Thesis Report

on

PERFORMANCE ANALYSIS OF WDM SYSTEM WITH FBG & DCF AS COMPENSATOR

Submitted in the partial fulfilment of requirement for the award of the Degree of

MASTER OF ENGINEERING

in

ELECTRONICS AND COMMUNICATION ENGINEERING

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DECLARATION

I hereby declare that the work, which is being presented in the report, entitled "**Performance Analysis Of WDM System using FBG And DCF As Dispersion Compensators**," in partial fulfilment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering at Electronics and Communication Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the guidance of **Dr. Hardeep Singh.**

I have not submitted the matter presented in the thesis for the award of any other degree of this or any other university.

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This is to certify that the above statement made by the student is correct to the best of my knowledge and belief.

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ABSTRACT

With the increasing growth and demand for capacity in national, regional, and even metropolitan optical networks, high bit rate fiber transmission has recently become an essential part of communications. The high bit rate transmission improves spectral utilization which results in increased overall system capacity and reduces overall cost. The optical communication systems are used as high speed long–haul communication systems. To release the potential of optical communication systems and achieve higher transmission capacity at high bit rate, a lot of research on modulates on formats and dispersed managed systems has been done in recent years. The goal of an optical fiber communication system is to transmit the maximum number of bits per second over the maximum possible distance with the fewest errors. The objective of this thesis is, to analyse the performance of dispersed managed RZ system, different modulation formats. The dispersed managed system is a promising way to transmit data in optical communication networks. The performance of 10 Gbps optical communication system with the dispersion managed return-to-zero (RZ) pulse has been reported. The return-to-zero (RZ) pulse is efficient for long-distance, high-bit-rate, wavelength division multiplexed (WDM) transmission dispersion-managed systems. In RZ pulse, the power is transmitted only for fraction of bit period. In this thesis, predictions are made by varying the dispersion parameter of single mode fiber in optical communication system. It has been reported that the performance of the system is improved with increase in the value of dispersion parameter.

The fiber nonlinear characteristics are the Optical Kerr effect and the stimulated scatterings. The fiber nonlinearities produce the input power limitations on the system as well as maximum transmission distance. To mitigate their effects, the dispersion mappings are used. Pre, post and hybrid or symmetrical compensation techniques are compared on the basis of bit error rate (BER) variation with the input power at higher bit rates. The dispersion compensation fiber (DCF) is used in the compensation techniques.

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CHAPTER 1

INTRODUCTION

1.1Optical Fiber

Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. First developed in the 1970s, fiber-optic communication systems have revolutionized thetelecom industry and have played a major role in the advent of the Information Age. Because of its advantages over electrical transmission, optical fibers have largely replaced copper wire communications in core networks in the developed world.

The process of communicating using fiber-optics involves the following basic steps: Creating the optical signal involving the use of a transmitter, relaying the signal along the fiber, ensuring that the signal does not become too distorted or weak, receiving the optical signal, and converting it into an electrical signal. Optical fiber is used by many telecommunications companies to transmit telephone signals, Internet communication, and cable television signals. Due to much lower attenuation and interference. optical fiber has large advantages over existing copper wire in long-distance and high-demand applications. However, infrastructure development within cities was relatively difficult and time-consuming, and fiber-optic systems were complex and expensive to install and operate. Due to these difficulties, fiber-optic communication systems have primarily been installed in long-distance applications, where they can be used to their full transmission capacity, offsetting the increased cost. Since 2000, the prices for fiber-optic communications have dropped considerably. The price for rolling out fiber to the home has currently become more cost-effective than that of rolling out a copper based network. Prices have dropped to $850 per subscriber in the US and lower in countries like The Netherlands, where digging costs are low.

Since 1990, when optical-amplification systems became commercially available, the telecommunications industry has laid a vast network of intercity and transoceanic fiber communication lines. By 2002, an intercontinental network of 250,000 km of submarine communications cable with a capacity of 2.56 Tb/s was completed, and although specific network capacities are privileged information, telecommunications investment reports indicate that network capacity has increased dramatically since 2004.

1.1.1 Optical Transmission in Fiber

Before discussing optical components, it is essential to understand the characteristics of the optical fiber itself. Fiber is essentially a thin filament of glass which acts as a waveguide. A waveguide is a physical medium or a path which allows the propagation of electromagnetic waves, such as light. Due to the physical phenomenon of total internal reflection, light can propagate the length of a fiber with little loss, which is illuminated as following.

Light travels through vacuum at a speed of c = 3 × l08 m/s. Light can also travel through any transparent material, but the speed of light will be slower in the material than in a vacuum. Let c_{mat} be the speed of light for a given material . The ratio of the speed of light in vacuum to that in a material is known as the material's refractive index (η), and is given by: η_{mat}=c/cmat. Given that η_{mat}=1.5 approximately for glass, the velocity of signal propagation in a fiber approximately equals 2 ×l08 m/s, which corresponds to a signal propagation delay of 5µs/km .When light travels from material of a given refractive index to material of a different refractive index (i.e., when refraction occurs), the angle at which the light is transmitted in the second material depends on the refractive indices of the two materials as well as the angle at which light strikes the interface between the two materials. Due to Snell's Law, $\eta_a \sin\theta a = \eta_b \sin\theta_b$ where η_a and η_b are the refractive indices of the first substance and the second substance, respectively; θa is the angle of incidence, or the angle with respect to normal that light hits the surface between the two materials;and θb is the angle of light in the second material. However, if $\eta_a > \eta_b$ and θa is greater than some critical value, the rays are reflected back into substance n from its boundary with substance.

Looking at Figures 1.2 we see that the fiber consists of a core completely surrounded by a cladding (both the core and the cladding consist of glass of different refractive indices). Let us first consider a step-index fiber, in which the change of refractive index at the core-cladding boundary is a step function. If the refractive index of the cladding is less than that of the core, then total internal reflection can occur in the core and light can propagate through the fiber as shown in Figure. 1.1

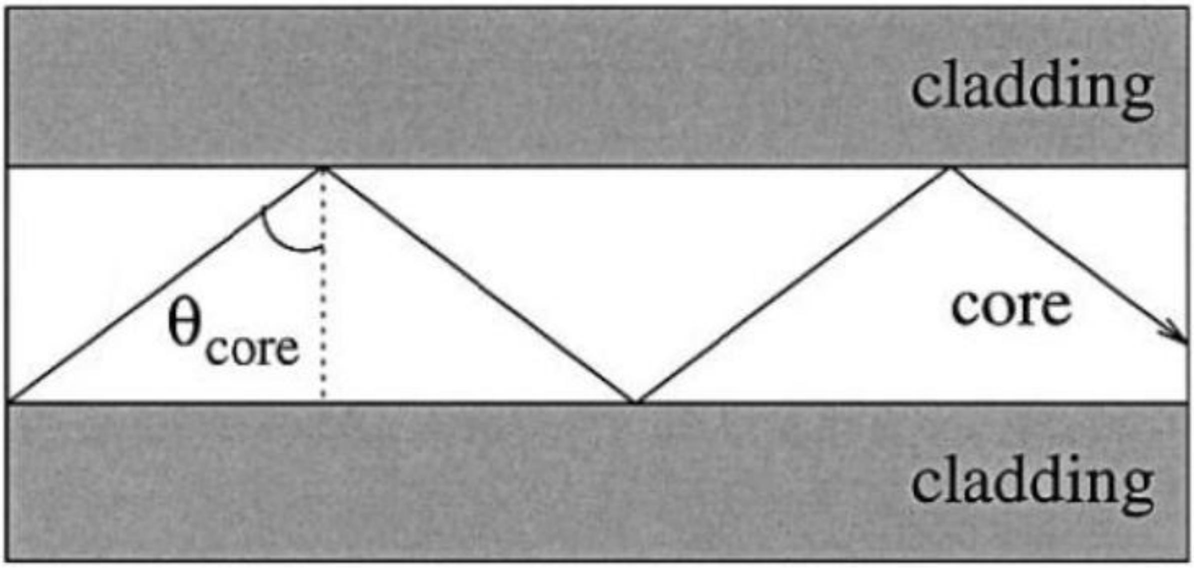

Figure1.1 : Light travelling via total internal reflection within a fiber[1]

The angle above which total internal reflection will take place is known as the critical angle [1], and is given by θcore which corresponds to θclad $=90^0$ From Snell's Law, we have:

$$\sin\theta_{clad} = \frac{\eta_{core}}{\eta_{clad}} . \sin\theta_{core} \qquad 1.1$$

The critical angle is then:

$$\theta_{crit} = \sin^{-1}\frac{\eta_{clad}}{\eta_{core}} \qquad 1.2$$

So, for total internal reflection, we require:

$$\theta_{crit} > \sin^{-1}\frac{\eta_{clad}}{\eta_{core}} \qquad 1.3$$

In other words, for light to travel down a fiber, the light must be incident on the core cladding

surface at an angle greater than θ_{crit} . In some cases, the fiber may have a graded index in which the interface between the core and the cladding undergoes a gradual change in refractive index with $\eta_i > \eta_{i+1}$(Fig 1.2)

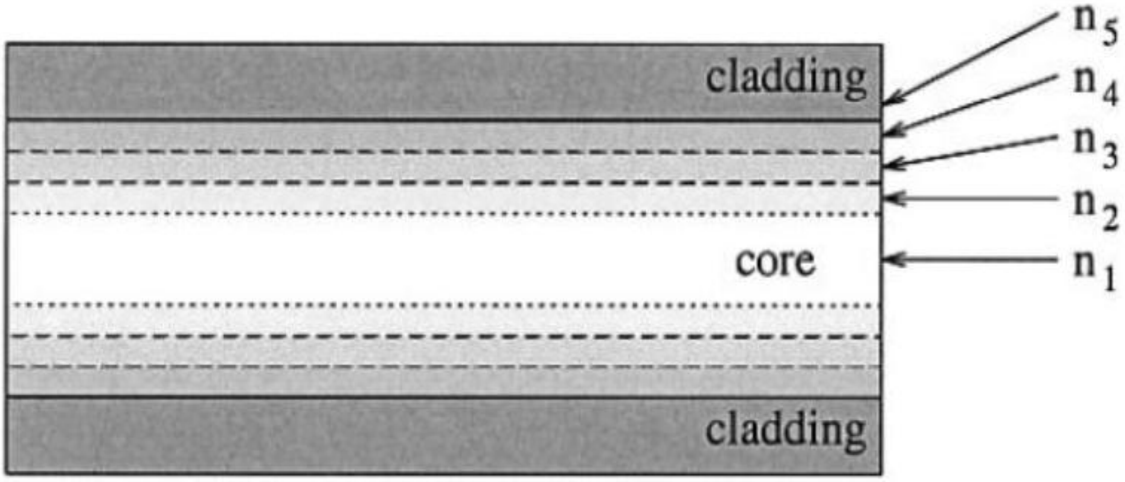

Figure1.2: Graded-index fiber[1]

A graded index fiber reduces the minimum θ_{crit} required for total internal reflection, and also helps to reduce the intermodal dispersion in the fiber. In order for light to enter a fiber, the incoming light should be at an angle such that the refraction at the air-core boundary results in the transmitted light being at an angle for which total internal reflection can take place at the core-cladding boundary.

As shown in Fig.1.4 , the maximum value of θ_{air} can be derived from:

$$\eta_{air}\sin\theta_{air} = \eta_{core}\sin(90^{\circ}-\theta_{crit}) = \eta_{core}\sqrt{\sin^{2}}\theta_{crit} \qquad 1.4$$

From Eqn. (1.2), since $\sin\theta_{crit} = (\frac{\eta_{clad}}{\eta_{core}})$ we can rewrite Eqn. (1.4) as:

$$\eta_{air}\sin\theta_{air} = \sqrt{\eta_{core}{}^{2} - \eta_{clad}{}^{2}} \qquad 1.5$$

The quantity $\eta_{air} \sin\theta_{air}$ is referred to as NA, the numerical aperture of the fiber and θ_{air} is the maximum angle with respect to the normal at the air-core boundary, so that the incident light that enters the core will experience total internal reflection inside the fiber[2,3]

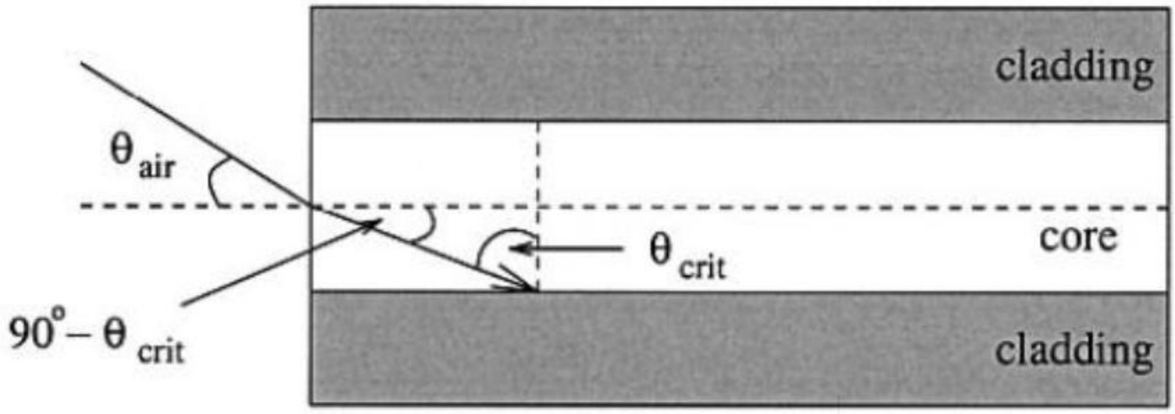

Figure1.3: Numerical aperture of a fiber[1]

According to Snell's Law and fiber refractive index, typical delay of optical propagation in optical fiber is 5µs/km.

1.2 Types Optical Fiber

There are two basic types of optical fibers:

1.2.1 Step Index Fiber

These types of fibers have sharp boundaries between the core and cladding, with clearly defined indices of refraction. The entire core uses single index of refraction.

1.2.1.1 Single Mode Step Index:

Single-mode fibre allows for a higher capacity to transmit information because it can retain the fidelity of each light pulse over longer distances, and it exhibits no dispersion caused by multiple modes. Single-mode fibre also enjoys lower fibre attenuation than multimode fiber.Single mode fibre has a core diameter of 8 to 9 microns, which only allows one light path or mode. Single-mode step index fibre has a small core that forces the light waves to stay in the same path, or mode. This keeps the light signals going farther before they need to be beefed up, or amplified. Most long-distance, or long-haul, fiber optic telephone lines use single-mode fibre.

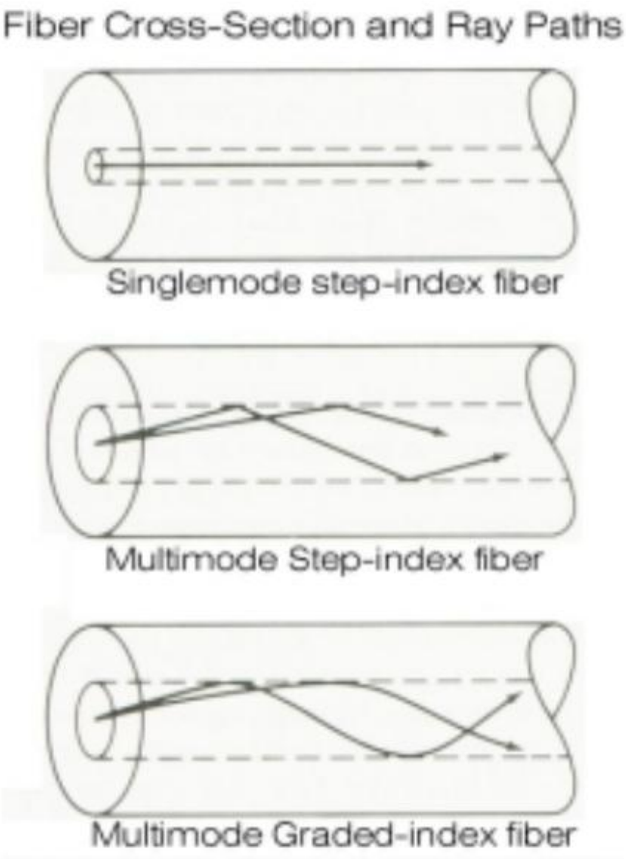

Figure 1.4 : Modes of optical fibers[1]

1.2.1.2 Multimode Fiber

Multimode fiber, the first to be manufactured and commercialized, simply refers to the fact that numerous modes or light rays are carried simultaneously through the waveguide. Modes result from the fact that light will only propagate in the fiber core at discrete angles within the cone of acceptance. This fiber type has a much larger core diameter, compared to single-mode fiber, allowing for the larger number of modes, and multimode fiber is easier to couple than single-mode optical fiber. Multimode fiber may be categorized as step-index or graded-index fiber

1.2.1.3Multimode Step Index Fiber

Multimode fiber has a core diameter of 50 or 62.5microns (sometimes even larger).It allows sever a light paths or modes. This causes modal dispersion some modes take longer to pass through the fiber than others because they travel a longer distance

1.2.2 Multimode Graded Index Fiber

Graded-index refers to the fact that the refractive index of the core gradually decreases farther from the centre of the core. The increased refraction in the center of the cores lows the speed of some light rays, allowing all the light ray store ach there receiving end at approximately the same time, reducing dispersion. Multimode fibers can carry only a third or less the information carrying capacity or bandwidth than single mode fiber and they won't work for long distances.[3]

1.2.3 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. Stimulated emission in the amplifier's gain medium causes amplification of incoming light. Optical amplifiers are important in optical communication and laser . The OA has made it possible to amplify all the wavelengths at once and without optical-electrical-optical (OEO) conversion. Besides being used on optical links, optical amplifiers also can be used to boost signal power after multiplexing or before demultiplexing, both of which can introduce loss into the system

1.2.4 Semiconductor Optical Amplifier (SOA)

Semiconductor optical amplifiers are amplifiers which use a semiconductor to provide the gain medium. Recent designs include anti-reflective coatings and tilted waveguide and window regions which can reduce end face reflection to less than 0.001%. Since this creates a loss of power from the cavity which is greater than the gain it prevents the amplifier from acting as a laser. Such amplifiers are often used in telecommunication systems in the form of fibre-pigtailed components, operating at signal wavelengths between 0.85 μm and 1.6 μm and generating gains of up to 30 dB. The semiconductor optical amplifier is of small size and electrically pumped. It can be potentially less expensive than the EDFA and can be integrated with semiconductor lasers, modulators, etc. However, the performance is still not comparable with the EDFA. The SOA has higher noise, lower gain, moderate polarization dependence and high nonlinearity with fast transient time.[4-6] This originates from the short nanosecond or less upper state lifetime, so that the gain reacts rapidly to changes of pump or signal power and the changes of gain also because phase changes which can distort the signals. This nonlinearity presents the most severe problem for optical communication applications. However it provides the possibility for gain in different wavelength regions form the EDFA. "Linear optical amplifiers" using gain clamping techniques have been developed.

1.2.5 Doped Fibre Amplifier

Doped fibre amplifiers (DFAs) are optical amplifiers which use a doped optical fibre as a gain medium to amplify an optical signal. They are related to fibre lasers. The π signal to be amplified and a pump laser are multiplexed into the doped fibre, and the signal is amplified through interaction with the doping ions. The most common example is the Erbium Doped Fiber Amplifier (EDFA), where core of a silica fiber is doped with trivalent Erbium ions (3 Er +), can be efficiently pumped with a laser at 980 nm or at 1,480 nm, and exhibits gain the 1,550 nm region. Amplification is achieved by stimulated emission of photons from dopant ions in the doped fibre. The pump laser excites ions into a higher energy. The amplification window of an optical amplifier is the range of optical wavelengths for which the amplifier yields a usable gain. The amplification window is determined by the spectroscopic properties of the dopant ions, the glass structure of the optical fibre, and the wave length and power of the pump laser. The broad gain-bandwidth of fibre amplifiers make them particularly useful in wavelength-division multiplexed communications systems as a single amplifier can be utilized to amplify all signals being carried on a fiber and whose wavelengths fall within the gain window.

1.2.6 Optsim

Optsim is an advanced optical communication system simulation package designed for professional engineering and cutting-edge research of WDM, DWDM, TDM, CATV, optical LAN, parallel optical bus, and other emerging optical systems in telecom, datacom, and other applications. It can be used to design optical communication systems and simulate them to determine their performance considering various component parameters. Optsim is designed to combine the greatest accuracy and modeling power with ease of use on both Windows and UNIX platforms. Optsim represents an optical communication system as an interconnected set of blocks, with each block representing a component or subsystem in the communication system. As physical signals are passed between components in a real world communication system, “signal” data is passed between component models in the Optsim simulation.

1.2.7 Simulation

Optsim provides multiple simulation engines that provide complementary simulation techniques. This enables the greatest flexibility in modeling and simulating systems ranging from short-distance data communication links, to ultra long-haul DWDM telecom systems, to large metro networks with feedback paths and EDFA transients due to adding and dropping of channels.

1.2.8 Analysis

Data Post-Processing and Display OptSim's data post-processing and display facilities provide an intuitive and flexible measurement graphical interface that acts as a lablike set of virtual instruments. Interactive and post-processing functionality (e.g. graph superimposition, correlation graphs, interactive cursor read-out data, peak search, eye-diagram measurements, BER/Q evaluation) allow one to simulate the project once and perform further analysis of results later (saving time during the design process).

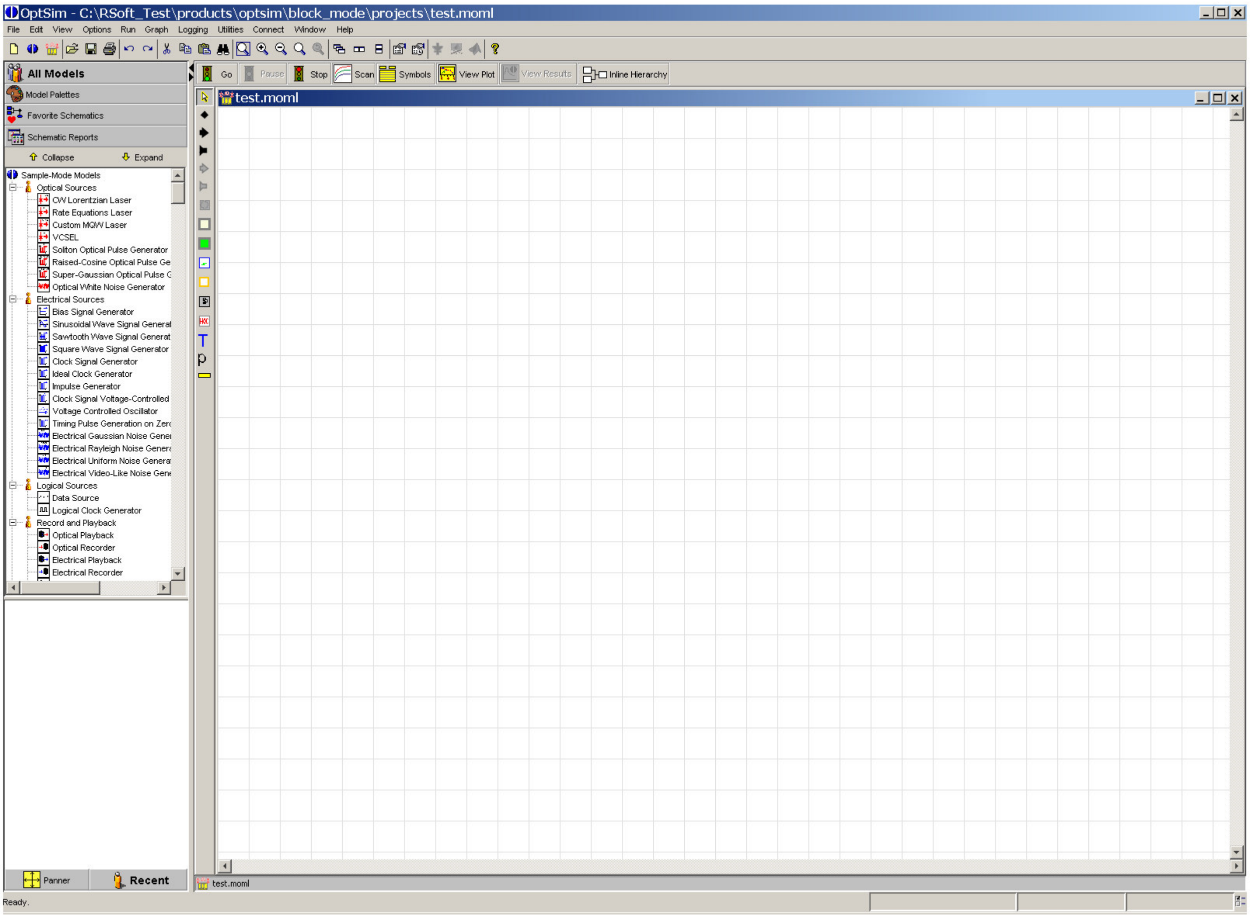

Figure 1.8: The Optsim graphical editor

Simulation results can be plotted in a number of forms including signal waveforms, eye diagrams, signal spectra, OSNR, Poincare sphere, dispersion maps, and more. A wide and complete choice of measurements is available including jitter, eye opening/closure, electrical/optical spectra, chirp, optical instantaneous phase/frequency and power.

CHAPTER 2

LITERATURE REVIEW

The polarization related and nonlinear impairments have become a major obstacle to increase the transmission rates in WDM systems. The work done by different authors is reviewed is given below.

2.1 Dispersion In Optical Fiber

- Gnanam Gnanagurunathan, Faidz Abd. Rahman [7] gave their ideas towards the grating device seems to be the better compensating solution for the long haul narrowband transmission. In addition, the FBG is also able to sustain the changes in traffic load and modulation scheme much better thanthe DCF.
- D.S Gasper, P. F. Wysocki, W. A. Reed, and A. M. Vengsarkar,[8] gave their ideas towards the small deviations from perfect circular symmetry in the core region of single mode fibers cause the optical pulses to become broadened as they propagate and causes inter symbol interference. They had also identified the three dimensional polarization vectors and characterize the polarization effects in narrowband sources.
- According to the paper given in [9],Ling Wei Guo, Ying-Wu Zhou, Zu Jie Fang gave their ideas towards the pulse broadening of optical signals in a single mode fiber was studied theoretically in presence of PMD, PDL, Chromatic dispersion and spectral chirping. Analytical expressions were derived for the parameters of the pulse broadening characteristics without simplification assumption w.r.t. the pulse shape and to the order of dispersion Misha Brodsky, Elizabeth C. George, Cristian Antonelli, Mark Shtaif [10] provided their ideas toward higher- order dispersion. new expressions induced pulse broadening and its compensation. In this paper they derived new expressions for the PMD vector including the second- and third order effects.
- These new expressions were used to obtain explicit expressions for PMD induced pulse broadening. The pulse broadening expressions reveal that an increase in the first- and second- order derivatives of DGD with respect to frequency always increases pulse broadening. A change of direction of the first order PMD vector also increases pulse broadening. In most cases, the second and third- order PMD cannot be compensated completely. This paper gives the expressions for minimum

pulse broadening in the presence of second and third order PMD. This paper derived the relation between them and the new relation lead to new expression for second and third order PMD induced pulse broadening.

- Md Zaini Jamaludin, Ahmad Fauzi Abas, Ahmad Shukri Muhammad Noor and Mohamad Khazani Abdullah in [11] analyzed dispersion characteristics. They found that a pulse spread of up to 15% of the pulse width is allowed depending on the receiver sensitivity penalty tolerated the system.

2.2 Dispersion Mapping

- In [6] John M. Senior, provides the background material and the mathematical tools needed for understanding the various nonlinear effects. Starting from the Maxwell’s equation, the wave equation in a nonlinear dispersive medium is used to discuss the fiber modes and to obtain the basic propagation equation.
- Wei ZHAO [12] has presented a numerical study of the performance of 40 Gbps return-to-zero differential phase-shift keying (RZ-DPSK) transmission with different dispersion maps. The optimum dispersion mapping for RZ-DPSK format are discussed and compared with those for on-off keying (OOK). Two pseudo-linear transmission systems, one using standard single-mode fiber and the other nonzero dispersion-shifted fiber, are investigated, respectively.
- Hayashi, M. B. Panish, P. W. Foy and S. Sumski [13] analyzed the 10-Gbps non dispersion managed and dispersion-managed wavelength-division multiplexed (WDM) systems that use pre-compensation, post-compensation, or dual-compensation of each channel to minimize dispersion and nonlinear effects.
- In [14]Yan Cui, Kun Xu, Jian Dai, Yitang Dai, Jian Wu, Jintong Lin, have reported the results of recirculating fiber loop experiments and computer simulations investigating the use of under-compensation to minimize the nonlinear distortion in multi-span compensated standard-fiber links. By numerical modelling and experiments it is shown that in multi span post-compensated SSMF systems, SPM leads to broadening of short pulses, resulting in vertical closure of the received signal eye after only a few spans.
- Luís M. Sá, Rogério Nogueira, and Paulo André1, [15] demonstrated a novel sensor which used the difference in strain and temperature response of Fiber Bragg Gratings and a long period fiber grating to discriminate between strain and temperature induced wavelength shifts. Sensor interrogation was performed

entirely on the Fiber Bragg Grating reflection signals. Strain and temperature were simultaneously measured to ±9 µstrain and ±1.5°C .

- S. S. Azmiri Khan and M. S. Islam[16] described a multiplexing approach for high-resolution sensing with Bragg gratings. The scheme used a band-pass wavelength division multiplexer to separate the returned wavelengths from an array of gratings, and interferometric processing to attain high-strain resolution. A strain resolution of 1.5 nano strain was demonstrated, with a sensor bandwidth of 10 Hz-2 kHz for four sensors.
- Davis et al [17] reported the demonstration of an instrumentation system capable of monitoring a large number of Bragg gratings using a common source and scanning narrowband filter. The system described monitored five arrays of 12 Bragg gratings sensors for a total of 60 sensor elements with µstrain resolution.

2.3 NRZ and RZ Modulation Format

- Kwok, Chow, Tsang and Bjarklev el at. [18] had theoretically and experimentally the conversion bandwidth of the cross-polarization-modulation based wavelength conversion scheme with a dispersion-flattened highly nonlinear photonic-crystal fiber for signals with a nonreturn-to-zero (NRZ) modulation format. It was showed that the conversion bandwidth can be extended to cover a very wide band, including S-, C-, and L-bands for 10 Gbit/s NRZ signals (a total bandwidth of 120 nm is experimentally demonstrated). It was studied the theoretical bandwidth limit for 40 Gbit/s NRZ signals. A significant extension of the conversion bandwidth using the cross-polarization-modulation approach compared with the four-wave mixing approach previously reported is demonstrated.
- Mob, Fiirst, Geiger and Flscher el at. [19] theoretically and experimentally analyses advantages of nonlinear RZ over NRZ on 10 GB/s single-span links. Griffin, Walker, and Johnstone el at. [20] demonstrated a four-stage integrated module for 10 Gb/s chirped return-to-zero modulation using GaAs/AIGaAs electro-optic guided wave technology and its performance is verified by dispersion-managed test bed transmission over 3000 km. Hodzic, Konrad, and Petermann el at. [21] had proposedalternative modulation formats in N 40 Gb/s WDM standard fiber RZ-transmission systems.

- Winzer and Leuthold el at. [22] experimentally demonstrate and discuss a new technique for variable duty cycle return-to-zero (RZ) modulation, employing a phase modulator driven by a single electrical non return-to-zero signal.
- Park, Wiesenfeld, and Garret el at. [23] demonstrated the transmission of a 40-Gb/s signal over multiple (up to six) 120-km spans of conventional single-mode fiber (SMF). It is proposed to use a very low duty cycle return-to-zero (RZ) format which employs optical pulses much shorter than the bit-period. The resulting broad spectrum of these short pulses reduces nonlinear effects and enables the transmission of the signal over long distances
- Tanaka, Moritd and Edagawa el at. [24] successfully demonstrated 5OGHz spaced 40Gbitis × 2 WDM transmission over 480km using band limited RZ signals and an SMF-based dispersion-flattened transmission line and the longest distance transmission for a spectral efficiency of 0.8 bits/Hz was achieved without using polai-isation multiplexing
- Sunnerud, Karlsson and Andrekson el at. [25] numerically analysed a comparison between NRZ and RZ data formats with respect to PMD-induced system degradation and showed that that RZ performs better than NRZ and the trade-off between power margin and acceptable PMD is studied.

2.4 Thesis Objectives

- To study the performance of 10 Gbps optical communication with different transmission distance.
- To analyze the different modulation formats for optical modulation system
- To study and analyze the impact of dispersion compensators on the performance of efficients optical communication system

CHAPTER 3

TYPES Of DISPERSION

Fiber optic communication is a way of exchanging the information between to places by sending the light signal through the optical fiber cable. Fiber optic communication brought the revolutionary change in the telecommunication industry and played a major role in the advent of information age. In the twenty first century, its advantages over electrical transmission cause the replacement of copper wire with the optical fiber in the communication system. Now the optical fiber is the most common type of channel used in communication system, but the other types of waveguides are also used within the communication system. Today, optical fibers are not only used in telecommunication links but also used in the Internet and local area networks to achieve high signaling rates. The core advantages of optical fiber such as low loss, which allows long distances between amplifiers and its high data carrying capacity as that of thousands of electrical links would be required to carry that much data. Also no cross talk introduces in optical fibers running alongside each other for long distances as introduces in some types of electrical transmission lines.

The use and demand for optical fiber has grown tremendously and optical-fiber applications are numerous. Telecommunication applications are widespread, ranging from global networks to desktop computers. These involve the transmission of voice, data, or video over distances of less than a meter to hundreds of kilometers, using one of a few standard fiber designs in one of several cable designs.[2]

But in the fiber optic communication system linear and nonlinear characteristics of fiber put limitations over high speed data transmission in the communication system. The Linear characteristics include attenuation, chromatic dispersion (CD), polarization mode dispersion (PMD), and optical signal-to-noise ratio (OSNR). The nonlinear characteristics include self-phase modulation (SPM), cross-phase modulation (XPM), four-wave mixing (FWM), stimulated Raman scattering (SRS), and stimulated Brillouin scattering (SBS). Nonlinear fibre effects such as self- and cross-phase modulation combined with the group velocity dispersion result in intensity distortion of the propagating signals in WDM links, limiting the maximum transmission distance. The transmission distances can be increased by optimizing the dispersion map to reduce the impact of nonlinearities.

Further the maximum transmission distance is limited by the dispersion or spreading of optical pulses as they travel along the fiber. It was not until the advent of Erbium Doped Fiber Amplifier (EDFA) in the late 1980's [26-27], that chromatic dispersion in the fiber become main limiting factor in the optical transmission systems rather than fiber losses.

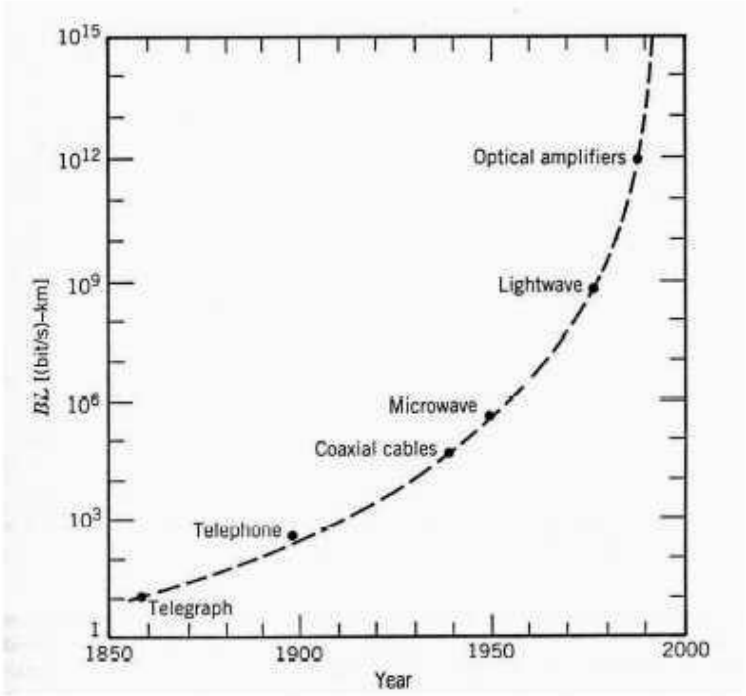

Figure 3.1 : Increase in the bit rate –distance (B-L) product[1]

3.1 Dispersion

There are two different types of dispersion in optical fibers.

The types are intramodal and intermodal dispersion. Intramodal, or chromatic, dispersion occurs in all types of fibers. Intermodal, or modal, dispersion occurs only in multimode fibers. Each type of dispersion mechanism leads to pulse spreading. As a pulse spreads, energy is overlapped. This condition is shown in figure [3.2] . The spreading of the optical pulse as it travels along the fiber limits the information capacity of the fiber. [1]

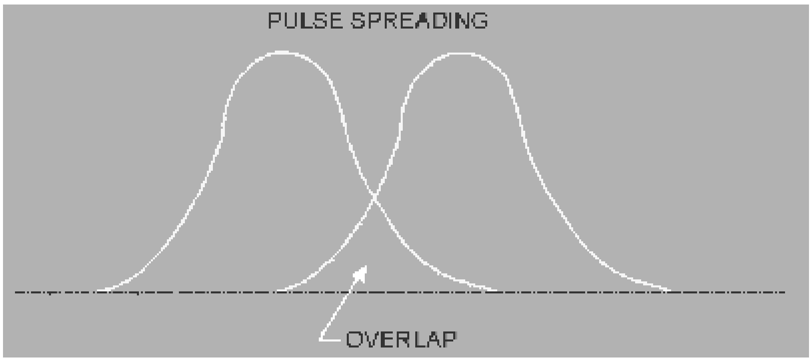

Figure 3.2 - Pulse overlap[1]

3.1.1 Intramodal Dispersion

Intramodal, or chromatic, dispersion depends primarily on fiber materials. There are two types of intramodal dispersion. The first type is material dispersion. The second type is waveguide dispersion.

Intramodal dispersion occurs because different colors of light travel through different materials and different waveguide structures at different speeds.[1]

3.1.2 Chromatic Dispersion

Chromatic dispersion (CD) is caused by the fact that singlemode glass fibers transmit light of different wavelengths at different speeds. The ratio of the speed of light in a medium to the speed in a vacuum defines the index of refraction or refractive index of the material. For optical fiber, the effective index of refraction is about 1.45, so the speed of light in glass is about 2/3 the speed of light in a vacuum. But the index of refraction, and thereby the speed of light in the fiber, is a function of the wavelength of light, the principle we all know from seeing a prism break light into aspectrum. Most sources used in long distance fiber optic links are lasers which have very little spectral width. And fibers are optimized for the wavelength of use. Both these factors minimize the effects of chromatic dispersion but cannot totally stop it. As the pulse proceeds down the fiber, the light of longer wavelength travels slightly faster and spreads thepulseoutasshownhere.

Figure 3.3:The light of longer wavelength travels slightly faster and spreads the pulse out[1]

There are two factors that cause chromatic dispersion: material dispersion and waveguide dispersion.

3.1.3 Material Dispersion

Material dispersion occurs because the spreading of a light pulse is dependent on the wavelengths' interaction with the refractive index of the fiber core. Different wavelengths travel at different speeds in the fiber material. Different wavelengths of a light pulse that enter a fiber at one time exit the fiber at different times. Material dispersion is a function of the source spectral width. The spectral width specifies the range of wavelengths that can propagate in the fiber. Material dispersion is less at longer wavelengths.

3.1.4 Waveguide Dispersion

Waveguide dispersion occurs because the mode propagation constant is a function of the size of the fiber's core relative to the wavelength of operation. Waveguide dispersion also occurs because light propagates differently in the core than in the cladding. In multimode fibers, waveguide dispersion and material dispersion are basically separate properties. Multimode waveguide dispersion is generally small compared to material dispersion. Waveguide dispersion is usually neglected. However, in single mode fibers, material and waveguide dispersion are interrelated. The total dispersion present in single mode fibers may be minimized by trading material and waveguide properties depending on the wavelength of operation. [2,3]

3.1.5 Polarization Mode Dispersion

Polarization Mode Dispersion (PMD) is a bit more complex. The polarization related impairments have become a major obstacle to the increase transmission rates in WDM systems. Such impairments include Polarization Mode Dispersion (PMD) in optical fibers, Polarization Dependent Loss (PDL) in passive optical components, Polarization Dependent Modulation (PDM) in electro optical modulators, and polarization dependent gain (PDG) in optical amplifiers [27]. Polarization is a phenomenon of light traveling in a medium as a wave with components at right angles. Some materials, like a glass optical fiber, have a different index of refraction for each of those components of the light wave, which is called birefringence. And a different index of refraction means light travels at a different speed, so in the simplest visualization, PMD in fiber looks like the drawing below, where each component of the polarized light travels at a different speed, causing dispersion. The magnitude of PMD in a fiber is expressed as this difference, which is known as the Differential Group Delay (DGD) and called $\Delta\tau$ (“delta Tau”)[28].

3.1.6 Birefringence

The birefringence in optical fiber can be expressed as a difference in the refractive index, and hence propagation constant , for the orthogonal polarization modes

$$\Delta\beta = \beta_s - \beta_f = \frac{\omega n_s}{c} - \frac{\omega n_f}{c} = \frac{\omega \Delta n}{c} = \frac{2\pi}{\lambda}\Delta n \qquad 3.1$$

Where ω is the angular frequency of the light, c is the speed of the light in vacuum and $\Delta n = n_s n_f > 0$ is the refractive index difference between the slow and fast axis, while λ is the wavelength of the light in vacuum. The difference can also change the state of polarization (SOP) of the light as it travels along the fiber as illustrated in the figure3.4 . Two orthogonal polarization states exist (eigenstates) that are unaffected by the birefringence. Any polarization state can be decomposed into the two eigenstates. In the uniformly birefringent segment, the eigenstates corresponds to the well defined birefringence axes.

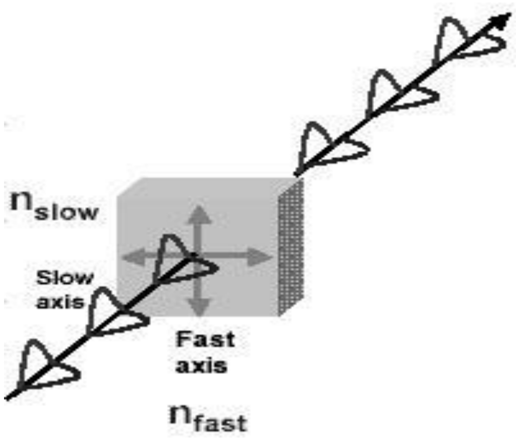

Figure 3.4 : The local birefringence in an optical fiber changing the polarization state of the light [2]

The phase retardation between the two orthogonal fields due to birefringence causes the polarization to evolve in a periodic manner and the period of this variation is referred to as the beat length, $L_{\beta} = \frac{\lambda}{\Delta n}$. For standard single mode fiber Δn is typically 10^{-7} , which leads to a beat length to around 15 m at the wavelength 1550 nm. The difference in phase velocity indicated by equation is usually accompanied by a difference in the local group velocity and by a subsequent splitting of pulses that travel through the fiber. This group velocity difference gives rise to a differential group velocity (DGD), Δt is a random variable that has a Maxwellian probability density function. Figure3.4 shows the pulse splitting that arises due to the birefringence. In long fibers, the birefringence is combined with random polarization mode coupling and the PMD grows with the square root of the fiber length.[2,3] The degeneracy can be lifted if, through a loss of the circular symmetry, any amount of anisotropy is introduced, leading to some birefringence . This is the general case of real fibers, where the loss of symmetry originates in the fiber manufacturing process from noncircular waveguide geometry (geometrical birefringence static) or in deployed fiber from non symmetrically distributed mechanical stress (stress birefringence time varying) [29]

3.2 Dispersion Compensation in Optical Transmission Lines

Depending on the place and realization where the dispersion compensation is made in a system, it can be distinguished between three compensating methods: a) pre-chirp techniques at the transmitter side b) dispersion compensation in the transmission line (inline compensation) and c) dispersion compensation at the receiver side (Fig. 3.5).

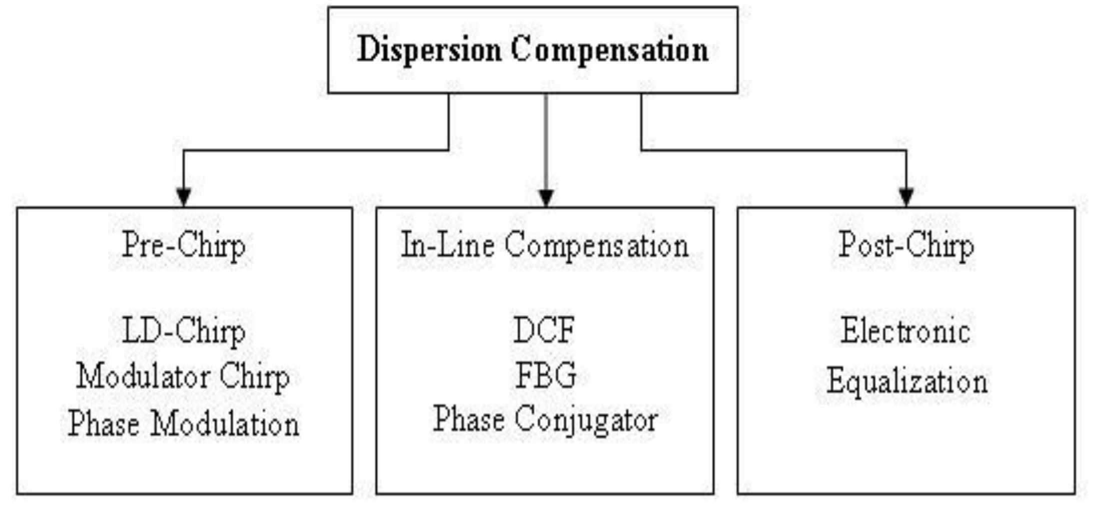

Figure 3.5: Dispersion compensation methods [3]

The idea behind the pre-chirping at the transmitter side is the implementation of chirp with the opposite sign to the fiber chirp in order to counter the GVD effects in the fiber. The main implementation area of this technique is cost effective, optical short-reach systems (e.g. MANs) with smaller channel bit rates, but in combination with other dispersion compensation techniques (e.g. in-line compensation) it can enable a performance improvement even in high-bit rate transmission systems over long distances [30]. In-line dispersion compensation represents the key enabling technology for the realization of long-haul transmission systems. The dispersion compensation is realized in the optical domain without electro-optical conversion of the signal, enabling better compensation of the signal because the optical phase is maintained. The post-chirp techniques at the receiver side are characterized by the compensation of the chromatic dispersion in electrical domain. This compensation method is cost effective, and in combination with in-line compensation, enables an enhanced transmission performance.

3.2.1 In Line Compensation Devices

Implementation of in-line compensation devices in the transmission line affects the transmission performance of the system because of the interaction of dispersion map with transmission disturbances (e.g. ASE-noise, nonlinearities). The following dispersion compensating devices are used for the realization of in-line dispersion compensation:

Dispersion Compensating Fiber (DCF) represents the most widely used in-line dispersion compensation technique in today’s transmission systems. The DCFs are characterized by a large negative dispersion and a small core diameter. The large negative dispersion values can be achieved by variation of the fiber profile by doping the fiber cladding (e.g. by fluorine), introducing an increase in the refractive index difference between the core and cladding. The demands on DCFs are a large negative dispersion (-70-300 ps/nm), low insertion losses, low polarization dependent (PDL) losses, a low polarization mode dispersion (<√0.05 ps/km), a large effective area (A_{eff}) and a negative dispersion slope. The DCFs can be used for simultaneous compensation of several channels, but due to imperfections in slope compensation, a small amount of residual dispersion remains especially in outer channels.

Fiber Bragg Grating (FBG) modules are fabricated by implementing refractive index changes in the fiber core. The regions with different refractive indices are called gratings. Depending on the distance between the gratings known as grating period, which can be realized as constant or varying (chirped), the shorter wavelengths will be reflected before the longer ones. The consequence is pulse compression and dispersion compensation. FBGs represent a promising technology for the realization of dynamic dispersion compensation in tuneable dispersion compensators. The advantages of FBGs are large nonlinear tolerance and lower device loss. The main FBG drawback is an increased device complexity because of the implementation of optical circulators and large ripples in insertion losses (IL) and group delay (GD).

Phase Conjugator is utilizes the concept known as mid-span spectral inversion (MSSI). The principle of MSSI is the spectral inversion of the optical signal spectrum in the middle of the transmission span by applying an active component (e.g. semiconductor laser) or highly nonlinear fiber (e.g. nonlinear phase-conjugating mirror). The short wavelengths of the signal are interchanged with the longer wavelengths making use of a nonlinearity based phase conjugation. This concept enables a full compensation of dispersion and dispersion slope, but it is less practical for the implementation in the transmission systems because of its complexity. For the system used in this work, conventional DCF based compensation devices are implemented because of the fact that they represent the state-of-the-art technology in today's optical communication systems.

3.2.2 Dispersion Compensating Schemes

Depending on the placement and the combination of in-line compensation devices in the transmission line, several different dispersion compensation schemes can be realized (Fig. 3.6). Common for all dispersion compensation schemes enabling the full dispersion compensation is that the compensation of the accumulated dispersion in the transmission fiber has to be performed according to the following rule:

$$D_{SMF}.L_{SMF} + D_{DCF}.L_{DCF} = 0 \tag{3.2}$$

Where D_{SMF}, D_{DCF} are the chromatic dispersion values of transmission and compensating fibers, respectively, and L_{SMF}, L_{DCF} the lengths of these fibers. This rule can be fulfilled by placing DCFs in different positions within a transmission line. Typically, a transmission line consists of several cascaded spans. Depending on the realization of the span infrastructure, it can be distinguished between three basic dispersion compensation schemes: pre, hybrid and post-compensation figure (3.6). In pre- and post-compensation the DCFs are placed before or after the SMF fiber. In hybrid-compensation 50% of the SMF dispersion is compensated before the SMF and the other 50% is compensated afterwards. The system behaviour can be quite different for the different schemes because of the influence of dispersion compensation on the linear and nonlinear effects.

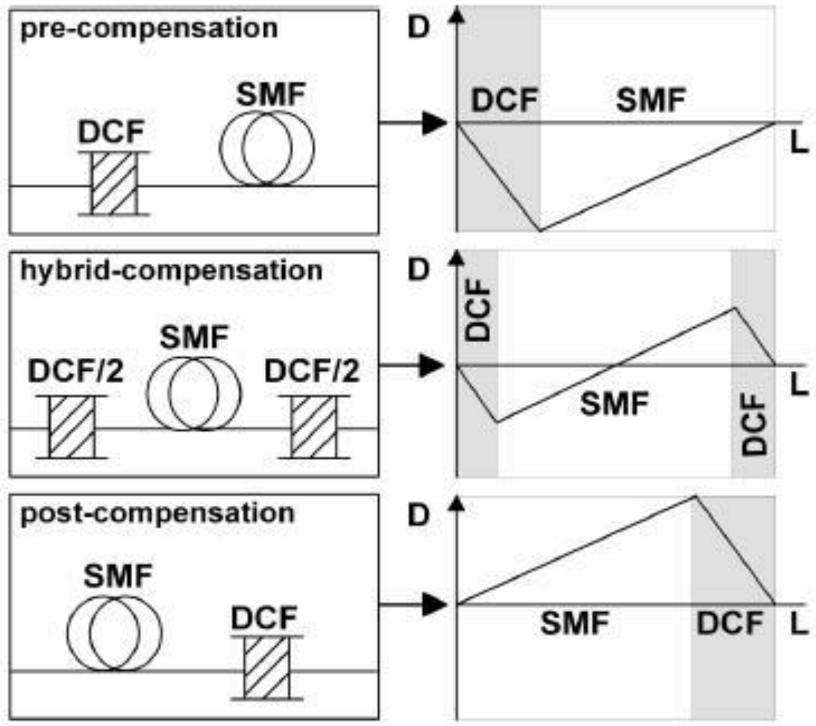

Figure 3.6: Various dispersion compensating techniques [2]

The full dispersion post-compensation scheme provides full compensation and signal shape regeneration after each span. This scheme is interesting for the practical implementation because the optical signal form is maintained after each span and the signal can be easily accessed or detected. The nonlinear characteristics of this scheme are rather poor, because the walk-off between adjacent channels in the system vanishes after each span resulting in an increased impact and accumulation of inter-channel nonlinearities (e.g. XPM), depending on the local dispersion of the transmission fiber. The nonlinear tolerance of this scheme can be improved by implementation of the pre chirp at the transmitter side [2]. A similar effect can be achieved by pre-compensation (under-compensation) of chromatic dispersion along the transmission line. Depending on the amount of under-compensation, the accumulated residual dispersion varies from span to span. The drawback of this approach is the necessity of additional or tuneable dispersion compensation at the end or within the transmission line, if some channel has to be dropped or switched. This can be critical in systems with higher channel bit rates (>10Gbps) because of a reduced dispersion tolerance. A more exotic compensation scheme, are known as compact dispersion compensation or hybrid-compensation where dispersion compensation of the total accumulated system dispersion is realized directly after the transmitter and before the receiver. The advantage of this approach is that the impact of nonlinearities in the transmission line can be significantly suppressed, because the pulses are fully dispersed during propagation. This scheme is less relevant for the practical implementation, because the optical channels cannot be accessed within the transmission line.

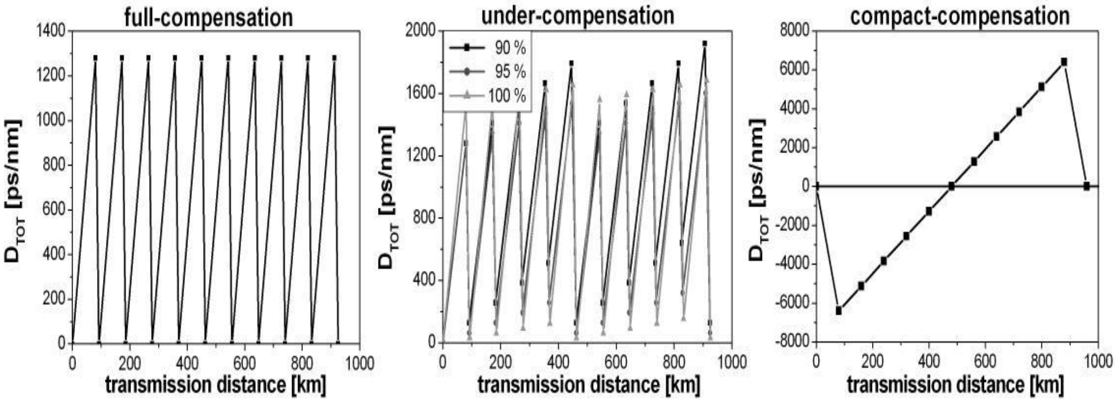

Figure 3.7: Dispersion compensation schemes in multi-span systems [3]

The compensation of onlyβ_2 (chromatic dispersion) alone is insufficient for the compensation of accumulated dispersion in high speed transmission systems, because of the existence of dispersion slope, which results in a wavelength dependent residual dispersion. Theoretically, the complete slope compensation could be realized if the DCF slope (S_{DCF}) can be tailored to:

$$S_{SMF}.L_{SMF} + S_{DCF}.L_{DCF} = 0 \tag{3.3}$$

The fiber nonlinearities like SBS (Stimulated Brillouin Scattering) and SRS (Stimulated Raman Scattering) also put the limitation on the input power up to a threshold value. Because the optical waveguides do not always behave as completely linear channel whose increase in output optical power is directly proportional to the input optical power [3]. The nonlinearities produces the effects which in case of scattering cause disproportionate attenuation, usually at high power levels. This effect causes the optical power from one mode to be transferred in either the forward or backward direction to the same, or other modes, at a different frequency. It depends critically upon the optical power density within the fiber and hence become significant above threshold power levels. It causes the distortion in the information with increase in input power.

CHAPTER 4

PERFORMANCE ANALYSIS OF WDM SYSTEM USING FBG AND DCF AS DISPERSION COMPENSATOR

4.1 Introduction

Recent growth in the capacity offered by optical fiber communication systems has been rapid due to the development of high-speed time division multiplexing (TDM) and wavelength division multiplexing (WDM) techniques. Fiber optics is an almost perfect transmission medium. Optical communication provides a higher bandwidth capacity, lower bit error rates, longer distance between repeaters, better resistance to electromagnetic interference and higher information security in comparison to other modes of communication i.e. copper cable and microwave [4] – [6]. A channel rate of 2.5 gigabit per second (Gb/s) is now widely used, and soon 40Gb/s will be extensively deployed [31]. However, dispersion poses a serious problem in WDM optical communication, thus, limiting either the bit-rate or the transmission distance severely. Dispersion is a phenomenon where the light pulse broadens as it travels along the fiber cable. This broadening of pulse has a destructive effect on sequential pulses. Our analysis is based on the chromatic dispersion which is dominant in the single mode fiber. We believe that the question of how well the DCF and FBG outperform one another is compared in this paper in a practical approach by varying the capacity load of the optical link and also varying the modulation schemes while keeping tab on the received power levels.The most effective and practical strategy for upgrading the already-installed transmission systems is using standard single mode fiber (SMF), the periodical insertion of dispersion compensating fiber (DCF) for suppressing the linear distortion induced by group velocity dispersion (GVD). The signal distortion cannot be fully suppressed because the generation of nonlinear phase modulation, in which induces intensity distortion through GVD is distributed during the propagation [32]. The transmission performance is dependent on the position of the DCF and the zero residual dispersion is not the best choice.

4.2 Simulation Setups

The various simulation setups under consideration are shown in following sections, the first section 4.2.1 is the simulation for FBG as dispersion compensator, the second section 4.2.2 is the simulation for DCF as dispersion compensator. The results of simulations are reported in last section 4.3.

4.2.1 Simulation for FBG as Dispersion Compensator

In order to illustrate how FBG as dispersion compensation can be studied, the system is simulated with block diagram shown in figure 4.1. In this case, the transmitter section consists of data source, electrical driver (NRZ), laser source (CW_ Lorentzian) and amplitude modulator ($\sin^2$_MZ) is connected. Two SOA and one FBG are connected through two SSMF. Here, FBG used as a dispersion compensator. The output of last SOA is given to optical raised cosine filter which is connected to receiver section. In receiver section PIN is connected to an electrical Bessel filter and the final result is shown through electrical scope, Q estimator and bit error rate estimator.

4.2.2 Simulation for DCF as Dispersion Compensator

In order to illustrate how DCF as dispersion compensation can be studied, the system is simulated with block diagram shown in figure 4.2. In this case, the transmitter section consists of data source, electrical driver (NRZ), laser source (CW_ Lorentzian) and amplitude modulator ($\sin^2$_MZ) is connected. Three SOA are connected to SSMF and DCF .Here, DCF is used as a dispersion compensator. The output of last SOA is given to optical raised cosine filter which is connected to receiver section. In receiver section PIN is connected to an electrical Bessel filter and the final result is shown through electrical scope, Q estimator and bit error rate estimator.

4.3 Results for Simulations

4.3.1 Results and Discussions Regarding Simulation for FBG as Dispersion Compensator Based on Length of 100 km

The simulation results from different simulation systems are predicted. The results of simulation setup in figures 4.3 to 4.7 shows the electrical spectrum of 100 km on different length of 20, 40, 60, 80, 100 km

Eye Diagrams for Different Length

The results of eye diagrams are shown in figures 4.8 to 4.12 for different length. Eye opening decreases and eye closure increases with increase the length of SSMF i.e. eye opening penalty increases as the length of single mode fiber increases. The best result is observed with 20 km length of single mode fiber.

Result Based on Q Estimator for Different Lengths

Figure 4.13 shows the result of Q value on 20, 40, 60, 80, 100, km length of fiber which is 19 dB at 20 km and 12 dB at 100 km.

Figure 4.14 shows the result of eye opening on 20, 40, 60, 80, 100, km length of fiber which is 0.83136E-03 at 20 km and 0.15375E- 04 at 100 km.

Figure 4.15 shows the result of equivalent Q at mean threshold on 20, 40, 60, 80, 100, km length of fiber which is 15.84 dB at 20 km and 11.75 dB at 100 km.

Figure 4.16 shows the result of equivalent Q at optimal threshold on 20, 40, 60, 80, 100, km length of fiber which is 0.31431E-03 dB at 20 km and 0.23477E-04 dB at 100 km.

Result Based on Bit Error Rate Estimator for Different Lengths

Figure 4.17 shows the result of eye closure on 20, 40, 60, 80, 100, km length of fiber which is 1.20 dB at 20 km and 3.82 dB at 100 km.

Figure 4.18 shows the result of Average eye opening on 20, 40, 60, 80, 100, km length of fiber which is 0.10011E-03 at 20 km, and 0.37128E-04 at 100 km.

Figure 4.19 shows the result of BER at optimal threshold on20, 40, 60, 80, 100, km length of fiber which is 0.74619E-18 at 20 km and 0.24546E-04 at 100 km.

Figure 4.20 shows the result of BER at mean threshold on 20, 40, 60, 80, 100, km length of fiber which is 0.28215E-09 at 20 km and 0.54516E-04 at 100 km.

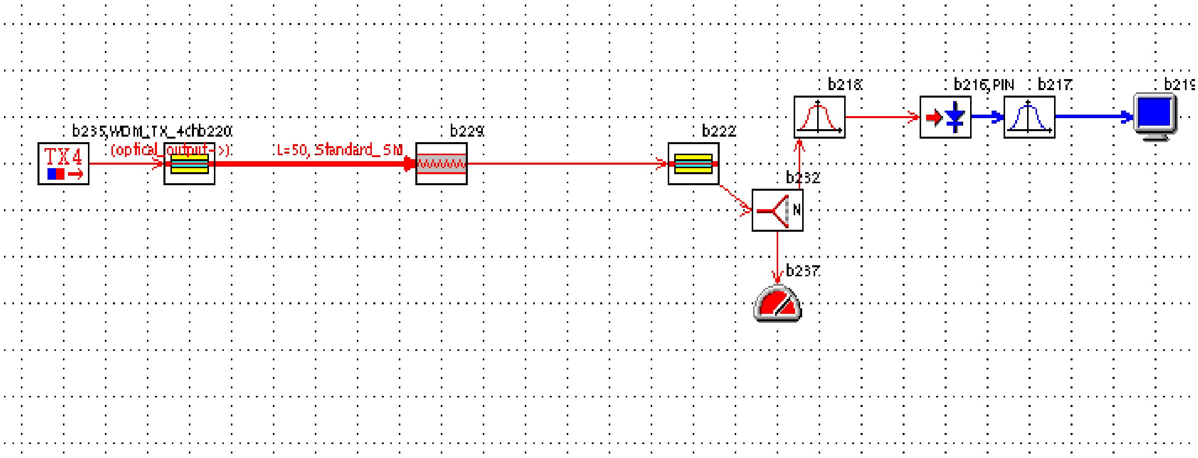

Figure 4.1: FBG as dispersion compensator

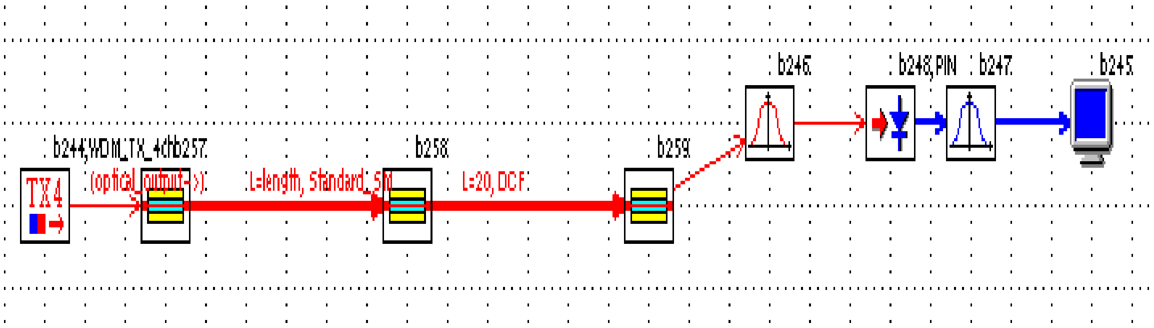

Figure 4.2: DCF as dispersion compensator

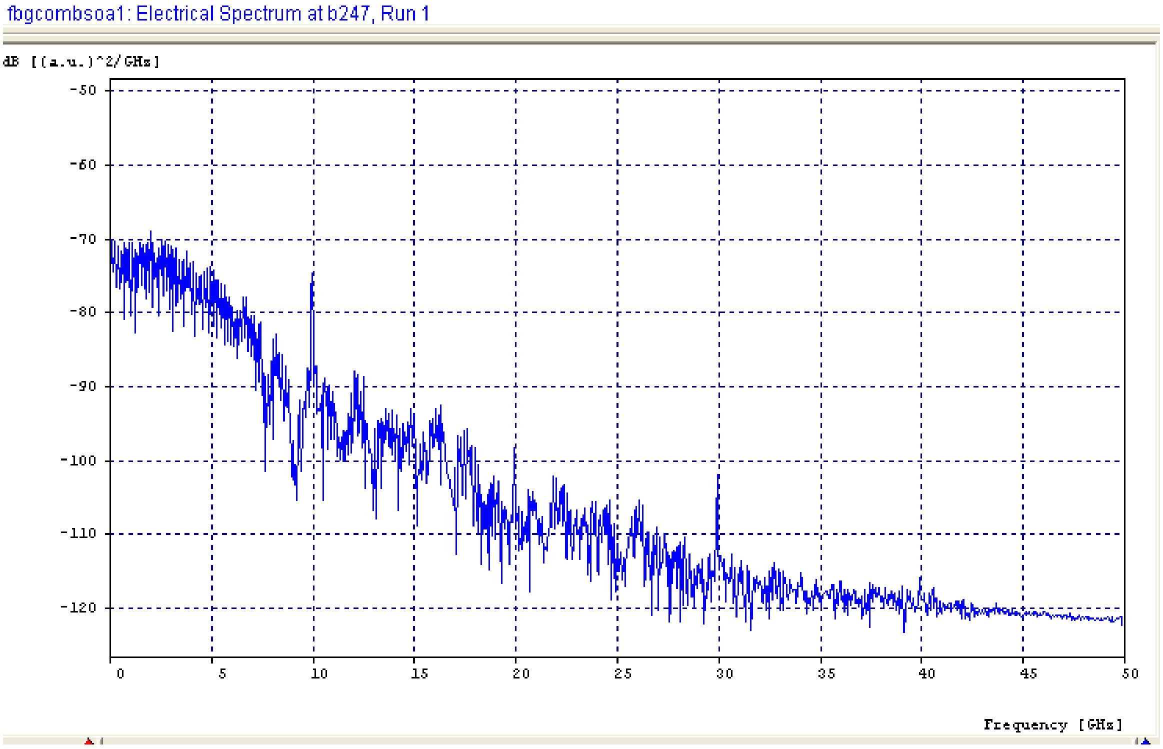

Figure 4.3: Electrical spectrum

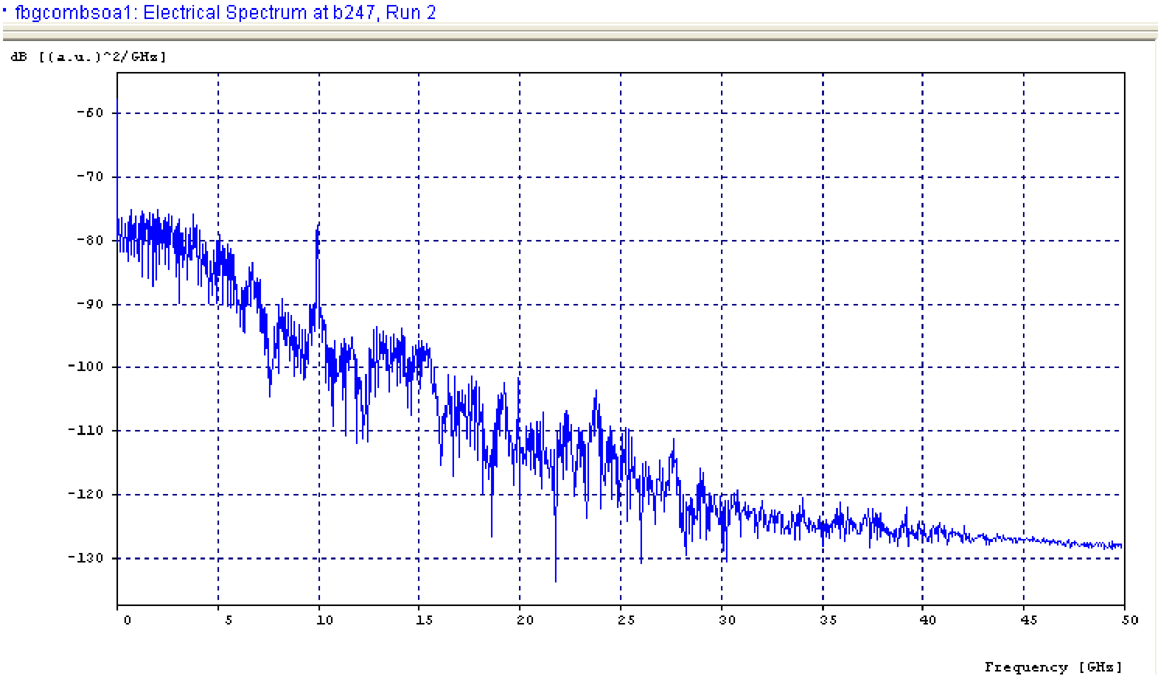

Figure 4.4: Electrical spectrum

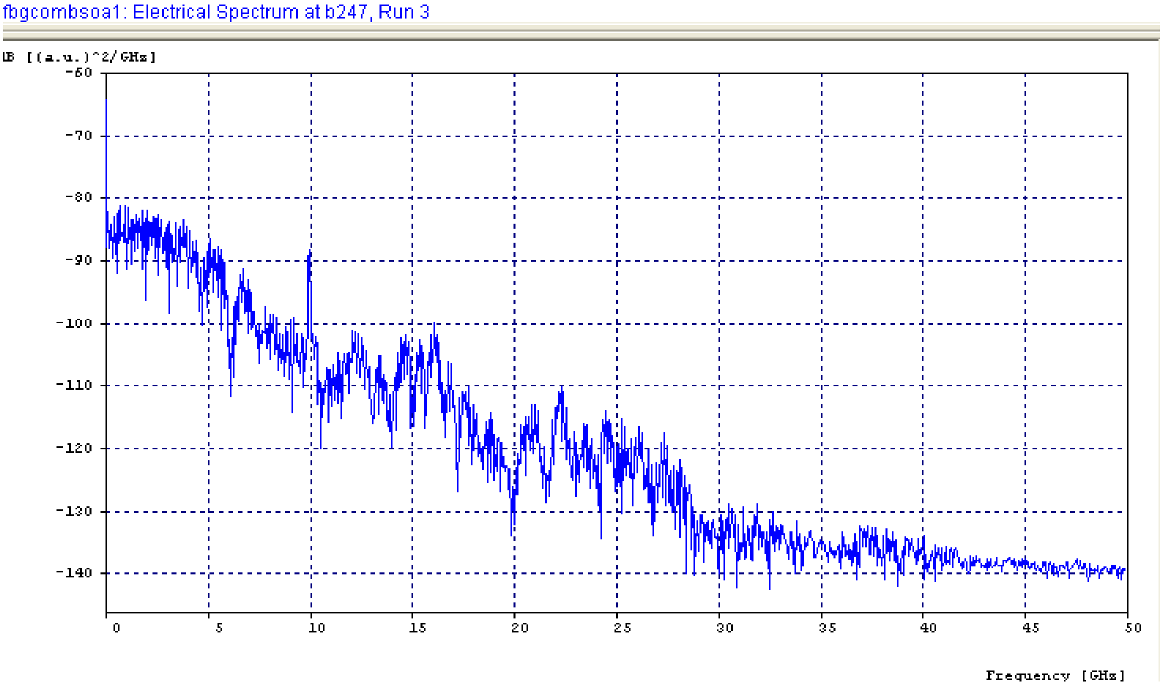

Figure 4.5: Electrical spectrum

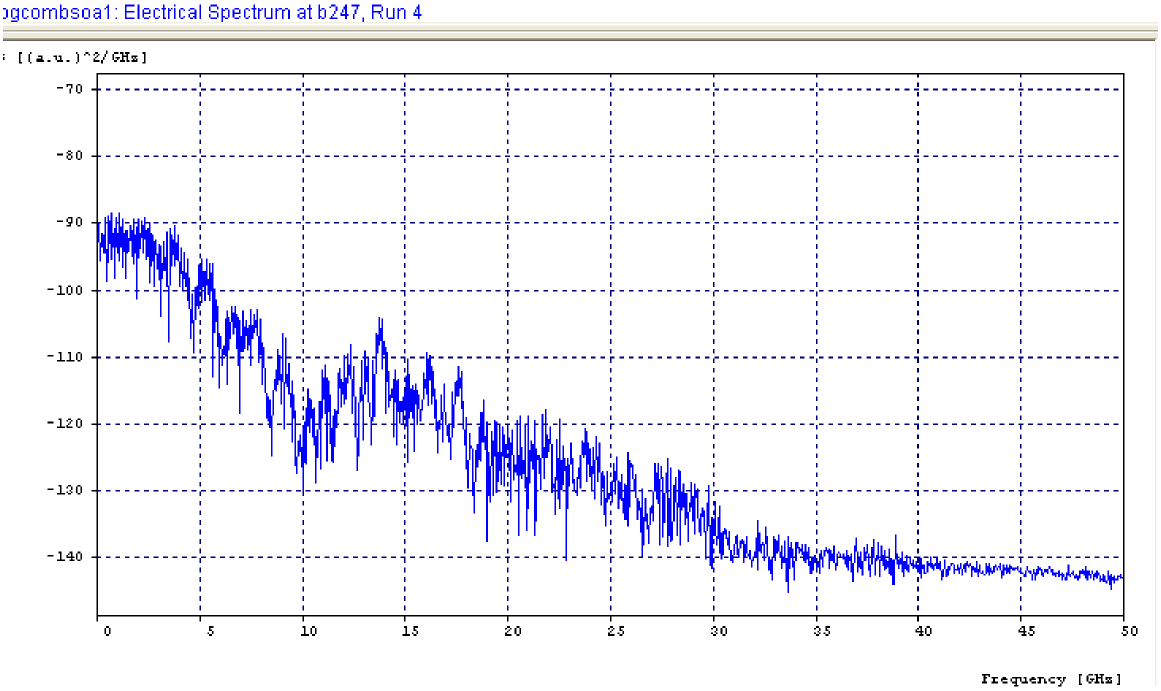

Figure 4.6: Electrical spectrum

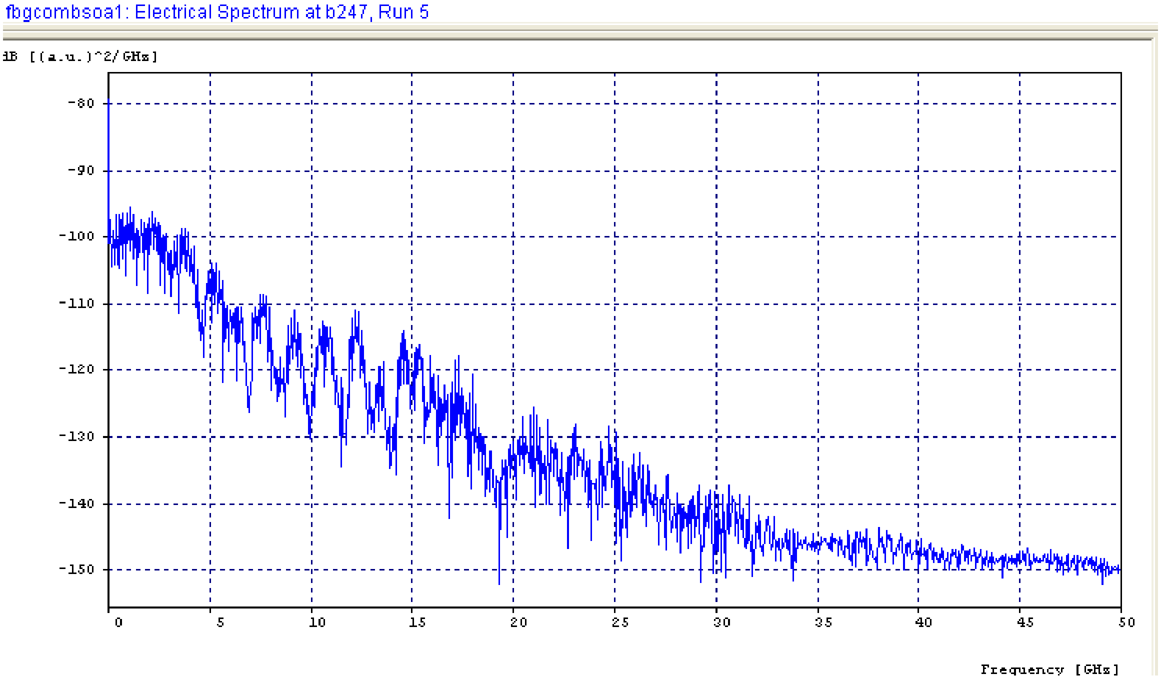

Figure 4.7: Electrical spectrum

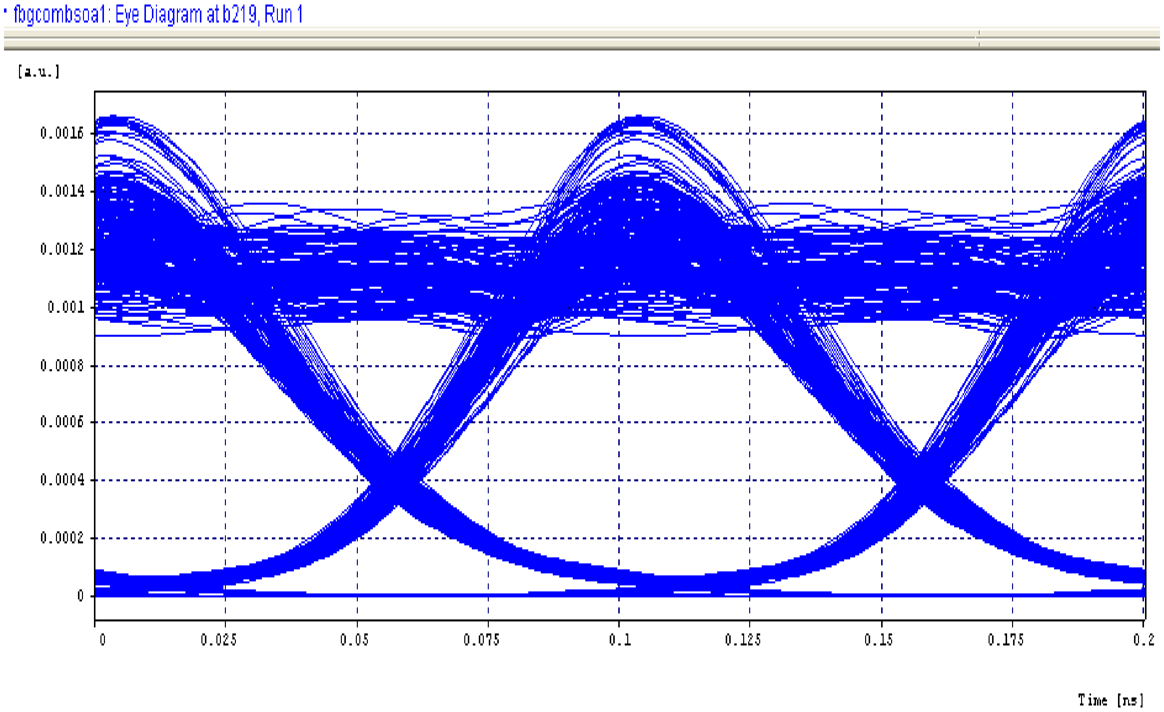

Figure 4.8: Eye diagram at 20 km length

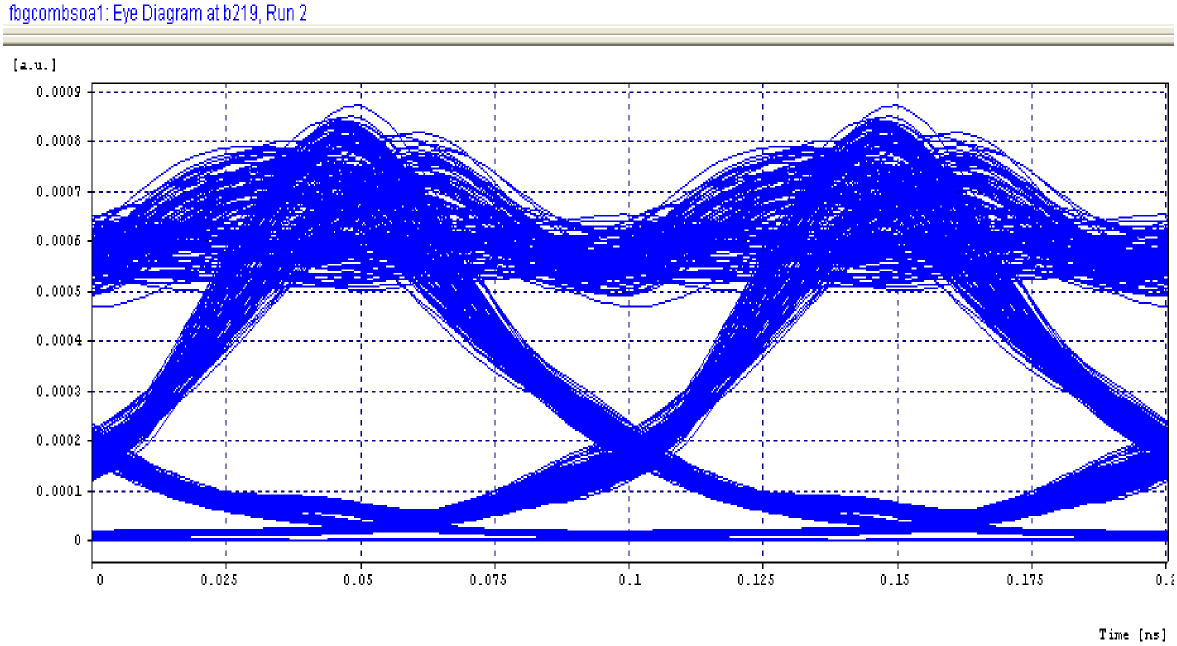

Figure 4.9: Eye diagram at 40 km length

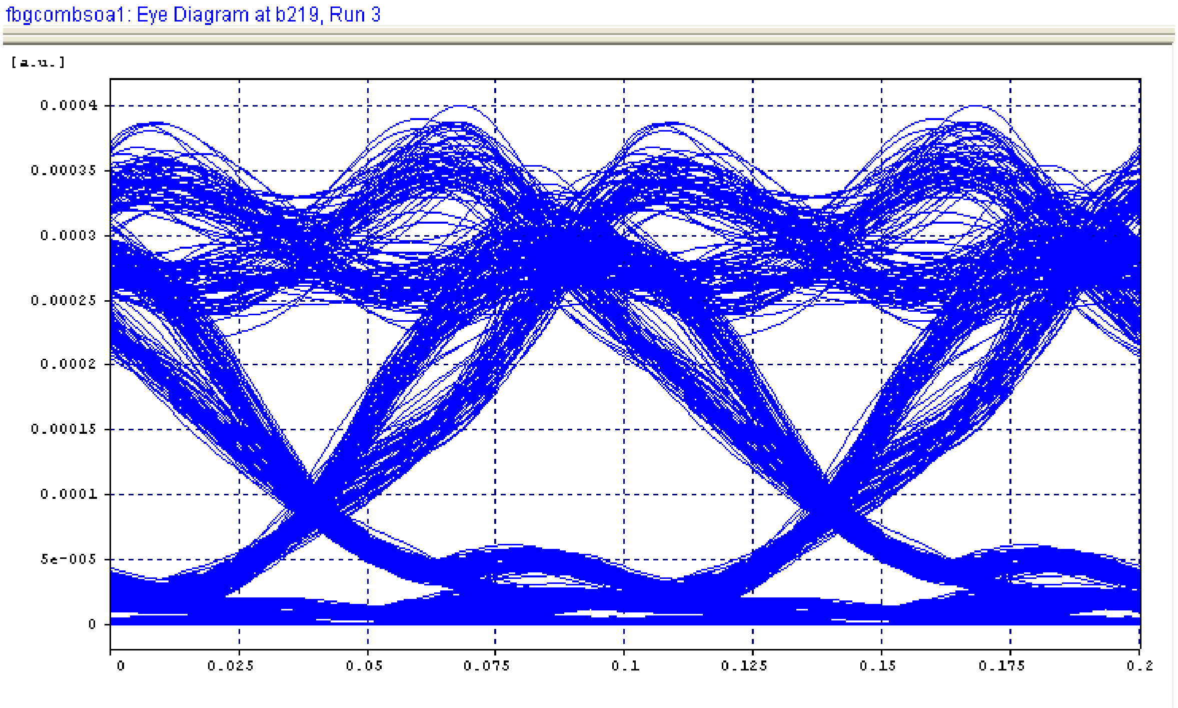

Figure 4.10: Eye diagram at 60 km length

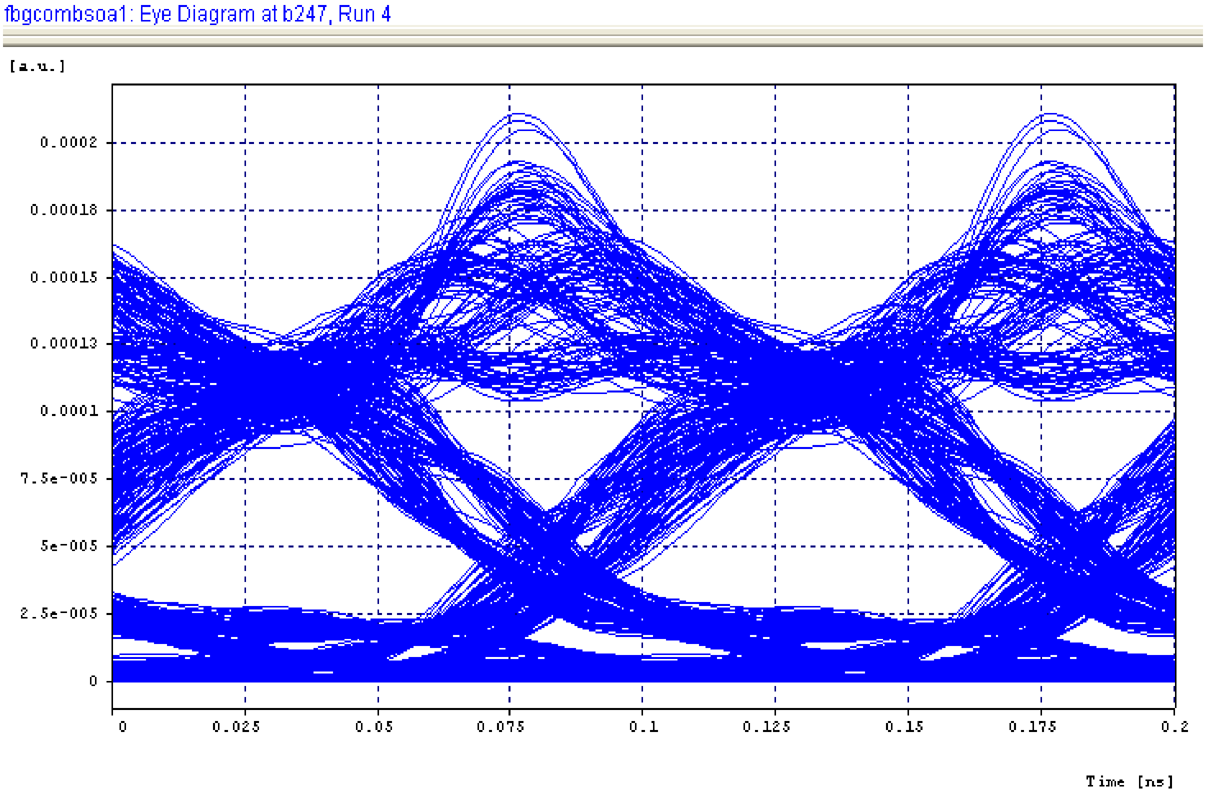

Figure 4.11: Eye diagram at 80 km length

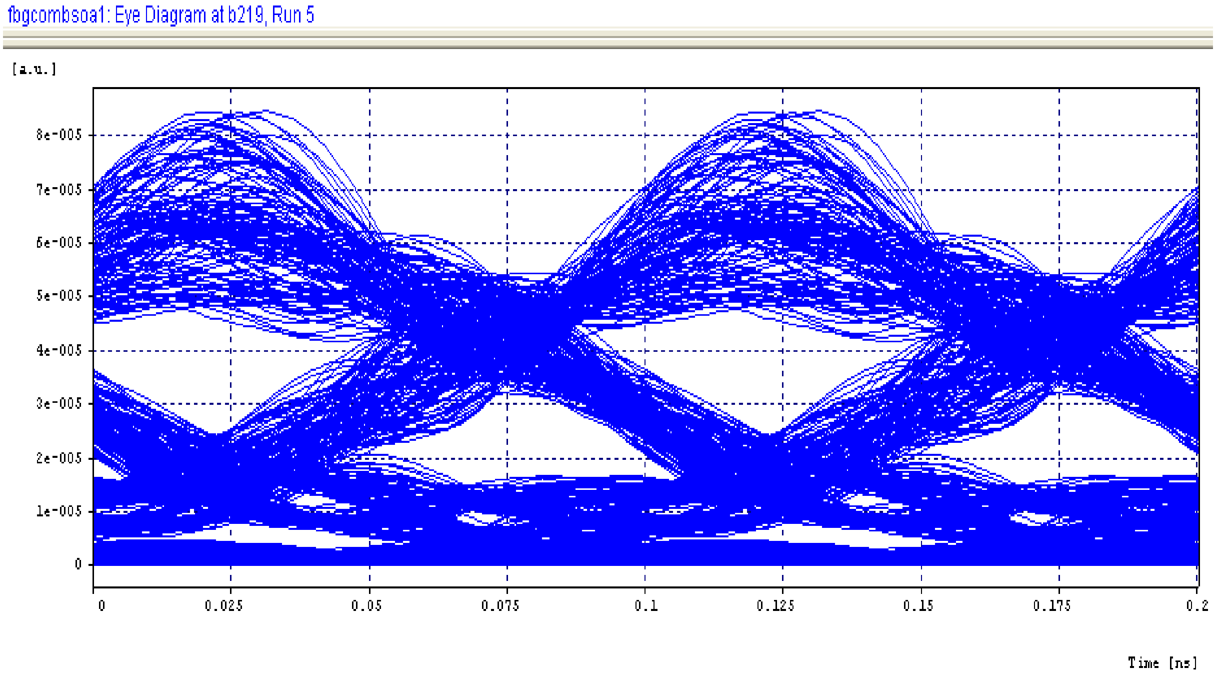

Figure 4.12: Eye diagram at 100 km length

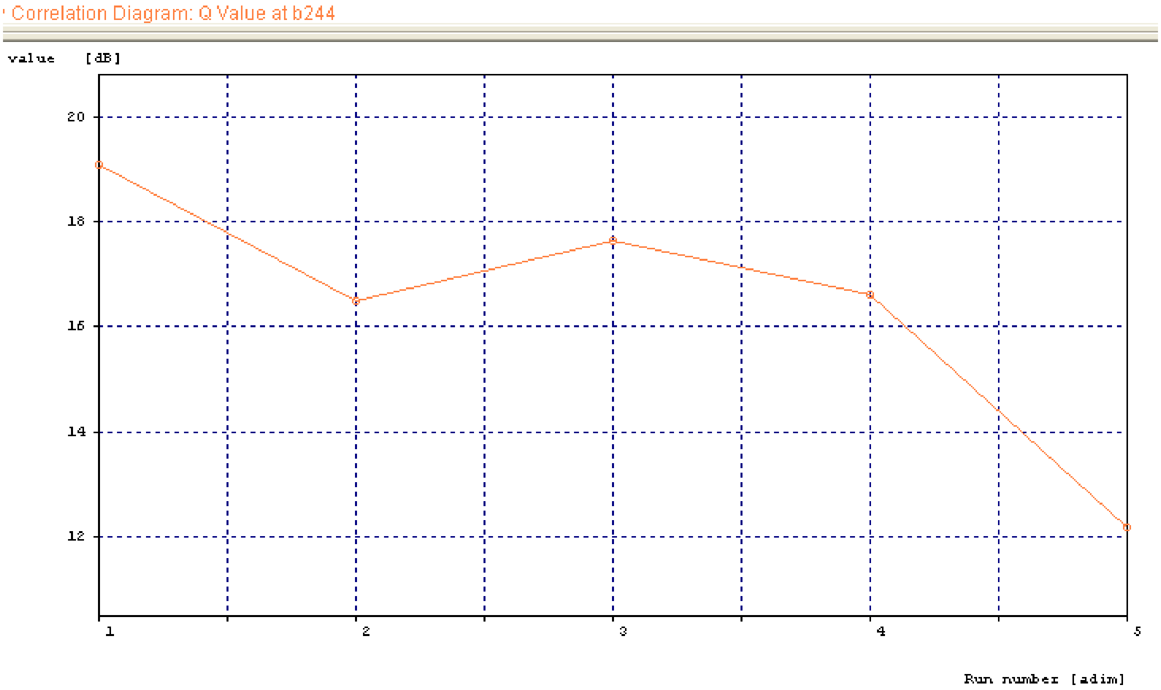

Figure 4.13: Q value

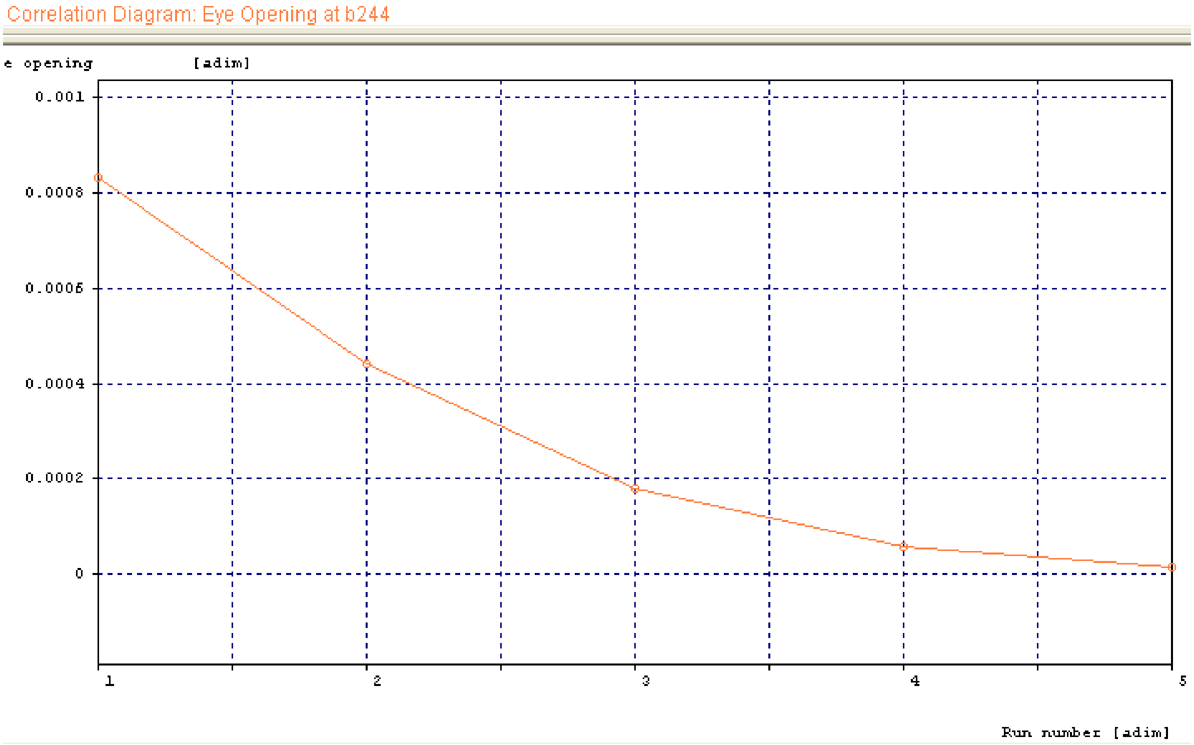

Figure 4.14: Eye opening

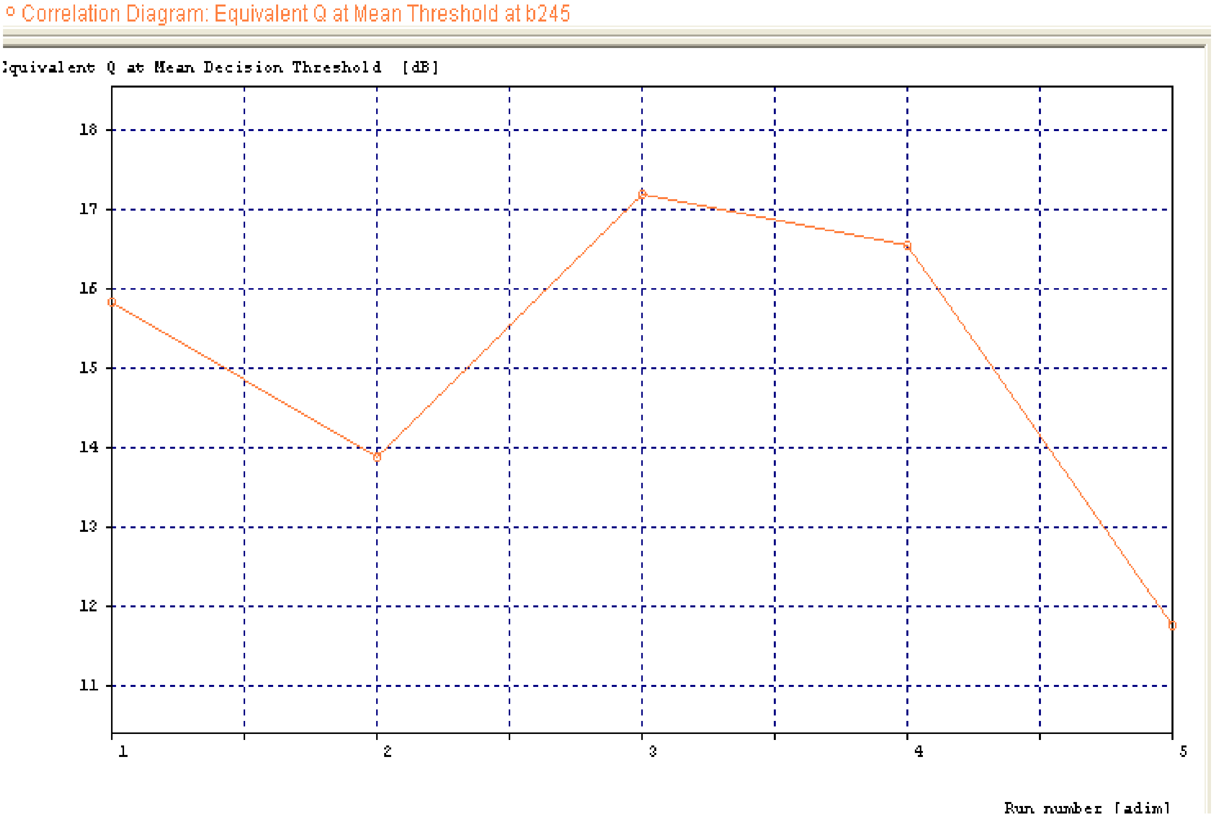

Figure 4.15: Equivalent Q at mean threshold

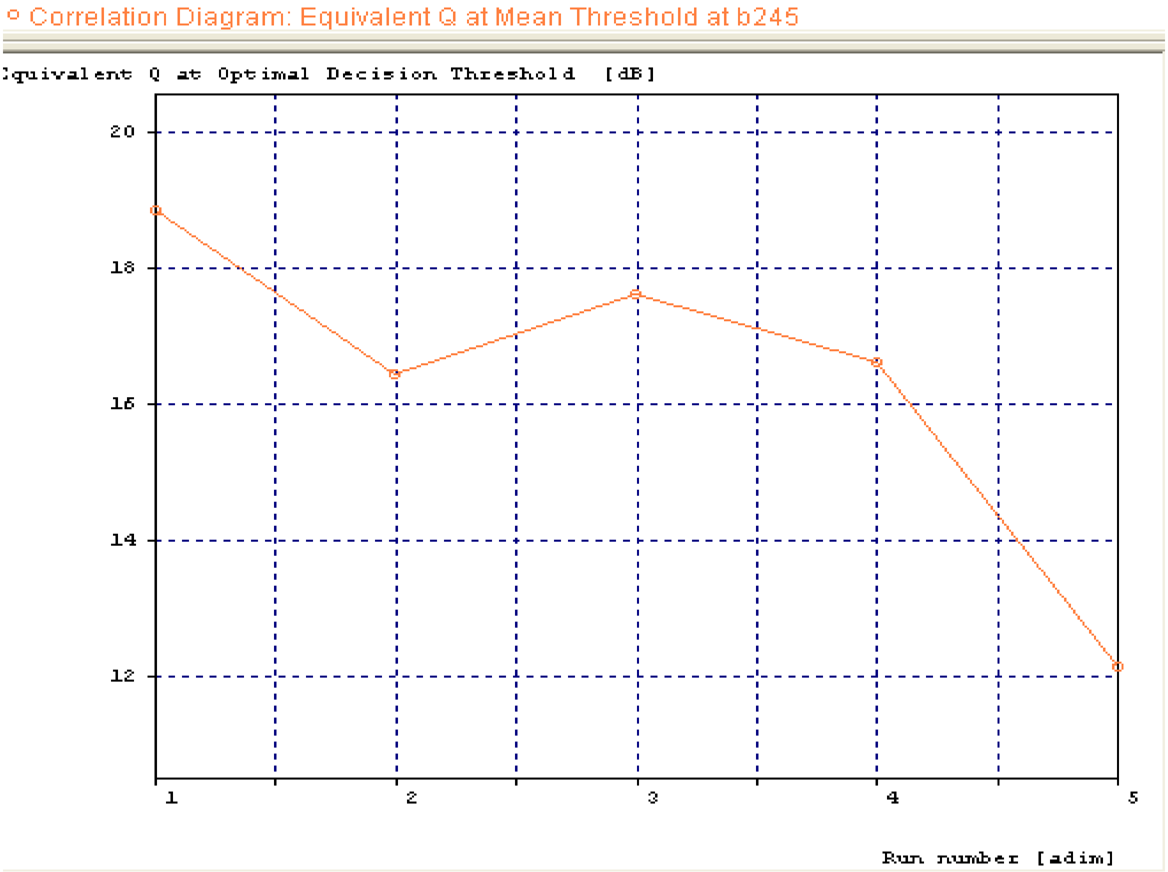

Figure 4.16: Equivalent Q at optimal threshold

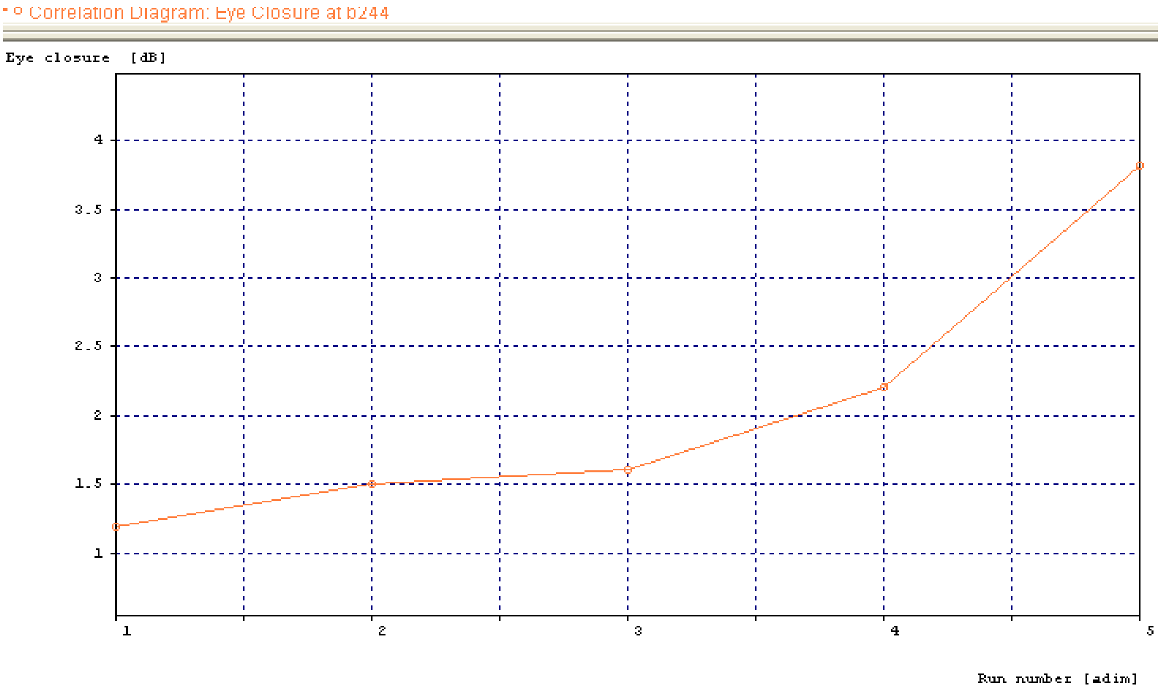

Figure 4.17: Eye closure

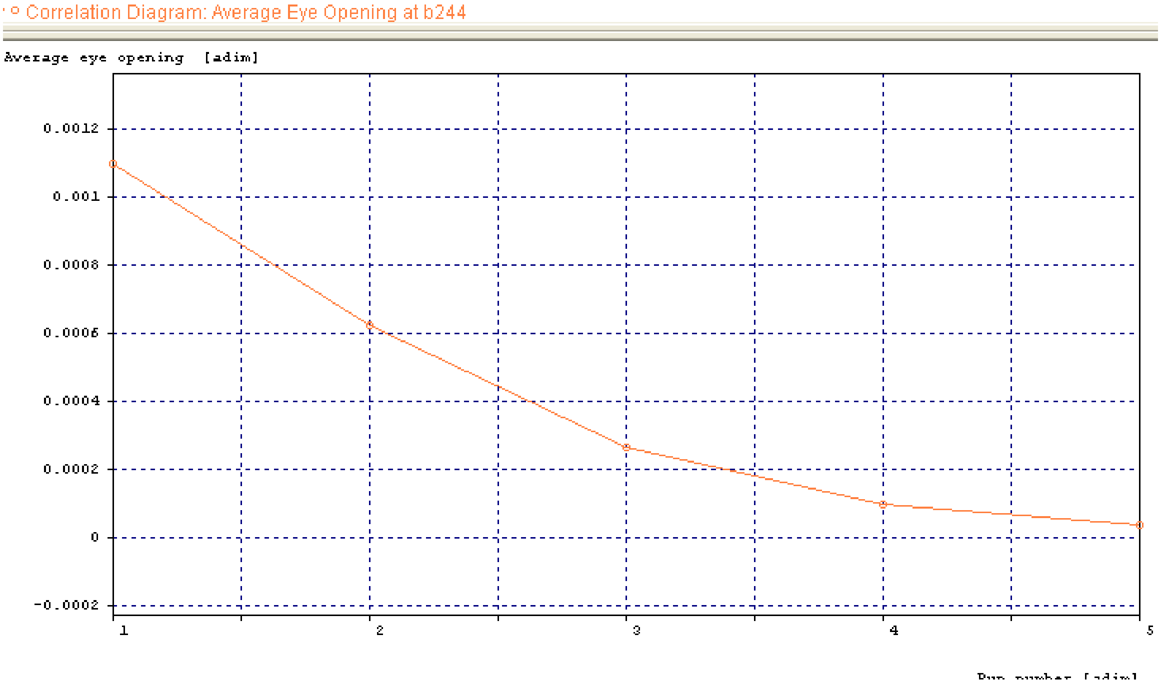

Figure 4.18: Average eye opening

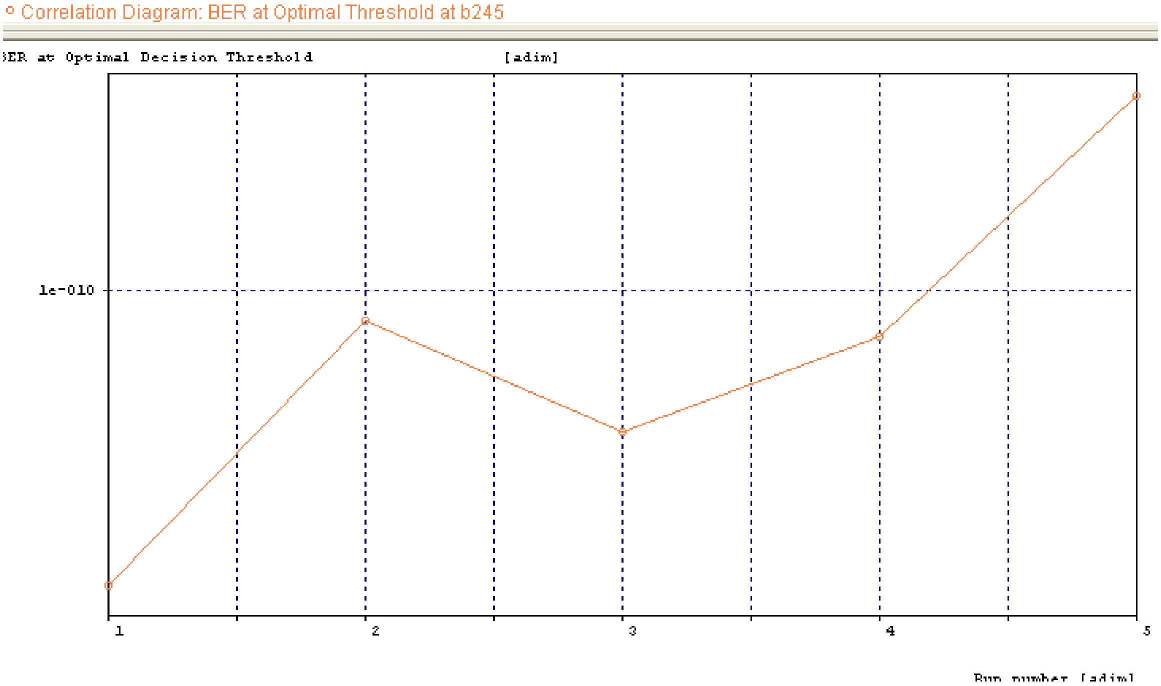

Figure 4.19: BER at optimal threshold

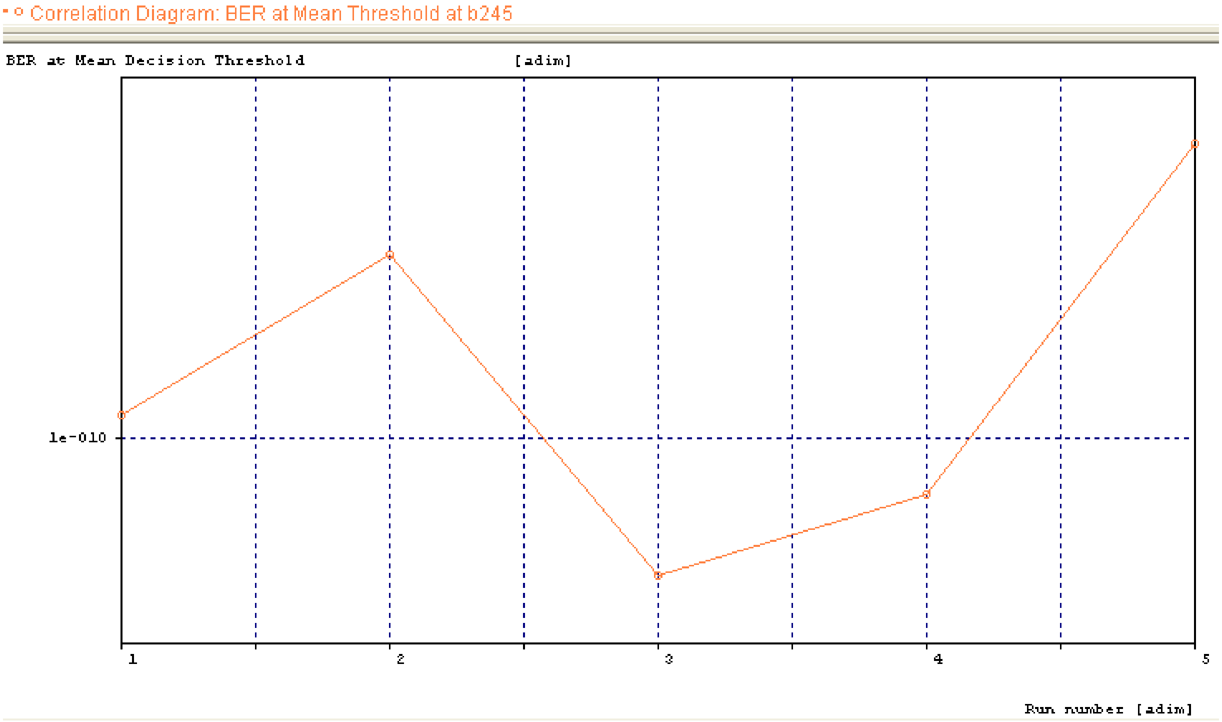

Figure 4.20: BER at mean threshold

4.3.2 Results and discussions regarding simulation for DCF as dispersion compensator based on length of 100 km

The simulation results from different simulation systems are predicted. The results of simulation setup are shown in figure 4.21 is electrical spectrum and figure 4.24 is eye diagram.

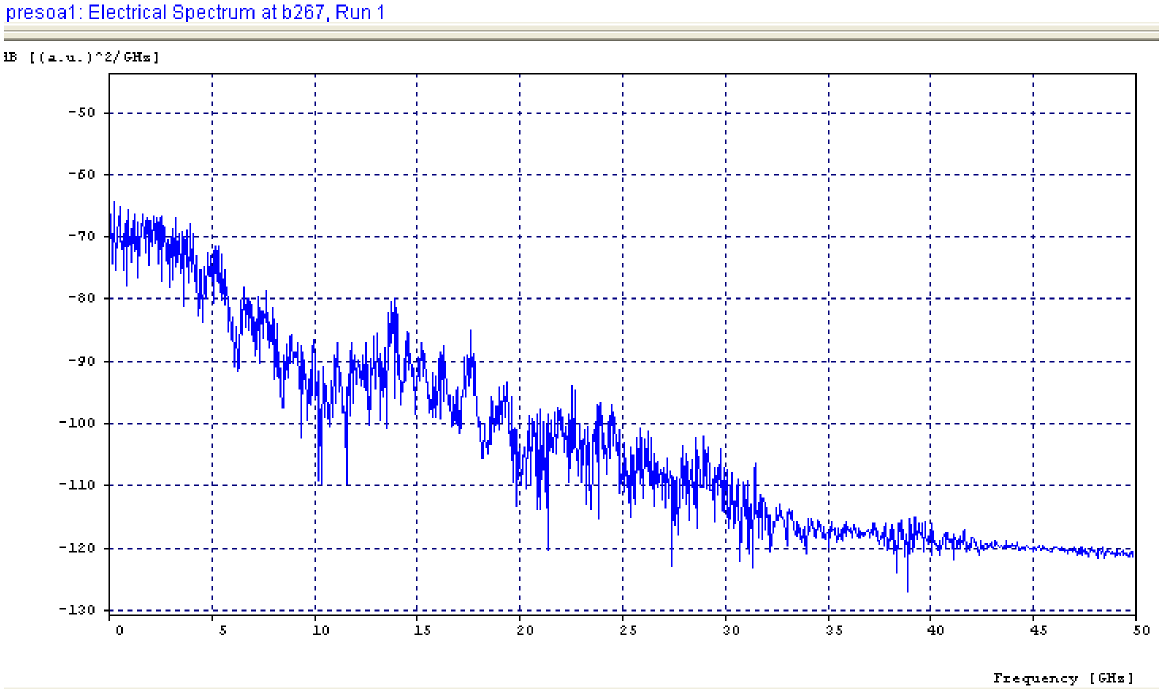

Figure 4.21: Electrical spectrum

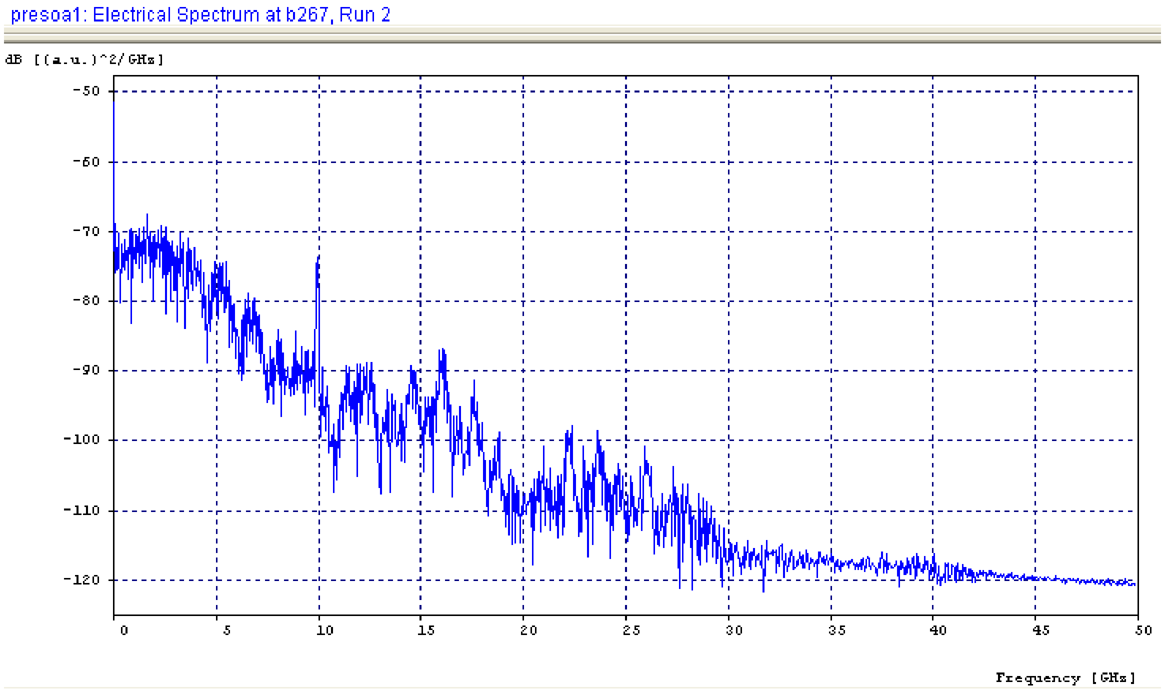

Figure 4.22: Electrical spectrum

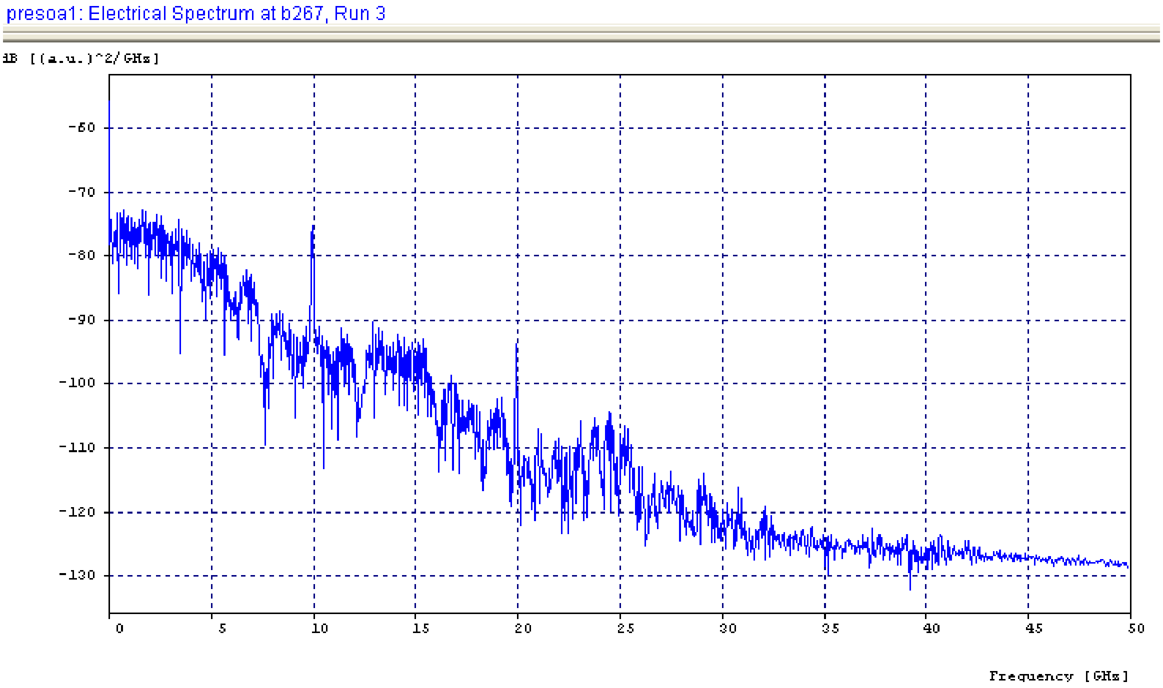

Figure 4.23: Electrical spectrum

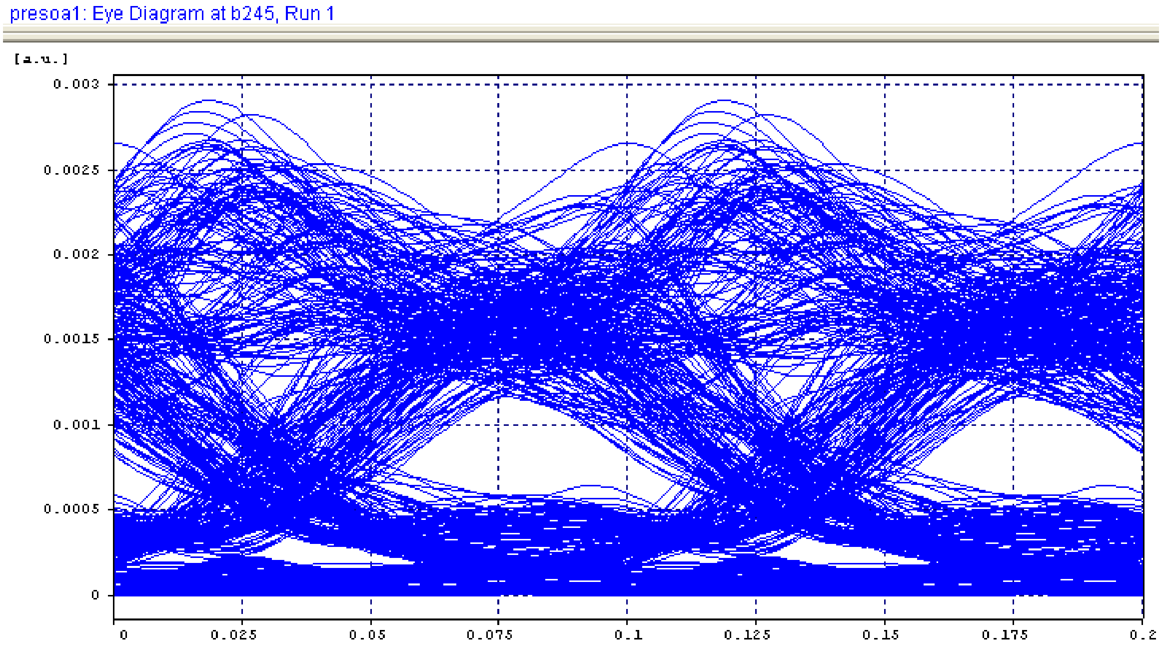

Figure 4.24: Eye diagram at 20 km length

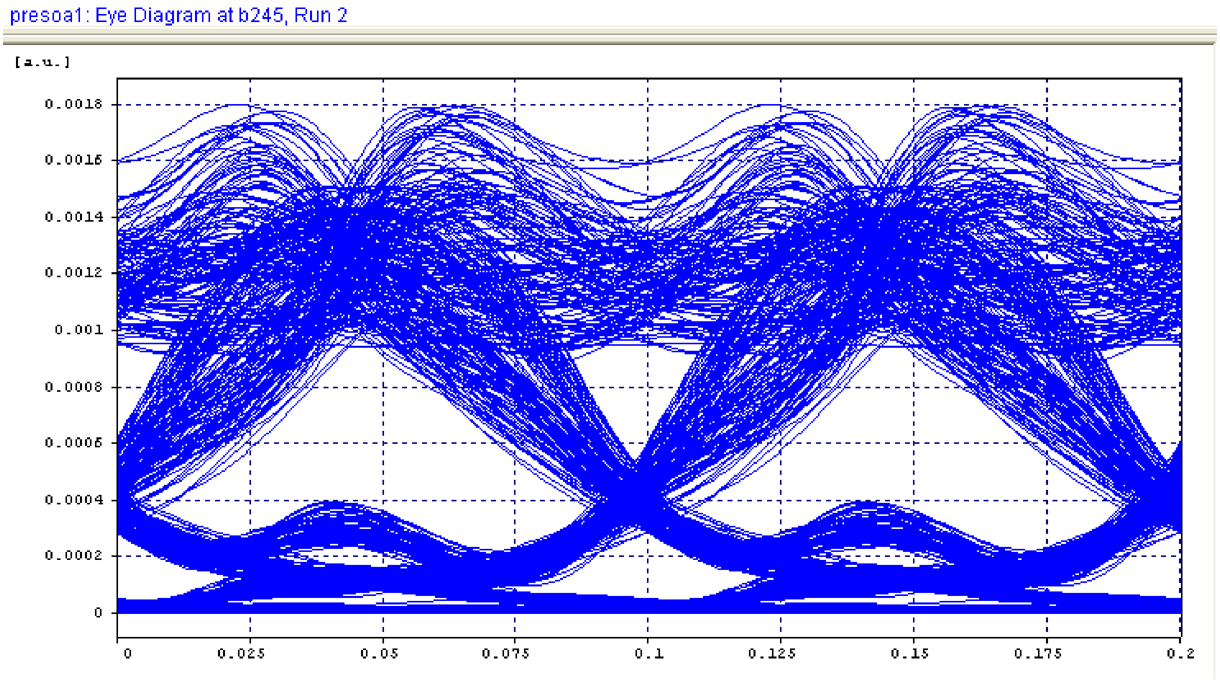

Figure 4.25: Eye diagram at 40 km length

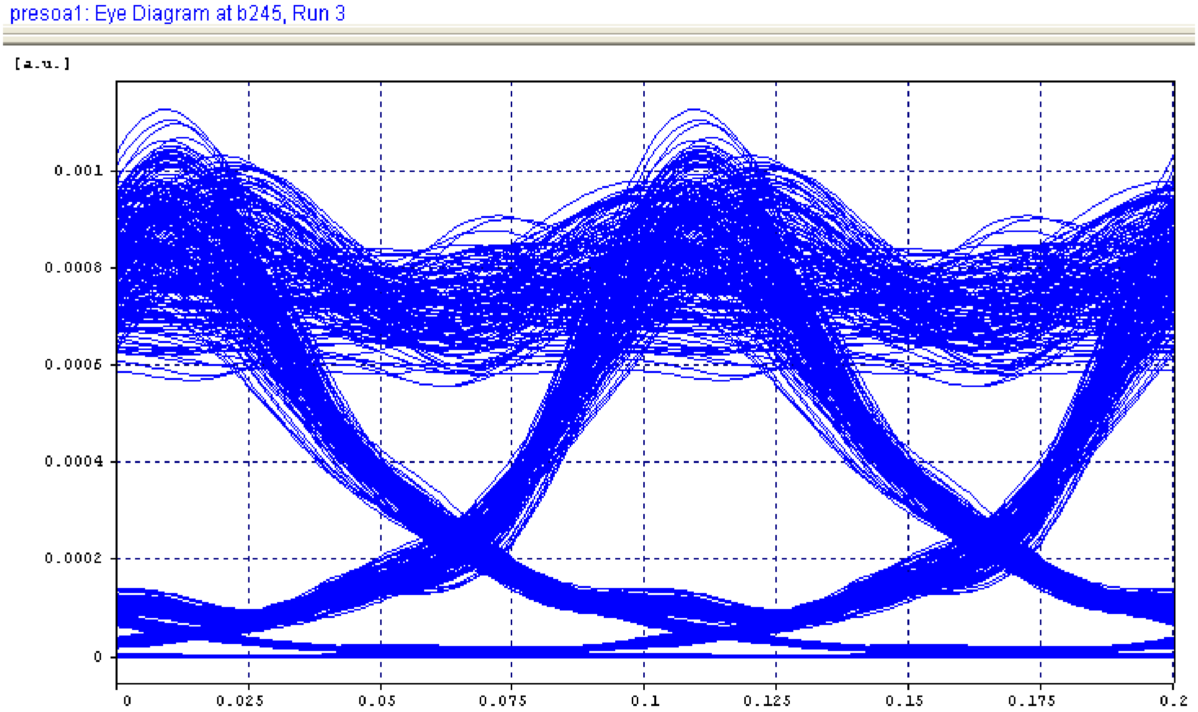

Figure 4.26: Eye diagram at 60 km length

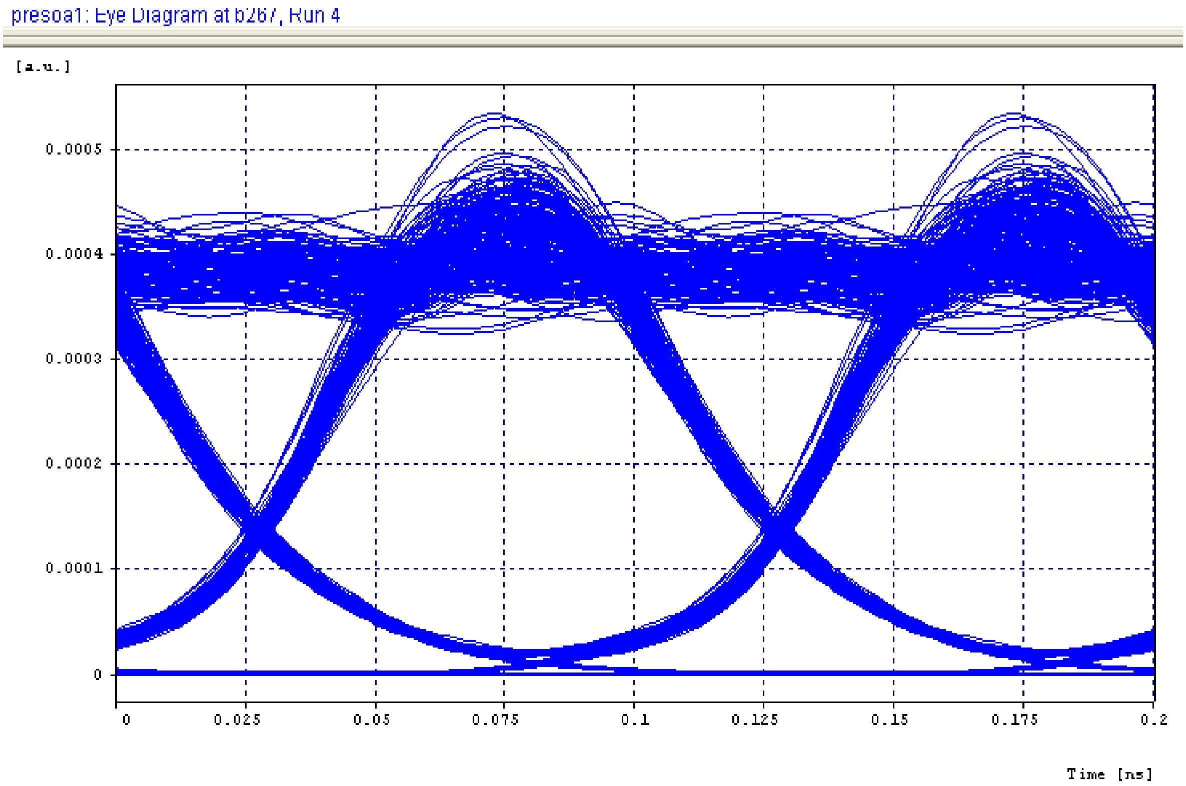

Figure 4.27: Eye diagram at 80 km length

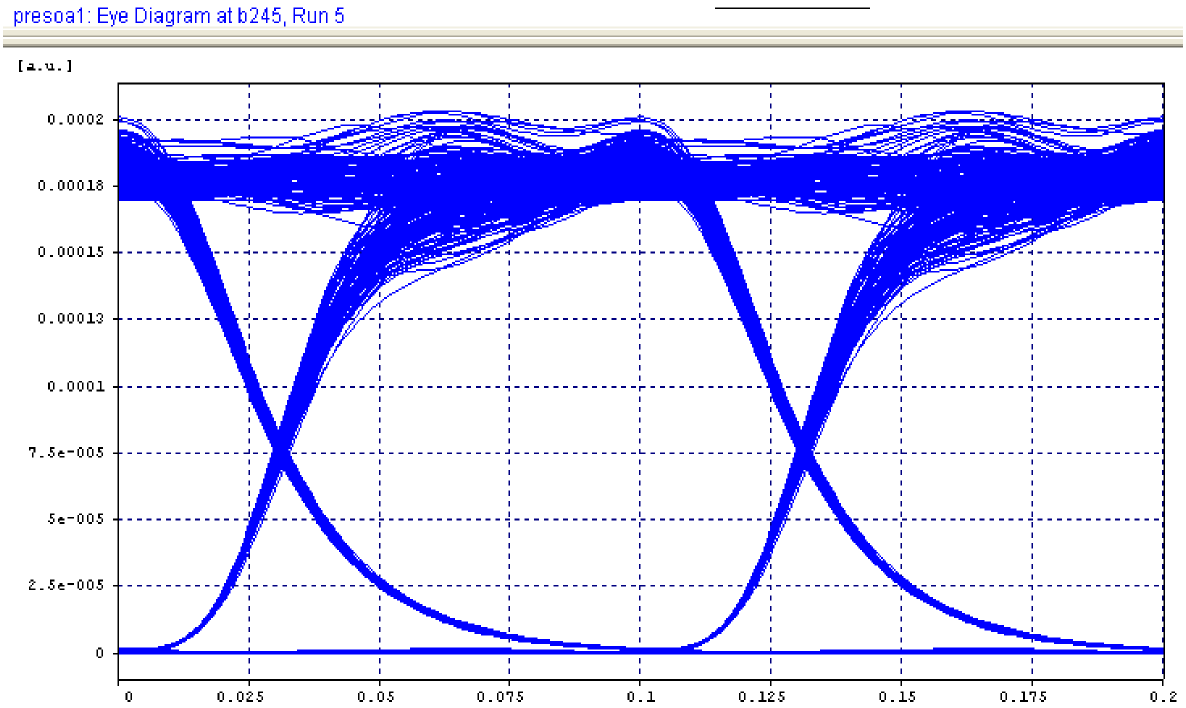

Figure 4.28: Eye diagram at 100 km length

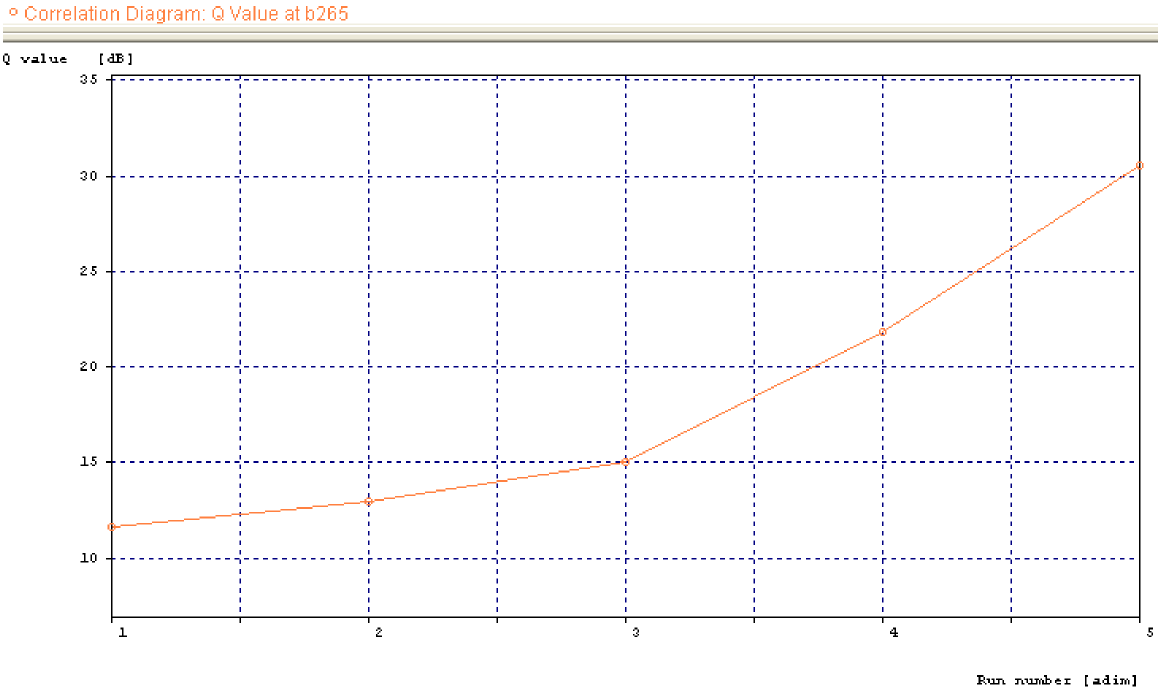

Figure 4.29: Q value

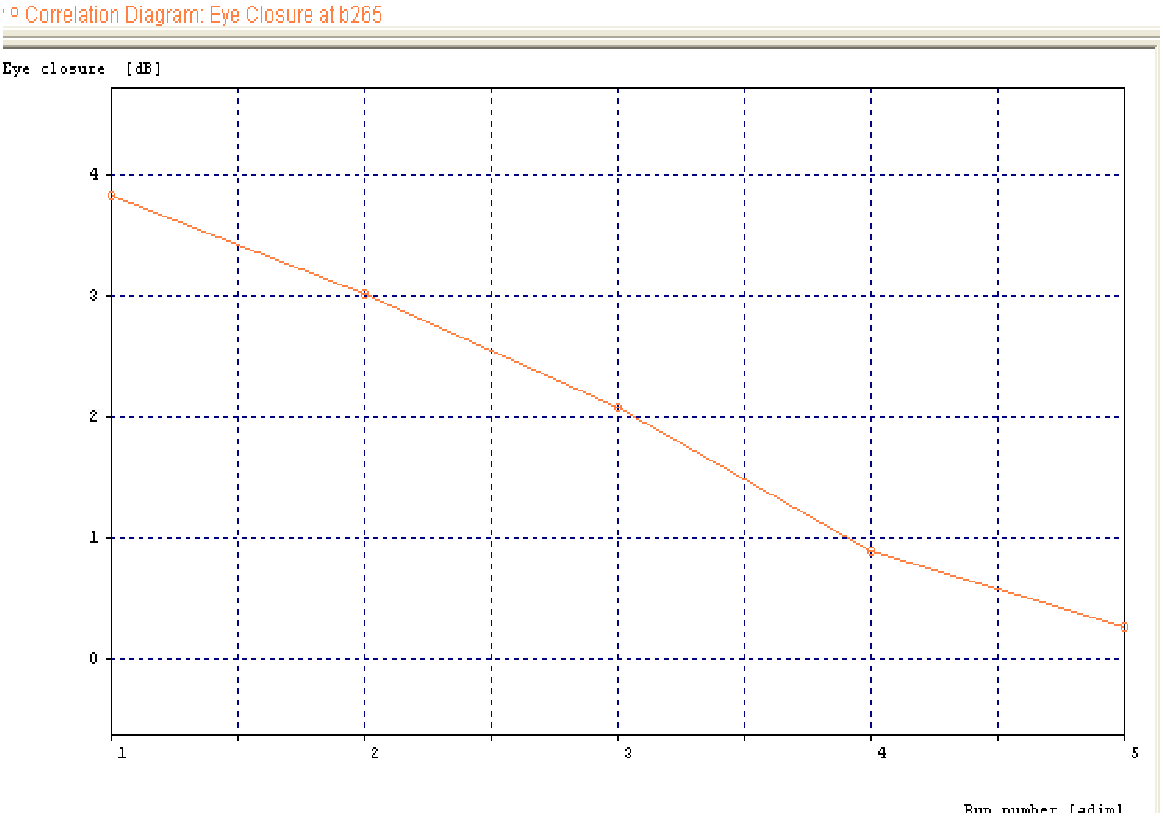

Figure 4.30: Eye closure

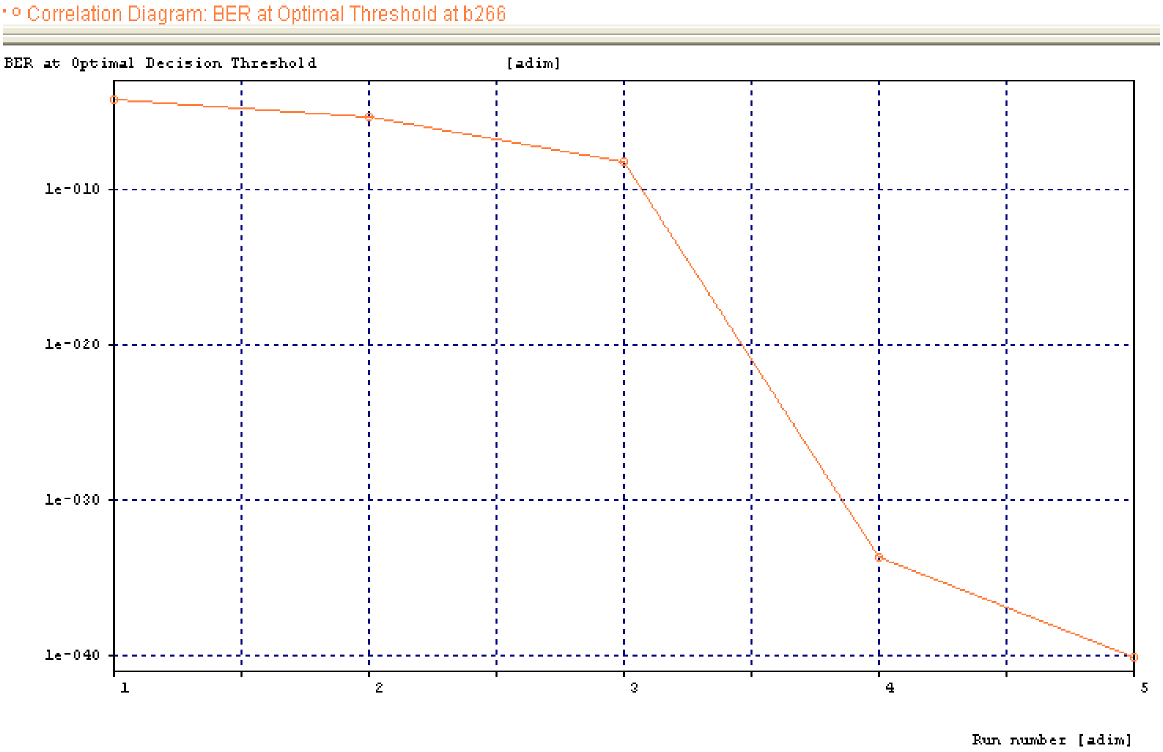

Figure 4.31: BER at optimal threshold

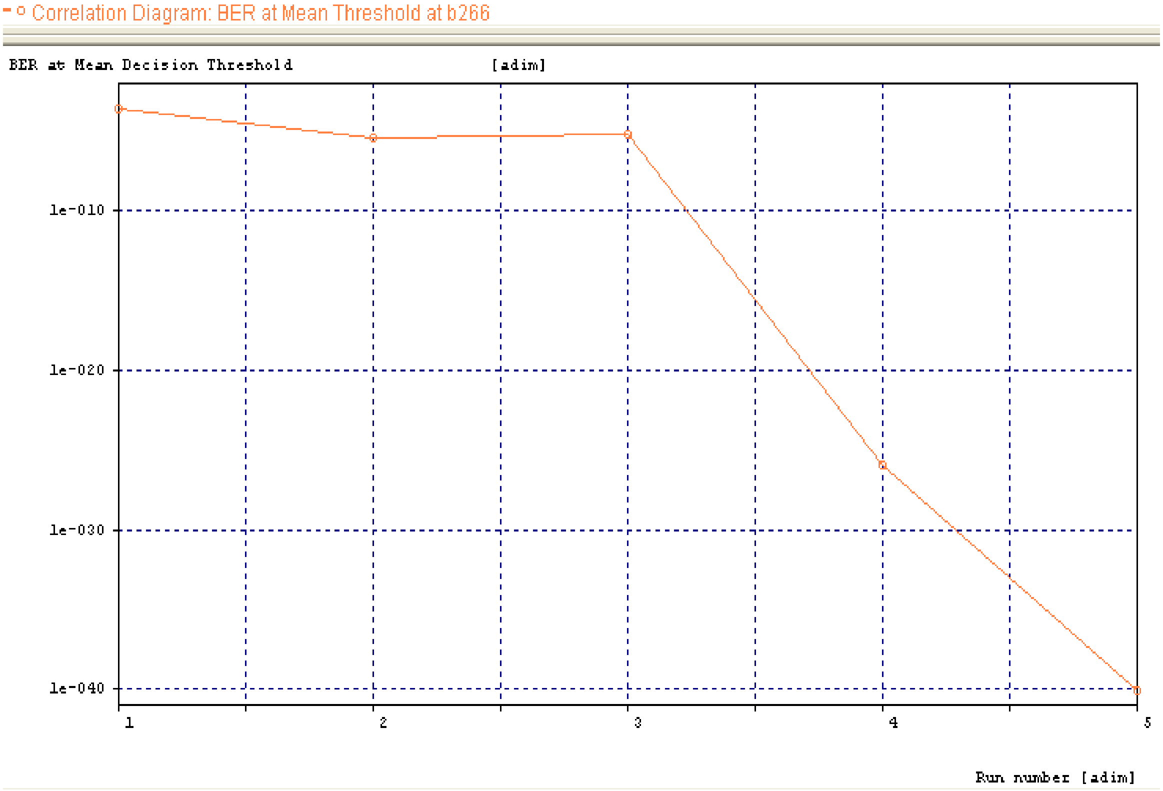

Figure 4.32: BER at mean threshold

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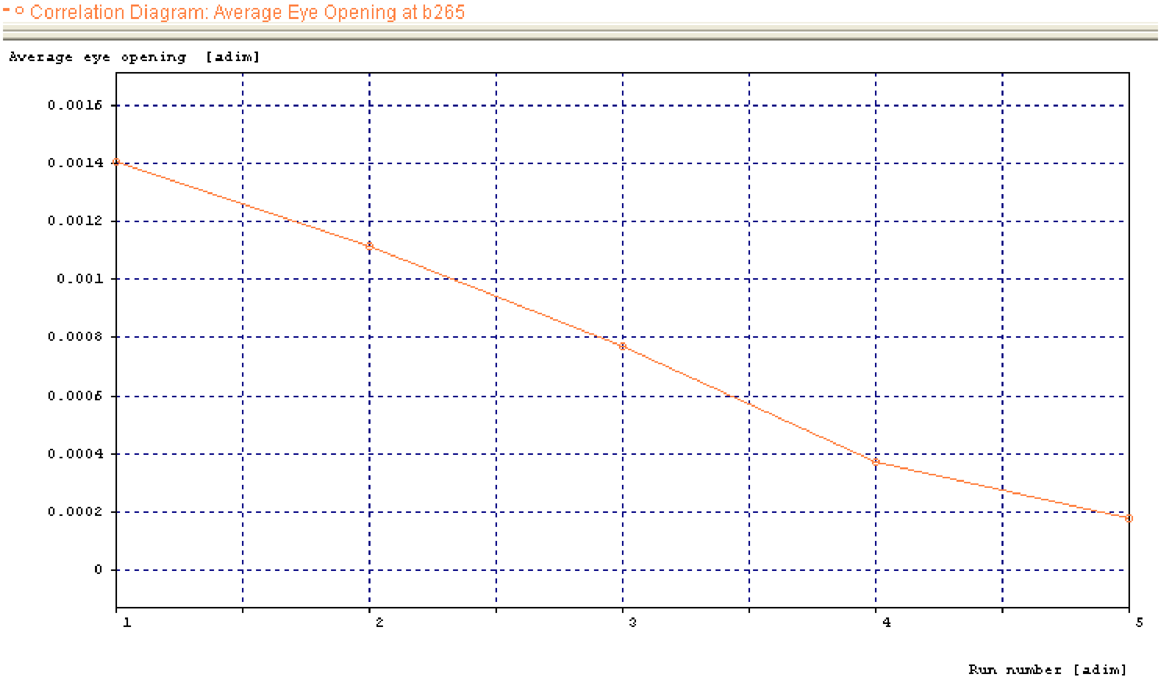

Figure 4.33: Average eye opening

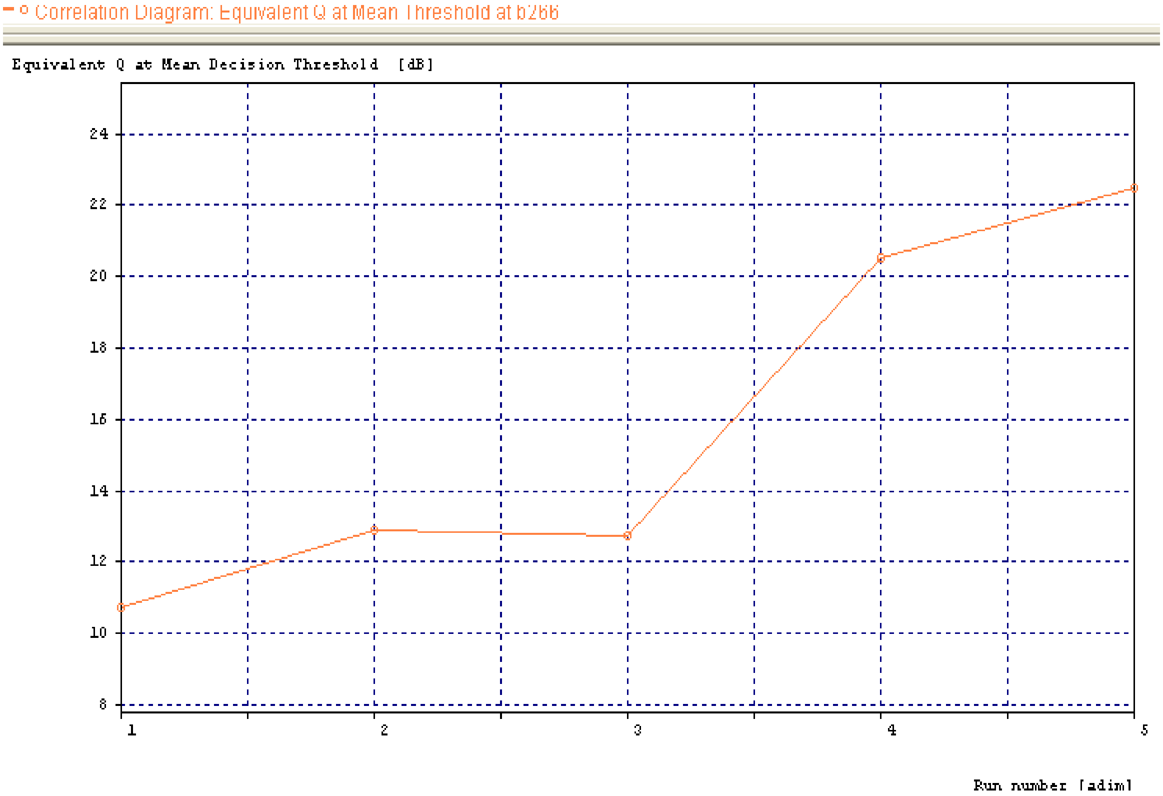

Figure 4.34: Equivalent Q at mean threshold

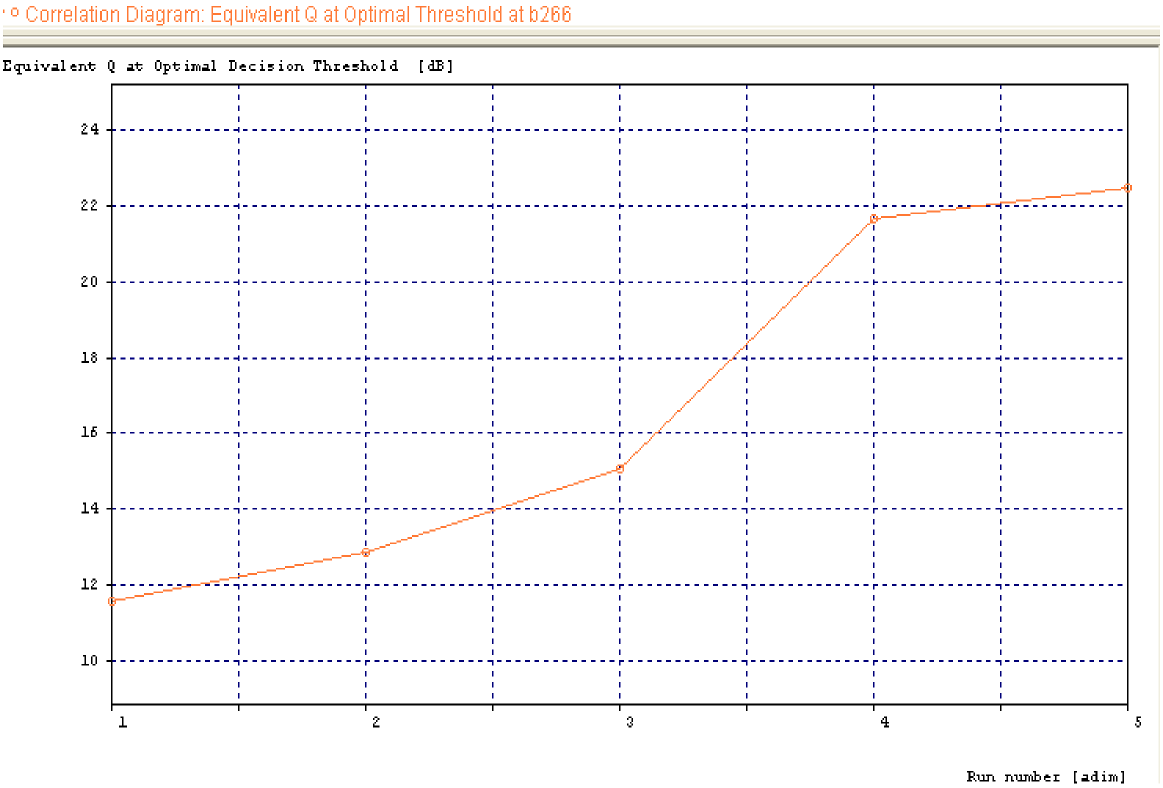

Figure 4.35: Equivalent Q at optimal threshold

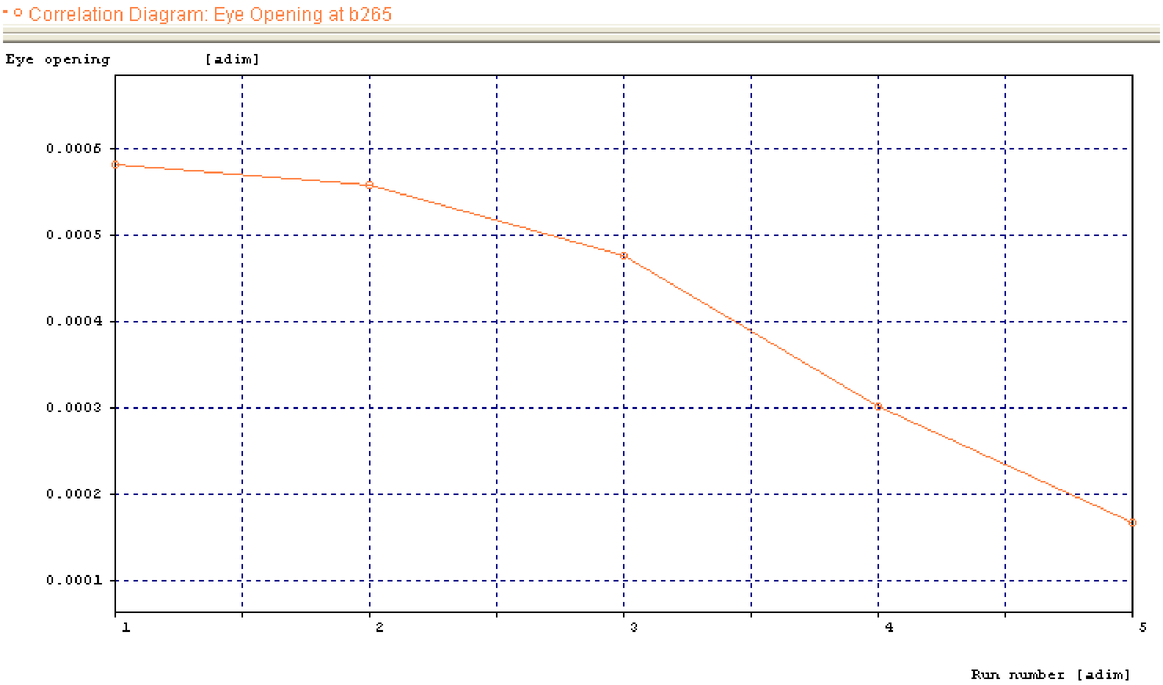

Figure 4.36: Eye opening

CHAPTER 5

DIFFERENT MODULATION TECHNIQUE

The optical signal used for the optical communication network can be generated with different modulation techniques. There are four basic physical attributes that can be modulated to optically transmit information: intensity, phase, frequency, and polarization. The electrical signal is modulated by the carrier signal. Depending on depending on which parameter of signal is modulated, the modulation techniques can be divided into amplitude shift keying (ASK), frequency shift keying (FSK), phase shift keying (PSK) and polarization shift keying (PolSK)

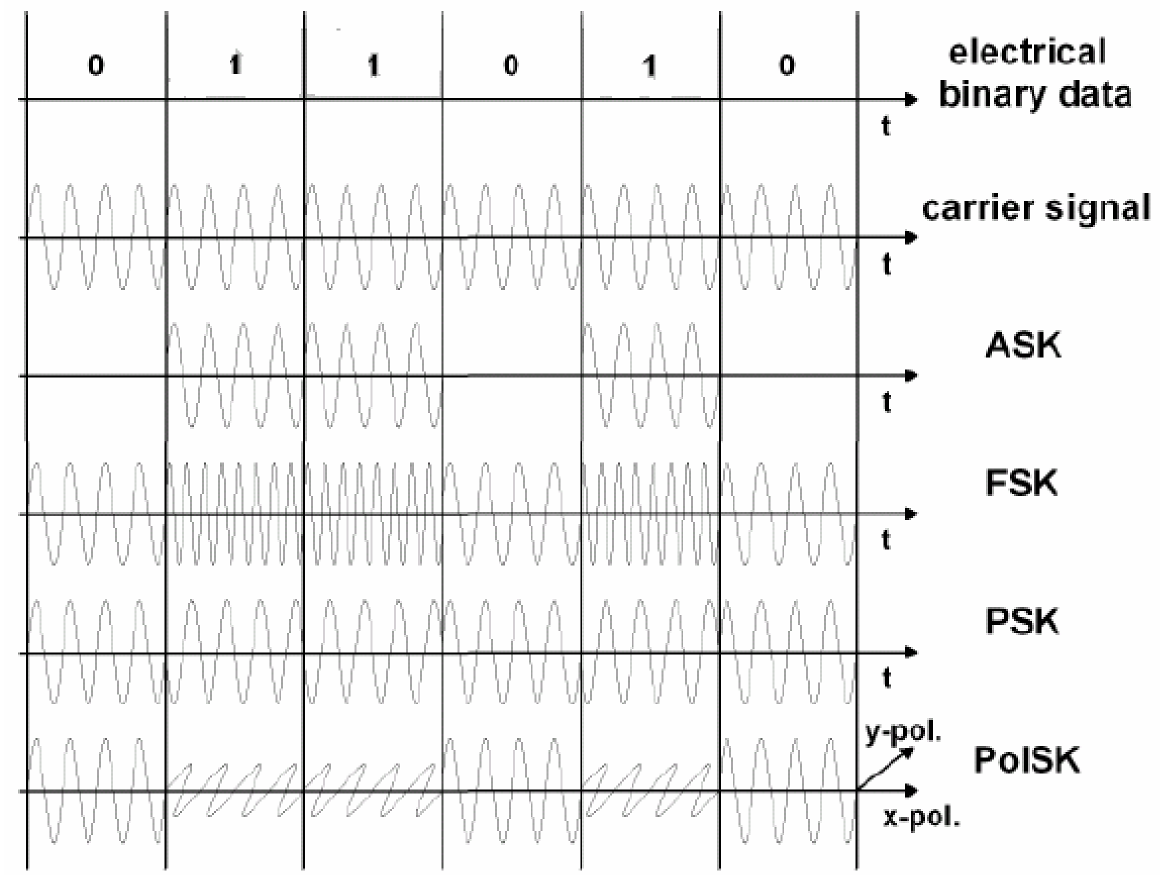

Figure 5.1: Principle of optical signal modulation

5.1 Amplitude Shift Keying

Amplitude-Shift-Keying (ASK) known as”On-Off”-keying (OOK) is the technique of modulating the intensity of the carrier signal is shown in figure (5.1). In the simplest form, a source is switched between on and off states. The ASK modulation is characterized by the relation between the signal levels in on and off states called extinction ratio (ER). The ER value is dependent on the approach used for the signal generation: direct or external modulation of the laser source. In case of external modulation, the ER is limited by the extinction ratio of the external modulator. Typical ER values vary between 8-12 dB depending on the signal bit rate in use. The ASK-based modulation formats are characterized by simple signal generation and detection, due to which all currently deployed optical transmission systems employ ASK-based modulation formats. In the following section various ASK-based modulation formats is discussed. Due to the use of different modulation methods for generation of these formats, they posses different signal shapes (e.g. return-to-zero or non return-to-zero) and spectral characteristics, resulting in different transmission behaviours.

5.1.2 Frequency Shift Keying

Frequency Shift Keying (FSK) is realized by switching the laser light frequency between two frequency values as shown in figure (5.1). In FSK, the optical signal envelope remains unchanged and the complexity of signal generation and detection increases compared to ASK modulation. FSK modulation is characterized by the modulation index. By the variation of modulation index, different FSK-based modulation format can be realized. The differences between FSK formats are reflected in the optical signal spectra, whereby a smaller modulation index enables more compact optical spectra. The FSK-based formats are not used in already deployed transmission systems because of complex signal detection. More recently, FSK-based modulation known as Dispersion Supported Transmission (DST) [2] format was intensively investigated for the implementation in MAN networks [33]. The main drawback of this new technique is that the transmitter and receiver parameters have to precisely match the characteristics of the transmission line, requiring a detailed characterization of the dispersion in the transmission line

5.1.3 Phase Shift Keying

Phase Shift Keying (PSK) uses the phase of the signal to encode information. Optical PSK signals posses a narrow spectrum and a constant signal envelope as shown in figure (5.1), which enables improved nonlinear tolerance, but on the other hand the PSK signals are sensitive to a phase modulation induced by multi-channel effects, which can result in decoding errors at the receiver side. At the same time, PSK-based modulation enables improved receiver sensitivity (up to 6 dB) compared to ASKformats. Especially interesting method of PSK modulation is differential PSK (DPSK). In DPSK signals, the information is encoded in the phase change between two successive bits. Basically, PSK signals only allow coherent detection, which require a local oscillator at the receiver to compare the phase of transmitted with the phase of the local signal, making the feasibility of this modulation more difficult. Also, a phase-locked-loop (PLL) is required to synchronize the local oscillator to the received signal. Pure PSK modulation is rather inapplicable for the system implementation, but some special binary and multilevel variants of PSK like DPSK [34] or differential quaternary PSK (DQPSK) allow the use of direct detection methods. DQPSK enables a further improvement of the code efficiency using 4 different phases, where the signal symbol rate is half of that in DPSK case. The DQPSK bit stream must be differentially encoded using a digital pre-coder. The signal detection in DPSK formats can be made using MZI interferometer based configurations [35] which enable a reduced detection complexity compared to coherent detection. In spite of increased realization complexity of PSK modulation, recently presented DPSK and DQPSK system are as good alternatives to ASK-based modulation formats in future high speed WDM systems.

5.1.4 Polarization Shift Keying

Polarization Shift Keying (PolSK) is the most exotic modulation format among all already presented. The optical PolSK signals are generated by switching the signal polarization between two orthogonal states of polarization. The PolSK is characterized by a constant signal envelope enabling an improved nonlinear tolerance, an improved sensitivity (3 dB) [36] compared to ASK-based modulation, and enable a better utilization of the system bandwidth by the use of orthogonal polarization as an additional degree of freedom. The drawbacks of PolSK are an increased complexity of signal generation and detection, as well as, the sensitivity to polarization disturbances in the transmission line, whose impact increases with an increased channel data rate.

5.2 Modulation Formats

The ASK-based modulation formats are characterized by simple signal generation and detection, due to which all currently deployed optical transmission systems employ ASK-based modulation formats. The two basic modulation formats of are non-return to- zero (NRZ) and return-to-zero (RZ). RZ pulse formats also have several variants, such as chirp-free RZ, chirped RZ (CRZ), CSRZ, RZ-DPSK, CSRZ-DPSK and _/2 alternate-phase (_/2-AP) RZ. Carrier suppressed RZ pulse is a special form of RZ pulse where the carrier is suppressed. A very interesting modulation format is optical duobinary, which offers high spectral efficiency and chromatic dispersion tolerance.

5.2.1 Non-Return-to-Zero (NRZ) Modulation Format

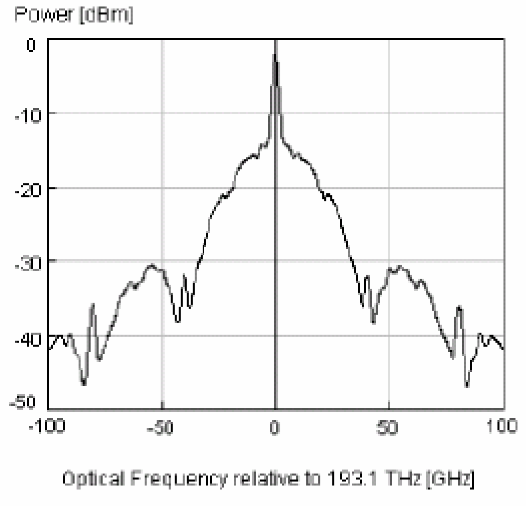

Figure 5.2: Optical spectrum of NRZ modulation format

The simplest modulation scheme is a non-return-to-zero (NRZ) format, where the pulse is on for the entire bit period. Most commercial systems use the NRZ modulation format [37]. The non-return-to-zero (NRZ) has been the most dominant modulation format in intensity modulated-direct detection fiber-optical communication systems for the last years. The reasons for using NRZ in the early days of fiber-optical communication as it is not sensitive to laser phase noise, requires a relatively low electrical bandwidth for transmitter and receivers compare with RZ and the simplest configuration of transmitter and receiver. The NRZ pulses have a narrow optical spectrum as shown in figure (5.2). The reduced spectrum width improves the dispersion tolerance but it has the effect of intersymbol interference between the pulses this modulation format is not suitable when high bit rates an distance are considered. The narrow spectrum of NRZ pulses yields a better realization of dense channel spacing in DWDM systems.

5.2.2 Return-to-Zero (RZ) Modulation Format

In return-to-zero (RZ) modulation format, power is transmitted only for a fraction of the bit period. A RZ signal with the same average power of a NRZ signal has a spectrum peak-power twice larger than the NRZ pulse. The main characteristic of RZ modulated signals is a relatively broad optical spectrum. The large spectral width results in a reduced dispersion tolerance and a reduced spectral efficiency of RZ based WDM systems. The RZ pulse shape enables an increased robustness to fiber nonlinear effects and to the effects of polarization mode dispersion (PMD) [38]. The RZ system implementation improves the system receiver sensitivity up to 3 dB [39]. Due to its broader spectrum, RZ pulse has a reduced dispersion tolerance and spectral efficiency. The duty cycle of RZ pulse is less than unity. The reduced pulse width implies a broader signal spectrum making this technique less interesting for the implementation in DWDM systems. Higher optical powers per channel can be tolerated in a RZ-based WDM system, resulting in an improved maximum transmission length. The RZ modulation format is used for long haul optical communication systems working at higher bit rates.

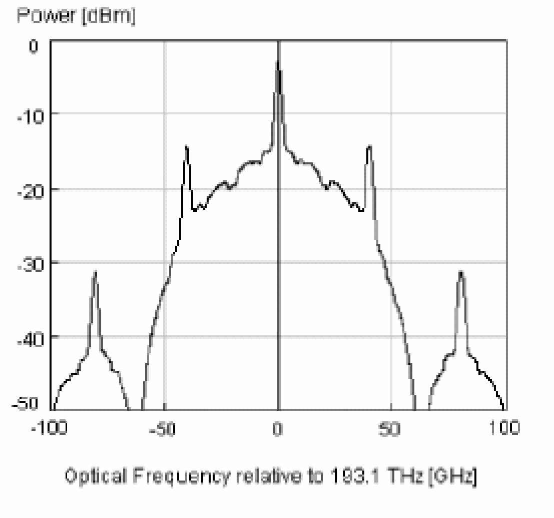

Figure 5.3: Optical spectrum of RZ modulation format

5.2.3 Carrier Suppressed Return-to-Zero (CSRZ) Modulation Format

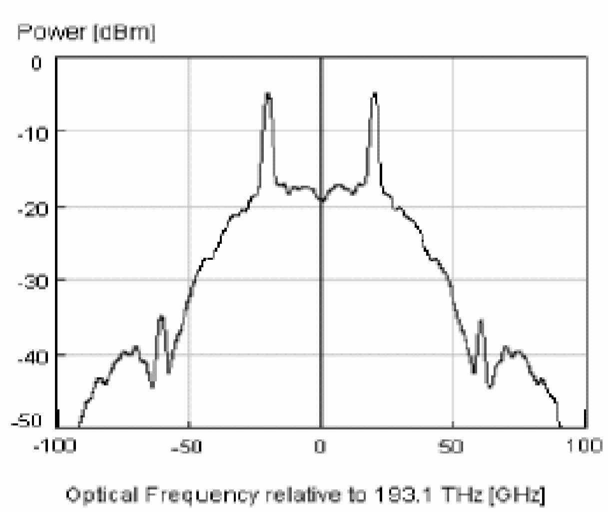

Figure 5.4: Optical spectrum of CSRZ modulation format

Carrier-suppressed RZ (CSRZ) modulation is one of the recently proposed modulation formats for high bit rate transmission systems, which has been intensively investigated in numerical and experimental works [40]. The main target of this modulation format is a reduction of the nonlinear impacts in a transmission line and an improvement of the spectral efficiency in high bit rate WDM systems. It can be expected that the dispersion tolerance of the transmission can be improved as well by CSRZ modulation, due to its reduced spectral width compared to conventional RZ modulation. Compared to the RZ case a spectral reduction with a factor of 2 occurs in CSRZ as shown in figure (5.4). The CSRZ pulses possess a RZ signal shape with an optical phase difference of p between adjacent bits. This inter-pulse phase condition can be beneficial for an increased nonlinear tolerance Carrier suppressed RZ pulse is a special form of RZ pulse where the carrier is suppressed. The difference between CSRZ and conventional RZ is that the CSRZ signal has a p phase shift between adjacent bits. This phase alternation, in optical domain, produces no DC component; thus, there is no carrier component for CSRZ. CSRZ modulation utilizes a return to zero modulation. It also alters the phase of the optical signal. CSRZ signal is far less sensitive to fiber nonlinear effects and provides better robustness against transmission impairments. The robustness of CSRZ modulation to narrow-band filtering can be improved, which can be beneficial for DWDM systems. By the use of an optimized narrow-band filtering in 40 GB/s CSRZ based DWDM transmission systems, a spectral efficiency beyond 0.4 bit/s/Hz can be realized.

5.2.4 Doubinary Modulation Format

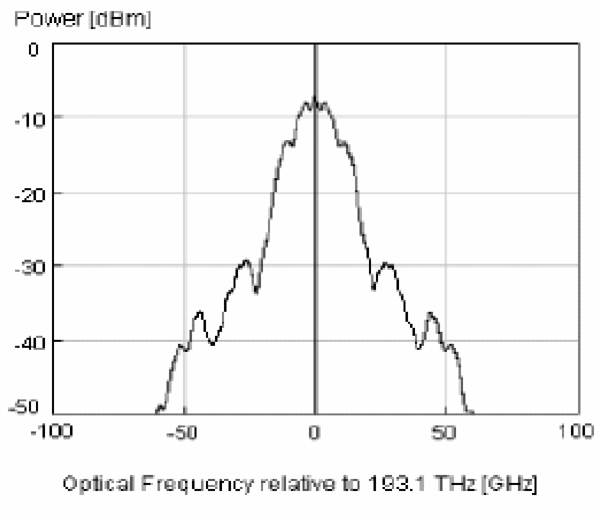

Figure 5.5: Optical spectrum of duo binary modulation format

A very interesting modulation format is optical duo binary, which offers high spectral efficiency and chromatic dispersion tolerance. Duobinary modulation can be described as a combination of a conventional ASK based modulation and phase shift keying (PSK). Depending on the realization, optical duobinary transmission can beunder stood as a multilevel transmission with phase encoded bits and a reduced spectral width. Duobinary transmission technology was introduced for the first timeby A. Lender in the 1960s as a mean of transmitting binary data over an electrical cable with high-frequency cut-off characteristics. Recently, duobinary modulation [41] has been applied to high-speed optical transmission systems with a channel data rate of 10 GB/s in order to improve their dispersion tolerance. In the duobinary format, the optical phases of “1” bits that are separated by an odd number of “0s” differ by p radians. The optical spectrum of the duobinary signal is very compressed as compared to many other binary formats. The optical duobinary format is generally realized via two possible methods, one through electronic low pass filter (LPF) and the other through optical filtering of a DPSK signal in a delayinterferometer (DI). The LPF duobinary has recently received significant attention. One reason for this is that duobinary can be easily created using simple low-cost techniques. The spectral width of the signal is reduced twice compared to a conventional NRZ signal as shown in figure (5.4). The reduction of the spectral width of the optical duobinary signal is the reason for its better dispersion tolerance compared to NRZ signals and enables an improved spectral efficiency in WDM systems. A further advantage of duobinary modulation is the suppression of SBS-effect, since in the optical duobinary spectrum; the carrier is effectively suppressed. The main disadvantage of duobinary signals, similar to NRZ signals, is a relatively strong impact of fiber nonlinearities, which represents the main limiting factor for the maximum transmission length and the achievable transmission quality. The new duobinary based modulation methods with the use of RZ-based signal enables the realization of WDM systems with dense channel spacing and with an improved transmission performance. Due to its large dispersion tolerance, the duobinary modulation is suitable for optical metro area networks (MANs) [42], in which the component costs and a signal generation realized in electrical domain play an important role.

CHAPTER 6

PERFORMANCE OF OPTICAL COMMUNICATION SYSTEM WITH DISPERSION MANAGED RZ PULSE

In this chapter, the performance of 10 Gbps optical communication system with the dispersion managed RZ pulse has been reported. The return-to-zero (RZ) pulse is efficient for long-distance, high-bit-rate, wavelength division multiplexed (WDM) transmission dispersion-managed systems. In RZ pulse, the power is transmitted only for fraction of bit period. The effect of varying the dispersion parameter of single mode fiber on optical communication system has been noted. It is observed that with increase in the value of dispersion parameter, there is an increase in the average eye opening and Q-factor value. Also a good desirable bit error rate value has been achieved and reported. Timing jitters are reduced with increase in value of dispersion parameter. Also the performance of the optical communication system with the varying duty cycle of the RZ pulse for a fixed value of dispersion parameter has been analysed. It is demonstrated that the performance of the system is improved by reducing the duty cycle.

6.1 Introduction

The goal of an optical fiber communication system is to transmit the maximum number of bits per second over the maximum possible distance with the fewest errors. There are many modulation schemes that are come into existence for long-haul systems, i.e., the format used to create the optical pulses. The simplest modulation scheme is a non-return-to-zero (NRZ) format, where the pulse is on for the entire bit period. Alternatively, a return-to-zero (RZ) format can be used where the pulse is on for only a portion of the bit period. Optical return-to-zero (RZ) signals are becoming increasingly important in optical communication systems. They have proven to be superior to the non return- to-zero (NRZ) format both in terms of receiver sensitivity [39], and in terms of fiber transmission performance. The RZ spectrum has a wider bandwidth than the NRZ spectrum. Receiver sensitivity is defined as the received optical power required in order achieving a certain bit error rate (BER) . The electrical power of an RZ pulse with a 0.5 duty cycle will be twice that of an NRZ pulse. The RZ pulse has a 3 dB improvement in receiver sensitivity. The RZ format would be beneficial for systems with few channels but would require NRZ as the number of channels increase [37]. The RZ format has the better receiver sensitivity

and nonlinearity tolerance due to which this modulation format is of great interest for research scholars these days. The work is going on achieving high bit rates which is above 40 Gb/s. Due to its relatively broad optical spectrum which results is results in reduced dispersion tolerance and a reduced spectral efficiency. RZ pulse is less
susceptible to inter symbol interference and better nonlinear robustness. RZ modulation has become a popular solution for 10 Gb/s systems because it has a higher peak power, a higher signal-to-noise ratio, and lower bit error rate that NRZ encoding .The duty cycle of pulses used also has its effect on the performance of system. So best suitable value for duty cycle must be taken. Dispersion is a big factor which degrades the performance of optical communication networks. Due to this several compensation technique had been developed. Some of the techniques are dispersion shifted fibers and dispersion compensation fibers. In dispersion compensation fibers the negative value of dispersion parameter is given. The amplifiers also have an important role in optical communication systems. With the Erbium doped fiber amplifier, the number of spans of standard single mode fibers has been decreased to great extant.

Mob, Fiirst, Geiger and Flscher el at. [43] theoretically and experimentally analyses advantages of nonlinear RZ over NRZ on 10 GB/s single-span links.

Griffin, Walker, and Johnstone el at. [44] demonstrated a four-stage integrated module for 10 Gb/s chirped return-to-zero modulation using GaAs/AIGaAs electro-optic guidedwave technology and its performance is verified by dispersion-managed test bed transmission over 3000 km.

Hodzic, Konrad and Petermann el at. [45] had proposed alternative modulation formats in N ×40 Gb/s WDM standard fiber RZ-transmission systems.

K. Ennser and K. Petermann et al. [46] had investigated theoretically and experimentally the performance of RZ- versus NRZ transmission on standard singlemode fibers. On the basis of computer simulations, the RZ-transmission for the optimum system performance taking into account the dispersion, Kerr nonlinearity, attenuation and ASE noise was investigated. The parameters such as bit rate, distance and power levels are estimated for the lowest system degradation. The work considers different duty ratios including NRZ-pulses.

Park, Wiesenfeld and Garret el at. [47] had demonstrated the transmission of a 40-Gb/s signal over multiple (up to six) 120-km spans of conventional single-mode fiber.

6.2 Simulation Setups

The various simulation setups under consideration are shown in following sections, the first section 6.2.1 is the simulation for FBG as dispersion compensator, the second section 6.2.2 is the simulation for DCF as dispersion compensator. The results of simulations are reported in last section 6.3.

6.2.1 Simulation for FBG as Dispersion Compensator

In order to illustrate how FBG as dispersion compensation can be studied, the system is simulated with block diagram shown in figure 6.1. In this case, the transmitter section consists of data source, electrical driver (RZ), laser source (CW_ Lorentzian) and amplitude modulator ($\sin^2$_MZ) is connected. Two SOA and one FBG are connected through two SSMF. Here, FBG used as a dispersion compensator. The output of last SOA is given to optical raised cosine filter which is connected to receiver section. In receiver section PIN is connected to an electrical Bessel filter and the final result is shown through electrical scope, Q estimator and bit error rate estimator.

6.2.2 Simulation for DCF as Dispersion Compensator

In order to illustrate how DCF as dispersion compensation can be studied, the system is simulated with block diagram shown in figure 6.2. In this case, the transmitter section consists of data source, electrical driver (NRZ), laser source (CW_ Lorentzian) and amplitude modulator ($\sin^2$_MZ) is connected. Three SOA are connected to SSMF and DCF .Here, DCF is used as a dispersion compensator. The output of last SOA is given to optical raised cosine filter which is connected to receiver section. In receiver section PIN is connected to an electrical Bessel filter and the final result is shown through electrical scope, Q estimator and bit error rate estimator.

6.3 Results for Simulations

6.3.1 Results and Discussions Regarding Simulation for FBG as Dispersion Compensator with RZ Pulse Based on Length of 50 km

The simulation results from different simulation systems are predicted. The results of simulation setup in figures 6.3 to 6.7 shows the electrical spectrum of 50 km on different length of 10, 20, 30, 40, 50 km

Eye Diagrams for Different Length

The results of eye diagrams are shown in figures 6.8 to 6.12 for different length. Eye opening decreases and eye closure increases with increase the length of SSMF i.e. eye opening penalty increases as the length of single mode fiber increases. The best result is observed with 10 km length of single mode fiber.

Result Based on Q Estimator for Different Lengths

Figure 6.13 shows the result of Q value on 10, 20, 30, 40, 50, km length of fiber which is 19 dB at 10 km and 12 dB at 50 km.
Figure 6.14 shows the result of eye opening on 10, 20, 30, 40, 50, km length of fiber which is 0.83216E-03 at 10 km and 0.15365E- 04 at 50 km.
Figure 6.15 shows the result of equivalent Q at mean threshold on 10, 20, 30, 40, 50, km length of fiber which is 15.84 dB at 10 km and 11.75 dB at 50 km.
Figure 6.16 shows the result of equivalent Q at optimal threshold on 10, 20, 30, 40, 50, km length of fiber which is 0.31211E-03 dB at 10 km and 0.32477E-04 dB at 50 km.

Result Based on Bit Error Rate Estimator for Different Lengths

Figure 6.17 shows the result of eye closure on 10, 20, 30, 40, 50, km length of fiber which is 1.23 dB at 10 km and 4.32 dB at 50 km.
Figure 6.18 shows the result of Average eye opening on 10, 20, 30, 40, 50, km length of fiber which is 0.12211E-03 at 10 km, and 0.23128E-04 at 50 km.
Figure 6.19 shows the result of BER at optimal threshold on10, 20, 30, 40, 50, km length of fiber which is 0.76239E-18 at 10 km and 0.21426E-04 at 50 km.
Figure 6.20 shows the result of BER at mean threshold on 10, 20, 30, 40, 50, km length of fiber which is 0.23215E-09 at 10 km and 0.34516E-04 at 50 km.

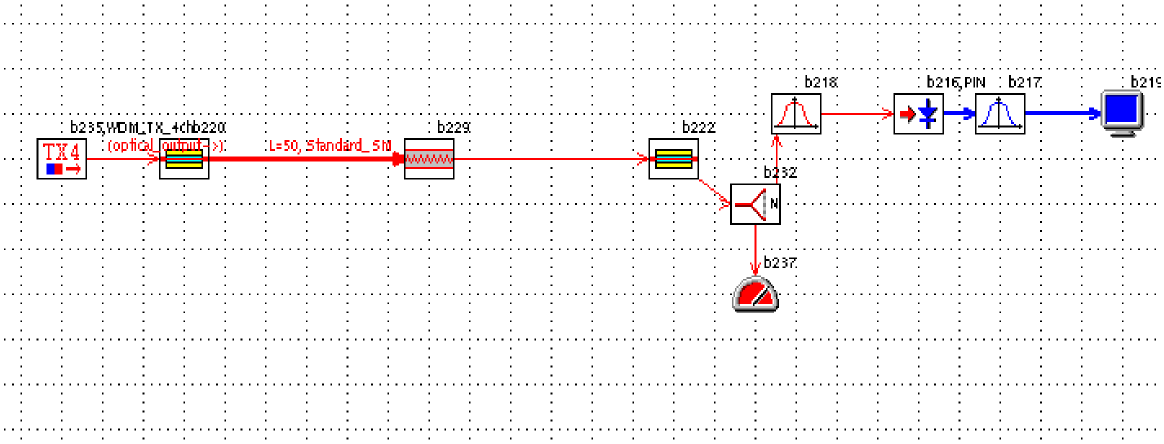

Figure 6.1: FBG as dispersion compensator

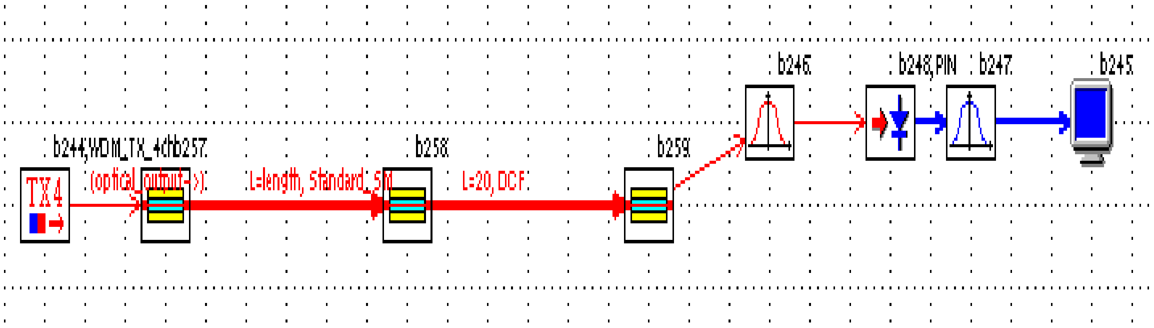

Figure 6.2: DCF as dispersion compensator

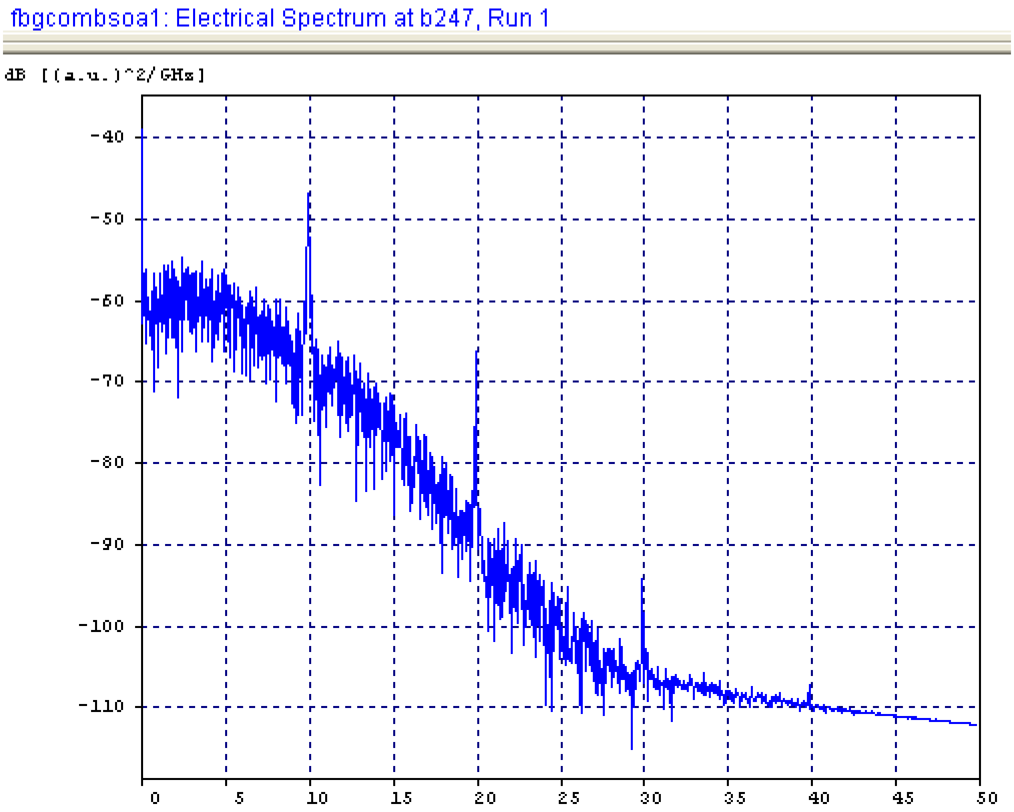

Figure 6.3: Electrical spectrum

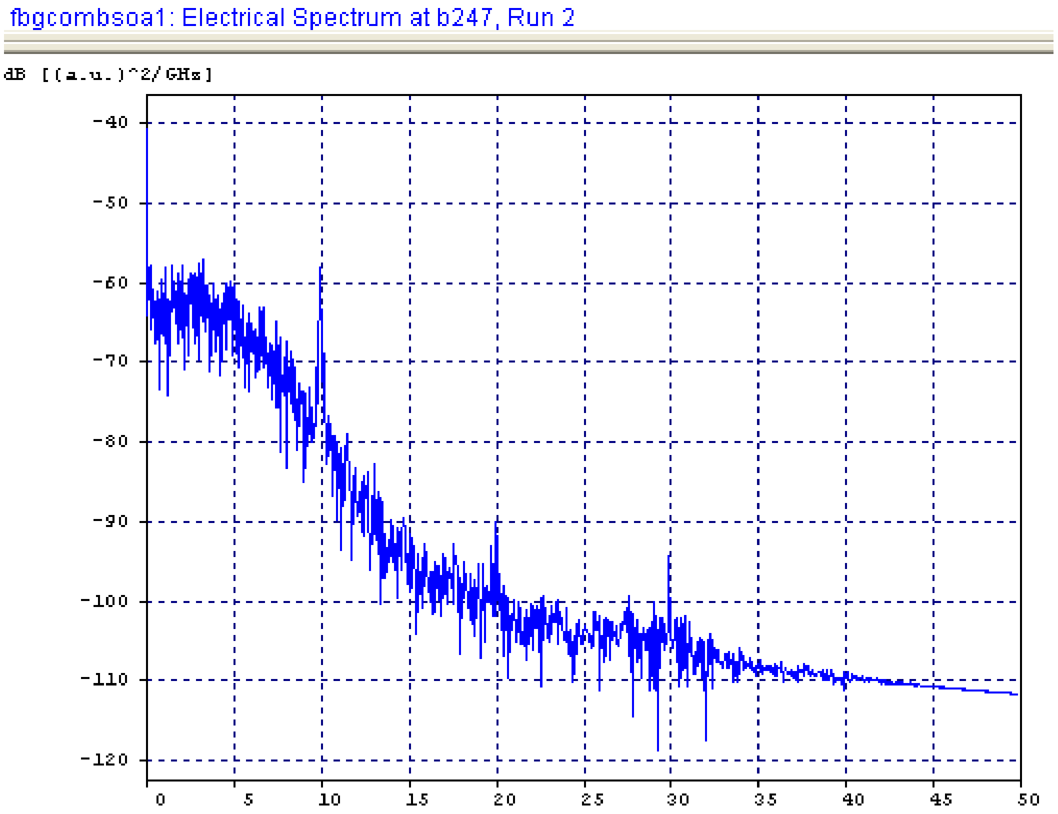

Figure 6.4: Electrical spectrum

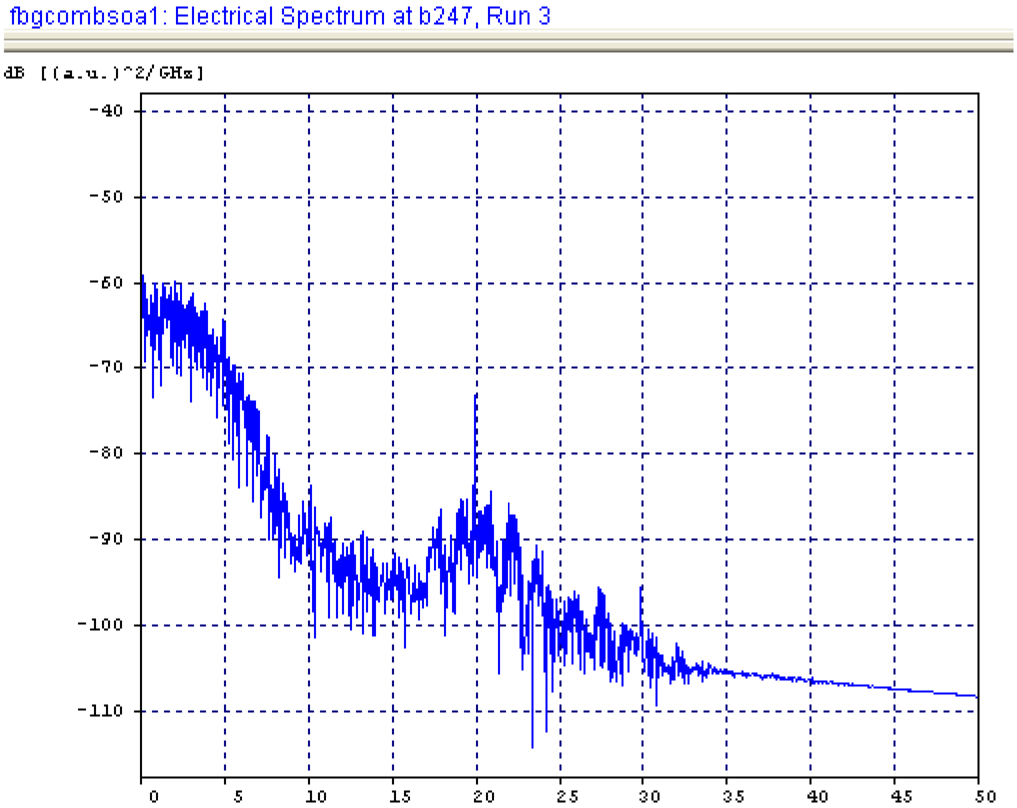

Figure 6.5: Electrical spectrum

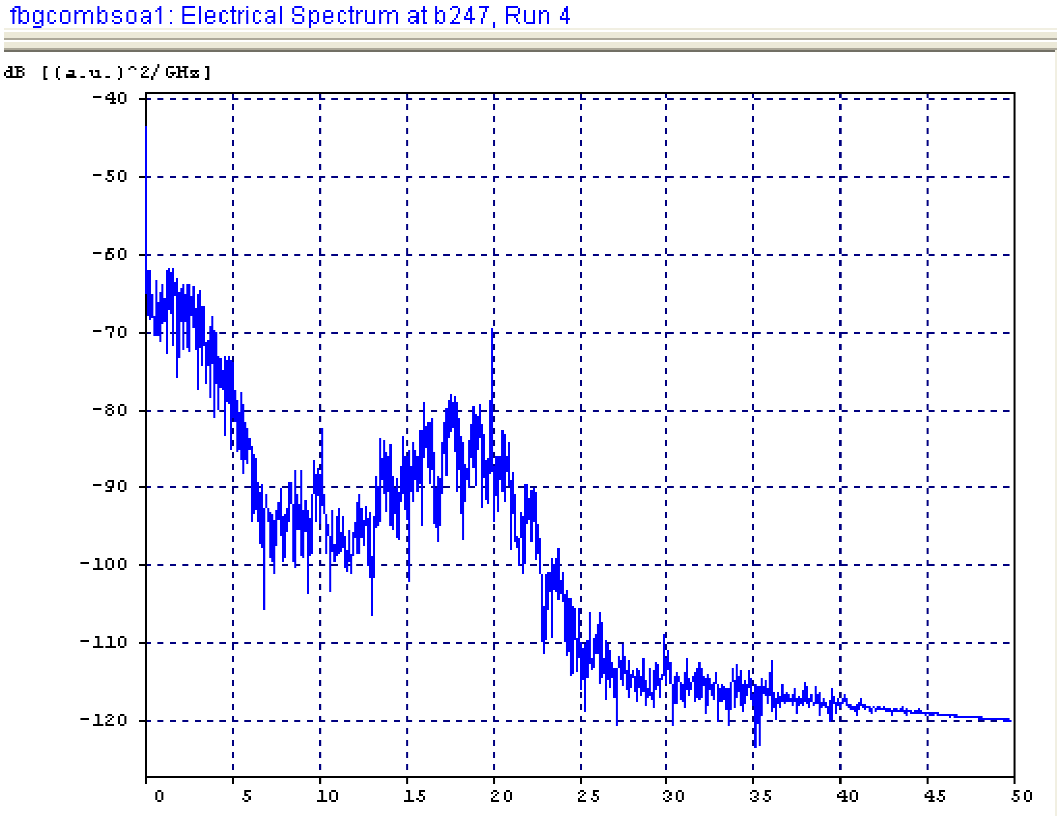

Figure 6.6: Electrical spectrum

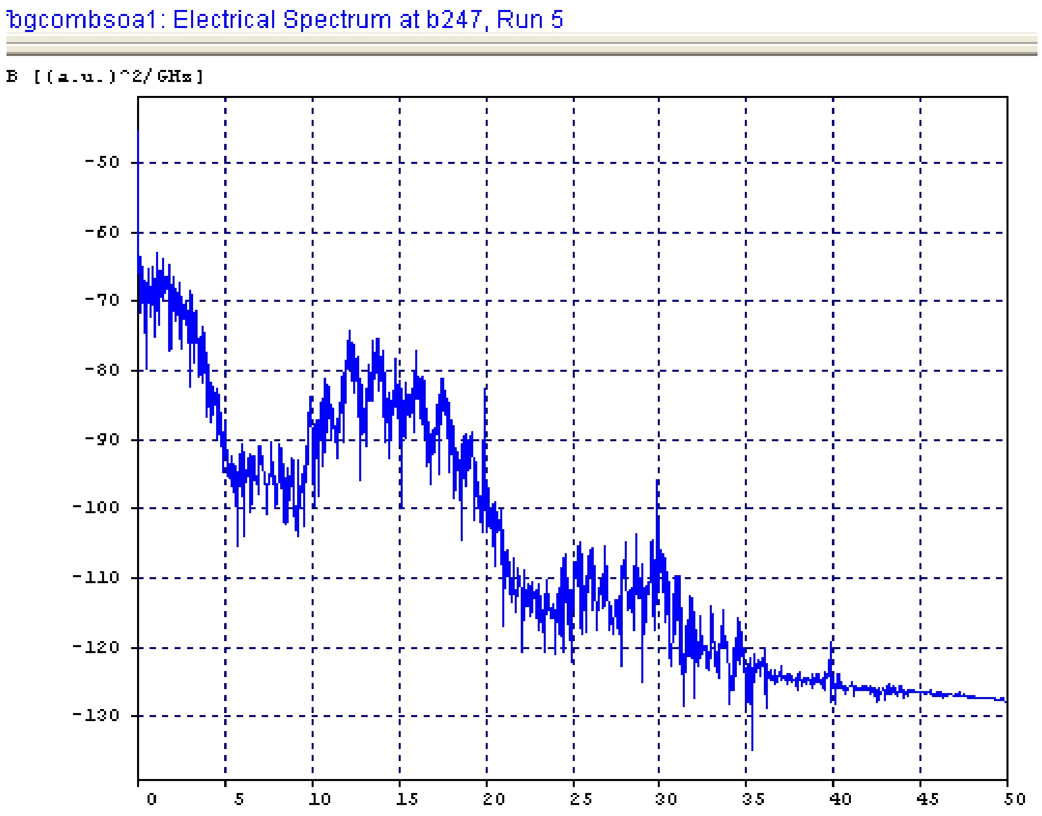

Figure 6.7: Electrical spectrum

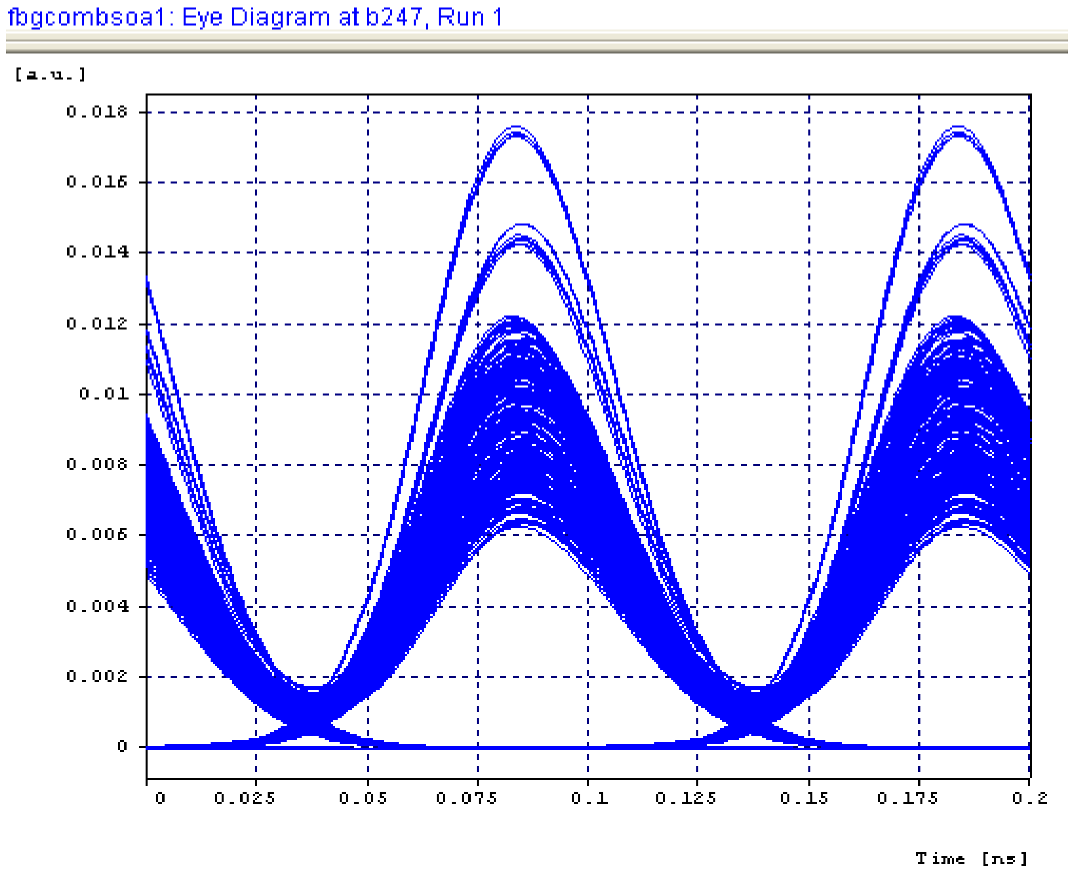

Figure 6.8: Eye diagram at 10 km length

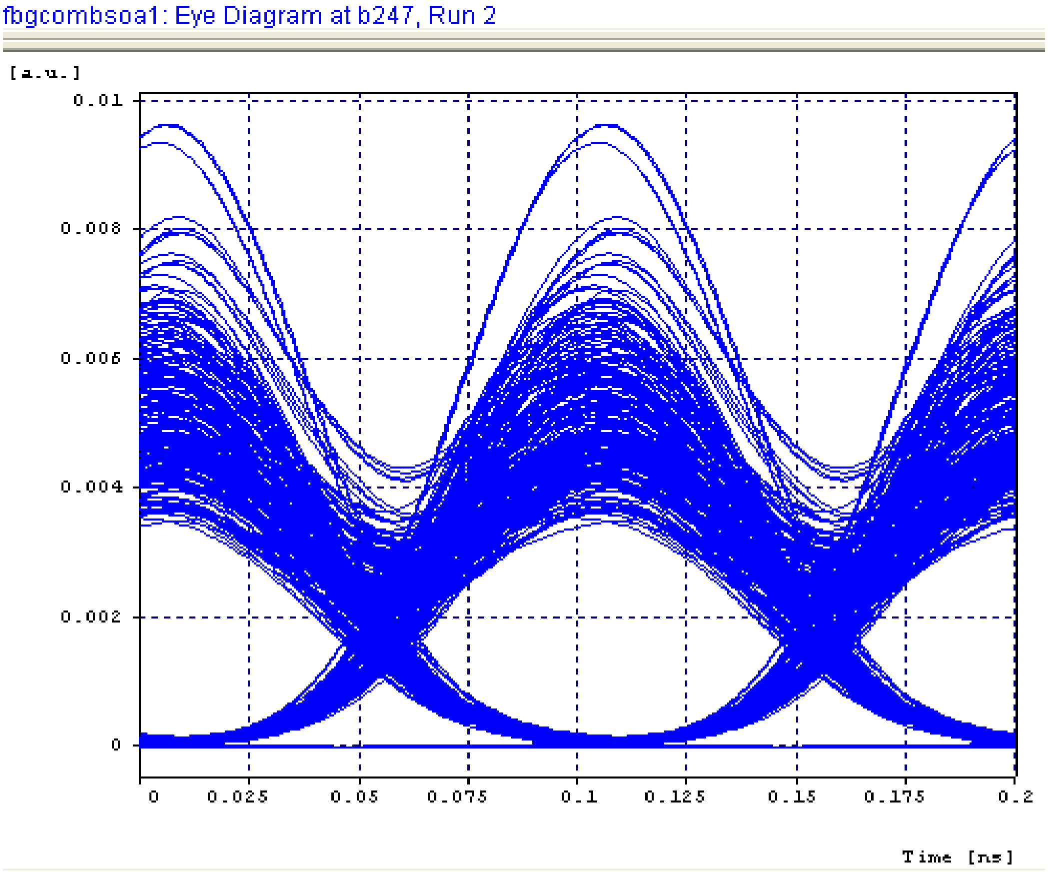

Figure 6.9: Eye diagram at 20 km length

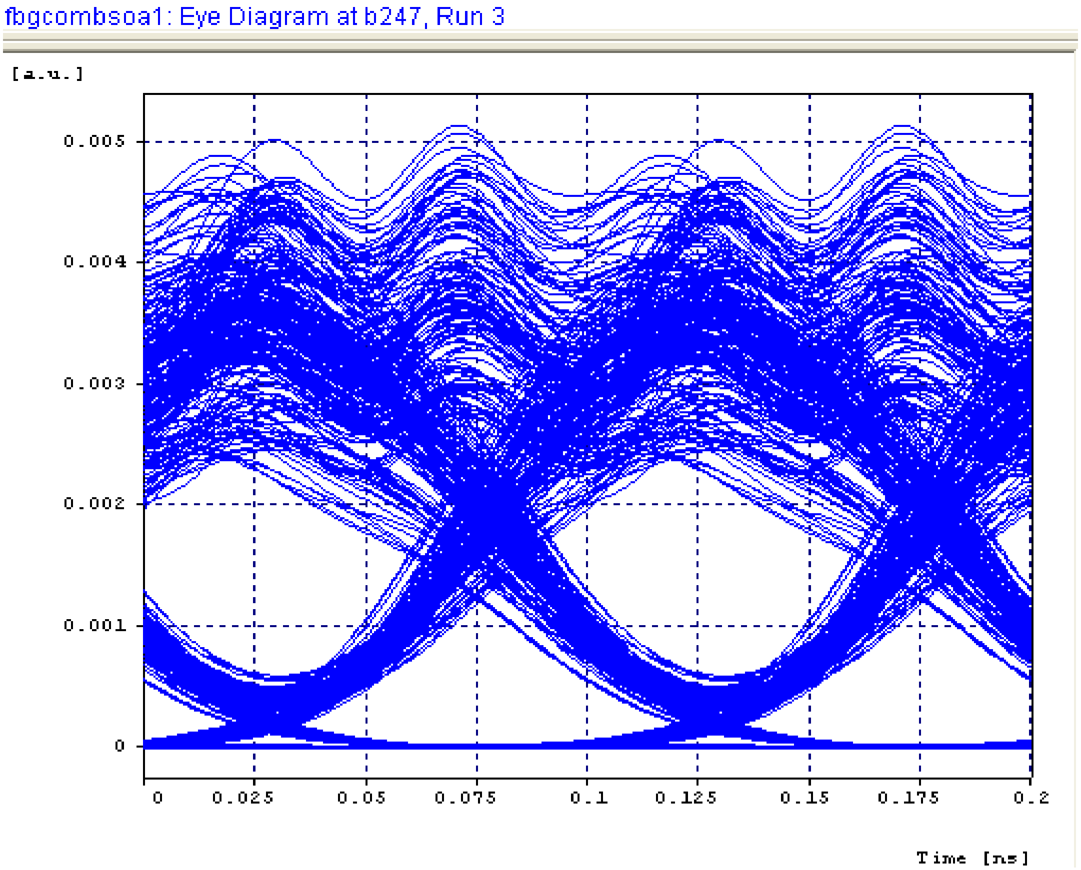

Figure 6.10: Eye diagram at 30 km length

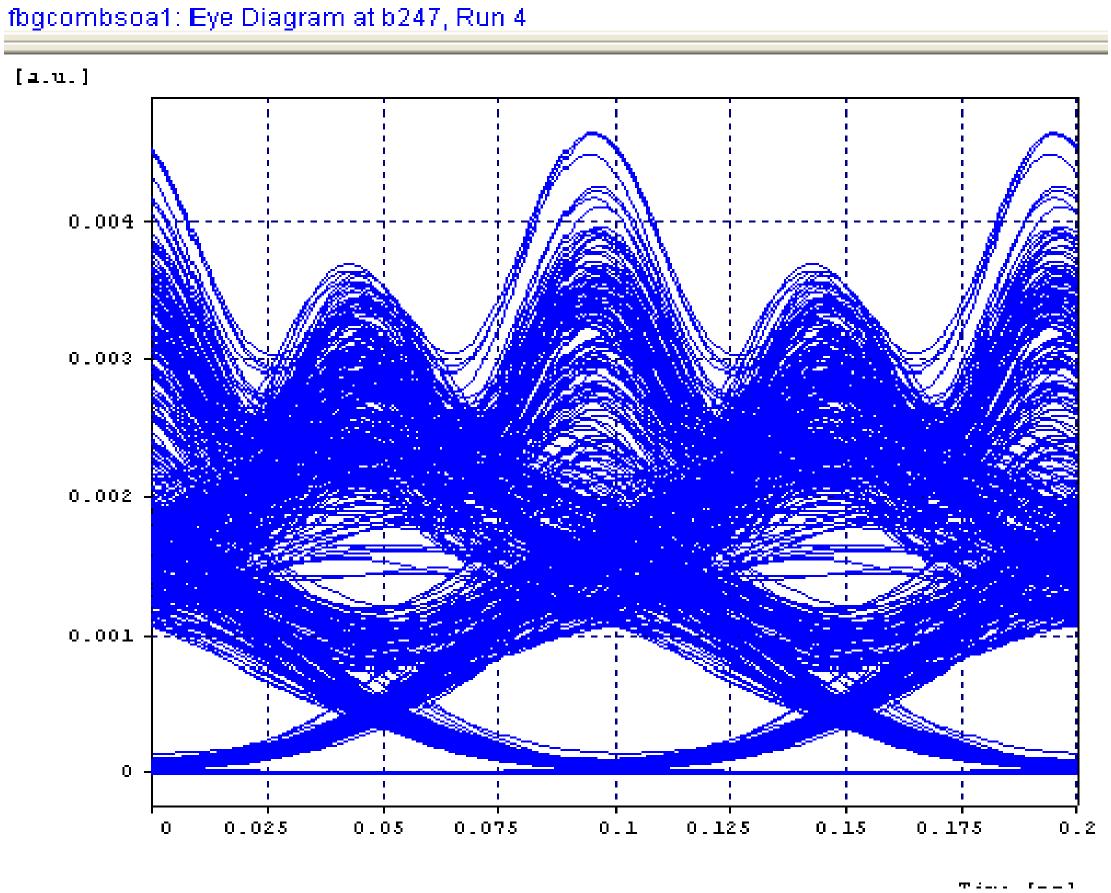

Figure 6.11: Eye diagram at 40 km length

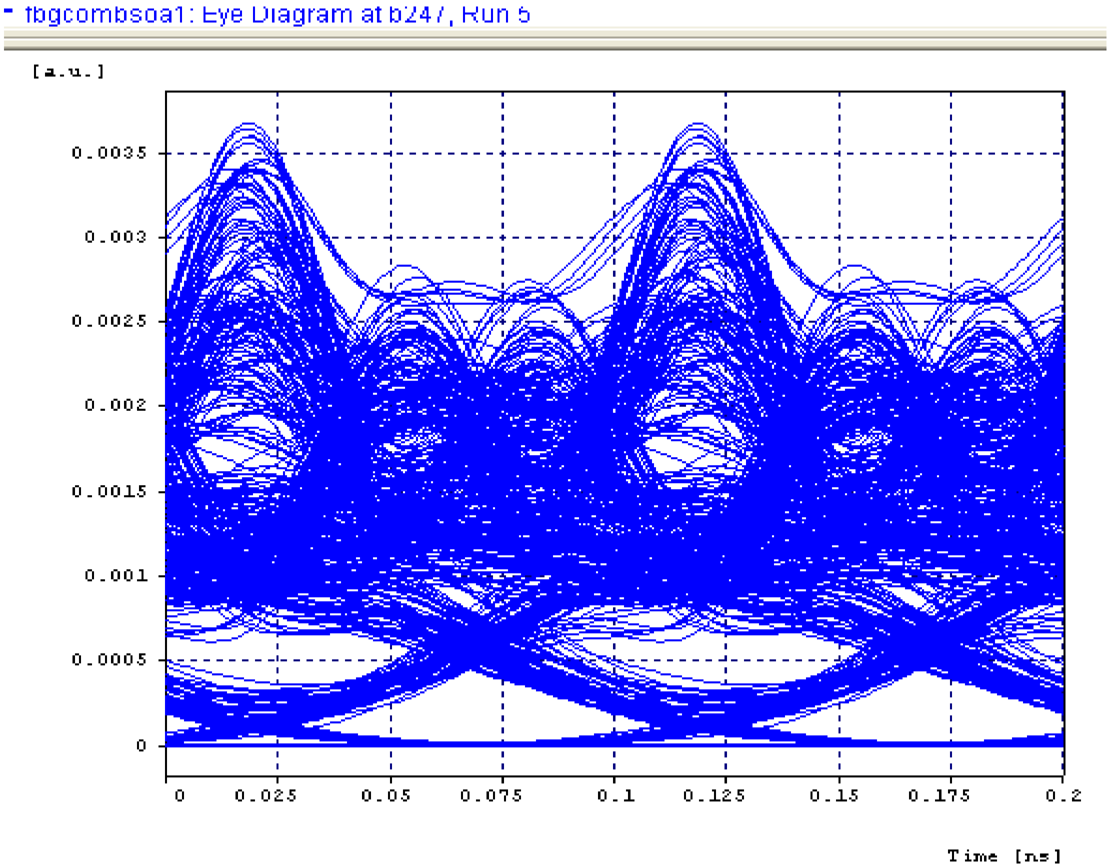

Figure 6.12: Eye diagram at 50 km length

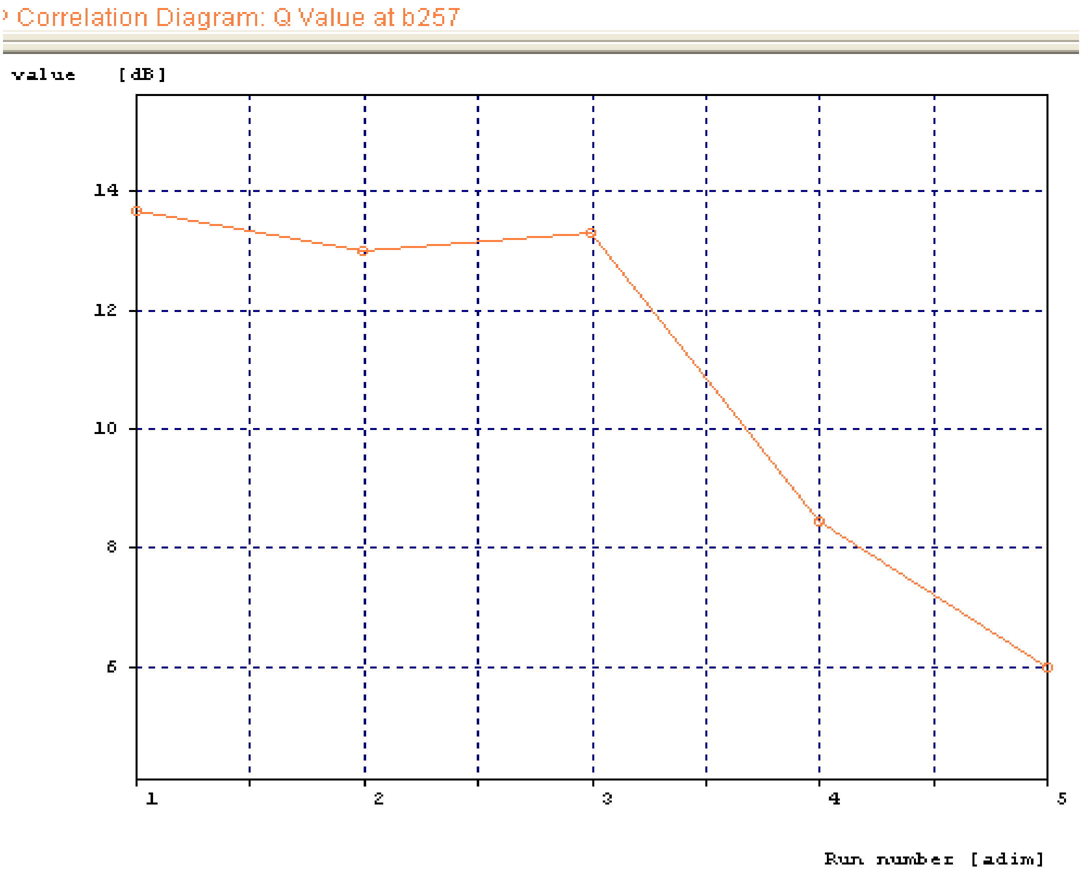

Figure 6.13: Q value

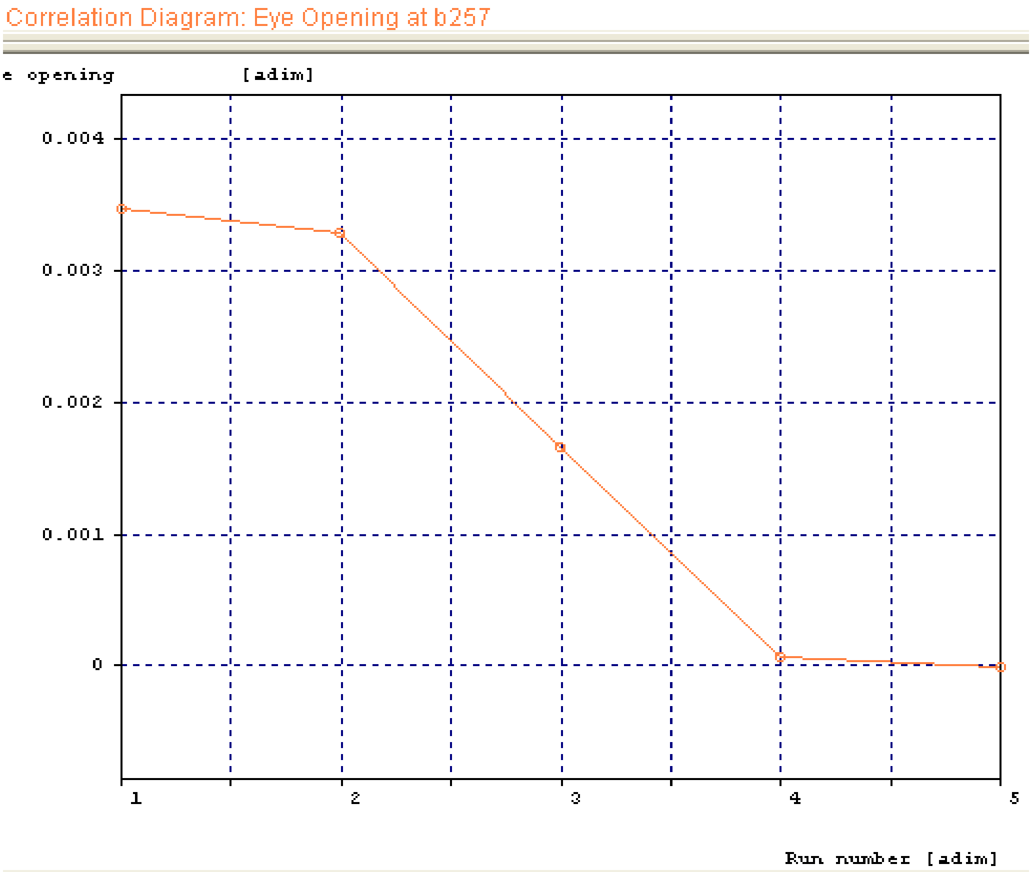

Figure 6.14: Eye opening

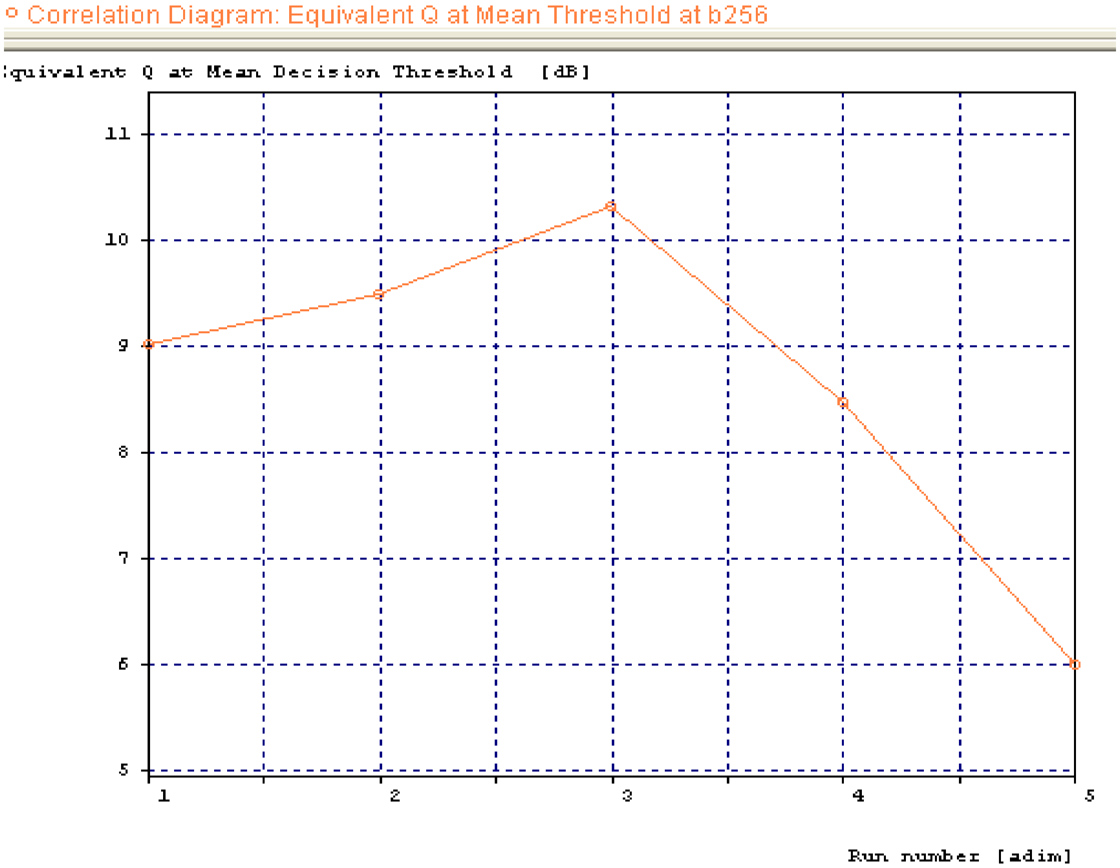

Figure 6.15: Equivalent Q At Mean Threshold

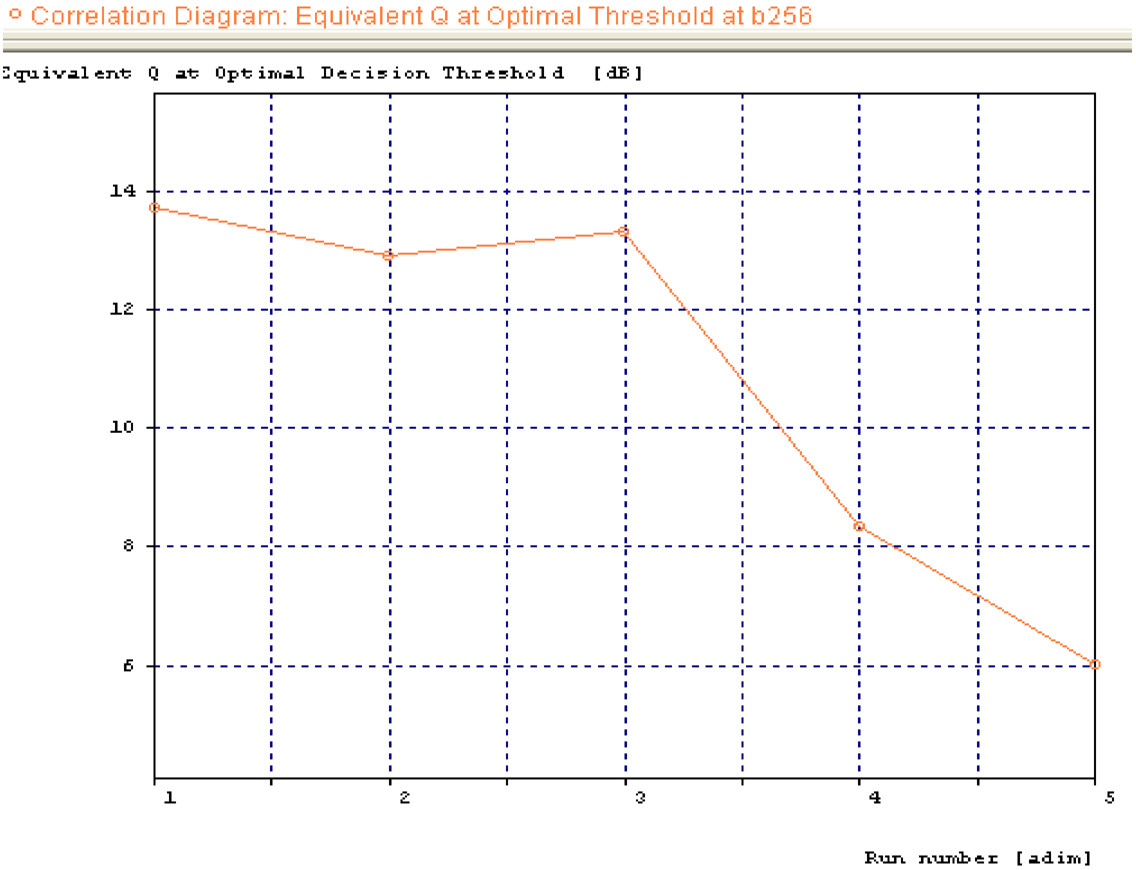

Figure 6.16: Equivalent Q At Optimal Threshold

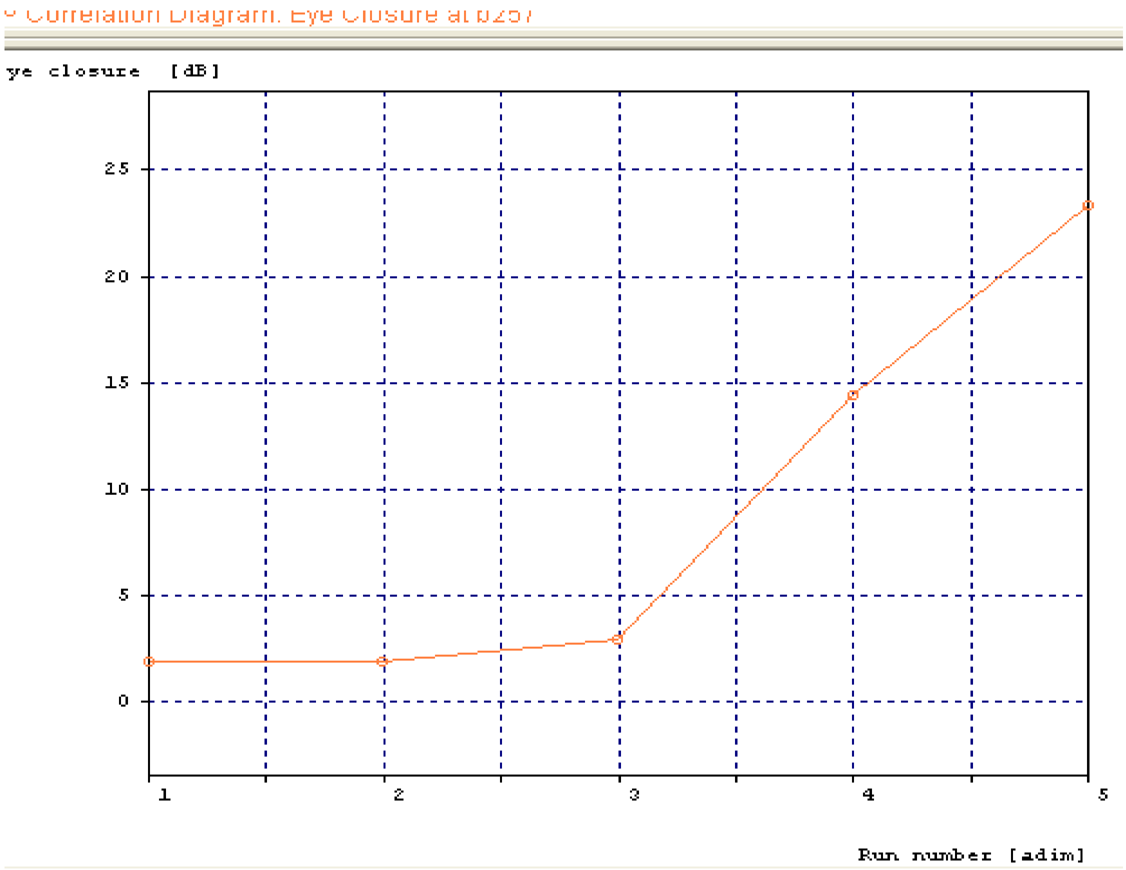

Figure 6.17: Eye Closer

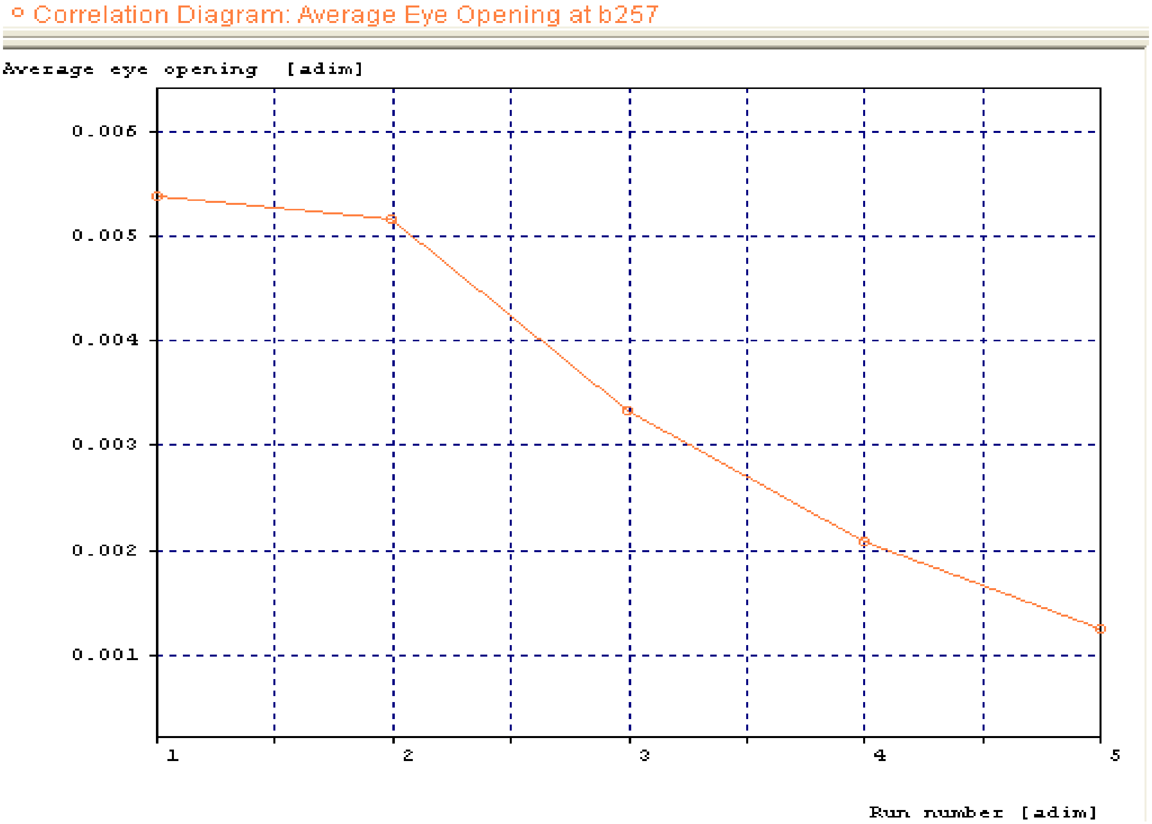

Figure 6.18: Average Eye Opening

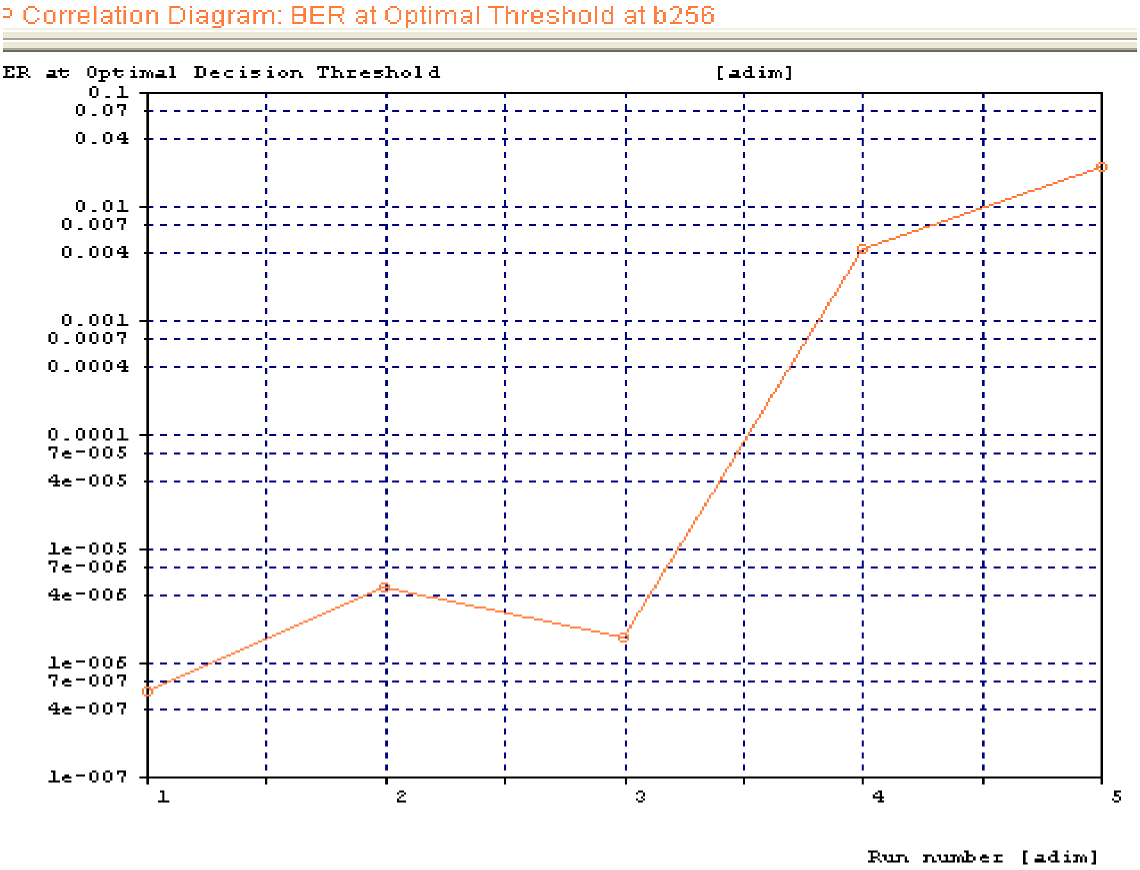

Figure 6.19: BER at optimal threshold

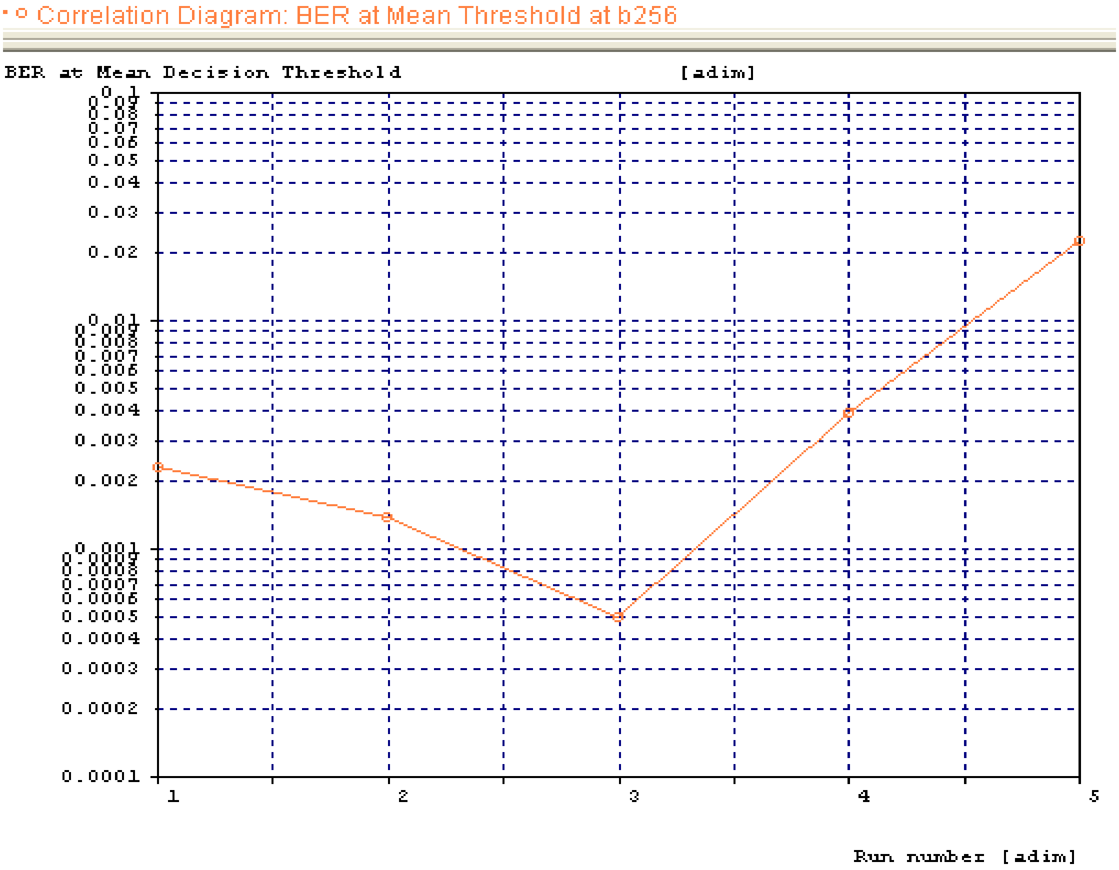

Figure 6.20: BER at Mean threshold

6.3.2 Results and Discussions Regarding Simulation for DCF as Dispersion Compensator with RZ Pulse Based on Length of 50 km

The simulation results from different simulation systems are predicted. The results of simulation setup are shown in figure 6.21 to 6.25 is electrical spectrum and figure 6.26 to 6.30 is eye diagram

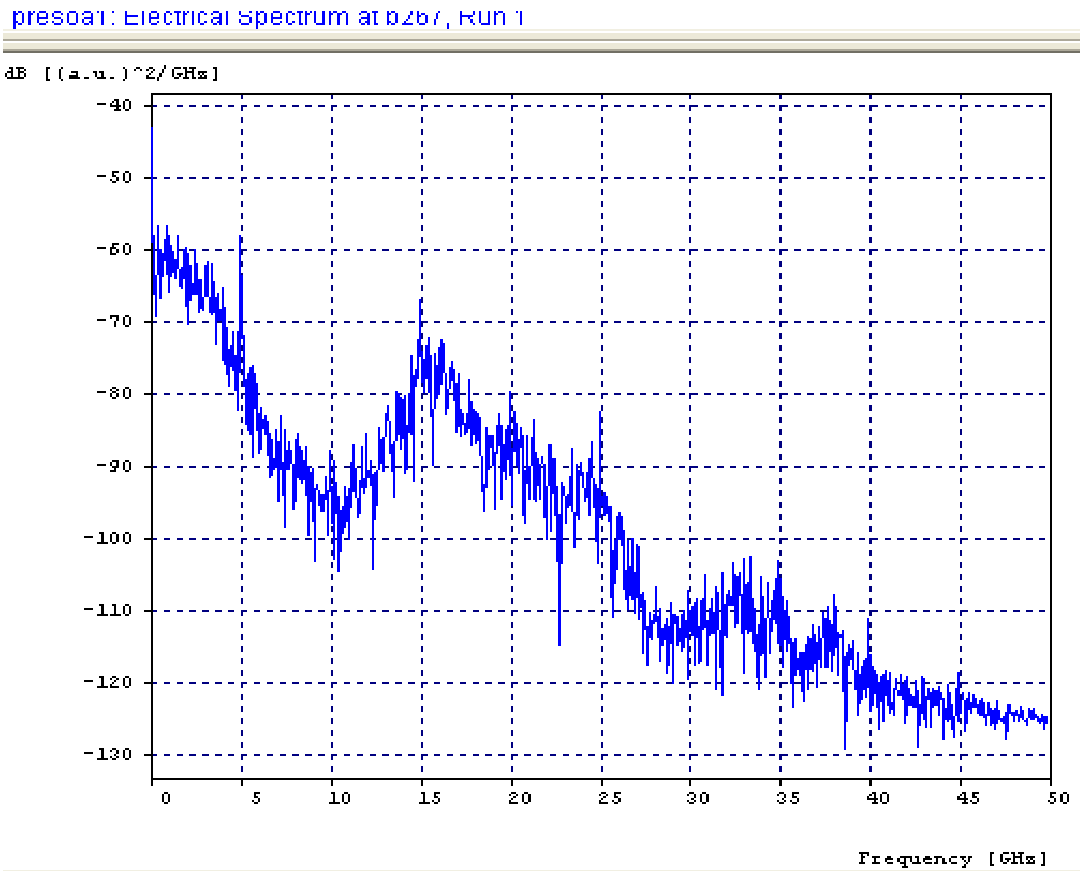

Figure 6.21: Electrical spectrum

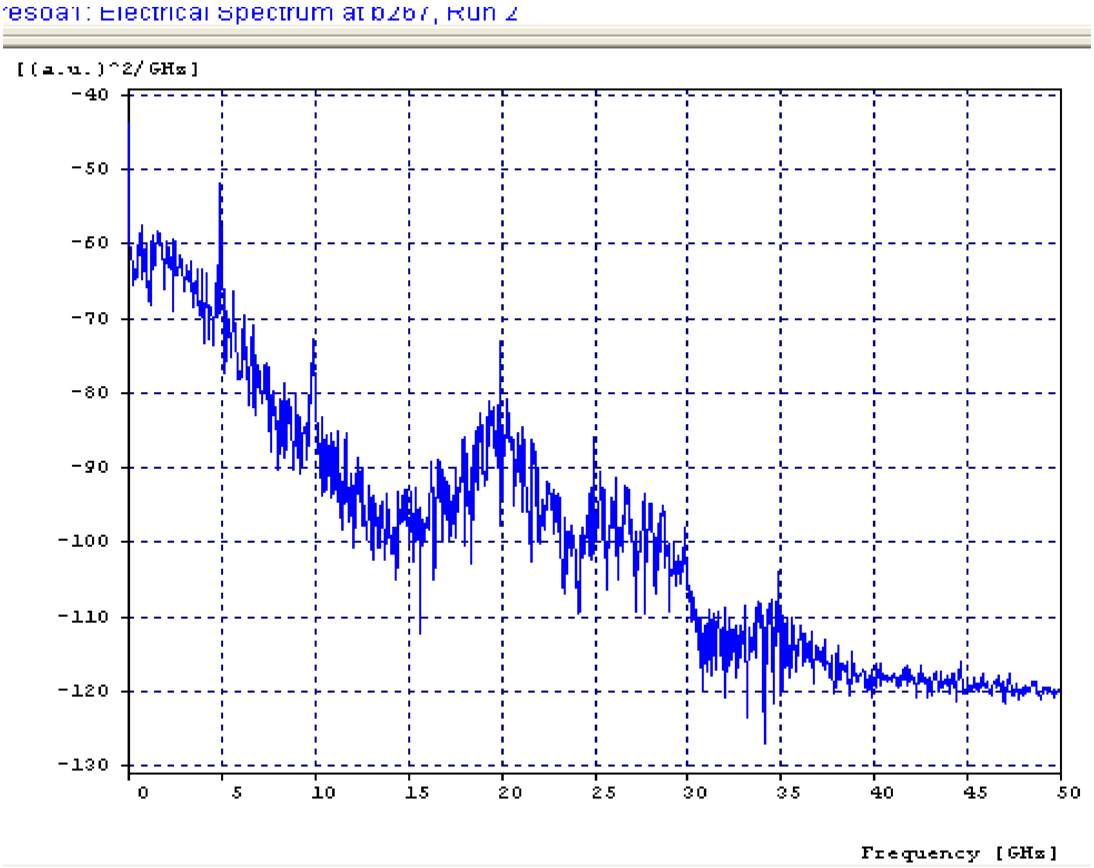

Figure 6.22: Electrical spectrum

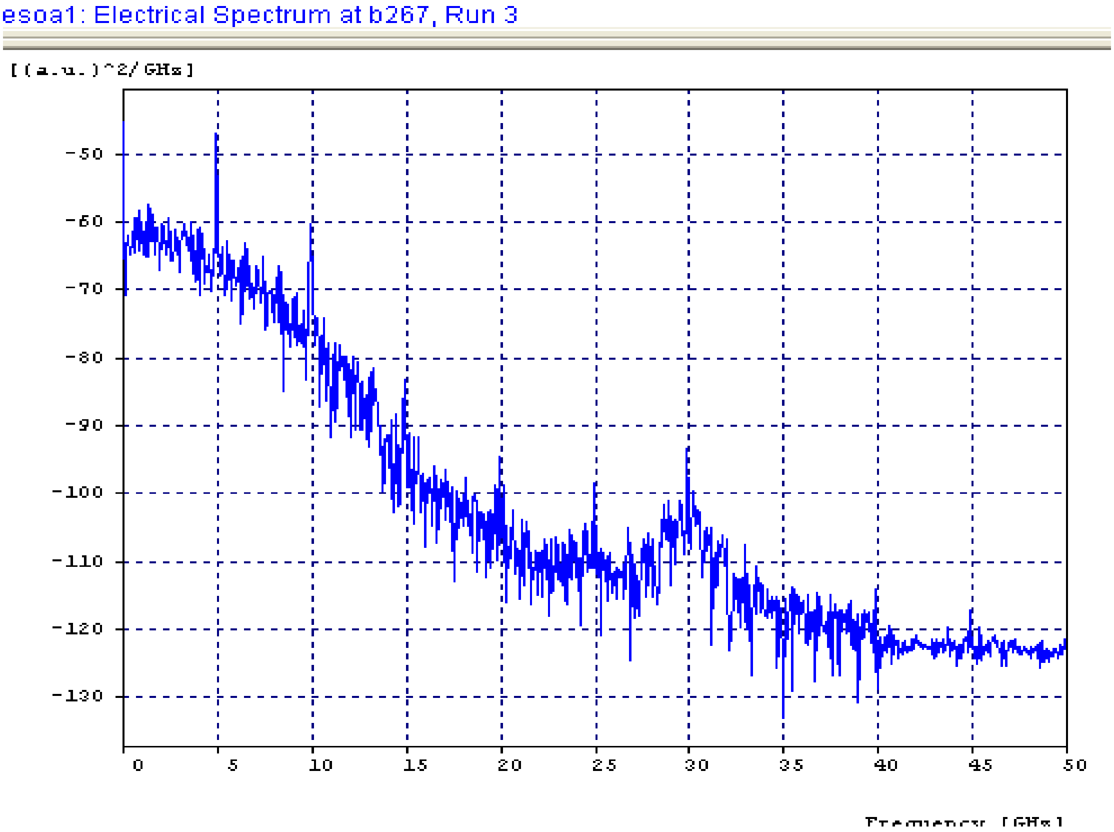

Figure 6.23: Electrical spectrum

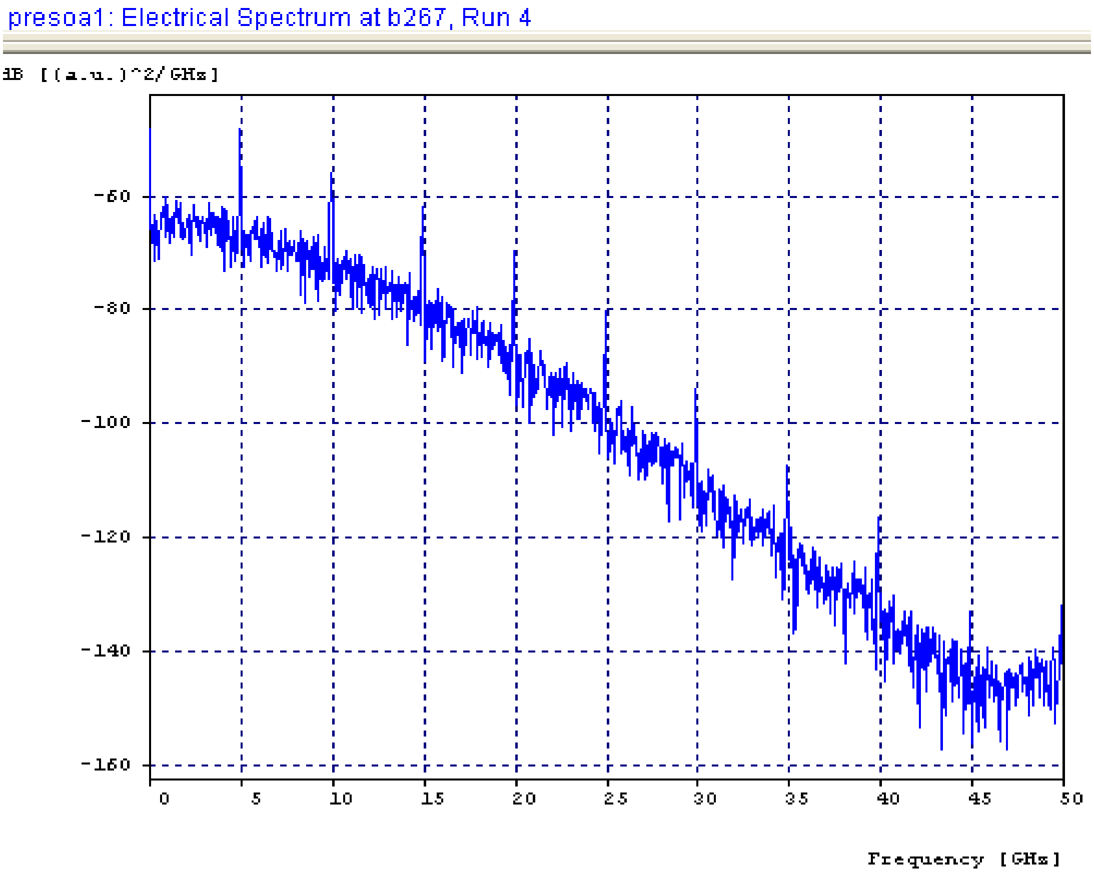

Figure 6.24: Electrical spectrum

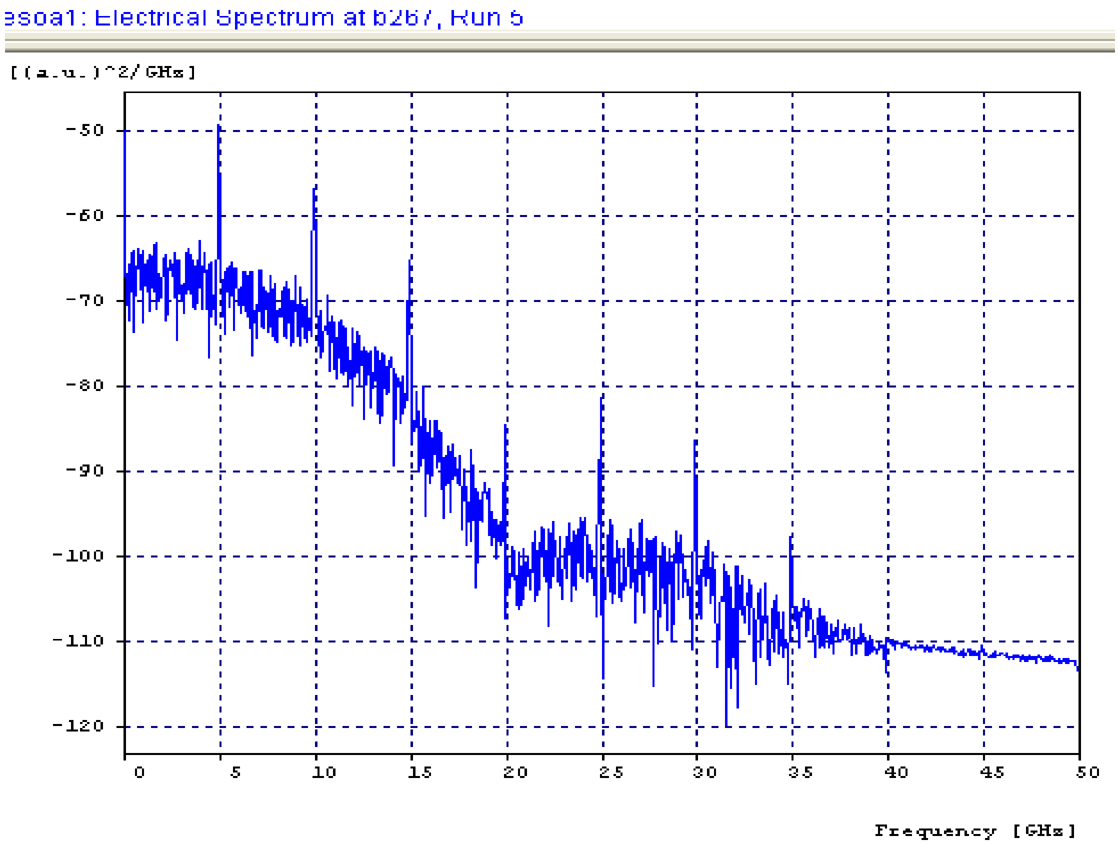

Figure 6.25: Electrical spectrum

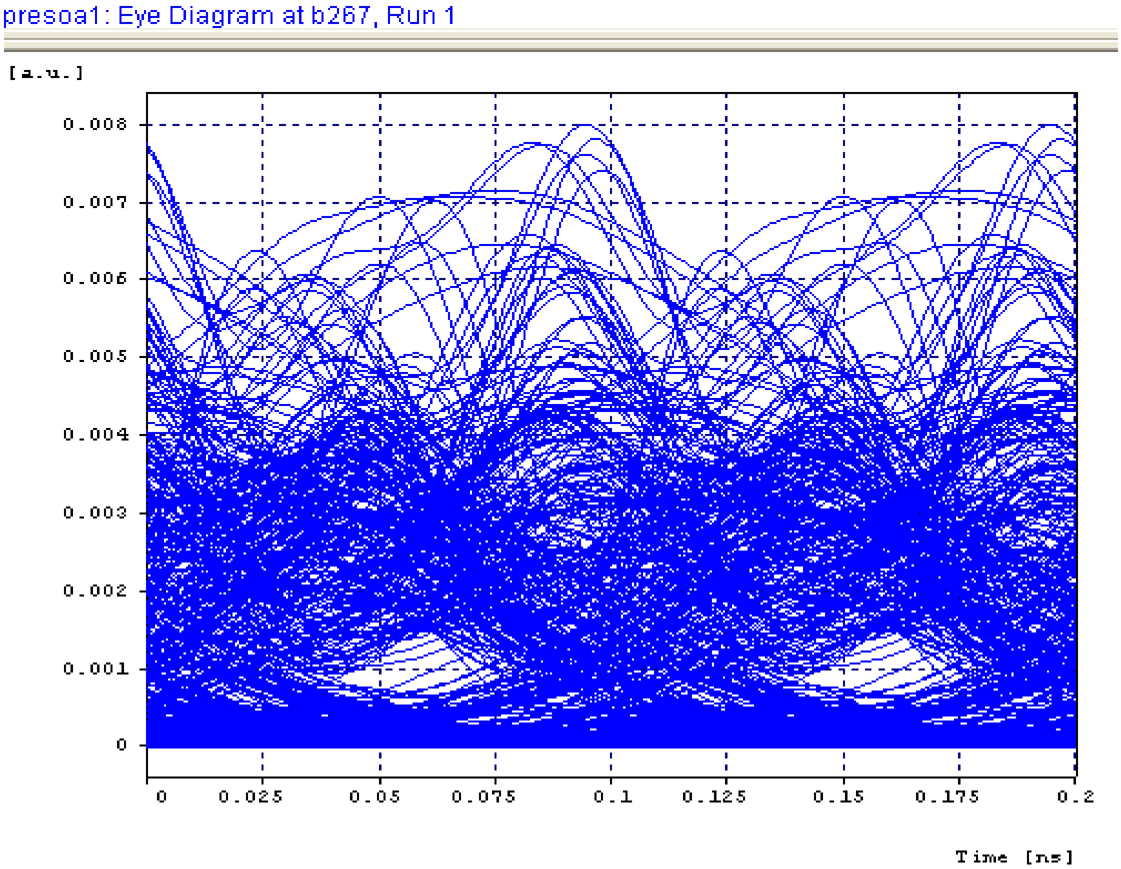

Figure 6.26: Eye diagram at 10 km length

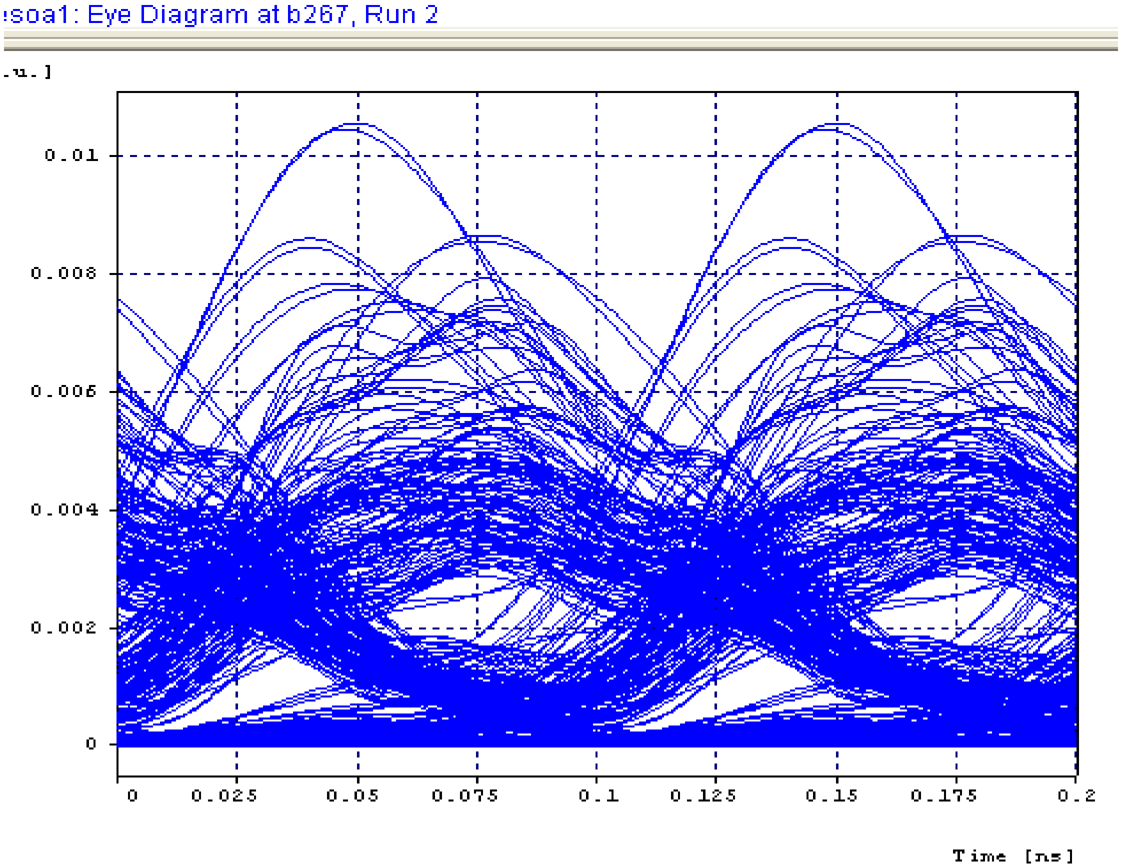

Figure 6.27: Eye diagram at 20 km length

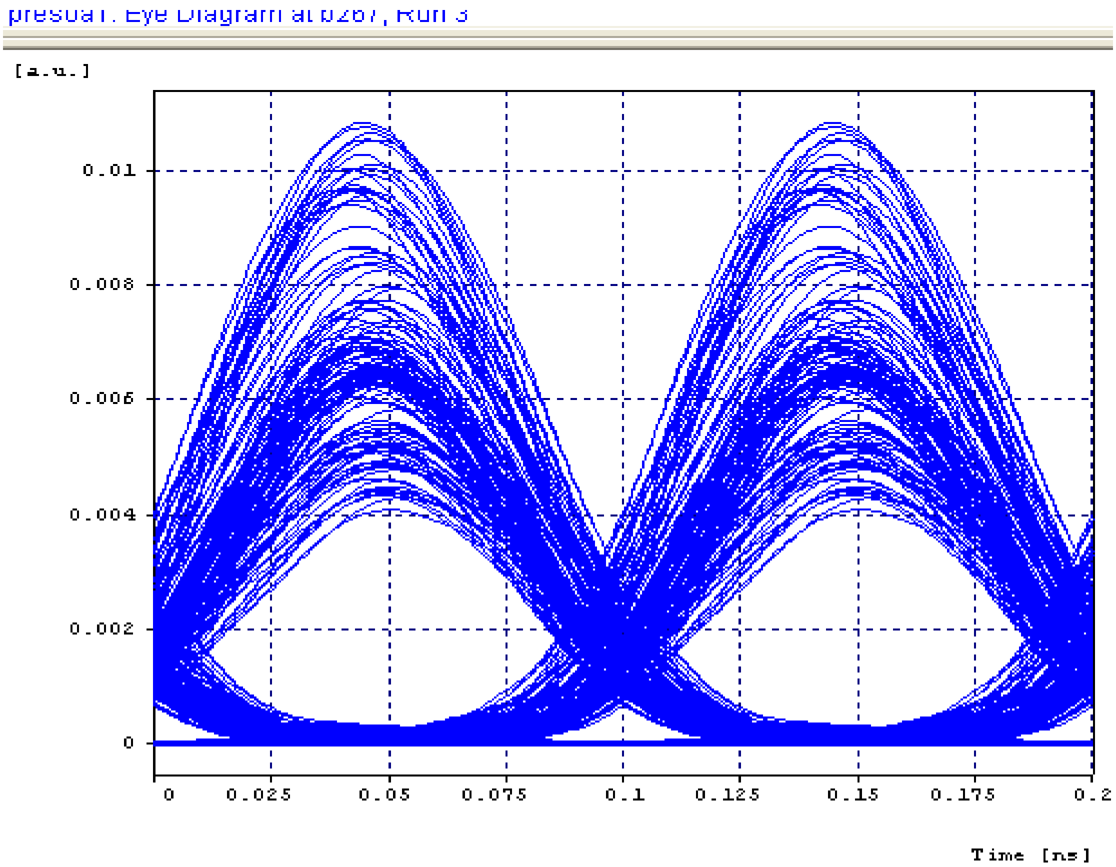

Figure 6.28: Eye diagram at 30 km length

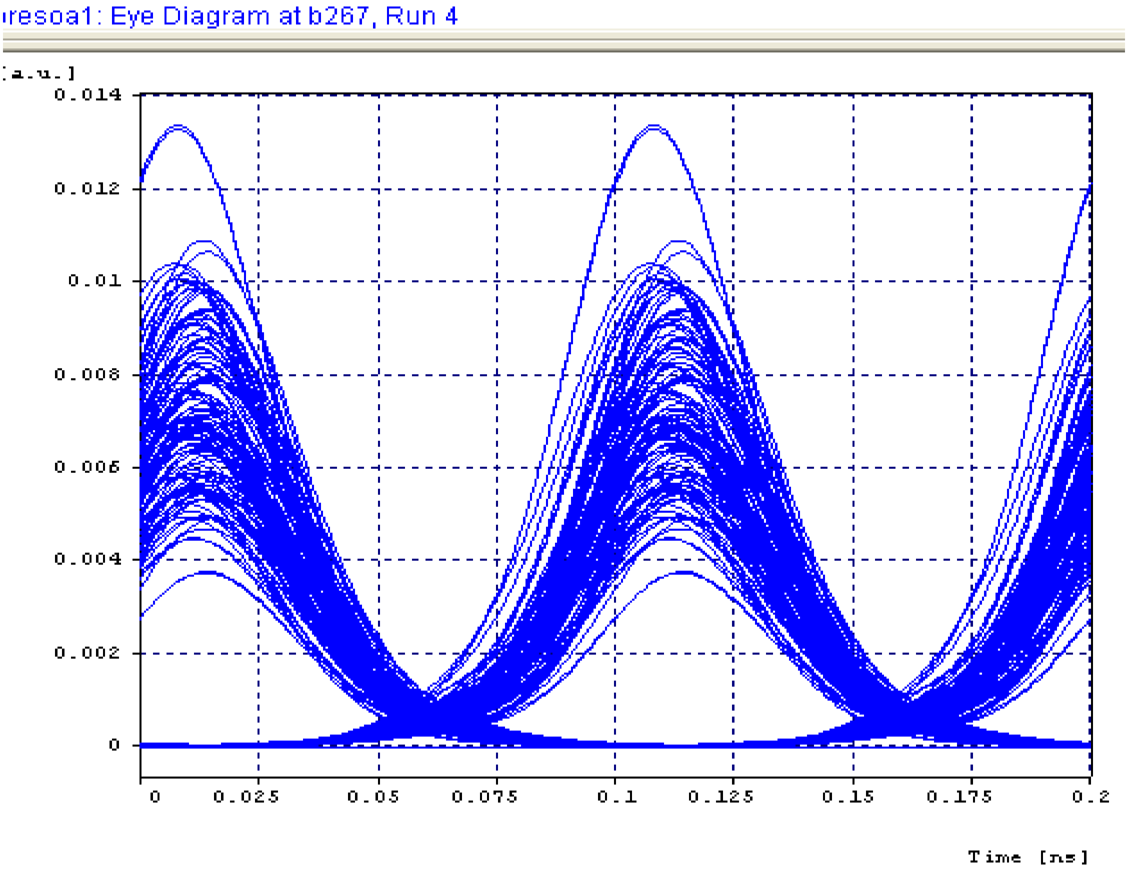

Figure 6.29: Eye diagram at 40 km length

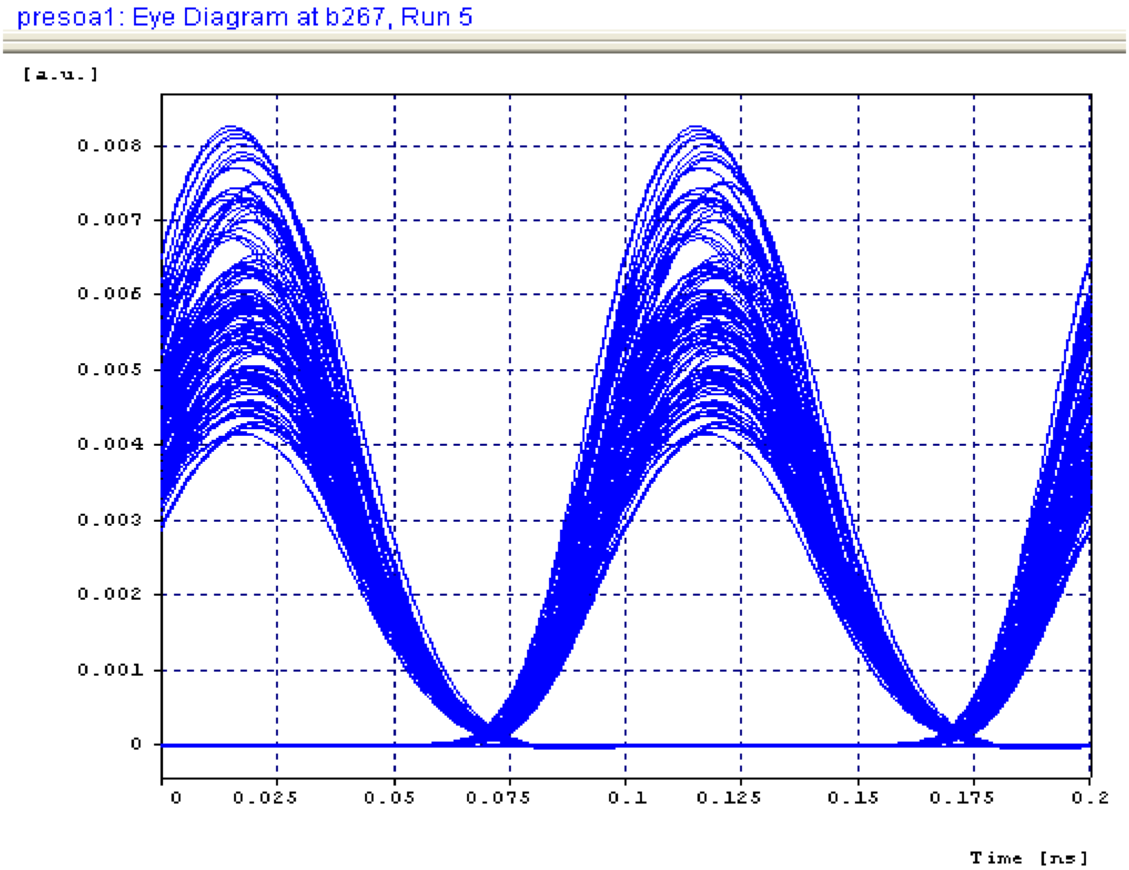

Figure 6.30: Eye diagram at 50 km length

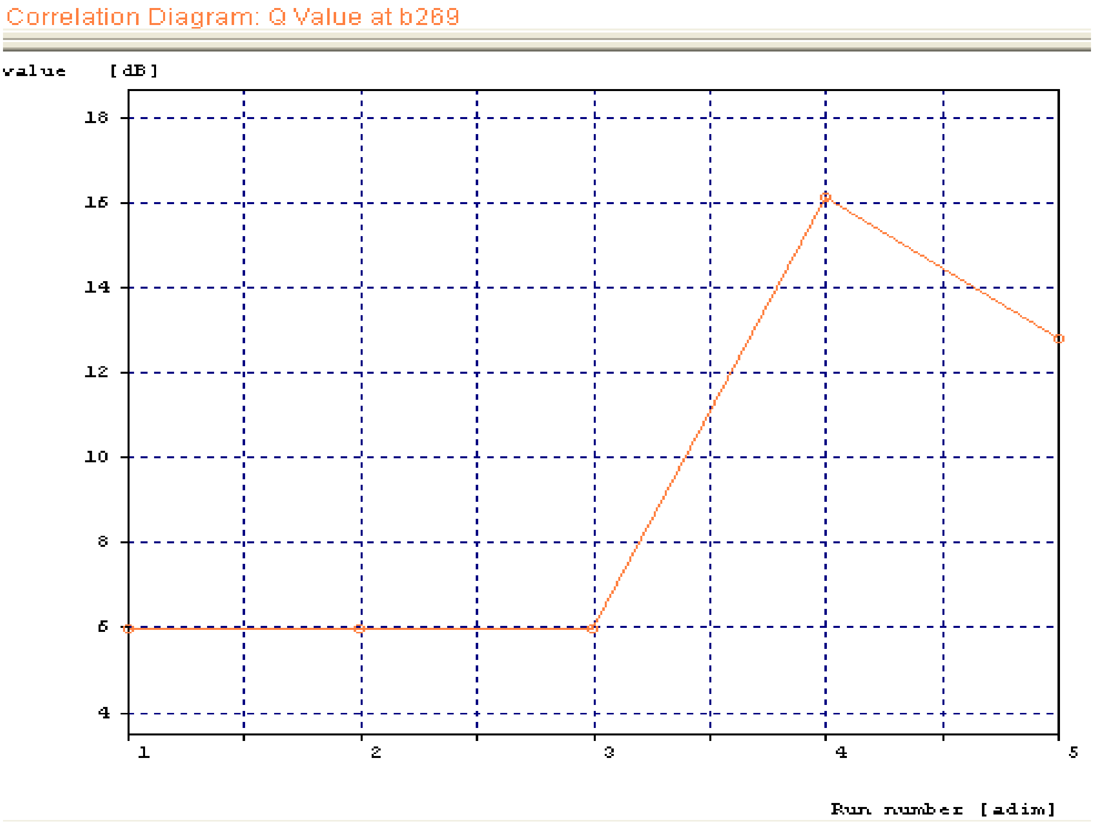

Figure 6.31: Q value

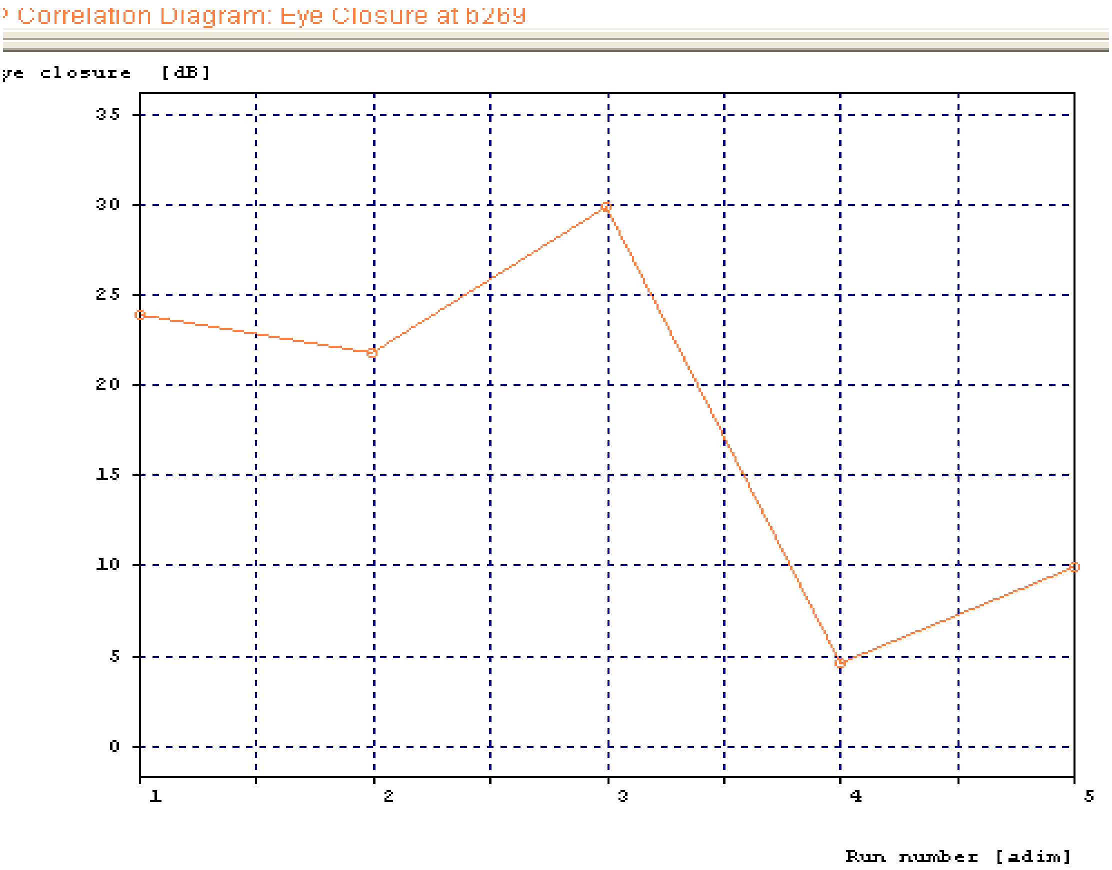

Figure 6.32: Eye closure

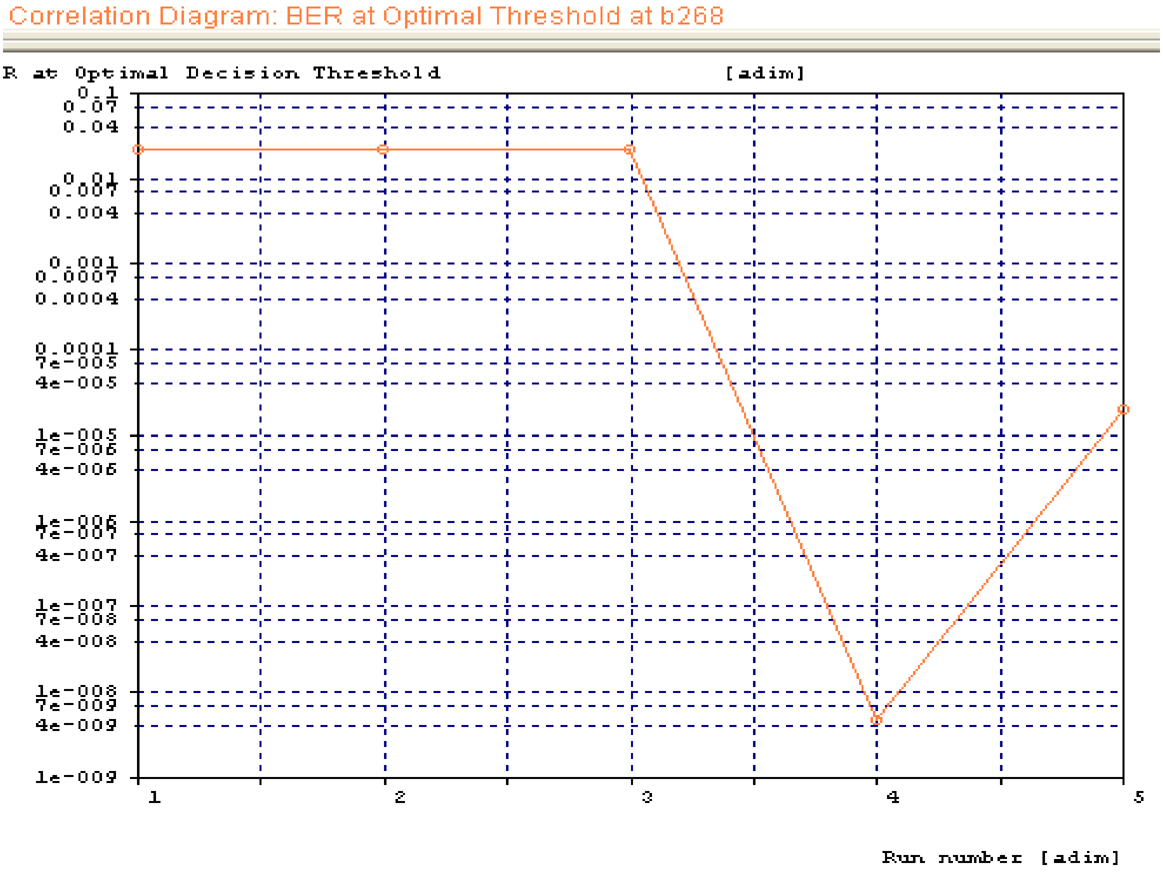

Figure 6.33: BER at optimal threshold

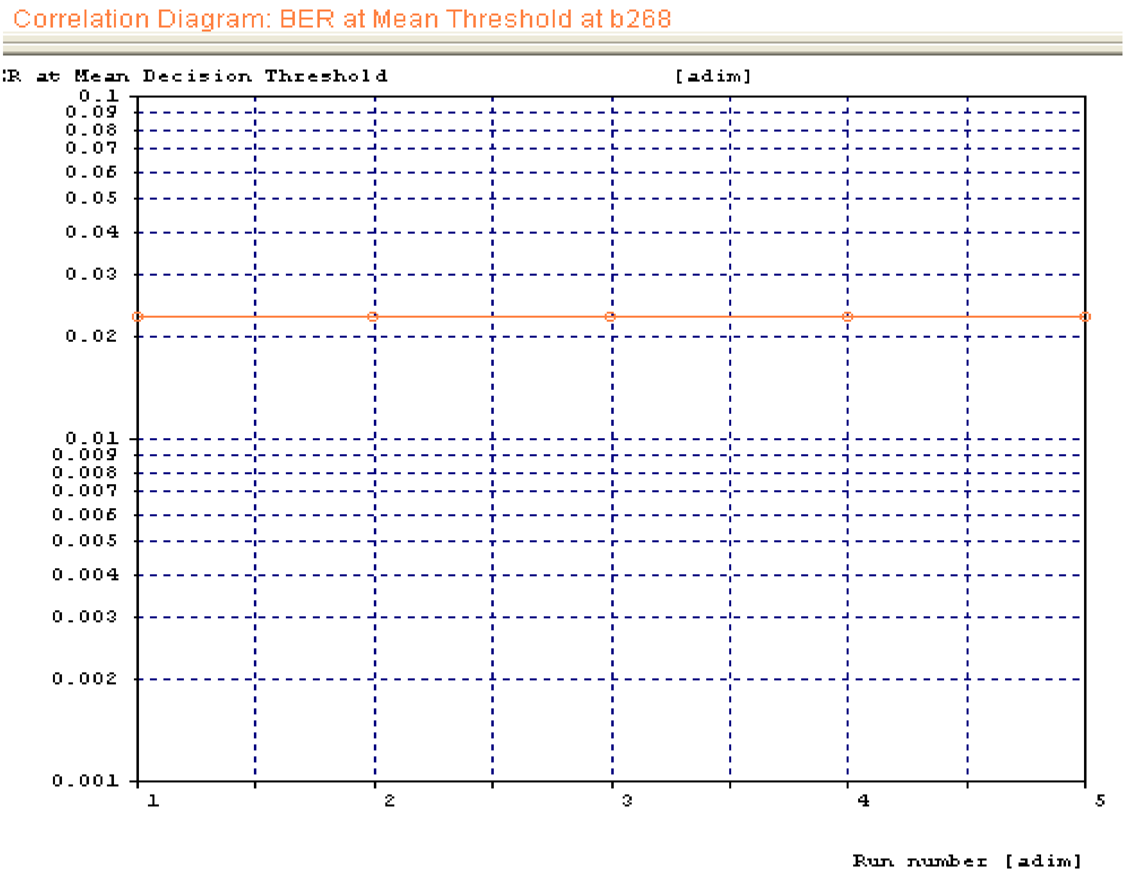

Figure 6.34: BER at mean threshold

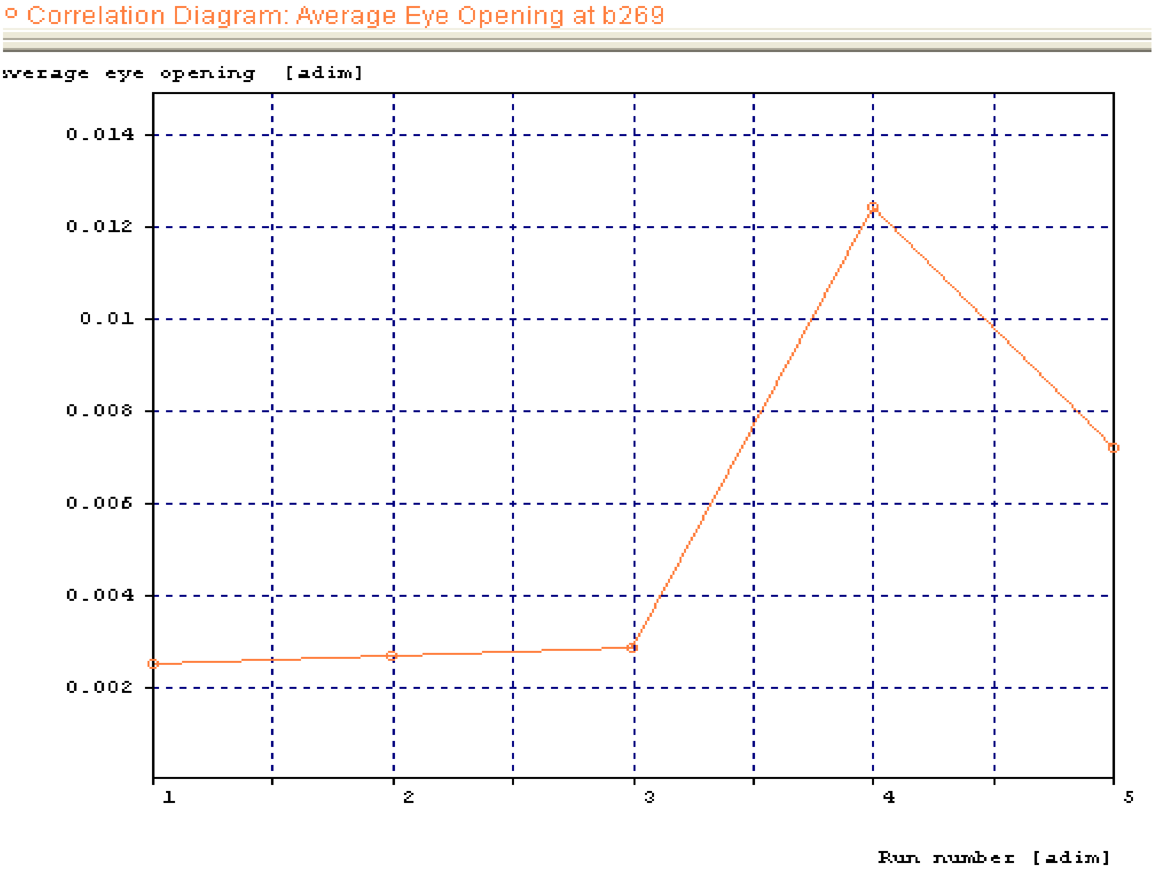

Figure 6.35: Average eye opening

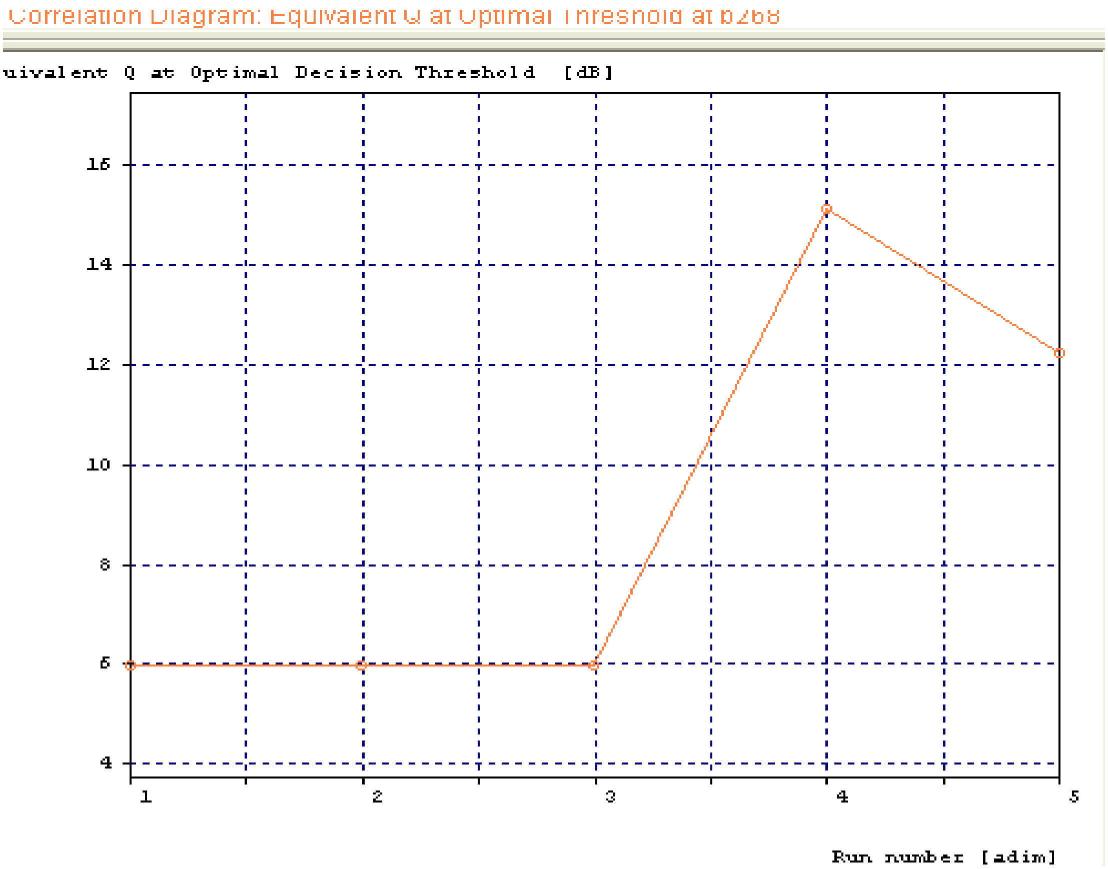

Figure 6.36: Equivalent Q at optimal threshold

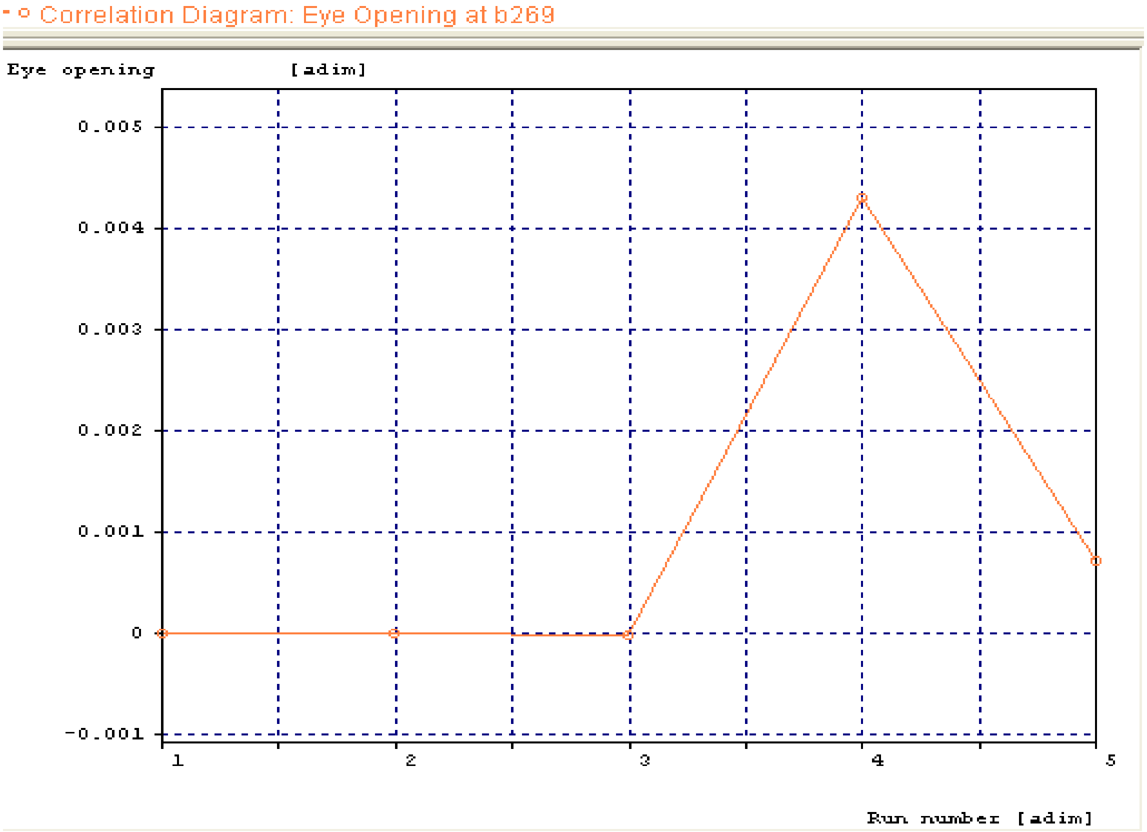

Figure 6.37: Eye opening

CHAPTER 7
CONCLUSION AND FUTURE SCOPE OF WORK

7.1 Conclusion

This chapter provides a summary of the findings of the study which has done so far. Included in the summary are conclusions from observations made during the execution of this study. The study of following objectives is reported. The objective of the thesis is, to observe the performance of 10 Gbps optical communication with the dispersion managed RZ pulse. The RZ pulse is efficient for long-distance, high-bit-rate, wavelength in division multiplexed (WDM) transmission dispersion-managed systems. The effect of varying the dispersion parameter of single mode fiber on optical communication system has been noted. It is observed that with increase in the value of dispersion parameter, there is an increase in the average eye opening and Q-factor value. Also a good desirable bit error rate value has been achieved and reported. Timing jitters are reduced with increase in value. The effect of varying duty cycle of the RZ pulse for a fixed value of dispersion parameter has been performed. It has been shown that by reducing the duty cycle, the performance of the system is improved. It is concluded that RZ pulse system enhance the performance of optical communication networks at high bit rate.

7.2 Future Scope of Work

In this thesis, the work is reported on WDM system with different modulation formats and dispersion compensation techniques at high bit rate. The DWDM system and OTDM system have large bandwidth as compared to the WDM system. So this work is further extended to DWDM and OTDM system. The nonlinear effects such as four wave mixing (FWM) and cross-phase modulation (XPM) are not included in this work. But these nonlinear effects can degrade the overall performance of the optical communication system. So these nonlinearities can be included so that their effect can be reduced by different modulation formats and dispersion compensation techniques at high bit rate. Dispersion and noise effects are ignored in this thesis. It can be included for further investigation

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