ANALYSIS OF THE EFFECT USING FIBER BRAGG GRATING AS DISPERSION COMPENSATOR ON RADIO OVER FIBER NETWORK SYSTEM

ESSAY

CONCENTRATION OF ELECTRICAL ENGINEERING TELECOMMUNICATIONS ENGINEERING

Intended to meet the requirements
obtained his Bachelor of Engineering

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UNIVERSITAS BRAWIJAYA

FAKULTAS TEKNIK

MALANG

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Validity Sheet

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ANALISIS PENGARUH PELETAKAN KOMPENSATOR DISPERSI DENGAN *FIBER BRAGG GRATING* PADA SISTEM JARINGAN *RADIO OVER FIBER*

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Thanks to :

My Beloved Father and Mother

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ABSTRACT

Adrian Satria Permana, *Department of Electrical Engineering, Faculty of Engineering University of Brawijaya*, 26 April 2018, *Analysis of the Effect Using Compensator Dispersion Fiber Bragg Grating on Radio over Fiber Network Systems*, *Academic Supervisor*: Dr. Ir. Sholeh Hadi Pramono, M.S. and Ir. Erfan Achmad Dahlan, M.T.

Radio over Fiber (RoF) is an integrated system between fiber-optic network and wireless broadband communications. RoF technology is a potential solution for capacity and mobility improvement in access networks. Using fiber optic cables as data transmission medium have problems pulse width extension it's mean dispersion, if this widening is allowed, will occur Intersymbol Interference (ISI) w*hich causes the output pulses in the system to overlap and undetected signal. Based on that problem, based on that problem, RoF communication system using Fiber Bragg Grating dispersion compensator on Optisystem software simulations and system effects on parameters such as* BER, *Q-Factor*, and Loss. *according to the data simulation of the effect of NRZ line coding format on fiber link length of* 90 km, 3.5 GHz *RF carrier*, and 10 Gbps *bit rate*. *The value of* BER *that had been obtained is* 5,242 x 10^{-15}, *Q-factor* 7,73281 and loss 2,561 dBm.

Keywords: Radio over Fiber, *Fiber Bragg Grating*, *Long Houl Telecommunations Systems*

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Foreword

Bismillahirrohmanirrohim. Alhamdulillah, *praise gratitude writer pray Allah SWT who has given His grace and guidance, so that writer can finish thesis entitled "Analysis of Influence Laying Compensator Dispersion Fiber Bragg Grating On Radio Network System Over Fiber" well. No freelance shalawat and greetings poured to our lord Prophet Muhammad who has become a role model for those who expect His grace and guidance.*

The author realizes that the preparation of this thesis can not be separated from the help, guidance and encouragement from various parties. On this occasion the authors extend their gratitude to:

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- Ms. Ir. Nurussa'adah, M.T. *as Secretary of Electrical Engineering* Universtias Brawijaya.
- Mr. Ali Mustofa, S.T., M.T. *as Head of Program Study* S1 of *of Electrical Engineering* Universitas Brawijaya.
- Ms. Rusmi Ambarwati, S.T., M.T. *as* KKDK *Telecommunication Program Study* S1 *of Electrical Engineering* Universitas Brawijaya.
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- *My Friend*, Ardillah, Anjani, Bram, Diqy, Fatur, Vicky, Galoh, Habib, Rendra, Idam, Azril, Udin, Rozaq, Adit, Musa and Vema.
- *Family of Electrical Engineering* 2013.

In the preparation of this paper, the author realized that this thesis is not complete, because of the limitations of science and other obstacles that occur during the execution of this thesis. Therefore, the authors expect criticism and suggestions for improvement of the writing in the future. Hopefully this article can be useful and can be used for further development.

Malang, 26 April 2018

Writter

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CHAPTER I
INTRODUCTION

1.1 Background

The development of telecommunications technology continues to evolve, demands High-speed telecommunications is a reality that can not be avoided, increased demand for services broadband and the emergence of new technologies for supports the need for data at gigabit era. In 2010, customers are increasingly focusing on data services, about 10% increase in traffic data service happens (EY, 2015). Network access to the next generation requires kovergensi of fiber optic cables and services wireless. Technology Radio over Fiber (ROF) is a potential solution to increase capacity and mobility as well as a decrease in costs in the access network.

Radio over Fiber (ROF) is a radio frequency signal transmission process through the optical fiber transmission medium. By using optical fibers as a medium intermediary, can transmit data and signals properly, as well as the transmission speed of optical fiber higher than copper cable and fiber optic cable has a resistance high against the noise generated by radio waves (Al raweshidy, 2002).

In the transmission system Radio over Fiber (ROF) using fiber optic cables, occur widening consequences of pulses, known as dispersion, elements such as numerical aperture, core diameter, refractive index, and the spectral width of the laser causes dilation pulse. If this is allowed widening signal format allows occurs Intersysmbol Interference (ISI) which causes the pulse output the system becomes overlapped and making it undetectable (Halina Abramczyk, 2007).

To reduce the problem of dispersion that occurs in all optical fiber, then required additional components namely Fiber Bragg Gratting (FBG). FBG is a type of reflector (Bragg) are distributed in the form of segments in optical fibers. FBG reflect some specific wavelengths of light and pass on the rest, where this can occur due to the addition of a periodic variation of the refractive index of the optical fiber core. With its characteristics of the FBG can function as a filter in the optical fiber for wavelength blocking certain desirable light or a specific wavelength of light reflector (Andreas Othonos, 1999).

In addition to the dispersion along the optical fiber transmission medium, there is also a decrease in the signal power level, the further the transmitted power level will fall signal. The transmitted signal must maintain the signal power level, so that electronic current *receiver can detect the signal well. This can be overcome by using Erbium doped Fiber Amplifier (EDFA) to increase the power level signal. The working principle of EDFA optical source (CW laser) as the input signal light and laser pumping as a signal pumping coupled menggukan pump coupler (Dutton, 1998: 160).*

Laying FBG, EDFA (Ebrium doped Fiber Amplifier), and the length of the FBG the optical system has a very important role. When FBG along with EDFA used at the end of transmitter in optical fiber transmission systems, performance produced better than when FBG and EDFA placed on the tip receiver (Sharma, Singh, & Sharma, 2013).

The research in this paper will discuss the influence of the transmission distance bit rate ROF system and analyzes the effect of laying FBG dispersion compensator to reduce dispersion that occurs done using simulation OptiSystem. Parameters be based on the value of the BER, Q-factor and loss.

1.2 Problem Formulation

Transmission of information through optical fibers occurs consequence of widening pulse known as dispersion, elements such as numerical aperture, core diameter, refractive index, and the spectral width of the laser pulse causes dilation. If the widening of this signal format allowed to allow the case Intersysmbol Interference (ISI) which causes the pulse output the system becomes overlapped and make it undetectable (Halina Abramczyk, 2007).

To mitigate these problems, we need one dispersion compensator can only use FBG in which the refractive index of the core changes periodically can retard different wavelengths, so it can function as a filter FBG namely optics for blocking specific wavelengths or as long reflector specific light waves (Agrawal, 2002).

Transmission system Radio over Fiber (ROF) to be simulated includes parts transmitters, fiber link, and receiver. Parameters that are affected by the laying of FBG is BER, Q-factor and loss. Based on these problems, the formulation of the problem as following:

1. *How to influence the transmission distance to the bit rate*?
2. *How to influence the laying Fiber Bragg Grating the performance of the transmission Radio over Fiber seen from the parameter BER, Q-factor, and loss*?

1.3 Scope of work

In this study consisted of a problem definition of research and research aspects. Place of research conducted in UB's Department of Electrical Engineering. aspects of the study to the problems that have been formulated, among others:

1. *The simulation was performed using software optisystem.*
2. *The simulation was performed using software optisystem.*
3. *Line coding used is RZ and NRZ.*
4. *The light source used is continuous Wave laser with a length 1552.52 nm wave.*
5. *RF frequency used is* 3.5 GHz.
6. *The length of optical fiber used is 10 to 100 km by increments of* 10 km.
7. *Photodetector used is* APD.
8. *Dispersion compensators used is Chirped Fiber Bragg Grating.*
9. *Bit rate which is used in the range of* 5 dan 10 Gbps.
10. *The parameters measured were the BER, Q-factor and loss.*

1.4 Purpose

The purpose of research in this paper is to analyze the effect of laying compensator dispersion Fiber Bragg Grating to reduce the dispersion that occurs in the transmission Radio over Fiber which aims to improve the quality of the signal seen BER parameter, Q-factor, and loss, using OptiSystem software.

1.5 Writing Format

Writing in this study consists of five chapters which generally is as following:

Chapter I contains an introduction that contains the background, the formulation of the problem, problem definition, purpose, and systematic writing.

Chapter II examines the theories that support the thesis that covers the basic concepts Radio over Fiber, Fiber Optics, line coding, dispersion, dispersion compensator Fiber Bragg Grating, optical communication components, performance parameters, as well as software OptiSystem.

Chapter III contains the research methods used to answer the problem formulation. Steps being taken in this chapter describes how to test the effect of distance transmission to bit rate, as well as the laying of the laying FBG effect on system performance ROF seen from the parameter BER, Q-factor and loss.

Chapter IV contains the research objectives in this paper is to analyze the effect of laying dispersion compensator Fiber Bragg Grating to reduce the dispersion that occurs in ROF system to perform simulations using OptiSystem software.

Chapter V contains conclusions and recommendations derived from the analysis conducted as well as the provision of advice.

CHAPTER II
LITERATURE REVIEW

2.1 *Radio over Fiber*

System Radio over Fiber a process of sending a radio signal via cable optical fiber. The basic principle of the ROF transmission is transmitting analog radio signal synthetically by a fiber-optic connection. By using fiber optic cable as a medium instrumentality, has the advantage that low attenuation, bandwidth the big one, high-speed transmission and high resistance to noise generated by radio waves. (Al raweshidy, 2002).

- *Wide Bandwidth And Low Attenuation*

Fiber optics deliver bandwidth Very wide Commercially type of fiber available is Single Mode Fiber (SMF), which is made of glass (silica) have losses low attenuation below 0.2 dB / km and 0.5 dB / km at a wavelength of 1550 nm and 1300 nm, POF has higher attenuation worth 10-40 dB / km range wavelength 500 - 1300 nm. This loss is lower than the commonly encountered, such as coaxial cable, where these cables have losses in 3-fold higher in a high frequency. For example, the attenuation on the coaxial cable along a 0.5-inch (RG-214) worth of> 500 dB / km at frequencies above 5 GHz. Therefore, transmits microwave on optical fiber, transmission distance can be increased many times and power transmission required can be minimized significantly. In the optical fiber, there are three The main transmission windows that provide low attenuation wavelength is 850 nm, 1310 nm and 1550 nm, can be seen in Figure 2.2

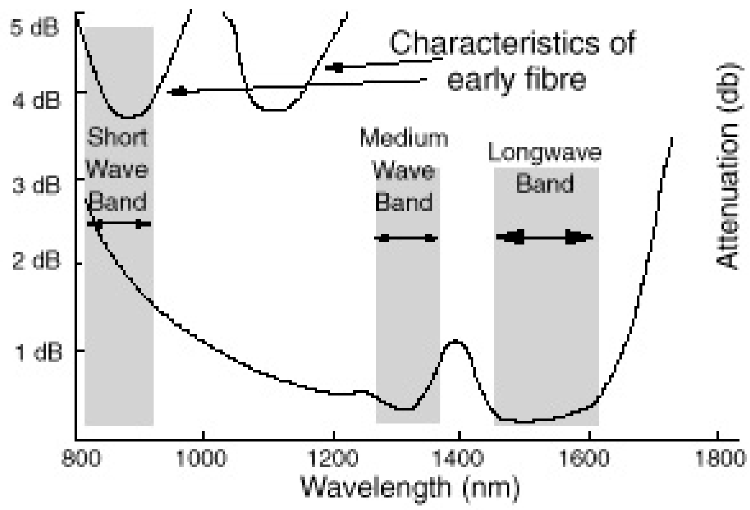

Figure 2.1 wavelengths to the attenuation spectra
(Source: imedea.uib-csic.es)

- *Resistance to Radio Frequency Interference*

Electromagnetic Interference (EMI) is an important property in system communication. the communication system based on optical fiber, it is not too significant effect on system performance, because the fiber optics and wave Electromagnetic manifest in different physical forms. Optical fiber cables are dielectric, thereby not impaired when plagued with signal Electromagnetic.

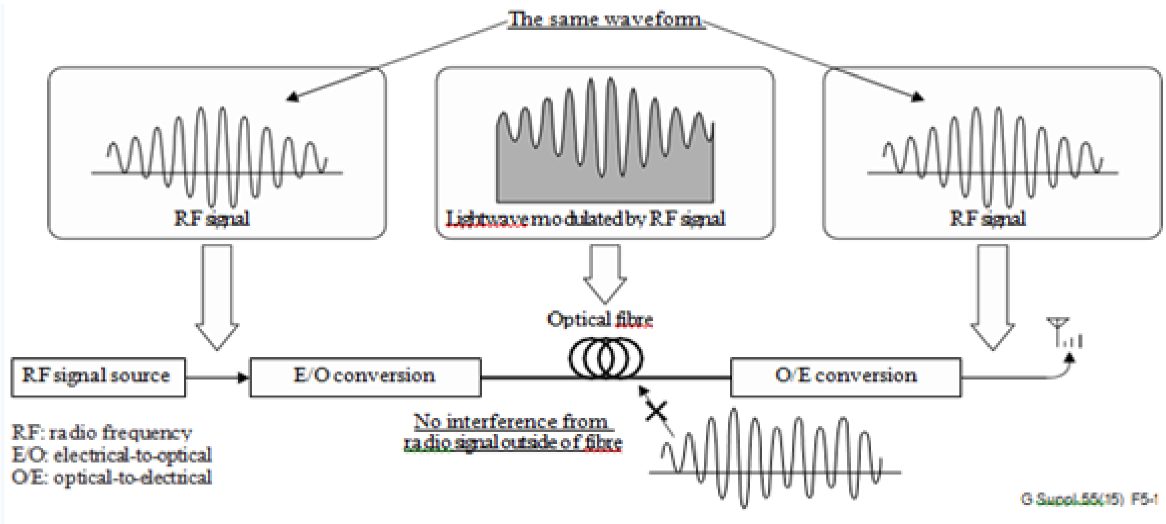

Figure 2.2 *Basic Concepts System* RoF
(Source**:** ITU-T Series G, 2015)

Figure 2.2 shows the basic concept ROF system. ROF is defined as the transmission from base station (BS) toward base transceiver station (BTS) using the medium optical fiber transmission. The waves were sent includes information for service format radio communication such as radio waves. ROF system consists of components for electrical to optical (E / O), optical to electrical (O / E), and the optical fiber transmission medium.

2.2 *Fiber Optic*

Fiber optics is a transmission medium that can distribute information to large capacity with high reliability. Optical fibers made of glass or plastic very smooth and very thin. The simplest form constituting fibre- optic core (Core) cylinder of silica glass sheath surrounded by refractive index lower than core (Agrawal, 2002). Here's the basic structure of the optical fiber can be seen in Figure 2.3.

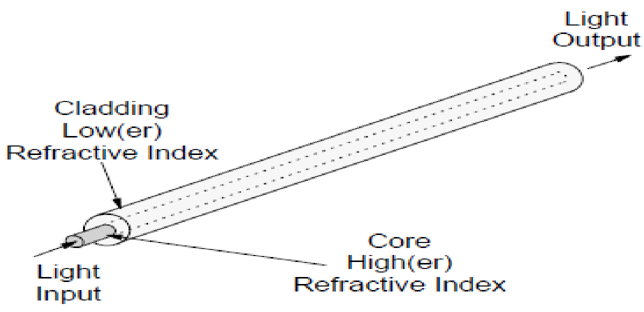

Figure 2.3 The Basic Structure of The Optic Fiber
(Source: Dutton, 1998)

Core (cores) is a core part of the optical fiber, the light is passed. On This section flow information to be communicated from the sender to the recipient, either such as data and voice with a wide range of applications and content in it. Made of ingredients silica (SiO 2) or plastic and is a light merambatnya. Its diameter ranging from 8 to 62.5 micron.

Sheath (c ladding) surrounds a core that serves to reflect light back to in the core (cores). Made from the same material as the core but has a refractive index smaller so that the light remains at the core of the optical fiber.

Most systems use a fiber optic light waves as channel communication because silica can transmit light with losses of 0.2 dB / km. reduced optical power even just 1% after the 100 km (Agrawal, 2002).

2.3 *Optical Fiber Type*

2.3.1. *Singlemode*

Fiber optic types singlemode having a diameter core (core) are small between 8-10 micron. Figure 2.4 shows the propagation of light in optical fibers singlemode. because the diameter core small, singlemode has only one mode of light passing inside it. Typically used for long distance transmission at high speed and loss smaller than the optical fiber multimode.

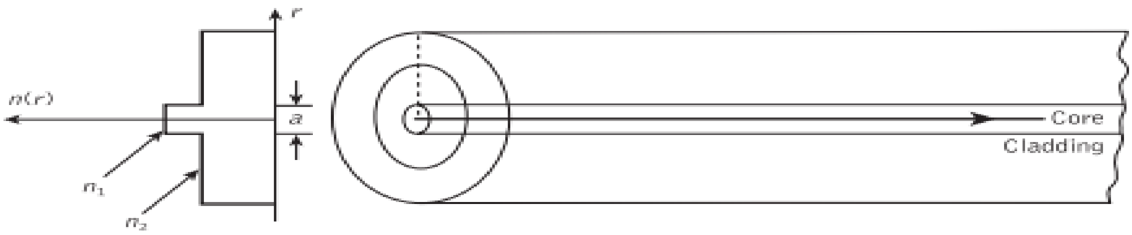

Figure 2.4 Fiber Optic Light Propagation Singlemode
(Source: John M. Senior, 2009)

2.3.2. *Multimode*

Fiber optic types multimode has a larger core of singlemode with 50-80 micron diameter. In this type of many modes of light that passes it. On when a pulse of light into an optical fiber multimode, distributed power pulses almost all modes where each mode has a different speed, so thatmode at higher speeds would be to advance the so-called with capital dispersion. Optical fibers of this type typically used for transmission distances short low speed because it has a large loss. based on the mode propagation, optical fiber multimode divided into two:

a. *Step index multimode*

optical fiber step index multimode have a refractive index of the core values that are uniform all parts of the core. This resulted in the difference between the refractive index of the core with the refractive index sheath. propagation of light step index multimode shown in Figure 2.5. Refractive index difference between core and cladding (Δ) systematically calculated using Equation (2.1) (Keiser, 1991):

$$\Delta \approx \frac{n_1 - n_2}{n_1} \qquad (2\text{-}1)$$

where:

n_1 = *the refractive index core*

n_2 = *the refractive index cladding*

Δ = *relative refractive index difference*

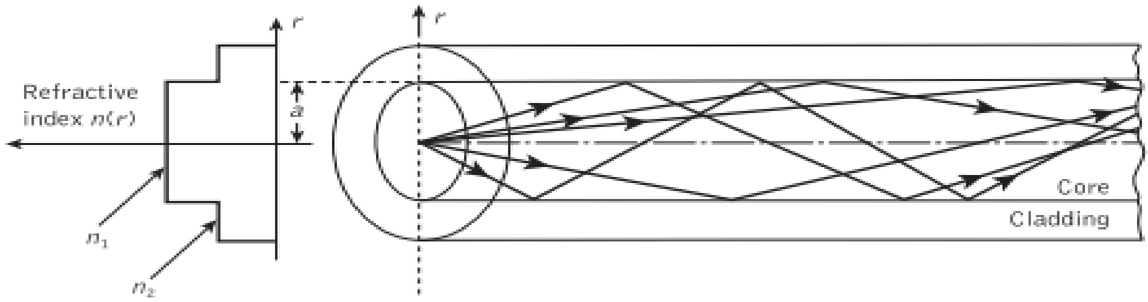

Figure 2.5 Propagation of Light Index Multimode
(Source**:** John M. Senior, 2009)

b. *Graded index multimode*

Fiber optic types Graded index multimode has a core with a gradual decrease the refractive index when the distance is getting away with and will form the core axis parabolic mode as shown in Figure 2.6.

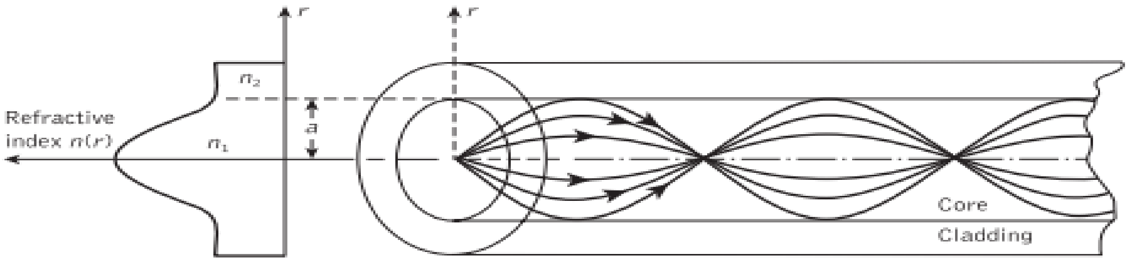

Figure 2.6 *Propagation of Light Graded Index Multimode*
(Source**:** John M. Senior, 2009)

2.4 *Line Coding*

line coding is the process of converting digital data into digital signals. Data in the form of text, numbers, graphics, images, audio, or video stored as a sequence of bits. line coding convert the digital signal to a bit sequence. At the sender, the digital data encoded intodigital signal, while at the receiver, the digital data is converted back to a signal digital by decoding. Figure 2.7 shows the process line coding and Figure 2.8 show sharing scheme line coding five broad categories.

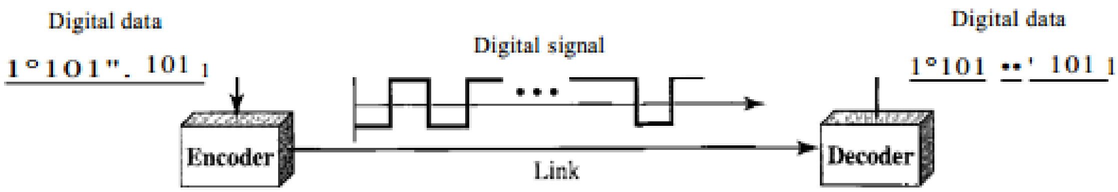

Figure 2.7 *Line Coding*
(Source**:** Forouzan, 2007)

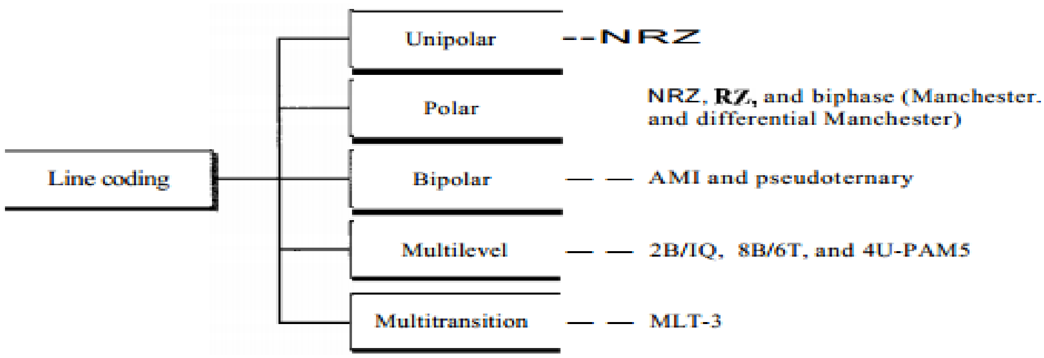

Figure 2.8 Schematic Line Coding
(Source**:** Forouzan, 2007)

2.4.1 *Unipolar*

in the scheme unipolar, all levels of the signal on one side of the axis of time, either at the top or below. In general scheme unipolar designed as a scheme Non-Return-to-

Zero (NRZ) where the positive voltage and the voltage defining a zero bit 1 defines a binary 0. It is therefore called NRZ because the signal does not return to zero the middle bits. Figure 2.9 shows the schematic unipolar NRZ.

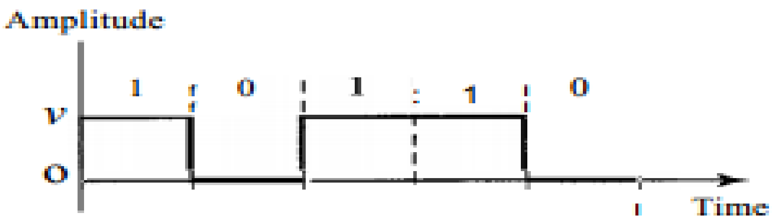

Figure 2.9 Schematic Unipolar NRZ
(Source: Forouzan, 2007)

2.4.2 *Polar*

in the scheme polar, the voltage on both sides of the axis of time. in signal polar, the logic is represented by a positive voltage level, and the other with negative voltage level.

2.4.3 *Nonreturn-to-Zero*

digital encoding nonreturn-to-zero (NRZ) is divided into two NRZ-Level (NRZ-L) and NRZ-Invert (NRZ-I). In NRZ-L voltage level determines the value of the bit, the bit 1 and bit 0 are represented by the voltage level of the signal, while the NRZ-I bit 1 and bit 0 are distinguished by the presence or absence of change in the voltage level of the signal, if there is no change in the bit is 0, but if any changes are: 1. Conversion of data digital to digital signals by using NRZ-L and NRZ-I are shown in Figure 2.10. By observing the signal form NRZ-L and NRZ-I we can see that both polar modulation is still going to have what is called the baseline wandering. NRZ-L at baseline wandering will happen if there is a long line binary 1 or binary 0, while the NRZ-I baseline wandering occurs only in a row Long bit 0 only. In this case the NRZ-I is better than NRZ-L.

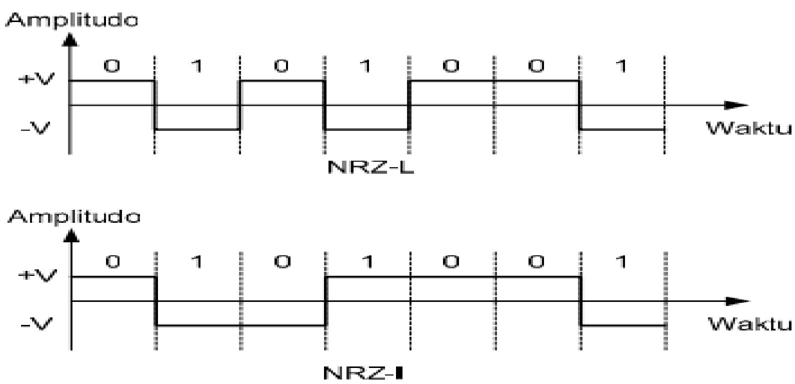

Figure 2.10 Digital Encoding with NRZ-L dan NRZ-I
(Source: Forouzan, 2007)

2.4.4 *Return-to-Zero*

Disadvantages of NRZ-L and NRZ-I improved by digital encoding return-to- zero (RZ). RZ uses three voltage levels (positive voltage, zero and negative) as in Figure 2.11. Thus the problem of the rise of the DC component at the NRZ can be eliminated by RZ.

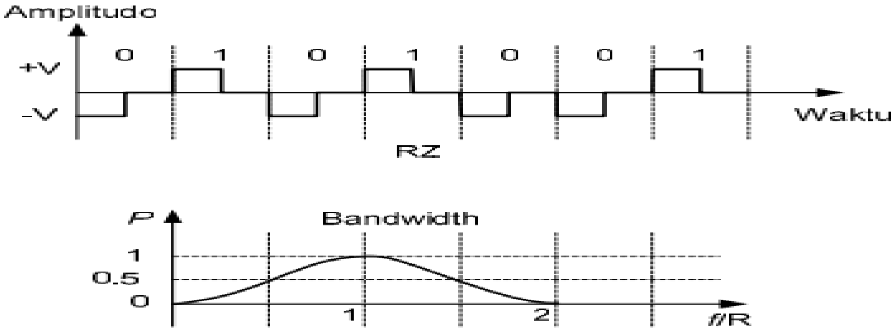

Figure 2.11 Digital Encoding Bandwidth Characteristics Bandwidth RZ
(Source**:** Forouzan, 2007)

RZ encoding always returns to zero voltage signal when the signal has reach half the duration of the signal. But since RZ using two signal elements for represents an element of data, this led to the increase in bandwidth as much as two-fold compared with NRZ. In addition, since RZ require three voltage level device with high complexity required for RZ signal generation, therefore the scheme is not used.

2.5 *Dispersion*

Dispersion in optical signals transmitted causing distortion to the transmission digital and analog transmission along optical fibers. When considering The main implementation of optical fiber that involves some form of digital modulation, the mechanism of dispersion in optical fibers that causes dilation of the light pulses transmitted along the channel (Senior, John, 2009). An illustration of the dispersion can seen in Figure 2.12.

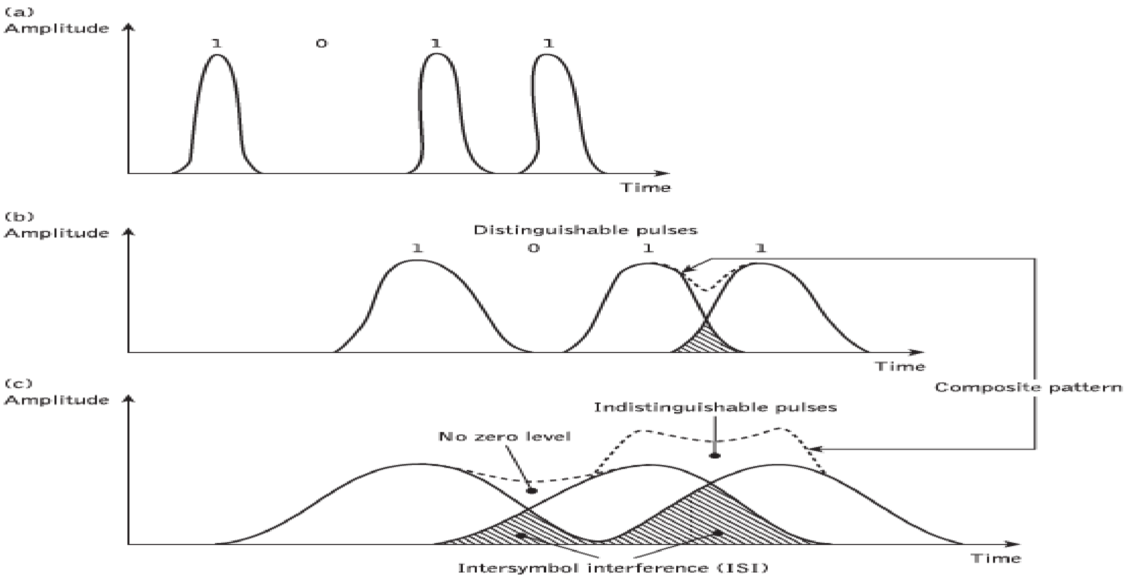

Figure 2.12 Illustration of the widening of the current light pulse propagates along optical fibers: (a) the input signal; (b) widening the pulse; (c) Intersymbol Interference
(Source**:** Senior, John, 2009)

Because of modal dispersion can not occur on the optical fiber single mode, main source of dispersion single mode is the chromatic dispersion, material dispersion and waveguide dispersion wave.

Total fiber dispersion is at the root of the sum of all dispersion in optical fibers. Mathematically expressed as (Ming-Kang Liu, 2002):

$$\tau_{fiber} = \sqrt{\tau^2{}_{material} + \tau^2{}_{waveguide} + \tau^2{}_{intermodal}} \quad (2\text{-}2)$$

dengan:

τ_{fiber}	= dispersi total serat (ps)
$\tau^2{}_{material}$	= dispersi pandu gelombang (ps)
$\tau^2{}_{intermodal}$	= dispersi intermodal (ps)
$\tau^2{}_{waveguide}$	= dispersi pandu gelombang (ps)

2.5.1 *Chromatic Dispersion*

Chromatic dispersion or dispersion intramodal can occur in all types of optical fiber and produced from linewidth Spectral visible from the optical source. Because the optical source not only emit a single frequency, may lead to a difference delay propagation between components spectral which is different from the transmitted signal. This causes dilation of each mode are transmitted, the difference delay caused by the dispersion *properties of the waveguide materials (material dispersion) and also the effect of the guidance in the fiber structure (waveguide dispersion) (senior, John, 2009).*

Intramodal dispersion is the sum of material dispersion and waveguide dispersion wave (Muflihatin, 2002):

$$\tau_{intramodal} = \tau_{material} + \tau_{waveguide} \tag{2-3}$$

dengan:

$\tau_{intramodal}$ = *Dispersion intramodal* (ps)
$\tau_{material}$ = *Dispersion material* (ps)
$\tau_{waveguide}$ = *Waveguide dispersion* (ps)

2.5.2 *Dispersion material*

Widening the pulse caused by the results of the group velocity dispersion material different at different spectral components are launched into the optical fiber optical source (Senior, John, 2009). The equation for the dispersion of the material shown in (DeCusatis, 2002):

$$\tau_{material} = \tau_{dm}\ x\ \Delta_\lambda\ x\ D \tag{2-4}$$

dimana:

$\tau_{material}$ = *material dispersion* (ps)
τ_{dm} = *Coefficient of material dispersion* (ps/(nm.km))
Δ_λ = *Spectral width of the light source* (nm)
D = *Length of optical fiber* (km)

2.5.3 *Dispersion waveguide*

Waveguides of optical fiber can also cause chromatic dispersion. This matter resulting from variations in the speed with wavelengths in a specific mode (Senior, John, 2009).

The equation for the waveguide dispersion that is (DeCusatis,2002):

$$\tau_{waveguide} = \frac{D}{C_\lambda}(n_1 - n_2)t_{wg}\Delta_\lambda \tag{2-5}$$

where:

$\tau_{waveguide}$ = *waveguide dispersion* (s)
D = *Length of optical fiber* (km)
n_1 = *Refractive index of the core*

n_2 = *Refractive index of the sheath*

t_{wg} = *Coefficient of dispersion without the dimensions obtained from the equation:*

$$t_{wg} = \frac{4(1 - \ln v)}{v^2} \tag{2-6}$$

v = *normalized frequency, said boundary modes of an optical signal that can be propagate in the optical fiber core, by the equation*:

$$v = \frac{2\pi}{\lambda} a\sqrt{n_1^2 - n_2^2} \tag{2-7}$$

dimana:

a = *finger - the finger core optical fiber* (μm)

λ = *wavelength emission center* (μm)

Δ_λ = *wide-spectrum light source* (nm)

C = *speed of light in vacuum* (m/s)

2.6 *Fiber Bragg Grating*

glass on the optical fiber can be changed using intense laser light. Reality This leads to a so-called manufacturing Fiber Bragg Grating (FBG). Figure 2.17 FBG showed applications. Lattice contained in the core of the fiber has revolutionized optical fiber communication systems. FBG can be used as a dispersion compensator, application filters, conversion of mode, equalization gain, and wavelength multiplexing. The first FBG discovered in 1978 by Hill et al. Initially grating is made by interference between waves radiating to the front and to the rear. Wave radiating rear Fresnel reflection is generated on the output side. At the height of the pattern This interference, which is the most powerful light, the interaction between light and Ge broken The inside of the glass so that the refractive index change Δn ≈ 10- 3 - 10- 5. Grating period is given in equation (2.8) (DeCusatis, 2002):

$$\Lambda = \frac{\lambda}{2n_{eff}} \tag{2-8}$$

where:

Λ = *grating period*

λ = *Wavelength of the reflected* (nm)

n_{eff} = *the effective refractive index of the grating in the fiber core*

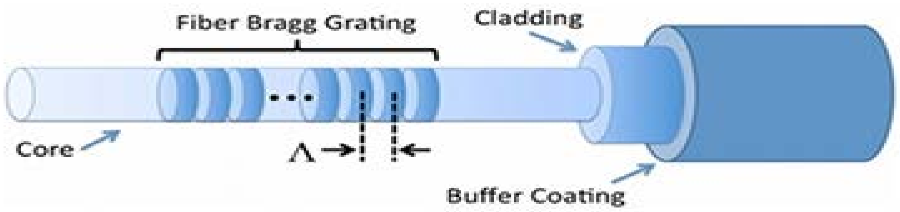

Figure 2.13 *Application of Fiber Bragg Grating on the optical fiber*
(Source**:** National Instrumen, 2011)

Figure 2.14 is the working principle of FBG. An optical fiber grating reflects wavelengths approaching the Bragg wavelength (λB = 2neff. Λ). Reflectionoccurs because light partially reflected at each peak refractive index and reflectanceThe maximum occurs when some reflection is one that is in phase withnext to it (DeCusatis, 2002).

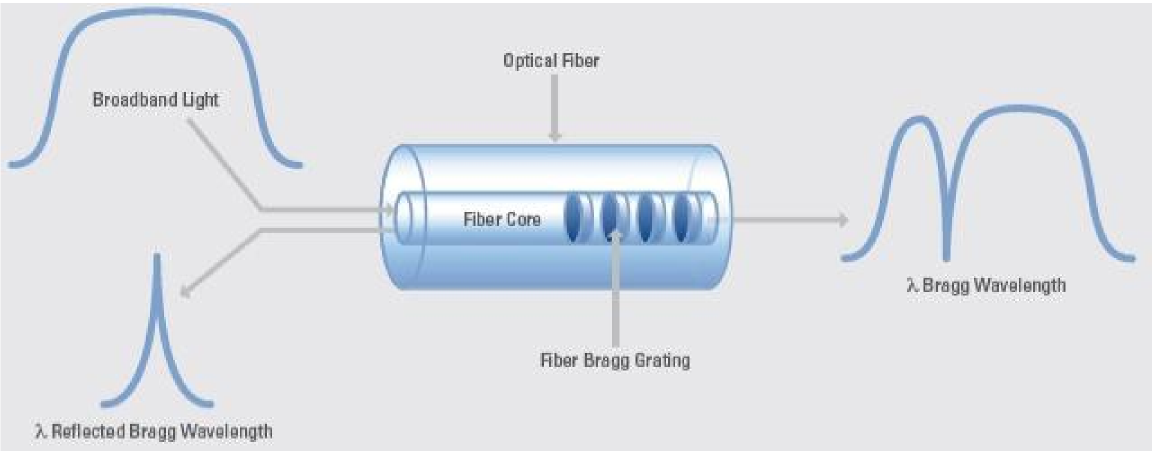

Figure 2.14 The working principle *bragg fiber grating*
(Source**:** National Instrumen, 2011)

One application of this FBG is a dispersion compensator. As has been mentioned earlier, the refractive index is a function of the wavelength on the glass. Pulses of light will always have a widening in function of time during propagation along the fiber. This widening becomes a big problem on systems with bandwidth high for causing pulses to join each other and therefore can not detected. By using FBG where grating period varies linearly in along the fiber (also called chirped FBG) wavelength can slow thus sharpening the pulses different in time. FBG dispersion compensator above 1500 ps / nm in the wavelength range around 1550 nm are commercially available.

Chirp the lattice has many forms. The period can vary symmetrical, an increase or decrease in the grating period. Chirp can be linear, quadratic, or even have a period that jump. A lattice can also be have a period that change randomly along the whole length. Chirp the most often used uniform and linear Chirp (Kashap, 1999).

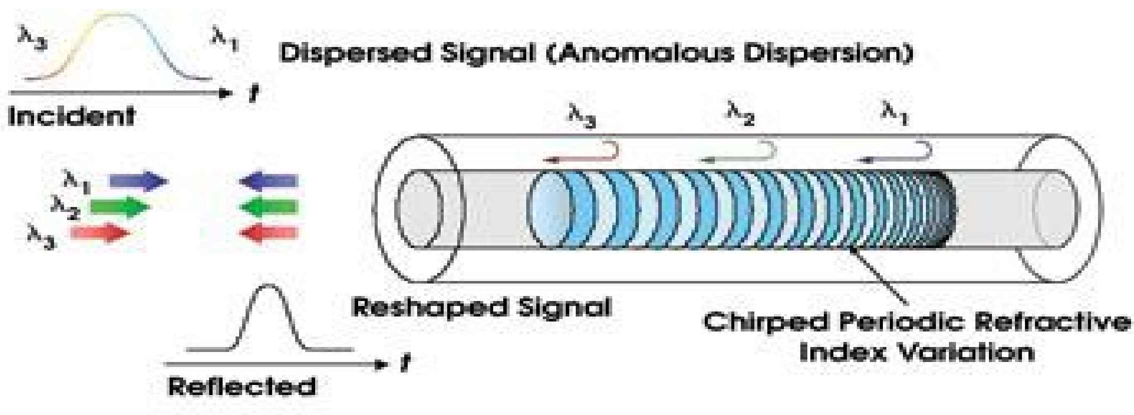

Figure 2.15 *The working principle chirped FBG as a dispersion compensator*
(Source***:*** *www.photonics.com*)

Figure 2.15 explain the working principle chirped FBG as a dispersion compensator. On chirped FBG, the period of induced modulation index varies along the grating. With the change of the lattice period along the axis, different wavelengths reflected by a different portion of the lattice and therefore delayed by differences time. The effect is the compression of input pulses tailored to compensate chromatic dispersion that occurs along the fiber. Although entry into the grid at a time different wavelength components of the pulse are experiencing widening all will return to the input lines at same time (www.photonics.com).

To obtain long-lattice, L adapted to delay reflection and bandwidth lattice desired output (Muflihatin, 2002).

$$L = \frac{c \cdot \Delta_{\lambda-g} \cdot t_g}{2n_{eff}} \qquad (2\text{-}9)$$

where:

L = *Length of the lattice* (m)
c = *Speed of light in vacuum* (m/s)
$\Delta_{\lambda-g}$ = *bandwidth lattice* (nm)
tg = *delay* FBG *reflection* (ps/nm)
neff = *effective refractive index of the grating in the fiber core*

bandwidth lattice is a wide range of wavelengths to be reflected in order output pulse width obtained FBG spectrum with the same characteristics.

$$\Delta_{\lambda-g} = \Delta_{\lambda} \qquad (2\text{-}10)$$

where:

$\Delta_{\lambda-g}$ = *grating bandwidth* (nm)

$\Delta\lambda$ = *broad spectrum optical source* (nm)

When bandwidth lattice is not equal to the width of the optical spectrum of the source, it will be affect the amount of dispersion that appear along the fiber after laying FBG also against the lattice. delay FBG reflection generated should be the same with a large dispersion appeared to get the whole wavelengths in the spectral width of the pulse optical arrived at the same time after passing through FBG.

$$t_g = \frac{\tau_{material} \cdot D_{(FBG)}}{\Delta_{\lambda-g}} \tag{2-11}$$

where:

t_g = *delay FBG reflection* (ps/nm)

$\tau_{material}$ = *Dispersion material* (ps)

$D_{(FBG)}$ = *distance* FBG (km)

$\Delta_{\lambda-g}$ = *Bandwidth grating* (nm)

Total dispersion optical fiber after laying chirped FBG can be calculated by following equation:

$$\tau_{fiber} = \sqrt{\left(\mathrm{tg} \cdot \Delta_{\lambda-g}\right)^2 + D^2({\tau^2}_{waveguide} - {\tau^2}_{intermodal})} \tag{2-12}$$

where:

τ_{fiber} = *Total dispersion fiber* (ps)

tg = *delay FBG reflection* (ps/nm)

$\Delta_{\lambda-g}$ = *Bandwidth grating* (nm)

D = *Length of optical fiber* (km)

$\tau_{waveguide}$ = *Waveguide dispersion* (ps)

$\tau_{intermodal}$ = *Intermodal dispersion* (ps)

The main advantage of using FBG as dispersion compensation techniques are the cost effective and have insertion loss low and there is a component passive matching single mode fiber. Application of FBG can be found at different fields such add and drop filter WDM, pump lasers, and the long stabilizer wave (Singh, 2015).

Formation of grating in an optical fiber can be made by irradiating fiber using optical sources to get a core refractive index changing with Certain parallel period (Edita Rosana, 2013). The types of FBG based on changes the refractive index can be seen in Figure 2.16.

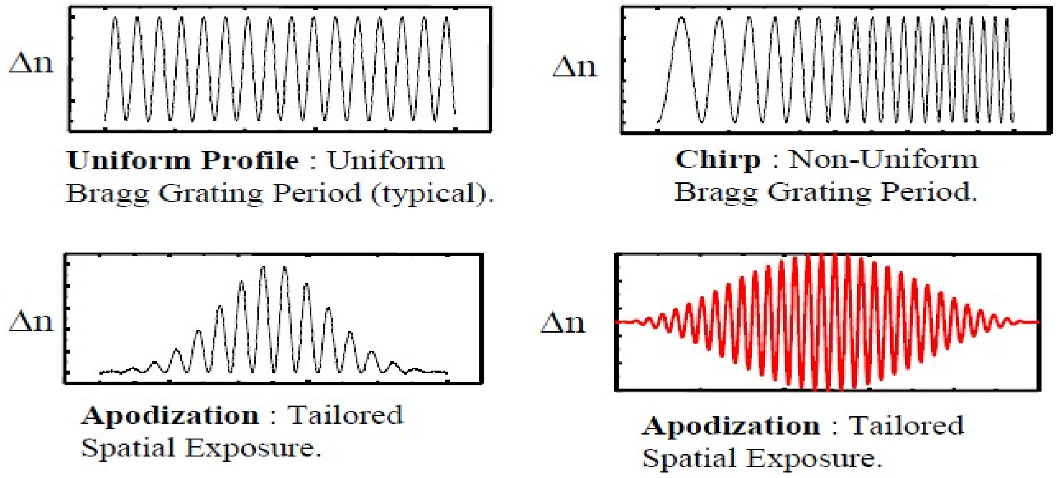

Figure 2.16 *refractive index changes for different types of lattice*
(Source**:** Chiareli, 1999)

lattice type uniform have a fixed period in the longitudinal direction with reflection wavelength steep and sharp peak. Possible bandwidth of 0.1 even less depending on the lattice.

lattice type chirped have a period of change in its longitudinal direction. Changes will be made continuous period of continuous change also to The reflected wavelengths and will get a wide waveform.

Mechanical lattice " apodization "Ie amplitude grating refractive index changes (Δn) changes

along the lattice in order to suppress the wavelength at lobes who does not desirable, but it is used to adjust the shape of the spectrum envelope reflection (Edita Rosana, 2013).

2.7 *Continuous wave (CW) laser*

CW laser emits electromagnetic waves that continually as is shown in Figure 2.17. LASER is an acronym Light Amplification by Stimulated Emission of Radiation. In this pecobaan CW laser set as the source light. CW laser is a laser with a continuous output of more than or equal to 0:25 watts which is constant in the delivery of laser power.

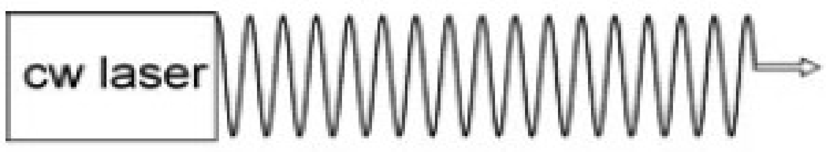

Figure 2.17 *CW* laser
(Source**:** *www.springer.com*)

Tabel 2.1 *Comparison of characteristics of* LED dan LD
(Source: Syauki, 2008)

No.	Karakteristik	LED	LD
1.	*Transmissible time* (detik)	2 – 10	0,3 – 1,0
2.	*Output power* (mW)	0,5 – 4,0	1,5 – 8,0
3.	*width of the spectrum* (nm)	30 – 150	1 – 10
4.	*Losses clutch*	*Greater than*	*Smaller*
5.	*Climate Sensitivity*	*more resistant*	*sensitive change*

2.8 *Mach-Zehnder Modulator*

For a transmitter with a high-speed, laser refracted at a constant current to deliver CW output, and an optical modulator placed after the laser CW function convert light into pulses encoded data strings with format appropriate modulation. optical modulator Mach Zehnder utilizing LiNbO3 material (lithium niobate) and Mach-Zehnder (MZ) interferometer for intensity modulation. two titanium diffused into LiNbO3 waveguides of two MZ interferometer arms. The refractive index electro-optical material such as LiNbO3 can be changed by applying an external voltage. In the absence of an external voltage, the optical field in the two arms of the MZ will interfere constructively. Additional phase shift occurs in one arm through changes index induced voltage which eliminates the constructive nature and reduce the intensity transmitted. Specifically, no light is transmitted when the phase difference between the two arms is equal to π, because of destructive interference occurs (Agrawal, 2002).

In an EO modulator light beam was split in two and then sent through two separate paths, as shown in Figure 2.18.

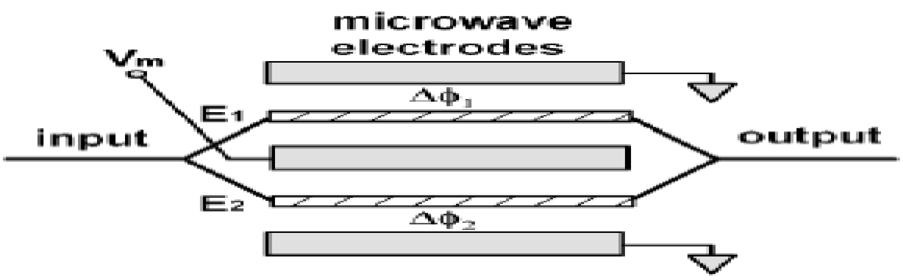

Figure 2.18 *Mach-Zehnder Structure Modulation*
(Source: Hodžić, 2004)

2.9 ***Erbium Doped Fiber Amplifier*** **(EDFA)**

EDFA consists of short fibers (typically 10 meters or more) who have a small amount of the element erbium (which is pretty rare earth element) is added to the glass in the form of an ion (Er^{3+}). *Figure* 2.19 *is an illustration of the* EDFA.

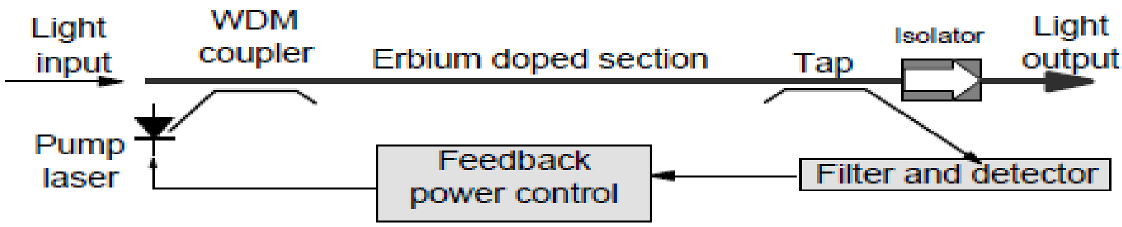

Figure 2.19 *Erbium Doped Fiber Amplifier*
(Source: Dutton, 1998:159)

The principle involved here is the principle of laser and very simple. Erbium ions can found in some energy conditions. When erbium ions in a high energy state, photon light will stimulate the ions to drain some of its energy (in the form of light) and back to the lower energy state (more stable). These conditions referred to "Stimulated emission".

In order for this principle to work, it needs a way to make erbium atoms are the highest energy condition. Laser diode in the diagram generating spotlight with a high power (between 10 and 100 mW) at a wavelength so that the ion erbium will absorb it and jump to the highest conditions (light on the length wave 980 nm or 1480 nm will do this quite well). (Dutton, 1998:160).

2.10 ***Optical Detectors***

Optical detector is a tool that can convert light energy into energy electricity. Optical detector works on the principle that the photoelectric emission liberation of electrons from the surface of the laser as a result of the absorption of the photon energy. There Two (2) types of optical detectors, ie PIN (*Positive-Intrinsic Negative)* and APD (*Avalanched Photo Diode)*. Characteristics Table 2.2 shows a comparison between PIN and APD.

Tabel 2.2 *Comparison of parameters and characteristics of PIN and APD*
(Source**:** Syauki, 2008)

No.	Karakteristik	PIN	APD
1.	*The minimum optical power*	*Greater than*	*Smaller*
2.	*Responsitivitas*	0,35 – 0,8	2,5 – 120
3.	*Strengthening*	1	10 – 250
4.	*noise detector*	*Smaller*	*Greater than*
5.	*Time transmissible*	0,06	0,1 – 0,3

2.11 *Performance Optical Fiber*

Optical fiber performance is affected by large losses (losses). Value losses fiber optics written in units decibel (dB) or in dBm. To count losses value power or voltage inputs and outputs must be known. The calculation method losses shown in equation (2.13) (Bhargava, 1984).

$$L = 10\ log\frac{P_i}{P_o} = 10\log\left(\frac{V_i^2}{V_o^2}\right) = 20\log\frac{V_i}{V_o} \qquad (2\text{-}13)$$

dimana:

L = *losses* (dB)

P_i = *input power* (Watt)

P_o = *output power* (Watt)

V_i = *The input voltage* (Volt)

V_o = *the output voltage* (Volt)

Voltage is an important parameter in measuring the performance of a system to know losses. Another parameter that is used to measure the quality of the system including optical fiber that BER performance and eye pattern.

2.12 *Q-factor*

Q-Factor is the factor that will determine the quality of the good or bad of a link on a network. Q-Factor Criteria to evaluate the performance of the transmission system often combined with BER measurement. Q-Factor is defined as a method which is used to calculate based on a Gaussian distribution inaccuracy (Vorgelegt, 2004: 78). The relationship between BER and Q-Factor is shown in equation (Wan Rizal, 2011):

$$BER = \frac{1}{\sqrt{2\pi Q}} e^{-\frac{Q^2}{2}} \qquad (2\text{-}14)$$

Q-Factor calculation method allows a good estimation of the BER. from Figure 2:20 shows the relationship of Q-Factor of the BER, as we see, the higher Q-Factor, BER happens the better.

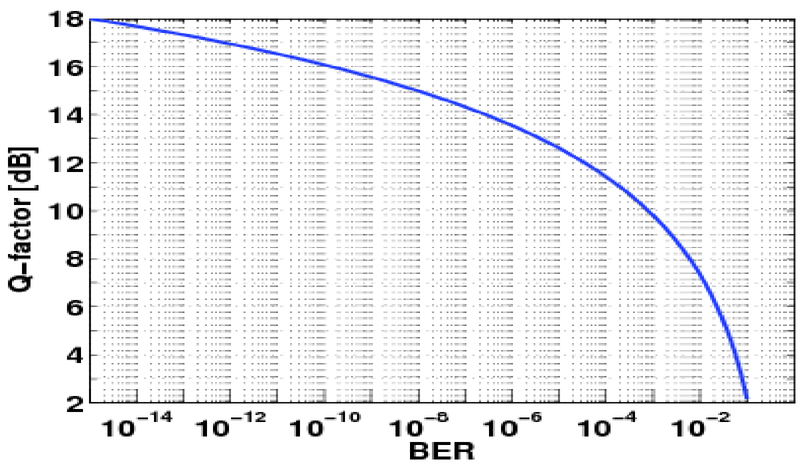

Figure 2.20 *Relationship Graph* BER *and Q-factor*
(Source: *www.photonics.com*)

2.13 *Bit Error Rate*

Losses in optical fiber reduce the size of the received power at the receiver. This matter will affect system performance parameters indicated in the Bit Error Rate as shown by the curve in Figure 2.18. When power is received, the small, Bit Error Rate value will be high. It shows a lot of data errors in the data transmitted in the system.

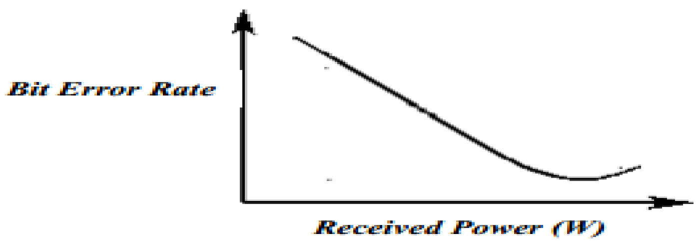

Figure 2.21 *Bit Error Rate curve against Received Power*
(Source: The Fiber Optic Association, 2009)

BER also called the bit error probability (P $_{e}$) the value of measuring signal quality accepted for digital data transmission system. BER states how many bits of one of the occurred within in seconds. BER can also be defined as the ratio of the number of bit wrong to total bits ditransmisika. Applications on the ITU-T G.691, ITU-T G.692, and ITU-T G.959.1 state that the optical system must be designed with the BER value does not less than 10^{-12}.

Error beet on the transmission of data can occur because of the distortion wave random. In other words, when the noise interfere with the transmission signal stable against time in t seconds then the calculation becomes easier to do, but if bust error happen the calculation bit error will menadi longer. BER is expressed as a function of time which is mathematically shown in Equation (2.15) (Hui, Rongqing, 2009).

$$BER = \frac{1}{\Delta t \ x \ BR} \tag{2-15}$$

where:

Δt = *Interval calculations, gettering time (* sec)

BR = *bit rate* (bit/sec)

2.14 *Eye Pattern*

*Eye pattern also called the eye diagram which is an oscilloscope display of data digital receiver have experienced several processes sampling to know the characteristics of the signals. Eye pattern shows the quality of the transmission signal high-speed data. Eye pattern will be shaped like a square in ideal conditions, but because the data transmission system are attenuation, the transition is not in the form of a vertical line straight and produce eye-like pattern, as shown in Figure*2.

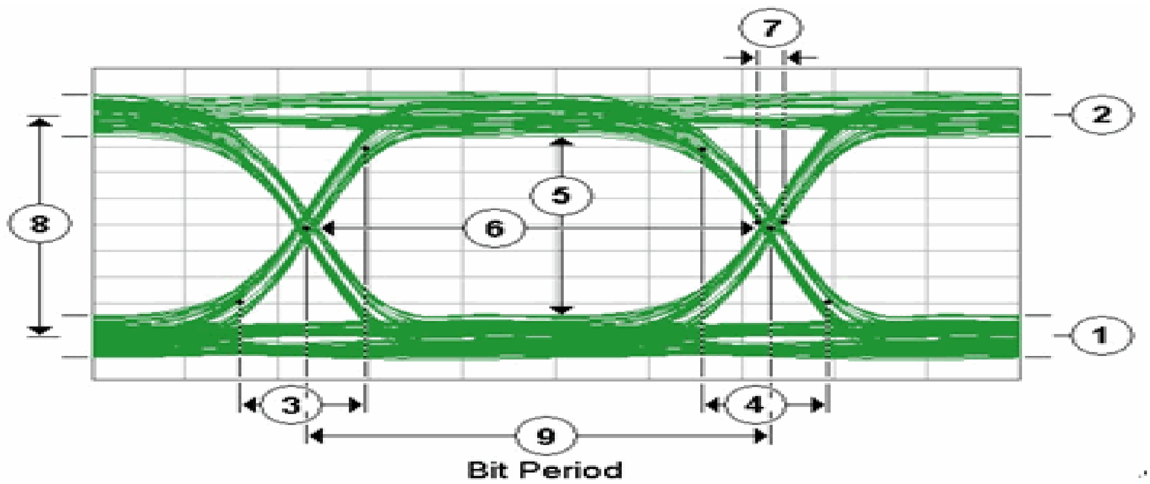

Figure 2.22 *Eye Diagram*
(Source**:** *http://na.support.keysight.com*)

1. Level 0

Level 0 is a measure of the average value of logic 0

2. Level 1

Level 1 is a measure of the average value of a logic 1

3. Rise Time

Rise time is the size of the data transition time of the level of 10% to a level of 90% on the upper slopes of eye diagram.

4. Fall Time

Fall time is a measure of the time of the data transition rate of 90% to a level of 10% the downward slope of the eye diagram.

5. Eye Height

Eye Height is the vertical size diagram eye opening. Eye opening The ideal would be measured from level 1 to level 0. However, noise on eye pattern will cause pattern close.

6. Eye Width

Eye Width is the horizontal size diagram eye opening. ideally, eye width will be measured between the point of intersection at eye pattern. However, jitter may appear on the wave and influence eye opening.

7. Deterministic Jitter

deterministic Jitter is the deviation from the ideal time transition caused by reflection relative to other transition.

8. Eye Amplitude

Eye Amplitude is the difference between the level of logic 1 and logic 0 level histogram of values the average of the eye diagram.

9. ***Bit Rate***

bit rate measuring the extent to which eye pattern open horizontally measured from crossing point. From bit rate, bias known data rate (1 / bit period). bit rate also call with Unit Interval (UI) on eye diagram.

2.13 *Power Link Budget*

Power link budget is a power calculation performed on a transmission system which is based on the channel characteristics (damping), optical sources, and sensitivity photodetector. Power calculation signal has the following equation:

$$\alpha\ total = (L1 \times \alpha \text{ serat}) + (L2 \times \alpha\ serat) \quad (2\text{-}16)$$

Info:

L_1 = *Length First optical fiber* (Km)
L_2 = *Length of the Second optical fiber* (Km)
α total = *Total system attenuation* (dB)
α serat = *Fiber attenuation* (dB/Km)

As for the value of the received power in photodetector or block recipients can calculated by the equation:

$$PRx = PTx - \alpha\ tot \quad (2\text{-}17)$$

Info:

$\alpha\ tot$ = *Total damping system* (dB)
PRx = *Power received, the receiver sensitivity* (dBm)
PTx = *Send power* (dBm)

2.15 ***Bit Rate***

The bit period is a measure of the horizontal opening eye diagram or eye opening on points of intersection of the eye and is usually measured in picoseconds for digital signals high speed. bit rate can be calculated from bit interval by using. For calculate bit rate shown in equation (2.18) (Agilent, 2012).

$$Bit\ Rate = \frac{1}{T_b} \tag{2-18}$$

bit interval calculated from the point zero crossing point which affects a large eye width. The wider eye width, the time required to transmit one bit of data the longer. Time to transmit one bit of data is called the bit interval. Big This time will affect the speed of data bits transmitted or bit rate. The smaller bit interval then the value bit rate will be even greater, as shown in Figure 2.23.

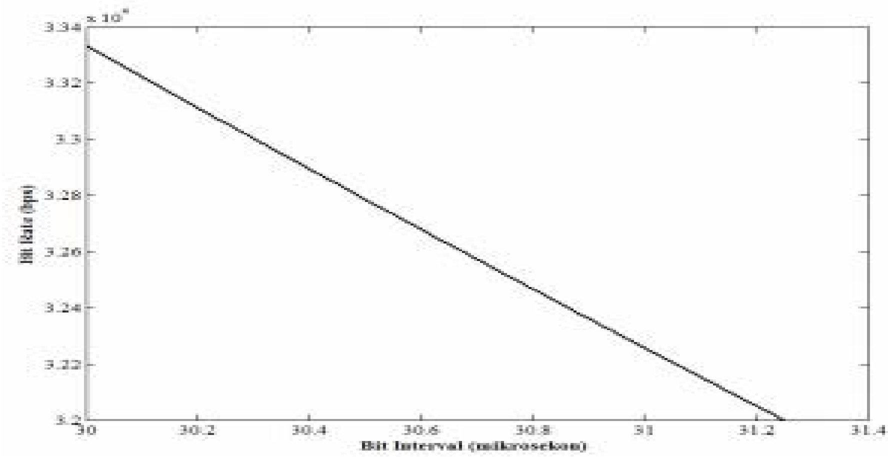

Figure 2.23 Characteristics *bit Rate* to Great *bit interval*

2.15 ***Radio Frequency***

In terms of the use of frequencies and the frequencies for each type called radio frequency radio frequency spectrum. Because the size of different frequencies, of course each frequency that has specific characteristics in its use. then the media radio transmissions are widely used can be distinguished:

- *Middle Frequency* – MF (300 – 3000 KHz)
- *High Frequency* – HF (3 – 30 MHz)
- *Very High Frequency* – VHF (30 – 300 MHz)
- *Ultra High Frequency* – UHF (300 – 3000 MHz)
- *Super High Frequency* – SHF (3 – 30 GHz)
- *Ekstra High Frequency* – EHF (30 – 300 GHz)

The characteristics of each specific use of the radio frequency is:

a. MF (*Middle Frequency*) *called a radio system with a wavelength being. Widely used in commercial private radio broadcasting, amateur radio, orari, and etc.*
b. HF (*High Frequency*) *called a radio system with a short wavelength. Widely used fatherly relationship to places that are far away or remote. Before used satellites and equipment for other frequencies, these frequencies types many used by government agencies, private agencies, including PTT (now Telkom) for the benefit of their telecommunications relationship. Users often called the HF frequency with SSB (single side band), or SSB radio.*
c. VHF (*Very High Frequency*) *or* UHF (*Ultra High Frequency*) *called radio system with short wavelengths, are widely used for the purposes of relations close range, for example for a motor vehicle radio (STKB), STJJ, and so on.*
d. *While* SHF (*Super High Frequency*) *and* EHF (*Ekstra High Frquency*) *called with a radio system which has a length of microwaves. Widely used for microwave systems (Telkom) and satellite systems including television broadcasting*.

CHAPTER III

RESEARCH METHODS

Research conducted is simulated using the software OptiSystem, that of testing the effect of the transmission distance of the ROF system bit rate and analysis FBG dispersion compensator laying effect on system performance ROF refers to study of literature. In this study, using a variation line coding, bit rate, RF signal, FBG and the laying of optical fiber length. Parameters observed that BER, Q-factor, and loss. Steps being taken, namely the determination of the type and method of data acquisition, variable and way analysis of data, as well as a framework solution to the problem. Flowchart stages of research can seen in Figure 3.1.

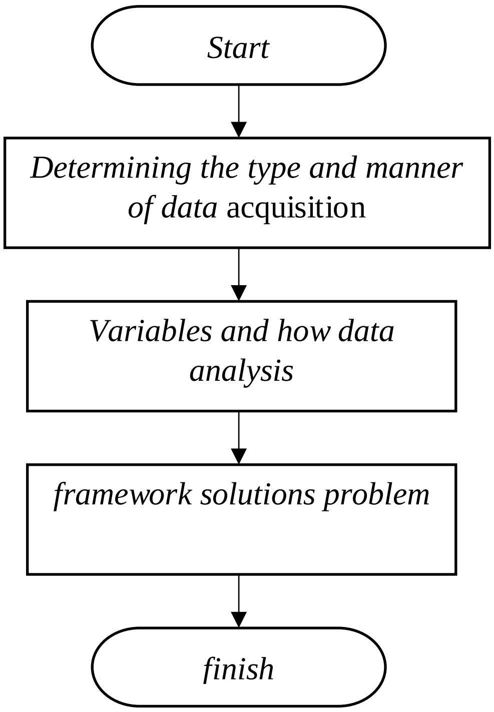

Figure 3.1 *Flowchart stages of research*

3.1 *Type and method of data acquisition*

Data needed in this research is primary data and secondary data. Data The primary is the effect of distance measurement data transmission to the ROF system beet rate and the effect of FBG laying on ROF system seen from the parameter BER, Q-factor, and loss.

The secondary data sourced from reference books, journals, theses, and website associated with ROF, optical fiber communication systems, line coding, dispersion, and FBG used to recognizing the characteristics, parameters and concepts associated with this research.

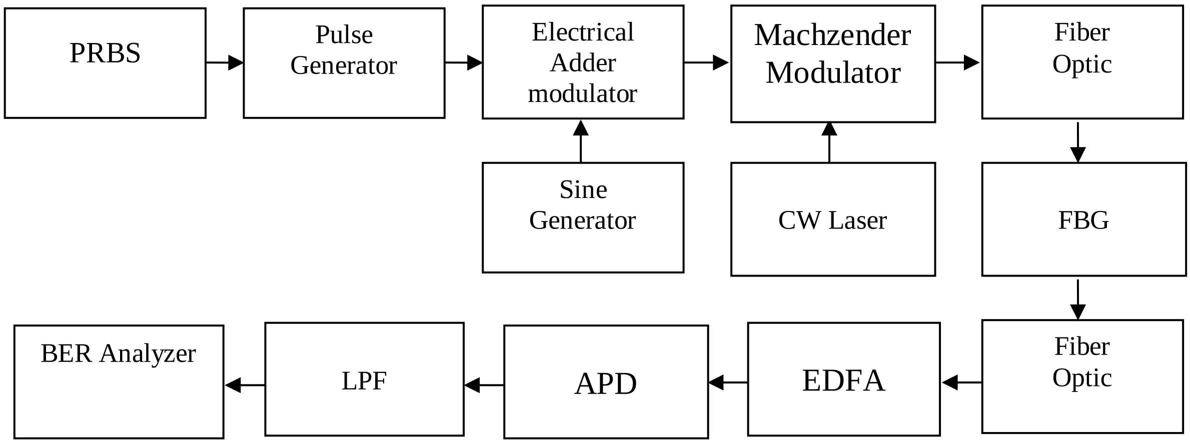

Figure 3.2 *Block diagram ROF transmission system using* FBG

In Figure 3.2 shows a series of ROF system in general, the following explanation of each of the block diagram.

On the transmitter there Pseudo Random Bit Sequence Generator (PRBS) to generate binary sequence pseudorandom, This bit sequence is designed for an approach the characteristics of random data, the value will be varied PRBS bit rate ie 5 Gbps and 10 Gbps. On line coding digital data in the form of text, video, audio, figures, images and charts stored in the bit sequence, a sequence of bits will be converted into a digital signal and line coding used is RZ and NRZ. Then for the input RF signal using sine generator with varied frequency that is equal to 3.5 GHz which is 5G communication frequency range below 6 GHz, then output from line coding in combine with output from sine generator electrical adder which aims to signal combining information from pulse generator and the carrier signal of sine generator. In this study, using an optical source that is Continuous Wave (CW) laser generate optical signals with wavelengths of 1552.52 nm and an input power of 0.8 mW, then the output of electrical adder modulated by the optical signal CW laser generated using external moduasi Mach-Zehnder because the process faster and there is a change signal electrical to optical (E / 0) to be in transmitted in optical fiber transmission medium.

Then on the fiber link optical signals passed through a fiber transmission medium optic types Single Mode Fiber (SMF) along the 10-100 km and a wavelength of 1550 nm. Then in the receiver there photodetector which serves to signal conversion optical to electrical. In this research photodetector used is Avalanche photodiode (APD) because it has a much greater responsiveness than PIN and require optical power smaller than Positive Intrinsic Negative (PIN). Signal electrical output of photodetector filtered using Low Pass Filter (LPF) *to remove noise with high frequency. In this study using Bessel LPF for waveform* *output will not suffer overshoot and will very similar to the input signal. Then output from Bessel LPF will be analyzed against parameters has been established using two components visualizer, ie BER analyzer and Eye Diagram Analyzer. Both of these components requires three inputs: first is output from PRBS generator, then the second is output from NRZ pulse generator or RZ Pulse Generator and the third is output from Bessel The* LPF.

3.2 *Variables and how to analyze data*

In this study, the parameters used in the data analysis that BER, Q-factor, and loss. Data analysis was performed using the results of primary data and make mathematically adjusted approach to the basic concept of secondary data.

3.3 *Framework for solutions to problems*

Framework solution to the problem in this research is the steps being taken to solve the problem in the form of a flowchart. Here are the steps – steps testing and calculations for each of the performance parameters that are described in the section following.

In Figure 3.3 shows a flow chart test measures the transmission distance of the bit rate. testing variations distance do to get the maximum distance that can transmitted by each bit rate with a good signal quality. bit rate that be used bit rate 5 Gbps and 10 Gbps. The analysis was conducted by preparing four ROF network system configuration which is 5 Gbps line coding RZ, NRZ and 10 Gbps with line coding RZ, NRZ on the same optical fiber length is 100 km. distances used is 10km, 20km, 30km, 40 km, 50 km, 60 km, 70 km, 80 km, 90 km and 100 km to bit rate 5 Gbps and 10 Gbps. The analysis was performed by calculating the BER, Q-factor, and loss for each bit rate and the distance used.

3.3.1 *Effect distance to bit rate*

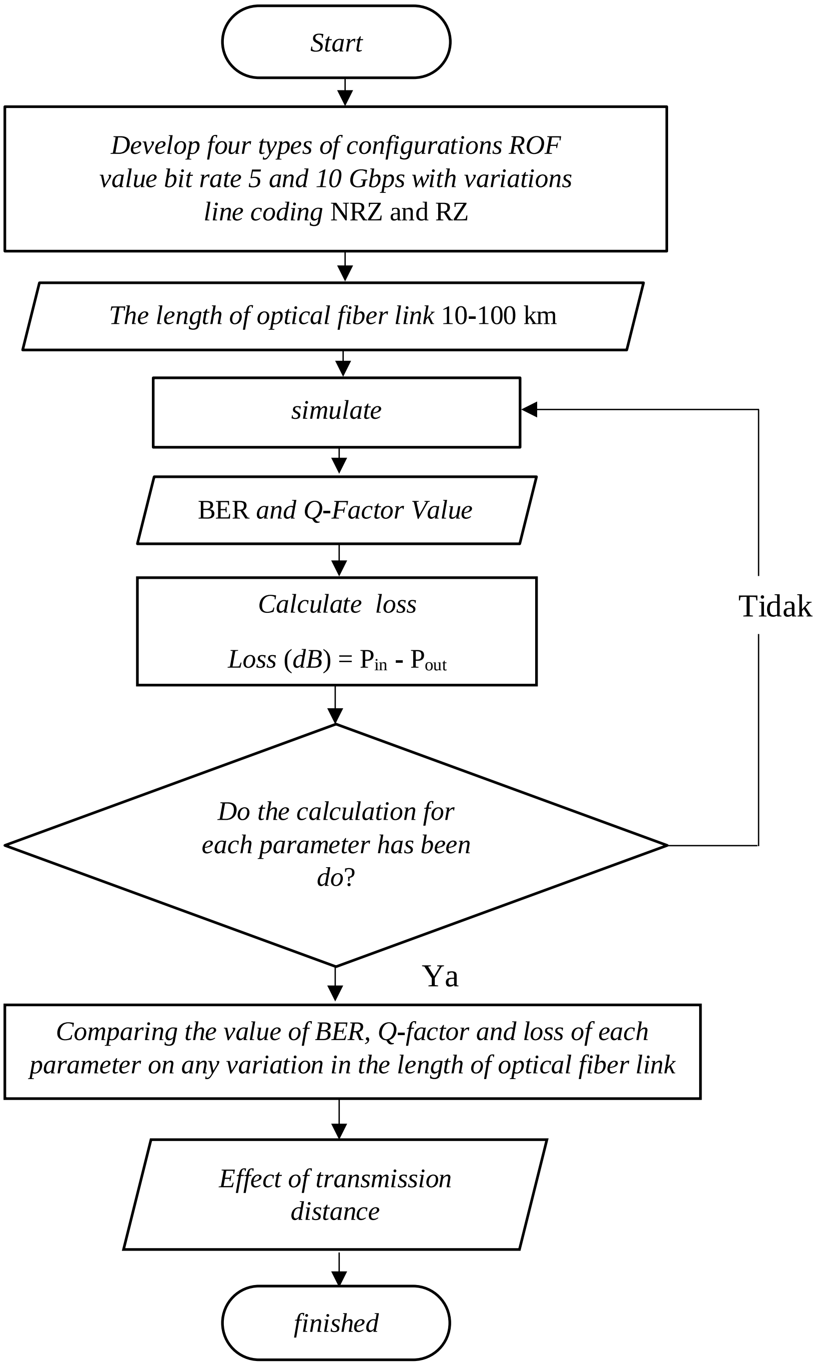

Figure 3.3 *Flowchart of testing variation bit rate and distance*

In Figure 3.4 shows a flow diagram of distance variation laying FBG test. FBG laying distance variation testing done to get results perfomansi best performance generated by the combination of parameters. Analyzes were performed with arrange four ROF network system configuration which is 5 Gbps line coding RZ, And 10 Gbps NRZ line coding RZ, NRZ. Variations in the distance used is 10 km, 20 km, 30 km, 40 km, 50 km, 60 km, 70 km, 80 km, 90 km, 100 km and laying FBG *placed in the middle of the total distance optical fiber* *link for bit rate 5 Gbps and 10 Gbps. The analysis was performed by calculating the BER, Q-factor, and loss for each parameter used.*

3.3.2 *Testing laying distance variation FBG*

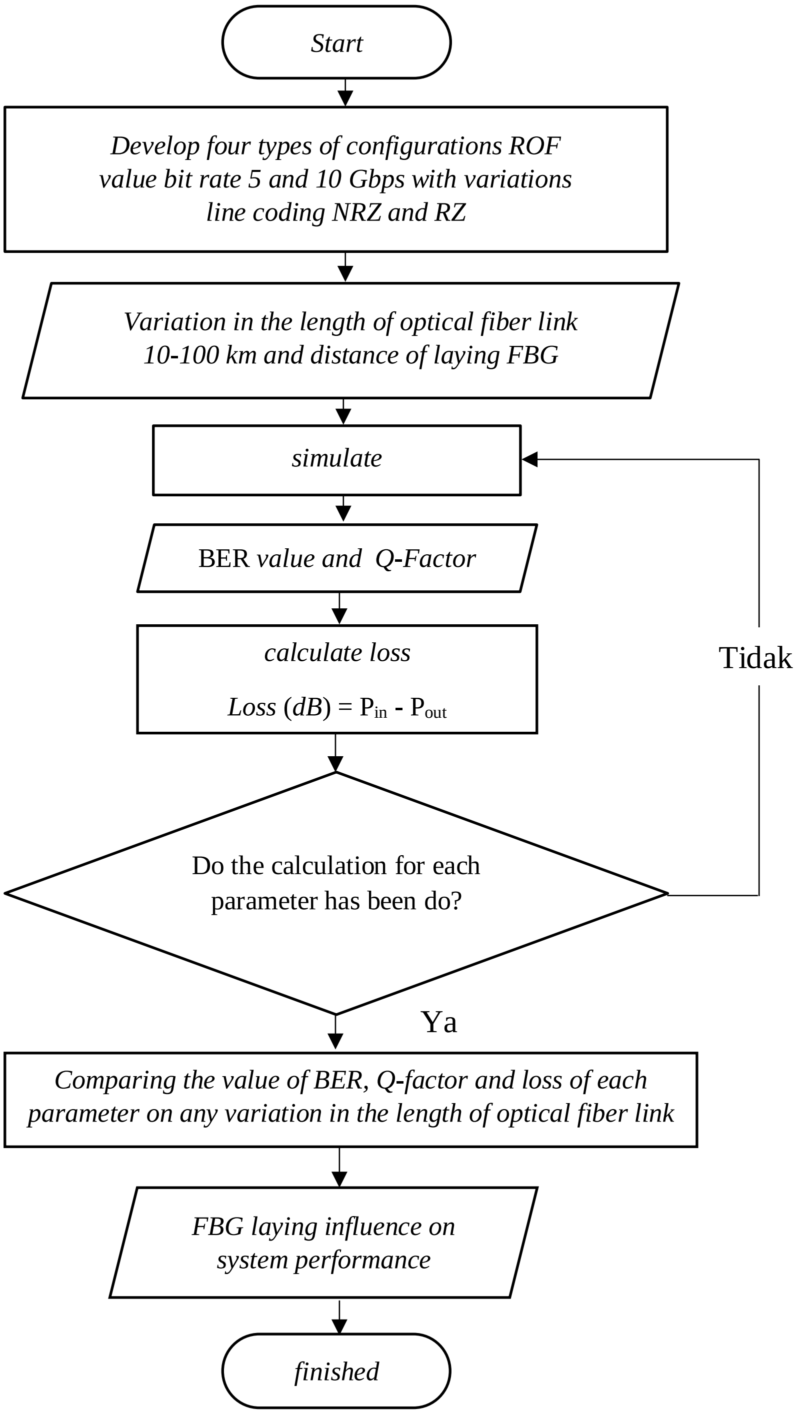

Figure 3.4 *Flowchart of testing variation laying distance* FBG

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CHAPTER IV

RESULTS AND DISCUSSION

In Chapter IV will explain the results and discussion of research. Data to be discussed is the result of the influence of the transmission distance bit rate system Radio over fiber (ROF) and the effect of dispersion compensators laying Fiber Bragg Grating (FBG) on system performance ROF seen from BER, Q-factor and loss. Writing Chapter IV cover research device configuration, data collection procedures, research data and discussion.

4.1 *Device Configuration Research*

In section 4.1 will discuss the components used in research. As for the components used in the study pseudorandom Squence Bit Generator, Line Coding, Sine Generator, Electrical Adder, Continuous Wave laser, Mach-Zehnder Modulator, Fiber Optics, Erbium doped Fiber Amplifiers, Fiber Bragg Grating, photodetector APD, low pass Bessel filter, Power Meter Visualizer, BER analyzer, and Eye Diagram Analyzer. Specification and explanation of each component research are as follows:

4.1.1 *Pseudorandom Bit Squence Generator*

Pseudo Random Bit Sequence Generator is used to generate a binary sequence pseudorandom as one of the test signals in a process of dynamic identification, sequence These bits are designed for an approach characteristic of random data, a similar PRBS random number sequences in real time, but can also be called pseudo (pseudo) because deterministic. bit rate it is raised at 5 Gbps and 10 Gbps.

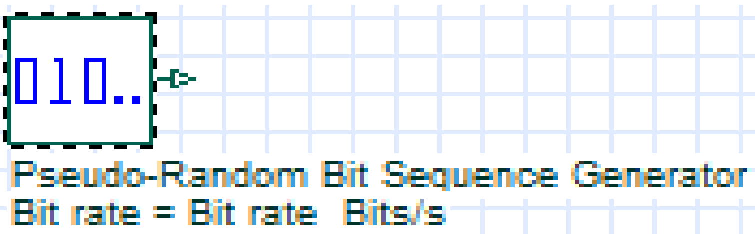

Figure 4.1 *Pseudo Random Bit Sequence Generator*
(Source**:** Optiwave, 2008)

4.1.2 *Line Coding*

line Coding is the process of converting digital data into digital signals. digital data in the form of text, video, audio, figures, images and graphics are stored in a sequence of bits, a sequence of bits This will be converted into a digital signal and line coding used is RZ and NRZ.

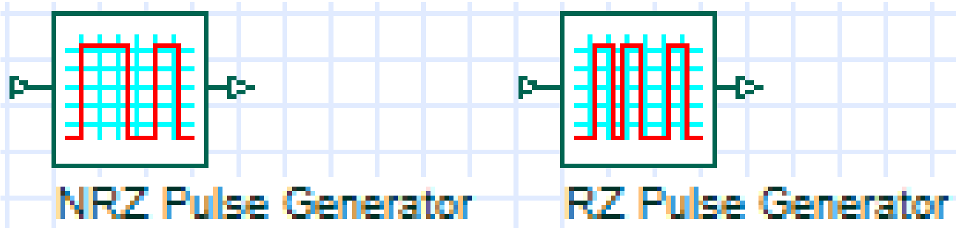

Figure 4.2 *Line Coding*
(Source**:** Optiwave, 2008)

4.1.3 *Sine Generator*

Sine Generator serves to generate radio frequency signals mm-wave. Radio frequency signals generated existing 3.5 GHz.

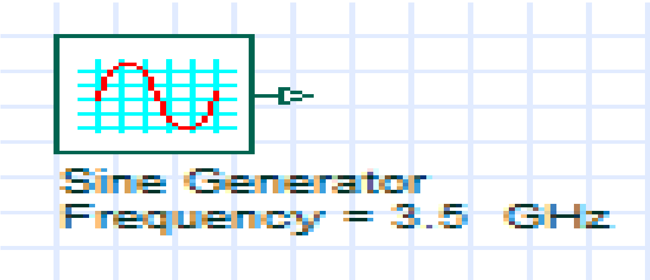

Figure 4.3 *Sine Generator*
(Source**:** Optiwave, 2008)

4.1.4 *Electrical Adder*

Electrical Adder electrically serves to modulate between radio frequency carrier Which produced from sine Generator and the electrical signal generated from the NRZ Pulse Generator or RZ Pulse Generator, then output of these components are used modulated in Mach-Zehnder Modulator.

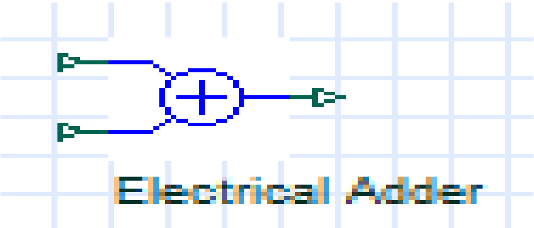

Figure 4.4 *Electrical Adder*
(Source**:** Optiwave, 2008)

4.1.5 *Continous Wave* (CW) laser

Optical source used is Continuous Wave (CW) laser. Selection CW laser due to a narrower beam than LED and the operation, the output of the laser relatively consistent over time. CW laser used by using a wavelength of 1552.52 nm with 1 mW power.

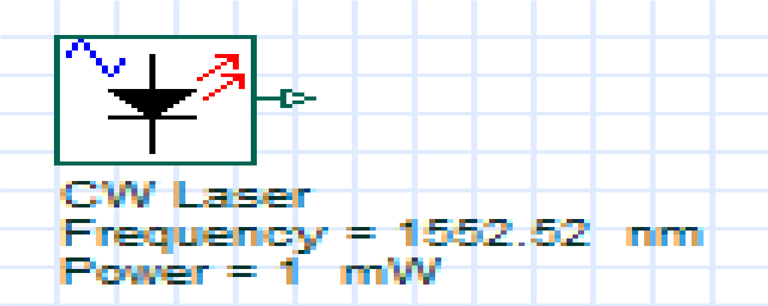

Figure 4.5 *Continous Wave* (CW) laser
(Source: Optiwave, 2008)

4.1.6 *Mach-Zehnder Modulator*

Mach-Zehnder Modulator is an interferometer that works by electro-optical principle, whereby a given electric field can affect characteristics of the light to pass through. Interferometer optical modulator Mach-Zehnder is a modulator that can be used in optical communication systems work based on the principle of the interferometer. Mach-Zehnder divides the incoming signal into two in two identical arms length and shape. Effective refractive index waveguide will turn, is directly proportional to the electric field changes imposed on the sleeve Mach - Zehnder. The changes also affect the electric field linearly with changes the phase of light passing through the interferometer Mach-Zehnder The. Thus, the phase light can be changed by an external electric field. Both beams are then coherently recombined at the end waveguide.

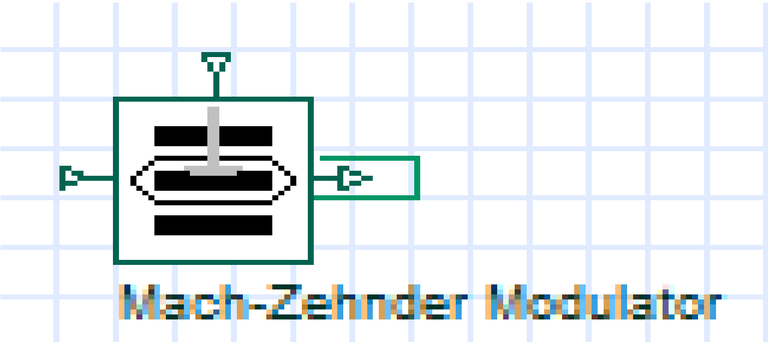

Figure 4.6 *Mach-Zehnder Modulator* (MZM)
(Source: Optiwave, 2008)

4.1.7 *Fiber Optics*

Optical fiber serves as a medium for transmitting optical signals. This type of fiber optics used in this system is optical fiber *Single Mode Fiber (* SMF) with attenuation worth 0.2 dB / km and *reference wavelength* worth 1550 nm.

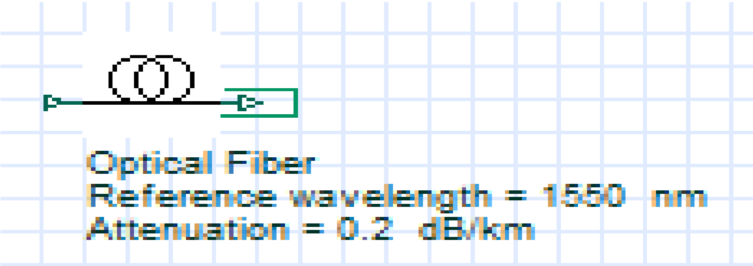

Figure 4.7 *Fiber Optics*
(Source**:** Optiwave, 2008)

Dispersion calculations required to obtain performance fiber communication systems optics within the maximum transmission range. Dispersion calculations include calculation of material dispersion, waveguide dispersion, and intermodal dispersion.

Tabel 4.1 *Specifications of the components used*

Parameter	***Definition***	***Value***
t_{dm}	*Material dispersion coeffient*	0,8 ps/(nm.km)
Δ_{λ}	*The width of the spectrum of the optical source*	1 nm
n_1	*Core refractive index values*	1,48
n_2	*The value of the refractive index sheath*	1,46
c	*The speed of light in vacuum*	$3x10^8$ m/s
λ	*Wavelength*	1550 nm
a	*The radius of the optical fiber core*	7 µm

Material dispersion value per unit length of optical fiber according to the equation (1):

$$t_{material} = t_{dm} \text{ x } \Delta_{\lambda}$$

$$t_{material} = 0.8 \text{ x } 1 = 0.8 \text{ ps/km}$$

Waveguide dispersion according to equation (2):

$$t_{waveguide} = \frac{(n_1 - n_2) t_{wg} . \Delta_{\lambda}}{\mathrm{c}.\lambda}$$

t_{wg} = *disperse dimensionless coefficients*

Based on the equation (3):

$$t_{wg} = \frac{4(1 - \ln v)}{\mathrm{v}^2}$$

V = *normalized frequency, according to the equation* (4):

$$\mathrm{v} = \frac{2\pi}{\lambda} a \sqrt{\mathrm{n}_1^2 - \mathrm{n}_2^2}$$

$$v = \frac{2\pi}{1550\ x\ 10^{-9}} 7\ x 10^{-6} \sqrt{1.48^2 - 1.46^2} = 6.88073$$

Then the dispersion coefficient without dimension:

$$t_{wg} = \frac{4(1-\ln 6.88073)}{6.88073^2} = 0.07846$$

So the value of waveguide dispersion per unit length:

$$t_{waveguide} = \frac{(1.48-1.46)0.07846.1x10^{-9}}{3x10^8.1550x10^{-9}} = 0.00337\ ps/km$$

Because this study used types of single mode optical fiber, it does not happen intermodal disperse, $t_{intermodal}$ = 0 ps/km. *Total dispersion value per unit length of optical fiber according to the equation* (4):

$$t_{fiber} = \sqrt{t^2_{\text{material}} + t^2_{\text{waveguide}} + t^2_{\text{intermodal}}}$$

$$t_{fiber} = \sqrt{(0.8^2 x10^{-12})^2 + (0.00337x10^{-12})^2 + 0} = 0.8\ ps/km$$

4.1.8 *Erbium Doped Fiber Amplifier*

In this research *repeater* used is *Erbium doped Fiber Amplifier* (EDFA) which serves to keep the power level infrmasi sent in order to detected. EDFA is an optical fiber doped by elements *erbium* (Er^{3+}). can be used as *booster amplifier* if placed after *laser,* as *an in-line amplifier* if it is between the sender and receiver, and as *pre-amplifier* if placed before *photodetector.* EDFA *used using laser pump power 10 mW and a wavelength of 980 nm.*

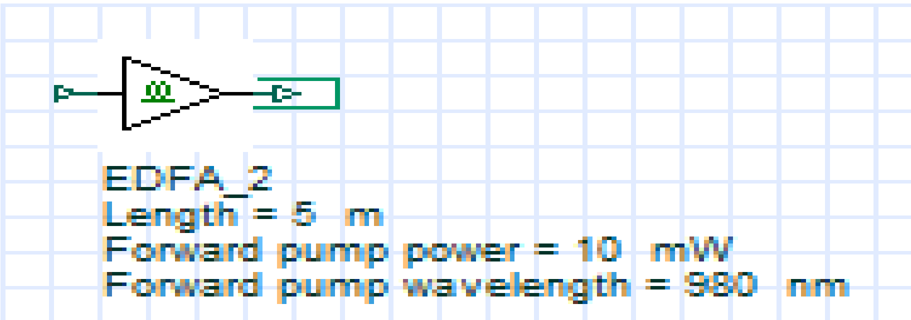

Figure 4. 8 *Erbium Doped Fiber Amplifier* (EDFA)
(Source: Optiwave, 2008)

4.1.9 *Fiber Bragg Grating*

Dispersion compensators used in this research is chirped Fiber Bragg Grating. On chirped FBG, several changes were made in the period lattice resulting in changes in response to different wavelengths. As grating period changes along its axis, different wavelengths reflected by different parts of the grid so that the experience delay with a *different time. The consequence is a pulse compression on widening and appropriate experience to compensates for chromatic dispersion in a communications network.*

to reduce the occurrence of pulse broadening due to dispersion that occurs along optical fiber, in this study using a dispersion compensator Fiber Bragg Grating (FBG), the study used chirped FBG where the grating with the number of periods the refractive index is not uniform along the optical fiber with wavelengths of 1552.52 nm and laying down chirped The FBG will be varied to the transmission distance.

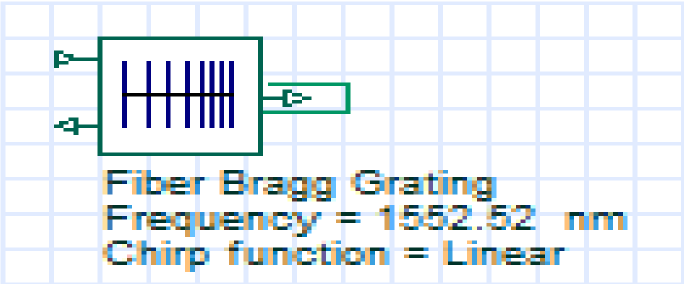

Figure 4.9 *Fiber Bragg Grating* (FBG)
(Source**:** Optiwave, 2008)

4.1.10 ***Photodetector*** **APD**

photodetector which serves to convert optical signals into electrical signals. photodetector used is Avalanche Photodiode (APD) because it has responsiveness far greater than Positive Intrinsic Negative (PIN) and require optical power smaller than Positive Intrinsic Negative (PIN). APD used is Indium Gallium arsenide (InGaAs) because of the low error and Nice used at a wavelength of 1550 nm.

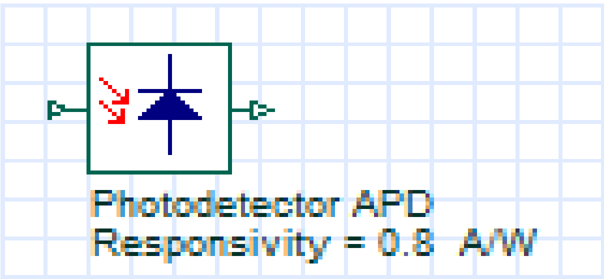

Figure 4.10 *Photodetector* APD
(Source**:** Optiwave, 2008)

4.1.11 ***Low Pass Bessel Filter***

One type of LPF is Besse l LPF. This filter serves to eliminate noise with high frequency, and the reason for using Bessel LPF for waveform output will not suffer overshoot and will be very similar to the input signal.

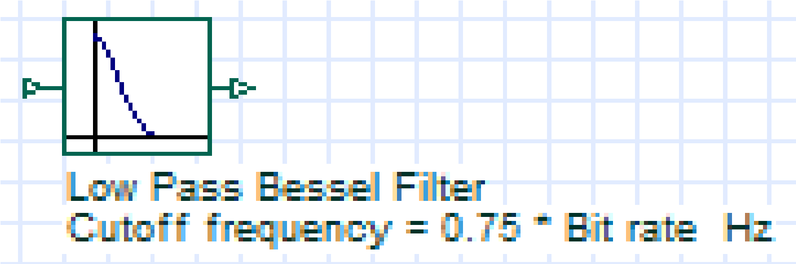

Figure 4.11 *Low Pass Bessel Filter* (LPF)
(Source: Optiwave, 2008)

4.1.12 *Optical Power Meter*

Power meter used to display the value of the power system. Power meter that used in this research is optical power meter (OPM), because power wants measured is power when the signal is transmitted in an optical fiber medium. OPM laid the modulator output for display power input and placed on the output fiber optics (the first problem formulation) / at the output of EDFA (for the formulation of the problem second), which aims to showcase the value of power output.

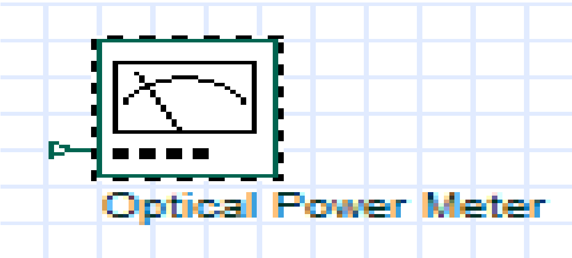

Figure 4.12 *Optical Power Meter Visualizer*
(Source: Optiwave, 2008)

4.1.14 *Eye Diagram Analyzer*

This component serves to show eye diagram. Eye diagram is parameters to determine the quality of the signal at domain digital. Name eye diagram taken because it looks similar to the human eye. This display is generated from superimposing waveform which respectively - helped to form the image belonging. Eye diagram This is used to view digital signals which aims to recognize the effects of distortion and find the source.

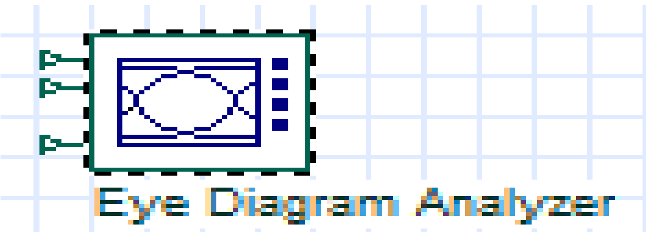

Figure 4.13 *Eye Diagram Analyzer*
(Source: Optiwave, 2008)

4.1.15 *Bit Error Rate Analyzer*

BER *analyzer is a tool to measure the BER value is based on an algorithm gaussian on the transmission of a short barrage of bit - bit. This tool can also measure value Q-factor.*

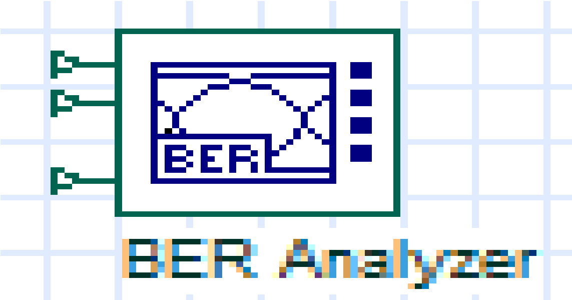

Figure 4.14 *Bit Error Rate* (BER) *Analyzer*
(Source**:** Optiwave, 2008)

4.2 *Data Collection Procedures*

In the data collection procedures, The first stage is done is prepare OptiSystem software, The second phase is to develop a configuration devices on OptiSystem software, enter the third stage variable value corresponding spec datasheet and the value of the variation, the fourth stage and perform simulations of the last stage BER results obtained, Q - factor, and Loss.

4.2.1 *Simulation Analysis of Effect Againts Transmission Distance bit rate*

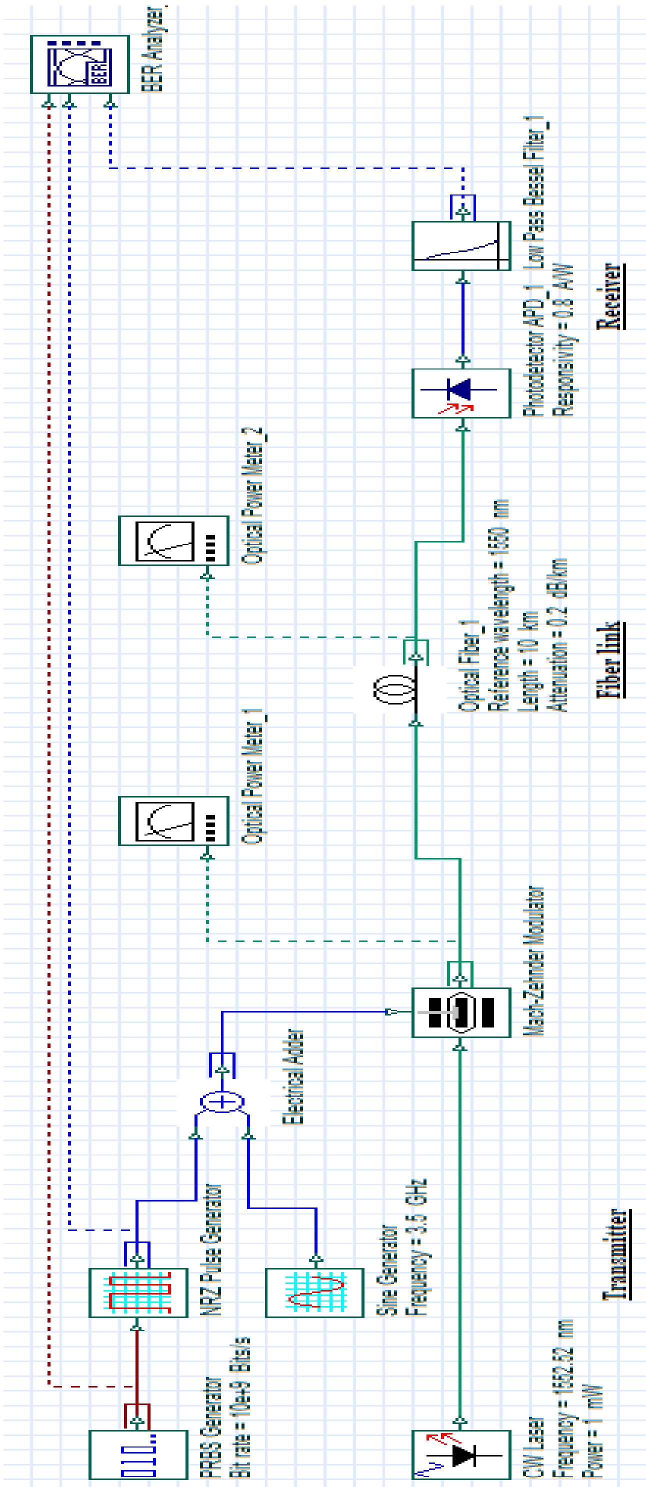

Figure 4.15 *Configuration Simulation of Influence bit rate Against Distance Transmission*

The first trial is a research on the analysis of the effect on the transmission distance bit rate. In section transmitter using the binary signal generator in the form of PRBS Generator. In PRBS Generator in the raised bits random sequence. Bit rate used is 5 Gbps and 10 Gbps, hereinafter bit rate which has raised will go through the conversion of digital data into *digital signals. The digital data in the form of text, video, audio, figures, images and graphics are stored in a sequence of bits, the sequence This bit will be converted into a digital signal. To generate RF signals used sine generators and RF signal generated at 3.5 GHz. Then the output of sine generator and NRZ, RZ Pulse This generator is electrically modulated at electrical adder. Furthermore, the optical source used to use continuous Wave Laser (CW laser) with input power of 1 mW and a wavelength of 1552.52 nm. Then output from the CW laser and electrical adder modulated by an external modulator Mach-Zehnder Modulator (MZM), MZM is an interferometer that works by electro-optical principle, whereby a given electric field can affect characteristics of the light pass through and output which dihasil MZM is an optical signal modulated. Then in the optical signal transmission medium is transmitted through optical fibers, optical fiber used is Single Mode Fiber (SMF) with a wavelength of 1550 nm, the fiber optic distance variation from 10 to 100 km with range increase of 10 km.*

Furthermore, on the receiver used components photodetector APD. photodetector Type InGaAs APD is used with the value of responsivity of 0.8 A / W. In the case of these components from the conversion of optical signals into electrical signals. then the signal electrically in- filter by using components Low Pass Bessel Filter. usefulness of This component is to eliminate noise at high frequencies and election Bessel LPF for waveform output will not suffer overshoot and will be very similar to the input signal.

After all the system configuration has been arranged, performed the calculations for analyzing the performance of this system. To determine the value of BER and Q-factor be used BER component analyzer which is connected with the output PRBS generator, NRZ and RZ Pulse Generators, and Bessel LPF. As for knowing Loss value is used component Optical Power Meter (OPM) connected with output MZM and output optical fiber.

Tabel 4.1 *Combination Bit Rate, Line Coding, and Fiber Optic Link*

No	*Bit Rate*	*Line Coding*	RF *Carrier* (GHz)	*Fiber Optic Link* (Km)
1	5 and 10 Gbps	NRZ dan RZ	3,5	10
2				20
3				30
4				40
5				50
6				60
7				70
8				80
9				90
10				100

4.2.2 *Simulation Analysisof Effect Laying FBG Dispersion Compensator*

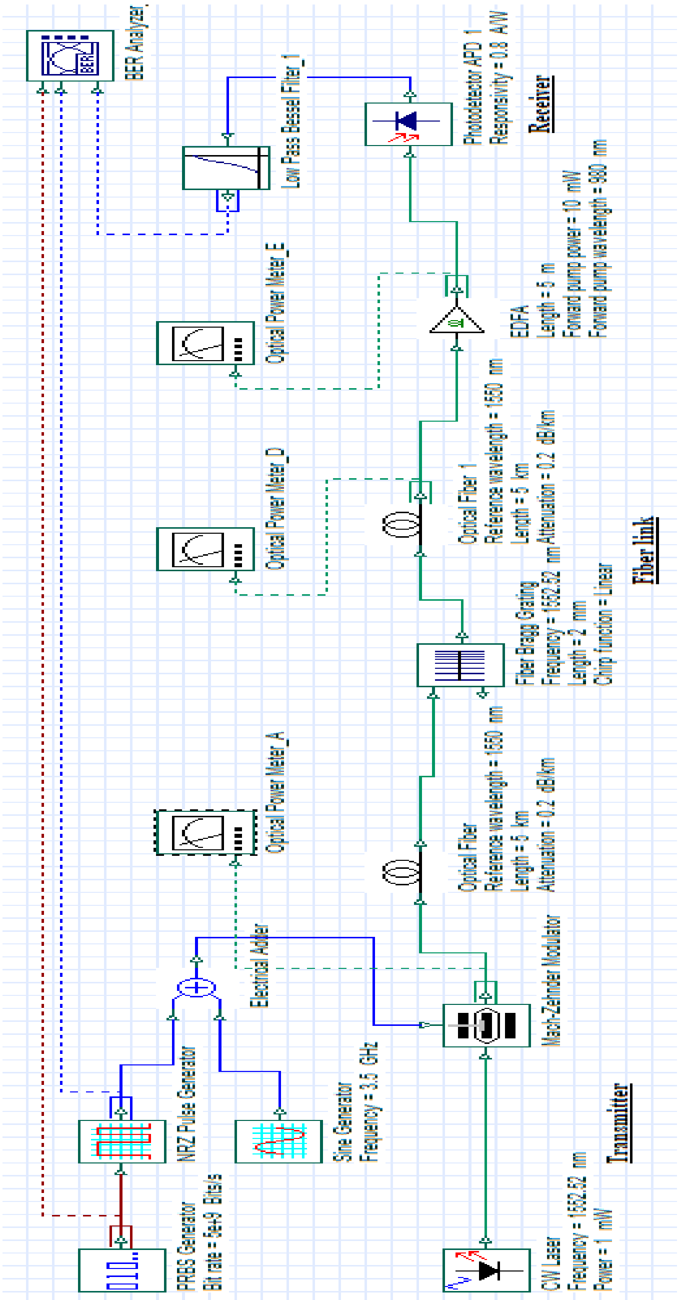

Figure 4.16 *Effect Simulation Configuration Laying FBG Dispersion Compensator*

The second trial is a research on the analysis of the effect of laying compensator FBG dispersion in ROF transmission system. At the transmitter PRBS generated at 5 and 10 Gbps, and line coding used NRZ and RZ Pulse Generator, then the value of RF is raised 3.5 GHz using sine Generator, then use electrical adder for modulation electrically connected to the output NRZ, RZ pulse And the output of the generator sine Generator, then the optical source used is a CW laser with a power of 1 mW and a wavelength of 1552.52 nm, then the output *from the CW laser and electrical adder modulated by modulator external Mach-Zehnder Modulator (MZM) that keluaranya form of the optical signal The modulated.*

In the optical signal transmission medium is transmitted through an optical fiber type SMF with a wavelength of 1550 nm and a distance variation that is used 10 to 100 km by accretion distance of 10 km., and then using FBG dispersion compensator of type chirped FBG. On chirped FBG, several changes were made in the period lattice resulting in changes in response to different wavelengths. As grating period changes along its axis, different wavelengths reflected by different parts of the grid so that the experience delay with a different time. The consequence is a pulse compression on widening and appropriate experience to compensates for chromatic dispersion in a communications network. Then chirped FBG in placed exactly in the middle - the middle of the total length of the optical fiber due to the reason FBG although it was better placed closer to the transmitter, but it needs to be in note the subsequent optical fiber length, long associated with optical fiber used pretty much then placed exactly in the middle - the middle of the total length of optical fiber used. Then the amplified optical signals using Erbium doped Fiber amplifier (EDFA) to the wavelength of the signal pump 980 nm and pump power 10 mW which serves as a amplifier fixing the optical signal power level signal, and EDFA is placed after the second optical fiber (optical fiber after laying FBG).

Later in this part of receiver used components photodetector APD, photodetector Type InGaAs APD is used with the value of responsivity of 0.8 A / W, then the electrical signal di-filter by using components Low Pass Bessel Filter. For knowing the value of BER and Q-factor used components BER analyzer connected the PRBS generator output, NRZ and RZ Pulse Generators, and Bessel LPF. While Loss used to determine the value of the component Optical Power Meter (OPM) connected with output MZM and output optical fiber.

Tabel 4.2 Kombinasi *Bit Rate*, *Line Coding*, FO *Link*, dan Jarak Peletakan FBG

No	*Bit Rate*	*Line Coding*	RF *Carrier* (GHz)	*Fiber Optic Link* (Km)
1	5 and 10 Gbps	NRZ and RZ	3,5	10
2				20
3				30
4				40
5				50
6				60
7				70
8				80
9				90
10				100

4.3 *The results and discussion*

The simulation results of the effect of the transmission distance bit rate and the effect of laying FBG dispersion compensator on ROF communication system and its deliberations would described in this section. The data obtained is the result of the simulation and the results analysis in accordance with the equations described in Section II. The performance of this system analyzed with the parameters that have been described are BER, Q-Factor, and Loss. The results of the simulation are shown in graphical form for each parameter analyzed.

4.3.1 *Analysis of the influence on the transmission distance bit rate 5 Gbps*

Here are the data of simulation of the effect on the transmission distance bit rate 5 Gbps seen from the parameter BER, Q-Factor, and Loss:

Tabel 4.3 *simulation results of the transmission distance bit rate 5 Gbps line coding NRZ*

No	RF Carrier	*Line Coding*	*fiber optic*	*Max. Q-Factor*	*Min. BER*	*P_{in} (dBm)*	*P_{out} (dBm)*	*Loss (dBm)*
1	3,5 GHz	NRZ	10 km	7,67775	8,09056 x 10^{-15}	-3,231	-5,231	2
2			20 km	7,67081	8,5447 x 10^{-15}		-7,118	4
3			30 km	7,65362	9,7147 x 10^{-15}		-9,579	6
4			40 km	7,61087	1,3533 x 10^{-15}		-11,234	8
5			50 km	7,59038	1,5307 x 10^{-14}		-13,586	10
6			60 km	7,54711	2,1786 x 10^{-14}		-15,717	12
7			70 km	7,19209	3,1215 x 10^{-13}		-17,35	14
8			80 km	7,07457	7,3997 x 10^{-13}		-19,236	16
9			90 km	6,78678	5,577 x 10^{-12}		-21,48	18
10			100 km	6,73654	7,6185 x 10^{-12}		-23,626	20

Tabel 4.4 *Simulation Results to the transmission distance bit rate 5 Gbps line coding RZ*

No	RF Carrier	*Line Coding*	*fiber optic*	*Max. Q-Factor*	*Min. BER*	*P_{in} (dBm)*	*P_{out} (dBm)*	*Loss (dBm)*
1	3,5 GHz	RZ	10 km	7,66844	8,6717 x 10^{-15}	-5,297	-7,297	2
2			20 km	7,65563	9,6127 x 10^{-15}		-9,269	4
3			30 km	7,65157	9,9218 x 10^{-15}		-11,272	6
4			40 km	7,59864	1,4962 x 10^{-15}		-12,947	8
5			50 km	7,57345	1,7010 x 10^{-14}		-15,851	10
6			60 km	7,5186	2,6916 x 10^{-14}		-17,292	12
7			70 km	7,10056	6,1077 x 10^{-13}		-19,212	14
8			80 km	7,03091	9,5458 x 10^{-13}		-21,997	16
9			90 km	6,77063	6,3044 x 10^{-12}		-23,996	18
10			100 km	6,71584	8,8772 x 10^{-12}		-24,907	20

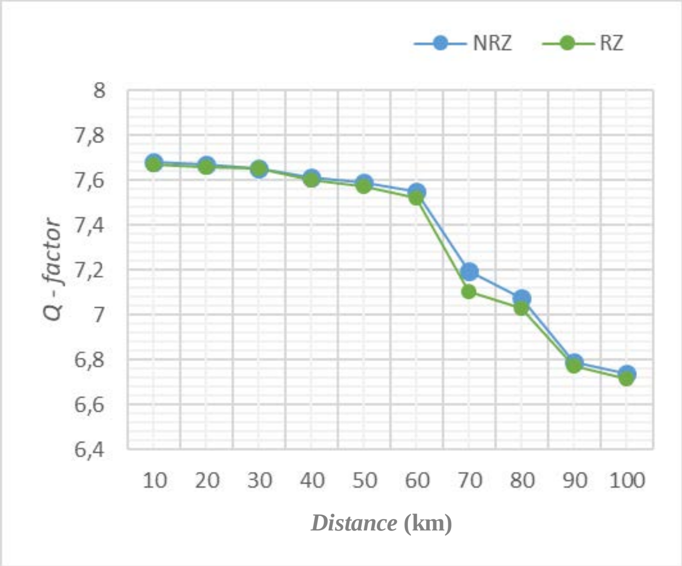

Figure 4.17 *graphs the effect of distance on Q-factor*

Value Q-factor (Quality factor) a quantitative picture of the signal kualitias optics and related to the BER. Q-factor can be used to evaluate propagation attenuation caused by dispersion. Based on the pictures 4:17 bit rate 5 Gbps line coding NRZ and RZ seen that the greater the distance transmission, value Q-factor getting smaller while the shorter the transmission distance will be greater. Value Q-factor The highest obtained line coding NRZ and RZ which is at a distance of 10 km of 7,67775 dan 7,66844.

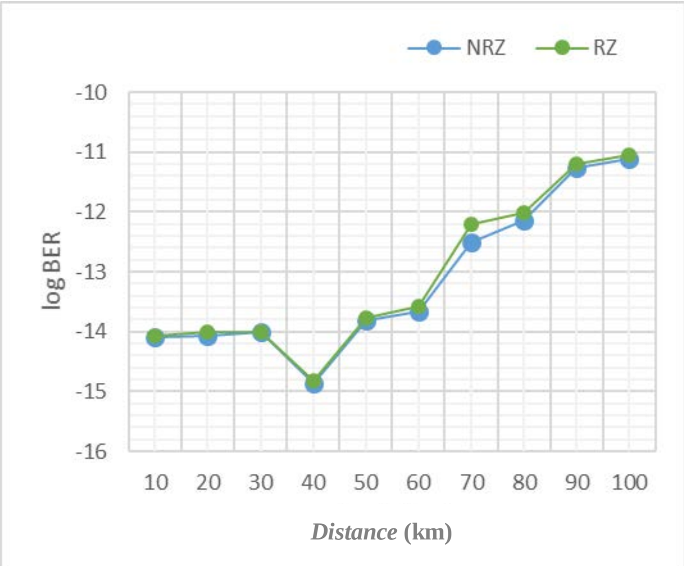

Figure 4.18 *graphs the effect of distance on the* BER

BER *value is a ratio of the bit value one when the transmission process underway. Calculated on the receiver side, in order to obtain a good signal quality, the value BER should be small. Kosekuensi of the high BER value is the data received into is not equal to the transmitted data. Based on the image the greater the distance it 4:18 BER greater value.*

BER high value resulting from the addition of the distance resulting in the widening of pulses that occur Intersysmbol Interference (ISI) which resulted in the increase error bit. Values obtained BER line coding NRZ and RZ at a distance of 8,0906 x 10^{-15}, dan 8,6717 x 10^{-15}.

From the experimental results using the format line coding NRZ on the length 10 km of optical fiber, obtained BER value BER 8,0906 x 10^{-15} *with value Q-factor by* 7,67775. *Systematically, the resulting BER value Q-factor can be proved by the equation*:

$$BER = \frac{1}{\sqrt{2\pi Q}} e^{-\frac{Q^2}{2}}$$

$$= \frac{1}{\sqrt{2\pi(7{,}67775)}} e^{-\frac{(7{,}67775)^2}{2}}$$

$$= 2{,}28 \times 10^{-14}$$

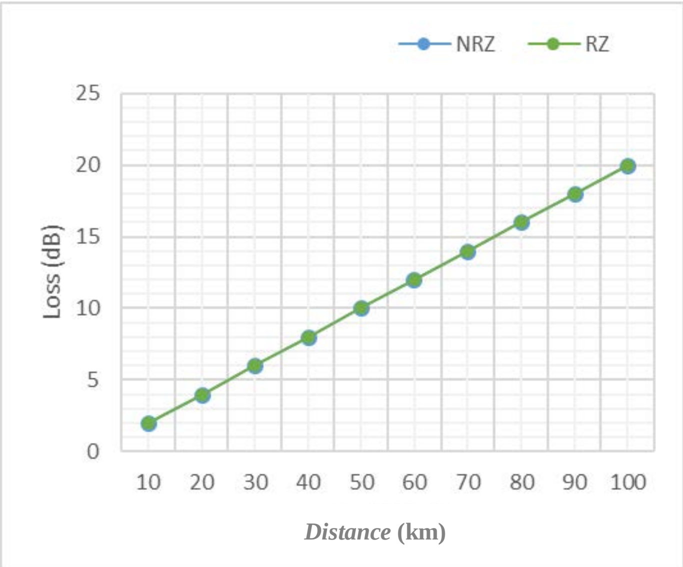

Figure 4.19 *graphs the effect of distance on loss*

Value loss (dBm) is the difference in power input with power ouput. loss happen due to the absorption and dispersion system on the optical fiber. The amount of loss depending on the distance and characteristics of optical fibers. Increase length of optical fiber that is used is directly proportional to the increase in loss. Getting further distance, then the value loss the greater it is. Value loss Lowest obtained line coding NRZ and RZ at a distance of 10 km which is 2 dBm.

From the experimental results using the format line coding NRZ on the length 10 km of optical fiber, obtained the value of a loss of 2 dBm. Systematically, the value of loss produced can be proved by the equation:

Loss (dBm) = P_{in} (dBm) – P_{out} (dBm)

= -3,231 – (-5,231)

= 2 dBm

4.3.2 *Analysis of the influence on the transmission distance bit rate 10 Gbps*

Here are the data of simulation of the effect on the transmission distance bit rate 10 Gbps seen from the parameter BER, Q-Factor, and Loss:

Tabel 4.5 *Results of the simulation transmission distance bit rate 10 Gbps line coding NRZ*

No	RF Carrier	*Line Coding*	*fiber optic*	*Max. Q-Factor*	*Min. BER*	P_{in} *(dBm)*	P_{out} *(dBm)*	*Loss (dBm)*
1	3,5 GHz	NRZ	10 km	7,76022	$4{,}2345 \times 10^{-15}$	-3,12	-5,12	2
2			20 km	7,54062	$2{,}3007 \times 10^{-14}$		-7,178	4
3			30 km	7,40695	$6{,}4404 \times 10^{-14}$		-9,117	6
4			40 km	7,23167	$2{,}3487 \times 10^{-13}$		-11,175	8
5			50 km	7,1011	$6{,}1871 \times 10^{-13}$		-13,119	10
6			60 km	6,97559	$1{,}5224 \times 10^{-12}$		-15,184	12
7			70 km	6,42124	$6{,}7568 \times 10^{-11}$		-17,128	14
8			80 km	6,19544	$2{,}9057 \times 10^{-10}$		-19,132	16
9			90 km	5,97609	$1{,}1428 \times 10^{-9}$		-12,683	18

Tabel 4.6 *simulation results of the transmission distance bit rate 10 Gbps line coding RZ*

No	RF Carrier	*Line Coding*	*fiber optic*	*Max. Q-Factor*	*Min. BER*	P_{in} *(dBm)*	P_{out} *(dBm)*	*Loss (dBm)*
1	3,5 GHz	RZ	10 km	7,68567	$7{,}6079 \times 10^{-15}$	-5,454	-7,453	2
2			20 km	7,59077	$1{,}5819 \times 10^{-14}$		-9,58	4
3			30 km	7,39801	$6{,}8109 \times 10^{-14}$		-11,634	6
4			40 km	7,14111	$4{,}4913 \times 10^{-13}$		-13,603	8
5			50 km	7,13757	$4{,}5846 \times 10^{-13}$		-15,714	10
6			60 km	7,02624	$1{,}0407 \times 10^{-12}$		-7,786	12
7			70 km	6,52168	$3{,}2811 \times 10^{-11}$		-4,267	14
8			80 km	6,18106	$2{,}7407 \times 10^{-10}$		-4,934	16
9			90 km	5,96629	$1{,}0958 \times 10^{-9}$		-5,116	18

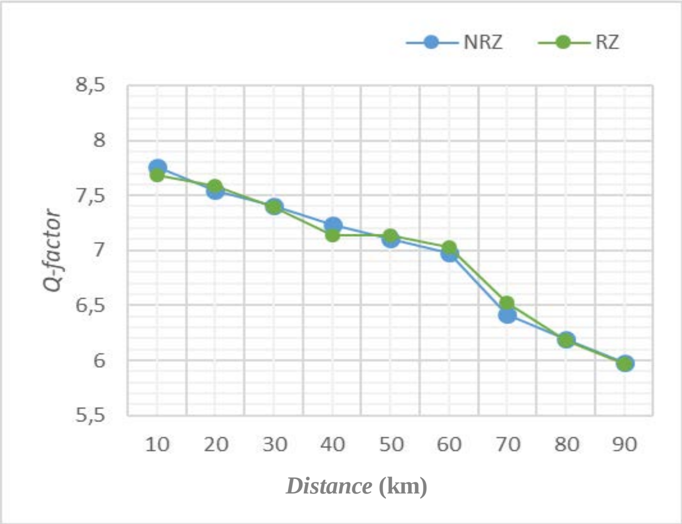

Figure 4.20 *graphs the effect of distance on Q-factor*

Based on the pictures 4:20 bit rate 10 Gbps, value Q-factor highest line coding NRZ at a distance of 10 km is 7,76022, while the value of Q-factor highest line coding RZ at a distance of 10 km is 7,68567.

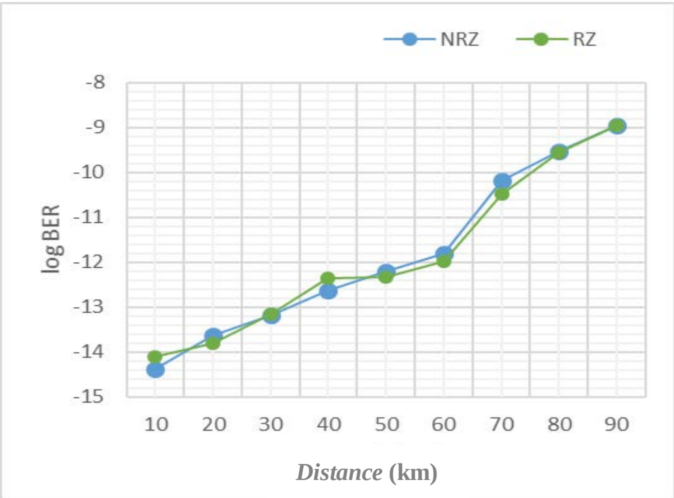

Figure 4.21 *graphs the effect of distance on the BER*

Based on the pictures 4.21 bit rate 10 Gbps, the lowest BER value obtained line coding NRZ at a distance of 10 km is 4,2345 x 10^{-15} , *Lowest BER obtained line coding NRZ at a distance of 10 km is* 7,6079 x 10^{-15}.

From the experimental results using the format line coding NRZ on the length 10 km of optical fiber, obtained BER value 4,2345 x 10^{-15} *with value Q-factor by* 7,76022. *Systematically, the resulting BER value Q-factor can be proved by the equation*:

$$BER = \frac{1}{\sqrt{2\pi Q}} e^{-\frac{Q^2}{2}}$$

$$= \frac{1}{\sqrt{2\pi(7{,}76022)}} e^{-\frac{(7{,}76022)^2}{2}}$$

$$= 1{,}199 \times 10^{-14}$$

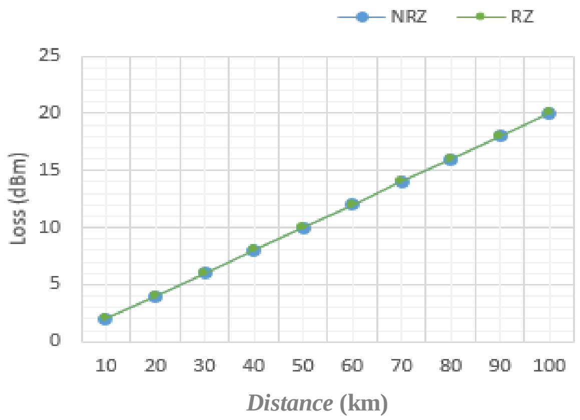

Figure 4.22 *graphs the effect of distance on the loss*

Based on the pictures 4.22 bit rate 10 Gbps, value loss Lowest obtained line coding NRZ and RZ at a distance of 10 km which is 2 dBm. And the farther the distance transmitted the resulting loss even greater.

From the experimental results using the format line coding NRZ on the length 10 km of optical fiber, obtained the value of a loss of 2 dBm. Systematically, the value of loss produced can be proved by the equation:

$$\text{Loss (dBm)} = P_{in}\text{ (dBm)} - P_{out}\text{ (dBm)}$$

$$= -3{,}12 - (-5{,}12)$$

$$= 2\text{ dBm}$$

4.3.3 *Analysis of the influence on the FBG Dispersion Compensator bit rate 5 Gbps*

Here are the data of simulation of the effect of the FBG bit rate 5 Gbps seen from BER parameter, Q-Factor, and Loss:

Tabel 4.7 *Simulation results Effect of laying FBG bit rate 5 Gbps NRZ*

No	RF Carrier	*Line Coding*	*fiber optic*	*Max. Q-Factor*	*Min. BER*	P_{in} (dBm)	P_{out} (dBm)	*Loss* (dBm)	P_{EDFA} (dBm)
1	3,5 GHz	NRZ	10 km	7,92864	$1{,}0981 \times 10^{-15}$	-3,59	-6,261	2,671	2,142
2			20 km	7,8975	$1{,}4208 \times 10^{-15}$		-7,267	4,672	1,778
3			30 km	7,87445	$1{,}687 \times 10^{-15}$		-10,021	6,674	0,743
4			40 km	7,85249	$2{,}0389 \times 10^{-15}$		-11,905	8,673	-0,036
5			50 km	7,82379	$2{,}5388 \times 10^{-15}$		-14,382	10,672	-1,198
6			60 km	7,80174	$3{,}0358 \times 10^{-15}$		-16,254	12,673	-2,213
7			70 km	7,75689	$4{,}3454 \times 10^{-15}$		-17,367	14,672	-2,882
8			80 km	7,73599	$5{,}1242 \times 10^{-15}$		-19,794	16,672	-4,516
9			90 km	7,71355	$5{,}9916 \times 10^{-15}$		-21,367	18,672	-5,701
10			100 km	7,70439	$6{,}2915 \times 10^{-15}$		-24,382	20,672	-8,208

Tabel 4.8 *Simulation results Effect of laying FBG bit rate 5 Gbps RZ*

No	RF Carrier	*Line Coding*	*fiber optic*	*Max. Q-Factor*	*Min. BER*	P_{in} (dBm)	P_{out} (dBm)	*Loss* (dBm)	P_{EDFA} (dBm)
1	3,5 GHz	RZ	10 km	7,90213	$1{,}3664 \times 10^{-15}$	-5,214	-7,881	2,667	1,556
2			20 km	7,87677	$1{,}6730 \times 10^{-15}$		-10,315	4,668	0,626
3			30 km	7,85937	$1{,}9039 \times 10^{-15}$		-11,523	6,666	0,128
4			40 km	7,82446	$2{,}5165 \times 10^{-15}$		-14,063	8,666	-1,038
5			50 km	7,79966	$3{,}0156 \times 10^{-15}$		-16,384	10,668	-2,288
6			60 km	7,77085	$3{,}7567 \times 10^{-15}$		-18,457	12,666	-3,585
7			70 km	7,73931	$4{,}6292 \times 10^{-15}$		-20,509	14,668	-5,043
8			80 km	7,71598	$5{,}4407 \times 10^{-15}$		-22,575	16,666	-6,67
9			90 km	7,69267	$6{,}8165 \times 10^{-15}$		-24,082	18,664	-7,947
10			100 km	7,65786	$8{,}7446 \times 10^{-15}$		-26,349	20,664	-9,974

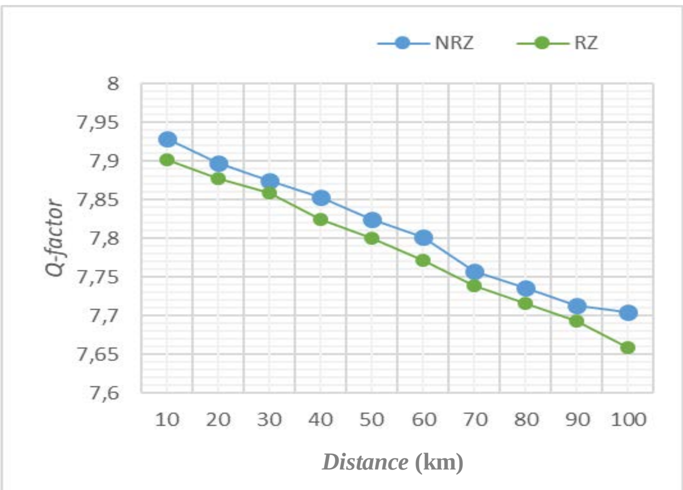

Figure 4.23 Graph FBG Laying influence on Q-factor

Based on the pictures 4:23 bit rate 5 Gbps, value Q-factor highest line coding NRZ at a distance of 10 km is 7.92864, while the value of Q-factor highest line coding RZ at a distance of 10 km is 7.90213. FBG and EDFA with an improvement value Q-factor compared with no use of FBG and EDFA on bit rate 5 Gbps.

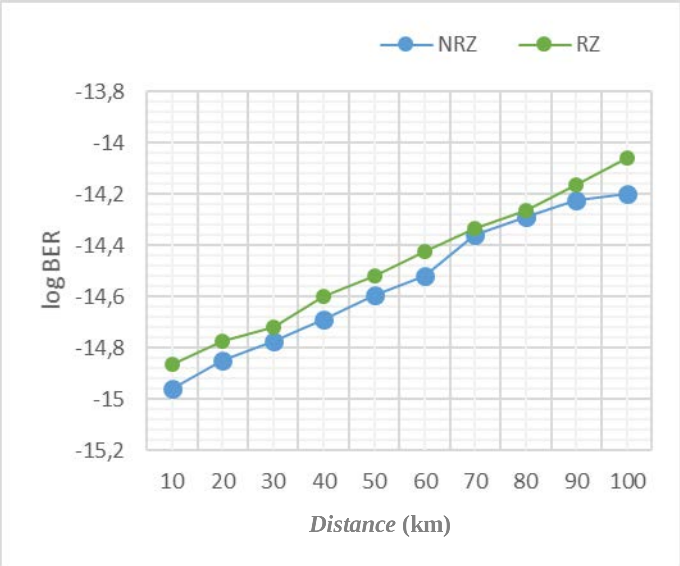

Figure 4.24 *Graph FBG Laying influence on the BER*

Based on the pictures 4.24 bit rate 5 Gbps, the lowest BER value obtained line coding NRZ at a distance of 10 km is 1,0981 x 10^{-15} *, Lowest BER obtained line coding NRZ at a distance of 10 km is* 1,3664 x 10^{-15}. *FBG and EDFA been improvements BER value compared with no use of FBG and EDFA on bit rate 5 Gbps.*

From the experimental results using the format line coding RZ on the length 10 km of optical fiber, obtained BER value 1,3664 x 10^{-15} *with value Q-factor by* 7,90213. *Systematically, the resulting BER value Q-factor can be proved by the equation*:

$$BER = \frac{1}{\sqrt{2\pi Q}} e^{-\frac{Q^2}{2}}$$

$$= \frac{1}{\sqrt{2\pi(\,7{,}90213)}} e^{-\frac{(7{,}90213)^2}{2}}$$

$$= 3{,}9135 \times 10^{-15}$$

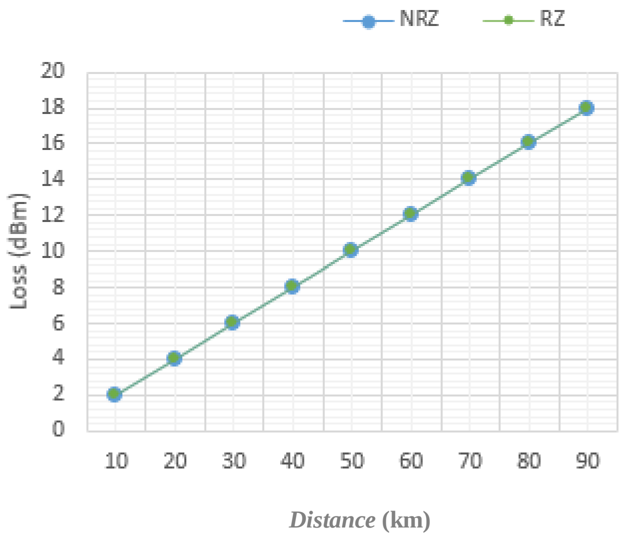

Figure 4.25 *Graph Laying influence FBG against loss*

Based on figure 4.25 at 5 Gbps bit rate, the lowest loss value obtained line coding NRZ 10 km is 2,671 dBm. and RZ at a distance of 10 km is 2,667 dBm. With using FBG loss value increase rather than without FBG.

From the experimental results using the format line coding RZ on the length 10 km of optical fiber, obtained the value of a loss of 2,667 dBm. Systematically, the value of loss produced can be proved by the equation:

Loss (dBm) = P_{in} (dBm) – P_{out} (dBm)

= -5,214 – (-7,881)

= 2,667 dBm

but With EDFA signal power value become better

P_{out} = -7,881 dBm

= 1W x $10^{(-7,881/10)}$/1000

= 162,89 x 10^{-6} W

P_{EDFA} = 1,556 dBm

= 1W x $10^{(1,556/10)}$/1000

= 1430,87 x 10^{-6} W

Amplification P signal = P_{EDFA} / P_{out}

= 1430,87 x 10^{-6} W / 162,89 x 10^{-6} W

= 8,78x

4.3.4 *Analysis of the influence on the FBG Dispersion Compensator bit rate 10 Gbps*

Here are the data of simulation of influence bit rate 10 Gbps to the distance seen from the parameter transmission BER, Q-Factor, and Loss:

Tabel 4.9 *Simulation results Effect of Laying bit rate 10 Gbps NRZ*

No	RF Carrier	*Line Coding*	*fiber optic*	*Max. Q-Factor*	*Min. BER*	*P_{in} (dBm)*	*P_{out} (dBm)*	*Loss (dBm)*	*P_{EDFA} (dBm)*
1	3,5 GHz	NRZ	10 km	7,77622	$3,7319 \times 10^{-15}$	-3,121	-5,789	2,668	2,312
2			20 km	7,6573	$9,4829 \times 10^{-15}$		-7,731	4,668	1,61
3			30 km	7,65156	$9,8012 \times 10^{-15}$		-9,787	6,668	0,834
4			40 km	7,6432	$1,0384 \times 10^{-14}$		-11,79	8,669	0,014
5			50 km	7,54282	$2,2893 \times 10^{-14}$		-13,847	10,668	-0,931
6			60 km	7,60608	$1,3986 \times 10^{-14}$		-15,912	12,668	-2,017
7			70 km	7,19471	$3,1287 \times 10^{-13}$		-17,736	14,667	-3,114
8			80 km	6,79711	$5,3342 \times 10^{-12}$		-15,092	16,666	-1,567
9			90 km	6,7145	$9,4329 \times 10^{-12}$		-12,444	18,666	-0,274

Tabel 4.10 *Simulation results Effect of Laying bit rate 10 Gbps RZ*

No	RF Carrier	*Line Coding*	*fiber optic*	*Max. Q-Factor*	*Min. BER*	*P_{in} (dBm)*	*P_{out} (dBm)*	*Loss (dBm)*	*P_{EDFA} (dBm)*
1	3,5 GHz	RZ	10 km	7,73281	$5,242 \times 10^{-15}$	-5,471	-8,122	2,651	1,465
2			20 km	7,71125	$6,1894 \times 10^{-15}$		-10,141	4,649	0,695
3			30 km	7,69096	$7,2292 \times 10^{-15}$		-12,135	6,649	-0,136
4			40 km	7,68816	$7,0782 \times 10^{-15}$		-14,381	8,646	-1,197
5			50 km	7,48951	$3,3286 \times 10^{-14}$		-16,443	10,645	-2,322
6			60 km	7,55376	$2,1060 \times 10^{-14}$		-6,725	12,64	1,975
7			70 km	7,22136	$2,5706 \times 10^{-13}$		-4,805	14,641	2,667
8			80 km	6,70392	$9,2565 \times 10^{-12}$		-4,756	16,642	2,685
9			90 km	6,69344	$9,9585 \times 10^{-12}$		-5,865	18,64	2,284

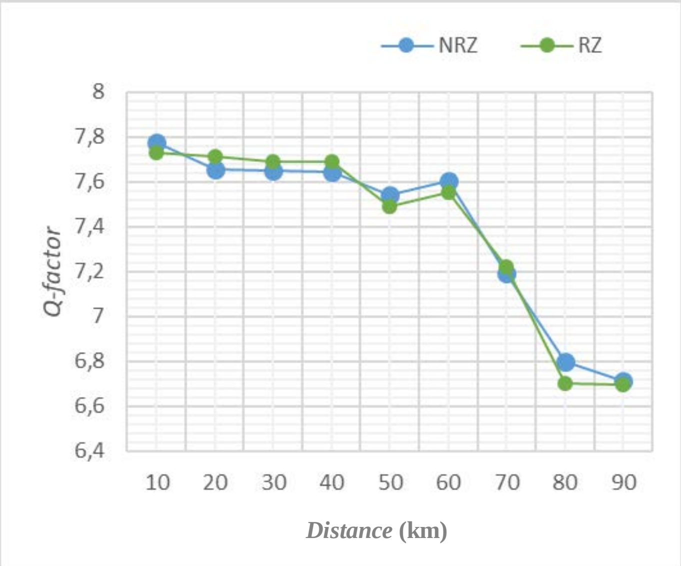

Figure 4.26 *Graph FBG Laying influence on Q-factor*

Based on the pictures 4.26 *at bit rate* 10 Gbps, value *Q-factor* highest *line coding* NRZ at a distance of 10 km is 7,77622, *while the value of Q-factor highest line coding RZ at a distance of 10 km is* 7,73281. *FBG and EDFA with an improvement value Q-factor compared with no use of FBG and EDFA on bit rate 10 Gbps line coding NRZ and RZ.*

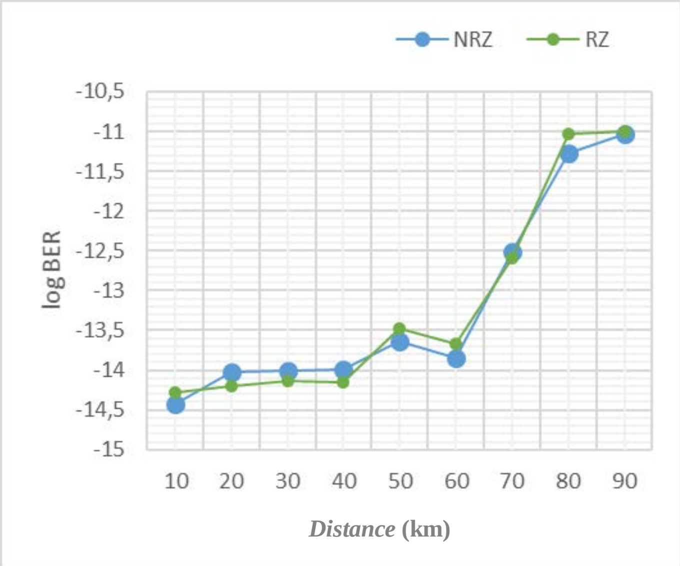

Figure 4.27 *graph FBG Laying influence on the BER*

Based on the pictures 4:27 bit rate 10 Gbps, the lowest BER value obtained line coding NRZ at a distance of 10 km is 3,7319 x 10^{-15} , *Lowest BER obtained line coding RZ at a distance of 10 km is* 5,242 x 10^{-15}. By FBG and EDFA been improvements BER value compared with no use of FBG and EDFA on *bit rate* 10 Gbps *line coding* NRZ and RZ.

From the experimental results using the format line coding RZ on the length 10 km of optical fiber, BER value obtained BER 5,242 x 10^{-15} *with value Q-factor is* 7,73281. Secara *Systematically, the resulting BER value Q-factor can be proved by the equation*:

$$BER = \frac{1}{\sqrt{2\pi Q}} e^{-\frac{Q^2}{2}}$$

$$= \frac{1}{\sqrt{2\pi(\,7{,}73281)}} e^{-\frac{(7{,}73281)^2}{2}}$$

$$= 1{,}4863 \times \ 10^{-14}$$

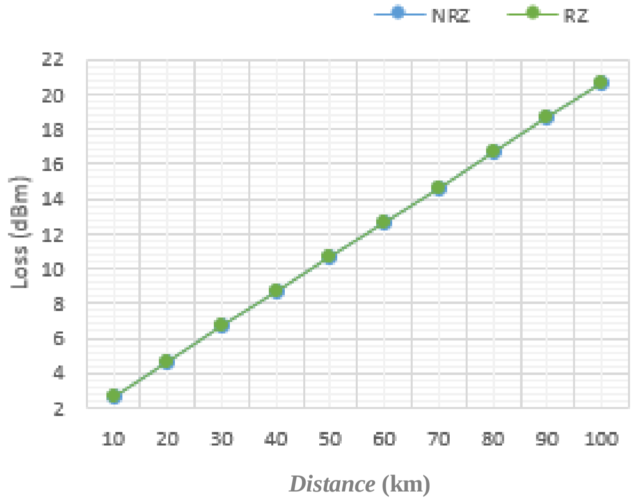

Figure 4.28 *Graph Laying influence FBG against loss*

Based on the pictures 4.28 bit rate 10 Gbps, value loss Lowest obtained line coding RZ 10 km is 2,668 dBm, *and RZ at a distance of 10 km is* 2,651 dBm. *With using FBG loss value increase rather than without FBG..*

From the experimental results using the format line coding RZ on the length 10 km of optical fiber, a score of 2,651 dBm loss. Systematically, the value of loss produced can be proved by the equation:

Loss (dBm) = P_{in} (dBm) – P_{out} (dBm)

= -5,471 – (-8,122)

= 2,651 dBm

but With EDFA level signal power value become better

Pout = -8,122 dBm

= 1W x 10 (-8,122/10)/1000

= 154,1 x 10^{-6} W

PEDFA = 1,465 dBm

= 1W x 10 (1,465/10)/1000

= 1401,2 x 10^{-6} W

Amplification P signal = PEDFA / Pout

= 1401,2 x 10^{-6} W / 154,1 x 10^{-6} W

= 9,09x

CHAPTER V

CONCLUSIONS AND SUGESSTIONS

5.1 *Conclusion*

Based on the results of research and analysis refers to the ITU-T as standard BER values 10^{-9} sampai 10^{-15} *and value Q-factor 6. Effect laying minimal compensator dispersion Fiber Bragg Grating (FBG) at bit rate 5 and 10 Gbps NRZ line coding and RZ, then made the following conclusion*:

- *Influence on the transmission distance bit rate seen from the parameter Q-factor with value of at least 6, the use of bit rate 5 Gbps line coding NRZ and RZ capable transmit up to a distance of 100 km, while the bit rate 10 Gbps with NRZ and RZ is only able to transmit up to a distance of 90 km*.
- *the use of FBG will improve the dispersion occurring at the time the pulse is transmitted on the optical fiber, but the use of FBG also has an adverse effect that is the value of loss that grows larger*.
- *the use of EDFA will improve signal power value, with the strengthening of the power signal.*
- *In bit rate 5 Gbps NRZ at a distance of 10 km, the value Q-factor 7.92864, BER* $1{,}0981 \times 10^{-15}$ *and loss* 2,667 dBm, but With EDFA level singal power *value become better seen form* P_{out}/P_{EDFA} $1401{,}2 \times 10^{-6}$ W / $154{,}1 \times 10^{-6}$ W = 8,78x *amplification.*
- *In bit rate 10 Gbps RZ at a distance of 10 km, value Q-factor 7,73281, BER* $5{,}242 \times 10^{-15}$ *and loss 2,561 dBm,* but With EDFA level signal power *value become better seen form* P_{out}/P_{EDFA} $1401{,}2 \times 10^{-6}$ W / $154{,}1 \times 10^{-6}$ W = 9,09x *amplification*.

5.2 *Suggestions*

Based on the analysis conducted in this paper suggestions are given is:

- *Transmission system with the ROF bit rate 40 Gbps at a frequency of 5G.*
- *Using multiple FBG dispersion compensator*.

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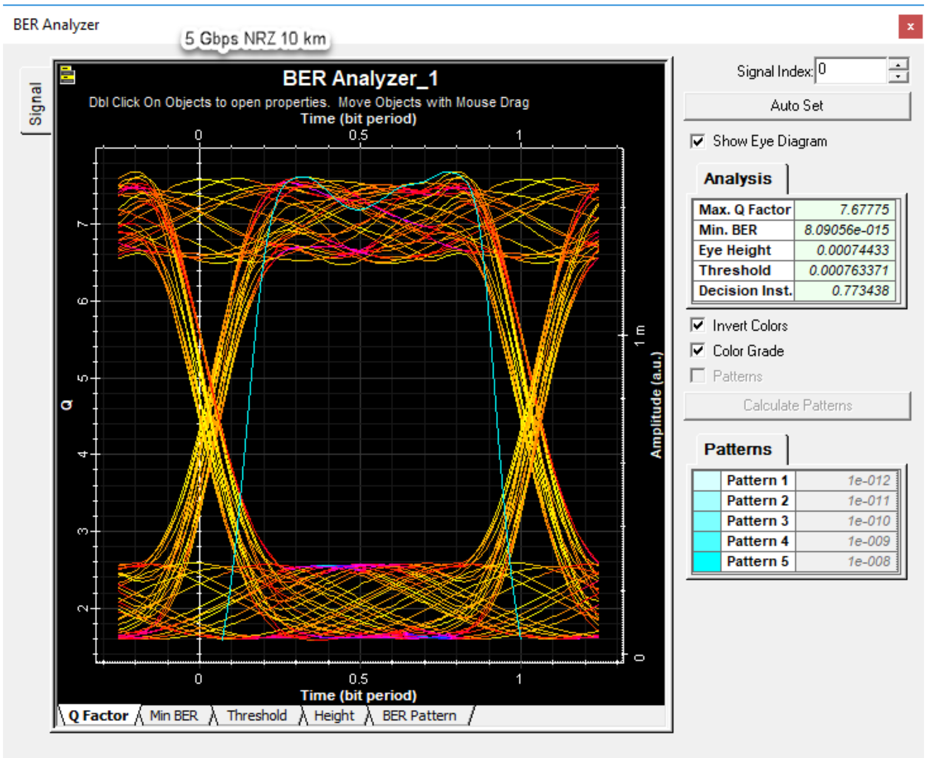
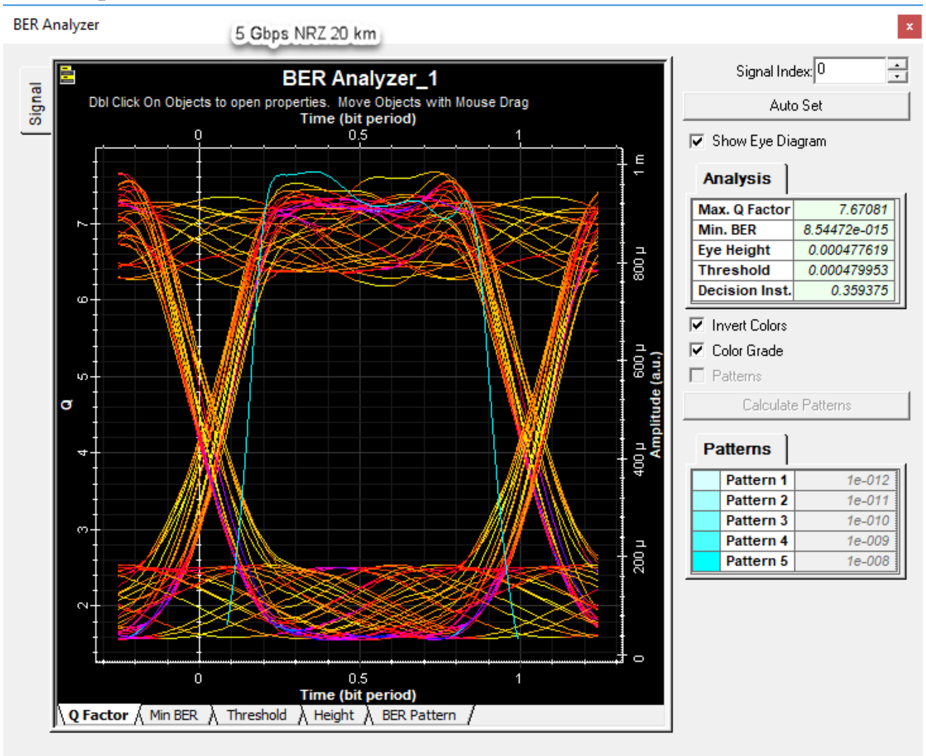
Attachment

Attachment 1 Eye Pattern

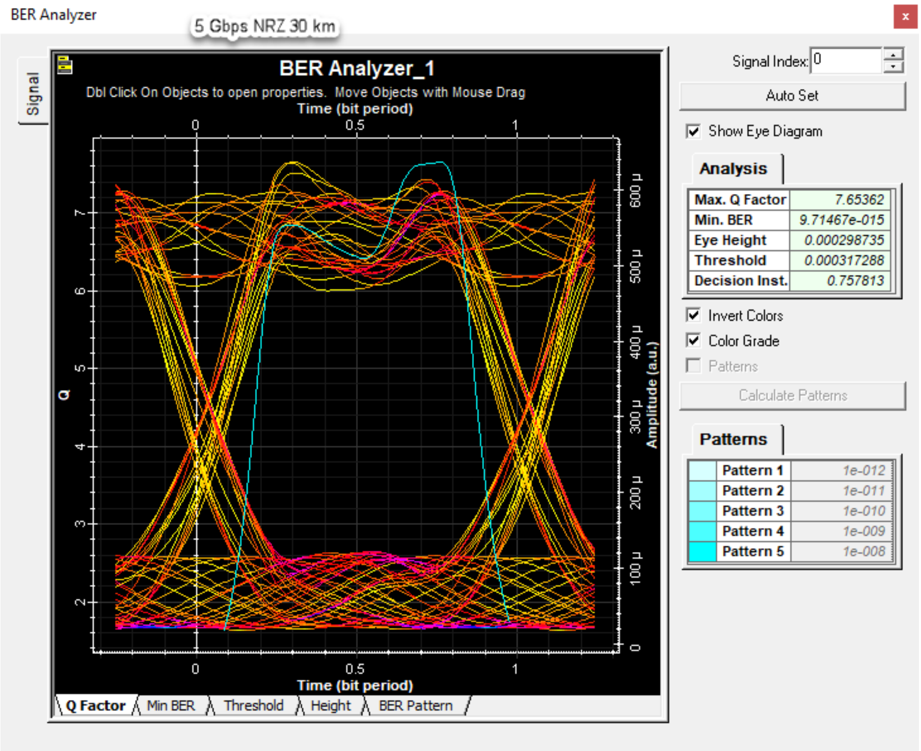
1. 5 Gbps NRZ 10 km



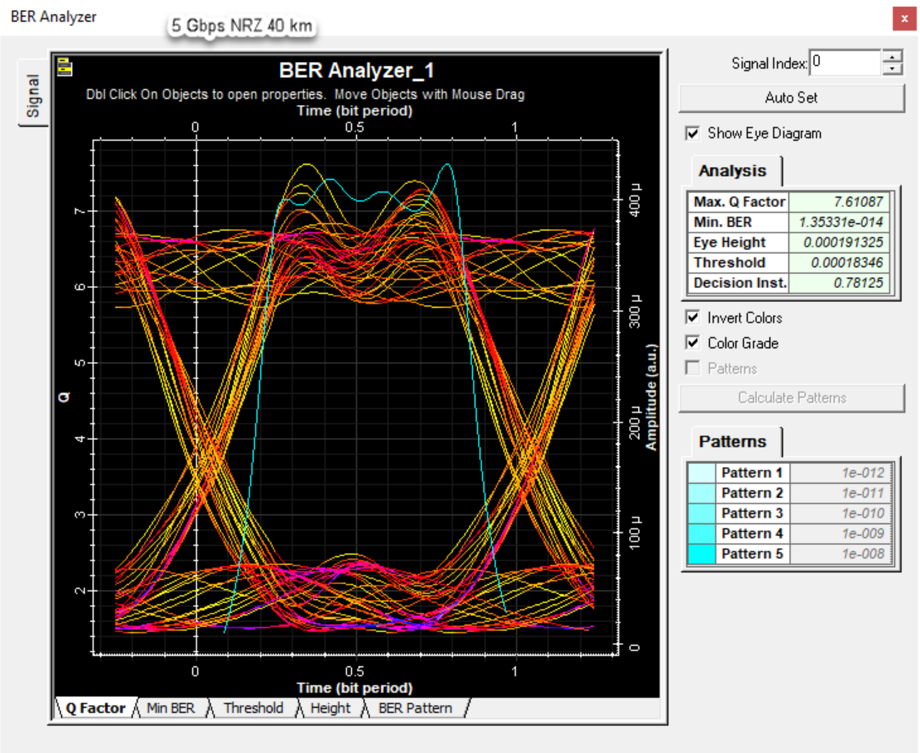
2. 5 Gbps NRZ 20 km



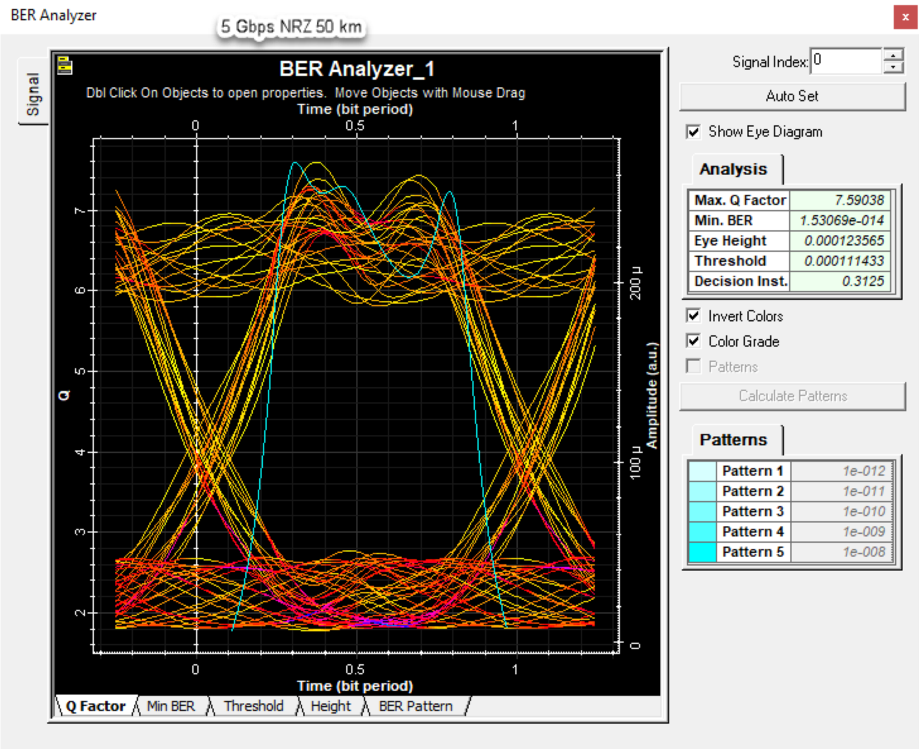
3. 5 Gbps NRZ 30 km



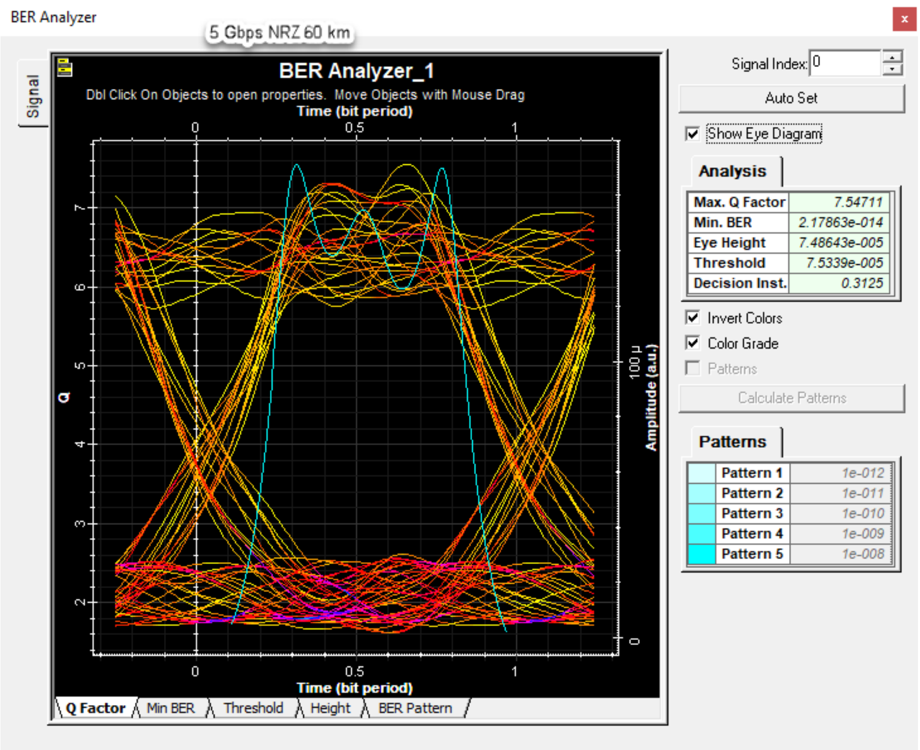
4. 5 Gbps NRZ 40 km



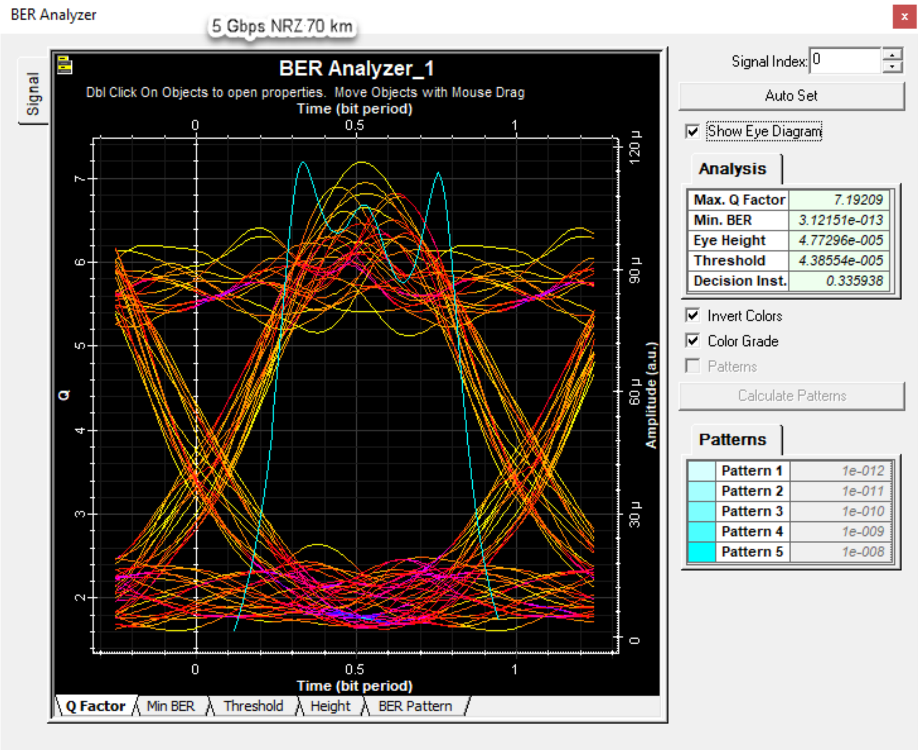
5. 5 Gbps NRZ 50 km



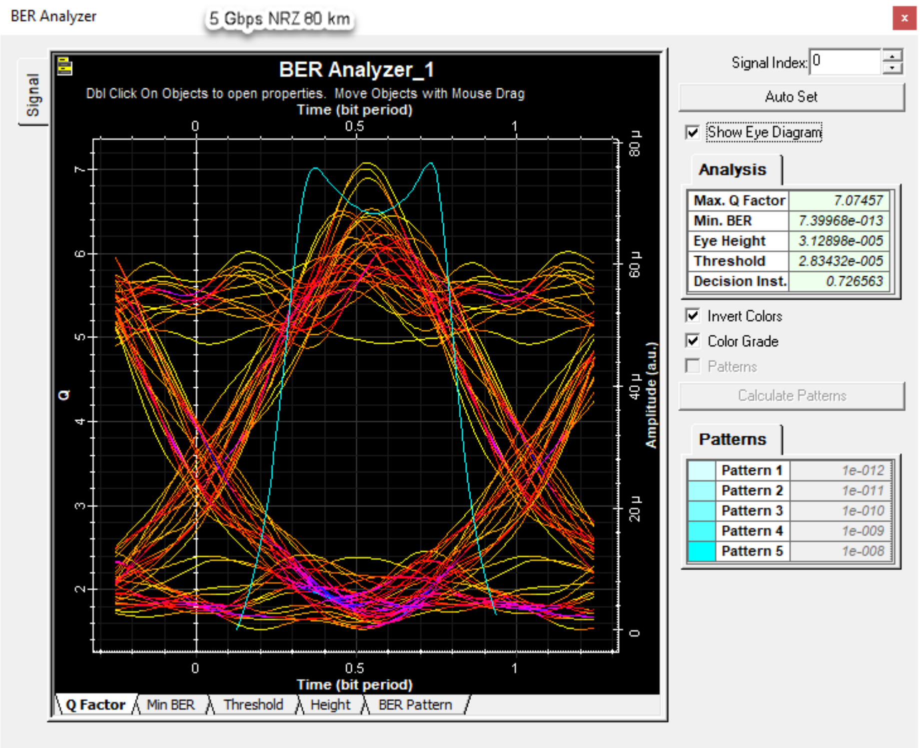
6. 5 Gbps NRZ 60 km



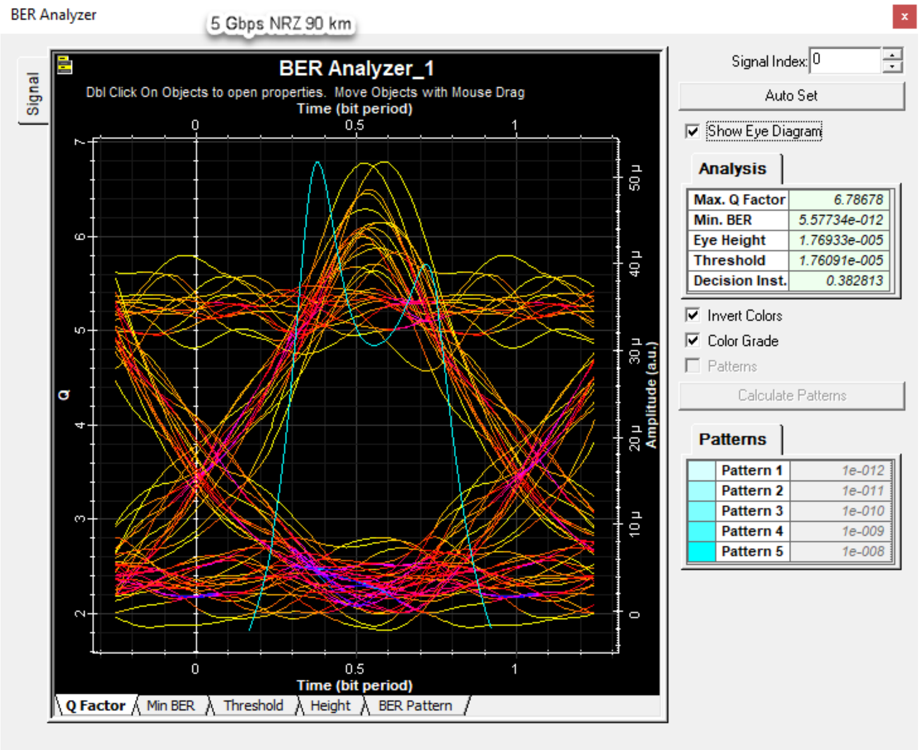
7. 5 Gbps NRZ 70 km



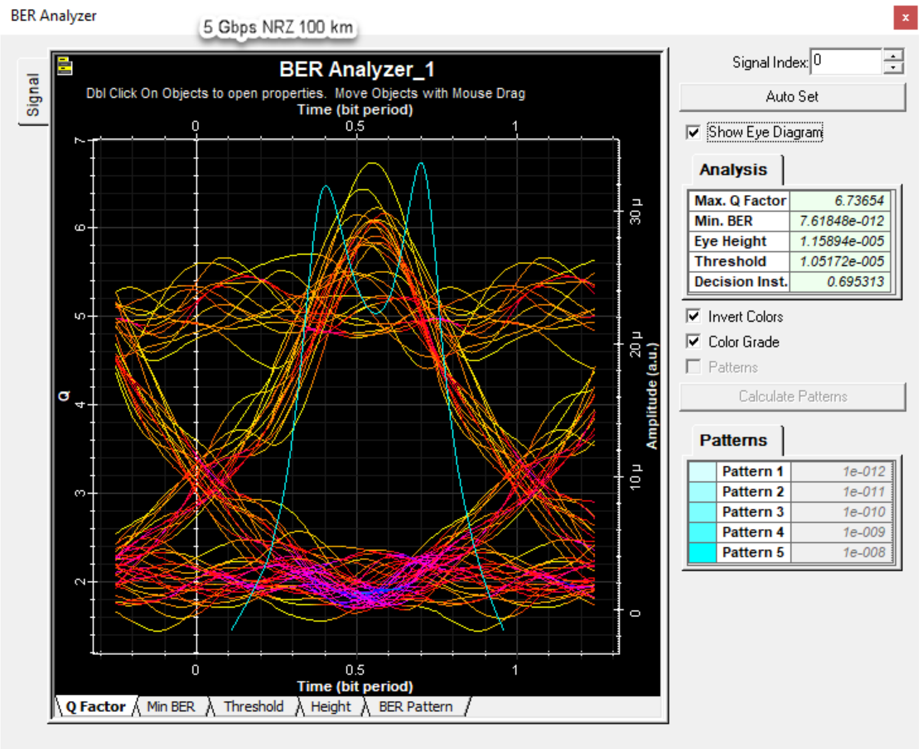
8. 5 Gbps NRZ 80 km



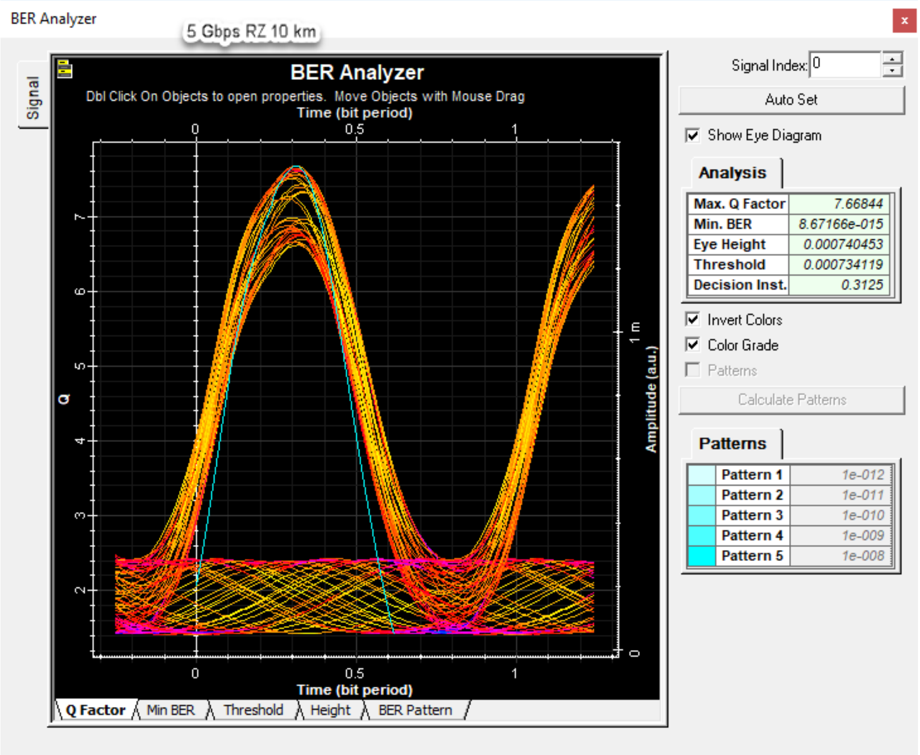
9. 5 Gbps NRZ 90 km



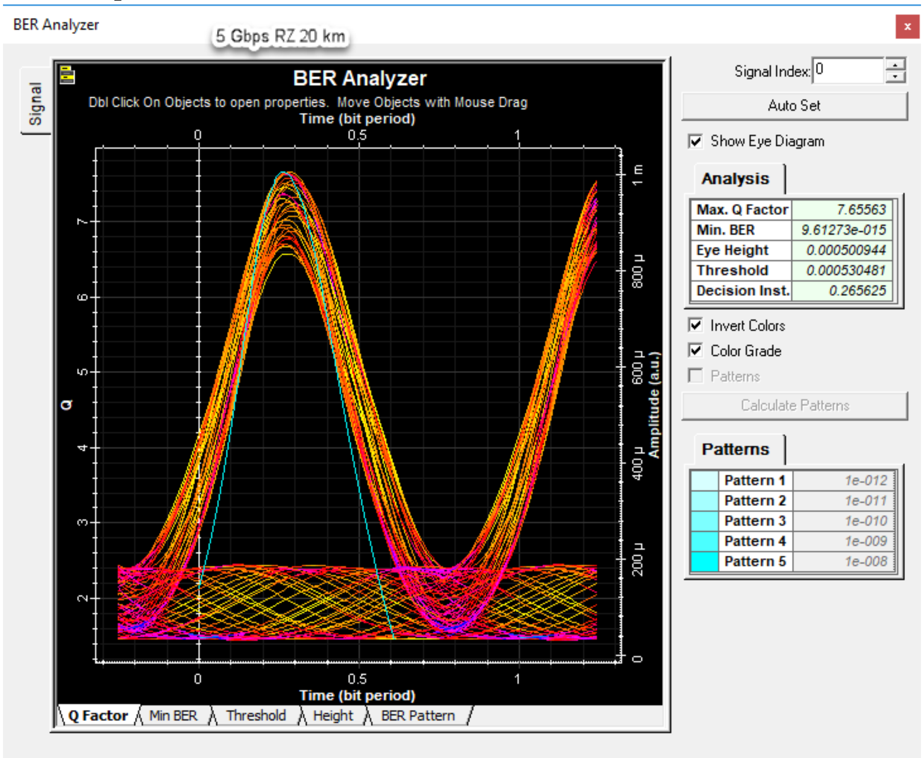
10. 5 Gbps NRZ 100 km



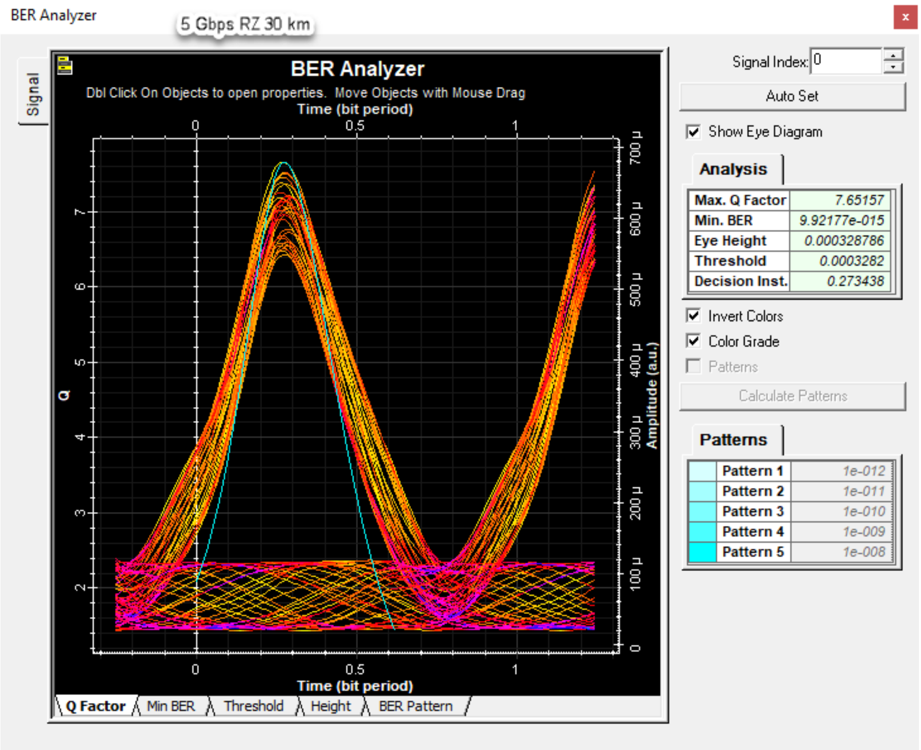
11. 5 Gbps RZ 10 km



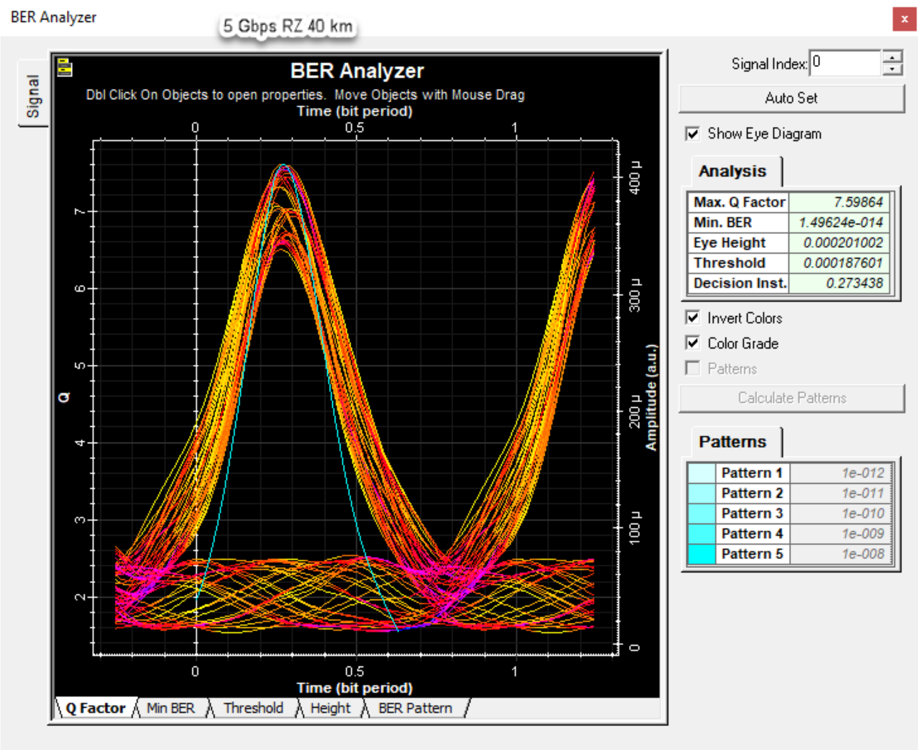
12. 5 Gbps RZ 20 km



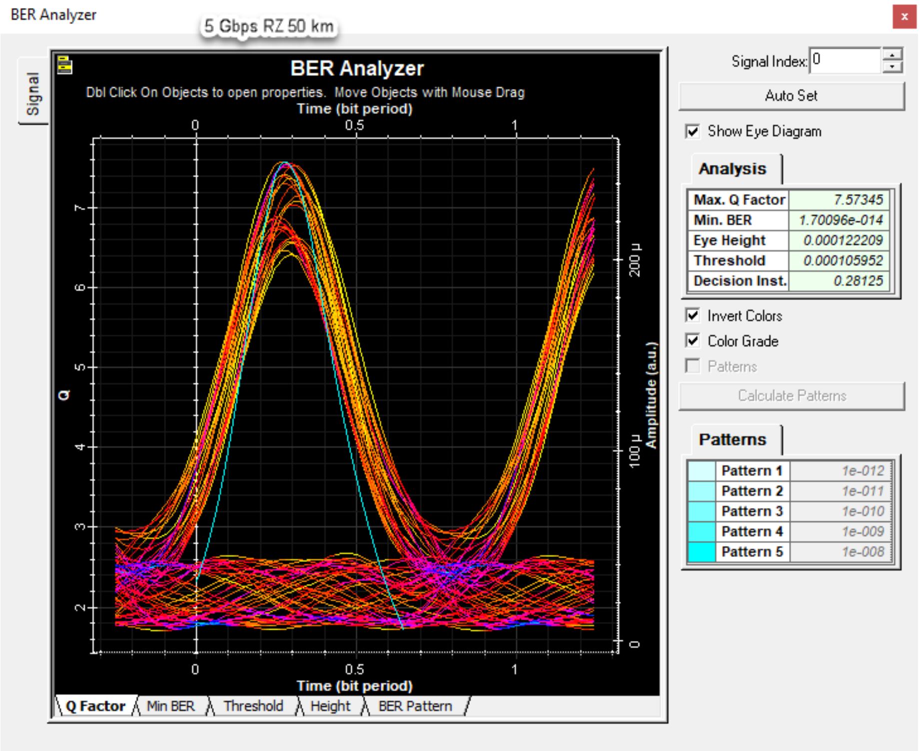
13. 5 Gbps RZ 30 km



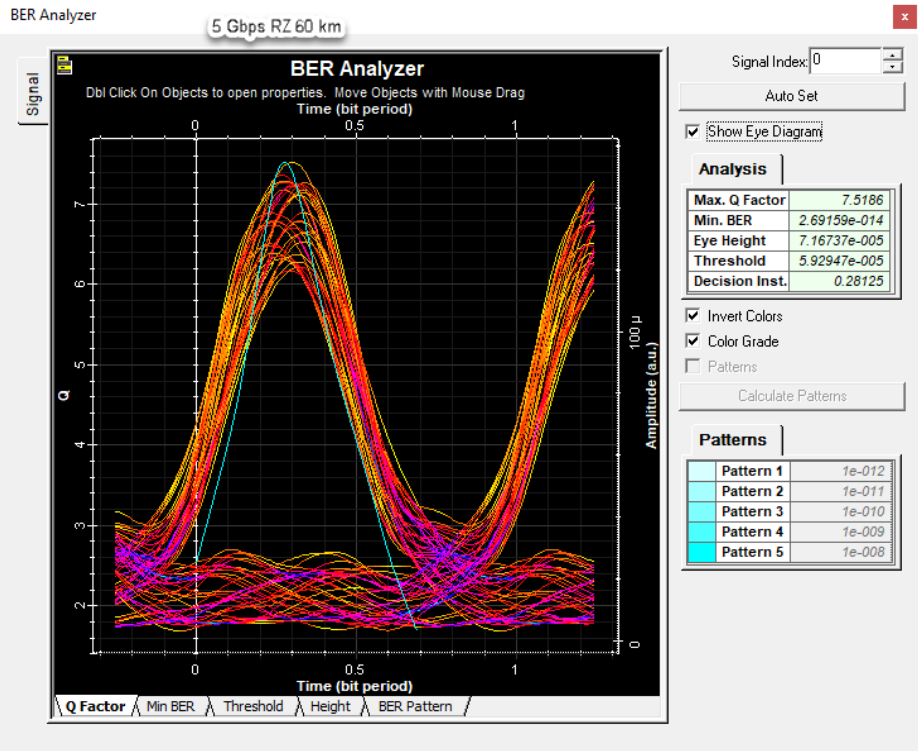
14. 5 Gbps RZ 40 km



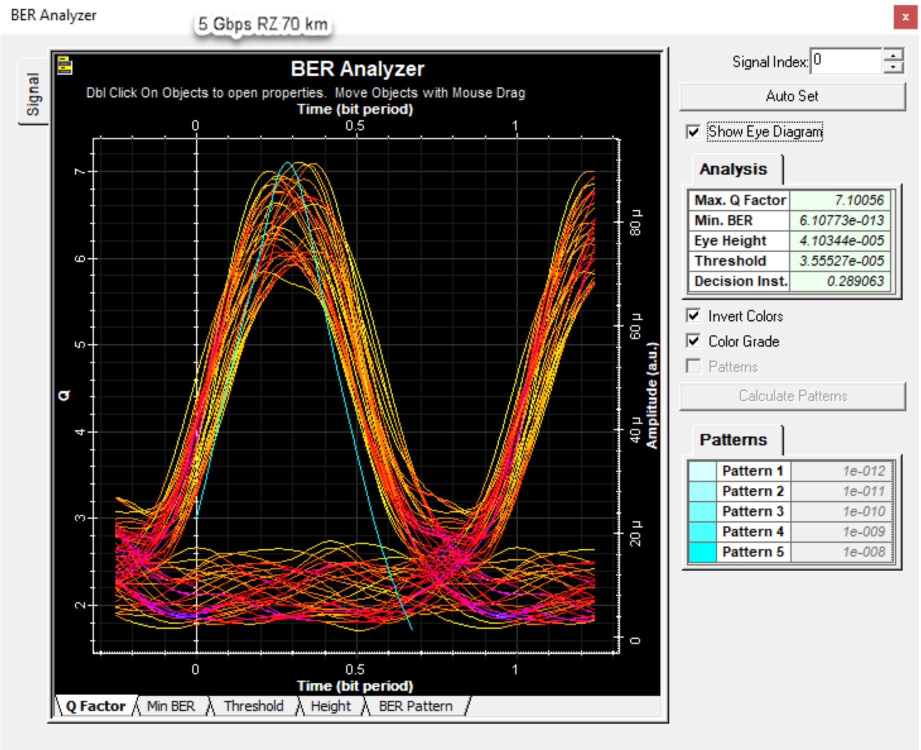
15. 5 Gbps RZ 50 km



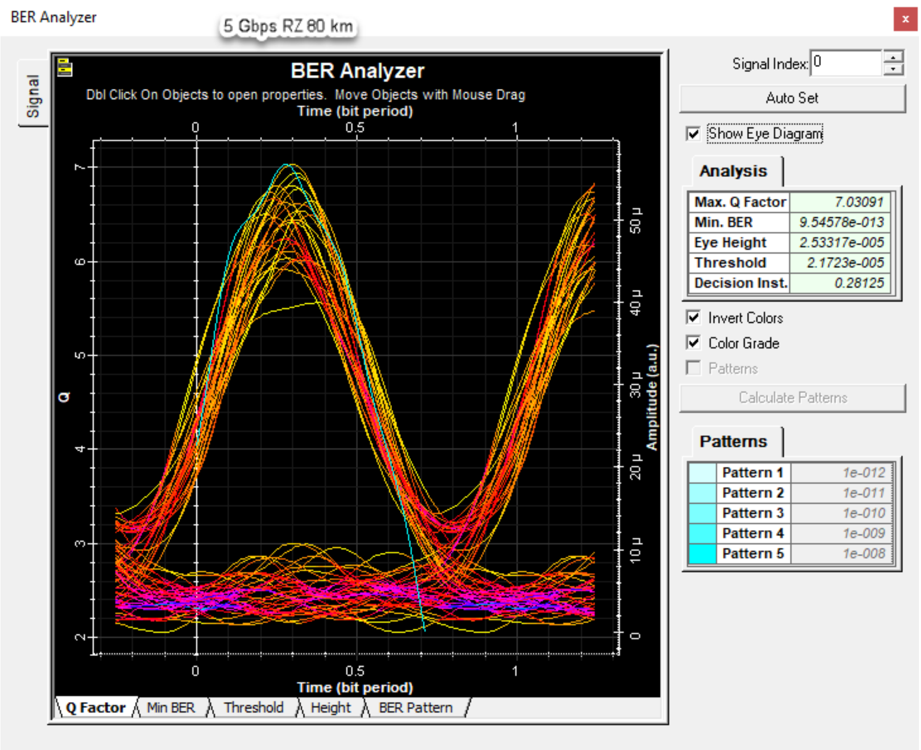
16. 5 Gbps RZ 60 km



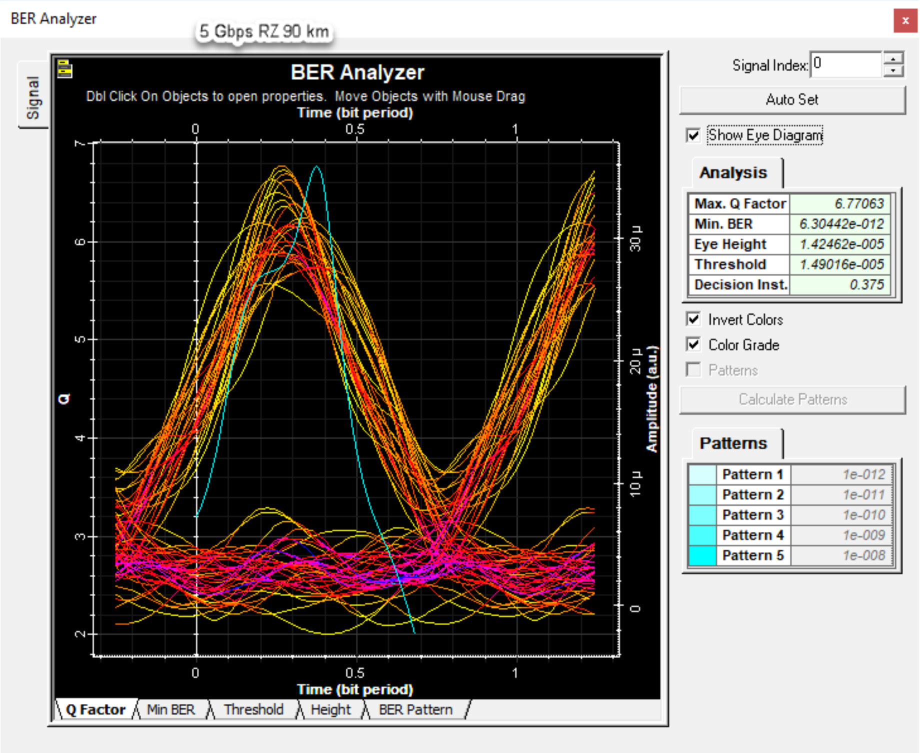
17. 5 Gbps RZ 70 km



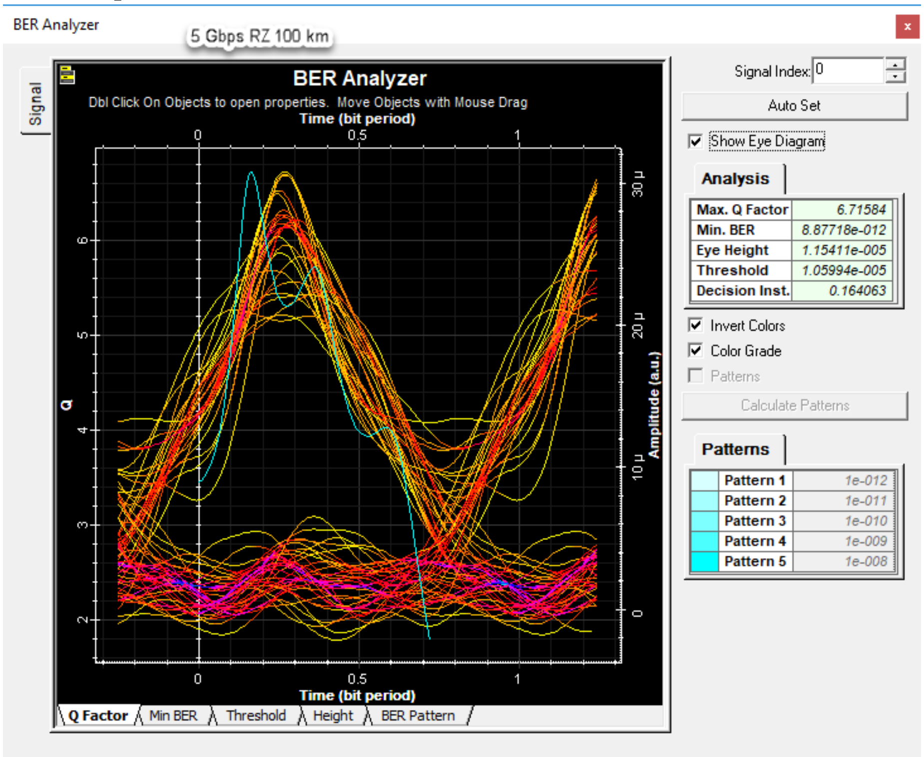
18. 5 Gbps RZ 80 km



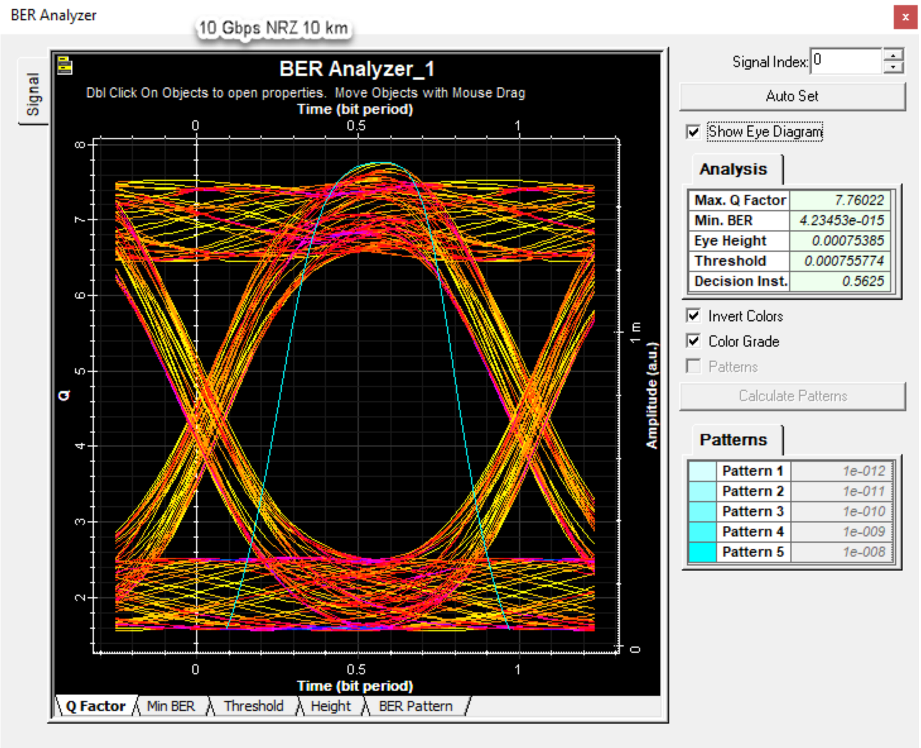
19. 5 Gbps RZ 90 km



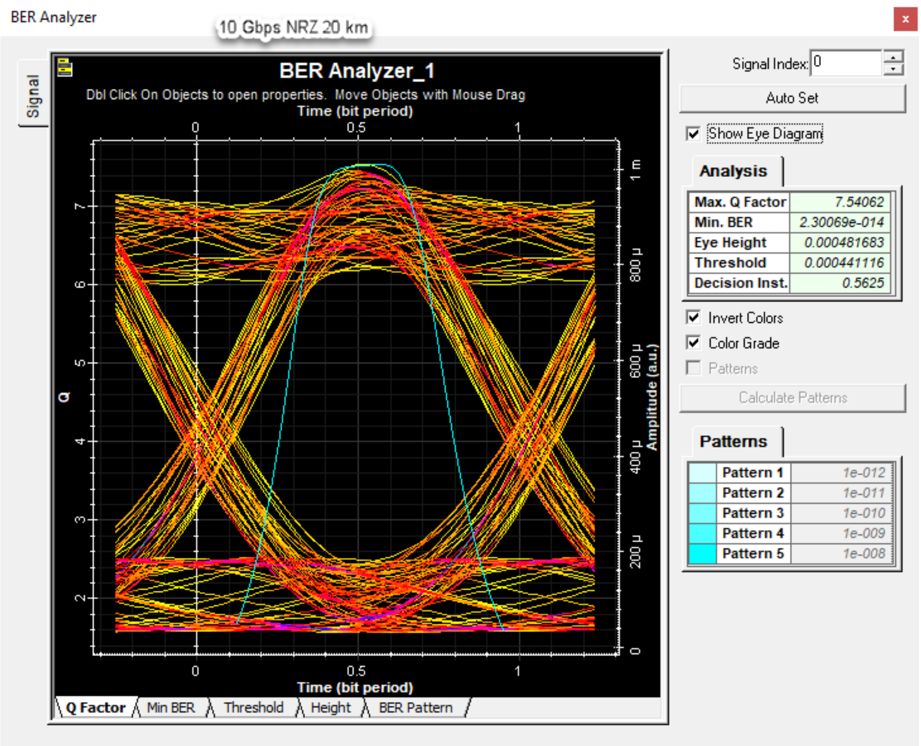
20. 5 Gbps RZ 100 km



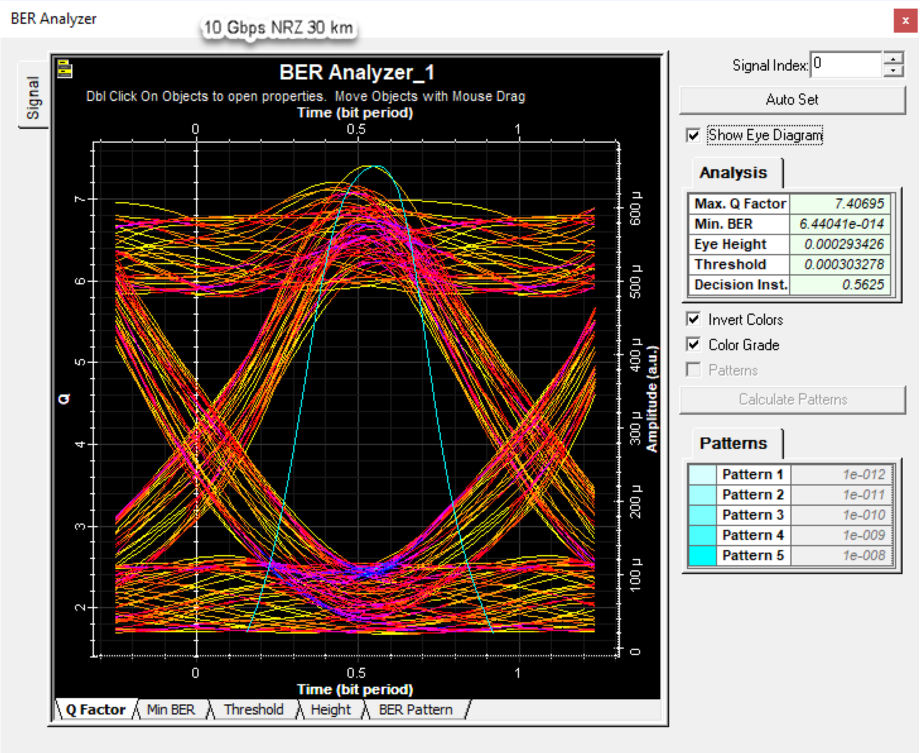
21. 10 Gbps NRZ 10 km



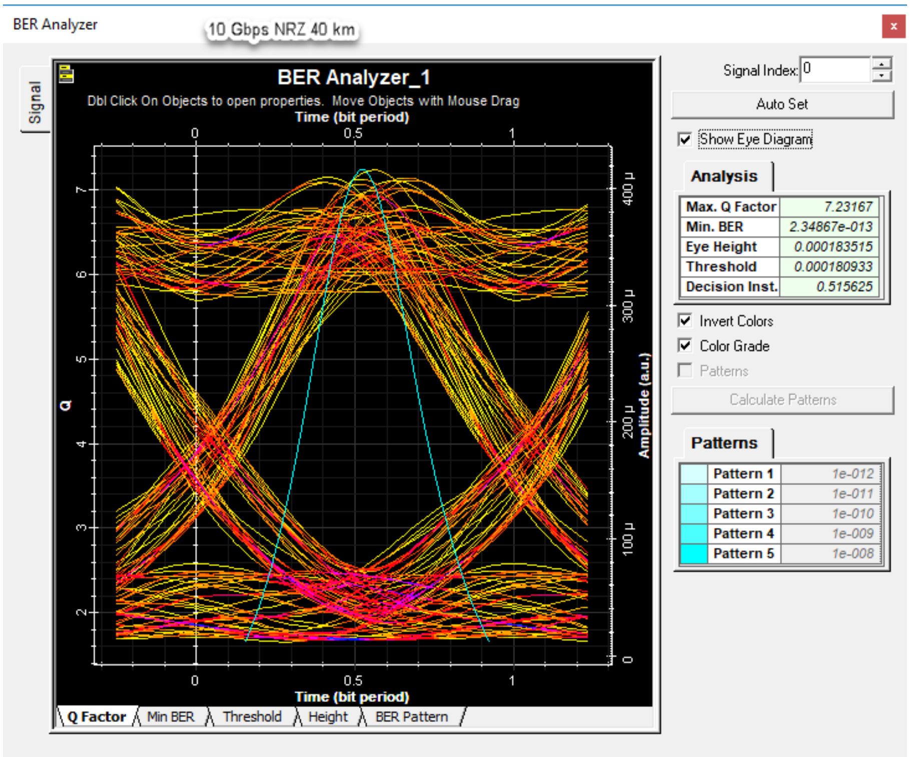
22. 10 Gbps NRZ 20 km



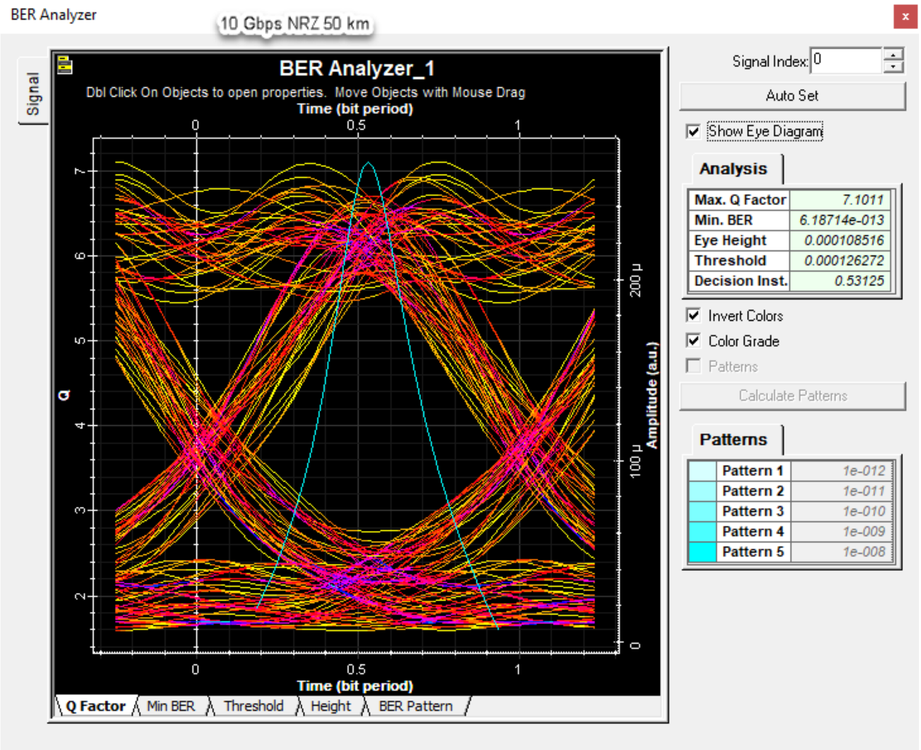
23. 10 Gbps NRZ 30 km



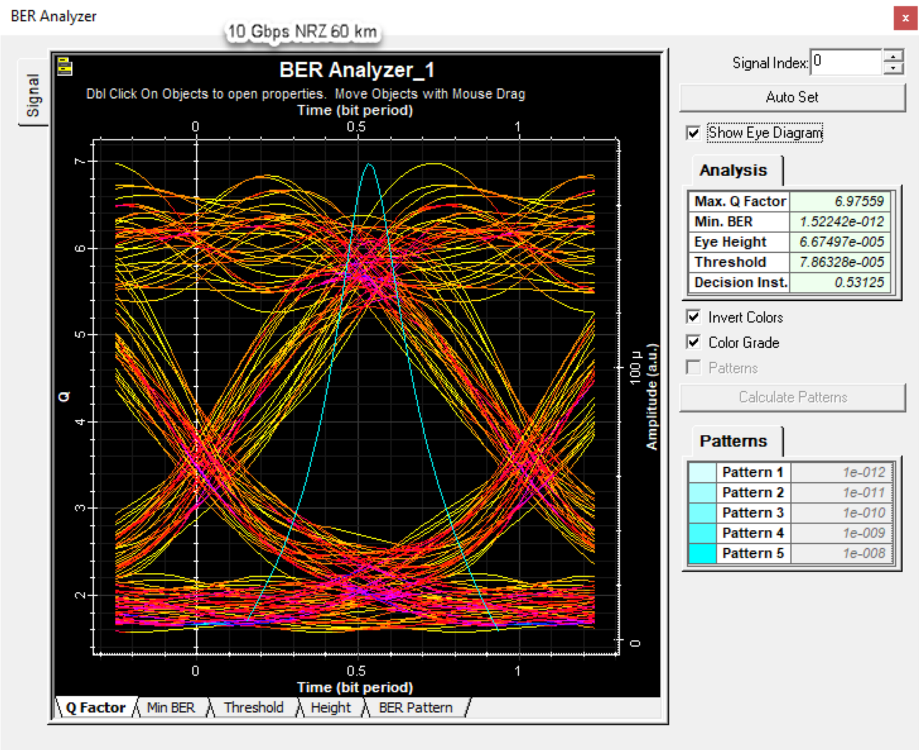
24. 10 Gbps NRZ 40 km



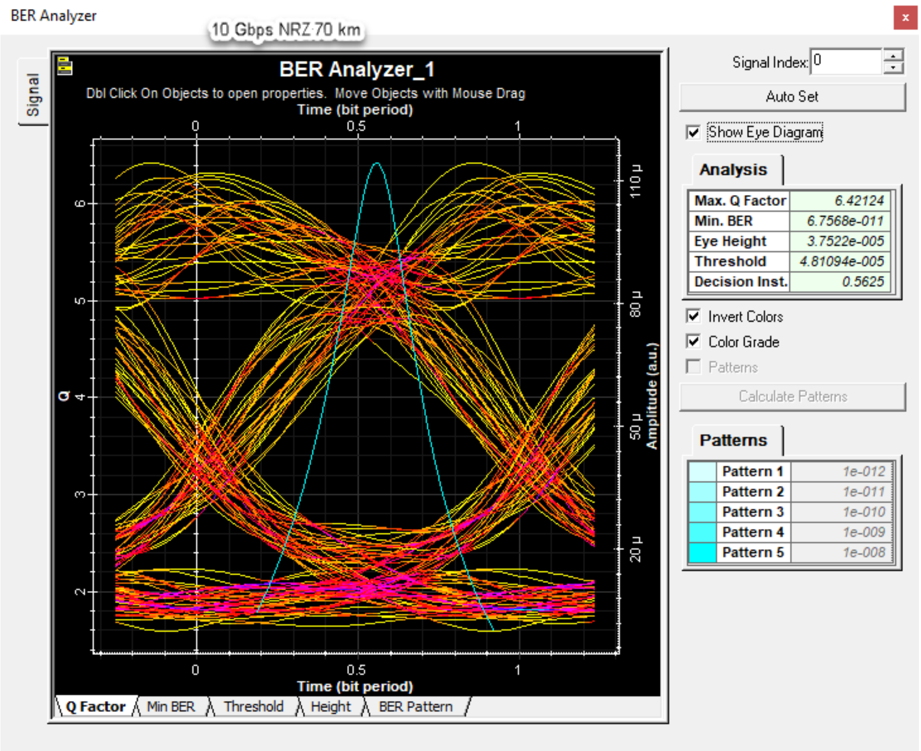
25. 10 Gbps NRZ 50 km



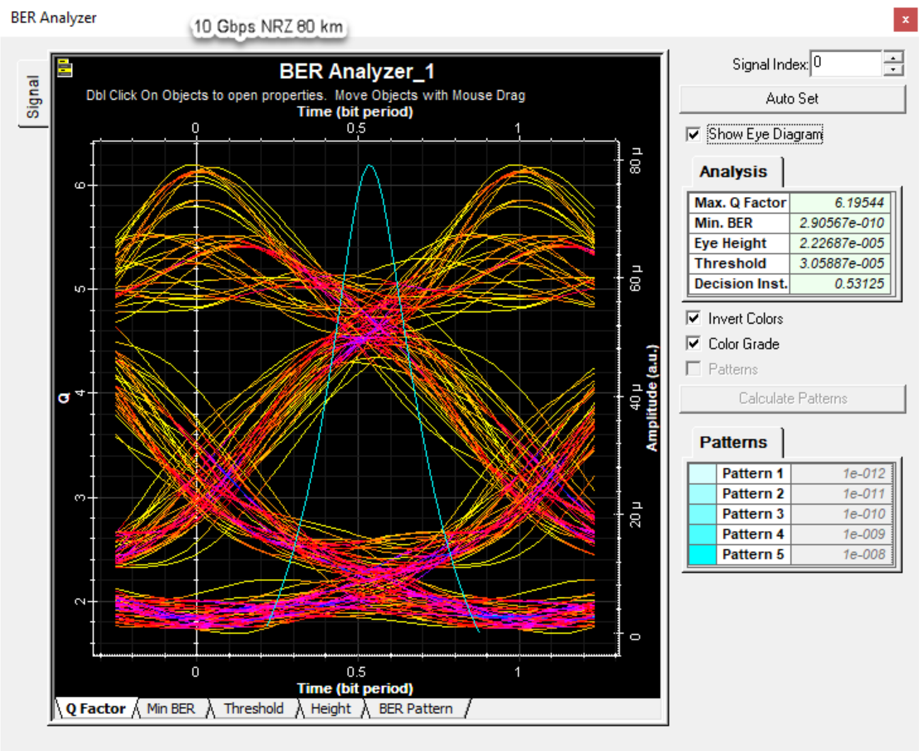
26. 10 Gbps NRZ 60 km



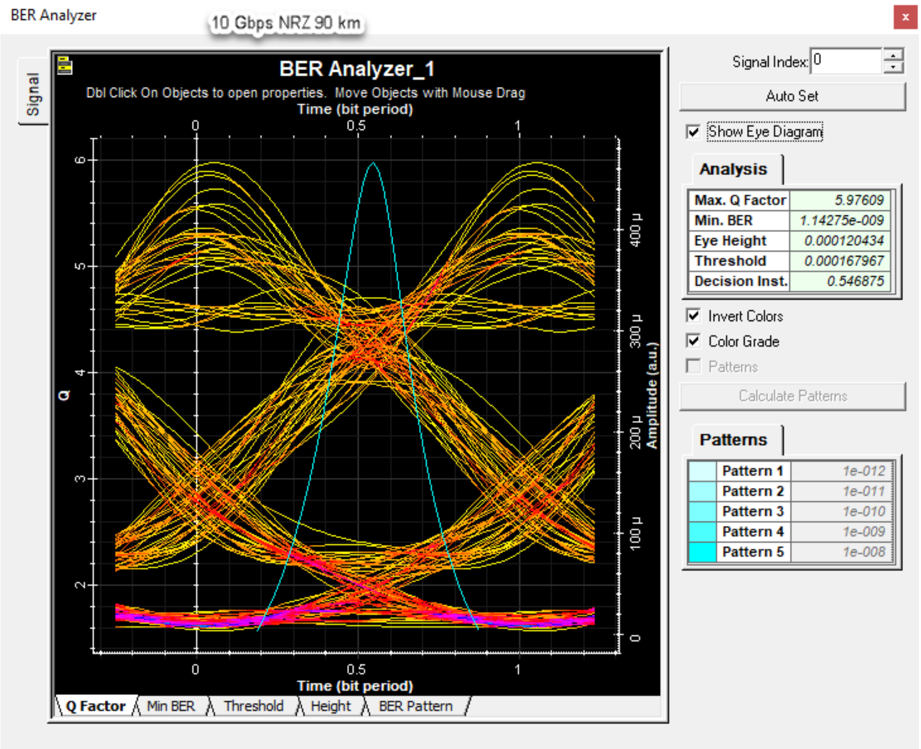
27. 10 Gbps NRZ 70 km



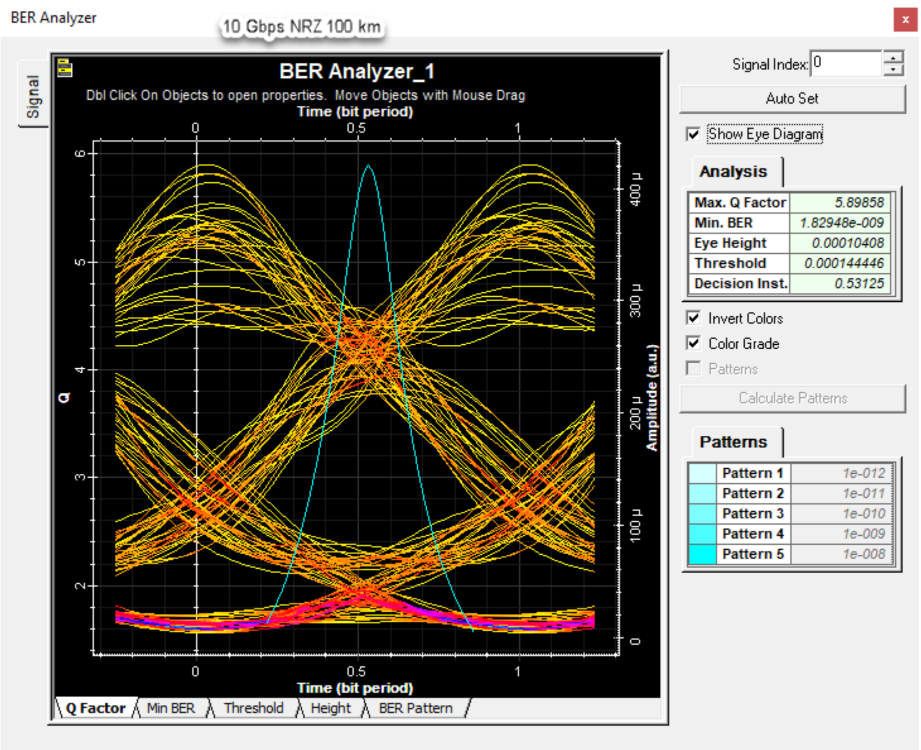
28. 10 Gbps NRZ 80 km



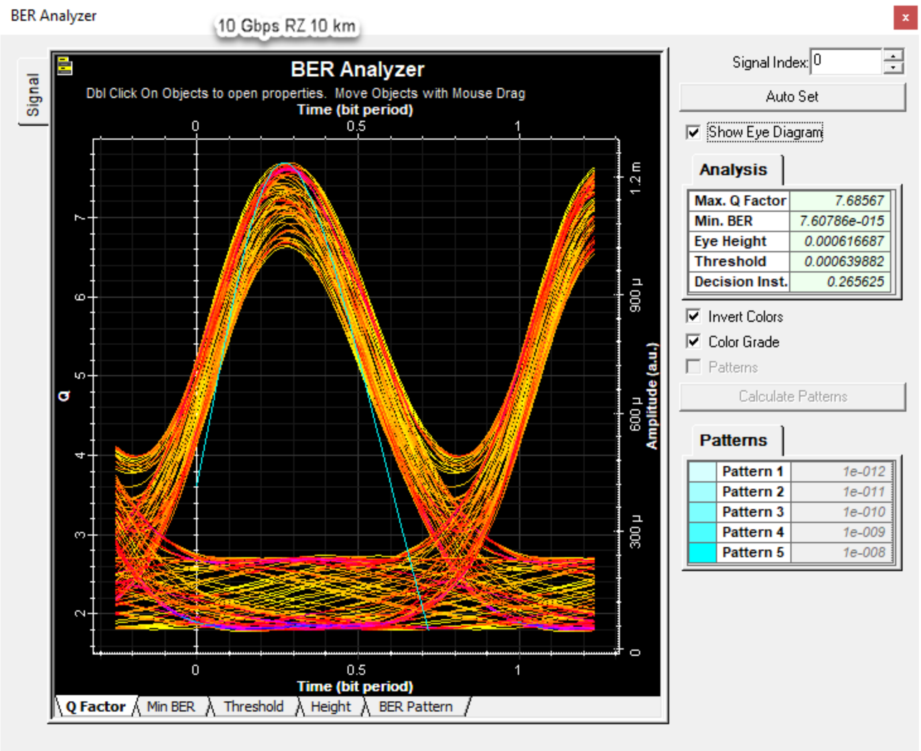
29. 10 Gbps NRZ 90 km



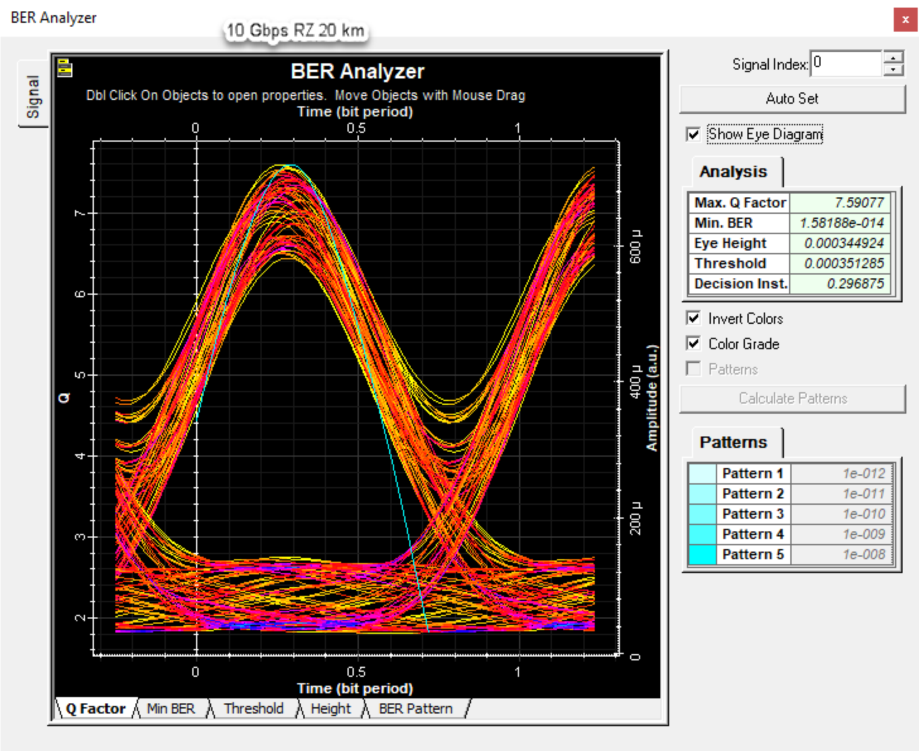
30. 10 Gbps NRZ 100 km



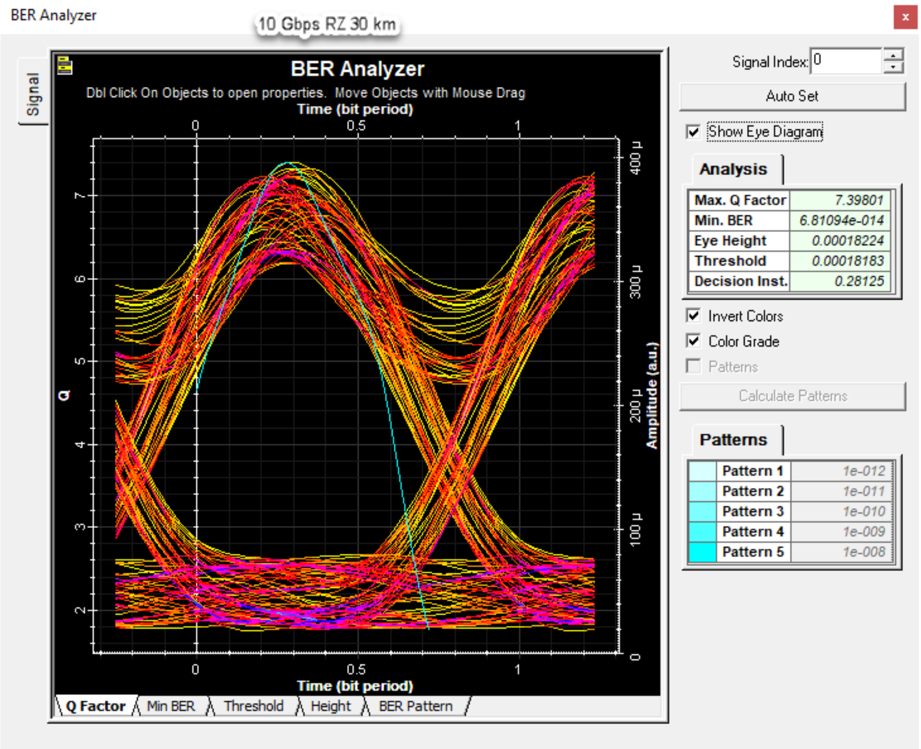
31. 10 Gbps RZ 10 km



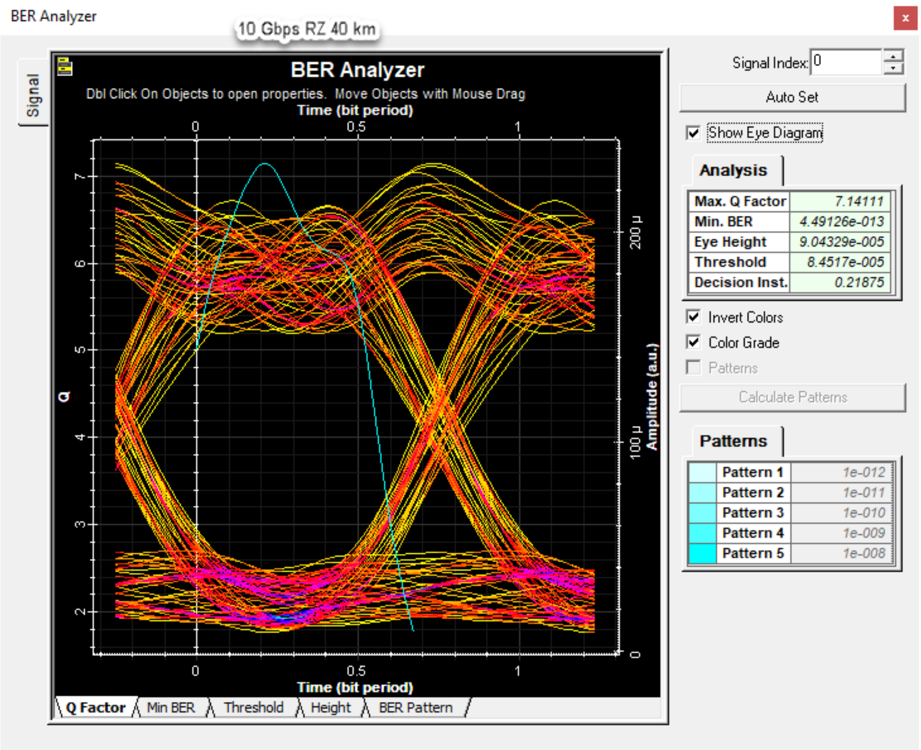
32. 10 Gbps RZ 20 km



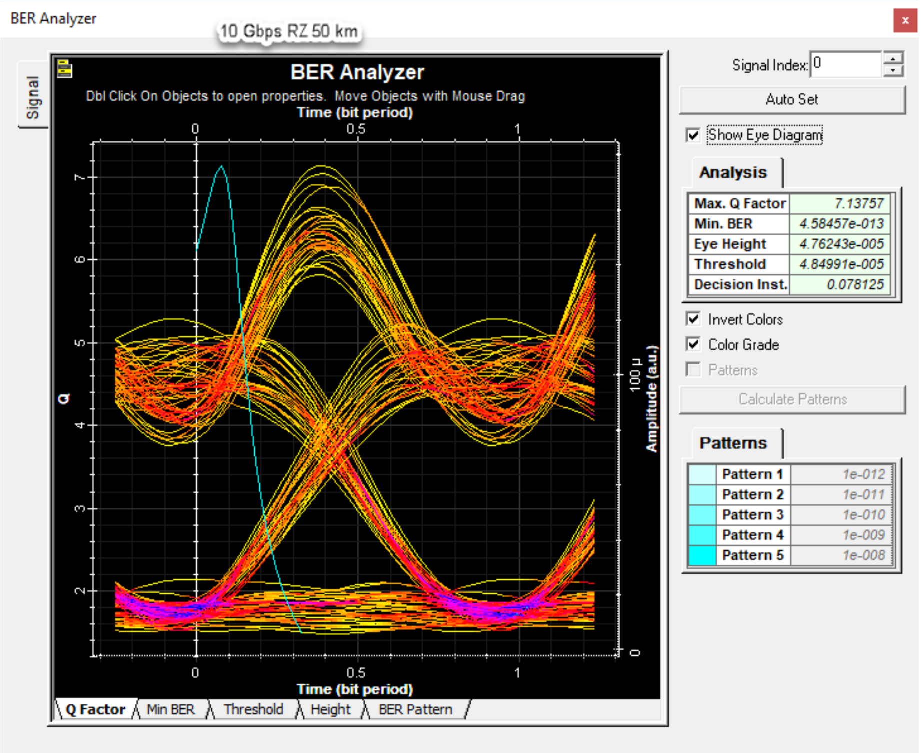
33. 10 Gbps RZ 30 km



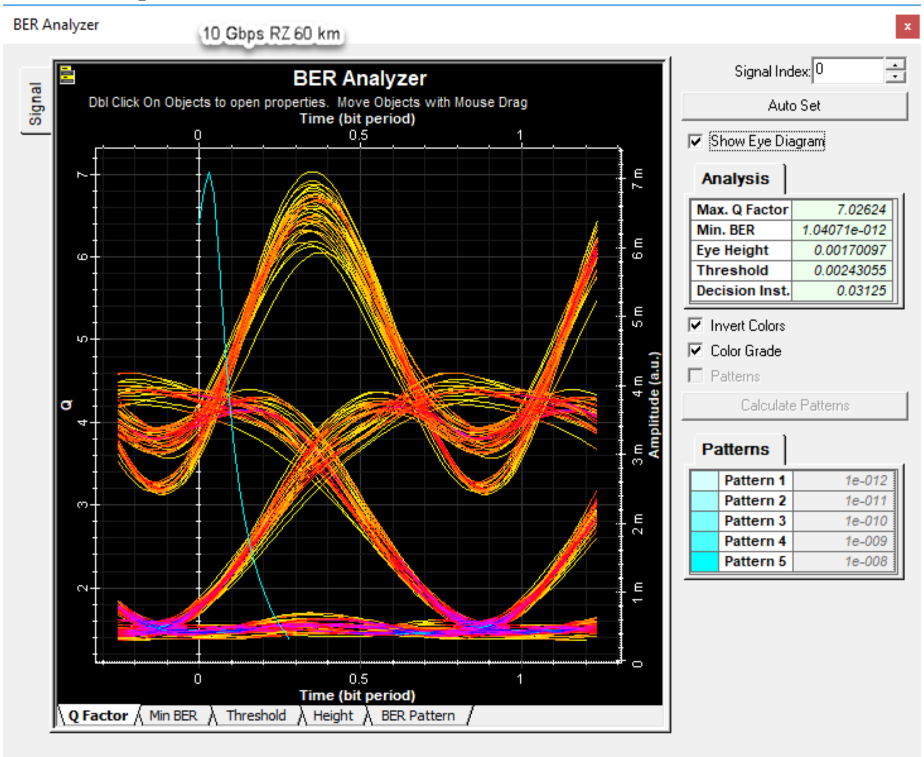
34. 10 Gbps RZ 40 km



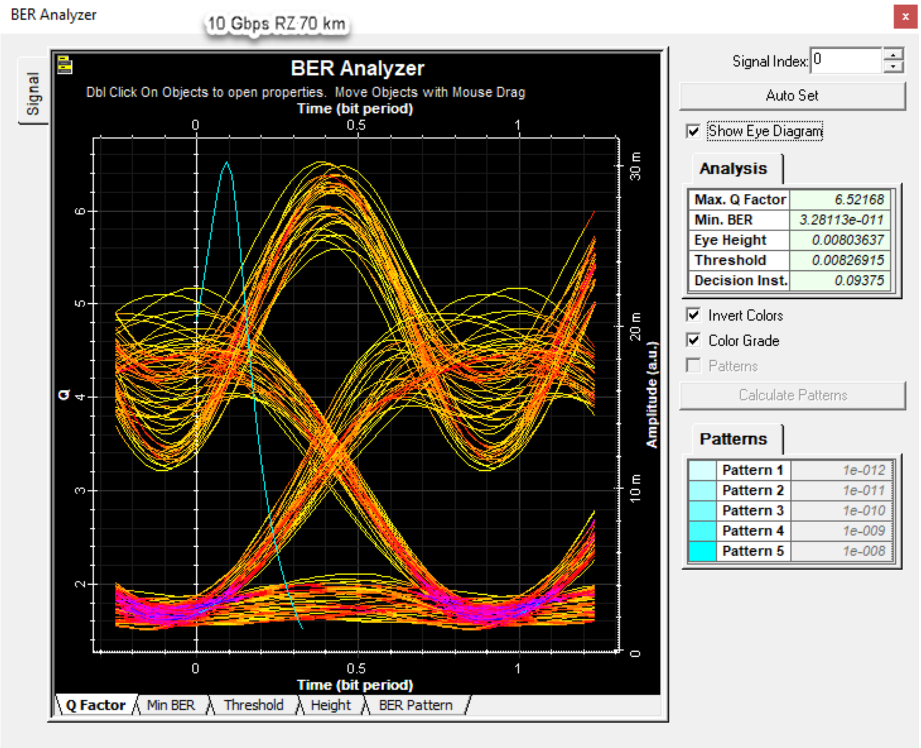
35. 10 Gbps RZ 50 km



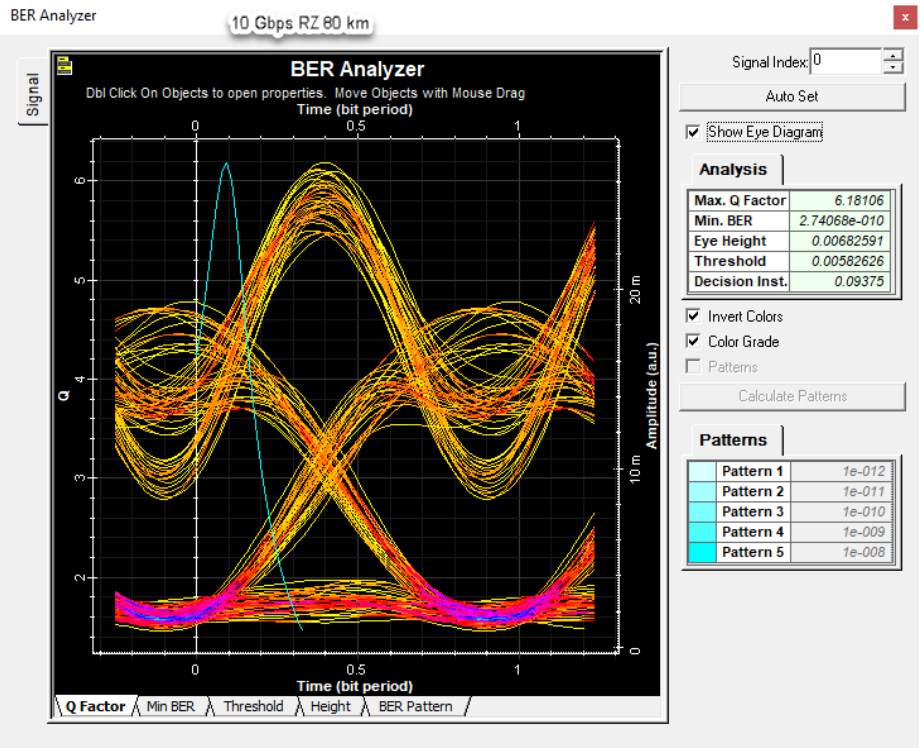
36. 10 Gbps RZ 60 km



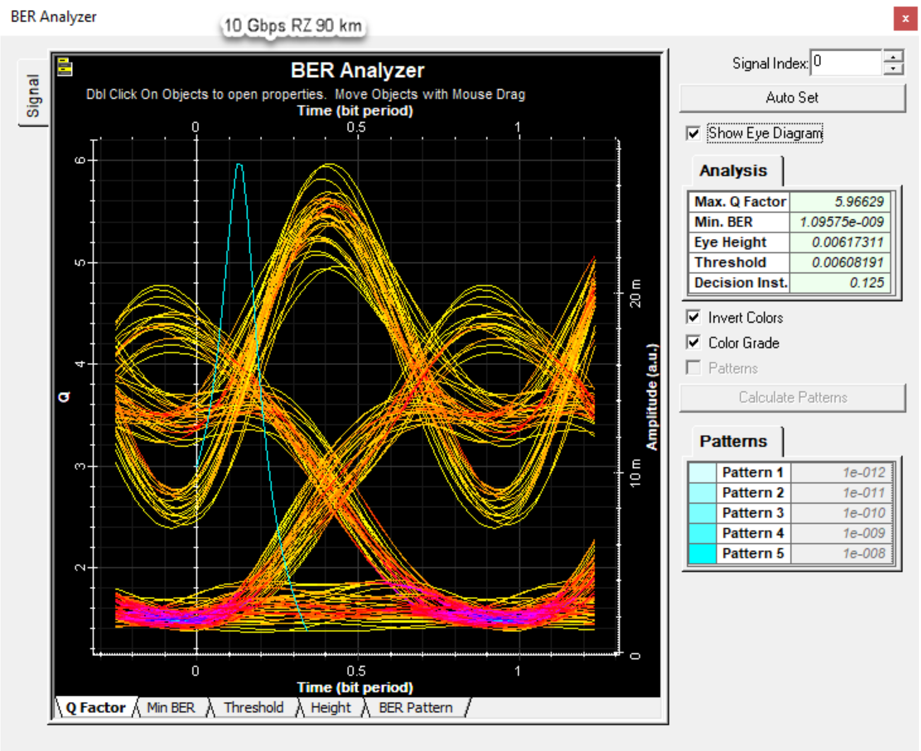
37. 10 Gbps RZ 70 km



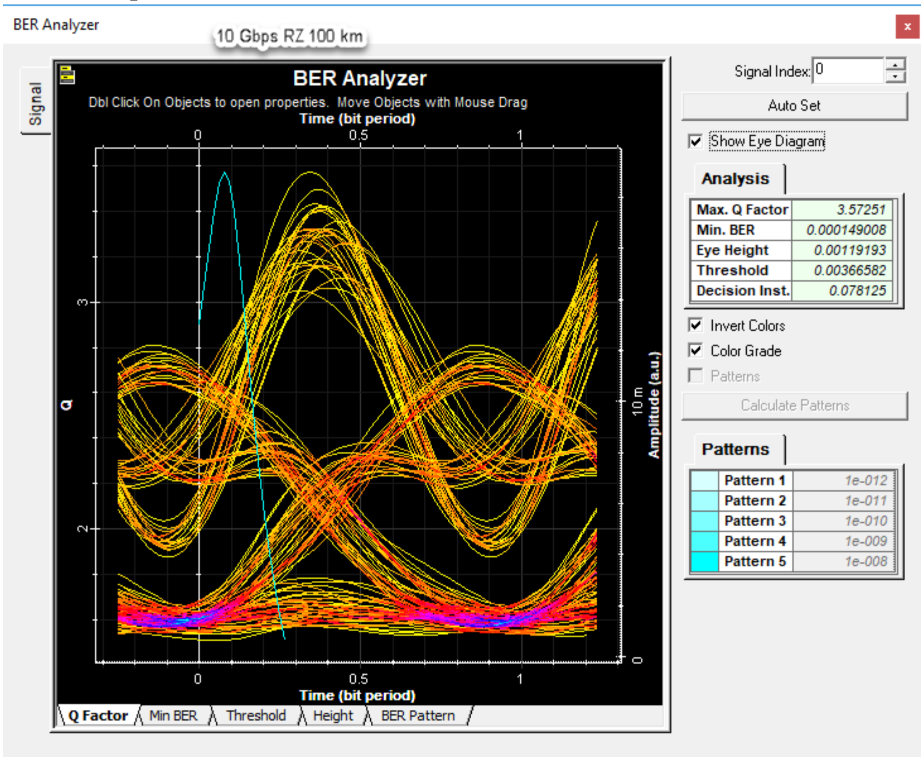
38. 10 Gbps RZ 80 km



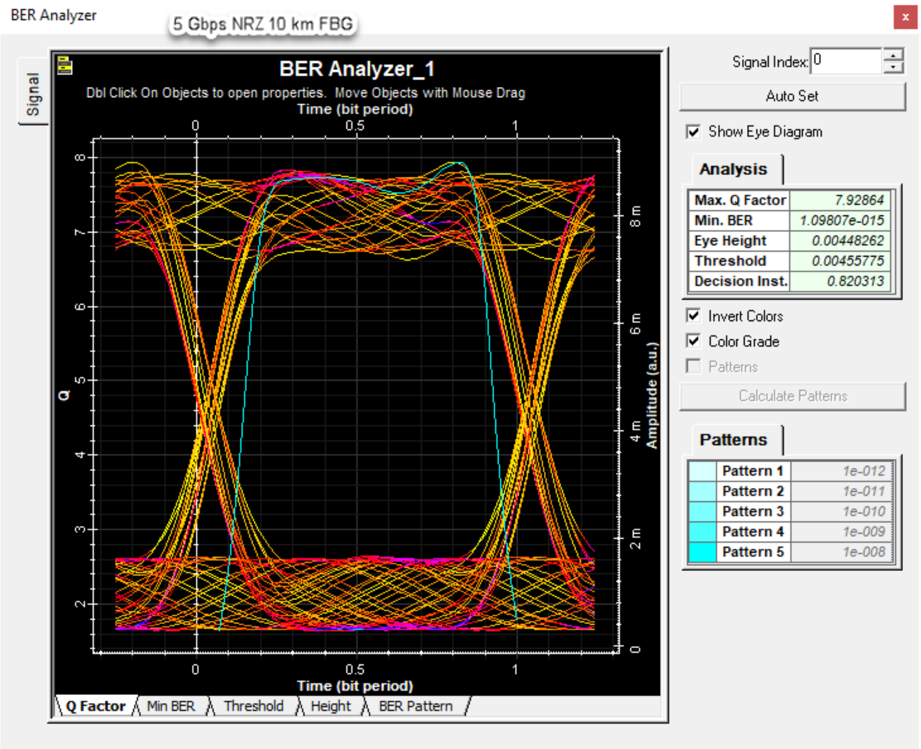
39. 10 Gbps RZ 90 km



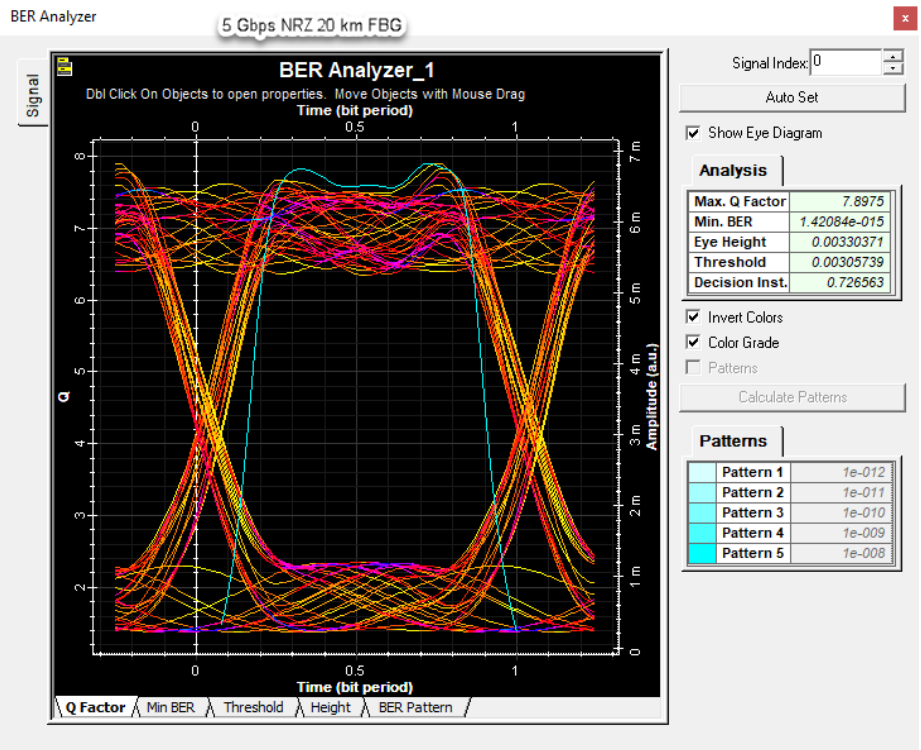
40. 10 Gbps RZ 100 km



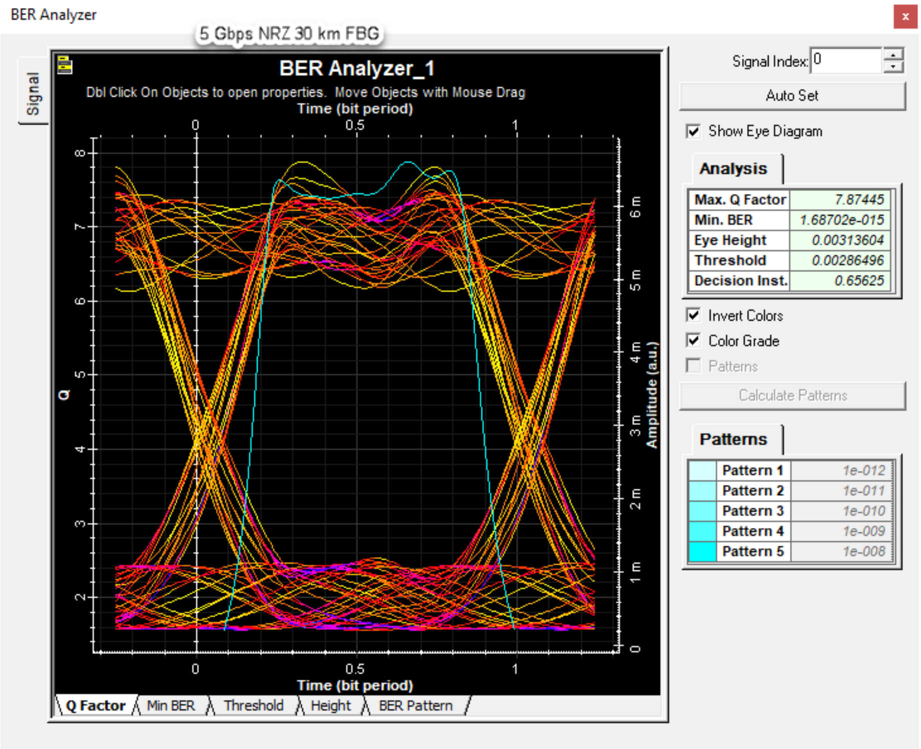
41. 5 Gbps NRZ 10 km FBG



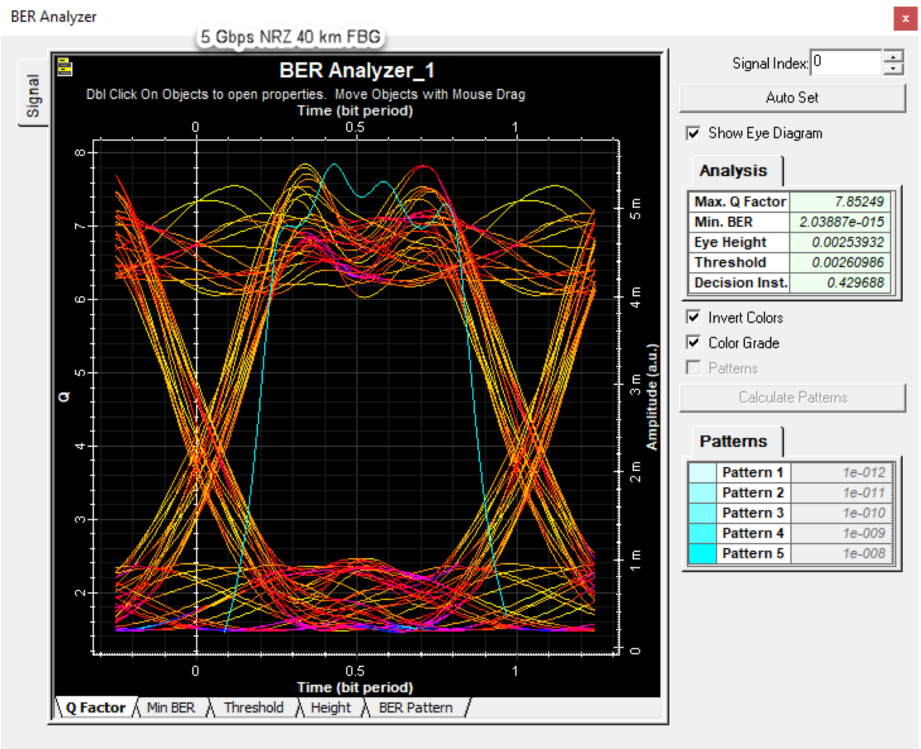
42. 5 Gbps NRZ 20 km FBG



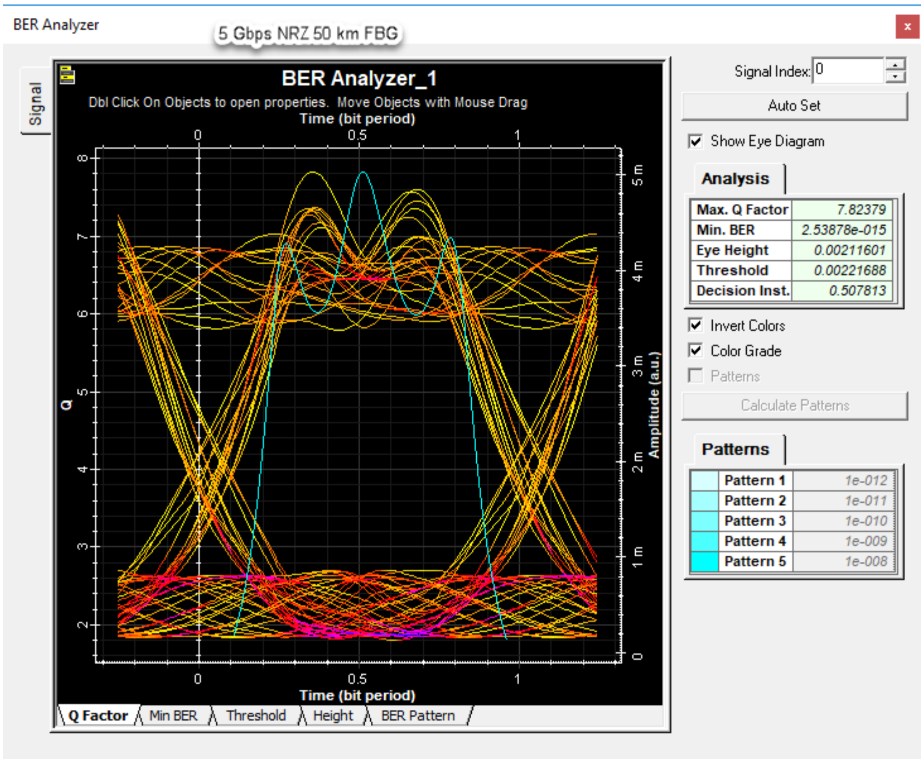
43. 5 Gbps NRZ 30 km FBG



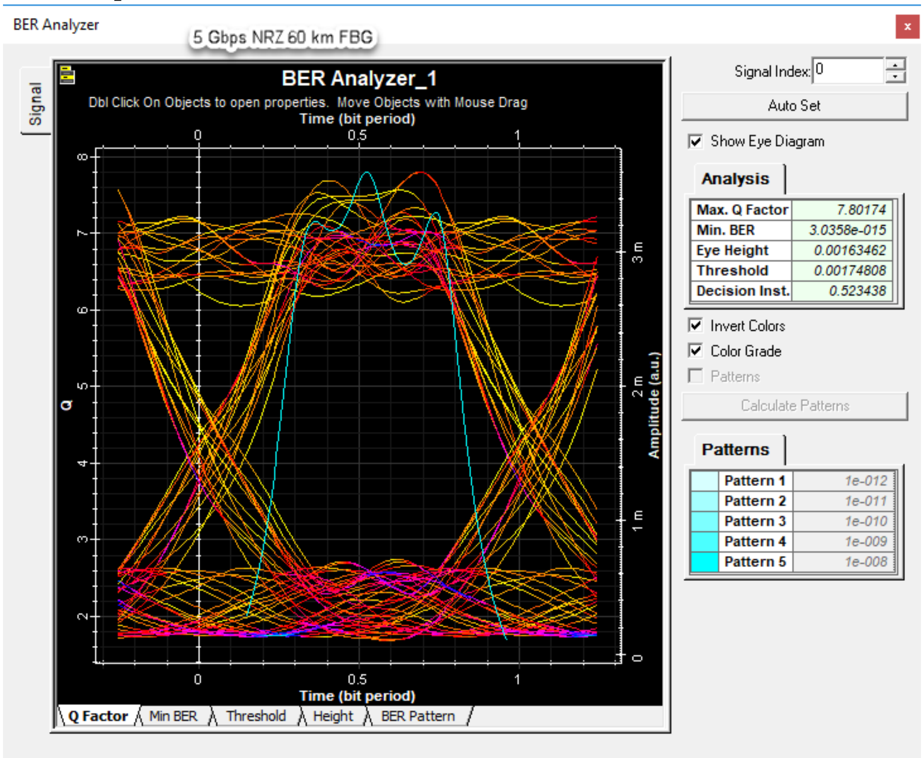
44. 5 Gbps NRZ 10 km FBG



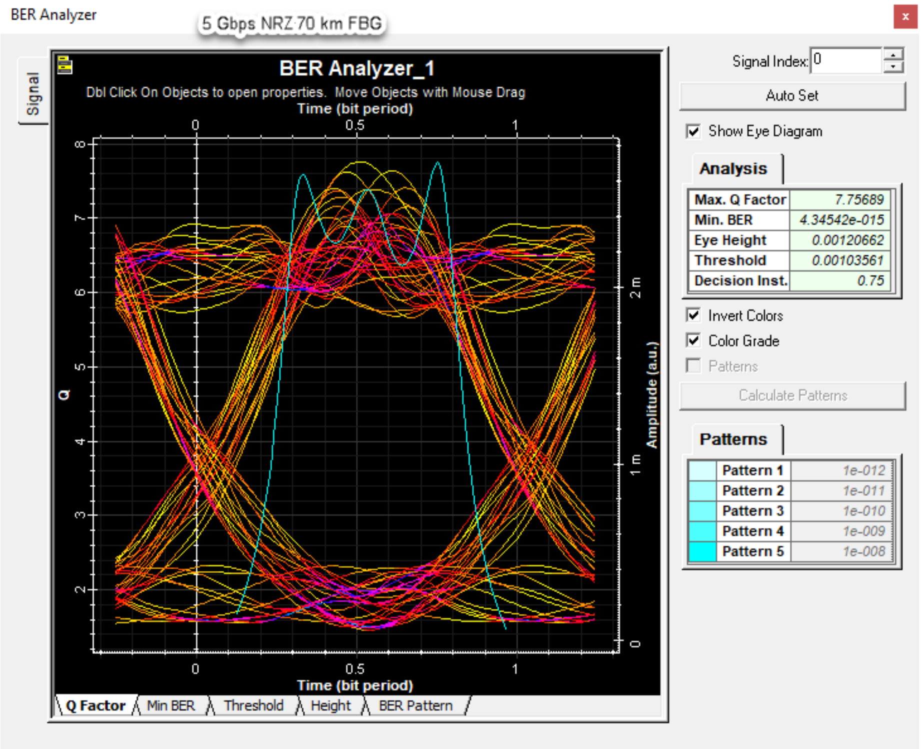
45. 5 Gbps NRZ 50 km FBG



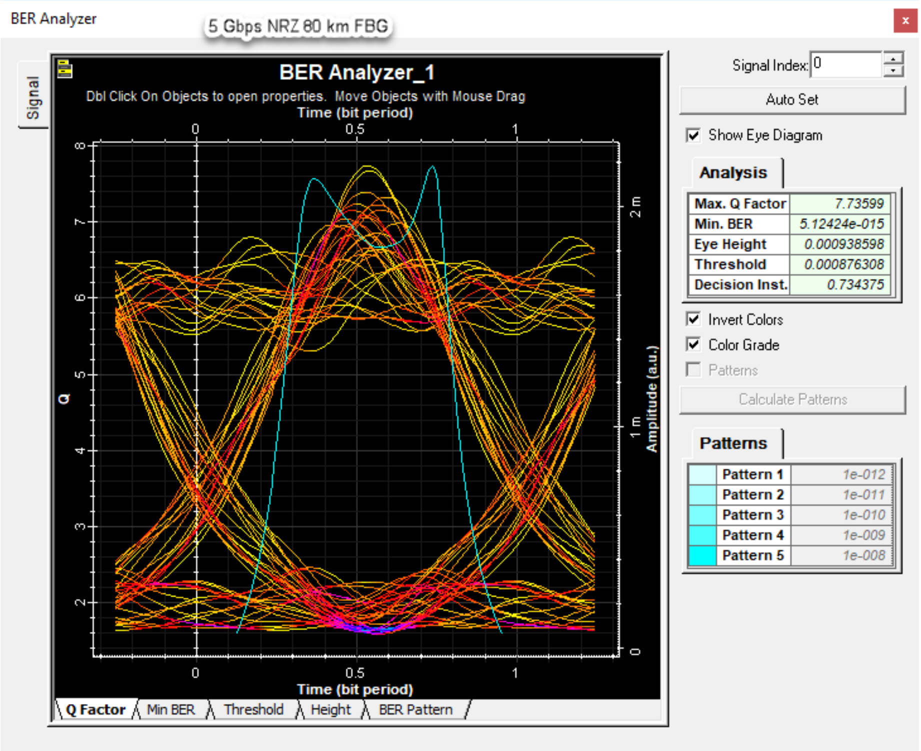
46. 5 Gbps NRZ 60 km FBG



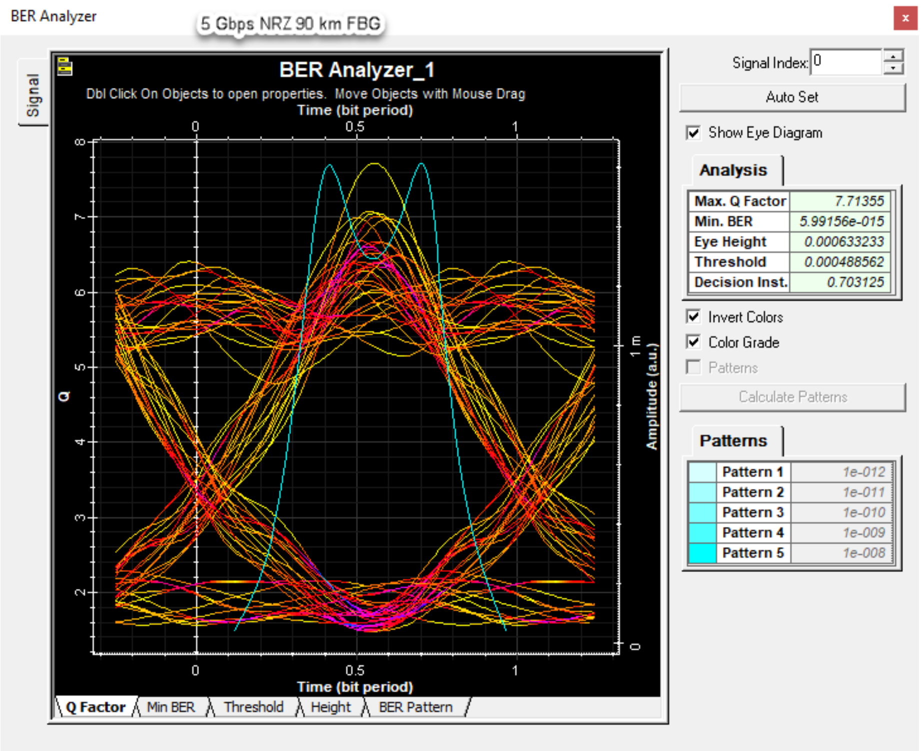
47. 5 Gbps NRZ 70 km FBG



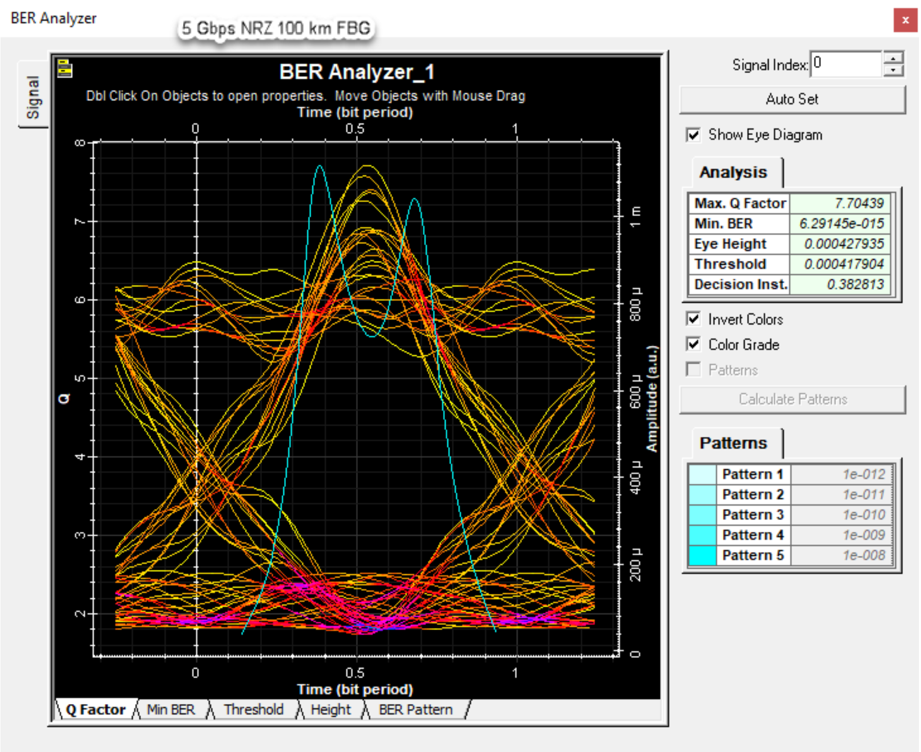
48. 5 Gbps NRZ 80 km FBG



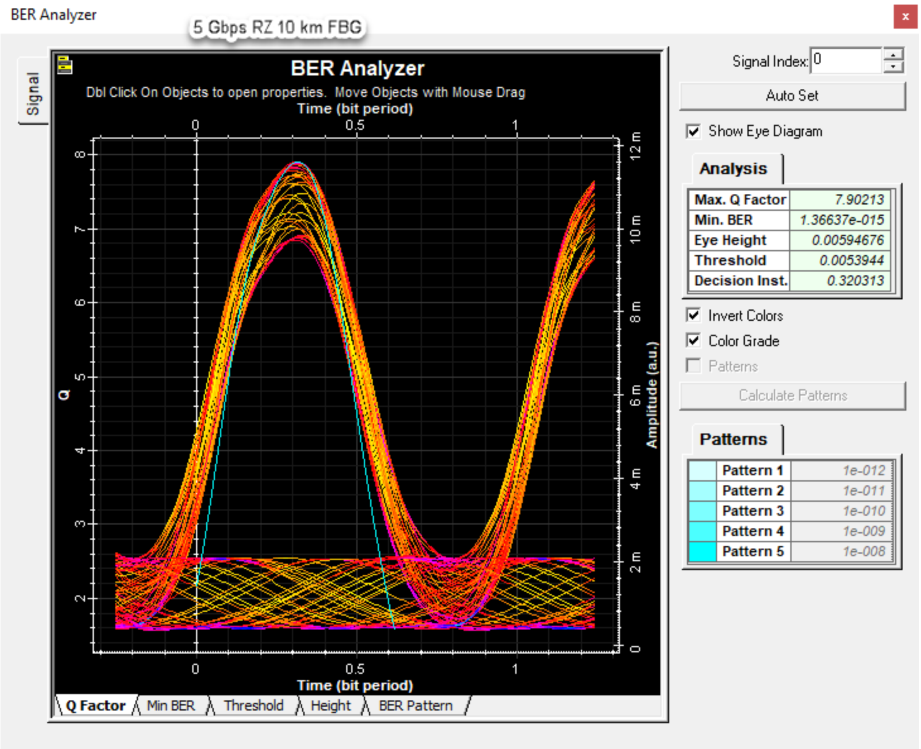
49. 5 Gbps NRZ 90 km FBG



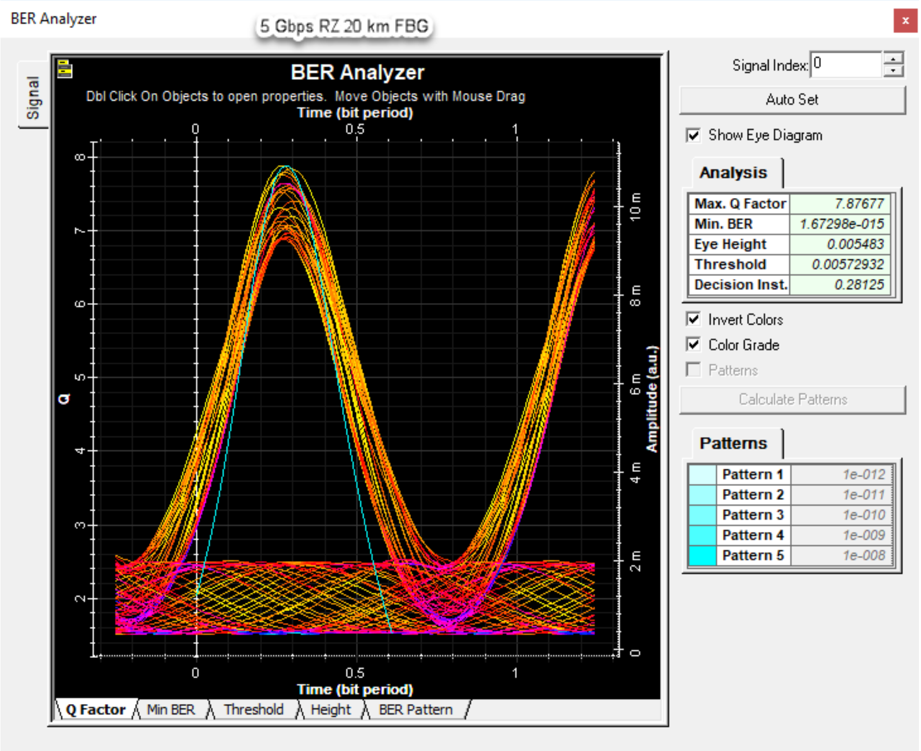
50. 5 Gbps NRZ 100 km FBG



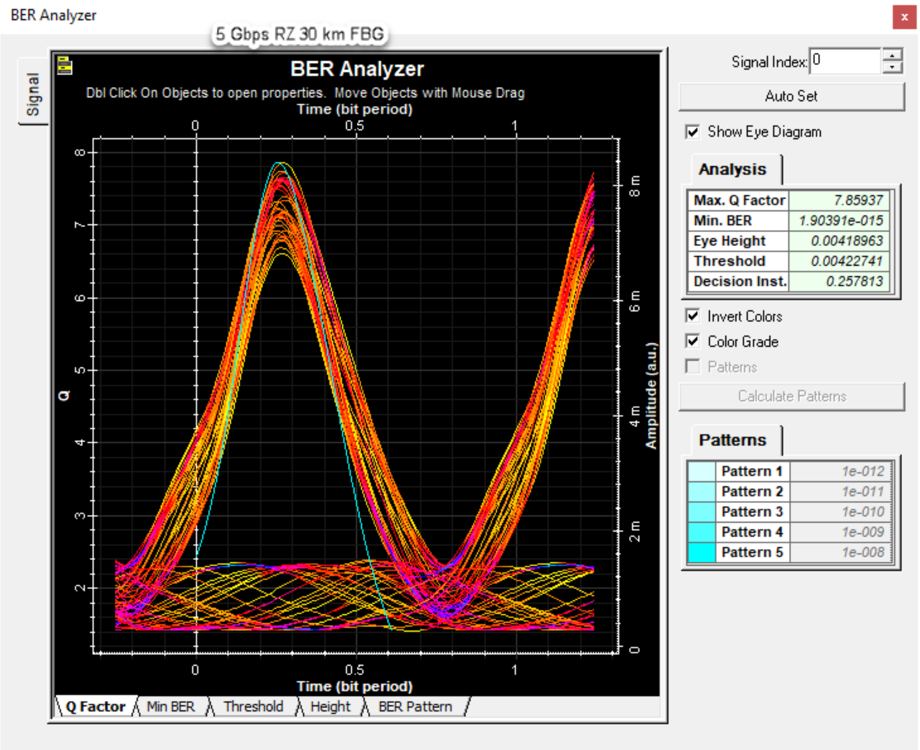
51. 5 Gbps RZ 10 km FBG



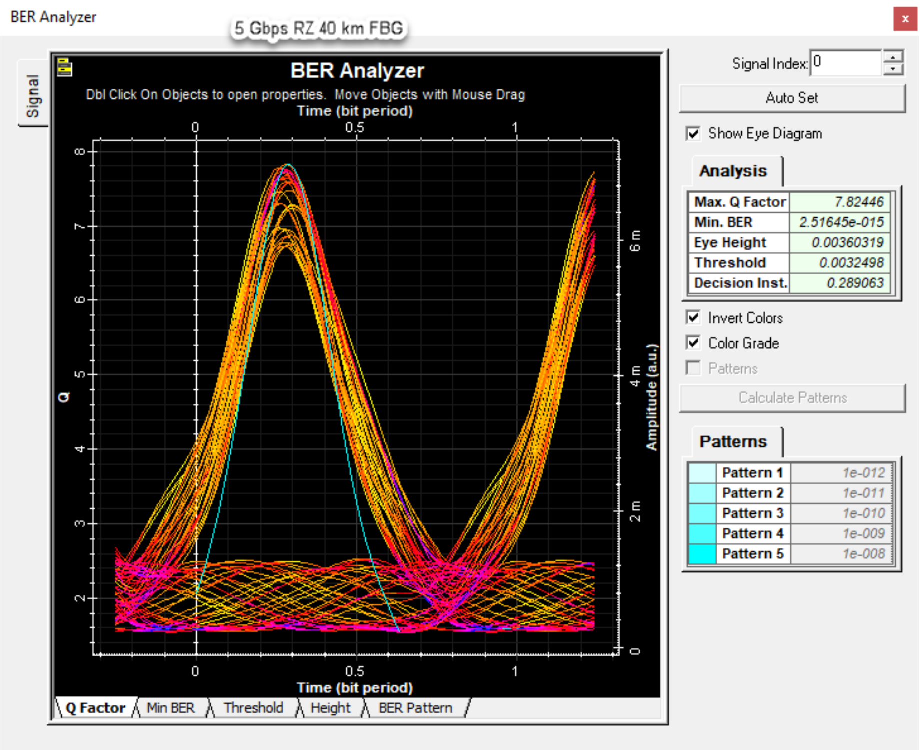
52. 5 Gbps RZ 20 km FBG



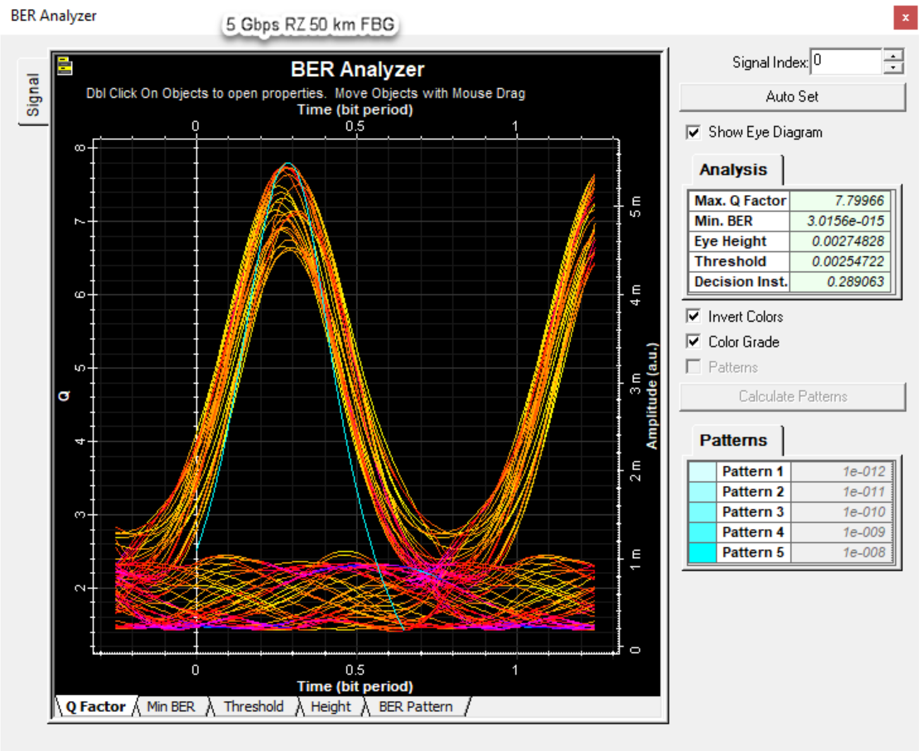
53. 5 Gbps RZ 30 km FBG



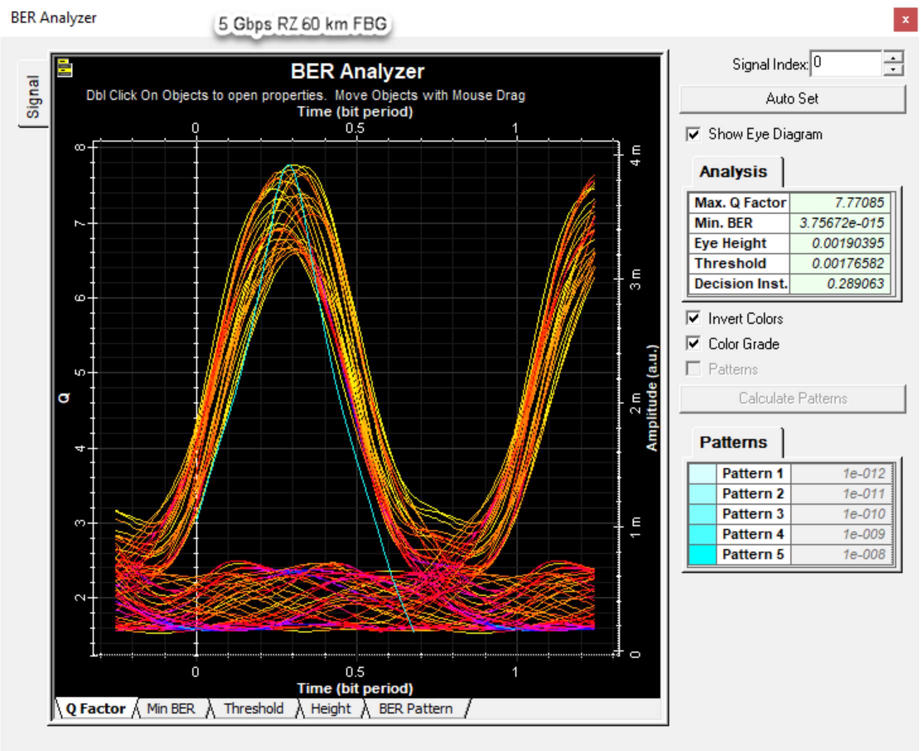
54. 5 Gbps RZ 40 km FBG



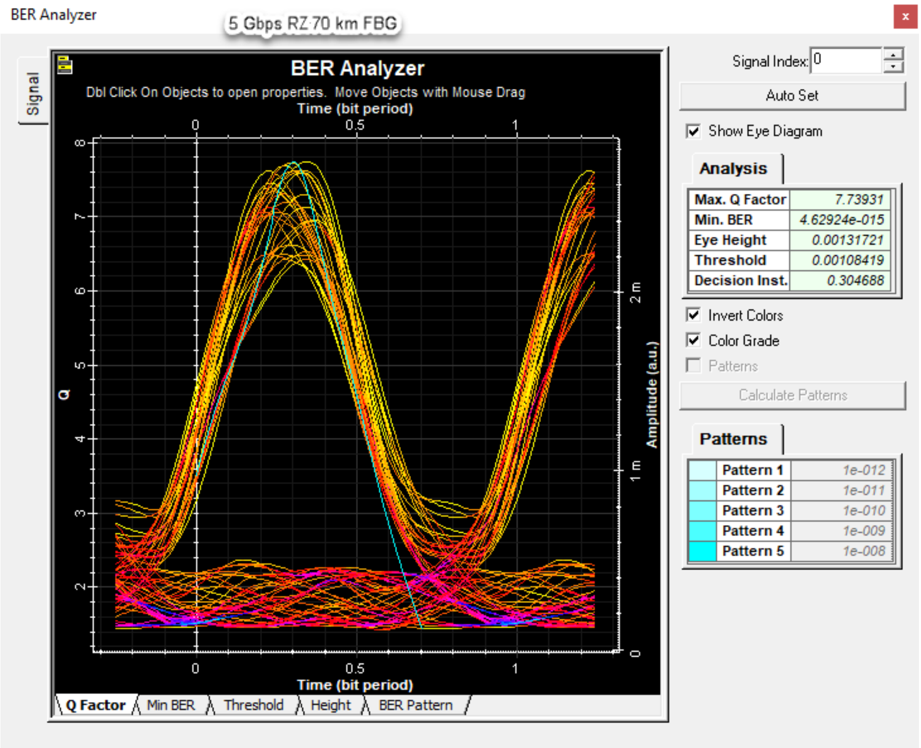
55. 5 Gbps RZ 50 km FBG



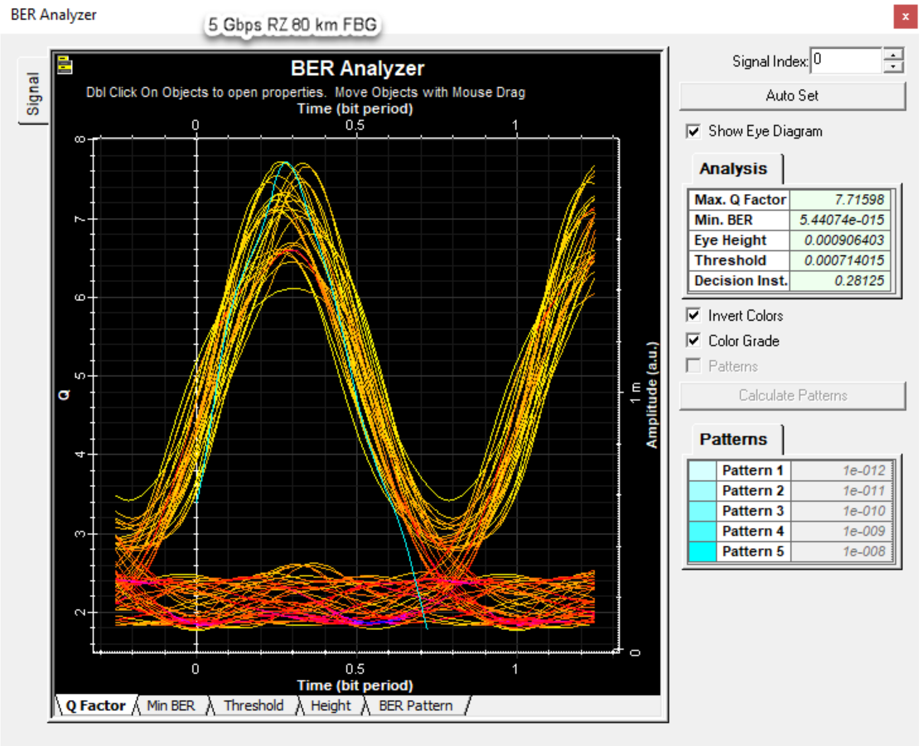
56. 5 Gbps RZ 60 km FBG



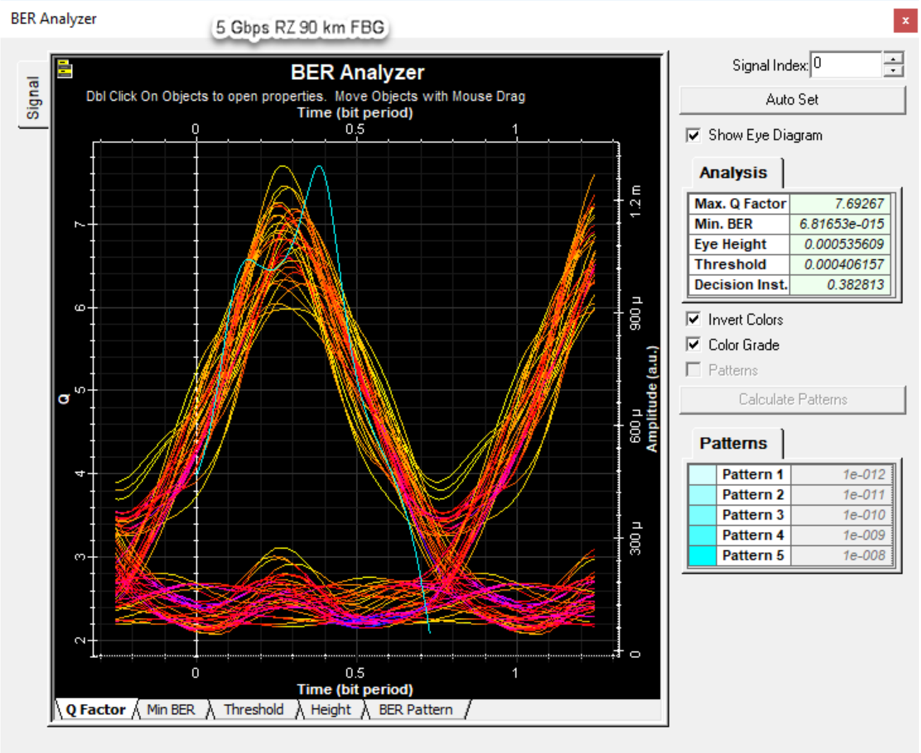
57. 5 Gbps RZ 70 km FBG



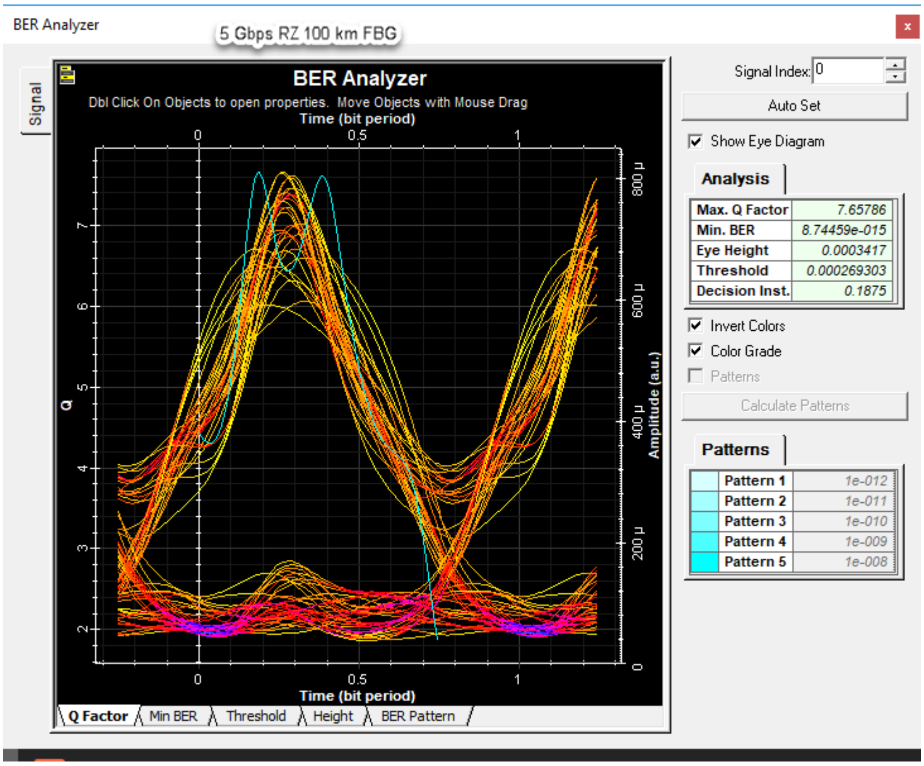
58. 5 Gbps RZ 80 km FBG



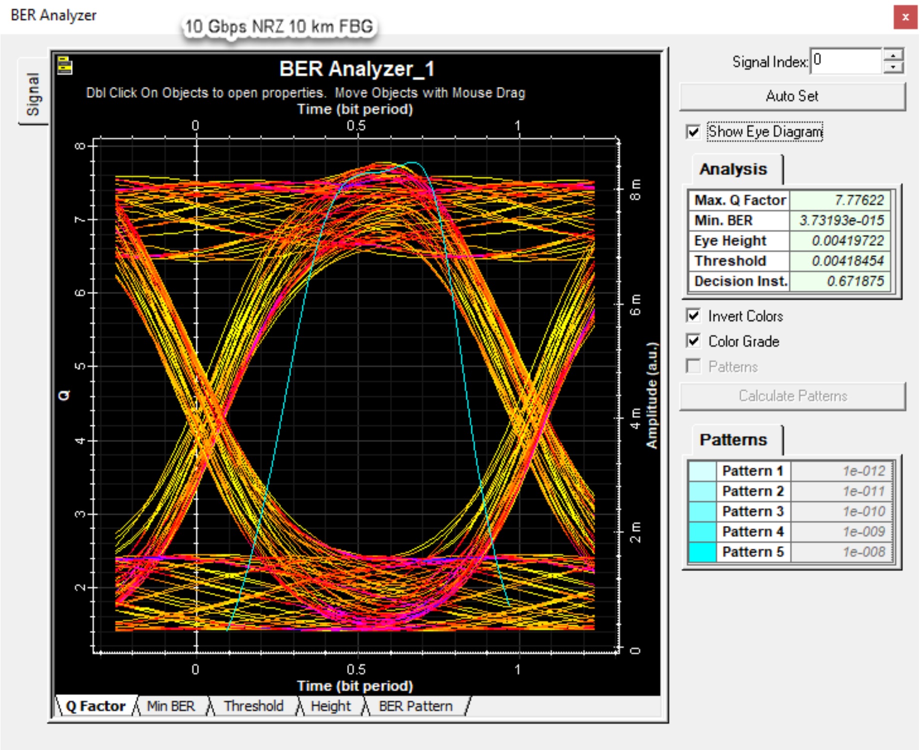
59. 5 Gbps RZ 90 km FBG



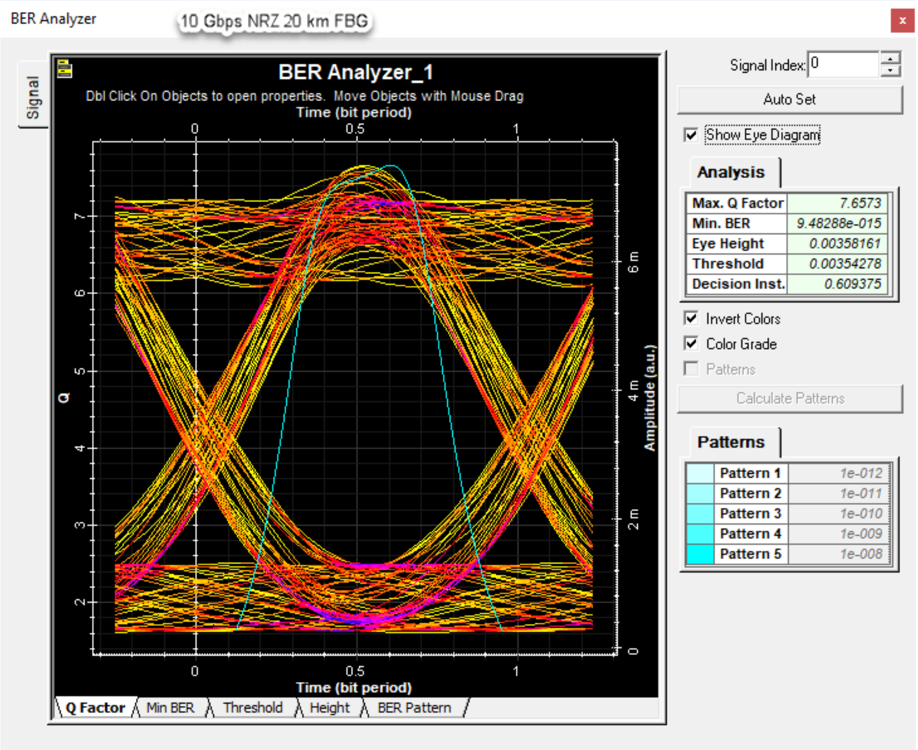
60. 5 Gbps RZ 100 km FBG



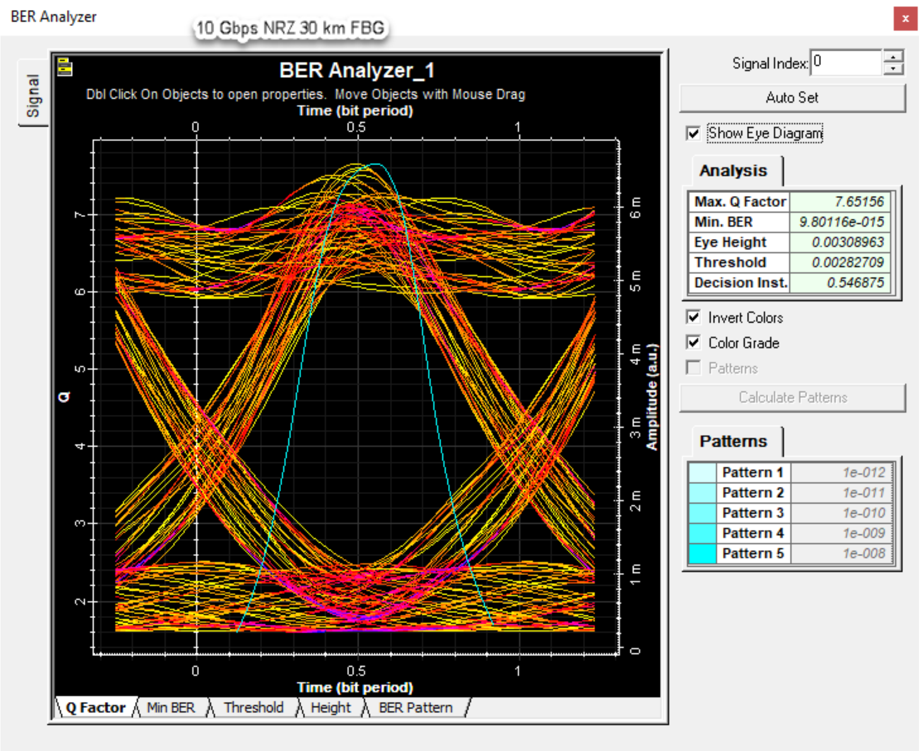
61. 10 Gbps NRZ 10 km FBG



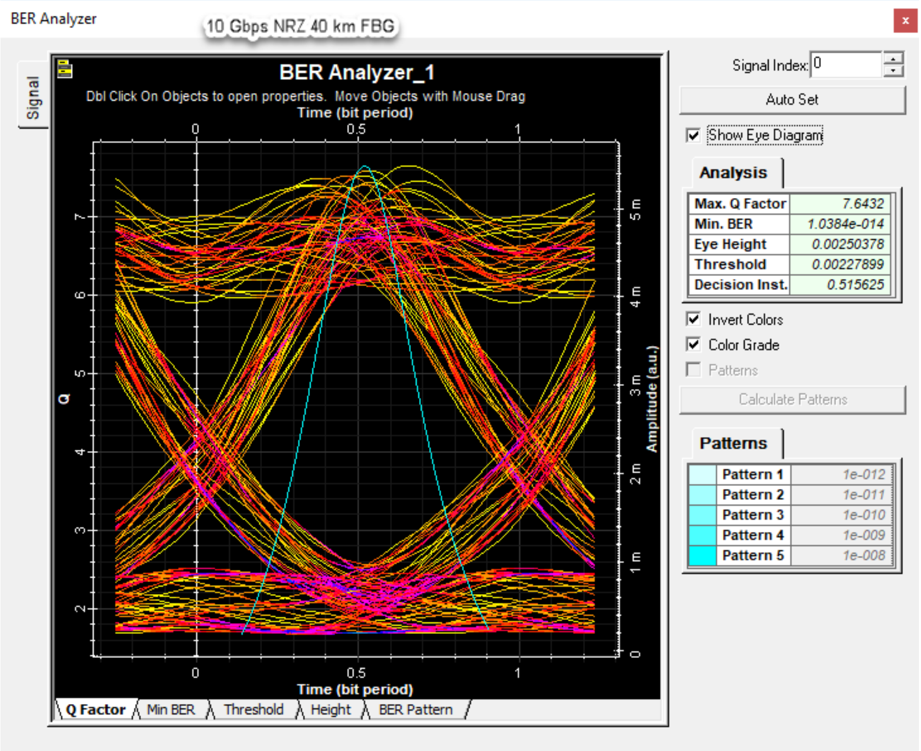
62. 10 Gbps NRZ 20 km FBG



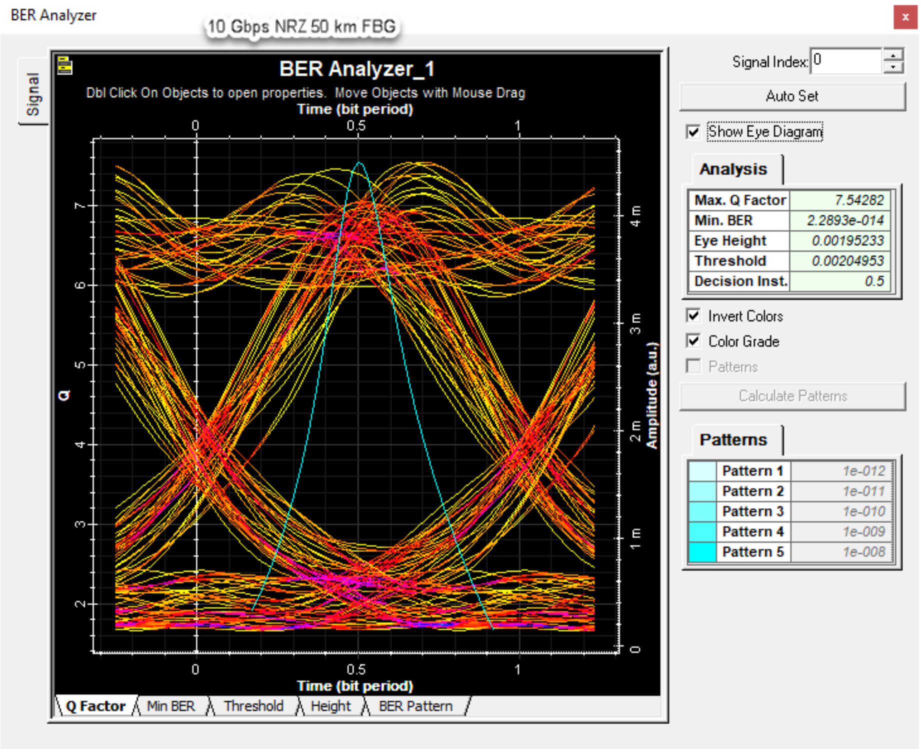
63. 10 Gbps NRZ 30 km FBG



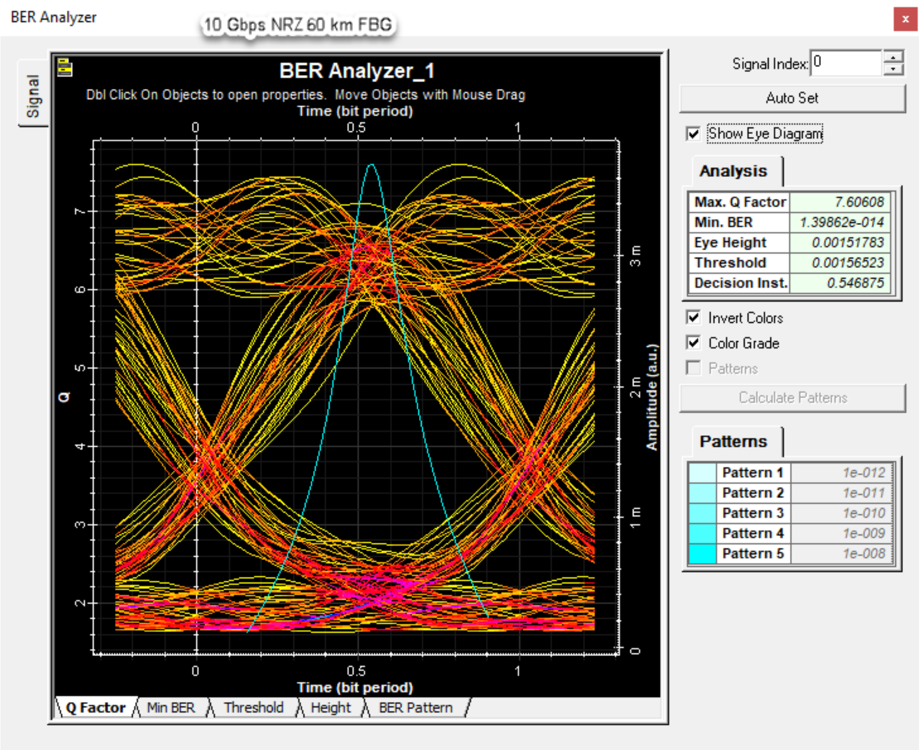
64. 10 Gbps NRZ 40 km FBG



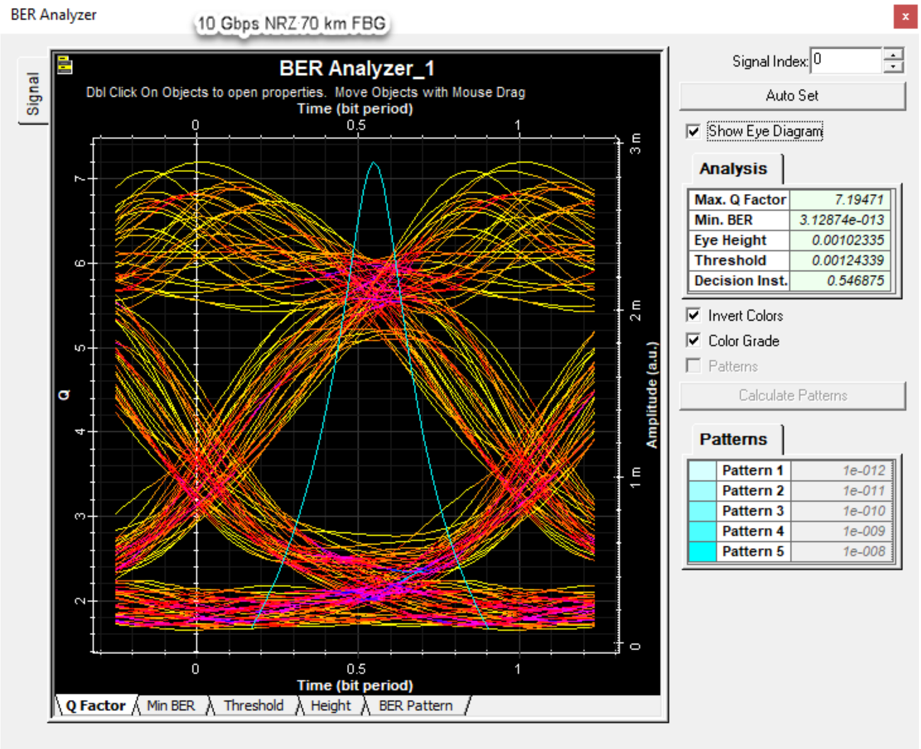
65. 10 Gbps NRZ 50 km FBG



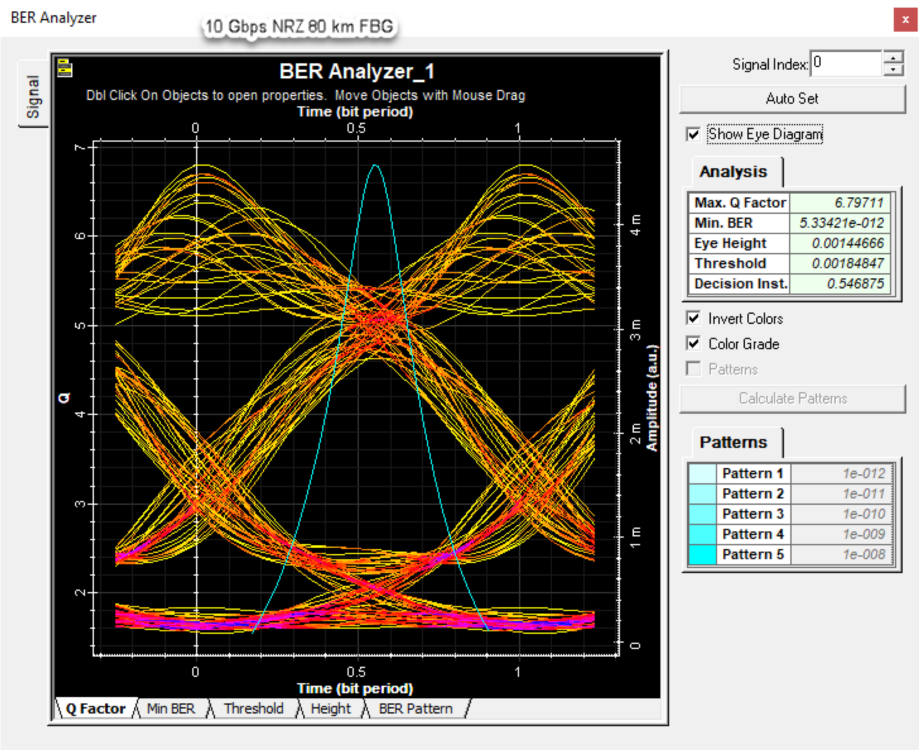
66. 10 Gbps NRZ 60 km FBG



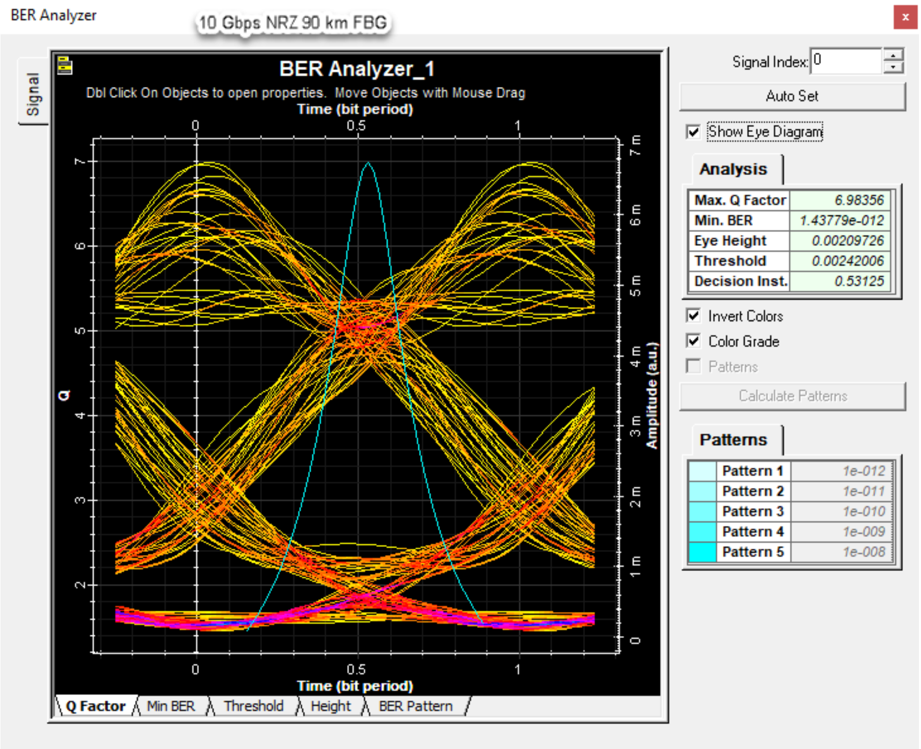
67. 10 Gbps NRZ 70 km FBG



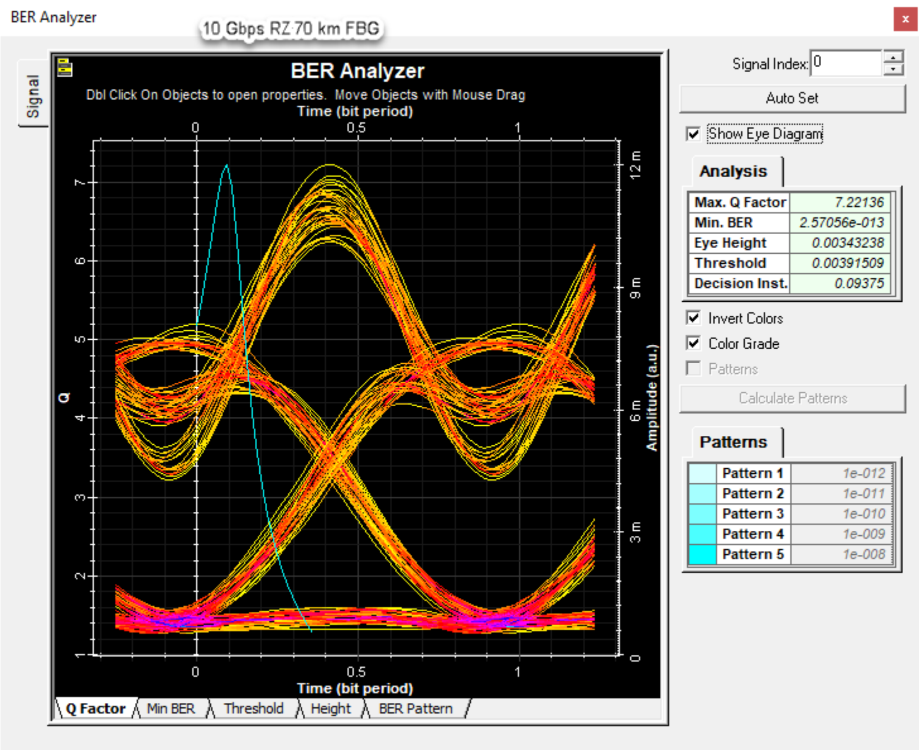
68. 10 Gbps NRZ 80 km FBG



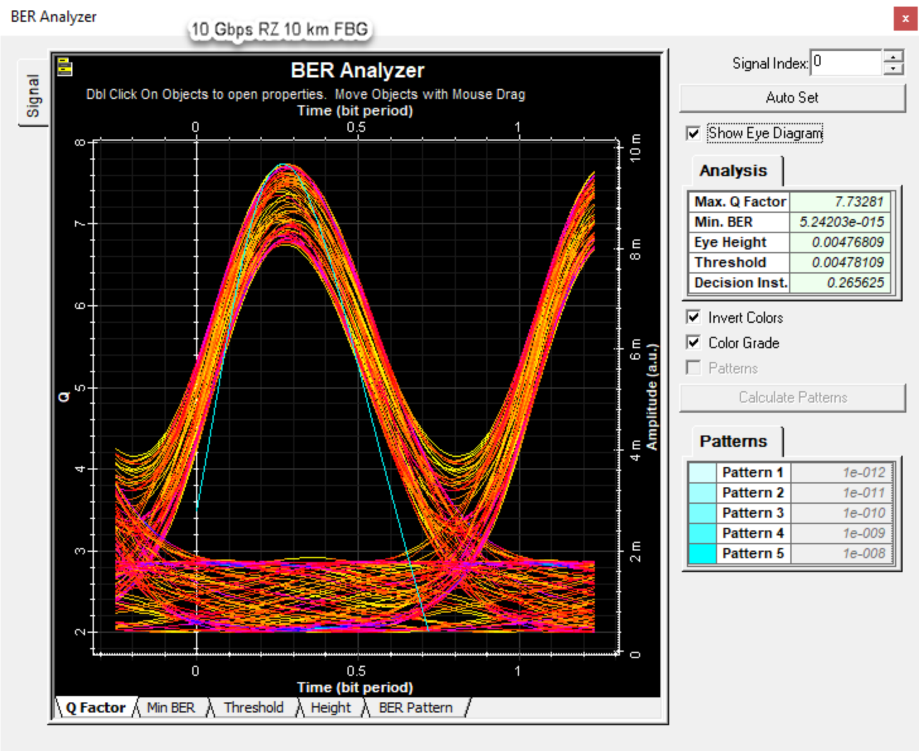
69. 10 Gbps NRZ 90 km FBG



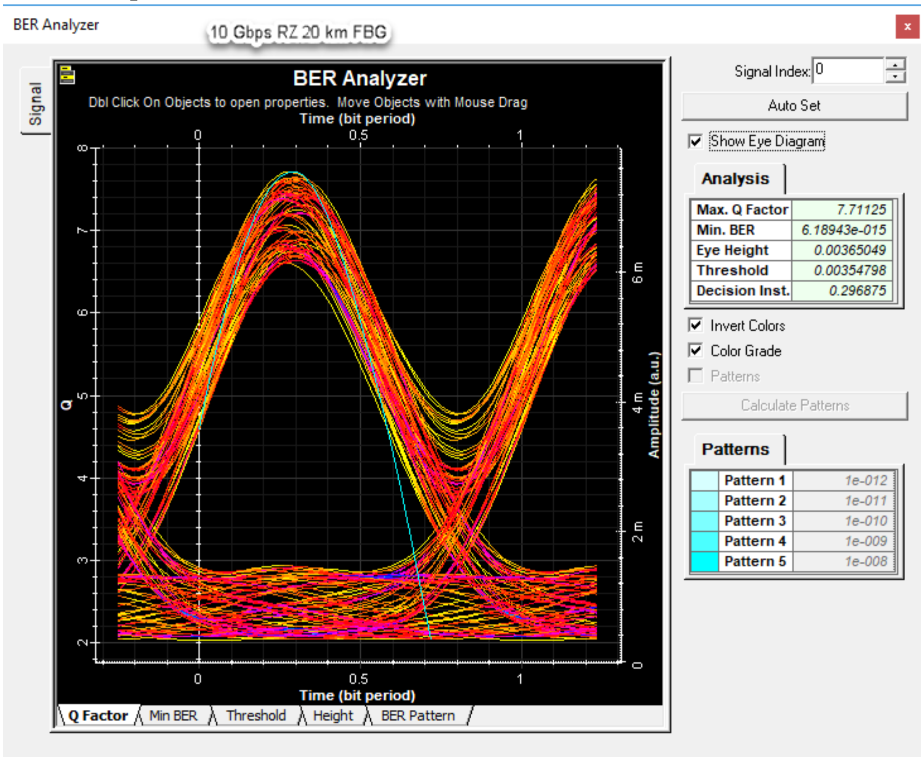
70. 10 Gbps NRZ 100 km FBG



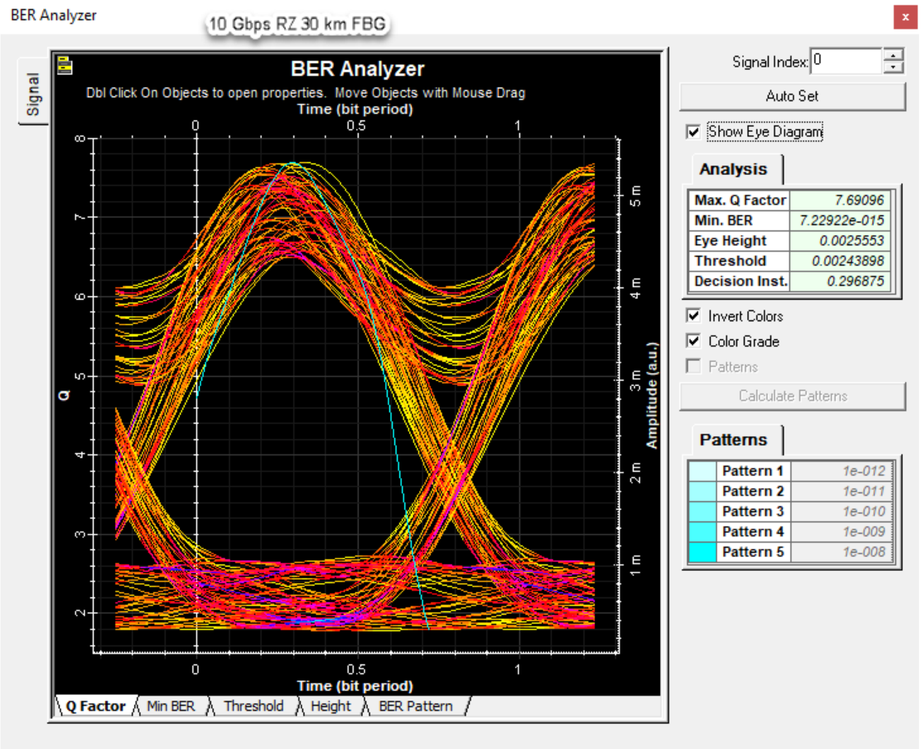
71. 10 Gbps RZ 10 km FBG



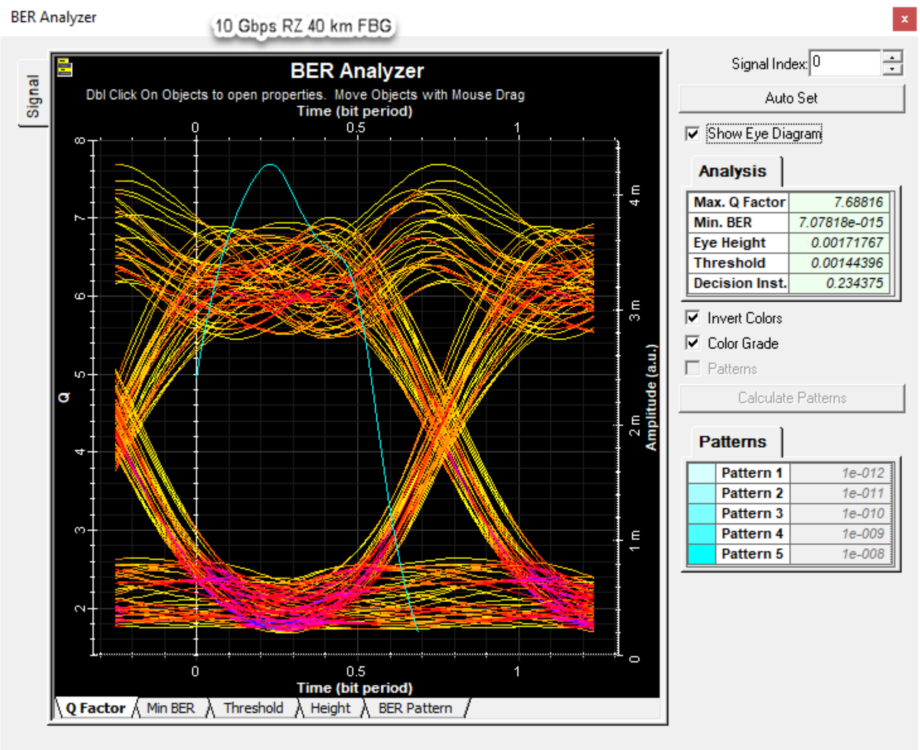
72. 10 Gbps RZ 20 km FBG



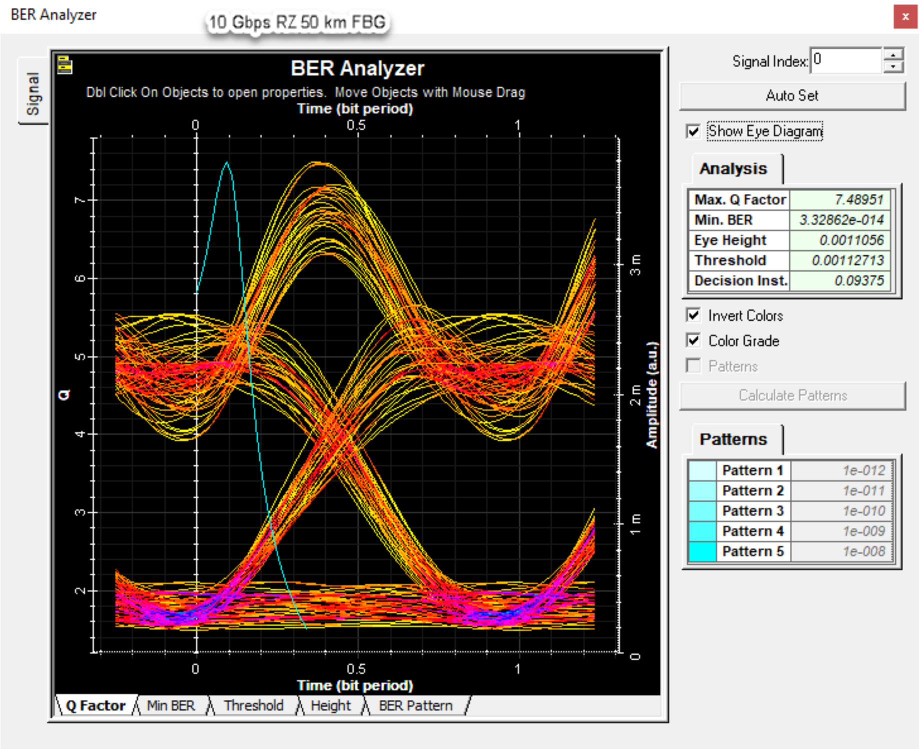
73. 10 Gbps RZ 30 km FBG



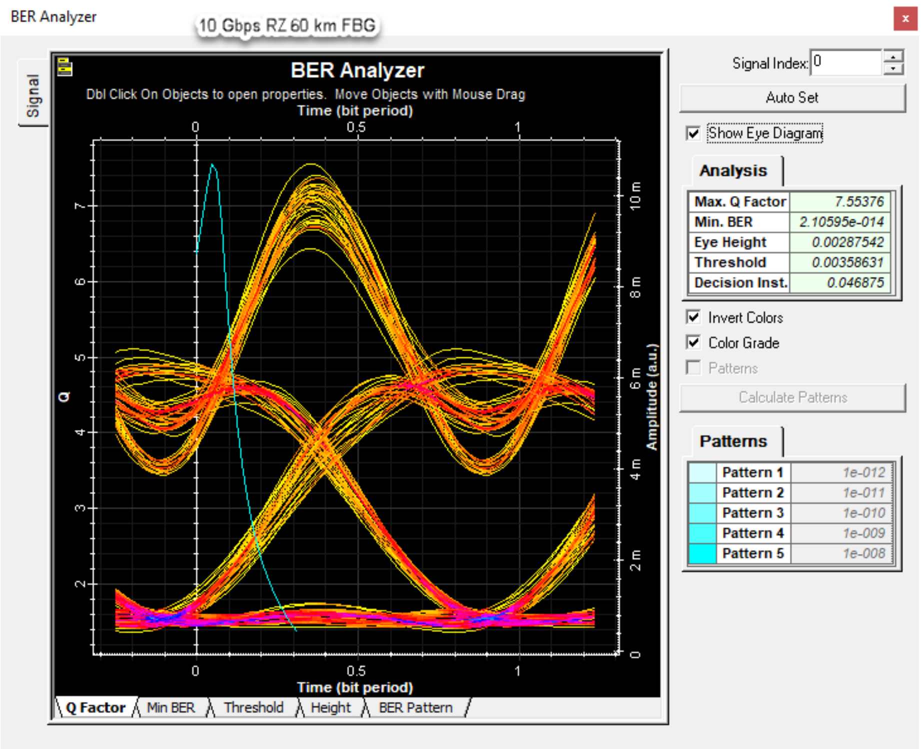
74. 10 Gbps RZ 40 km FBG



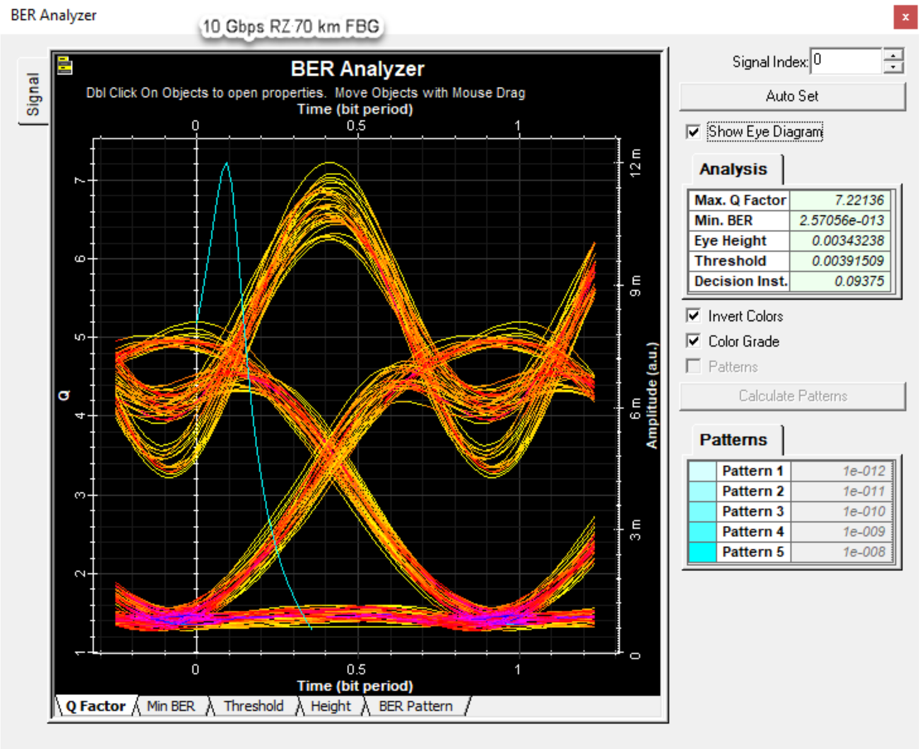
75. 10 Gbps RZ 50 km FBG



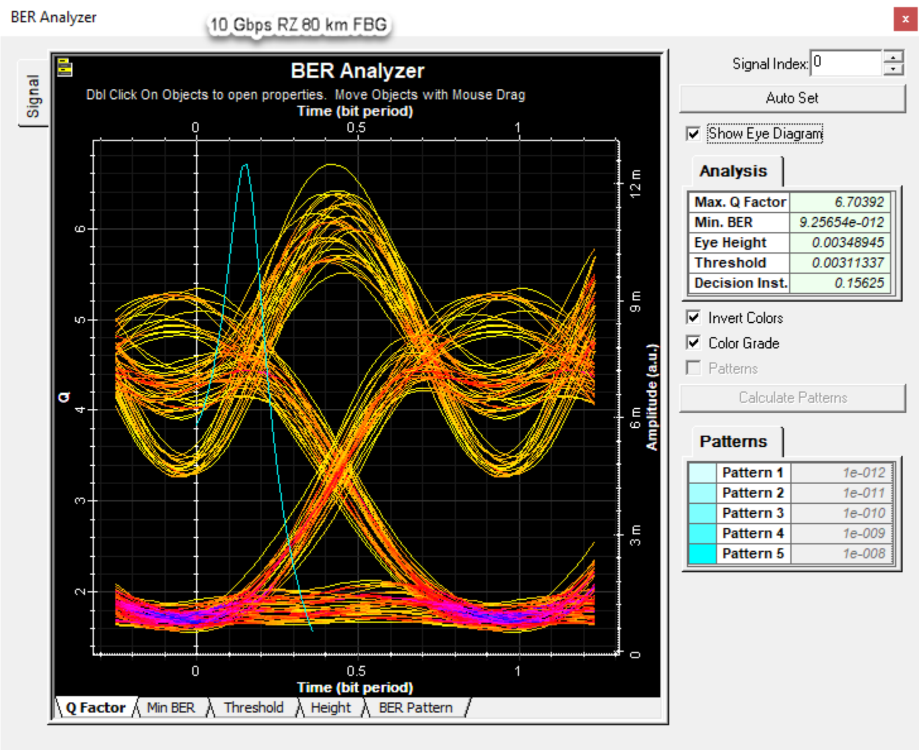
76. 10 Gbps RZ 60 km FBG



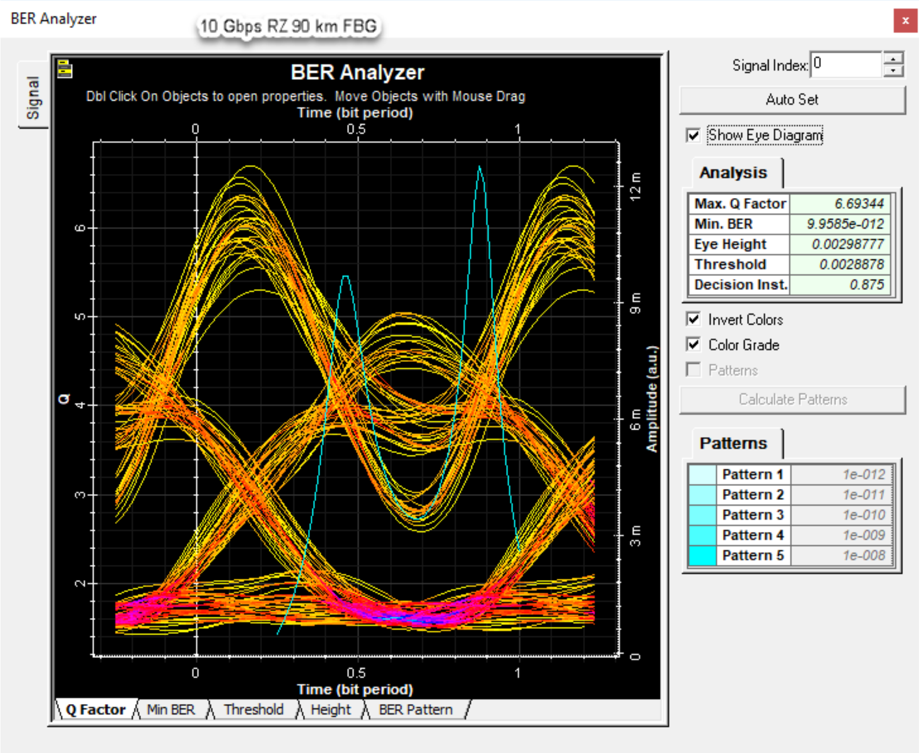
77. 10 Gbps RZ 70 km FBG



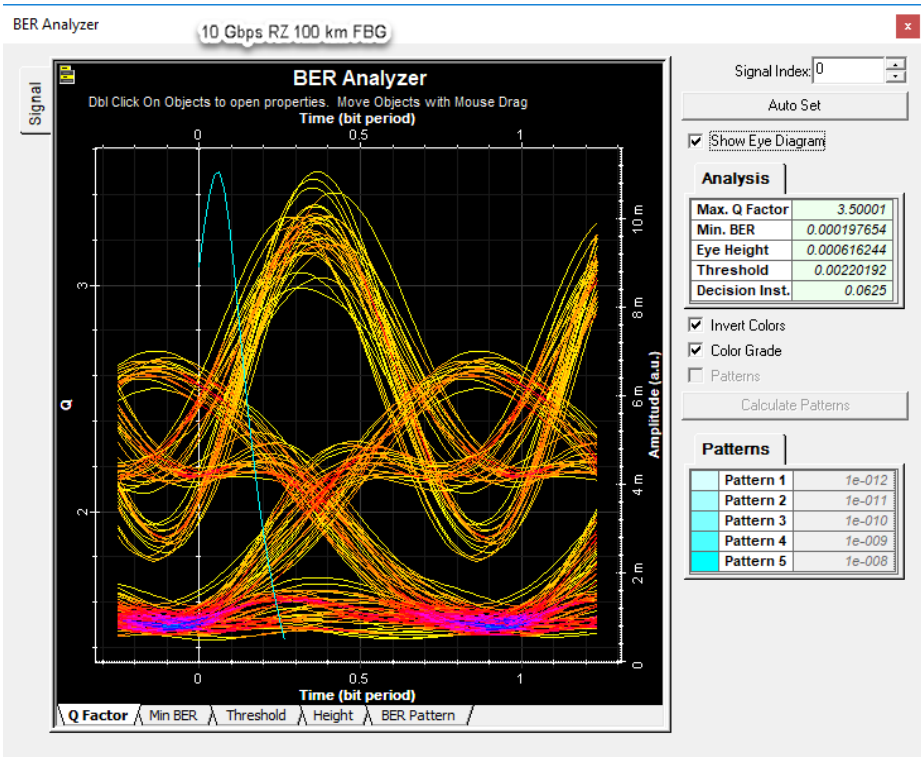
78. 10 Gbps RZ 80 km FBG



79. 10 Gbps RZ 90 km FBG



80. 10 Gbps RZ 100 km FBG



Attachment 2 DataSheet

1. *bit rate*

SONET/SDH Signal Hierarchy

Synchronous Transport Signal Level n = STS-n = $n \times 51.84$ Mbps
STM=Synchronous Transport Module, OC=Opical Carrier level

ANSI Designation	Optical Signal	CCITT Designation	Data Rate (Mbps)	Payload Rate (Mbps)
STS-1	OC-1		51.84	50.112
STS-3	OC-3	STM-1	155.52	150.336
STS-9	OC-9	STM-3	466.56	451.008
STS-12	OC-12	STM-4	622.08	601.344
STS-18	OC-18	STM-6	933.12	902.016
STS-24	OC-24	STM-8	1244.16	1202.688
STS-36	OC-36	STM-12	1866.24	1804.032
STS-48	OC-48	STM-16	2488.32	2405.376
STS-96	OC-96	STM-32	4976.64	4810.176
STS-192	OC-192	STM-64	9953.28	9620.928

The Ohio State University Raj Jain

2. Wavelength

Figure 8-17 *Wavelength-division multiplexing*

Table 8-3 ITU GRID

Center Wavelength – nm (vacuum)	Optical Frequency (THz)
1530.33	195.9
1531.12	195.8
1531.90	195.7
1532.68	195.6
1533.47	195.5
1534.25	195.4
1535.04	195.3
1535.82	195.2
1536.61	195.1
1537.40	195.0
1538.19	194.9
1538.98	194.8
1539.77	194.7
1540.56	194.6
1541.35	194.5
1542.14	194.4
1542.94	194.3
1543.73	194.2
1544.53	194.1
1545.32	194.0
1546.12	193.9
1546.92	193.8
1547.72	193.7
1548.51	193.6
1549.32	193.5
1550.12	193.4
1550.92	193.3
1551.72	193.2
1552.52	193.1
1553.33	193.0
1554.13	192.9
1554.93	192.8
1555.75	192.7
1556.55	192.6
1557.36	192.5
1588.17	192.4
1558.98	192.3
1559.79	192.2
1560.61	192.1
1561.42	192.0
1562.23	191.9
1563.05	191.8
1563.86	191.7

3. Photodetector APD

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The most commonly used photodetectors are the PIN and avalanche photodiodes (APD). The material composition of the device determines the wavelength sensitivity. In general, silicon devices are used for detection in the visible portion of the spectrum; InGaAs crystal are used in the near-infrared portion of the spectrum between 1000 nm and 1700 nm, and germanium PIN and APDs are used between 800 nm and 1500 nm. Table 8-5 gives some typical photodetector characteristics:

Table 8-5 Typical Photodetector Characteristics

Photodetector	Wavelength (nm)	Responsivity (A/W)	Dark Current (nA)	Rise Time (ns)
Silicon PN	550–850	0.4–0.7	1–5	5–10
Silicon PIN	850–950	0.6–0.8	10	0.070
InGaAs PIN	1310–1550	0.85	0.5–1.0	0.005–5
InGaAs APD	1310–1550	0.80	30	0.100
Germanium	1000–1500	0.70	1000	12

Some of the more important detector parameters listed below are defined and described in Module 1-6, *Optical Detectors and Human Vision.*

Responsivity—the ratio of the electrical power to the detector's output optical power

Quantum efficiency—the ratio of the number of electrons generated by the detector to the number of photons incident on the detector

Quantum efficiency = (Number of electrons)/Photon

Dark current—the amount of current generated by the detector with no light applied. Dark current increases about 10% for each temperature increase of 1°C and is much more prominent in Ge and InGaAs at longer wavelengths than in silicon at shorter wavelengths.

Noise floor—minimum detectable power that a detector can handle. The noise floor is related to the dark current since the dark current will set the lower limit.

Noise floor = Noise (A)/Responsivity (A/W)

Response time—the time required for the detector to respond to an optical input. The response time is related to the bandwidth of the detector by

$$BW = 0.35/t_r$$

where t_r is the rise time of the device. The rise time is the time required for the detector to rise to a value equal to 63.2% of its final steady-state reading.

Noise equivalent power (NEP)—at a given modulation frequency, wavelength, and noise bandwidth, the incident radiant power that produces a signal-to-noise ratio of *one* at the output of the detector (Source: Electronic Industry Association—EIA)

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4. RF *Frequency*

Frequency bands

The radio spectrum of frequencies is divided into bands with conventional names designated by the International Telecommunications Union (ITU):

Frequency	Wavelength	Designation	Abbreviation[6]	IEEE bands[7]
3–30 Hz	10^5–10^4 km	Extremely low frequency	ELF	-
30–300 Hz	10^4–10^3 km	Super low frequency	SLF	-
300–3000 Hz	10^3–100 km	Ultra low frequency	ULF	-
3–30 kHz	100–10 km	Very low frequency	VLF	-
30–300 kHz	10–1 km	Low frequency	LF	-
300 kHz – 3 MHz	1 km – 100 m	Medium frequency	MF	-
3–30 MHz	100–10 m	High frequency	HF	HF
30–300 MHz	10–1 m	Very high frequency	VHF	VHF
300 MHz – 3 GHz	1 m – 10 cm	Ultra high frequency	UHF	UHF, L, S
3–30 GHz	10–1 cm	Super high frequency	SHF	S, C, X, Ku, K, Ka
30–300 GHz	1 cm – 1 mm	Extremely high frequency	EHF	Ka, V, W, mm
300 GHz – 3 THz	1 mm – 0.1 mm	Tremendously high frequency	THF	-

Frequencies of 1 GHz and above are conventionally called microwave,[8] while frequencies of 300 GHz and above are designated millimeter wave. More detailed band designations are given by the standard IEEE letter- band frequency designations[7] and the EU/NATO frequency designations.[9]

5. Power Laser

Performance Specifications: Typical Product Configurations (more options available)

PD-LD Part No.[1]	Wavelength (nm) Min. Typ. Max.	Min. Fiber Coupled Power (mW)	Threshold Current (mA) Typ. Max.	Operating Current (mA) Typ. Max.	Monitor PD Current (mA) Min. Typ.
Continuous Wavelength InGaAsP Lasers @ 25C					
PL13U001100B-R-I-01	1290 **1310** 1330	1 mW	6 20	18 40	InGaAs 0.1 0.8
PL13N0.51FAA-0-I-01	1290 **1310** 1330	0.5mW FC/APC	6 20	18 40	InGaAs 0.1 0.8
PL13U0011SAA-0-I-01	1295 **1310** 1325	1 mW SC/APC	6 20	18 40	InGaAs 0.1 0.8
PL15M0011FAA-0-I-01	1530 **1550** 1570	1mW FC/APC	10 30	30 60	InGaAs 0.1 -
PL15N0.51FAC-R-I-01	1530 **1550** 1570	0.5 mW FC/APC	10 30	30 60	InGaAs 0.1 0.8

Parameter	Condition	Min	Typ	Max	Unit
Optical Isolation	Temp.= +25°C	30	45	—	dB
	Temp.=-40~+85°C	20	—	—	

6. 5G *Frequency*

5G expected to use a wide range of frequency bands

The ability to use a range of frequency bands and access technologies to deliver the particular requirements of a specific use case or service, will be a key characteristic of 5G networks.[60] This is likely to require the use of frequency bands other than those currently dedicated to mobile broadband use, and the flexible use of unlicensed spectrum or sharing of underutilised spectrum to provide extra capacity when required.

5G networks are expected to require a wide range of frequencies both below and above 6 GHz, although the exact frequencies are yet to be identified. A number of industry groups, academics and governments around the world have begun to explore the possibility of using higher frequencies for mobile broadband communications.

The ACMA and Australian industry representatives recently attended the International Telecommunication Union (ITU) Radiocommunication Sector 2015 World Radiocommunication Conference (WRC–15). The WRC–15 made a number of decisions that will influence how the issue of additional spectrum for mobile broadband will be considered around the world, and in Australia.

[58] ACMA, *Beyond 2020—A spectrum management strategy to address the growth in mobile broadband capacity*, September 2015, pages 33–34.
[59] ACMA, *Beyond 2020—A spectrum management strategy to address the growth in mobile broadband capacity*, September 2015 and ACMA, *Five-year spectrum outlook 2015–19: The ACMA's spectrum demand analysis and strategic direction for the next five years*, August 2015, page 38.
[60] Huawei, 5G: A Technology Vision, January 2014, page 6.

Under WRC–15 Agenda item 1.1 additional spectrum allocations for mobile services on a primary basis and additional identifications for International Mobile Telecommunications (IMT) were made in a number of bands. The main outcome of this agenda item was the significant international harmonisation of the frequency ranges 1 427–1 518 MHz and 3 400– 3 600 MHz for IMT.