Methodology

3.1 Simulation software

Our VCSEL based optical data transmission system is designed and simulated in "OPTI-SYSTEM" software.

Opti-system software is an innovative optical communication system simulation package that designs, tests and optimizes virtually any type of optical link in the physical layer of a board spectrum of optical networks, from analog video broadcast systems to intercontinental backbones. Opti-system is a standalone product that does not rely on other simulation frameworks. It is physical layer simulator based on the realistic modeling of fiber optic communication systems. It possesses a powerful new simulation environment and a truly hierarchical definition of components and systems. Its capability can be extended easily with the addition of user components and can be seamlessly interfaces to a wide range of tools. The extensive library of active and passive components includes realistic, wavelength dependent parameters. Parameter sweeps allow the user to investigate the effect of particular device specifications on system performance [40]. Opti-system calculates the signals using the appropriate algorithms related to the required simulation by determining the order of execution of component modules according to the selected data flow model. The main data flow model that addresses the simulation transmission layer is the component Iteration Data Flow (CIDF) [41]. The CIDF domain uses run time scheduling, supporting conditions, data dependent iteration and true recursion.

The opti-system software consists of three major sections which are Transmission section, Channel section and Receiver section.

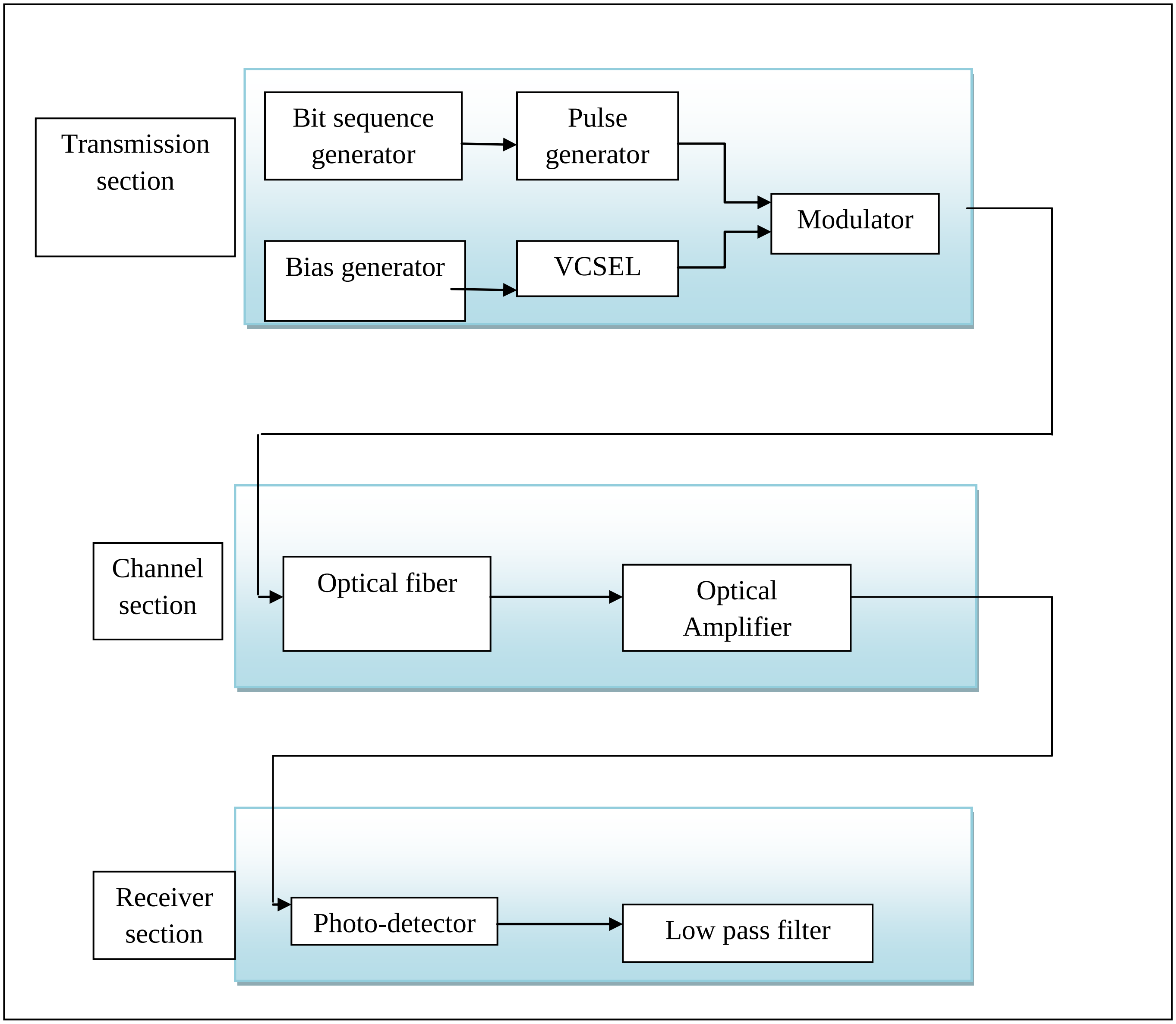

Fig 3.1: Main block diagram of designed system

3.2 Transmission section

In data transmission section we have used VCSEL laser of 1550 nm wavelength as an optical source which is driven by a bias generator in order to get proper stability and reduce nonlinear effect. For generating digital data we have used Pseudo Random Bit sequence Generator and we have also used Non Return to Zero and Return to Zero pulse generator. After that Mach Zender modulator with extinction ratio of 6 dB is used to mix the electrical signal with the input signal to produce optical output signal which is then sent into receiver section through single mode optical fiber.

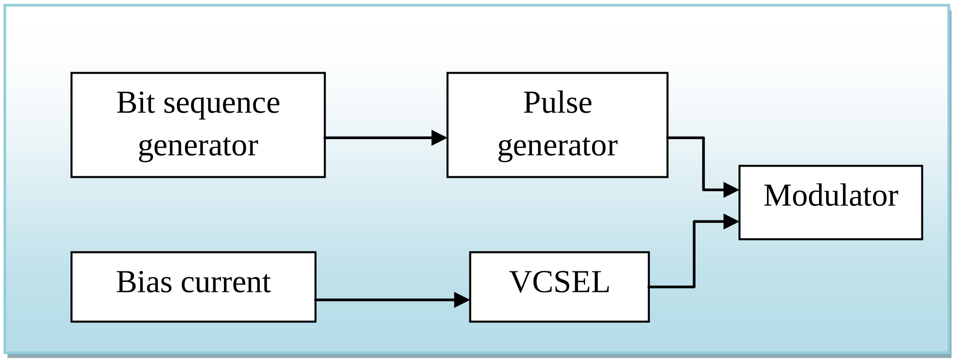

Fig 3.2: Block diagram of transmission section

3.2.1 Bit Sequence Generator

A random bit sequence generator is a device or algorithm which outputs a sequence of statistically independent and unbiased binary digits. We have used pseudorandom bit sequence generator of alternate operation mode. A Pseudorandom bit sequence generator is a deterministic algorithm, which given a truly random binary sequence of length k, outputs a binary sequence of length (1>k) which "appears" to be random. The input to the PRBSG is called the seed, while the output of the PRBSG is called a pseudorandom bit sequence. There are several types of PRBSG such as MLS, QRB, HAB, TPB and QRT. MLS is one of the most important classes of PRBSG and used in designing the PRBS generator due to its simplicity in construction. It has excellent pseudo randomness properties and fulfills all randomness criteria below.

(a) Balance property
(b) In each period of random sequence the number of logic zeros should not differ from the number of logic ones by at most one.
(c) Run property

Let a run refer to a string of consecutive ones. The 0 runs and 1 runs alternate with equally many 0 runs and 1 runs of the same length. The lengths of runs in each period are distributed such that one half the runs are of length 1, one quarter the runs are of length 2, one eighth the runs are of length 3 etc.

(d) Correlation property

If aperiod of the random sequence is compared term by term with any cyclic shift of itself, then the number of agreements and disagreements should not differ by more than one.

3.2.2 Pulse generator

The output of PRBSG is then sent to pulse generator to convert the bit sequence into rectangular pulse. A pulse generator is either an electronic circuit or a piece of electronic test equipment used to generate rectangular pulses. Electrical bit “1” was associated with a higher optical intensity, while bit “0” was associated with a lower optical intensity. Two formats are included in this modulation group: NRZ and RZ. NRZ is the oldest and simplest modulation format and it’s obtained by switching a laser source between ON or OFF. RZ describes a line code used in telecommunication signals in which the signal drops to zero between each pulse. Pulse generator is used to drive devices such as lasers and optical components, modulators. It has been demonstrated numerically and experimentally that the conventional NRZ modulation format is superior compared to the RZ modulation causes a significant eye closer penalty near end channels. As a pulse generator, we have used NRZ and RZ pulse generator which has rectangular shape, 1a.u amplitude, 0.05 bit rise time, 0.05 fall time.

3.2.3 Light source

One of the key components in optical communication is the monochromatic light source. It is the heart of an optical communication system. In optical communications, light sources must be compact, monochromatic, stable and long lasting. In practice, there are no monochromatic light sources; there are merely light sources that generate light within a very narrowband of wavelengths. The light sources used in spectrograph are neither practical nor economical in communications. Stability of a light source implies constant intensity level and constant wavelength. Solid state technology has made it possible to have such optical sources of light. There are two different types of light source. The first type transmits a continuous wave (CW). Continuous emitting lasers and light emitting diodes are examples of CW light sources. This type of light source requires an external modulator at its optical output. Commonly used light sources include LEDs, ELEDs, SLED and LDs. LEDs produce nonlinear incoherent light whereas a Laser Diode produces linear coherent light. Incoherent light sources used in multimode systems as where laser diodes in single mode system. Laser diodes must operate above their threshold region to produce coherent light, otherwise operating as ELED. Laser diodes are much faster in switching response than LEDs. Tunable laser is able to produce coherent light output with controlled variable wavelength used in multi wavelength systems by replacing a system where many sources are coupled into a multiplexing device system.

We use Vertical Cavity Surface Emitting Laser as a light source for its great advantages over Edge Emitting Laser and LED. It can be easily fabricated into one or two dimensional arrays to scale power output to match specific application requirements, enables that use of traditional semiconductor manufacturing equipment to keep fabrication costs down. Also VCSEL do not have the failure modes of traditional laser structures such as dark line defects. In our thesis we used 1550 nm wavelength VCSEL whose parameters are listed below:

Table 3.1 VCSEL parameters for 1550 nm

Parameters	**Value(1550 nm)**
Thermal Impedance	2600 C/W
Thermal Time Constant	1e-6
Scaling Factor	2.6e-8
Gain coefficient	1600 I/S
Carrier number of transparency	19400000
Carrier lifetime	1e-9
Photon lifetime	3e-12
Spontaneous Emission factor	3e-5
Max. input current	40 mA
Bias current	2 mA
Modulation peak current	10 mA
Injection efficiency	1

3.2.4 Bias generator

Bias generator is also known as a driver circuit which is used to drive the VCSEL in the optical data transmission system. It constitutes an electrical source that generates current on the laser input. Amplitude of 1 a.u. is used here to design this bias generator for this system.

3.2.5 Optical Modulator

An optical modulator is a device which is used to modulate a beam of light. The beam may be carried over free space, or propagate through an optical waveguide. Depending on the parameter of a light beam which is manipulated, modulators may be categorized into amplitude modulators, phase modulators, polarization modulators etc. Modulators consist of a material that changes its optical properties under the influence of an electric or magnetic field. Ingeneral three approaches are used

(i) Electro-optic and Magneto-optic Effects

There are many materials that change their optical properties in the presence of either an electric or a magnetic field. This property change is usually a change in refractive index and most often this change is different forincident light of different polarizations. Any changes in the RI cause changes in phase of the light passing through it. Phase modulation of this kind is not very useful to us. However, other devices may be used to convert the phase change into an amplitude change. Most high speed modulators are built around this principle.

(ii) Electro-Absorption Effects

An ideal simple modulator might consist of a material that had a variable absorption of light depending on the presence of an applied electric field. But there are not too many materials like this. However, A p-n junction in a 3-5 semiconductor does behave this way and this material is used to build modulators.

(iii) Acoustic Modulators

Acoustic modulators use very high frequency sound travelling within a crystal or planar wave guide to deflect light from one path to another. By controlling the intensity of the sound we can control the amount of light deflected and hence construct a modulator.

In our proposed method we use Mach-Zender modulator with extinction ratio of 6dB and symmetry factor of 1, Where small changes in refractive index induced by an electric field cause large changes in signal amplitude at the output. In one arm the RI will increase and in the other arm it will decrease. This causes the signal in one arm to be retarded in phase and the signal in the other arm to be advanced. When the signal is recombined at the output junction, the very small phase changes will cause interference effects. These interference effects cause very large variations in the amplitude of the optical signal very significantly according to an applied electric field. The usual material used to make interferometer modulators is lithium niobate. As considerable precision in manufacture is needed these are usually made in planar waveguide technology rather than as fiber devices.

3.3 Channel Section

For data transmission channel we have used single mode optical fiber of 26 km with dispersion around 16.75 ps/nm/km and attenuation of 0.2 dB/km. SOA and EDFA amplifiers are used alternatively at wavelengths under consideration for compensating the fiber linear loss and achieving better output performance.

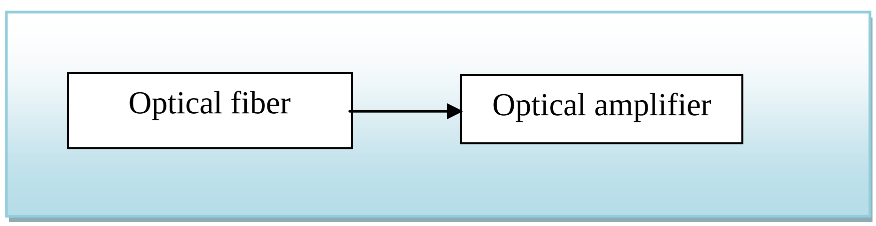

Fig 3.3: Block diagram of channel section

3.3.1 Optical fiber

Optical fibers can be used to transmit light and thus information over long distances. They are widely used for telephony, but also for Internet traffic, long high-speed local area networks, cable TV and increasingly also for shorter distances within buildings. In most cases, silica fibers are used, except for very short distances, where plastic optical fibers can be advantageous. Compared with systems based on electric cables, the approach of optical fiber communications has advantages, the most important of which are:

1. The capacity of fibers for data transmission is huge: a single silica fiber can carry hundreds of thousands of telephone channels, utilizing only a small part of the theoretical capacity. In the last 30 years, the progress concerning transmission capacities of fiber links has been significantly faster than e.g. the progress in the speed or storage capacity of computers.
2. The losses for light propagating in fibers are amazingly small; ~ 0.2 dB/km for modern single mode silica fibers, so that many tens of kilometers can be bridged without amplifying the signals.
3. A large number of channels can be re-amplified in a single fiber-amplifier, if required for very large transmission distances.
4. Due to the huge transmission rate achievable, the cost per transported bit can be extremely low.
5. Compared with electrical cables, fiber-optic cable are very lightweight.

Two types of optical fiber are used in optical communication system. In case of medium or long-distance transmission, the fiber is usually a single mode fiber but for short distances communication multi-mode fiber is used. When light enters one end of the fiber, it spread out during transmission through the fiber and dispersion occurs. Because of dispersion a short pulse becomes longer and ultimately joins with the pulse behind, making recovery of a reliable bit stream impossible. There are many kinds of dispersion, each of which works in a different way, but the most important three are discussed below:

(i) Material Dispersion

This is caused by the fact that the refractive index of the glass we are using varies with the wavelength. Some wavelengths therefore have higher group velocities and so travel faster than others. Since every pulse consists of a range of wavelengths it will spread out to some degree during its travel. All optical signals consist of a range of wavelengths. This range may be only a fraction of a nanometer wide but there is always a range involved.

(ii) Waveguide Dispersion

The shape of the fiber has a very significant effect on the group velocity. This is because the electric and magnetic fields that constitute the pulse of light extend outside of the core into the cladding. The amount that the fields overlap between core and cladding depends strongly on the wavelength. The longer the wavelength the further the electromagnetic wave extends into the cladding.

(iii) Modal Dispersion

When using multimode fiber, the light is able to take many different paths as it travels within the fiber. The distance traveled by light in each mode is different from the distance travelled in other modes. When a pulse is sent, parts of that pulse take many different modes. Therefore, some components of the pulse will arrive before others. The difference between the arrival times of light taking the fastest mode versus the slowest obviously gets greater as the distance gets greater.

The good news here is that these two forms of dispersion have opposite signs, so they tend to counteract one another hence dispersion will be minimized. So, single mode fiber has lower dispersion than multi-mode fiber.

Table 3.2 Optical fiber specifications for 1550 nm wavelength

Parameters	**1550 nm**
Length	90 km
Attenuation constant	0.2 dB/km
Attenuation effect	Constant
Dispersion	16.75 ps/nm/km
Dispersion slope	0.075 ps/nm^2/km

3.3.2 Optical Amplifier

An optical amplifier is a device that amplifies an optical signal directly, without the need to first convert it to an electrical signal. An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed. Optical amplifiers are important in optical communication and laser physics. An important practical goal is to develop an amplifier adequate for use as an optical repeater in the long distance fiber optic cables which carry much of the world's telecommunication links. Existing fiber optic repeaters must convert the light beam to an electronic signal to amplify it, then convert it back to light.

There are several different physical mechanisms that can be used to amplify a light signal, which correspond to the major types of optical amplifiers. In doped fiber amplifiers and bulk lasers, stimulated emission in the amplifier's gain medium causes amplification of incoming light. In semiconductor optical amplifiers (SOAs), electron-hole recombination occurs. In Raman amplifiers, Raman scattering of incoming light with phonons in the lattice of the gain medium produces photons coherent with the incoming photons. Parametric amplifiers use parametric amplification.

3.3.2.1 Semiconductor Optical Amplifier (SOA)

A semiconductor optical amplifier is an optical amplifier based on a semiconductor gain medium. It is essentially like a laser diode where the end mirrors have been replaced with anti-reflection coatings; a tilted waveguide can be used to further reduce the end reflectivities. The signal light is usually sent through a semiconductor single-mode waveguide with transverse dimensions of e.g. 1–2 μm and a length of the order of 0.5–2 mm. The waveguide mode hassignificant overlap with the active (amplifying) region, which is pumped with an electric current. The injection current creates a certain carrier density in the conduction band, allowing for optical transitions from the conduction band to the valence band. The gain maximum occurs for photon energies slightly above the band gap energy.

In principle, one can also use a semiconductor optical amplifier where the end reflectivities are not minimized. One has to operate such a *Fabry–Pérot amplifier* (*FP amplifier*) slightly below the laser threshold; in that regime, the output power depends strongly on the input power, i.e., one obtains a high effective signal gain. However, the available optical bandwidth is then very small, and the occurrence of strong reflections may be detrimental to the system in which such a device is used. For these reasons, in most cases one uses traveling-wave amplifiers, where the end reflectivities are suppressed as far as possible.

The amplification is intrinsically polarization-sensitive, but amplifier designs have been developed which provide nearly polarization-independent characteristics. For example, one may use two identical amplifiers in series, where the second one is rotated against the first one by 90°C. There are also configurations with two parallel amplifiers for the two polarization directions, with polarizing beam splitters before and after these amplifiers. Another possibility is to use a double pass through a single amplifier, where there is a Faraday rotator between the device and the reflecting mirror.

SOAs can be used in telecom systems in the form of fiber-pigtailed components (with either normal single-mode fibers or polarization-maintaining fibers), operating at signal wavelengths near 1.3 μm or 1.5 μm, and offering a gain of up to ≈ 30 dB, limited essentially by amplified spontaneous emission (ASE). The strong gain saturation in SOAs can be a problem for some applications, but it can also be exploited for nonlinear signal processing in telecom systems – for example, for channel translation in a wavelength division multiplexes system.

3.3.2.2 Erbium Doped Fiber Amplifier (EDFA)

E*rbium*-d*oped* f*iber* a*mplifier* *(*EDFA*)* is an optical repeater device that is used to boost the intensity of optical signals being carried through a fiber optic communications system. The erbium-doped fiber amplifier (EDFA) is the most deployed fiber amplifier as its amplification window coincides with the third transmission window of silica-based optical fiber.Two bands have developed in the third transmission window – the Conventional, or C-band, from approximately 1525 nm – 1565 nm, and the Long, or L-band, from approximately 1570 nm to 1610 nm. Both of these bands can be amplified by EDFAs, but it is normal to use two different amplifiers, each optimized for one of the bands.EDFAs have two commonly used pumping bands – 980 nm and 1480 nm. The 980 nm band has a higher absorption cross-section and is generally used where low-noise performance is required. The absorption band is relatively narrow and so wavelength stabilized laser sources are typically needed. The 1480 nm band has a lower, but broader, absorption cross-section and is generally used for higher power amplifiers. A combination of 980 nm and 1480 nm pumping is generally utilized in amplifiers.

Advantages of EDFA

- High power transfer efficiency from pump to signal power
- Minimal polarization sensitivity
- Low insertion loss
- High output power > 1mW (10 to 25 dBm)

- Very high sensitivity
- Low distortion and minimal inter-channel crosstalk
- Relatively low in cost and higher efficiency

Here are some parameters with their respective value for EDFA

Table 3.3: EDFA Specification

Parameters	**Value**
Core radius	2.2 um
E_r doping radius	2.2 um
E_r metastable lifetime	10 ms
Numerical Aperture	0.24
E_r ion density	$1\times10^{25}(m^{-3})$
Length	5m

Whenever there is gain in a system there is also noise. It also have some limitations as it does not operate over the entire range of wavelengths of interest (Wavelength range of about 1525 nm and 1570 nm), it give different amounts of gain at different wavelengths. In our proposed model we have used Erbium Doped Fiber amplifiers for transmission at 1550 nm as it has several advantages over semiconductor optical amplifier (SOA).

3.4 Receiver section

In the receiver section an optical receiver is used to receive the data which is transmitted from transmitting section. The optical receiver consists of a photo detector and a low pass filter. Photo detector receivers the transmitting data and send it to low pass filter for discarding the high frequency signals. Low pass filter passes low frequency signals by discarding the higher ones. We have accounted the effect of short noise, thermal noise, Amplified spontaneous emission (ASE) noise and estimate receiver noise at the receiver end of the system.

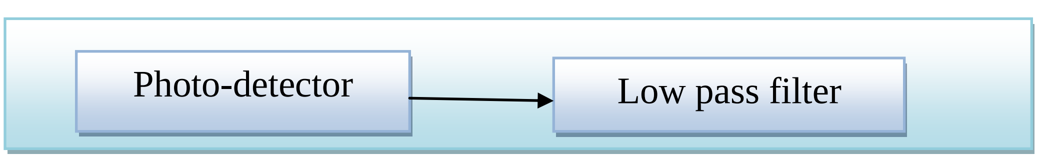

Fig 3.4: Block diagram of Receiver section

3.4.1 Photo-detector

Photo sensors or photo detectors are sensors of light or other electromagnetic energy. A photo detector has a junction that converts light photons into current. The junction is covered by an illumination window, usually having an anti-reflective coating. The absorbed photons make electron-hole pairs in the depletion region. Photodiodes and photo transistors are a few examples of photo detectors. Solar cells convert some of the light energy absorbed into electrical energy.

Types:

Photo detectors may be classified by their mechanism for detection:

- Photoemission or photoelectric effect: Photons cause electrons to transition from the conduction band of a material to free electrons in a vacuum or gas.
- Photoelectric: Photons cause electrons to transition from the valence band to the conduction band of a semiconductor.
- Photovoltaic: Photons cause a voltage to develop across a depletion region of a photovoltaic cell.
- Thermal: Photons cause electrons to transition to mid-gap states then decay back to lower bands, inducing phonon generation and thus heat.
- Polarization: Photons induce changes in polarization states of suitable materials, which may lead to change in index of refraction or other polarization effects.
- Photochemical: Photons induce a chemical change in a material.
- Weak interaction effects: photons induce secondary effects such as in photon drag detectors or gas pressure changes in Go lay cells.

Photodetectors may be used in different configurations. Single sensors may detect overall light levels. A 1-D array of photodetectors, as in a spectrophotometer or a Line scanner, may be used to measure the distribution of light along a line. A 2-D array of photodetectors may be used as an image sensor to form images from the pattern of light before it.

Properties:

There are a number of performance metrics, also called figures of merit, by which photodetectors are characterized and compared

- Spectral response: The response of a photodetector as a function of photon frequency.
- Quantum efficiency: The number of carriers (electrons or holes) generated per photon.
- Responsively: The output current divided by total light power falling upon the photodetector.
- Noise-equivalent power: The amount of light power needed to generate a signal comparable in size to the noise of the device.
- Directivity: The square root of the detector area divided by the noise equivalent power.
- Gain: The output current of a photodetector divided by the current directly produced by the photons incident on the detectors, i.e., the built-in current gain.
- Dark current: The current flowing through a photodetector even in the absence of light.
- Response time: The time needed for a photodetector to go from 10% to 90% of final output.
- Noise spectrum: The intrinsic noise voltage or current as a function of frequency. This can be represented in the form of a noise spectral density.
- Nonlinearity: The RF-output is limited by the nonlinearity of the photodetector.

In optical communication system Avalanche Photo-Diode (APD) and P-I-N photodiode are widely used for their various advantages over others photo-detectors.

3.4.1.1 Avalanche Photo-diode (APD)

An avalanche photodiode (APD) is a highly sensitive semiconductor electronic device that exploits the photoelectric effect to convert light to electricity. APDs can be thought of as photo detectors that provide a built-in first stage of gain through avalanche multiplication. From a functional standpoint, they can be regarded as the semiconductor analog to photomultipliers. By applying a high reverse bias voltage (typically 100-200 V in silicon), APDs show an internal current gain effect (around 100) due to impact ionization (avalanche effect). Since APD varies with the applied reverse bias and temperature, it is necessary to control the reverse voltage to keep a stable gain. The most important characteristics of APDs are their sensitivity, their operating speed, their gain-bandwidth product and their level of noise. They are more sensitive compared to other semiconductor photodiodes. If very high gain is needed certain APDs can be operated with a reverse voltage above the APDs breakdown voltage. APDs are inherently noisy as the multiplier effect applies to all free electrons. This is especially a problem in longer wavelength devices where the band gap energy is low.

3.4.1.2 PIN Photodiode

PIN photodiode is a kind of photo detector it can convert optical signals into electrical signals. The PIN diode operates with an applied reverse bias voltage and when reverse bias is applied, the space charge region must cover the intrinsic region completely. Electron hole pairs are generated in the space charge region by photo absorption. For the photo detector applications where the speed of response is important, the depletion region width should be made as large as possible for small minority carrier lifetime as a result the switch speed also increases.

PIN photo detectors performance is quit high as the short noise affects it lightly. But in case of APD, when the dark current is high the short noise dominates the system and the performance is greatly affected. PIN signal to noise ratio is higher than the APD. The PIN performs better as the thermal noise effects decrease. Whereas, in the APD, as short noise dominates over thermal noise its performance becomes worse. We use PIN photo detector with responsivity of 1A/W, 10 nA dark current as an optical detector.

3.4.2 Low pass filter

Low pass filter is used at demodulator or receivers. Before sending the data through optical fiber, we modulate the data, so modulated data have very high frequency components. Hence we need to demodulate the data to low frequency and in this case we need low pass filter which passes signals with a frequency lower than a certain cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency. Its type may vary according to its applications and type of receivers. Here are the common types of filter response-

1. Butterworth
2. Chebyshev
3. Inverse Chebyshev
4. Elliptical
5. Bessel

3.5 Modulation technique

Modulation technique is mainly two types- direct modulation and External modulation.

3.5.1 Direct modulation

In this modulation technique laser is modulated directly without the help of any modulation circuitry.

3.5.2 External modulation

In this modulation technique laser is modulated externally with the help of pulse generator and modulator. Frequently used modulation techniques are:

3.5.2.1 QAM modulation

QAM (Quadrature amplitude modulation) is a method of combining two amplitude-modulated (AM) signals into a single channel, thereby doubling the effective bandwidth.QAM is used with pulse amplitude modulation (PAM) in digital systems, especially in wireless applications. In a QAM signal, there are two carriers, each having the same frequency but differing in phase by 90 degrees (one quarter of a cycle, from which the term quadrature arises). One signal is called the I signal, and the other is called the Q signal. Mathematically, one of the signals can be represented by a sine wave, and the other by a cosine wave. The two modulated carriers are combined at the source for transmission. At the destination, the carriers are separated, the data is extracted from each, and then the data is combined into the original modulating information.

3.6 Visualizes used for performance testing

To see the performance of our VCSEL based system like output power value, signal quality, Bit error rate, Optical signal to noise ratio we used three visualizes which are optical power meter, optical spectrum analyzer and BER analyzer. They are briefly described in this section:

3.6.1 Optical power meter

An optical power meter (OPM) is a device used measure the power in an optical signal. The term usually refers to a device for testing average power in fiber optic systems. Other general purpose light power measuring devices are usually called radiometers, photometers, laser power meters (can be photodiode sensors or thermopile laser sensors), light meters or lux meters. A typical optical power meter consists of a calibrated sensor, measuring amplifier and display. The sensor primarily consists of a photodiode selected for the appropriate range of wavelengths and power levels. On the display unit, the measured optical power and set wavelength is displayed.

3.6.2 BER analyzer

Bit error rate analyzer measures the performance of the system based on the signal before and after the propagation. Bit error rate analyzer is used to see the Quality factor, Bit error rate, Eye height, optical signal to noise ratio. It is an experimental tool for the evaluation of the combined effects of channel noise on the performance of a baseband pulse transmission system.

3.6.3 Optical Spectrum Analyzer

An Optical Spectrum Analyzer (or OSA) is a precision instrument designed to measure and displays the distribution of power of an optical source over a specified wavelength span. An OSA traces displays power in the vertical scale and the wavelength in the horizontal scale.The expanding field of optics related applications has created a vast variety of industries and organizations that require advanced optical spectral measurements for both R&D and manufacturing. These industries include telecommunications, consumer electronics, healthcare, life science/medical research, security, sensing, microscopy, and gas/chemical analysis, and environmental monitoring. The most common application of an OSA is characterizing optical components and testing optical signals in telecommunication networks. OSA typically uses either direct spectral measurement or fast Fourier transform (FFT) based measurement[42-43].

Chapter 4

Simulation and Results

In order to predict the system performance, Optisystem software calculates parameters such as SNR, power, BER and Q factor using numerical analysis or semi-analytical techniques for systems limited by inter symbol and noise.

4.1 Simulation Model

We have design two separate models one is NRZ based and other is RZ based which is VCSEL based system by making VCSEL an efficient transmitter.

4.1.1 M-QAM based system model

Simulation model of 1550 nm 8-QAMmodulated VCSEL based optical data transmission system is given below:

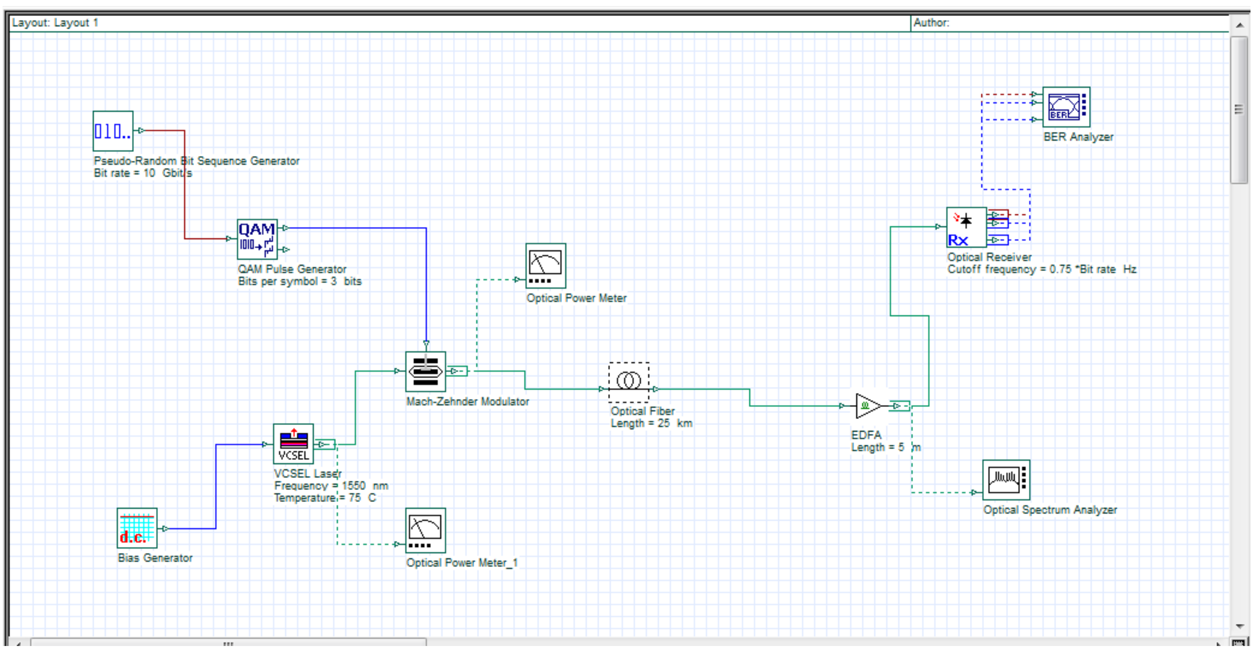

Fig 4.1: Simulation layout of 8-QAM modulation

In this model we have used VCSEL laser of 1550nm. 10 Gbps data can be transmitted through this system over 25km long optical fiber. An optical amplifier namely EDFA is used here to maintain signal strength up to the receiver section. In receiver section PIN photo detector is used to detect the signal and then the signal passed through low pass filter to discard the higher frequencies. VCSEL laser, Optical fiber, optical photo detector all of this component of our system model are designed by setting different parameters in their internal design section.

4.2 Performance Measure Parameters

Characterization of an optical transmission link which is one of the main criterions for the effective performance metrics modeling of optical data transmission system depends on the proper choice of Performance metrics should present a precise determination of systems limitation and measurement to improve the performance of the system. There are many performance measure parameters are used in optical data transmission system to analyze system performance but most widely used performance measures are the Q-factor, BER and eye pattern.

4.2.1 Q factor

Q factor represents the optical signal to noise ratio (SNR) for a binary optical communication system and allows simplified analysis of system performance. It combines the separate SNRs associated with the high and low levels into overall system SNR [44]. Q factor is also helpful as an intuitive Figure of Merit (FoM) that is directly tied to the BER. BER can be improved by either-

(a) Increasing the difference between the high and low levels in the numerator of the Q factor or

(b) Decreasing the noise terms in the denominator of the Q factor.

4.2.2 Bit Error Rate

BER is the number of erroneous bit divided by the total number of transferred bits during a studied time interval. In digital transmission, data stream can be altered due to noise, distortion or synchronization errors. The BER gives the upper limit for the signal because some degradation occurs at the receiver end. The bit error probability is the expectation value of the BER. The BER can be considered as an approximate estimate of the bit error probability. In a noisy channel, The BER is often expressed as a function of the normalized carrier to noise ratio. In most of the cases for optical data transmission the standard value of BER for error free system is 10^{-12}.

4.2.3 Eye pattern

Eye pattern is used to visualize how the waveforms used to send multiple bits of data can potentially lead to errors in the interpretation of those bits. Vertical eye opening indicates the amount of difference in signal level that is present to indicate the difference between one and zero bit. The bigger the difference the easier it is to discriminate between one and zero. Whereas, horizontal eye opening indicates the amount of jitter present in the signal. An open eye pattern corresponds to minimal signal distortion. Distortion of the signal waveform due to inter symbol interference and noise appears as closure of the eye diagram [45].

4.3 Results

Firstly we designed temperature sustainable VCSEL laser and then tested its performance by incorporating it in our data transmission model. This VCSEL based 1550nm system represents error free data communication where we considered BER<10^{-12} as a standard, meaning that in every 10 bits, one bit was error. Whenever we got BER performance higher than our standard we considered it as an error value and we did not count this error value in our error free system performance analysis.

4.4 Performance analysis for 16-QAM model

4.4.1 Performance analysis at different temperatures for 16-QAM model

We have discussed earlier that from our 1550nm VCSEL based optical link we found temperature performance up to 95^0C, now this temperature performance is analyzed with the help of power, Q-factor and OSNR curves which are depicted in table fig 4.2, fig 4.3 and fig 4.4. In this case the bit error rate of the system is kept fixed at 10 Gbps and also fiber length is kept fixed at 100 km.

Table 4.1 BER performance at different temperatures for 1550nm

Temperature [^oC]	Q factor
5	0.00330284
10	0.00660299
20	0.0014986
25	0.00745698
30	0.00189496
40	0.00420586
50	0.00446886
60	0.00350708
70	0.00144643
75	0.00606284
80	0.00578908
90	0.00644146
95	0.00747923

We consider BER standard for our error free system is BER<10^{-12}. And we got error free temperature performance from our system up to 70^0C. At 95^0C the system fails to provide error free operation.

Fig 4.2 shows power in VCSEL based 1550nm system and then with the increase of temperature power value decreases and we have got output power -1.341 dBm at 95^0C. As 95^0C failed to give error free performance, we did not consider it in our system.

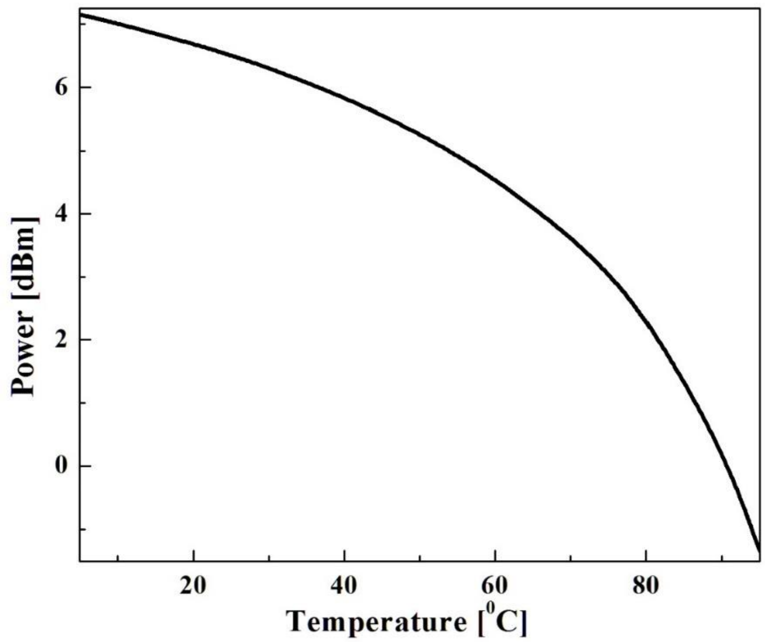

Fig 4.2: Temperature dependence of Powerat 1550 nm for 16-QAM

In figure 4.3 the system performance has analyzes in terms of Q factor with different temperatures. It can be seen that Q factor performance decays very small amount with the increase of temperature but 95^0C it decays to 0, which means that our system is performing up to 70^0C.

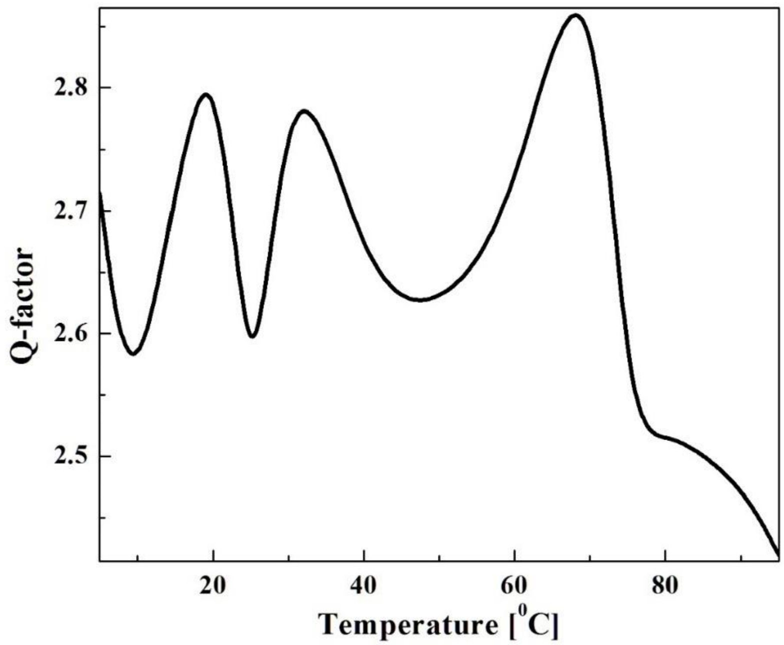

Fig 4.3: Temperature dependence of Q-factor at 1550 nm for 16-QAM

In fig 4.3 the system performance at different temperatures are shown with the help of eye diagrams and it can be seen that the openness of eye decreases with the increase of temperature. When the temperature goes passed 95^{0}C the system stops performing because no particular eye openness can be identified in this temperature and there are multiple copies of eyes which indicate that the system noise level has increased.

So, from the temperature analysis by varying bit rate and fiber length analysis we have found that our 1550nm 16-QAM modulated VCSEL optical link is capable of transmitting data at 10Gbps over 100 km at a maximum temperature of 70^{0}C by using EDFA amplifier.

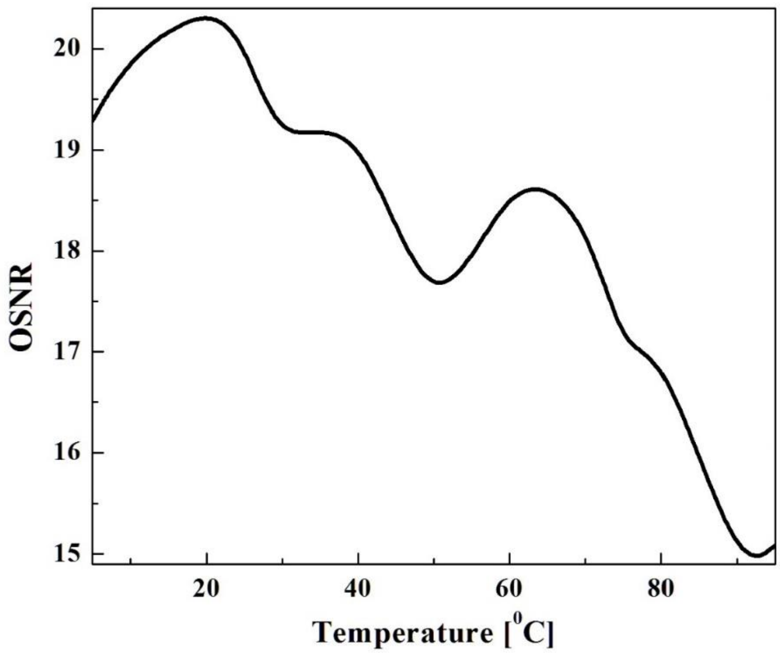

Fig 4.4: Temperature dependence of OSNR at 1550nm for 16-QAM

Optical signal to noise ratio (OSNR) performance with varying temperature is analyzed in fig 4.4. At 20^{0}C we get highest OSNR of 19.25dBm after that with the increase of temperature OSNR decreases.

Optical Spectrum analysis is shown in fig 4.4 where with the increase of temperature the noise also increases. Then the signal becomes affected by noise fully and that is why we did not consider this temperature in our error free system.

4.4.2 Performance Analysis of different bit rates in 16-QAM

Bit rate is very important parameter of an optical data transmission system. The higher bit rates, the higher the complexity of the system and chances of error occurred. We have analyzed our 1550nm VCSEL based optical link performance at different bit rates with the help of Q factor curves which are shown in table 4., fig 4.5. In this case the temperature of the system is kept fixed at 75^{0}C and also fiber length is kept fixed at 25 km.

Table 4.2 BER performance at different bit rates for 1550 nm

Bit Rate [Gbps]	BER
2.5	0.0110509
5	0.00888039
10	0.0047894
11	0.00104866
12	0.0109262
13	0.0201483
14	0.0158163
15	0.0132424
16	0.0143906
17	0.0104818
18	0.0247085
19	0.0248858
20	0.0186324

Table 4.2 depicts BER performance at varying bit rates. We have found decreasing BER performance with the increase of bit rate.

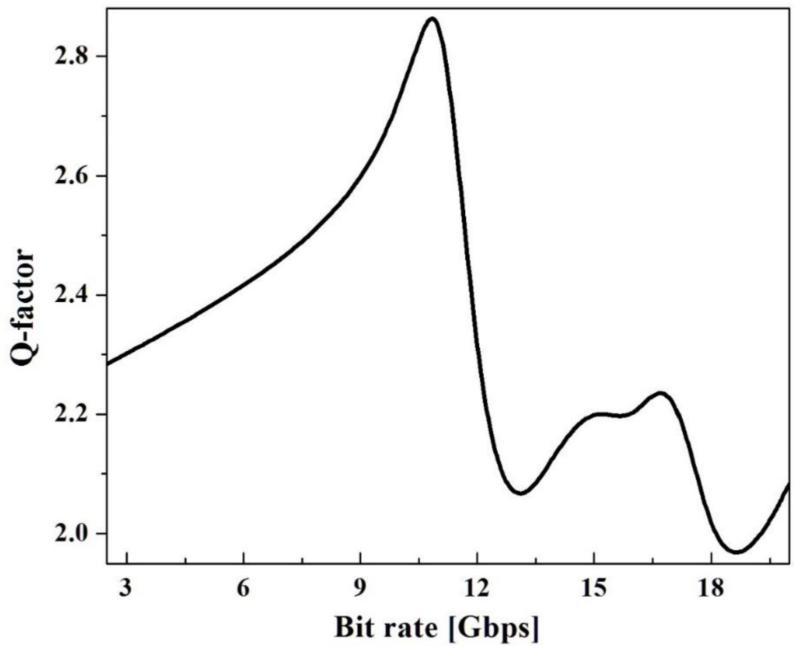

Fig 4.5: Bit rate dependence of Q-factorat 1550nm for 16-QAM

Fig 4.5 the system performance has analyzed in terms of Q factor with different Bit rate. It can be seen that Q factor performance decays very large amount with the increase of bit rate but at 20Gbps it is down to zero which is not acceptable because the system quality becomes very low at this bit rate. So, we did not consider in our system.

In fig 4.5 the system performance at different bit rates are shown with the help of eye diagrams and it can be seen that the openness of eye decreases with the increase of bit rate. When the temperature goes passed 20 Gbps the system stops performing because no particular eye openness can be identified in this bit rate and there are multiple copies of eyes which indicate that the system noise level has increased.

4.4.3 Performance analysis at fiber length

In our 1550nm VCSEL based optical data transmission model we have succeeded to transmit 10Gbps data up to 75^0C and by kept this findings fixed we also have analyzed the maximum distance where we can send error free data at 10Gbps up to 75^0C. Fig 4.6, fig4.7, fig4.8 represent the optical fiber length analysis with the help of Q factor, OSNR and BER respectively. The figure depicts that with the increase of fiber length the system performance decays.

Table 4.3 BER performance at different fiber length for 1550nm

Distance [km]	BER
10	0.00209382
20	0.00316865
30	0.00406785
40	0.00417289
50	0.00231778
60	0.00427501
70	0.00195549
80	0.00329005
90	0.00215579
100	0.00672277
110	0.00372951
120	0.0064342
130	0.0059723
140	0.00653714
150	0.00420771
160	0.0121062
170	1

Table 4.3 depicts BER performance at varying fiber length. We have found increasing BER performance with the increase of fiber length.

Q factor decreases with the increasing fiber length as shown in fig 4.6

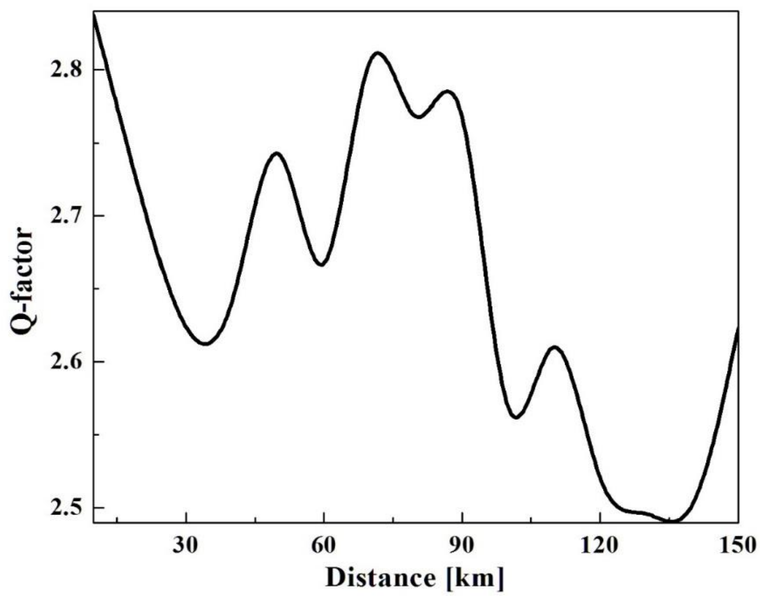

Fig 4.6: Distance dependence of Q-factor at 1550 nm for 16-QAM

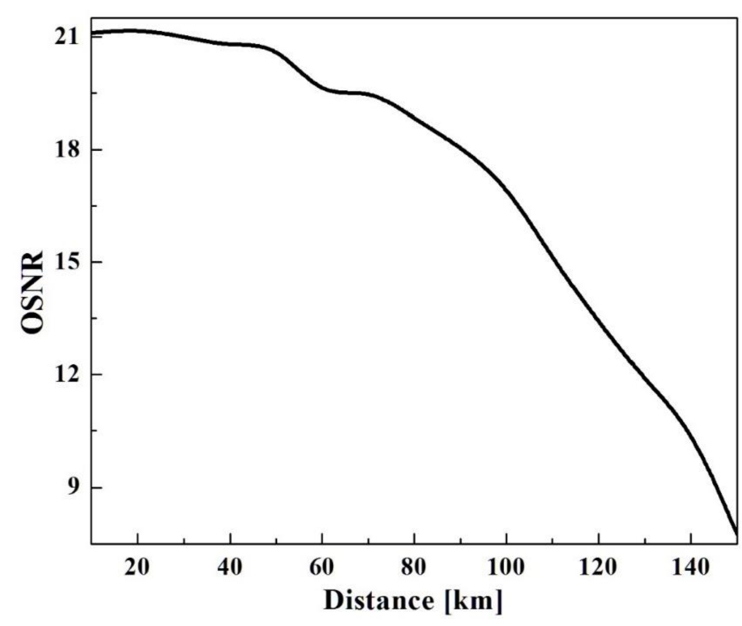

Fig 4.7: Distance dependence of OSNR at 1550nm for 16-QAM

Fig 4.7 represents a relationship between optical signal to noise ratio (OSNR) and fiber length. It is found that OSNR decreases with the increase fiber length. 19.2dBm is the maximum OSNR value which can be achieved at 100 Km length.

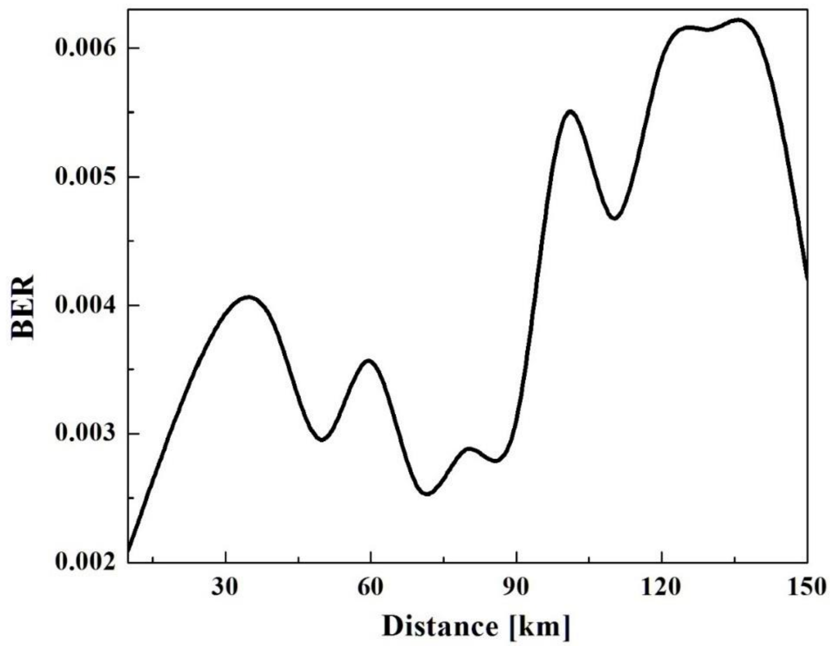

Fig 4.8: Distance dependence of BER at 1550 nm for 16-QAM

Fig 4.8 represents a relationship between BER and distance. 5.30262e-018 is the maximum BER value which can be achieved at 100 Km length.

4.5 Performance analysis for 32-QAM model

4.5.1 Performance analysis at different temperatures for 32-QAM model

We have discussed earlier that from our 1550 nm VCSEL based optical link we found temperature performance up to 125^0C, now this temperature performance is analyzed with the help of BER value, power, and Q factor curves which are depicted in table 4.8, fig 4.9, fig 4.30 and fig 4.10. In this case the bit error rate of the system is kept fixed at 10 Gbps and also fiber length is kept fixed at 40 km.

Table 4.4 BER performance at different temperatures for 1550 nm

Temperature [^oC]	BER
5	0.0142745
10	0.00401976
20	0.00487347
25	0.007168
30	1
40	0.00401532
50	1
60	0.0242951
70	0.00731379
80	0.00898971
90	0.0159889
95	0.00798207

Table 4.4 depicts BER performance varying at temperatures.

We consider BER standard for our error free system is BER<10^{-12}. And we got error free temperature performance from our system up to 75^0C. At 125^0C the system fails to provide error free operation.

Fig 4.30 shows that we have got highest power of 6.67dBm at 20^0C from its VCSEL based 1550 nm system and then with the increase of temperature further power value decreases and we have got output power -40dBm at 120^0C. As 120^0C failed to give error free performance, we did not consider it in our system.

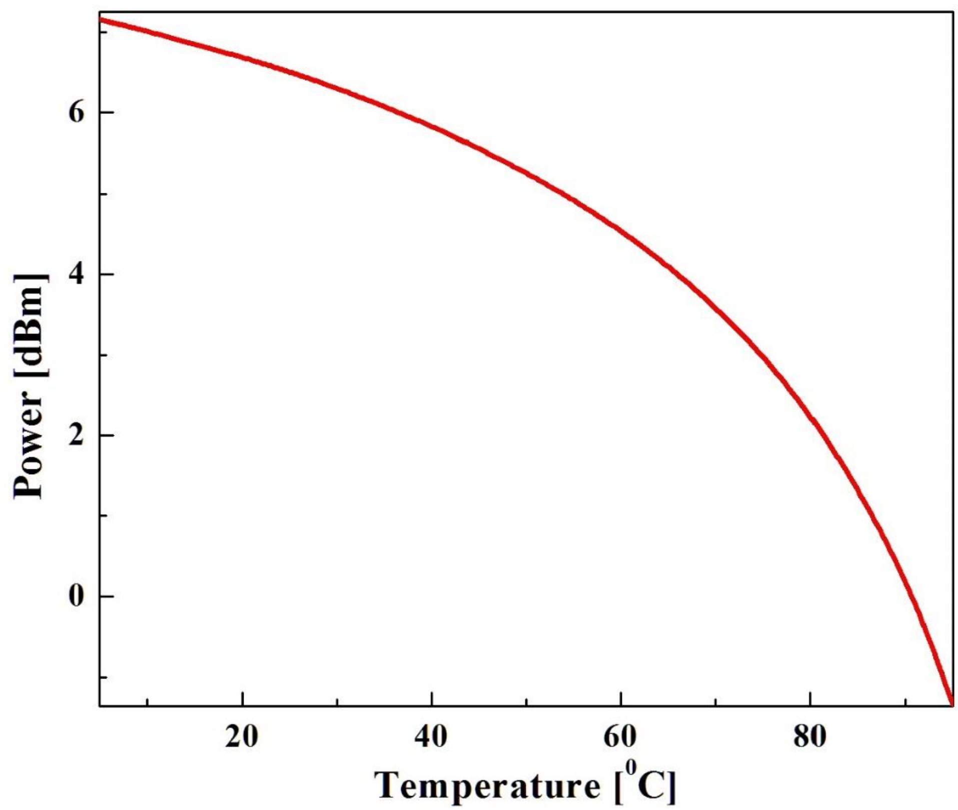

Fig 4.9: Temperature dependence of Power at 1550 nm for 32-QAM

In figure 4.9 the system performance has analyzes in terms of Q factor with different temperatures. It can be seen that Q factor performance decays very small amount with the increase of temperature but 120^{0}C it decays to 0, which means that our system is performing up to 75^{0}C.

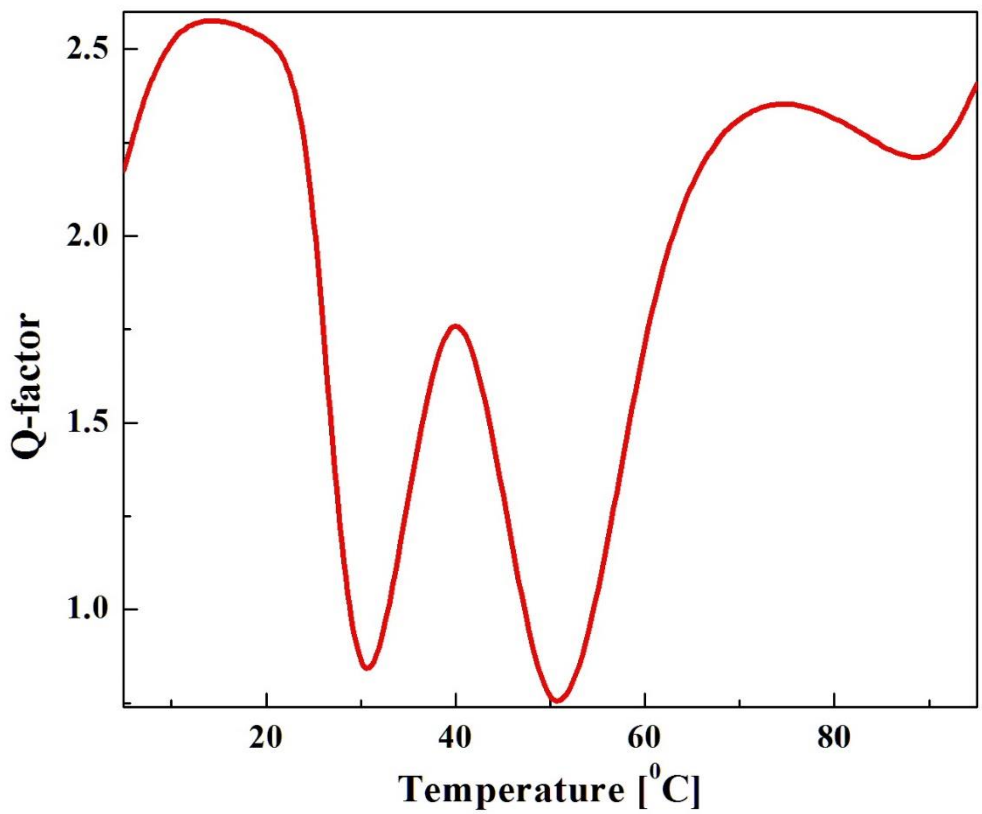

Fig 4.10: Temperature dependence of Q-factor at 1550 nm for 32-QAM

In fig 4.10 the system performance at different temperatures are shown with the help of eye diagrams and it can be seen that the openness of eye decreases with the increase of temperature. When the temperature goes passed 125^{0}C the system stops performing because no particular eye openness can be identified in this temperature and there are multiple copies of eyes which indicate that the system noise level has increased.

So, from the temperature analysis by varying bit rate and fiber length analysis we have found that our 1550nm RZ modulated VCSEL optical link is capable of transmitting data at 10Gbps over 41km at a maximum temperature of 75^{0}C by using EDFA amplifier.

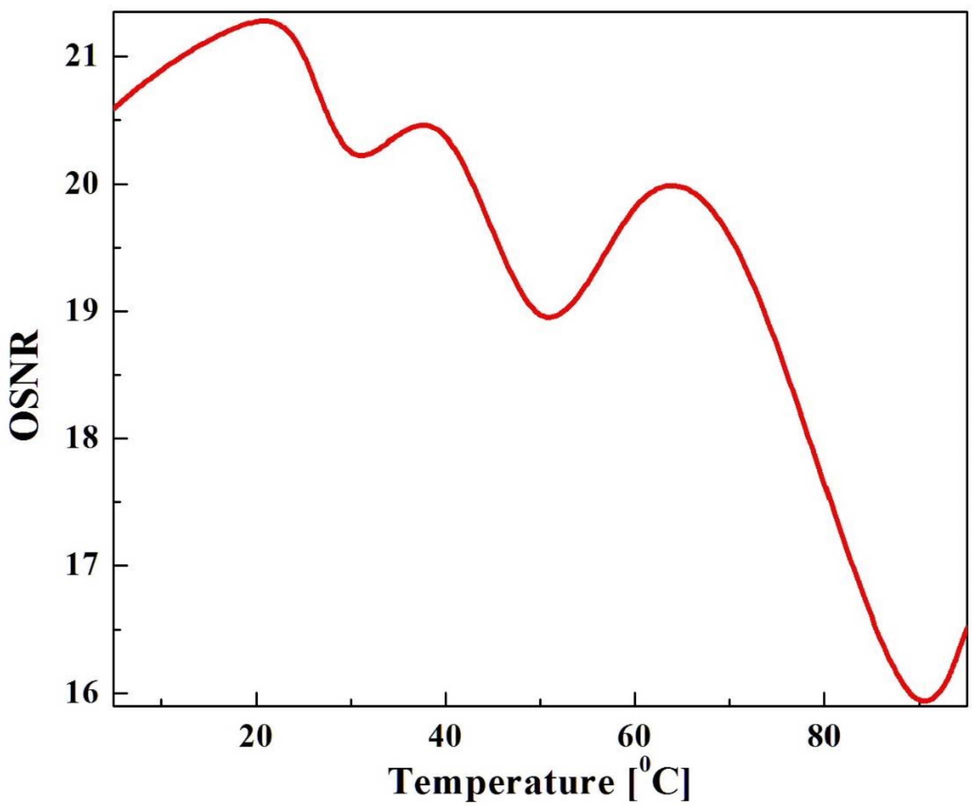

Fig 4.11: Temperature dependence of OSNR at 1550nm for 32-QAM

Optical signal to noise ratio (OSNR) performance with varying temperature is analyzed in fig 4.11. At 20^0 C we get highest OSNR of 19.25dBm after that with the increase of temperature OSNR decreases and 125^0C we get OSNR value of -24.9 dBm which is not acceptable for error free system.

Optical Spectrum analysis is shown in fig 4.39 where with the increase of temperature the noise also increases. At the point of 125^0C the noise level goes passed the signal power level. Then the signal becomes affected by noise fully and that is why we did not consider this temperature in our error free system.

4.5.2 Performance Analysis of different bit rates in 32 QAM

Bit rate is very important parameter of an optical data transmission system. The higher bit rates, the higher the complexity of the system and chances of error occurred. We have analyzed our 1550nm VCSEL based optical link performance at different bit rates with the help of BER value, power, Q factor curves which are shown in table 4.9, fig 4.32, fig 4.33 and fig 4.34. In this case the temperature of the system is kept fixed at 75^0C and also fiber length is kept fixed at 25 km.

Table 4.4 BER performance at different bit rates for 1550 nm

Bit Rate [Gbps]	BER
2.5	0.00108868
5	0.0112124
10	0.0149035
11	0.00594057
12	0.00522417
13	0.0155234
14	0.00317159
15	0.00407083
16	0.0399661
17	0.0180518
18	0.0209977
19	0.0369934
20	0.00810782

Table 4.4 depicts BER performance at varying bit rates. We have found decreasing BER performance with the increase of bit rate.

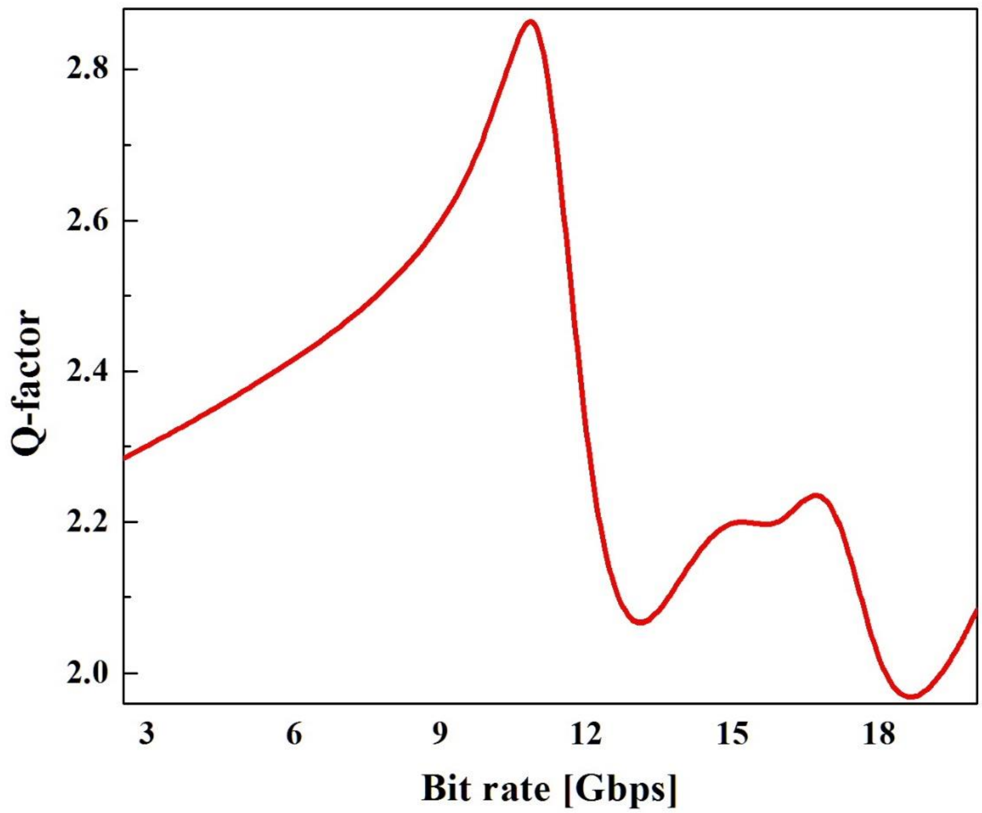

Fig 4.12: Bit rate dependence of Q-factor at 1550 nm for 32-QAM

Fig 4.12 the system performance has analyzed in terms of Q factor with different Bit rate. It can be seen that Q factor performance decays very large amount with the increase of bit rate but at 25Gbps it is down to zero which is not acceptable because the system quality becomes very low at this bit rate. So, we did not consider in our system.

In fig 4.35 the system performance at different bit rates are shown with the help of eye diagrams and it can be seen that the openness of eye decreases with the increase of bit rate. When the temperature goes passed 20 Gbps the system stops performing because no particular eye openness can be identified in this bit rate and there are multiple copies of eyes which indicate that the system noise level has increased.

4.5.3 Performance analysis at fiber length

In our 1550nm VCSEL based optical data transmission model we have succeeded to transmit 10Gbps data up to 75^0C and by kept this findings fixed we also have analyzed the maximum distance where we can send error free data at 10Gbps up to 75^0C. Table 4.7, fig 4.23, 4.24, represent the optical fiber length analysis with the help of BER, Q factor and eye diagram respectively. The figure depicts that with the increase of fiber length the system performance decays.

Table 4.5 BER performance at different fiber length for 1550 nm

Distance [km]	BER
10	0.018079
20	0.0189181
30	0.0166944
40	0.0287248
50	0.007194
60	0.00489787
70	0.00345127
80	0.00739705
90	0.0150971
100	0.0175006
110	0.0132898
120	0.00914063
130	0.0173791
140	0.0219555
150	0.00397018
160	0.0116546

Table 4.5 depicts BER performance at varying fiber length. We have found increasing BER performance with the increase of fiber length.

Q factor decreases with the increasing fiber length as shown in fig 4.36

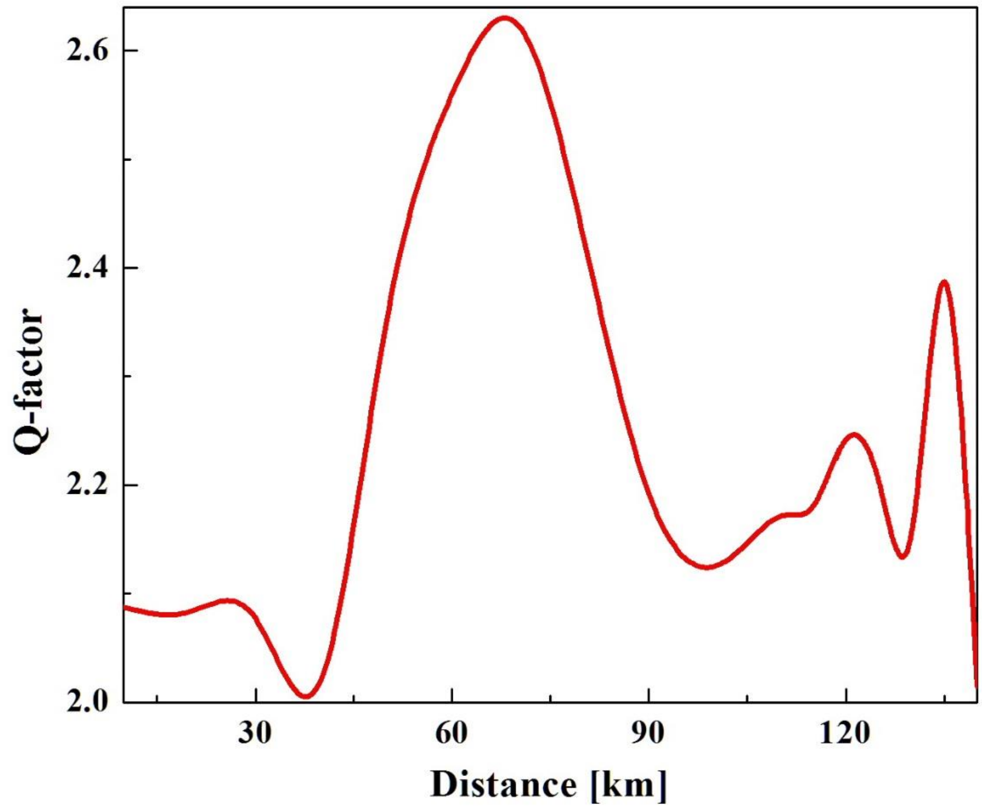

Fig 4.13: Distance dependence of Q-factor at 1550 nm for 32-QAM

(Red zone denotes the signal power and green zone the noise power)

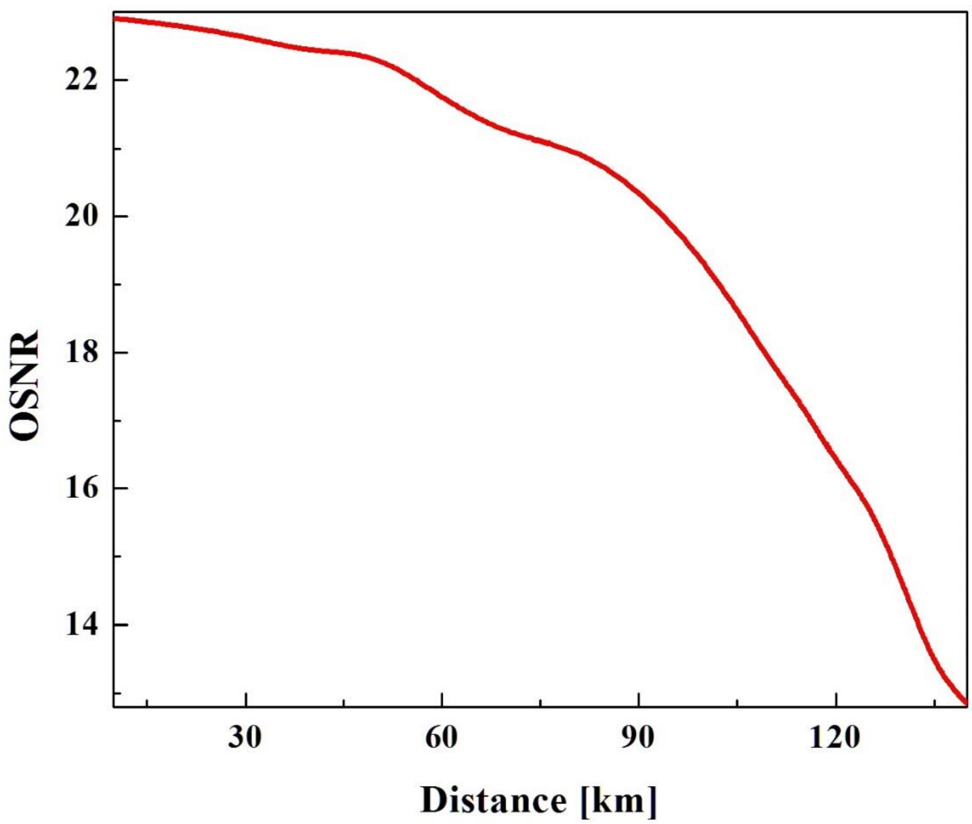

Fig 4.13: Distance dependence of OSNR at 1550 nm for 32-QAM

Fig 4.40 represents a relationship between optical signal to noise ratio (OSNR) and fiber length. It is found that OSNR decreases with the increase fiber length. 19.2dBm is the maximum OSNR value which can be achieved at 25 Km length.

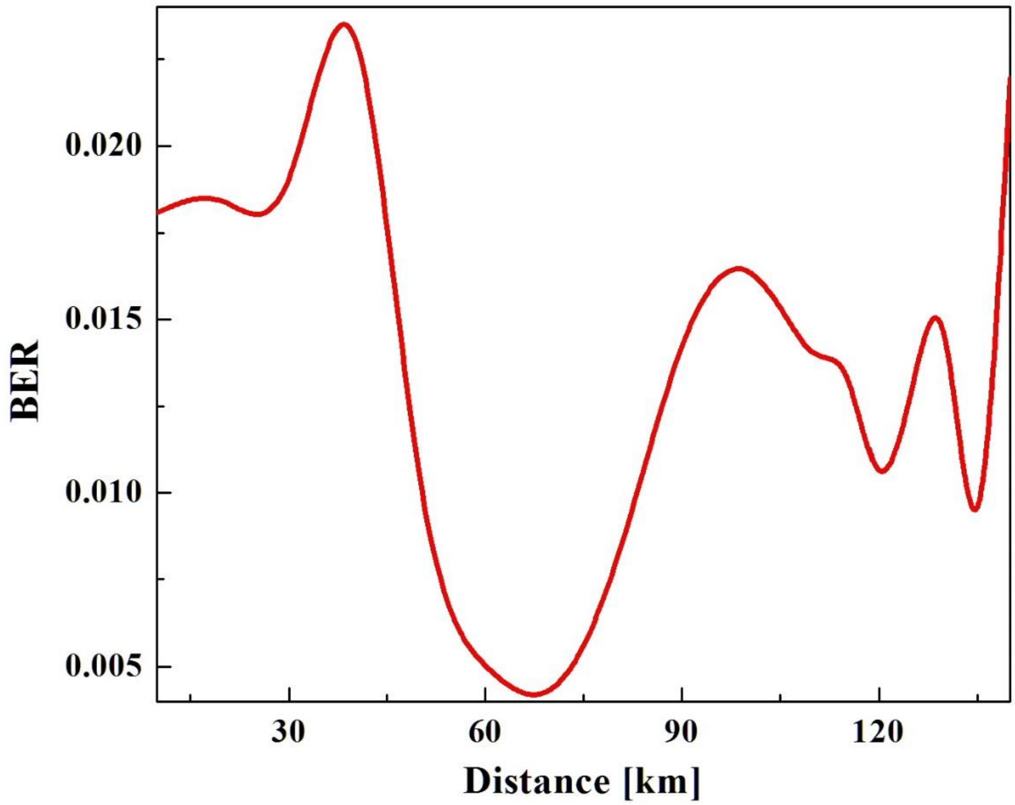

Fig 4.14: Distance dependence of BER at 1550 nm for 32-QAM

Fig 4.41 represents a relationship between BER and distance. 5.30262e-018 is the maximum BER value which can be achieved at 35 Km length.

4.6 Performance analysis for 64-QAM model

4.6.1 Performance analysis at different temperatures for 64 QAM model

We have discussed earlier that from our 1550 nm VCSEL based optical link we found temperature performance up to 125^0C, now this temperature performance is analyzed with the help of BER value, power, and Q factor curves which are depicted in table 4.8, fig 4.29, fig 4.30 and fig 4.31. In this case the bit error rate of the system is kept fixed at 10 Gbps and also fiber length is kept fixed at 40 km.

Table 4.6 BER performance at different temperatures for 1550 nm

Temperature [^oC]	BER
5	0.00869359
10	0.0092441
20	0.00788927
25	0.00614219
30	0.00393634
40	0.00379661
50	0.0218674
60	0.00924073
70	0.00454542
80	0.00374769
90	0.0124492
95	0.00279963

Table 4.6 depicts BER performance varying at temperatures.

We consider BER standard for our error free system is BER<10^{-12}. And we got error free temperature performance from our system up to 75^0C. At 125^0C the system fails to provide error free operation.

Fig 4.30 shows that we have got highest power of 6.67dBm at 20^0C from its VCSEL based 1550 nm system and then with the increase of temperature further power value decreases and we have got output power -40dBm at 120^0C. As 120^0C failed to give error free performance, we did not consider it in our system.

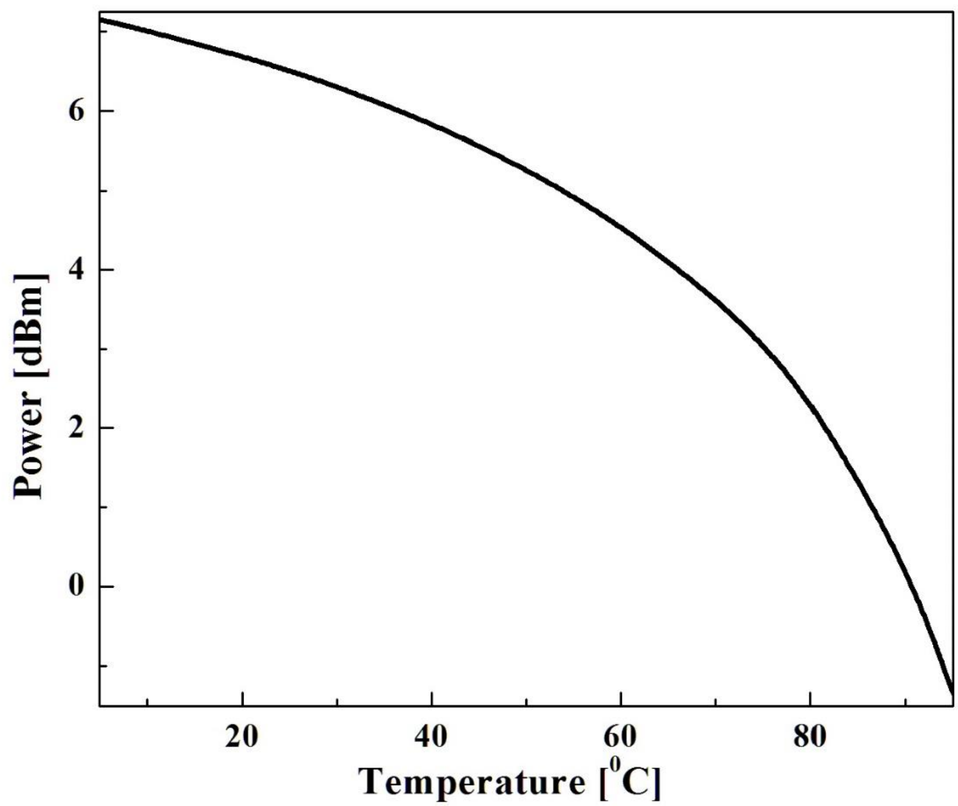

Fig 4.15: Temperature dependence of Power at 1550 nm for 16-QAM

In figure 4.31 the system performance has analyzes in terms of Q factor with different temperatures. It can be seen that Q factor performance decays very small amount with the increase of temperature but 120^{0}C it decays to 0, which means that our system is performing up to 75^{0}C.

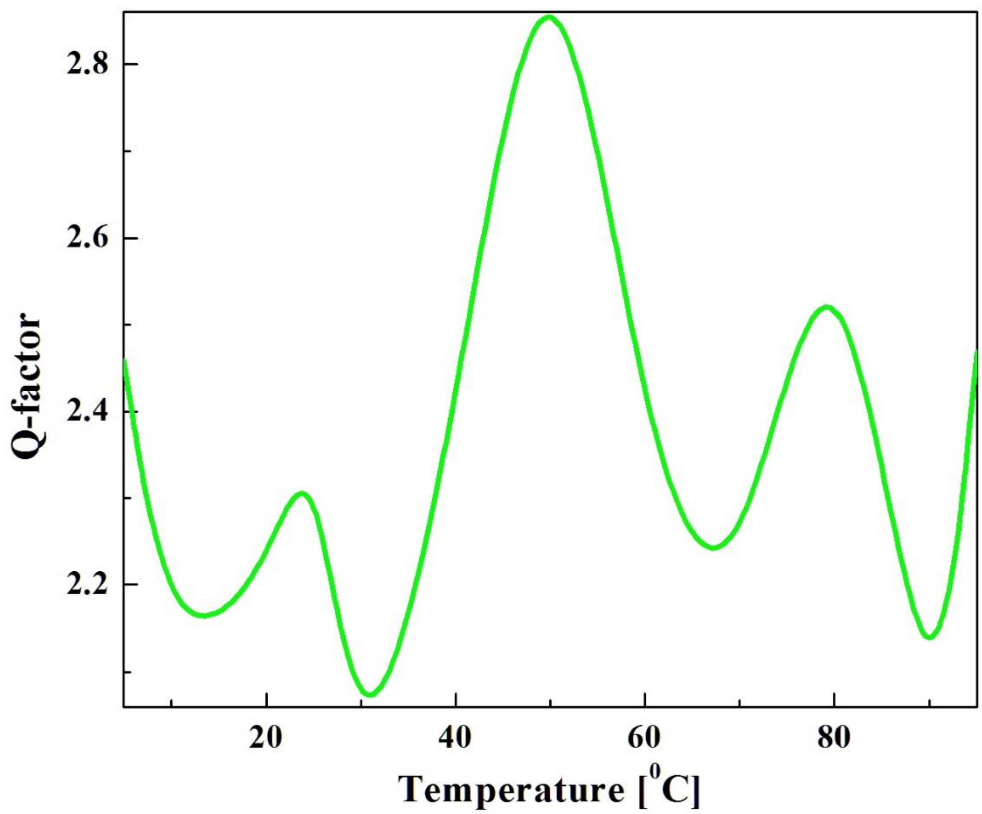

Fig 4.16: Temperature dependence of Q-factor at 1550 nm for 16-QAM

In fig 4.32 the system performance at different temperatures are shown with the help of eye diagrams and it can be seen that the openness of eye decreases with the increase of temperature. When the temperature goes passed 125^{0}C the system stops performing because no particular eye openness can be identified in this temperature and there are multiple copies of eyes which indicate that the system noise level has increased.

So, from the temperature analysis by varying bit rate and fiber length analysis we have found that our 1550nm RZ modulated VCSEL optical link is capable of transmitting data at 10Gbps over 41km at a maximum temperature of 75^{0}C by using EDFA amplifier.

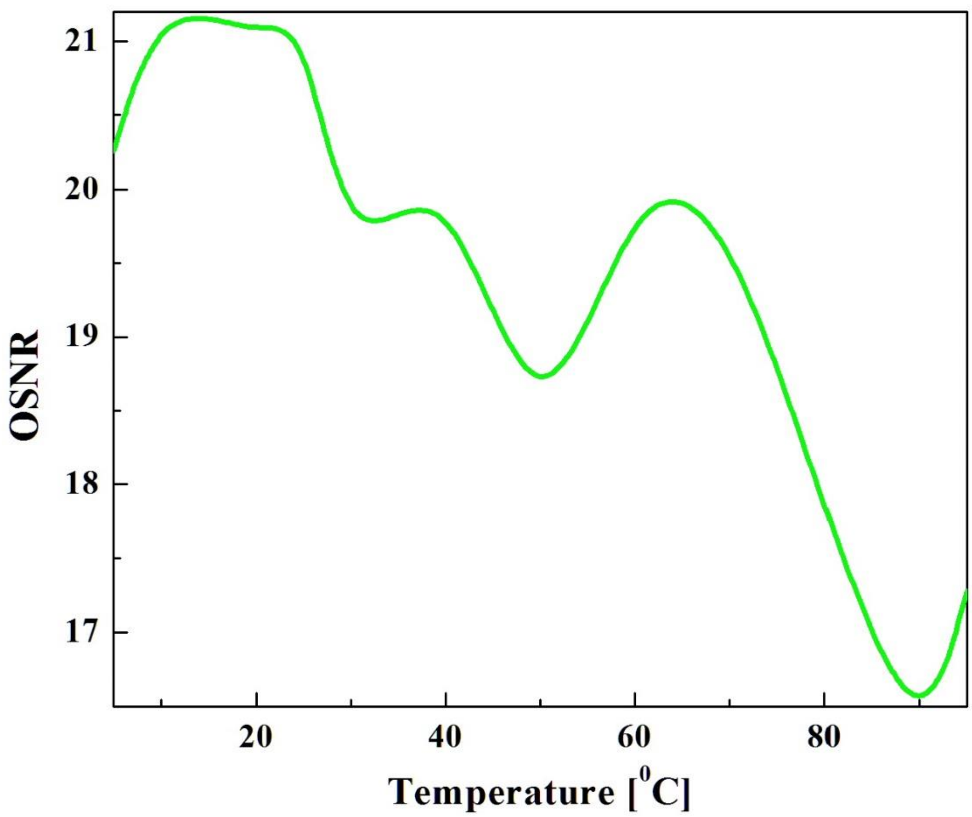

Fig 4.17: Temperature dependence of OSNR at 1550nm for 32-QAM

Optical signal to noise ratio (OSNR) performance with varying temperature is analyzed in fig 4.38. At 20^0C we get highest OSNR of 19.25dBm after that with the increase of temperature OSNR decreases and 125^0C we get OSNR value of -24.9 dBm which is not acceptable for error free system.

Optical Spectrum analysis is shown in fig 4.39 where with the increase of temperature the noise also increases. At the point of 125^0C the noise level goes passed the signal power level. Then the signal becomes affected by noise fully and that is why we did not consider this temperature in our error free system.

4.6.2 Performance Analysis of different bit rates in 64-QAM

Bit rate is very important parameter of an optical data transmission system. The higher bit rates, the higher the complexity of the system and chances of error occurred. We have analyzed our 1550nm VCSEL based optical link performance at different bit rates with the help of BER value, power, Q factor curves which are shown in table 4.9, fig 4.32, fig 4.33 and fig 4.34. In this case the temperature of the system is kept fixed at 75^0C and also fiber length is kept fixed at 25 km.

Table 4.7 BER performance at different bit rates for 1550 nm

Bit Rate [Gbps]	BER
2.5	0.0015988
5	0.0315863
10	0.00358846
11	0.00911204
12	0.0240513
13	0.0189865
14	0.021557
15	0.00423733
16	0.00786797
17	0.00483227
18	0.00637024
19	1
20	0.0227122

Table 4.7 depicts BER performance at varying bit rates. We have found decreasing BER performance with the increase of bit rate.

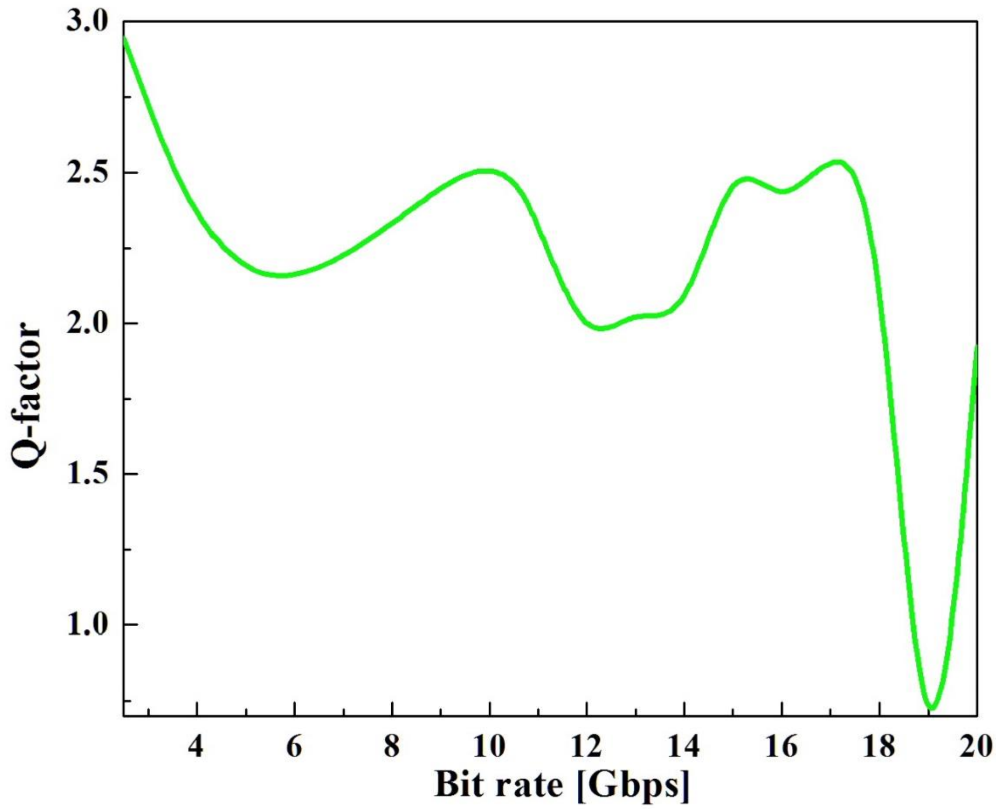

Fig 4.18: Bit rate dependence of Q-factor at 1550 nm for 64-QAM

Fig 4.18 the system performance has analyzed in terms of Q factor with different Bit rate. It can be seen that Q factor performance decays very large amount with the increase of bit rate but at 25Gbps it is down to zero which is not acceptable because the system quality becomes very low at this bit rate. So, we did not consider in our system.

In fig 4.35 the system performance at different bit rates are shown with the help of eye diagrams and it can be seen that the openness of eye decreases with the increase of bit rate. When the temperature goes passed 20 Gbps the system stops performing because no particular eye openness can be identified in this bit rate and there are multiple copies of eyes which indicate that the system noise level has increased.

4.6.3 Performance analysis at fiber length

In our 1550nm VCSEL based optical data transmission model we have succeeded to transmit 10Gbps data up to 75^0C and by kept this findings fixed we also have analyzed the maximum distance where we can send error free data at 10Gbps up to 75^0C. Table 4.7, fig 4.23, 4.24, represent the optical fiber length analysis with the help of BER, Q factor and eye diagram respectively. The figure depicts that with the increase of fiber length the system performance decays.

Table 4.8 BER performance at different fiber length for 1550 nm

Distance [km]	BER
10	0.0266504
20	0.0255109
30	0.0261817
40	0.028523
50	0.0177584
60	0.030291
70	0.0098255
80	0.0109967
90	0.0105031
100	0.0166377
110	0.0287535
120	0.0173128
130	0.0269765
140	0.0187247
150	0.00478826
160	0.00529871

Table 4.8 depicts BER performance at varying fiber length. We have found increasing BER performance with the increase of fiber length.

Q factor decreases with the increasing fiber length as shown in fig 4.36

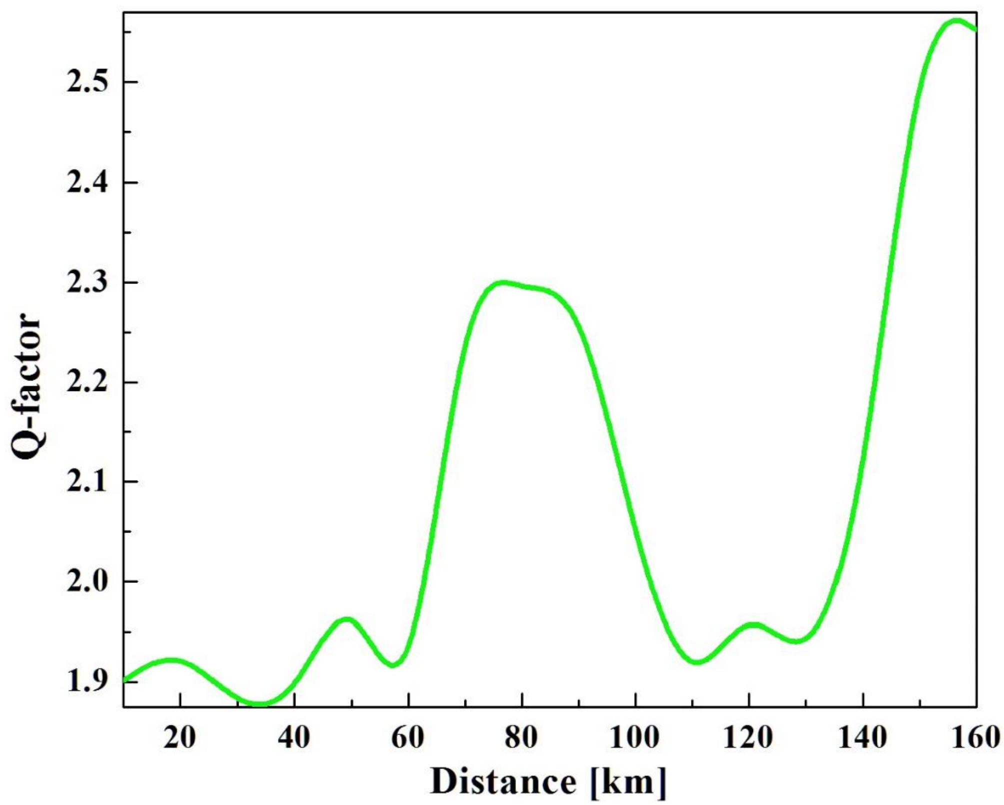

Fig 4.19: Distance dependence of Q-factor at 1550 nm for 64-QAM

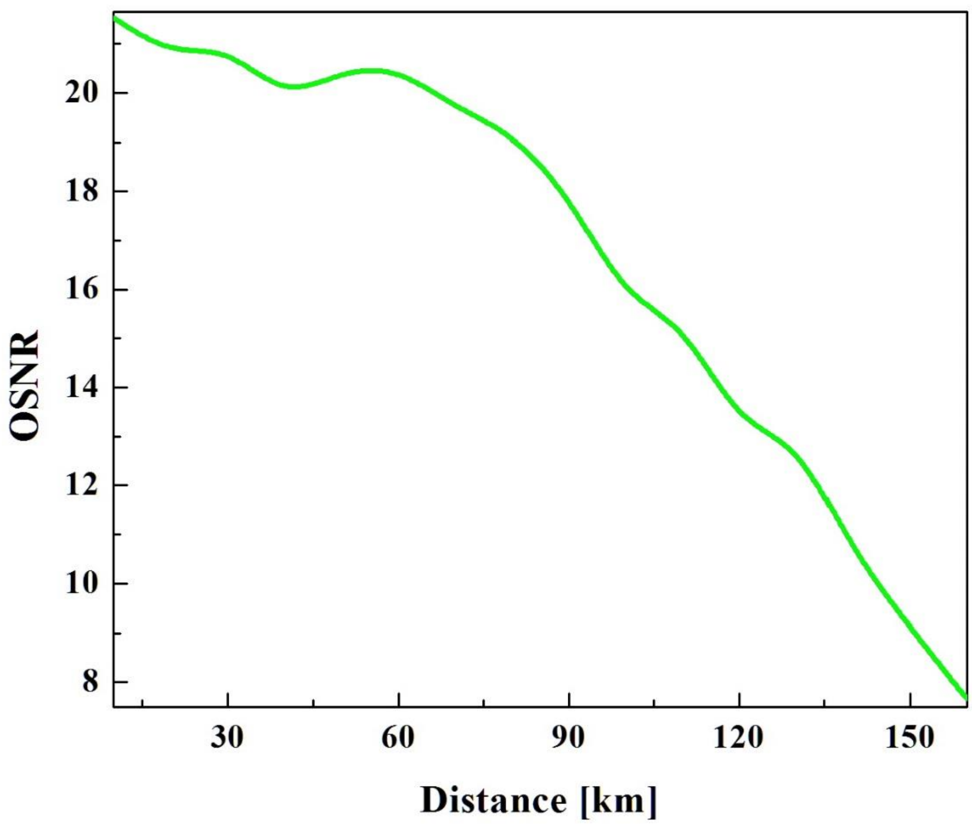

Fig 4.20: Distance dependence of OSNR at 1550 nm for 64-QAM

Fig 4.20 represents a relationship between optical signal to noise ratio (OSNR) and fiber length. It is found that OSNR decreases with the increase fiber length. 19.2dBm is the maximum OSNR value which can be achieved at 25 Km length.

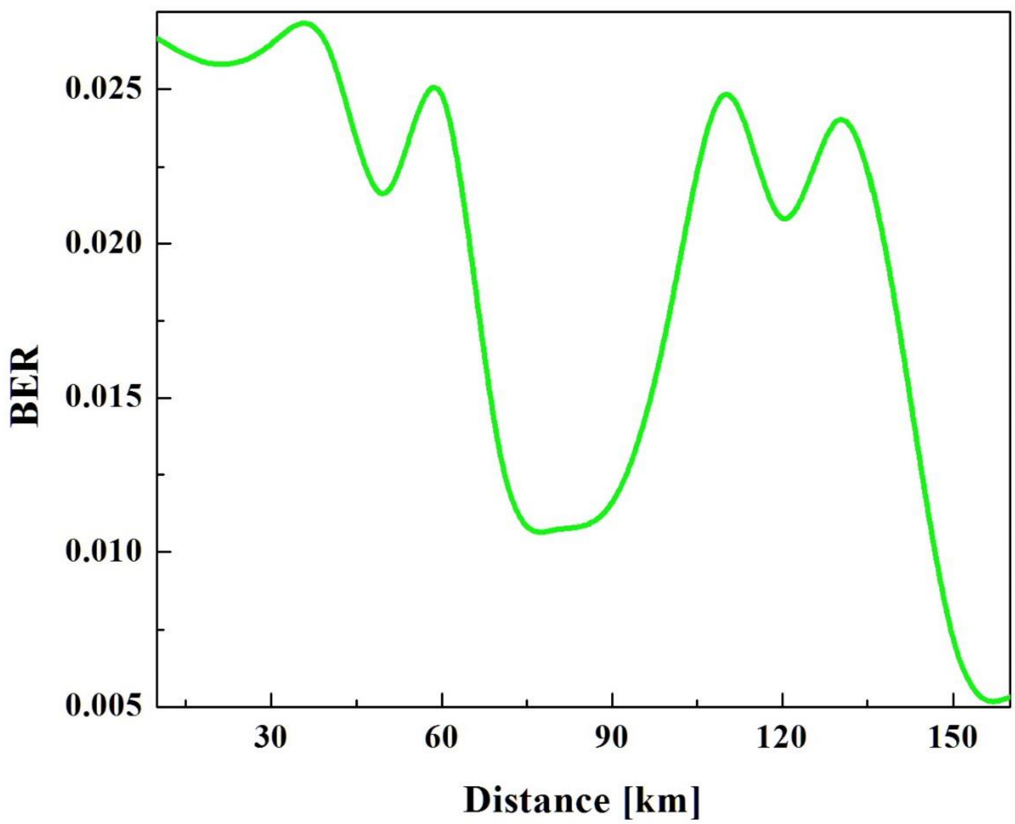

Fig 4.21: Distance dependence of BER at 1550 nm for 64-QAM

Fig 4.21 represents a relationship between BER and distance. 5.30262e-018 is the maximum BER value which can be achieved at 35 Km length.

4.7 Performance analysis for 128-QAM model

4.7.1 Performance analysis at different temperatures for 128-QAM model

We have discussed earlier that from our 1550 nm VCSEL based optical link we found temperature performance up to 125^{0}C, now this temperature performance is analyzed with the help of BER value, power, and Q factor curves which are depicted in table 4.8, fig 4.29, fig 4.30 and fig 4.31. In this case the bit error rate of the system is kept fixed at 10 Gbps and also fiber length is kept fixed at 40 km.

Table 4.9 BER performance at different temperatures for 1550 nm

Temperature [^{o}C]	BER
5	0.0141696
10	0.00344809
20	0.00803868
25	0.0111253
30	0.0284973
40	0.0021427
50	0.0116959
60	0.0174088
70	0.00107707
80	0.0110409
90	0.0266723
95	0.0230688

Table 4.9 depicts BER performance varying at temperatures.

We consider BER standard for our error free system is BER<10^{-12}. And we got error free temperature performance from our system up to 75^{0}C. At 125^{0}C the system fails to provide error free operation.

Fig 4.30 shows that we have got highest power of 6.67dBm at 20^0C from its VCSEL based 1550 nm system and then with the increase of temperature further power value decreases and we have got output power -40dBm at 120^0C. As 120^0C failed to give error free performance, we did not consider it in our system.

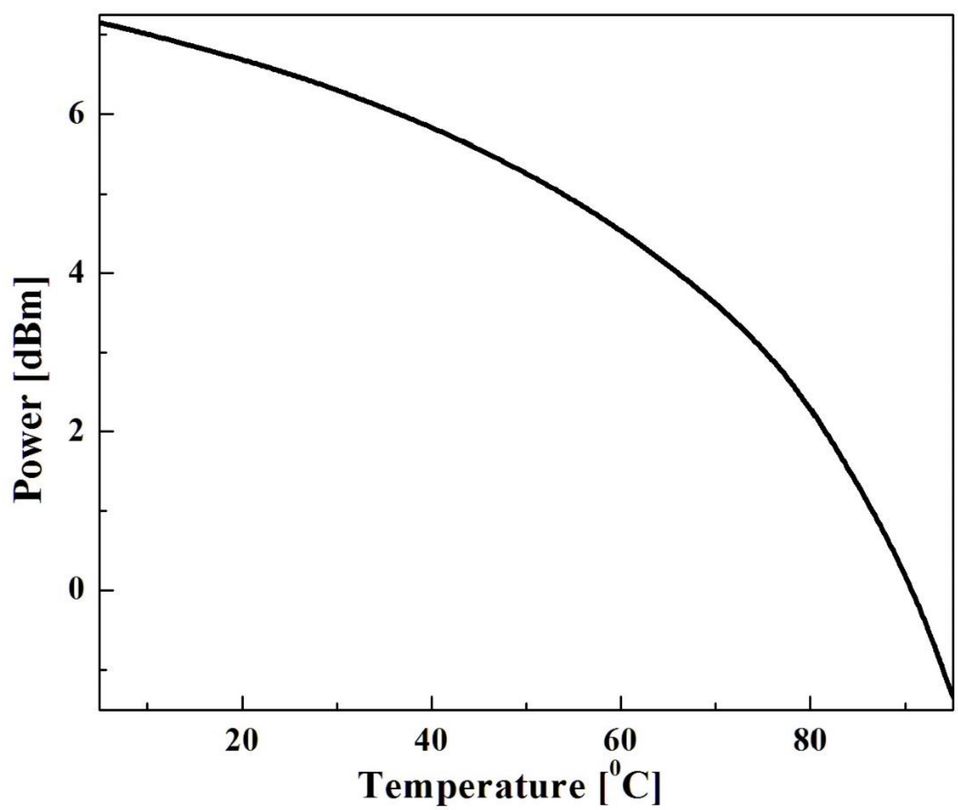

Fig 4.22: Temperature dependence of Power at 1550 nm for 64-QAM

In figure 4.31 the system performance has analyzes in terms of Q factor with different temperatures. It can be seen that Q factor performance decays very small amount with the increase of temperature but 120^0C it decays to 0, which means that our system is performing up to 75^0C.

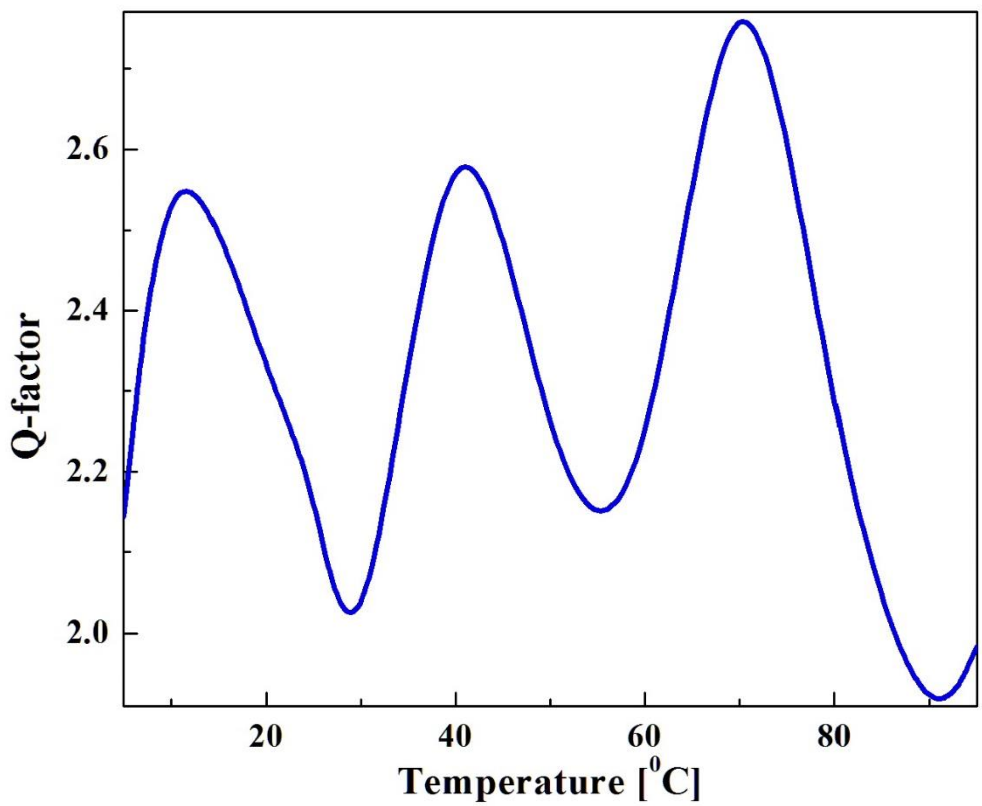

Fig 4.23: Temperature dependence of Q-factor at 1550 nm for 128-QAM

In fig 4.23 the system performance at different temperatures are shown with the help of eye diagrams and it can be seen that the openness of eye decreases with the increase of temperature. When the temperature goes passed 125^{0}C the system stops performing because no particular eye openness can be identified in this temperature and there are multiple copies of eyes which indicate that the system noise level has increased.

So, from the temperature analysis by varying bit rate and fiber length analysis we have found that our 1550nm RZ modulated VCSEL optical link is capable of transmitting data at 10Gbps over 41km at a maximum temperature of 75^{0}C by using EDFA amplifier.

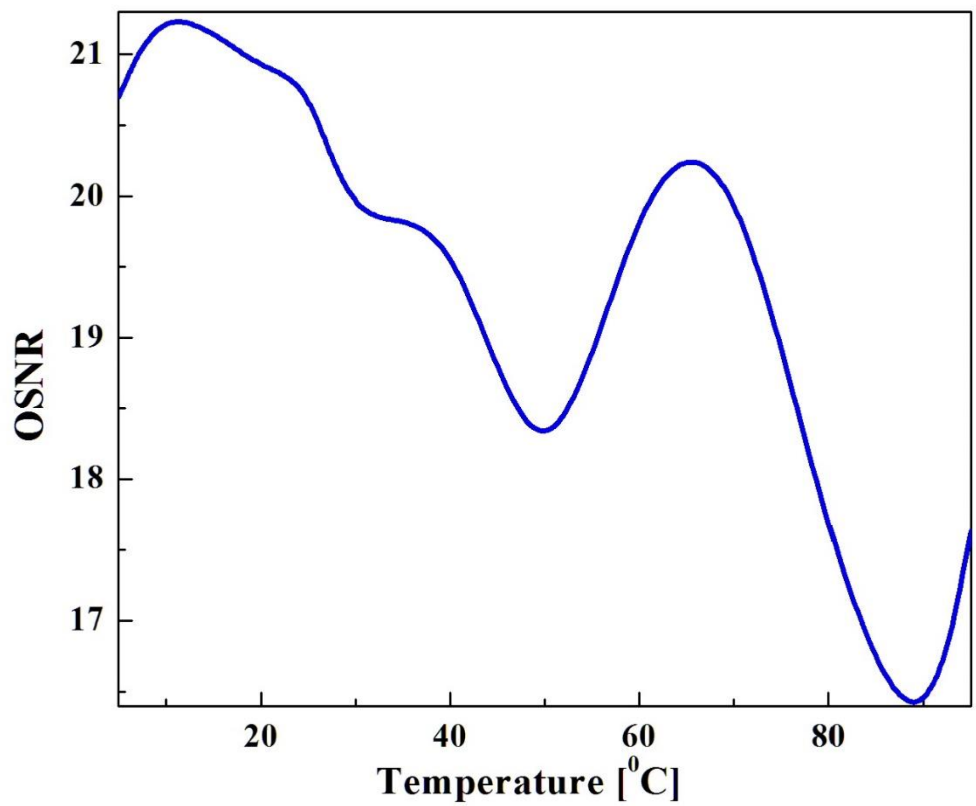

Fig 4.24: Temperature dependence of OSNR at 1550nm for 128-QAM

Optical signal to noise ratio (OSNR) performance with varying temperature is analyzed in fig 4.38. At 20^0C we get highest OSNR of 19.25dBm after that with the increase of temperature OSNR decreases and 125^0C we get OSNR value of -24.9 dBm which is not acceptable for error free system.

Optical Spectrum analysis is shown in fig 4.39 where with the increase of temperature the noise also increases. At the point of 125^0C the noise level goes passed the signal power level. Then the signal becomes affected by noise fully and that is why we did not consider this temperature in our error free system.

4.7.2 Performance Analysis of different bit rates in 128 QAM

Bit rate is very important parameter of an optical data transmission system. The higher bit rates, the higher the complexity of the system and chances of error occurred. We have analyzed our 1550nm VCSEL based optical link performance at different bit rates with the help of BER value, power, Q factor curves which are shown in table 4.9, fig 4.32, fig 4.33 and fig 4.34. In this case the temperature of the system is kept fixed at 75^0C and also fiber length is kept fixed at 25 km.

Table 4.10 BER performance at different bit rates for 1550 nm

Bit Rate [Gbps]	BER
2.5	1.12777e-006
5	0.00614726
10	0.0209909
11	0.00980185
12	1
13	0.0165671
14	0.00696672
15	0.013901
16	0.0183923
17	0.006524
18	0.0068708
19	0.00427689
20	1

Table 4.10 depicts BER performance at varying bit rates. We have found decreasing BER performance with the increase of bit rate.

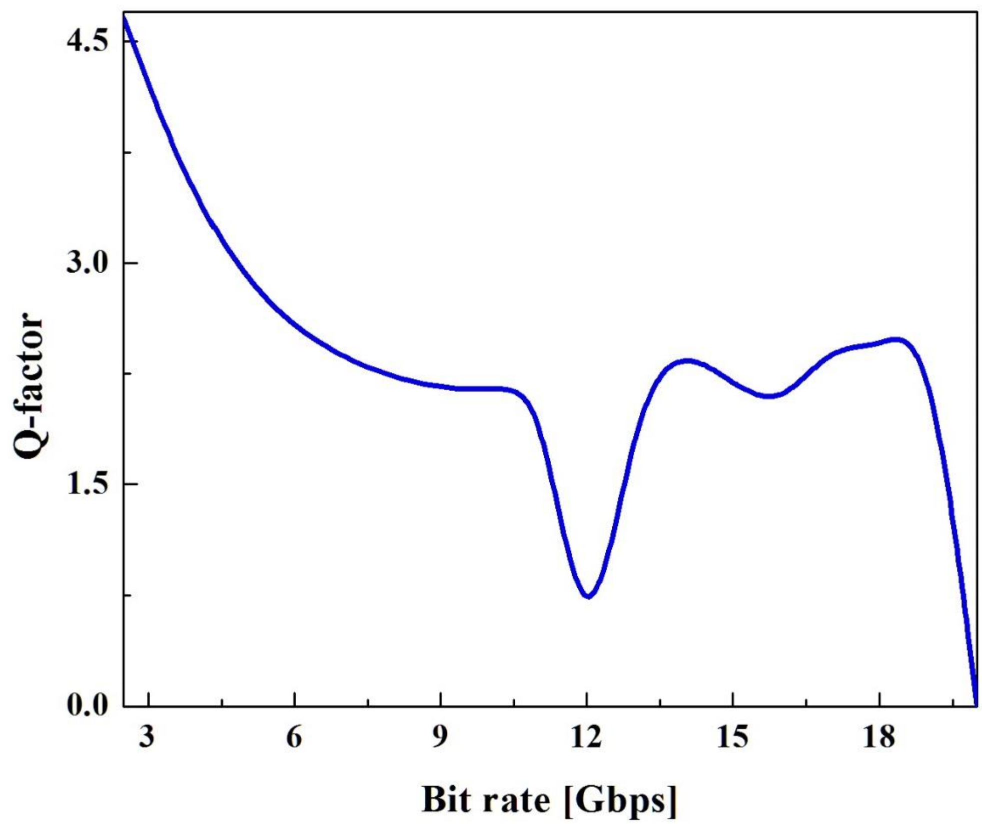

Fig 4.25: Bit rate dependence of Q-factor at 1550 nm for 128-QAM

Fig 4.25 the system performance has analyzed in terms of Q factor with different Bit rate. It can be seen that Q factor performance decays very large amount with the increase of bit rate but at 25Gbps it is down to zero which is not acceptable because the system quality becomes very low at this bit rate. So, we did not consider in our system.

In fig 4.35 the system performance at different bit rates are shown with the help of eye diagrams and it can be seen that the openness of eye decreases with the increase of bit rate. When the temperature goes passed 20 Gbps the system stops performing because no particular eye openness can be identified in this bit rate and there are multiple copies of eyes which indicate that the system noise level has increased.

4.7.3 Performance analysis at fiber length

In our 1550nm VCSEL based optical data transmission model we have succeeded to transmit 10Gbps data up to 75^0C and by kept this findings fixed we also have analyzed the maximum distance where we can send error free data at 10Gbps up to 75^0C. Table 4.7, fig 4.23, 4.24, represent the optical fiber length analysis with the help of BER, Q factor and eye diagram respectively. The figure depicts that with the increase of fiber length the system performance decays.

Table 4.11 BER performance at different fiber length for 1550 nm

Distance [km]	BER
10	0.00131287
20	0.0647287
30	0.0540612
40	0.0197843
50	0.00428015
60	0.0194517
70	0.0100235
80	0.0245236
90	0.0248487
100	1
110	0.00460231
120	0.00582299
130	0.0615429
140	0.0119353

Table 4.11 depicts BER performance at varying fiber length. We have found increasing BER performance with the increase of fiber length.

Q factor decreases with the increasing fiber length as shown in fig 4.36

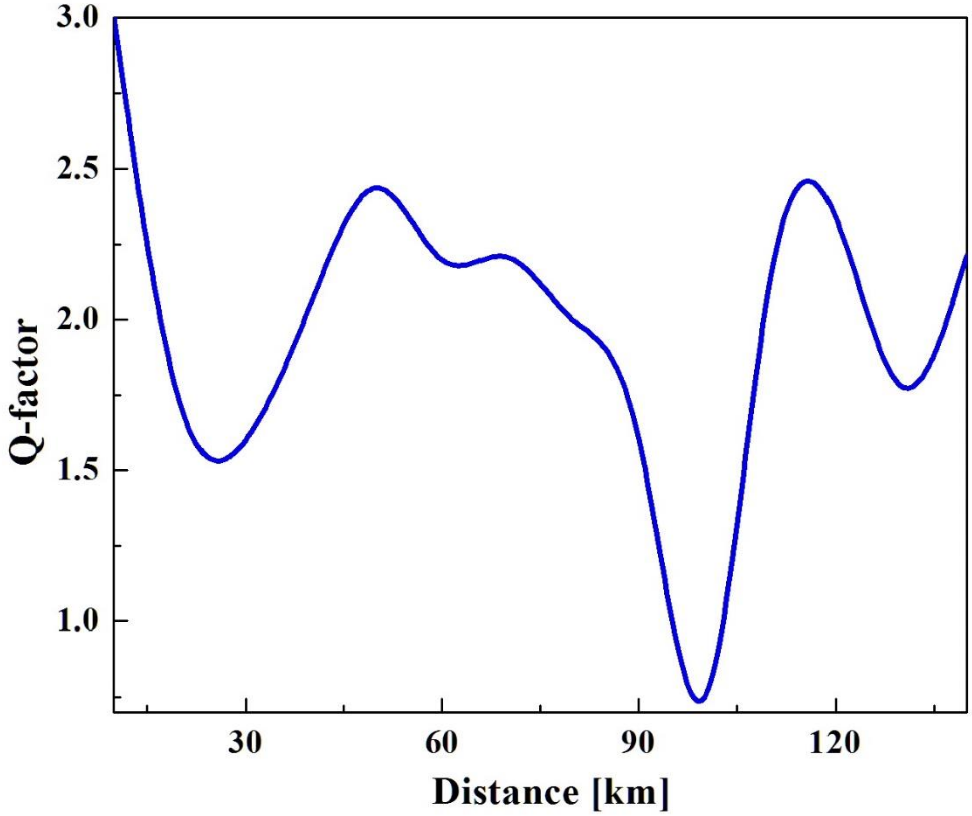

Fig 4.26: Distance dependence of Q-factor at 1550 nm for 128-QAM

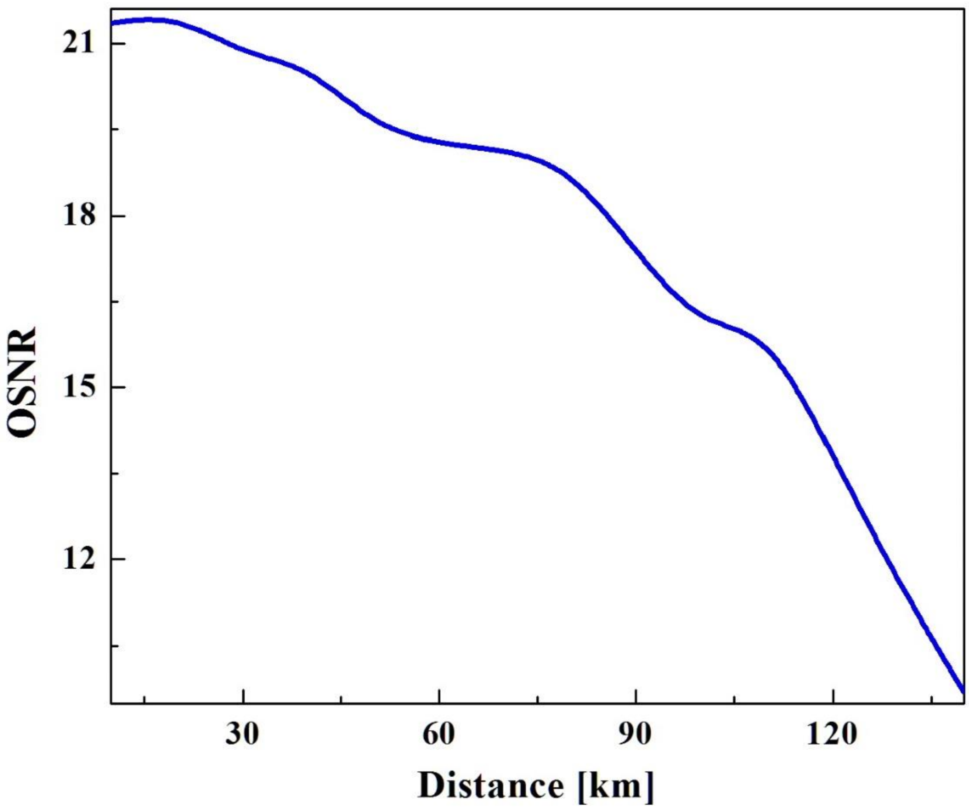

Fig 4.27: Distance dependence of OSNR at 1550 nm for 128-QAM

Fig 4.27 represents a relationship between optical signal to noise ratio (OSNR) and fiber length. It is found that OSNR decreases with the increase fiber length. 19.2dBm is the maximum OSNR value which can be achieved at 25 Km length.

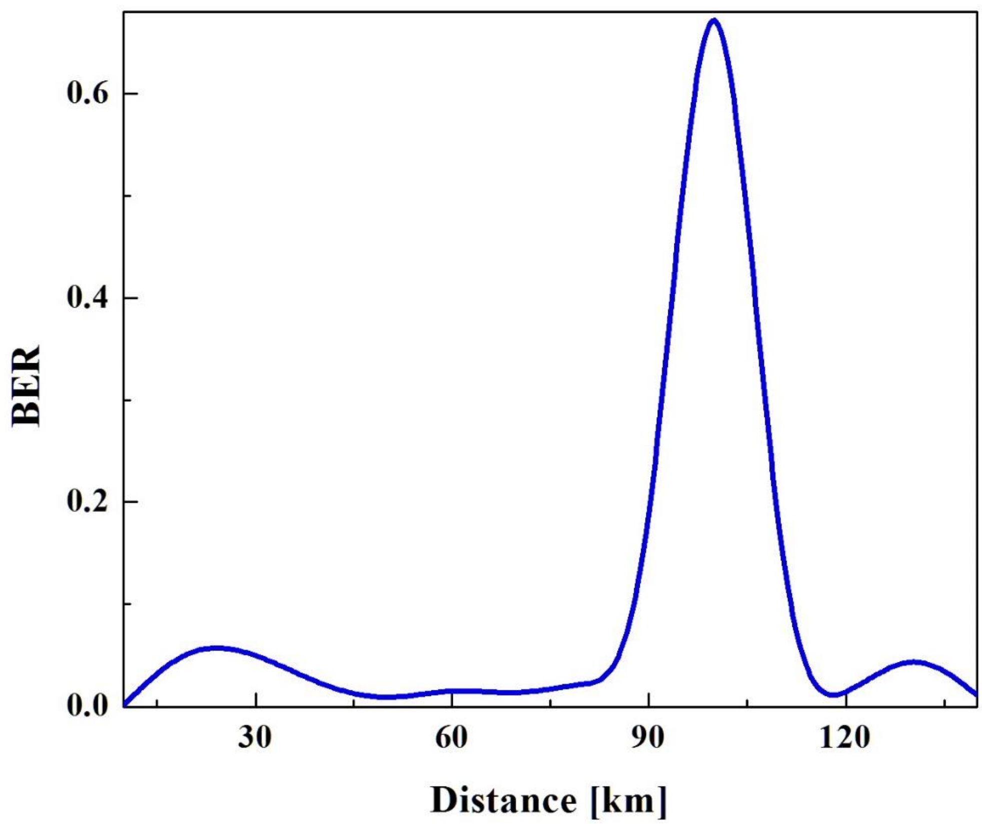

Fig 4.28: Distance dependence of BER at 1550 nm for 128-QAM

Fig 4.28 represents a relationship between BER and distance. 5.30262e-018 is the maximum BER value which can be achieved at 35 Km length.

4.8 Performance analysis for 256-QAM model

4.8.1 Performance analysis at different temperatures for 256 QAM model

We have discussed earlier that from our 1550 nm VCSEL based optical link we found temperature performance up to 125^0C, now this temperature performance is analyzed with the help of BER value, power, and Q factor curves which are depicted in table 4.8, fig 4.29, fig 4.30 and fig 4.31. In this case the bit error rate of the system is kept fixed at 10 Gbps and also fiber length is kept fixed at 40 km.

Table 4.12 BER performance at different temperatures for 1550 nm

Temperature [^{o}C]	BER
5	0.00316693
10	0.000800661
20	0.014043
25	0.03361
30	0.0283052
40	0.00651412
50	0.000702871
60	0.0280106
70	0.00443743
75	0.0072934
80	0.00327335
90	0.00896422
95	0.0266057

Table 4.12 depicts BER performance varying at temperatures.

We consider BER standard for our error free system is $BER<10^{-12}$. And we got error free temperature performance from our system up to 75^0C. At 125^0C the system fails to provide error free operation.

Fig 4.30 shows that we have got highest power of 6.67dBm at 20^0C from its VCSEL based 1550 nm system and then with the increase of temperature further power value decreases and we have got output power -40dBm at 120^0C. As 120^0C failed to give error free performance, we did not consider it in our system.

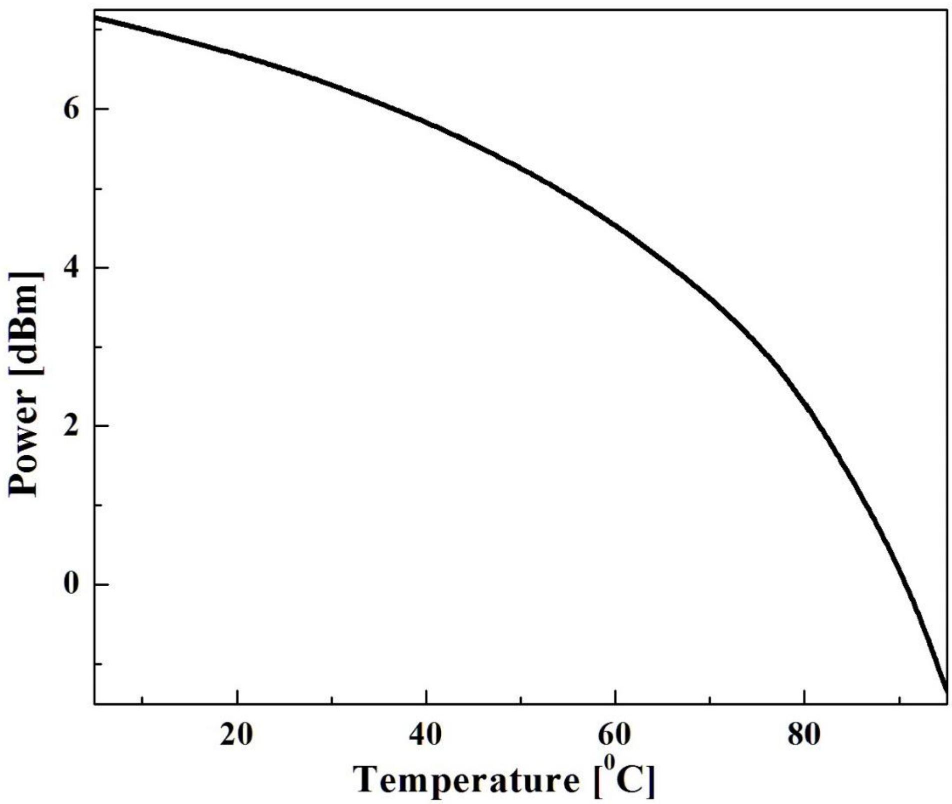

Fig 4.29: Temperature dependence of Power at 1550 nm for 256-QAM

In figure 4.31 the system performance has analyzes in terms of Q factor with different temperatures. It can be seen that Q factor performance decays very small amount with the increase of temperature but 120^0C it decays to 0, which means that our system is performing up to 75^0C.

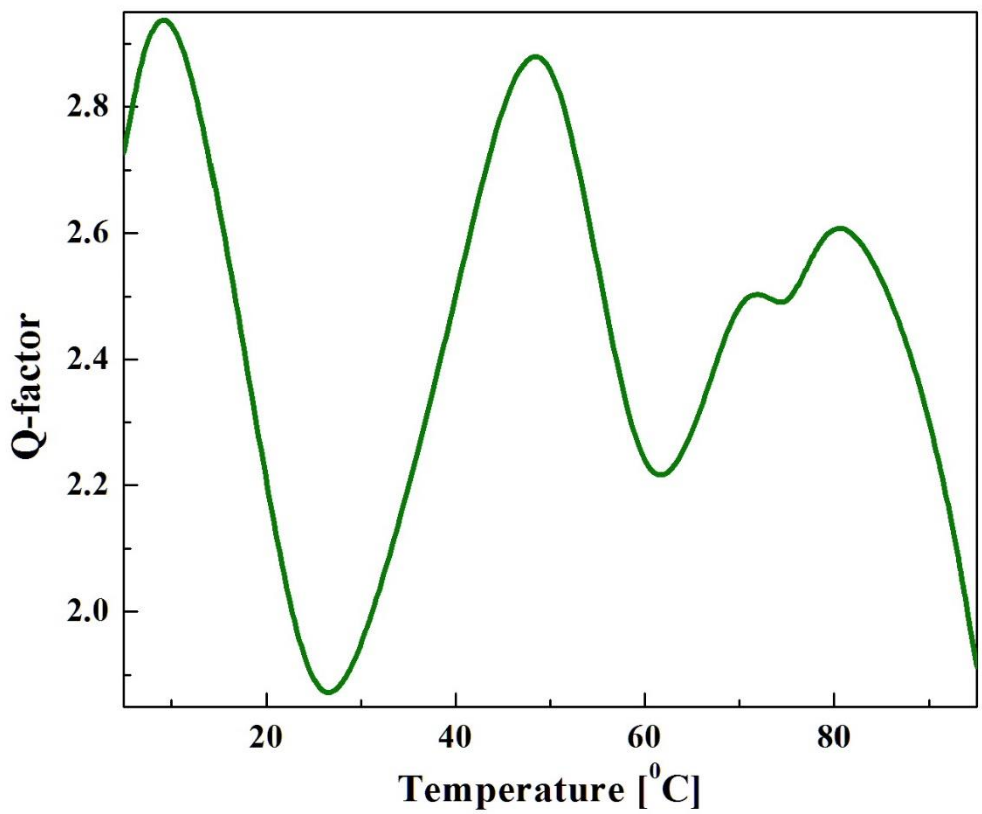

Fig 4.30: Temperature dependence of Q-factor at 1550 nm for 256-QAM

In fig 4.32 the system performance at different temperatures are shown with the help of eye diagrams and it can be seen that the openness of eye decreases with the increase of temperature. When the temperature goes passed 125^{0}C the system stops performing because no particular eye openness can be identified in this temperature and there are multiple copies of eyes which indicate that the system noise level has increased.

So, from the temperature analysis by varying bit rate and fiber length analysis we have found that our 1550nm RZ modulated VCSEL optical link is capable of transmitting data at 10Gbps over 41km at a maximum temperature of 75^{0}C by using EDFA amplifier.

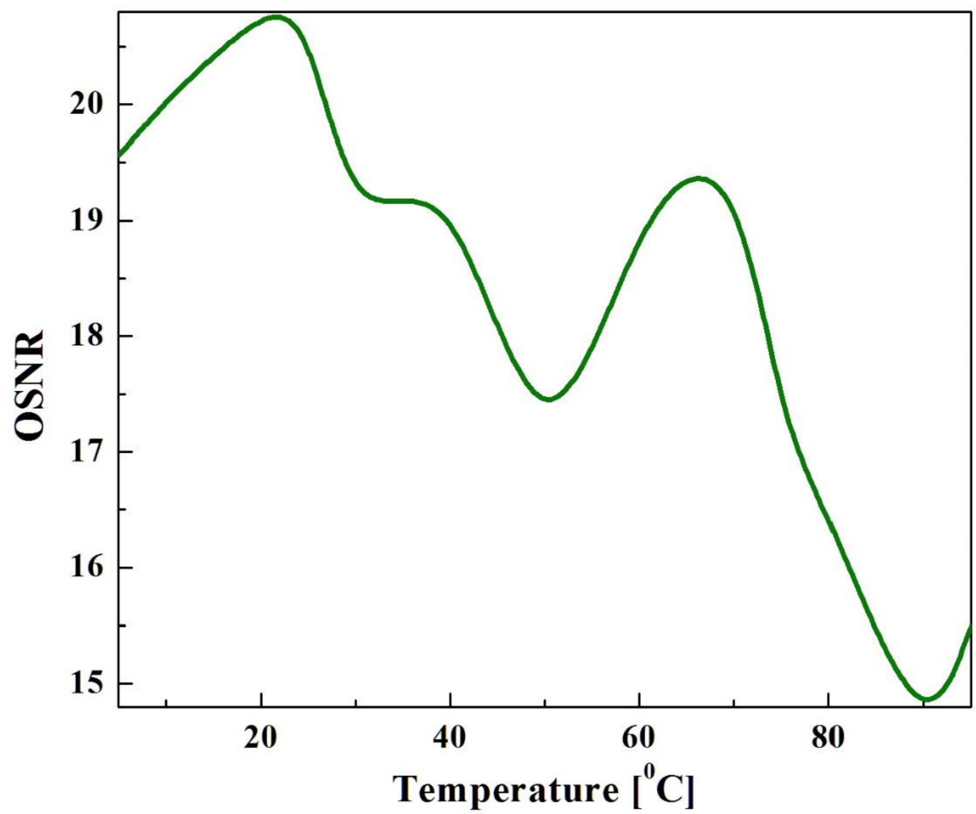

Fig 4.31: Temperature dependence of OSNR at 1550nm for 16-QAM

Optical signal to noise ratio (OSNR) performance with varying temperature is analyzed in fig 4.38. At 20^{0}C we get highest OSNR of 19.25dBm after that with the increase of temperature OSNR decreases and 125^{0}C we get OSNR value of -24.9 dBm which is not acceptable for error free system.

Optical Spectrum analysis is shown in fig 4.39 where with the increase of temperature the noise also increases. At the point of 125^{0}C the noise level goes passed the signal power level. Then the signal becomes affected by noise fully and that is why we did not consider this temperature in our error free system.

4.8.2 Performance Analysis of different bit rates in 256 QAM

Bit rate is very important parameter of an optical data transmission system. The higher bit rates, the higher the complexity of the system and chances of error occurred. We have analyzed our 1550nm VCSEL based optical link performance at different bit rates with the help of BER value, power, Q factor curves which are shown in table 4.9, fig 4.32, fig 4.33 and fig 4.34. In this case the temperature of the system is kept fixed at 75^0C and also fiber length is kept fixed at 25 km.

Table 4.13 BER performance at different bit rates for 1550 nm

Bit Rate [Gbps]	BER
2.5	0.00101003
5	0.00170481
10	0.00766182
11	0.020774
12	0.0148089
13	0.0069058
14	0.0261419
15	0.0127361
16	0.0270619
17	0.024959
18	0.00600402
19	0.00647153
20	0.0209925

Table 4.13 depicts BER performance at varying bit rates. We have found decreasing BER performance with the increase of bit rate.

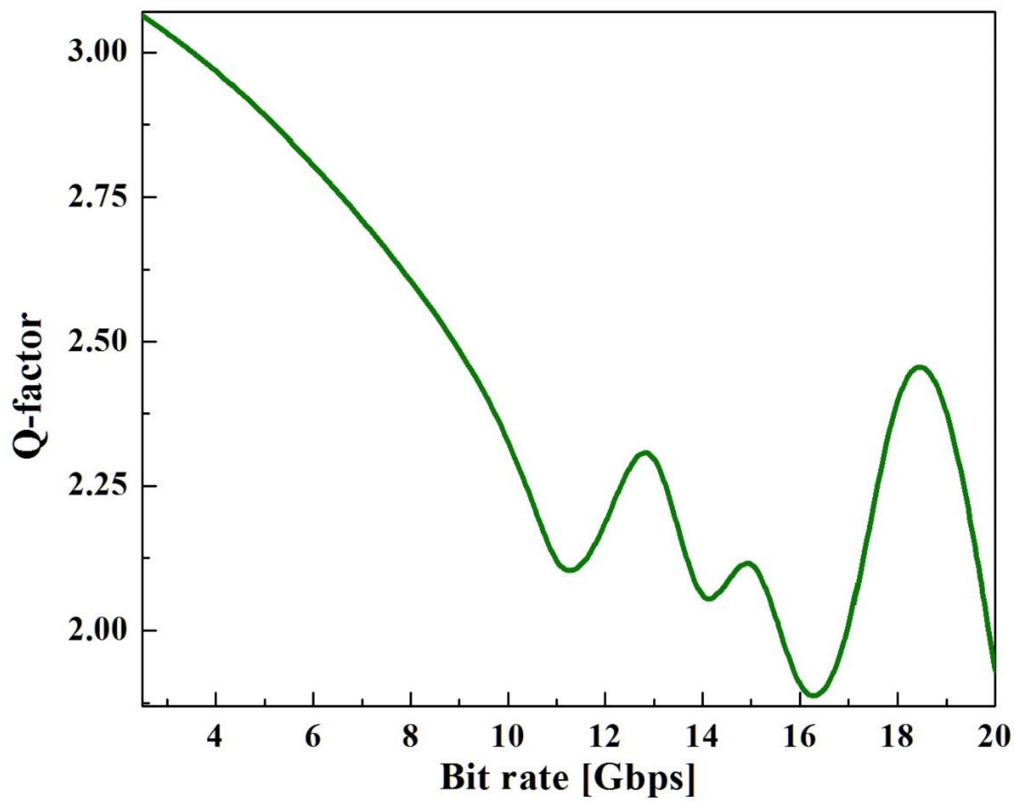

Fig 4.32: Bit rate dependence of Q-factor at 1550 nm for 16-QAM

Fig 4.32the system performance has analyzed in terms of Q factor with different Bit rate. It can be seen that Q factor performance decays very large amount with the increase of bit rate but at 25Gbps it is down to zero which is not acceptable because the system quality becomes very low at this bit rate. So, we did not consider in our system.

In fig 4.35 the system performance at different bit rates are shown with the help of eye diagrams and it can be seen that the openness of eye decreases with the increase of bit rate. When the temperature goes passed 20 Gbps the system stops performing because no particular eye openness can be identified in this bit rate and there are multiple copies of eyes which indicate that the system noise level has increased.

4.4.3 Performance analysis at fiber length

In our 1550nm VCSEL based optical data transmission model we have succeeded to transmit 10Gbps data up to 75^0C and by kept this findings fixed we also have analyzed the maximum distance where we can send error free data at 10Gbps up to 75^0C. Table 4.7, fig 4.23, 4.24, represent the optical fiber length analysis with the help of BER, Q factor and eye diagram respectively. The figure depicts that with the increase of fiber length the system performance decays.

Table 4.14 BER performance at different fiber length for 1550 nm

Distance [km]	BER
10	0.00817823
20	0.00780116
30	0.0256359
40	0.0121446
50	0.00622495
60	0.004636
70	0.00558488
80	0.0507747
90	0.0193576
100	0.0247533
110	0.012052
120	0.025705
130	0.00446956
140	0.00621638
150	0.00230743

Table 4.14 depicts BER performance at varying fiber length. We have found increasing BER performance with the increase of fiber length.

Q factor decreases with the increasing fiber length as shown in fig 4.36

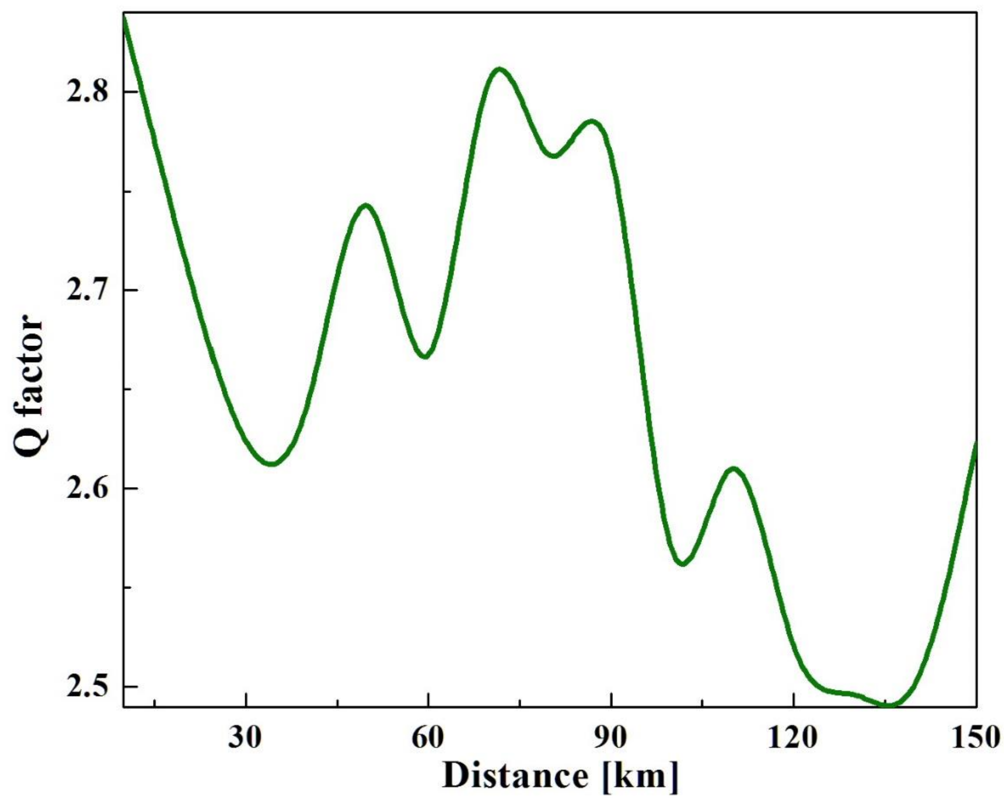

Fig 4.33: Distance dependence of Q-factor at 1550 nm for 256-QAM

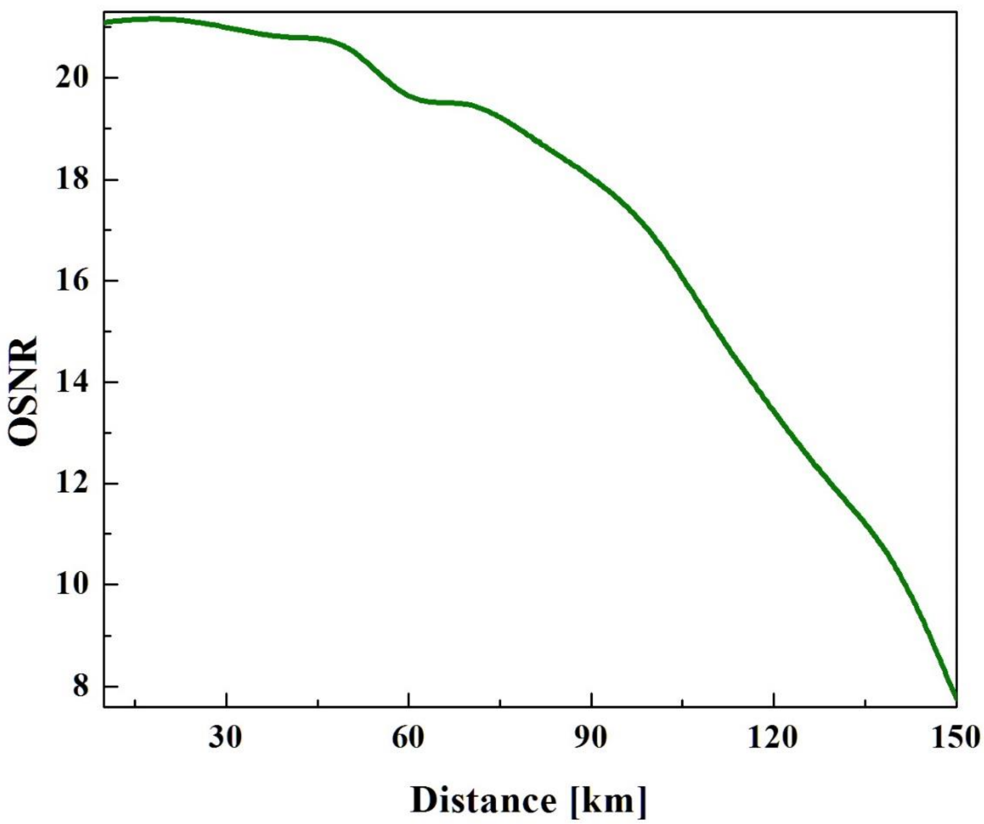

Fig 4.34: Distance dependence of OSNR at 1550 nm for 256-QAM

Fig 4.34 represents a relationship between optical signal to noise ratio (OSNR) and fiber length. It is found that OSNR decreases with the increase fiber length. 19.2dBm is the maximum OSNR value which can be achieved at 25 Km length.

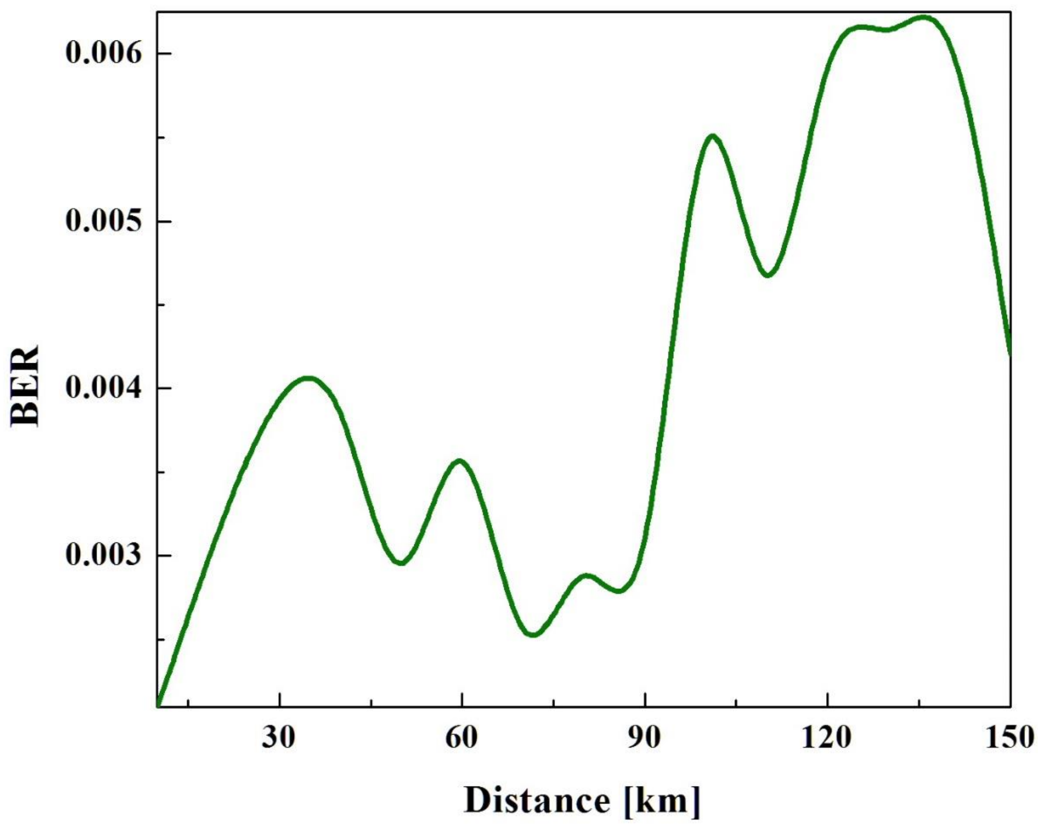

Fig 4.35: Distance dependence of BER at 1550 nm for 256-QAM

Fig 4.41 represents a relationship between BER and distance. 5.30262e-018 is the maximum BER value which can be achieved at 35 Km length.

4.6 Comparison for M-QAM modulation technique curve for 1550nm

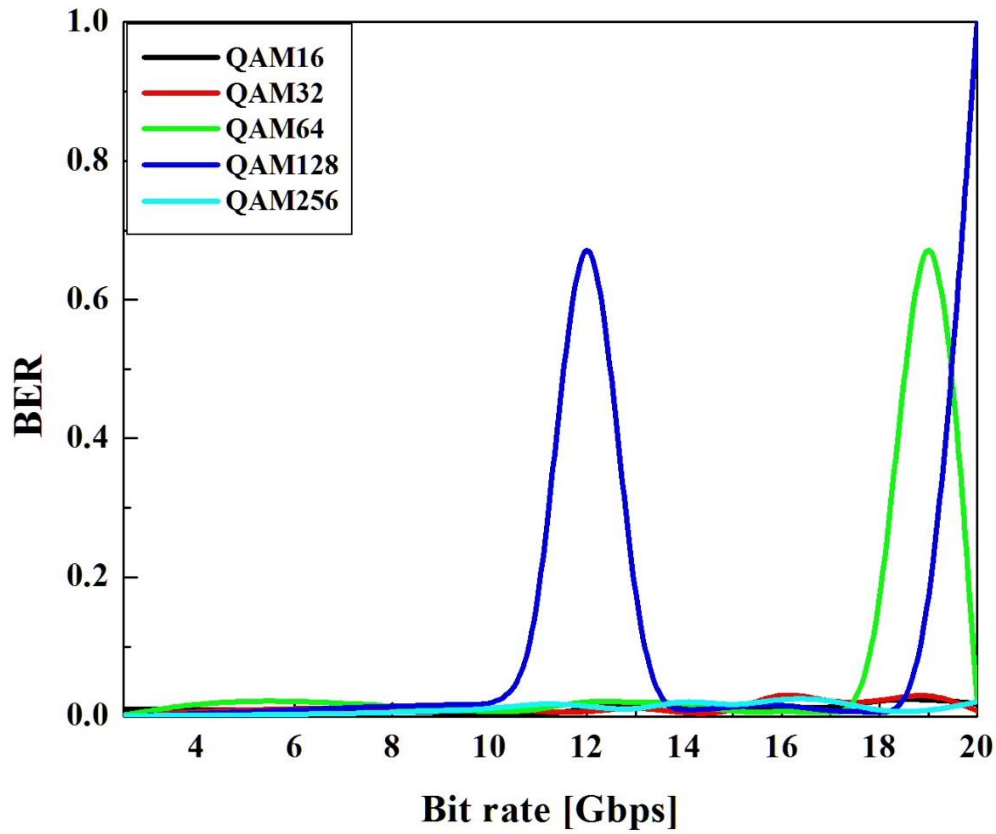

Fig 4.35: Bit rate dependence of BERat 1550nm for (16,32,64,128,256-QAM)

In fig 4.35 we can see that 256-QAM is best Bit error rate vs. Bit rate curve for 1550nm compare to other modulation technique.32-QAM is best because its Bit error rate is almost close to zero.

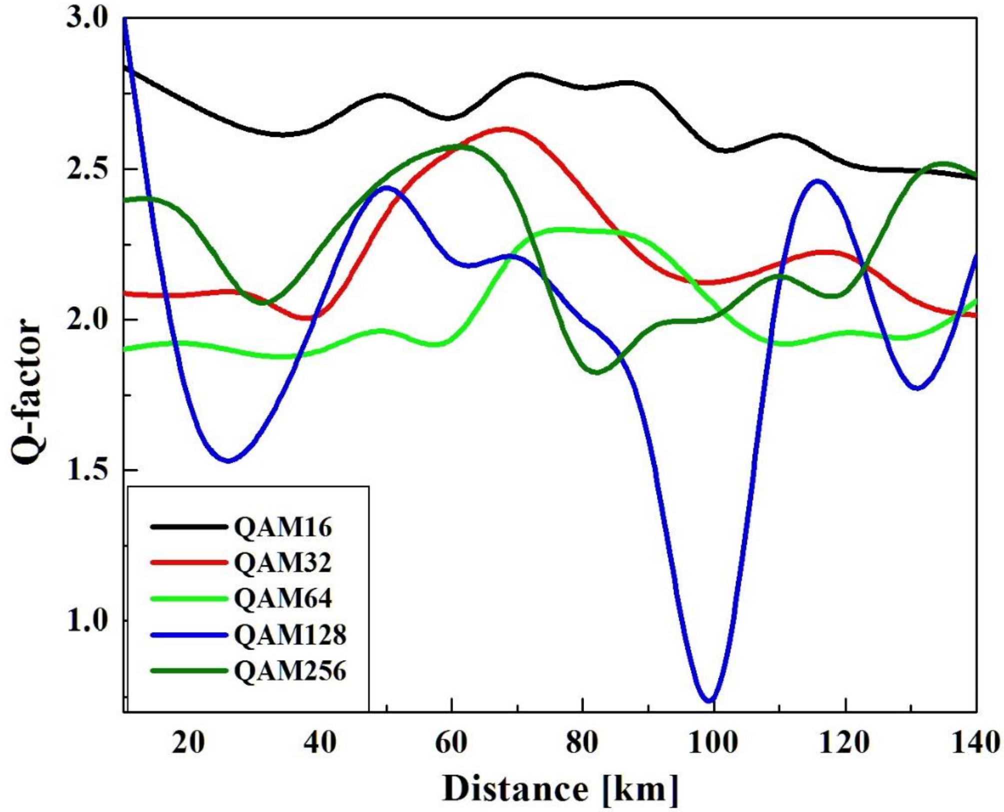

Fig 4.36 Distance dependence of Q-factorat 1550nm for (16, 32, 64, 128, 256-QAM)

In fig 4.36 we can see that 16-QAM is best Q-factor vs. Distance curve for 1550nm compare to other modulation technique. 16-QAM is best because its Q-factor is highest compare to other modulation.

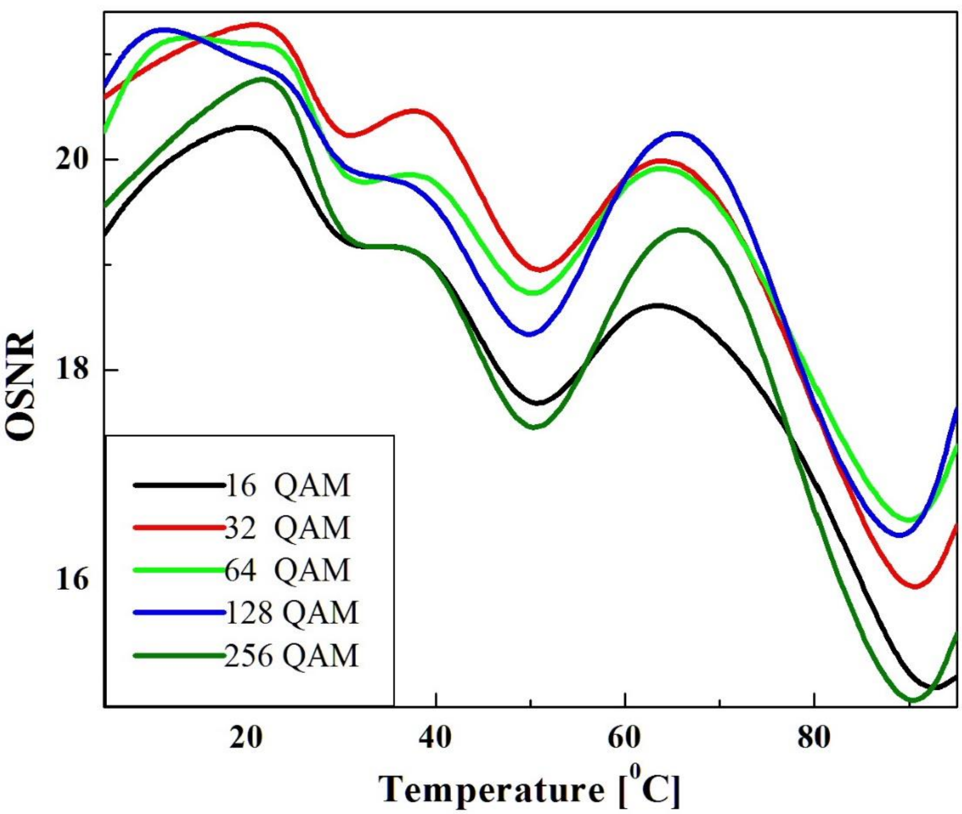

Fig 4.37: Temperature dependence of OSNR at1550nm for (16, 32, 64, 128, 256-QAM)

In fig 4.37 we can see that 128-QAM is best OSNR vs. Temperature curve for 1550nm compare to other modulation technique.

Chapter 05

Conclusion

5.1 Summary

In this work we designed and simulated a VCSELbased single mode fiber optic link for 1550 nm data transmission using optisystem. First of all, we designed temperature sustainable VCSEL by setting its internal and global design parameters namely bias current, thermal impedance, gain coefficient, carrier number of transparency. Secondly, we incorporated that VCSEL in our optical data transmission system. We investigated the dependence of temperature, link distance and bit rate on Q-factor, power dissipation and BER for 16 QAM,32 QAM, 64 QAM, 128 QAM, 256 QAM modulation schemes. The obtained results show that the 256-QAM modulation technique has a better performance in noisy environments and get minimum BER. It is also found that for high temperature (above 70^0C) operation 128-QAM provides better OSNR compared to other QAM. In the 10-Gbps single-channel optical networks, using 16-QAM modulation technique is recommended, because of its high Q-factor for 90km optical transmission network

Future Work

Future work may include-

- Short reach data transmission by using multimode fiber.
- Long reach data transmission by using multimode fiber.
- System design and its performance analysis by using PSK, QAM (512,1024) modulation techniques and our developed VCSEL.
- Highest Achievable bit rate at 1550 nm, 1700nm wavelength.
- Performance analysis of the data transmission system by using APD photo detector instead of PIN photo detector.

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