CHAPTER-1
INTRODUCTION

1.1 Introduction

The word telecommunication is derived from two Greek words, first one is *tele,* which means “over a distance” and second one is *communication,* which means the “exchange of information.” Therefore, the definition of telecommunication is “exchange of information over a distance.” In better way telecommunication is exchange of information over a distance with the help of some equipment.

Basically there are three type of information which is to be exchanged: voice, video, and data. To transmit these informations, various technology and transmission media is used. Now a day we have moved towards modern technology whose aim is capacity and more and more information carrying capacity. Information carrying capacity of telecommunication link is basically transmission of certain amount of information per unit of time.

Since important feature of telecommunication industry is its information carrying capacity, but there are other many important features. For Example, for bank network security is more important as compare to information capacity while for brokerage house, information carrying capacity is more important as compare to security. We cannot increase capacity as much as we want because of Shannon-Hartley limit which is given as-

$$C = BW \times \log_{?} \text{ÆÈ} \quad ??\ ? \qquad (1.1)$$

Where C is information carrying capacity (bits/sec), BW is bandwidth (Hz), and SNR is the signal-to-noise power ratio.

From eqn. (1), the Shannon-Hartley theorem states that information carrying capacity of any telecommunication system is directly proportional to channel bandwidth, which is the range of frequency within which the signal is transmitted without attenuation.

The channel bandwidth is frequency of signal carrier, higher the carrier's frequency, the greater the bandwidth and hence greater the information carrying capacity of the telecommunication system. According to rule of thumb, bandwidth is generally around 10 percent of the carrier signal frequency.

A copper wire can transmit a signal upto 1MHz, while coaxial cable can transmit upto 100 MHz. A radio frequency has a range of 500 KHz to 100 MHz. Microwaves link and satellite channels operate upto 100 GHz.

Fiber optic communication systems use light as a carrier whose frequency is between 100 and 1000 THz. Hence, according to the rule of thumb, the estimated bandwidth of fiber optic communication system is around 50 THz [1].

Fiber optics technology has come in the last 20 years. Fiber optics is basically transmission medium for communication system. Since, at present demand for high bit rate capacity double every three years. Only fiber optic can support Ultra-High bit rate transmission. Telecommunication system engineers have designed fiber optic system and once designed these systems can be maintained like any other system [2].

Performance and impairments comparison of various communication systems is shown below [2]-

Performance	**Radio/Wireless**	**Wireline**	**Fiber Optics**
Bit error rate	1×10^{-9}	1×10^{-10}	1×10^{-12}
Link loss (dB)	principal impairment	principal impairment	principal Impairment
Dispersion	at high bit rates can be be principal impairment	secondary or tertiary impairment	at high bit may be principal impairment
Fading	Yes	No	No
Jitter accumulation	Medium	High	Low
Vulnerability	Low	Medium	High
Bit rate capacity	Low/medium	Low/medium	Very high
Rainfall absorption	Above 10GHz major Impairment	No	No

EMC Susceptibility	Yes	Yes	No
EMC emanation	Yes	Some	No

Fiber optics has not only changed the all visible features of telecommunication industry but it is still doing so. Since fiber optics technology uses the light as a carrier-signal which has the highest frequency among all the practical signals. This is why optical communication systems have the highest bandwidth in THz and therefore support the Ultra-High bit rate transmission upto several Tb/s. At present, advent of major recent technology- Wavelength Division Multiplexing (WDM), Dense Wavelength Division Multiplexing (DWDM), Erbium doped fiber amplifier (EDFA) has boosted the existing optical communication system and have brought the dramatic improvements in the information carrying capacity of systems.

With the help of current technology, DWDM, EDFA, fiber capacity can be upgrade as high as 100Gb/s. A single fiber can transmits 800Gb/s.

1.2 Dense Wavelength Division Multiplexing (DWDM) Technology

Since, at present optical communication system use DWDM transmission for high bit rate transmission. The most important components of DWDM systems are transmitter which can be lasers source to radiate the light of particular wavelength, DWDM MUX to combine the all optical signal, optical fiber as a transmission media, amplifier to boost the signal over long distance transmission, DWDM DEMUX to separate the all signal, photo-detector to detect the optical signal and error detector to analyse the signal. A DWDM system is shown below-

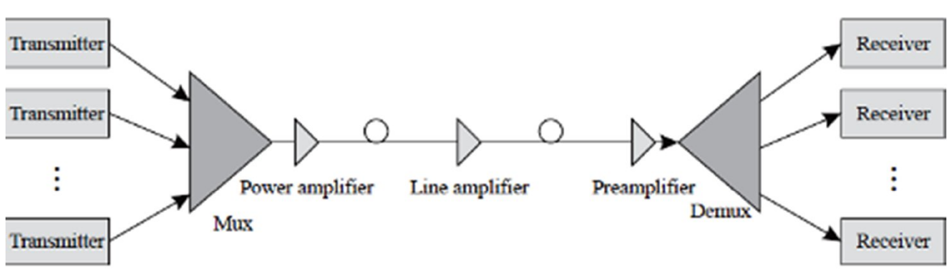


Fig.1.1 A Block Diagram of DWDM System.

(Ref. Rajiv Ramaswami, Kumar N. Sivrajan, Galen A. Sasaki, Optical Networks, 3'rd edition, Fig.5.1)

1.3 Problem in Fiber Optics Technology

Optical fiber is better communication media as compare to copper wire or free space. It provides low loss transmission over a very large frequency range of at least 25 THz. Still, fiber has some physical limitation which must be taken into account while designing the network. There are three phenomenon's that limit the fiber transmission: **loss, nonlinear effects, dispersion.**

There are two main **loss mechanisms** in optical fiber: **material absorption** and **Rayleigh scattering**. Material absorption is responsible for absorption of lights by silica and impurity of fiber. Rayleigh scattering arises due to density fluctuations, bulk imperfections like bubbles, in homogeneities, and crack during fiber fabrication or by irregularities at core-cladding interface. Rayleigh scattering is dominating in all wavelength domains: 800-nm, 1310-nm, and 1550-nm. Since, optical fibers are bent during installation in some particular field and within equipment. This bending causes leakage of power from core into cladding and thus results in additional loss in optical fiber. A bend is characterized by bend radius which is the radius of curvature. It must be in the range of few centimetres in order to keep the bending loss small. Bending loss is high in 1550-nm window as compare to 1310-nm window. According to ITU-T standard bending loss must be in the range of 0.5-1dB, depending upon fiber type [3].

Dispersion is a phenomenon in which different signal components travel at different velocity and hence at receiver end they reach at different time which causes the broadening of signals. Dispersion limits the high bit rate transmission. There are various type of dispersion in optical fiber: **intermodal, intramodal (chromatic dispersion-material dispersion), waveguide dispersion, polarization mode dispersion.** Intermodal dispersion occurs in multimode fiber where various mode travel with different velocity. Intramodal dispersion occurs in single mode fiber that is within single mode. Generally intramodal dispersion reduces to chromatic dispersion which is composed of material dispersion and waveguide dispersion. Material dispersion is caused by wavelength dependence of the refractive index of the material which is used to fabricate the fiber [4]. Since single mode consists of light of different wavelength, and refractive index is the ratio of speed of light in free space to the speed of light in material. Therefore different wavelengths travel with different velocity, result in broadening of pulse during transmission. To calculate the material dispersion or chromatic dispersion, material dispersion parameter, D(λ) is calculated which is given below-

$$D_{mat}(\lambda)(ps/\text{nm.km}) = \frac{??}{?}\,?? - \frac{???}{??}? \qquad (1.2)$$

Where S_0 is zero dispersion slope (ps/nm^2.km), λ is the operating wavelength (nm) and λ_0 is the zero dispersion wavelength (nm). Hence pulse broadening due to material dispersion is given by-

$$\Delta t_{\text{mat}}(\text{ns}) = D_{mat}(\lambda)\, L\, \Delta\lambda \qquad (1.3)$$

Waveguide dispersion doesn't exist in open transmission media. Since light is guided by a structure, optical fiber. Waveguide dispersion also occur in multimode fiber but pulse broadening due to this is negligible as compare to pulse broadening due to intermodal dispersion and material dispersion. While in single mode fiber, intermodal dispersion doesn't exist and material dispersion is small hence waveguide dispersion is major component of chromatic dispersion. Waveguide dispersion depends on the mode- field distribution within core and cladding of optical fiber that is on mode field diameter (MFD). Waveguide dispersion is calculated from waveguide dispersion parameter $D_{wag}(\lambda)$. Hence pulse broadening due to waveguide dispersion is given by –

$$\Delta t_{\text{wag}}(\text{ns}) = D_{wag}(\lambda)\, L\, \Delta\lambda \qquad (1.4)$$

Polarization mode dispersion arises due to asymmetric distortion to the fiber from cylindrical geometry. In prctical fiber is not completely cylindrical waveguide. Since Standard Single Mode Fiber (SSMF) supports only one fundamental mode which consists of two orthogonal polarization modes but this asymmetry causes small refractive index difference for the two orthogonal polarization mode. This characteristic is called birefringence which causes one orthogonal polarization mode travel faster than the other polarization mode resulting in difference in travelling time along fiber. This is called the differential group delay (DGD).Polarization mode dispersion is not a big issue at lower bit rate transmission but become noticeable at higher bit rate transmission in DWDM system [5]. Pulse broadening due to polarization mode dispersion is given by-

$$\Delta t = D_{PMD} \sqrt{L} \quad (1.5)$$

Where D_{PMD} is coefficient of polarization mode dispersion (ps/√km), and L is the length of optical fiber.

In fiber optic linear and nonlinear mean power independent and power dependent. Hence an effect is called nonlinear effect if it depends on power that is on light intensity. The nonlinear effect depends on the transmission fiber length. The longer the fiber, the more light will interact with fiber material and hence greater the nonlinear effect. If the power decreases while light travels along the optical fiber, then the effect of nonlinearity is very small [1]. Nonlinear effects include self-phase modulation (SPM), cross-phase modulation (XPM), four-wave mixing (FWM), stimulated Raman scattering (SRS), and stimulated Brillouin scattering (SBS).

Self-phase modulation is modulation of phase by itself. It increases as signal power level is increased. It causes phase shift and nonlinear pulse spreading. **Cross-phase modulation** is phase modulation of signal by adjacent signal. XPM affects the WDM system. Thus XPM results from different carrier frequencies in WDM system including associated phase shift on one another. **Four-wave mixing** arises when three different wavelengths interact in the nonlinear medium and give rise to a fourth wavelength which is generated due to scattering of three incident photons and give rise to fourth photon. FWM effect increases with increasing the signal power and decreasing the channel spacing. Since, when light propagates through the fiber, the photons interact with the silica molecules of fiber. These photons also interact with themselves and causes **Stimulated Raman Scattering** in forward and backward direction of propagation which result in distribution of energy in random direction. In SRS lower wavelengths transfer their energy to longer wavelengths result in higher wavelengths suppressing the lower wavelengths. In SRS a low wavelength wave called stoke’s wave is generated which amplify the longer wavelength. **Stimulated Brillouin Scattering (SBS)** is generated due to acoustic properties of photon interaction with the fiber material result in backward scattering of light.

1.4 Objective of the Project

The main objective of the project is to efficient utilization of low loss optical window 1550-nm to achieve the Ultra-High bit rate transmission. For achieving the Ultra-high bit rate transmission, we designed a DWDM system with channel spacing 0.4-nm (50GHz) [6] for eight channels and each channel is modulated by 40 Gb/s PRBS generator. M-Z modulator (Mach-Zehnder) is used to modulate the signal. NRZ modulation format is used [7]. To minimize the pulse spreading due to dispersion dispersion compensated fiber is used [8]. Since system is designed for 1550-nm wavelength domain, and erbium doped fiber amplifier (EDFA) [9] amplify the signal in this domain. Hence for taking the full advantage of low loss window 1550-nm, EDFA is used to amplify the signal.

1.5 Scope of the Project

At present DWDM is major research area in fiber optics. Still, many research are going on in DWDM field to minimize the channel spacing below 0.4-nm (50GHz) so that large number of channels can be multiplexed to achieve the Ultra-High data rate. Proposed project is designed for 8 channel with 0.4-nm channel spacing but in future with advancement in technology, it can be extended for very large number of channel with less channel spacing will result in Ultra-high transmission capacity in the range of several Tb/s.

1.6 Organization of the Thesis

In **Chapter 2** Literature review for project.

In **Chapter 3** System components description and operating principle.

In **Chapter 4** Methodology for project designing.

In **Chapter 5** Results and discussion.

In **Chapter 6** Project designing by using corning SMF-28 and standard DCF

In **Chapter 7** Conclusion and scope for future work.

CHAPTER-2

LITERATURE REVIEW

In fiber optics by using the dense wavelength division multiplexing technique multiple information streams can be transmitted simultaneously over a single optical fiber with high data rate upto several Gb/s. At present 1550-nm wavelength domain is highly used to design the DWDM system because it is the window which have smallest attenuation and also exist in the band in which EDFA operate. A DWDM system is also designed by using algorithm approach in this wavelength domain [10]. In long distance optical transmission system, signal power level is generally maintained at high level, but in such system dependence of the refractive index of optical fiber on power cann't be ignored. Dependency of fiber refractive index on optical power or light intensity is called nonlinear effect. A soliton transmission is one of the techniques to cope with the nonlinear waveform distortion. A soliton pulse has $sech^2$ waveform whose shape remain constant during propagation because they generated as a balance between the chirp caused by nonlinearity phenomenon and dispersion which must be maintained along fiber length set by soliton period [11]. An optical phase conjugation is another technique to cope with nonlinearity waveform distortion [12]. It is implemented by using the four wave mixing process in a third order nonlinear medium. When input optical signal interact with high pump signal in nonlinear media a new wave is generated due to four wave mixing phenomenon which is complex conjugate replica of input signal. To implement the optical phase conjugator a practical nonlinear media: dispersion-shifted fiber [13] and semiconductor optical amplifier [14] is used. In this technique optical signal passes through the first half of transmission length and then distorted signal pass through the optical phase conjugator which restore the original optical signal in the second half of transmission length. To cope with four wave mixing effect many methods have been given like: non-zero dispersion shifted fiber, dispersion management, unequal channel spacing [15, 16]. Since four wave mixing is increased at low dispersion, small and equal channel spacing as compare to unequal channel spacing. Hence to mitigate the four wave mixing effect, equal and unequal channel spacing with polarization, alternate channel delay in equal channel spacing can be used [17].

To achieve the ultra-high data rate various modulation format technique: carrier-suppressed return-to-zero (CSRZ), duo binary return-to-zero (DRZ), modified duo binary return-to-zero (MDRZ) is proposed for DWDM system [18]. Invention of different type of optical amplifiers, helped us in achieving the Ultra-High data rate through DWDM system. Erbium doped fiber amplifier (EDFA), hybrid optical amplifier RAMAN-EDFA [19] boosted the optical communication system. To minimize the dispersion in fiber a dispersion compensated fiber (DCF) of opposite dispersion coefficient can be used [20].

At present DWDM systems use extensively non-zero dispersion shifted fiber (NZ-DSF) to minimize the four wave mixing effect but other nonlinear effect still affect the transmission capacity of DWDM system. Another technique to reducing the nonlinear effect is increasing the transmitting fiber effective area [21].

Since chromatic dispersion is sensitive to

(i) An increase in link lengths and number of links in tandem.

(ii) Increasing in bit rate because as bit rate is increased, modulation rate of laser increases the width of sidebands.

And in WDM system chromatic dispersion is not influenced by

(i) Decreasing the channel spacing.

(ii) Increasing the number of channels.

Chromatic dispersion effects can be reduced by

(i) Decreasing the absolute value of chromatic dispersion of fiber i.e.by decreasing the value of D.

(ii) Dispersion compensation technique.

In fiber optics PMD affects the optical communication system by-

(i) Increasing the channel bit rate.

(ii) Increasing in link length.

(iii) Increasing in number of channels.

It can be reduced by using the quality control fabrication stage of fiber [22].

There is device which is used to compensate the chromatic dispersion: dispersion compensated fiber (DCF).

If the dispersion coefficient has opposite sign with equal magnitude that of transmission optical fiber, then the dispersion of transmission fiber becomes zero [11]. The length of DCF should be small as possible and it is calculated by the fallowing formula:

$$L_2 = -(D_1/D_2)\, L_1 \qquad (2.1)$$

Where L_1 is length of transmission fiber and L_2 is length of DCF. D_1 and D_2 is dispersion coefficient of transmission fiber and DCF respectively.

CHAPTER-3
SYSTEM COMPONENTS DESCRIPTION AND OPERATING PRINCIPLE

3.1 Introduction

In this chapter we will describe the main optical and electrical components which we have used in our experimental setup. The main optical and electrical component is given below:

(1) Continuous wave (CW) laser

(2) Pseudo-random bit sequence generator

(3) NRZ pulse generator

(4) Mach-Zehnder modulator

(5) WDM MUX and DEMUX

(6) Erbium doped fiber amplifier (EDFA)

(7) PIN photo detector

(8) 3R-regenerator.

3.2 Continuous Wave (CW) Laser

Continuous-wave (CW) operation of a laser means that the laser is continuously pumped and continuously emits light. The emission can occur in a single resonator mode (single frequency operation) or on multiple modes. It emits the light through the process of optical amplification based on stimulated emission of electromagnetic radiation. The term "laser" is acronym for Light Amplification by Stimulated Emission of Radiation. Lasers differ from other sources of light in the sense of they emit light coherently. Its spatial coherence allows a laser to be focused to a tight spot. In our experiment setup we use laser to generate optical carrier signal to modulate the information signal.

The field equation of the continuous wave laser is given as –

$$E(t) = E_0 \exp(j\omega_c t) \qquad (3.1)$$

Where E_0 the magnitude of laser output field and ω_c is frequency of optical carrier.

3.3 Pseudo-Random Bit Sequence Generator

It Generates a Pseudo Random Binary Sequence (PRBS) according to different operation modes. The bit sequence is designed to approximate the characteristics of random data.

3.4 NRZ Pulse Generator

It generates a Non Return to Zero (NRZ) coded signal. It is the most common signal format and in fiber optics binary 1 is the active signal element while binary 0 is passive element.

3.5 Mach-Zehnder Modulator

The Mach-Zehnder modulator is an intensity modulator based on an interferometric principle which is shown in fig.3.1. It consists of two 3 dB couplers which are connected by two waveguides of equal length. By means of an electro-optic effect, an externally applied voltage can be used to vary the refractive indices in the waveguide branches.

The different paths can lead to constructive and destructive interference at the output, depending on the applied voltage. Then the output intensity can be modulated according to the voltage

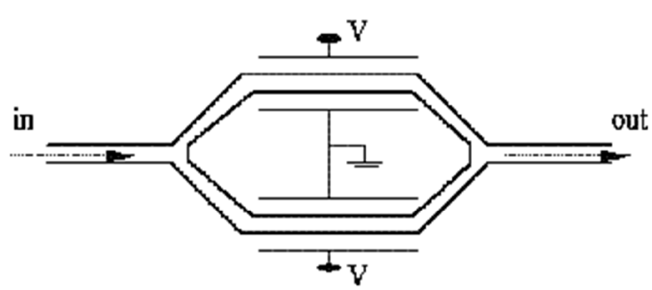


Fig.3.1 Mach-Zehnder modulator.

The equations that describe the behavior of the MZ modulator are:

$$E_{out}(t) = E_{in}(t)\ .\cos(\Delta\theta(t))\ .\exp(\ j.\Delta\phi(t)) \qquad (3.2)$$

Where $\Delta\theta$ is the phase difference between the two branches and is defined as:

$$\Delta\theta(t) = \frac{?}{?}\,(0.5 - ER.(modulation(t) - 0.5)) \qquad (3.3)$$

Where

$$ER = 1 - \frac{?}{?}\ .\arctan \frac{?}{\sqrt{???????}} \qquad (3.4)$$

And $\Delta\phi$ is the signal phase change.

3.6 WDM MUX and DEMUX

Wavelength division multiplexers and demultiplexers (WDM MUX and DEMUX) are the devices that combine and separate the different wavelengths. A WDM MUX combines several wavelength channels into one fiber; while WDM DEMUX does just opposite. The input signals are filtered by an optical filter and combined in one signal. The optical filter can be a Rectangle, Gaussian, or Bessel optical filter. The WDM MUX and DEMUX internal function is shown below –

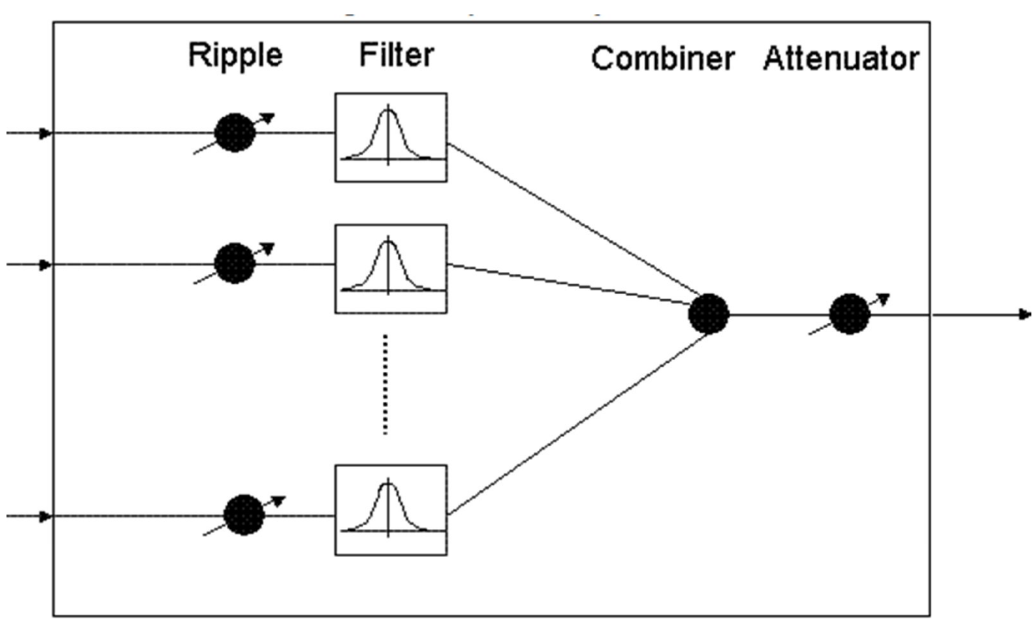


Fig.3.2 Internal function of WDM MUX.

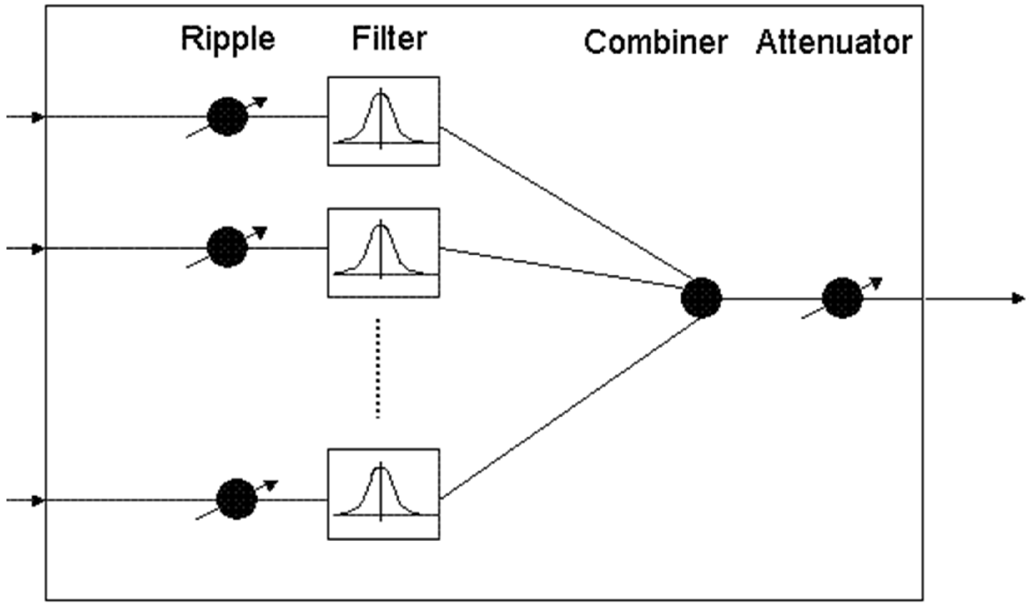


Fig.3.3 Internal function of WDM DEMUX.

3.7 Erbium Doped Fiber Amplifier (EDFA)

An erbium-doped fiber amplifier (EDFA) is shown in Figure 3.4. It consists of a length of silica fiber whose core is doped with ionized atoms (ions), Er3+, of the rare Earth element erbium. This fiber is pumped using a pump signal from a laser, typically at a wavelength of 980 nm or 1480 nm. In order to combine the output of the pump laser with the input signal, the doped fiber is preceded by a wavelength-selective coupler. At the output, another wavelength-selective coupler may be used if needed to separate the amplified signal from any remaining pump signal power. Usually, an isolator is used at the input and/or output of any amplifier to prevent reflections into the amplifier.

A combination of several factors has made the EDFA the amplifier of choice in today's optical communication systems: (1) the availability of compact and reliable high-power semiconductor pump lasers, (2) the fact that it is an all-fiber device, making it polarization independent and easy to couple light in and out of it, (3) the simplicity of the device, and (4) the fact that it introduces no crosstalk when amplifying WDM signals. This last aspect is discussed later in the context of semiconductor optical amplifiers.

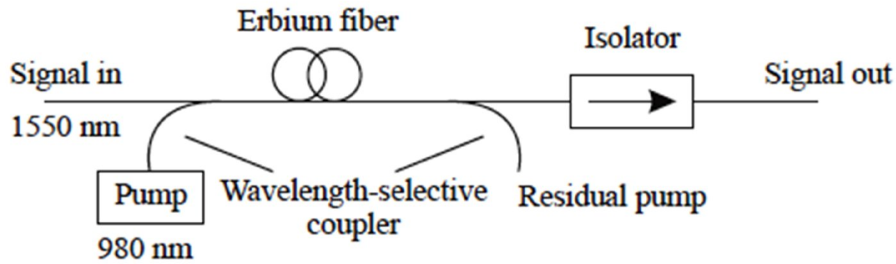


Fig.3.4 An erbium-doped fiber amplifier.

3.7.1 Principle of Operation

Three of the energy levels of erbium ions in silica glass are shown in Figure 3.5. In this figure the three energy levels E1, E2, and E3 of Er3+ ions in silica glass. The fourth energy level, E4, is present in fluoride glass but not in silica glass. The energy levels are spread into bands by the Stark splitting process. The difference between the energy levels is labeled with the wavelength in nm of the photon corresponding to it. The upward arrows indicate wavelengths at which the amplifier can be pumped to excite the ions into the higher energy level. The 980 nm transition corresponds to the band gap between the E1 and E3 levels. The 1480 nm transition corresponds to the gap between the bottoms of the E1 band to the top of the E2 band. The downward transition represents the wavelength of photons emitted due to spontaneous and stimulated emission. Each energy level that appears as a discrete line in an isolated ion of erbium is split into multiple energy levels when these ions are introduced into silica glass. This process is called **Stark splitting**. Moreover, glass is not a crystal and thus does not have a regular structure. Thus the Stark splitting levels introduced are slightly different for individual erbium ions, depending on the local surroundings seen by those ions. Macroscopically, that is, when viewed as a collection of ions, this has the effect of spreading each discrete energy level of an erbium ion into a continuous **energy band**. This spreading of energy levels is a useful characteristic for optical amplifiers since they increase the frequency or wavelength range of the signals that can be amplified. Within each energy band, the erbium ions are distributed in the various levels within that band in a nonuniform manner by a process known as thermalization. It is due to this thermalization process that an amplifier is capable of amplifying several wavelengths simultaneously. Note that Stark splitting denotes the phenomenon by which the energy levels of free erbium ions are split into a number of levels, or into an energy band, when the ion is introduced into silica glass. Thermalization refers to the process by which the erbium ions are distributed within the various (split) levels constituting an energy band.

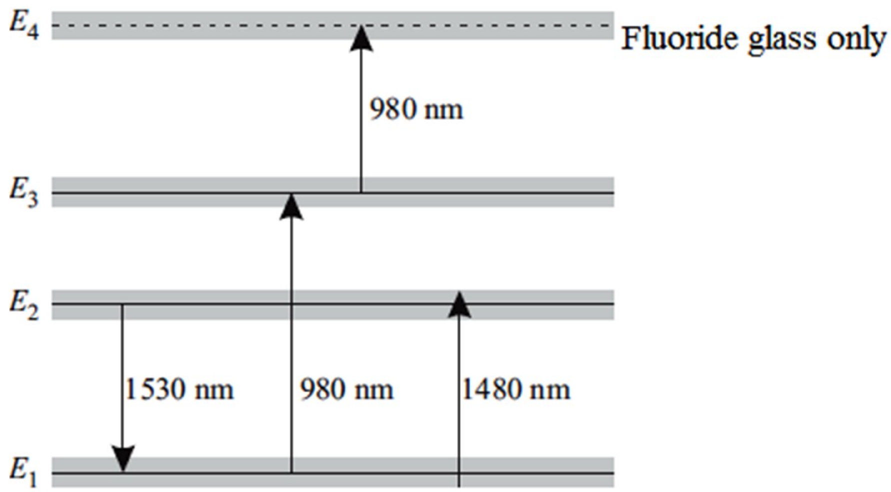


Fig.3.5 Energy bands of erbium ions in a silica fiber.

Since, only an optical signal at the frequency fc satisfying hf_c = E2 −E1 could be amplified in that case. If these levels are spread into bands, all frequencies that correspond to the energy difference between some energy in the E2 band and some energy in the E1 band can be amplified. In the case of erbium ions in silica glass, the set of frequencies that can be amplified by stimulated emission from the E2 band to the E1 band corresponds to the wavelength range 1525–1570 nm, a bandwidth of 50 nm, with a peak around 1532 nm. By a lucky coincidence, this is exactly one of the low-attenuation windows of standard optical fiber that optical communication systems use. Denote ionic population in level Ei by Ni, i = 1, 2, 3. In thermal equilibrium, N1 > N2 > N3. The population inversion condition for stimulated emission from E2 to E1 is N2 > N1 and can be achieved by a combination of absorption and spontaneous emission as follows. The energy difference between the E1 and E3 levels corresponds to a wavelength of 980 nm. So if optical power at 980 nm—called the pump power—is injected into the amplifier, it will cause transitions from E1 to E3 and vice versa. Since N1 > N3, there will be a net absorption of the 980 nm power. This process is called pumping. The ions that have been raised to level E3 by this process will quickly transit to level E2 by the spontaneous emission process. The lifetime for this process, τ32, is about 1μs. Atoms from level E2 will also transit to level E1 by the spontaneous emission process, but the lifetime for this process, τ21, is about 10ms, which is much larger than the E3 to E2 lifetime. Moreover, if the pump power is sufficiently large, ions that transit to the E1 level are rapidly raised again to the E3 level only to transit to the E2 level again. The net effect is that most of the ions are found in level E2, and thus we have population inversion between the E2 and E1 levels. Therefore, if simultaneously a signal in the 1525–1570 nm band is injected into the fiber, it will be amplified by stimulated emission from the E2 to the E1 level. Several levels other than E3 are higher than E2 and, in principle, can be used for pumping the amplifier. But the pumping process is more efficient, that is, uses less pump power for a given gain, at 980 nm than these other wavelengths. Another possible choice for the pump wavelength is 1480 nm. This choice corresponds to absorption from the bottom sublevel of the E1 band to the top sublevel of the E2 band itself. Pumping at 1480 nm is not as efficient as 980 nm pumping. Moreover, the degree of population inversion that can be achieved by 1480 nm pumping is lower. The higher the population inversion, the lower the noise figure of the amplifier. Thus 980 nm pumping is preferred to realize low-noise amplifiers. However, higher-power pump lasers are available at 1480 nm, compared to 980 nm, and thus 1480 nm pumps find applications in amplifiers designed to yield high output powers. Another advantage of the 1480 nm pump is that the pump power can also propagate with low loss in the silica fiber that is used to carry the signals. Therefore, the pump laser can be located remotely from the amplifier itself. This feature is used in some systems to avoid placing any active components in the middle of the link.

3.7.2 Gain Flatness of EDFA

Since the population levels at the various levels within a band are different, the gain of an EDFA becomes a function of the wavelength. Fig.3.6, shows the gain of a typical EDFA as a function of the wavelength for different values of the pump power. When such an EDFA is used in a WDM communication system, different WDM channels undergo different degrees of amplification. This is a critical issue, particularly in WDM systems with cascaded amplifiers.

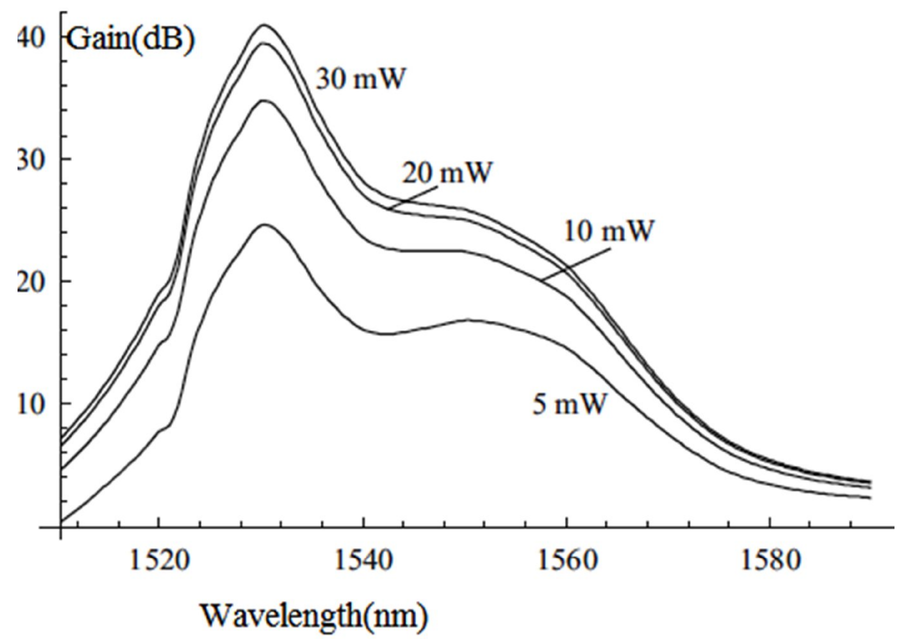


Fig.3.6 The gain of a EDFA as a function of the wavelength for four different values of the pump power.

One way to improve the flatness of the amplifier gain profile is to use fluoride glass fiber instead of silica fiber, doped with erbium. Such amplifiers are called erbium-doped fluoride fiber amplifiers (EDFFAs). The fluoride glass produces a naturally flatter gain spectrum compared to silica glass. However, there are a few drawbacks to using fluoride glass. The noise performance of EDFFAs is poorer than EDFAs. One reason is that they must be pumped at 1480 nm and cannot be pumped at 980 nm. This is because fluoride glass has an additional higher energy level E4 above the E3 level, as shown in Fig.3.5, with the difference in energies between these two levels corresponding to 980 nm. This causes the 980 nm pump power to be absorbed for transitions from the E3 to E4 level, which does not produce useful gain. This phenomenon is called excited state absorption.

In addition to this drawback, fluoride fiber itself is difficult to handle. It is brittle, difficult to splice with conventional fiber, and susceptible to moisture. Nevertheless, EDFFAs are now commercially available devices. Another approach to flatten the EDFA gain is to use a filter inside the amplifier. The EDFA has a relatively high gain at 1532 nm, which can be reduced by using a notch filter in that wavelength region inside the amplifier. Long-period fiber gratings and dielectric thin-film filters are currently the leading candidates for this application.

3.7.3 L-Band EDFA

As we have discussed about EDFAs operating in the C-band (1530–1565 nm). But erbium-doped fiber, has a relatively long tail to the gain shape extending well beyond this range to about 1605 nm. This has stimulated the development of systems in the so-called L-band from 1565 to 1625 nm. Note that current L-band EDFAs do not yet cover the top portion of this band from 1610 to 1625 nm. L-band EDFAs operate on the same principle as C-band EDFAs. However, there are significant differences in the design of L- and C-band EDFAs. The gain spectrum of erbium is much flatter intrinsically in the L-band than in the C-band. This makes it easier to design gain-flattening filters for the L-band. However, the erbium gain coefficient in the L-band is about three times smaller than in the C-band. This necessitates the use of either much longer doped fiber lengths or fiber with higher erbium doping concentrations. In either case, the pump powers required for L-band EDFAs are much higher than their C-band counterparts. Due to the smaller absorption cross sections in the L-band, these amplifiers also have higher amplified spontaneous emission. Finally, many of the other components used inside the amplifier, such as isolators and couplers, exhibit wavelength-dependent losses and are therefore specified differently for the L-band than for the C-band.

As a result of the significant differences between C- and L-band amplifiers, these amplifiers are usually realized as separate devices rather than as a single device. In a practical system application, the C- and L-band wavelengths on a fiber are first separated by a demultiplexer, then amplified by separate amplifiers, and recombined together afterward.

3.7.4 Gain Saturation in EDFA

An important consideration in designing amplified systems is the saturation of the EDFA. Depending on the pump power and the amplifier design itself, the output power of the amplifier is limited. As a result, when the input signal power is increased, the amplifier gain drops. This behaviour can be defined by the following equation:

$$G = 1 + \frac{?^{???}}{?_{??}}\,Ú\,\frac{?_{?\ ??}}{?} \qquad (3.5)$$

Here, G_{max} is the unsaturated gain, and G the saturated gain of the amplifier, P^{sat} is the amplifier's internal saturation power, and P_{in} is the input signal power. Fig.3.7 plots the amplifier gain as a function of the input signal power for a EDFA.

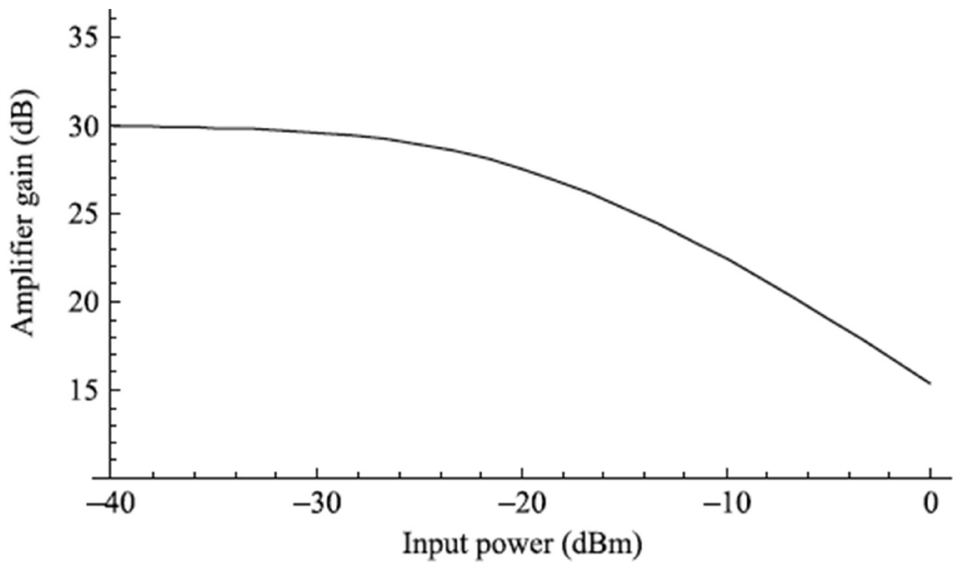


Fig.3.7 Gain saturation in an optical amplifier. Unsaturated gain G_{max} = 30 dB and saturation power P^{sat} = 10 dBm.

For low input powers, the amplifier gain is at its unsaturated value, and at very high input powers, $G \rightarrow 1$ and the output power P_{out} = Pin. The output saturation power Psat out is defined to be the output power at which the amplifier gain has dropped by 3dB. Using (5.5) and the fact that Pout = GP_{in}, and assuming that G >> 1, the output saturation power is given by

$$?^{???}_{???} \approx p^{sat} \ln 2 .$$

The saturation power is a function of the pump power and other amplifier parameters. It is quite common to have output saturation powers on the order of 10 to 100 mW(10 to 20 dBm). There is no fundamental problem in operating an EDFA in saturation, and power amplifiers usually do operate in saturation. The only thing to keep in mind is that the saturated gain will be less than the unsaturated gain.

3.7.5 Gain Equalization in EDFA

The flatness of the EDFA passband becomes a critical issue in WDM systems with cascaded amplifiers. The amplifier gain is not exactly the same at each wavelength. Small variations in gain between channels in a stage can cause large variations in the power difference between channels at the output of the chain. For example, if the gain variation between the worst channel and the best channel is 1 dB at each stage, after 10 stages it will be 10 dB, and the worst channel will have a much poorer signal-to- noise ratio than the best channel. Building amplifiers with flat gain spectra is therefore very important and is the best way to solve this problem. In practice, it is possible to design EDFAs to be inherently flat in the 1545–1560 nm wavelength regions, and this is where many early WDM systems operate. However, systems with a larger number of channels will need to use the 1530–1545 nm wavelength range, where the gain of the EDFA is not flat. The gain spectrum of L-band EDFAs is relatively flat over the L-band from about 1565 nm to about 1625 nm so that gain flattening over this band is not a significant issue.

At the system level, a few approaches have been proposed to overcome this lack of gain flatness. The first approach is to use pre equalization, or pre emphasis, as shown in Figure 3.8(b). Based on the overall gain shape of the cascade, the transmitted power per channel can be set such that the channels that see low gain are launched with higher powers. The goal of pre equalization is to ensure that all channels are received with approximately the same signal-to-noise ratios at the receiver and fall within the receiver's dynamic range. However, the amount of equalization that can be done is limited, and other techniques may be needed to provide further equalization. Also this technique is difficult to implement in a network, as opposed to a point-to-point link.

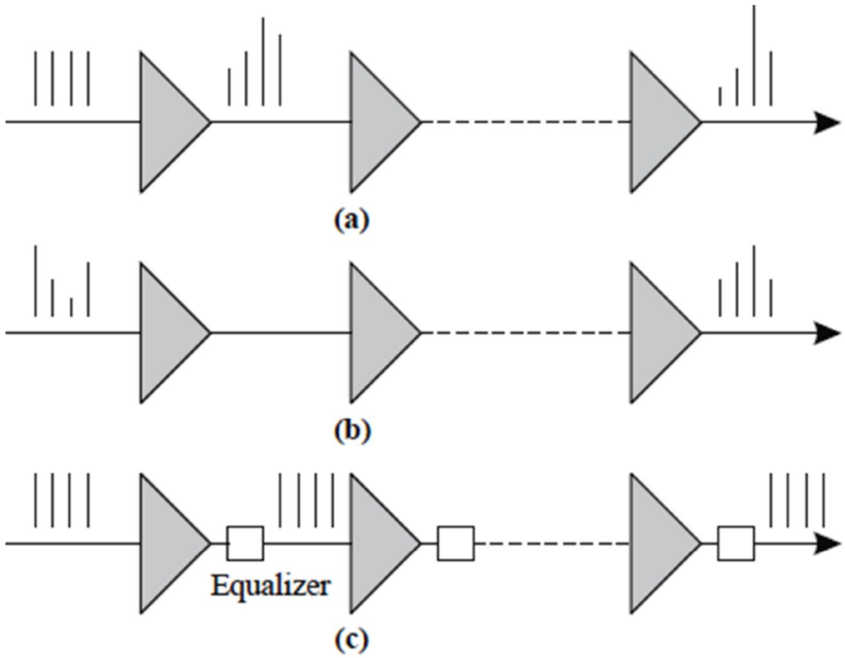


Fig.3.8 Effect of unequal amplifier gains at different wavelengths. (a) A set of channels with equal powers at the input to a cascaded system of amplifiers will have vastly different powers and signal-to-noise ratios at the output. (b) This effect can be reduced by pre equalizing the channel powers. (c) Another way to reduce this effect is to introduce equalization at each amplifier stage. The equalization can be done using a filter inside the amplifier as well.

The second approach is to introduce equalization at each amplifier stage, as shown in Figure 3.8(c). After each stage, the channel powers are equalized. This equalization can be done in many ways. One way is to demultiplex the channels, attenuate each channel differently, and then multiplex them back together. This approach involves using a considerable amount of hardware. It adds wavelength tolerance penalties due to the added muxes and demuxes. For these reasons, such an approach is impractical. Another approach is to use a multichannel filter, such as an acousto-optic tunable filter (AOTF). In an AOTF, each channel can be attenuated differently by applying a set of RF signals with different frequencies. Each RF signal controls the attenuation of a particular center wavelength, and by controlling the RF powers of each signal, it is possible to equalize the channel powers. However, an AOTF requires a large amount of RF drive power (on the order of 1 W) to equalize more than a few (2–4) channels. Both approaches introduce several decibels of additional loss and some power penalties due to crosstalk. The preferred solution today is to add an optical filter within the amplifier with a carefully designed passband to compensate for the gain spectrum of the amplifier so as to obtain a flat spectrum at its output. Both dielectric thin-film filters and long-period fiber gratings are good candidates for this purpose.

3.8 PIN Photo Detector

In PIN photo detector, a very lightly doped *intrinsic* semiconductor is introduced between the p-type and n-type semiconductors to improve the efficiency of the photo detector. In these photodiodes, the depletion region extends completely across this intrinsic semiconductor (or region). The width of the p-type and n-type semiconductors is small compared to the intrinsic region, so that much of the light absorption takes place in this region. This increases the efficiency and thus the responsivity of the photodiode.

A more efficient method of increasing the responsivity is to use a semiconductor material for the p-type and n-type regions that is transparent at the wavelength of interest. Thus the wavelength of interest is larger than the cutoff wavelength of this semiconductor, and no absorption of light takes place in these regions. This is shown in Fig.3.9, where the material InP is used for the p-type and n-type regions, and InGaAs for the intrinsic region. Such a pin photodiode structure is termed a double heterojunction or a heterostructure since it consists of two junctions of completely different semiconductor materials.

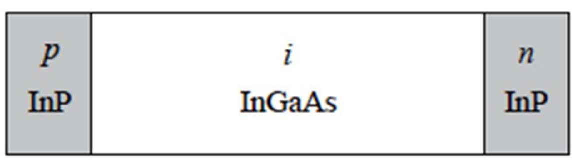


Fig.3.9 A PIN photodetector.

3.9 3R-Regenerator

This component regenerates an electrical signal. It generates the original bit sequence, and a modulated electrical signal to be used for BER analysis. By using the **3R Regenerator**, there is no need for connections between the transmitter and the BER Analyzer. This is especially important for WDM systems, where we have with multiple transmitters, receivers and BER Analyzers.

CHAPTER-4

METHODOLOGY FOR PROJECT DESIGNING

4.1 Introduction

In this chapter we discuss the method to implement the DWDM system to transmit the high speed data upto 320Gb/s through standard single mode fiber in 1550-nm wavelength domain. For designing the proposed system Optysystem-7, Optical Communication System Design Software is used.

4.2 Block Diagram of Experimental Setup

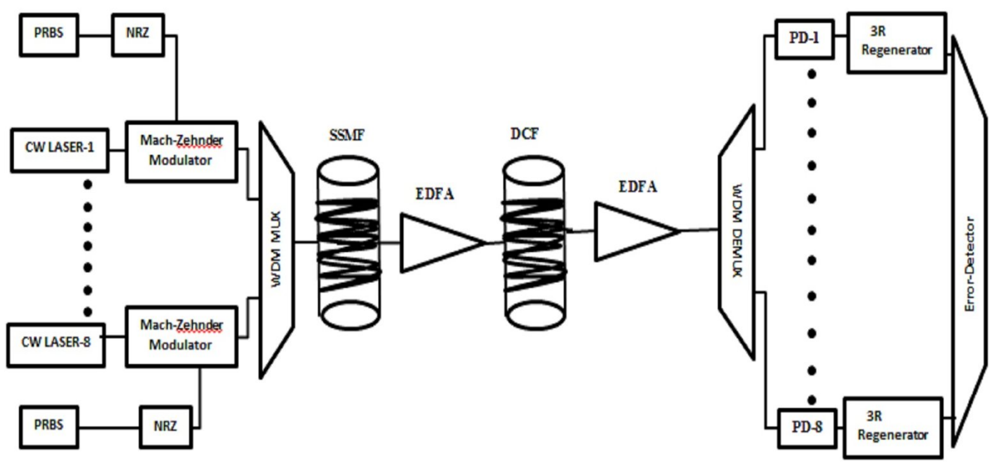


Fig.4.1 Block diagram of experimental setup for 8×40 Gb/s DWDM system.

Here we describe the experimental setup for our designed system. Transmitter consist of eight continuous wave (CW) laser to transmit the eight different wavelengths from 196THz to 195.65THZ with channel spacing 0.05THz(~0.4-nm or 50GHz).Each CW laser transmits -1dBm power. Each channel is modulated by 40 Gb/s Pseudo Random Bit Sequence (PRBS) generator. Mach-Zehnder modulator is used to modulate the signal and NRZ modulation format is used [7]. Mach-Zehnder modulator has extinction ratio 30dB. After modulating each channel ,all channels are multiplexed by WDM MUX .To minimize the losses and interfering with each other the bandwidth of WDM MUX is 50 GHz ,depth is 100dB,filter type is Gaussian ,filter order is 4 and noise threshold is -100dB. After multiplexing each signal power is drop to around -23dBm. Than multiplexed signal is passed through standard single mode fiber (SSMF) of length around 90 km .To compensate the linear losses in transmission fiber Erbium doped fiber amplifier (EDFA) of gain 20dB is used. To reduce the first order Dispersion exactly zero Dispersion Compensated Fiber (DCF) is used [8]. That is

$$D_{SSMF}L_{SSMF} = D_{DCF}\,L_{DCF}$$

Where D stands for first order dispersion and L stands for a length of respective fiber.

At the receiver side signal are de-multiplexed by WDM DEMUX then detected by the PIN photo-detector. The responsivity of PIN photo-detector is 1A/W and dark current is 10na. Than applied to 3R Regenerator. It regenerates an electrical signal then applied to error detector. As an error detector BER analyzer is used to analyze the Q factor, Min BER, Threshold and Eye Opening etc.

4.3 Simulation Setup of DWDM System

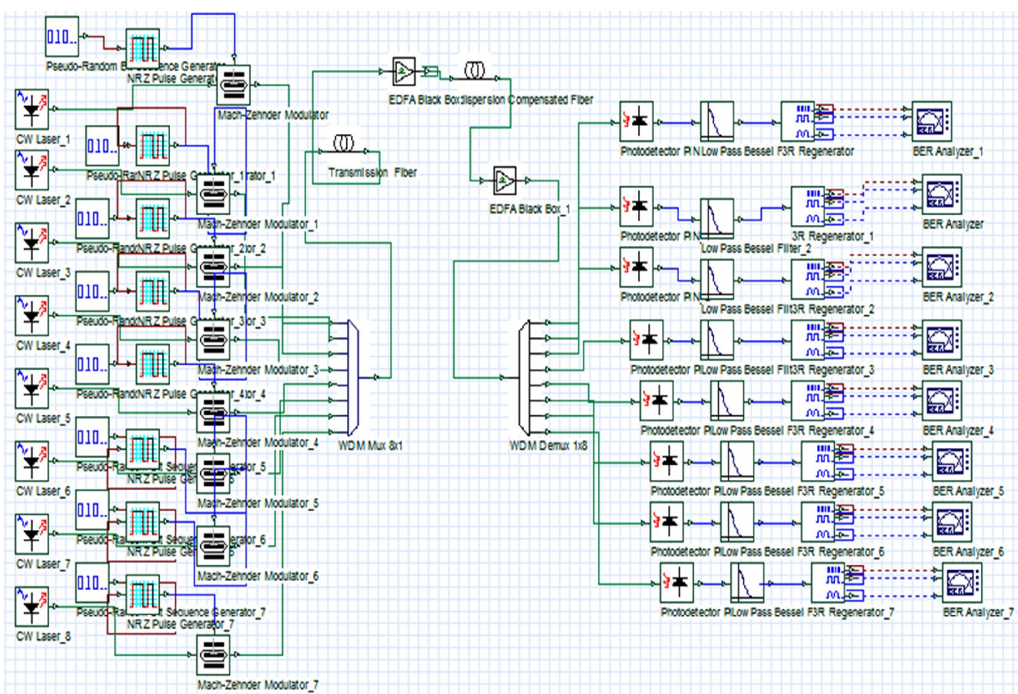


Fig.4.2 OptiSystem simulation setup for 8×40-Gb/s DWDM system.

OptiSystem simulation window for DWDM system is shown in fig.4.2. Its description is given in section 4.2. Parameter of each component used in designing of 8×40 Gb/s DWDM system is given below:

Simulation | Signals | Spatial effects | Noise | Signal tracing

Name	Value	Units	Mode
Simulation window	Set bit rate		Normal
Reference bit rate	☑		Normal
Bit rate	40e+009	bit/s	Normal
Time window	3.2e-009	s	Normal
Sample rate	5.12e+012	Hz	Normal
Sequence length	128	Bits	Normal
Samples per bit	128		Normal
Guard Bits	0		Normal
Symbol rate	2.5e+009	symbols/s	Normal
Number of samples	16384		Normal
Cuda GPU	☐		Normal

Fig.4.3 Simulation parameter for experimental setup.

Main | Polarization | Simulation | Noise | Random nu... | Custom o...

Disp	Name	Value	Units	Mode
☑	Frequency	196	THz	Normal
☑	Power	-1	dBm	Normal
☐	Linewidth	10	MHz	Normal
☐	Initial phase	0	deg	Normal

Fig.4.4 property of CW laser.

Fig.4.4 shows the property of first CW laser which generate the frequency of 196 THz. Remaining seven CW lasers have the same property except the generating frequency i.e. CW laser1 to CW laser8 generate frequency 196 THz to 195.65 THz respectively with channel spacing 0.05 THz.

Main | Channels | Ripple | Simulation | Noise | Custom order

Disp	Name	Value	Units	Mode
☐	Bandwidth	50	GHz	Normal
☐	Insertion loss	0	dB	Normal
☐	Depth	100	dB	Normal
☐	Filter type	Gaussian		Normal
☐	Filter order	4		Normal

Fig.4.5 Property of WDM MUX and DEMUX.

Main | **Channels** | Ripple | Simulation | Noise | Custom order

Disp	Name	Value	Units	Mode
☐	Frequency[0]	196	THz	Normal
☐	Frequency[1]	195.95	THz	Normal
☐	Frequency[2]	195.9	THz	Normal
☐	Frequency[3]	195.85	THz	Normal
☐	Frequency[4]	195.8	THz	Normal
☐	Frequency[5]	195.75	THz	Normal
☐	Frequency[6]	195.7	THz	Normal
☐	Frequency[7]	195.65	THz	Normal

Fig.4.6 Channel separation in WDM MUX and DEMUX.

4.3.1 Transmission Fiber Parameters

Main | Dis... | PMD | No... | Nu... | Gr... | Sim... | N... | Ran... | Cus...

Disp	Name	Value	Units	Mode
☐	User defined reference w	☑		Normal
☐	Reference wavelength	1550	nm	Normal
☑	Length	90	km	Normal
☐	Attenuation effect	☑		Normal
☑	Attenuation data type	Constant		Normal
☐	Attenuation	0.2	dB/km	Normal
☑	Attenuation vs. wavelengt	C:\Users\RAUSHAN KUMA...		Normal

(a)

Main | **Dis...** | PMD | No... | Nu... | Gr... | Sim... | N... | Ran... | Cus...

Disp	Name	Value	Units	Mode
☐	Group velocity dispersion	☑		Normal
☐	Third-order dispersion	☑		Normal
☑	Dispersion data type	Constant		Normal
☐	Frequency domain param	☐		Normal
☐	Dispersion	17	ps/nm/km	Normal
☐	Dispersion slope	0.075	ps/nm^2/k	Normal
☐	Beta 2	-20	ps^2/km	Normal
☐	Beta 3	0	ps^3/km	Normal
☐	Dispersion file format	Dispersion vs. wavelength		Normal
☑	Dispersion file name	C:\Users\RAUSHAN KUMA...		Normal

(b)

Main | Dis... | **PMD** | No... | Nu... | Gr... | Sim... | N... | Ran... | Cus...

Disp	Name	Value	Units	Mode
☐	Birefringence type	Deterministic		Normal
☐	Differential group delay	0.2	ps/km	Normal
☐	PMD coefficient	0.2	ps/sqrt(km	Normal
☐	Mean scattering section l	500	m	Normal
☐	Scattering section disper	100	m	Normal

(c)

Main | Dis... | PMD | **No...** | Nu... | Gr... | Sim... | N... | Ran... | Cus...

Disp	Name	Value	Units	Mode
☐	Self-phase modulation	☑		Normal
☐	Effective area data type	Constant		Normal
☐	Effective area	85	um^2	Normal
☑	Effective area vs. wavelen	C:\Users\RAUSHAN KUMA ...		Normal
☐	n2 data type	Constant		Normal
☐	n2	26e-021	m^2/W	Normal
☐	n2 vs. wavelength	n2.dat ...		Normal
☐	Self-steepening	☐		Normal
☐	Full Raman Response	☐		Normal
☐	Intrapulse Raman Scatt.	☐		Normal
☐	Raman self-shift time1	14.2	fs	Normal
☐	Raman self-shift time2	3	fs	Normal
☐	Fract. Raman contribution	0.18		Normal
☐	Orthogonal Raman factor	0.75		Normal

(d)

Fig.4.7 Parameters of standard single mode fiber (a) attenuation (b) dispersion (c) polarization mode dispersion (d) fiber nonlinearity.

4.3.2 Dispersion Compensated Fiber Parameter

To reduce the first order Dispersion exactly zero Dispersion Compensated Fiber (DCF) is used. For this, the dispersion of the DCF should be of opposite and equal to the transmission standard single mode fiber. In simulation, parameters of SSMF are shown in fig.4.7. Hence using the equation-2.1, we calculate the dispersion coefficient of DCF if length of DCF is taken 15km.

$$L_2 = -(D_1/D_2)\, L_1$$

Where L_1 is length of transmission fiber and L_2 is length of DCF. D_1 and D_2 is dispersion coefficient of transmission fiber and DCF respectively. The length of DCF should be small in order to minimize the attenuation due to DCF. All parameters of DCF is shown in fig.4.8

Main | Dis... | PMD | No... | Nu... | Gr... | Sim... | N... | Ran... | Cus...

Disp	Name	Value	Units	Mode
☐	User defined reference w	☑		Normal
☐	Reference wavelength	1550	nm	Normal
☑	Length	15	km	Normal
☐	Attenuation effect	☑		Normal
☑	Attenuation data type	Constant		Normal
☐	Attenuation	0.5	dB/km	Normal
☑	Attenuation vs. wavelengt	C:\Users\RAUSHAN KUMA ...		Normal

(a)

Main | Dis... | PMD | No... | Nu... | Gr... | Sim... | N... | Ran... | Cus...

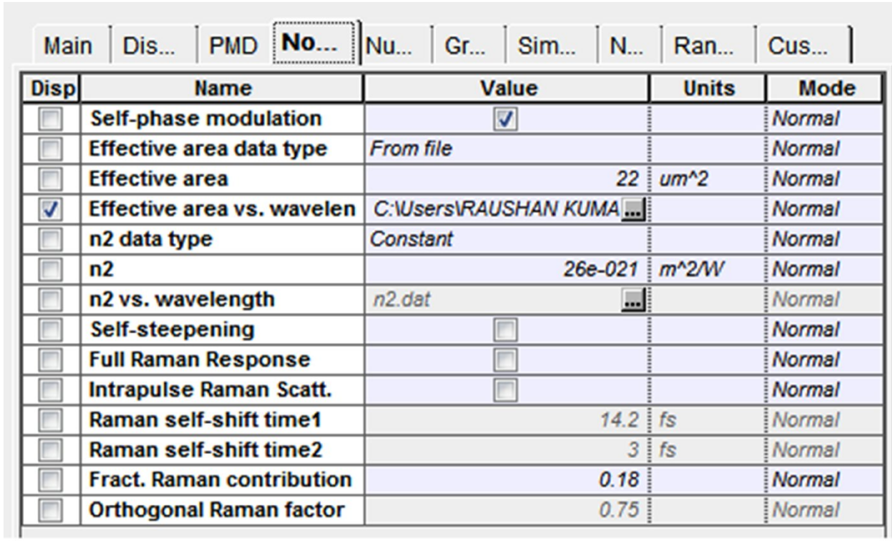
Disp	Name	Value	Units	Mode
☐	Group velocity dispersion	☑		Normal
☐	Third-order dispersion	☑		Normal
☑	Dispersion data type	Constant		Normal
☐	Frequency domain param	☐		Normal
☐	Dispersion	-102	ps/nm/km	Normal
☐	Dispersion slope	-0.3	ps/nm^2/k	Normal
☐	Beta 2	-20	ps^2/km	Normal
☐	Beta 3	0	ps^3/km	Normal
☐	Dispersion file format	Dispersion vs. wavelength		Normal
☑	Dispersion file name	C:\Users\RAUSHAN KUMA ...		Normal

(b)

Main | Dis... | PMD | No... | Nu... | Gr... | Sim... | N... | Ran... | Cus...

Disp	Name	Value	Units	Mode
☐	Birefringence type	Deterministic		Normal
☐	Differential group delay	0.2	ps/km	Normal
☐	PMD coefficient	0.05	ps/sqrt(km	Normal
☐	Mean scattering section l	500	m	Normal
☐	Scattering section disper	100	m	Normal

(c)



Disp	Name	Value	Units	Mode
☐	Self-phase modulation	☑		Normal
☐	Effective area data type	From file		Normal
☐	Effective area	22	um^2	Normal
☑	Effective area vs. wavelen	C:\Users\RAUSHAN KUMA		Normal
☐	n2 data type	Constant		Normal
☐	n2	26e-021	m^2/W	Normal
☐	n2 vs. wavelength	n2.dat		Normal
☐	Self-steepening	☐		Normal
☐	Full Raman Response	☐		Normal
☐	Intrapulse Raman Scatt.	☐		Normal
☐	Raman self-shift time1	14.2	fs	Normal
☐	Raman self-shift time2	3	fs	Normal
☐	Fract. Raman contribution	0.18		Normal
☐	Orthogonal Raman factor	0.75		Normal

(d)

Fig.4.8 Parameters of dispersion compensated fiber (a) attenuation (b) dispersion (c) polarization mode dispersion (d) fiber nonlinearity.

4.4 Conclusion

In this chapter basically we design the DCF which will compensate the first order chromatic dispersion of transmission fiber exactly zero. The dispersion coefficient of DCF is equal in magnitude and opposite to transmission fiber. Hence pulse broadening due to chromatic dispersion in transmission fiber is exactly compensated by DCF.

CHAPTER-5

RESULTS AND DISCUSSION

5.1 Introduction

In this chapter we will discuss the result of simulation of proposed system as described in chapter 4. Simulation setup for the proposed system is shown below:

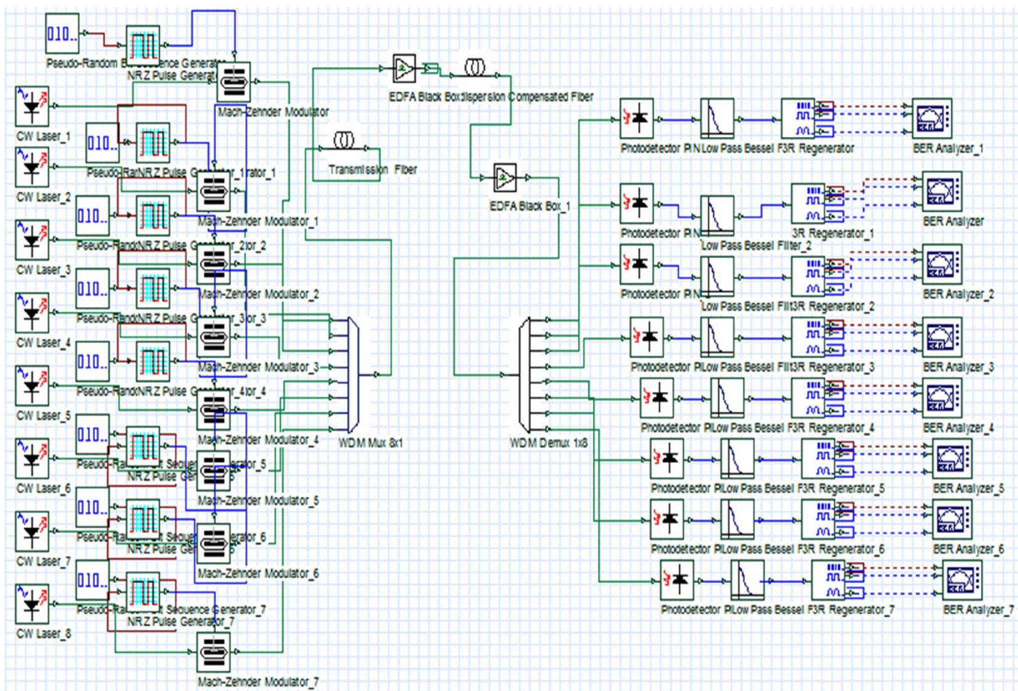


Fig.5.1 OptiSystem simulation setup for 8×40-Gb/s DWDM system.

5.2 Optical Spectra after WDM MUX

Eight optical signal of frequency range 196 THz to 195.65 THz from CW laser is multiplexed in WDM MUX whose optical spectra are given below:

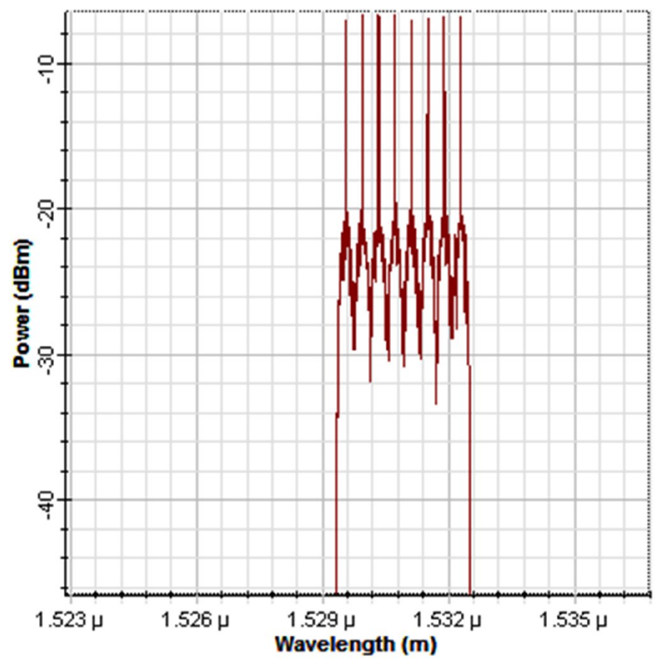


Fig.5.2 Optical spectra of 8×40-Gb/s DWDM in 1550-nm wavelength domain after WDM MUX.

Since power transmitted by each CW laser is -1dBm but after multiplexing the signal power drop to -6dBm. Since each channel is separated from each other by 0.05 THz (0.4-nm) hence power penalty depend upon interchannels cross-talk in WDM MUX. All parameters signal power, noise power, SNR, and OSNR after the WDM MUX are shown in table-5.1.

Table 5.1

Frequency(THz)	Signal Power (dBm)	Noise Power (dBm)	SNR(dB)	OSNR(dB)
196	-6.7350091	-100	93.264991	93.264991
195.95	-6.2215896	-100	93.77841	93.77841
195.90	-6.272074	-100	93.727926	93.727926
195.85	-6.3182204	-100	93.68178	93.68178
195.80	-6.686236	-100	93.313764	93.313764
195.75	-6.44474522	-100	93.552548	93.552548
195.70	-6.3282823	-100	93.671718	93.671718
195.65	-6.3876541	-100	93.612346	93.612346

Table 5.1 Signal power, noise power, SNR, and OSNR after the WDM MUX.

5.3 Optical Spectra after Transmission Fiber

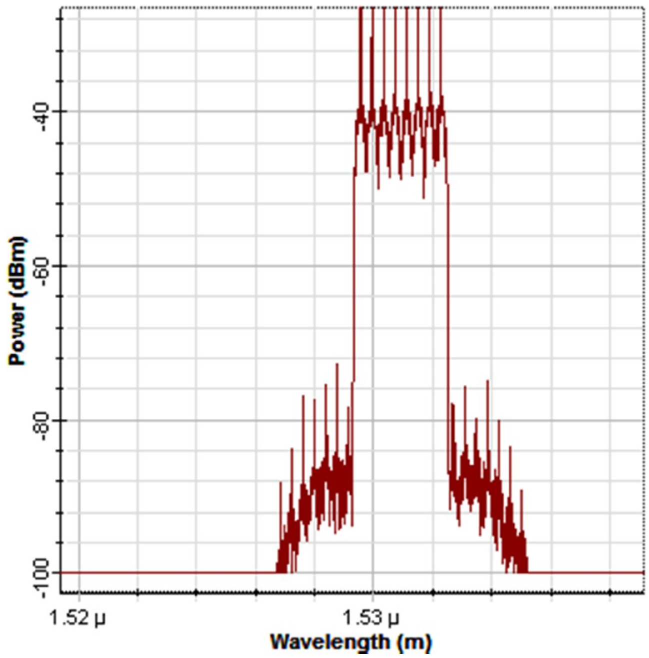


Fig.5.3 Optical spectra of 8×40-Gb/s DWDM in 1550-nm wavelength domain after transmission fiber.

An optical spectrum of multiplexed signal after the transmission fiber is shown in fig.5.3. It shows that the end channels are more affected by non-linearity phenomenon like inter channel cross talk, Four Wave Mixing (FWM), Self- Phase Modulation (SPM) as compare the middle channels. Hence end channel creates more spurious frequency which degrades the signal quality. All parameters signal power, noise power, SNR, and OSNR after the transmission fiber are shown in table-5.2

Table- 5.2

Frequency(THz)	Signal Power (dBm)	Noise Power (dBm)	SNR(dB)	OSNR(dB)
196	-24.723001	-100	75.27699	75.27699
195.95	-24.224686	-100	75.775314	75.775314
195.90	-24.261208	-100	75.738792	75.738792
195.85	-24.299945	-100	75.700055	75.700055
195.80	-24.680954	-100	75.319046	75.319046
195.75	-24.444576	-100	75.555424	75.555424
195.70	-24.321974	-100	75.678026	75.678026
195.65	-24.379181	-100	75.620819	75.620819

Table 5.2 Signal power, noise power, SNR, and OSNR after the transmission fiber.

5.4 Signal Power after In-Line EDFA

Since after transmission through 90 km fiber, signal strength is attenuated. To increase the signal power level In-Line EDFA of gain 20 dB is used. All parameters signal power, noise power, SNR, and OSNR after the In-Line EDFA are shown in table-5.3

Table- 5.3

Frequency(THz)	Signal Power (dBm)	Noise Power (dBm)	SNR(dB)	OSNR(dB)
196	-7.9933991	-34.629861	26.864657	22.885247
195.95	-7.526608	-34.629861	27.027166	23.092766
195.90	-7.5800442	-35.024135	27.342122	23.362722
195.85	-7.8544812	-35.024135	26.924483	22.945083
195.80	-8.4900478	-35.024135	26.918375	22.937975
195.75	-8.444576	-35.301913	26.77645	22.97705
195.70	-8.321974	-35.301913	26.212799	22.233398
195.65	-9.379181	-38.138641	28.694574	24.715147

Table 5.3 Signal power, noise power, SNR, and OSNR after the In-Line EDFA.

After the In-Line EDFA, multiplexed signals passes through the DCF to minimize the first order dispersion completely zero. Then before demultiplexing the all signal, it is amplify by Post EDFA of gain 20dB to compensate the losses in DCF. All parameters signal power, noise power, SNR, and OSNR after the Post EDFA are shown in table-5.4

Table- 5.4

Frequency(THz)	Signal Power (dBm)	Noise Power (dBm)	SNR(dB)	OSNR(dB)
196	5.0985694	-21.313941	26.864657	22.433111
195.95	5.264874	-21.313941	26.578815	22.599415
195.90	5.1159479	-22.039193	27.155141	23.175741
195.85	4.4465129	22.039193	26.485706	22.506306
195.80	4.172292	22.039193	26.211485	22.232085
195.75	3.3082357	-23.183674	26.49291	22.51351
195.70	2.2734483	-23.183674	25.458123	21.478723
195.65	1.3304583	-27.243528	28.573986	24.594586

Table 5.4 Signal power, noise power, SNR, and OSNR after the Post EDFA.

5.5 Eye Diagram and BER Analysis

Performance of this designed system is calculated in terms of BER, Q factor and eye opening. Since BER for optical communication system is acceptable within the range of 10^{-9} to 10^{-15} [23]. For error free transmission, communication system has generally BER greater than or equal to 10^{-12} which correspond to a Q value of greater than or equal to 6.8 [8,24].

Eye diagram for all channels are shown below:

5.5.1 Result of channel-1 (196 THz)

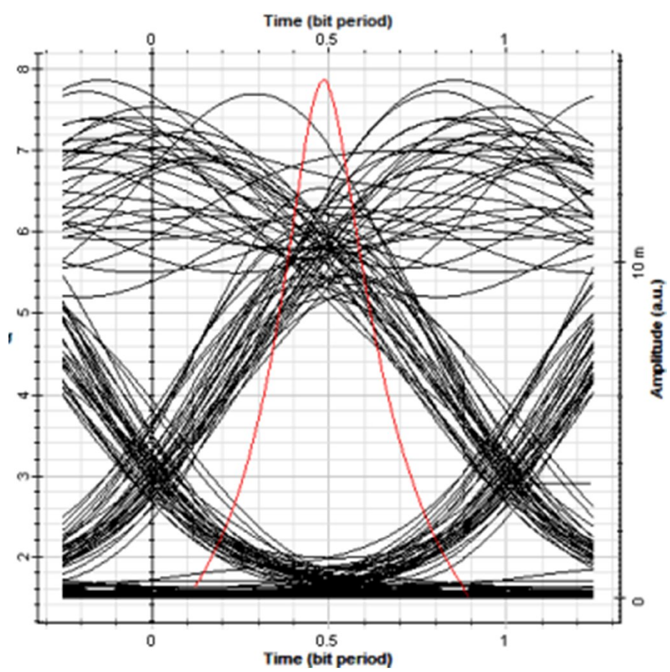


Fig.5.4 Result of 8×40Gb/s BER measurement for channel-1 (196 THz).

Table- 5.5

Max. Q Factor	Min. BER	Eye Height
7.86832	1.47569×10^{-15}	0.00629551

Table-5.5 Q factor, Min BER, Eye Height of channel-1.

5.5.2 Result of channel-2 (195.95 THz)

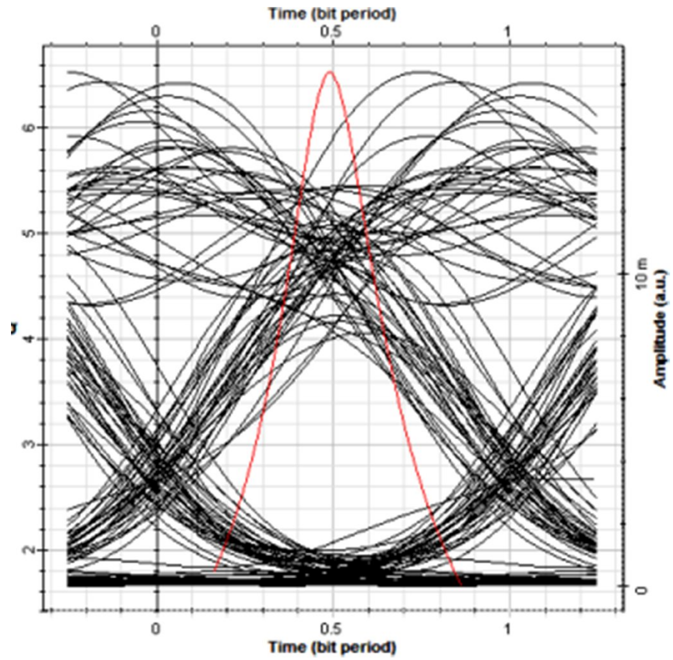


Fig.5.5 Result of 8×40Gb/s BER measurement for channel-2 (195.95 THz).

Table- 5.6

Max. Q Factor	Min. BER	Eye Height
6.53313	2.59293×10^{-11}	0.00549242

Table-5.6 Q factor, Min BER, Eye Height of channel-2.

5.5.3 Result of channel-3 (195.90 THz)

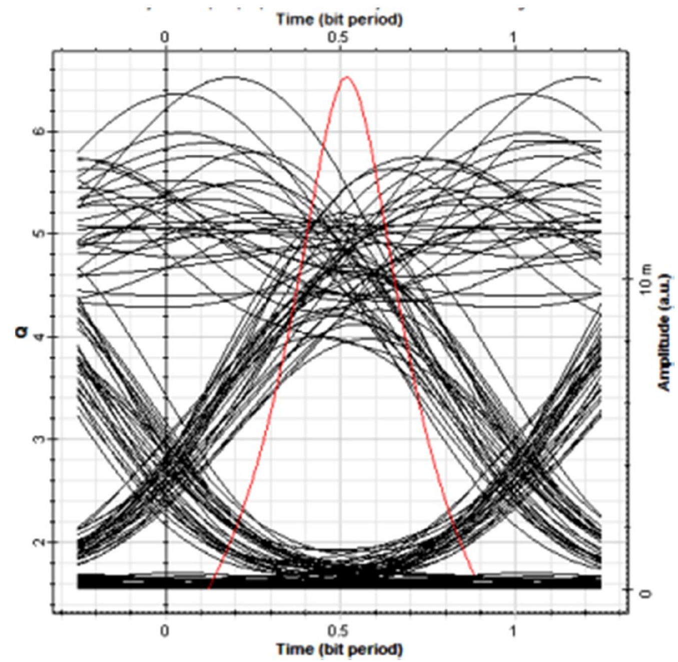


Fig.5.6 Result of 8×40Gb/s BER measurement for channel-3 (195.90 THz).

Table- 5.7

Max. Q Factor	Min. BER	Eye Height
6.51636	2.82772×10^{-11}	0.00540167

Table-5.7 Q factor, Min BER, Eye Height of channel-3.

5.5.4 Result of channel-4 (195.85 THz)

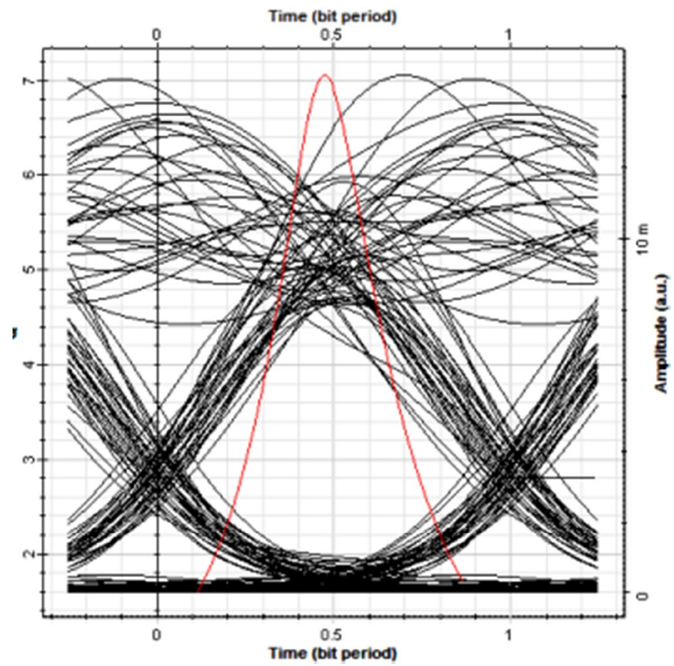


Fig.5.7 Result of 8×40Gb/s BER measurement for channel-4 (195.85 THz).

Table- 5.8

Max. Q Factor	Min. BER	Eye Height
7.05397	6.67215×10^{-13}	0.00527025

Table-5.8 Q factor, Min BER, Eye Height of channel-4.

5.5.5 Result of channel-5 (195.80 THz)

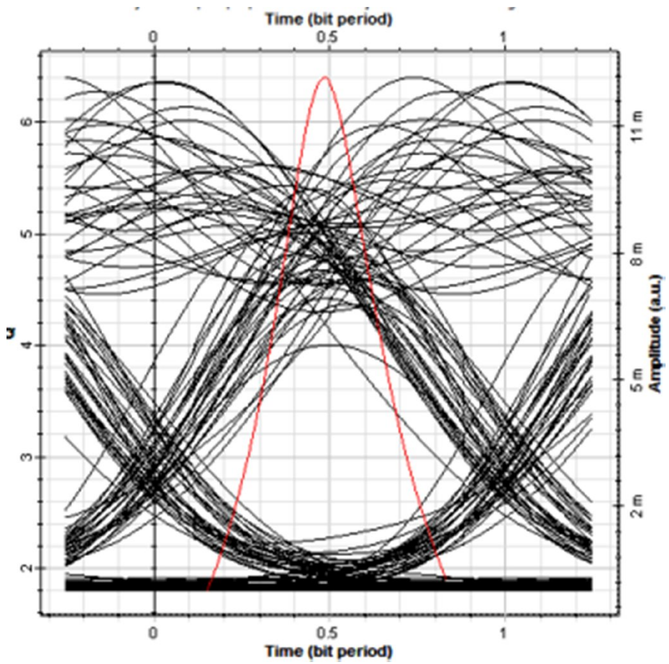


Fig.5.8 Result of 8×40Gb/s BER measurement for channel-5 (195.80 THz).

Table- 5.9

Max. Q Factor	Min. BER	Eye Height
6.40021	6.26037×10^{-11}	0.00415031

Table-5.9 Q factor, Min BER, Eye Height of channel-5.

5.5.6 Result of channel-6 (195.75 THz)

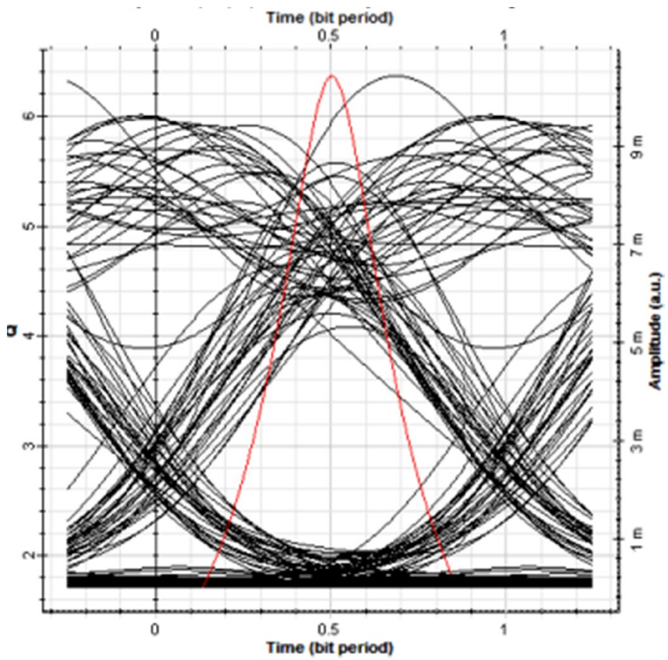


Fig.5.9 Result of 8×40Gb/s BER measurement for channel-6 (195.75 THz).

Table- 5.10

Max. Q Factor	Min. BER	Eye Height
6.36665	6.62249×10^{-11}	0.00347498

Table-5.10 Q factor, Min BER, Eye Height of channel-6.

5.5.7 Result of channel-7 (195.70 THz)

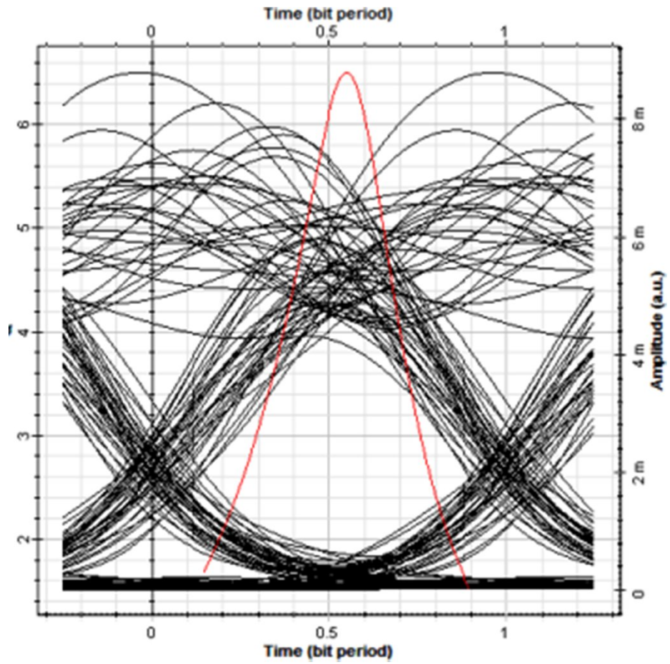


Fig.5.10 Result of 8×40Gb/s BER measurement for channel-7 (195.70 THz).

Table- 5.11

Max. Q Factor	Min. BER	Eye Height
6.50221	3.04754×10^{-11}	0.00281778

Table-5.11 Q factor, Min BER, Eye Height of channel-7.

5.5.8 Result of channel-8 (195.65 THz)

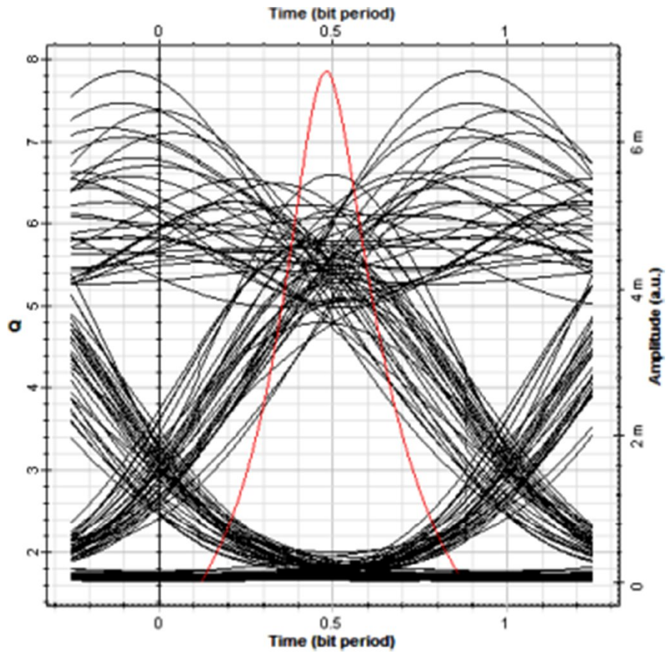


Fig.5.11 Result of 8×40Gb/s BER measurement for channel-8 (195.65 THz).

Table- 5.12

Max. Q Factor	Min. BER	Eye Height
7.84669	1.64318×10^{-15}	0.00258448

Table-5.12 Q factor, Min BER, Eye Height of channel-8.

5.6 Conclusion:

Thus our proposed system shows the excellent performance in terms of eye opening, BER and Q factor which is acceptable for the optical communication system.

CHAPTER-6
PROJECT DESIGNING BY USING CORNING SMF-28 AND STANDARD DCF

In chapter-4 we design the 8×40 Gb/s DWDM System in 1550-nm wavelength domain with channel spacing 0.4-nm in which attenuation in SMF is fixed 0.2 dB/km, dispersion is fixed for each wavelength 17 ps/nm/km and effective area vs wavelength is also fixed to 85 μm^2. In the same manner all the data type of DCF is also fixed as discussed in chapter-4.

But in this chapter we design the 8 × 40 Gb/s DWDM System in 1550-nm wavelength By using the practical fiber, SMF-28 which is used in industry and Standard DCF, we will discuss the result and simulation and compare the result in terms of eye pattern, BER and Q- factor with the result as discuss in chapter-5.

6.1 Transmission Fiber (SMF-28) Parameters

Table-6.1

Wavelength (nm)	Attenuation (dB/km)
1.5000000000E+03	1.9932963981E-01
1.5010000000E+03	1.9895943379E-01
1.5020000000E+03	1.9859530489E-01
1.5030000000E+03	1.9823727631E-01
1.5040000000E+03	1.9788537361E-01
1.5050000000E+03	1.9753962472E-01
1.5060000000E+03	1.9720005984E-01
1.5070000000E+03	1.9686671147E-01
1.5080000000E+03	1.9653961432E-01
1.5090000000E+03	1.9621880532E-01
1.5100000000E+03	1.9590432354E-01
1.5110000000E+03	1.9559621024E-01
1.5120000000E+03	1.9529450878E-01
1.5130000000E+03	1.9499926464E-01
1.5140000000E+03	1.9471052536E-01
1.5150000000E+03	1.9442834060E-01
1.5160000000E+03	1.9415276202E-01
1.5170000000E+03	1.9388384336E-01

1.5180000000E+03	1.9362164040E-01
1.5190000000E+03	1.9336621091E-01
1.5200000000E+03	1.9311761471E-01
1.5210000000E+03	1.9287591363E-01
1.5220000000E+03	1.9264117149E-01
1.5230000000E+03	1.9241345413E-01
1.5240000000E+03	1.9219282940E-01
1.5250000000E+03	1.9197936715E-01
1.5260000000E+03	1.9177313923E-01
1.5270000000E+03	1.9157421952E-01
1.5280000000E+03	1.9138268388E-01
1.5290000000E+03	1.9119861023E-01
1.5300000000E+03	1.9102207849E-01
1.5310000000E+03	1.9085317063E-01
1.5320000000E+03	1.9069197063E-01
1.5330000000E+03	1.9053856455E-01
1.5340000000E+03	1.9039304051E-01
1.5350000000E+03	1.9025548869E-01
1.5360000000E+03	1.9012600136E-01
1.5370000000E+03	1.9000467288E-01
1.5380000000E+03	1.8989159974E-01
1.5390000000E+03	1.8978688053E-01
1.5400000000E+03	1.8969061601E-01
1.5410000000E+03	1.8960290908E-01
1.5420000000E+03	1.8952386482E-01
1.5430000000E+03	1.8945359050E-01
1.5440000000E+03	1.8939219562E-01
1.5450000000E+03	1.8933979188E-01
1.5460000000E+03	1.8929649327E-01
1.5470000000E+03	1.8926241601E-01
1.5480000000E+03	1.8923767866E-01
1.5490000000E+03	1.8922240207E-01
1.5500000000E+03	1.8921670942E-01
1.5510000000E+03	1.8922072628E-01
1.5520000000E+03	1.8923458060E-01
1.5530000000E+03	1.8925840273E-01
1.5540000000E+03	1.8929232548E-01
1.5550000000E+03	1.8933648410E-01
1.5560000000E+03	1.8939101635E-01
1.5570000000E+03	1.8945606250E-01
1.5580000000E+03	1.8953176537E-01
1.5590000000E+03	1.8961827037E-01
1.5600000000E+03	1.8971572548E-01

Table-6.1 Optical fiber data SMF-28_Attenuation.

Table-6.2

Wavelength (nm)	Dispersion (ps/nm/km)
1.5000000000E+03	1.3358204341E+01
1.5010000000E+03	1.3405808633E+01
1.5020000000E+03	1.3464409064E+01
1.5030000000E+03	1.3551975772E+01
1.5040000000E+03	1.3585683096E+01
1.5050000000E+03	1.3673087521E+01
1.5060000000E+03	1.3733582096E+01
1.5070000000E+03	1.3778140114E+01
1.5080000000E+03	1.3851782860E+01
1.5090000000E+03	1.3911942161E+01
1.5100000000E+03	1.3958414401E+01
1.5110000000E+03	1.4031793145E+01
1.5120000000E+03	1.4089149306E+01
1.5130000000E+03	1.4121731804E+01
1.5140000000E+03	1.4222009696E+01
1.5150000000E+03	1.4254370894E+01
1.5160000000E+03	1.4300112917E+01
1.5170000000E+03	1.4370340980E+01
1.5180000000E+03	1.4429545510E+01
1.5190000000E+03	1.4488650832E+01
1.5200000000E+03	1.4547478786E+01
1.5210000000E+03	1.4606396988E+01
1.5220000000E+03	1.4676195802E+01
1.5230000000E+03	1.4748553910E+01
1.5240000000E+03	1.4779632474E+01
1.5250000000E+03	1.4851818627E+01
1.5260000000E+03	1.4923927411E+01
1.5270000000E+03	1.4980567331E+01
1.5280000000E+03	1.5023677068E+01
1.5290000000E+03	1.5081774384E+01
1.5300000000E+03	1.5153554199E+01
1.5310000000E+03	1.5211479676E+01
1.5320000000E+03	1.5254883566E+01
1.5330000000E+03	1.5310065671E+01
1.5340000000E+03	1.5381523208E+01
1.5350000000E+03	1.5424985779E+01
1.5360000000E+03	1.5482406238E+01
1.5370000000E+03	1.5542439045E+01
1.5380000000E+03	1.5621777807E+01
1.5390000000E+03	1.5664764345E+01
1.5400000000E+03	1.5721791439E+01
1.5410000000E+03	1.5778732802E+01
1.5420000000E+03	1.5831322911E+01
1.5430000000E+03	1.5888855053E+01
1.5440000000E+03	1.5945481150E+01

1.5450000000E+03	1.6030315046E+01
1.5460000000E+03	1.6086791195E+01
1.5470000000E+03	1.6128918858E+01
1.5480000000E+03	1.6164178943E+01
1.5490000000E+03	1.6252169975E+01
1.5500000000E+03	1.6308252899E+01
1.5510000000E+03	1.6349900425E+01
1.5520000000E+03	1.6434321433E+01
1.5530000000E+03	1.6488957090E+01
1.5540000000E+03	1.6542348028E+01
1.5550000000E+03	1.6569296095E+01
1.5560000000E+03	1.6624808321E+01
1.5570000000E+03	1.6694494776E+01
1.5580000000E+03	1.6765546445E+01
1.5590000000E+03	1.6793558395E+01
1.5600000000E+03	1.6856568374E+01

Table-6.2 Optical fiber data SMF-28_dispersion.

Table-6.3

Wavelength (nm)	Effective Area (μm^2)
1.5000000000E+03	7.2736467069E+01
1.5010000000E+03	7.2805707539E+01
1.5020000000E+03	7.2875049988E+01
1.5030000000E+03	7.2944495060E+01
1.5040000000E+03	7.3014030906E+01
1.5050000000E+03	7.3083676505E+01
1.5060000000E+03	7.3153419455E+01
1.5070000000E+03	7.3223258950E+01
1.5080000000E+03	7.3293202296E+01
1.5090000000E+03	7.3363249867E+01
1.5100000000E+03	7.3433389032E+01
1.5110000000E+03	7.3503639143E+01
1.5120000000E+03	7.3573988490E+01
1.5130000000E+03	7.3644434626E+01
1.5140000000E+03	7.3714992388E+01
1.5150000000E+03	7.3785642448E+01
1.5160000000E+03	7.3856397964E+01
1.5170000000E+03	7.3927257362E+01
1.5180000000E+03	7.3998217449E+01
1.5190000000E+03	7.4069283599E+01
1.5200000000E+03	7.4140449366E+01
1.5210000000E+03	7.4211721527E+01
1.5220000000E+03	7.4283097738E+01
1.5230000000E+03	7.4354576653E+01

1.5240000000E+03	7.4426155856E+01
1.5250000000E+03	7.4497842225E+01
1.5260000000E+03	7.4569635949E+01
1.5270000000E+03	7.4641529111E+01
1.5280000000E+03	7.4713524964E+01
1.5290000000E+03	7.4785628765E+01
1.5300000000E+03	7.4857840699E+01
1.5310000000E+03	7.4930154065E+01
1.5320000000E+03	7.5002571015E+01
1.5330000000E+03	7.5075095513E+01
1.5340000000E+03	7.5147728933E+01
1.5350000000E+03	7.5220464477E+01
1.5360000000E+03	7.5293309287E+01
1.5370000000E+03	7.5366256528E+01
1.5380000000E+03	7.5439315350E+01
1.5390000000E+03	7.5512476403E+01
1.5400000000E+03	7.5585747534E+01
1.5410000000E+03	7.5659121783E+01
1.5420000000E+03	7.5732606448E+01
1.5430000000E+03	7.5806197669E+01
1.5440000000E+03	7.5879898486E+01
1.5450000000E+03	7.5953710377E+01
1.5460000000E+03	7.6027626273E+01
1.5470000000E+03	7.6101646307E+01
1.5480000000E+03	7.6175777196E+01
1.5490000000E+03	7.6250023030E+01
1.5500000000E+03	7.6324373582E+01
1.5510000000E+03	7.6398828986E+01
1.5520000000E+03	7.6473404215E+01
1.5530000000E+03	7.6548082254E+01
1.5540000000E+03	7.6622870961E+01
1.5550000000E+03	7.6697765249E+01
1.5560000000E+03	7.6772772779E+01
1.5570000000E+03	7.6847893748E+01
1.5580000000E+03	7.6923128364E+01
1.5590000000E+03	7.6998463283E+01
1.5600000000E+03	7.7073914083E+01
1.5000000000E+03	7.2736467069E+01

Table-6.3 Optical fiber data SMF-28_effective area.

6.2 Standard DCF Parameters

Table-6.4

Wavelength (nm)	Attenuation (dB/km)
1.5000000000E+03	1.9947882043E-01
1.5010000000E+03	1.9910767168E-01
1.5020000000E+03	1.9874254315E-01
1.5030000000E+03	1.9838345679E-01
1.5040000000E+03	1.9803043690E-01
1.5050000000E+03	1.9768351012E-01
1.5060000000E+03	1.9734270537E-01
1.5070000000E+03	1.9700805380E-01
1.5080000000E+03	1.9667958879E-01
1.5090000000E+03	1.9635734589E-01
1.5100000000E+03	1.9604136281E-01
1.5110000000E+03	1.9573167936E-01
1.5120000000E+03	1.9542833747E-01
1.5130000000E+03	1.9513138117E-01
1.5140000000E+03	1.9484085651E-01
1.5150000000E+03	1.9455681161E-01
1.5160000000E+03	1.9427929662E-01
1.5170000000E+03	1.9400836371E-01
1.5180000000E+03	1.9374406704E-01
1.5190000000E+03	1.9348646279E-01
1.5200000000E+03	1.9323560910E-01
1.5210000000E+03	1.9299156612E-01
1.5220000000E+03	1.9275439597E-01
1.5230000000E+03	1.9252416274E-01
1.5240000000E+03	1.9230093251E-01
1.5250000000E+03	1.9208477331E-01
1.5260000000E+03	1.9187575516E-01
1.5270000000E+03	1.9167395007E-01
1.5280000000E+03	1.9147943199E-01
1.5290000000E+03	1.9129227690E-01
1.5300000000E+03	1.9111256274E-01
1.5310000000E+03	1.9094036946E-01
1.5320000000E+03	1.9077577901E-01
1.5330000000E+03	1.9061887535E-01
1.5340000000E+03	1.9046974447E-01
1.5350000000E+03	1.9032847439E-01
1.5360000000E+03	1.9019515518E-01
1.5370000000E+03	1.9006987895E-01
1.5380000000E+03	1.8995273991E-01
1.5390000000E+03	1.8984383433E-01
1.5400000000E+03	1.8974326059E-01
1.5410000000E+03	1.8965111918E-01
1.5420000000E+03	1.8956751272E-01

1.5430000000E+03	1.8949254599E-01
1.5440000000E+03	1.8942632593E-01
1.5450000000E+03	1.8936896166E-01
1.5460000000E+03	1.8932056451E-01
1.5470000000E+03	1.8928124804E-01
1.5480000000E+03	1.8925112805E-01
1.5490000000E+03	1.8923032260E-01
1.5500000000E+03	1.8921895206E-01
1.5510000000E+03	1.8921713909E-01
1.5520000000E+03	1.8922500870E-01
1.5530000000E+03	1.8924268825E-01
1.5540000000E+03	1.8927030750E-01
1.5550000000E+03	1.8930799860E-01
1.5560000000E+03	1.8935589615E-01
1.5570000000E+03	1.8941413721E-01
1.5580000000E+03	1.8948286132E-01
1.5590000000E+03	1.8956221056E-01
1.5600000000E+03	1.8965232952E-01

Table-6.4 Optical fiber data DCF attenuation.

Table-6.5

Wavelength (nm)	Dispersion (ps/nm/km)
1.5000000000E+03	-9.3529189890E+01
1.5010000000E+03	-9.3140934490E+01
1.5020000000E+03	-9.2932563707E+01
1.5030000000E+03	-9.2813671983E+01
1.5040000000E+03	-9.2604012735E+01
1.5050000000E+03	-9.2394280939E+01
1.5060000000E+03	-9.2122620066E+01
1.5070000000E+03	-9.1727808069E+01
1.5080000000E+03	-9.1696970759E+01
1.5090000000E+03	-9.1392283761E+01
1.5100000000E+03	-9.1087404894E+01
1.5110000000E+03	-9.0963587655E+01
1.5120000000E+03	-9.0749132336E+01
1.5130000000E+03	-9.0442601574E+01
1.5140000000E+03	-9.0134633479E+01
1.5150000000E+03	-8.9918579829E+01
1.5160000000E+03	-8.9725930667E+01
1.5170000000E+03	-8.9586830128E+01
1.5180000000E+03	-8.9275952078E+01
1.5190000000E+03	-8.9055335096E+01
1.5200000000E+03	-8.8834629155E+01
1.5210000000E+03	-8.8706956386E+01
1.5220000000E+03	-8.8299783231E+01

1.5230000000E+03	-8.8077494502E+01
1.5240000000E+03	-8.8040443760E+01
1.5250000000E+03	-8.7631375731E+01
1.5260000000E+03	-8.7368143692E+01
1.5270000000E+03	-8.7273456150E+01
1.5280000000E+03	-8.6953494894E+01
1.5290000000E+03	-8.6820535362E+01
1.5300000000E+03	-8.6593287290E+01
1.5310000000E+03	-8.6178474305E+01
1.5320000000E+03	-8.6137208172E+01
1.5330000000E+03	-8.5908371496E+01
1.5340000000E+03	-8.5491604344E+01
1.5350000000E+03	-8.5449106778E+01
1.5360000000E+03	-8.5218676069E+01
1.5370000000E+03	-8.4830810743E+01
1.5380000000E+03	-8.4640264047E+01
1.5390000000E+03	-8.4312013432E+01
1.5400000000E+03	-8.4077819998E+01
1.5410000000E+03	-8.3937862923E+01
1.5420000000E+03	-8.3703515437E+01
1.5430000000E+03	-8.3467737070E+01
1.5440000000E+03	-8.3326378094E+01
1.5450000000E+03	-8.2994530249E+01
1.5460000000E+03	-8.2757096127E+01
1.5470000000E+03	-8.2577174834E+01
1.5480000000E+03	-8.2340186780E+01
1.5490000000E+03	-8.2193240248E+01
1.5500000000E+03	-8.1952125374E+01
1.5510000000E+03	-8.1613928149E+01
1.5520000000E+03	-8.1275493973E+01
1.5530000000E+03	-8.1129642475E+01
1.5540000000E+03	-8.0789490454E+01
1.5550000000E+03	-8.0642167502E+01
1.5560000000E+03	-8.0397572216E+01
1.5570000000E+03	-8.0152854917E+01
1.5580000000E+03	-7.9981062288E+01
1.5590000000E+03	-7.9654639709E+01
1.5600000000E+03	-7.9354548132E+01

Table-6.5 Optical fiber data DCF dispersion.

Table-6.6

Wavelength (nm)	Effective Area (μm^2)
1.5000000000E+03	2.5456394550E+01
1.5010000000E+03	2.5557089151E+01
1.5020000000E+03	2.5658333632E+01
1.5030000000E+03	2.5760127787E+01
1.5040000000E+03	2.5862335183E+01
1.5050000000E+03	2.5965091196E+01
1.5060000000E+03	2.6068339331E+01
1.5070000000E+03	2.6172047950E+01
1.5080000000E+03	2.6276430910E+01
1.5090000000E+03	2.6381211261E+01
1.5100000000E+03	2.6486526801E+01
1.5110000000E+03	2.6592516536E+01
1.5120000000E+03	2.6698901563E+01
1.5130000000E+03	2.6805820591E+01
1.5140000000E+03	2.6913273179E+01
1.5150000000E+03	2.7021258919E+01
1.5160000000E+03	2.7129837633E+01
1.5170000000E+03	2.7239049266E+01
1.5180000000E+03	2.7348639063E+01
1.5190000000E+03	2.7458891390E+01
1.5200000000E+03	2.7569663364E+01
1.5210000000E+03	2.7681098014E+01
1.5220000000E+03	2.7792907916E+01
1.5230000000E+03	2.7905379933E+01
1.5240000000E+03	2.8018514381E+01
1.5250000000E+03	2.8132022013E+01
1.5260000000E+03	2.8246191490E+01
1.5270000000E+03	2.8361089756E+01
1.5280000000E+03	2.8476327933E+01
1.5290000000E+03	2.8592363651E+01
1.5300000000E+03	2.8708903326E+01
1.5310000000E+03	2.8825946282E+01
1.5320000000E+03	2.8943787651E+01
1.5330000000E+03	2.9062132026E+01
1.5340000000E+03	2.9180978683E+01
1.5350000000E+03	2.9300624588E+01
1.5360000000E+03	2.9420772496E+01
1.5370000000E+03	2.9541480190E+01
1.5380000000E+03	2.9662848848E+01
1.5390000000E+03	2.9784856634E+01
1.5400000000E+03	2.9907503628E+01
1.5410000000E+03	3.0030789872E+01
1.5420000000E+03	3.0154715427E+01
1.5430000000E+03	3.0279280369E+01
1.5440000000E+03	3.0404484730E+01
1.5450000000E+03	3.0530328580E+01
1.5460000000E+03	3.0656811944E+01

1.5470000000E+03	3.0783934897E+01
1.5480000000E+03	3.0911734244E+01
1.5490000000E+03	3.1040231912E+01
1.5500000000E+03	3.1169357720E+01
1.5510000000E+03	3.1299111619E+01
1.5520000000E+03	3.1429493634E+01
1.5530000000E+03	3.1560659783E+01
1.5540000000E+03	3.1692454564E+01
1.5550000000E+03	3.1825034546E+01
1.5560000000E+03	3.1958243690E+01
1.5570000000E+03	3.2092082010E+01
1.5580000000E+03	3.2226706868E+01
1.5590000000E+03	3.2361944717E+01
1.5600000000E+03	3.2497954424E+01

Table-6.6 Optical fiber data DCF effective area.

6.3 Eye Diagram and BER Analysis

Performance of this designed system is calculated in terms of BER, Q factor and eye opening. BER, Q factor and eye opening of all channels are given below:

6.3.1 Result of Channel-1 (196 THz)

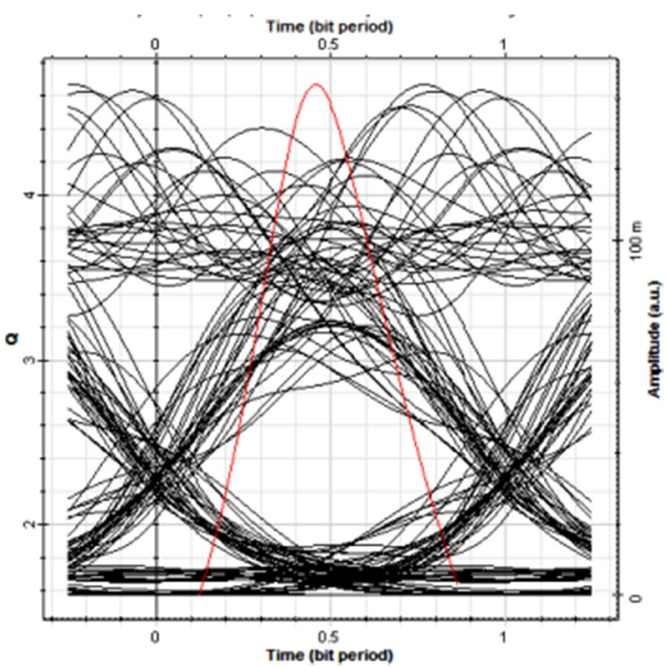


Fig.6.1 Result of 8×40Gb/s BER measurement for channel-1 (196 THz).

Table-6.7

Max. Q Factor	Min. BER	Eye Height
4.6664	1.17865×10^{-6}	0.0302897

Table-6.7 Q factor, Min BER, Eye Height of channel-1.

6.3.2 Result of Channel-2 (195.95 THz)

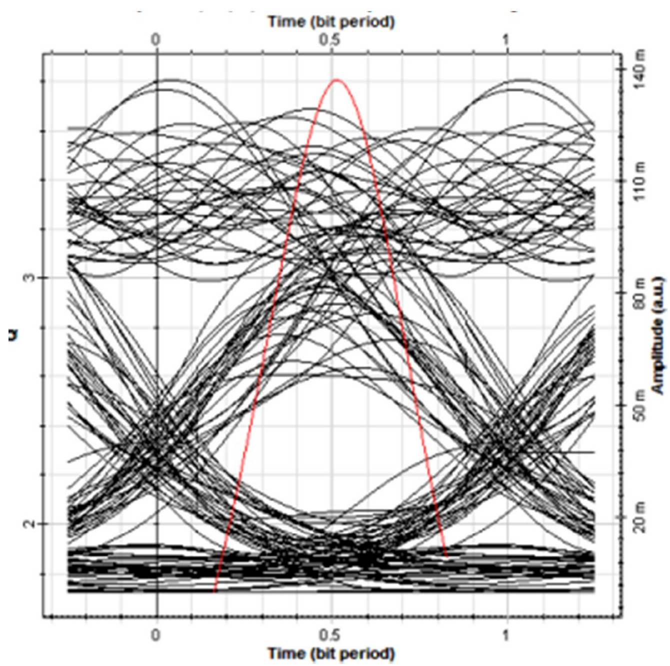


Fig.6.2 Result of 8×40Gb/s BER measurement for channel-2 (195.95 THz).

Table-6.8

Max. Q Factor	Min. BER	Eye Height
3.80599	6.05414×10^{-5}	0.0173738

Table-6.8 Q factor, Min BER, Eye Height of channel-2.

6.3.3 Result of Channel-3 (195.90 THz)

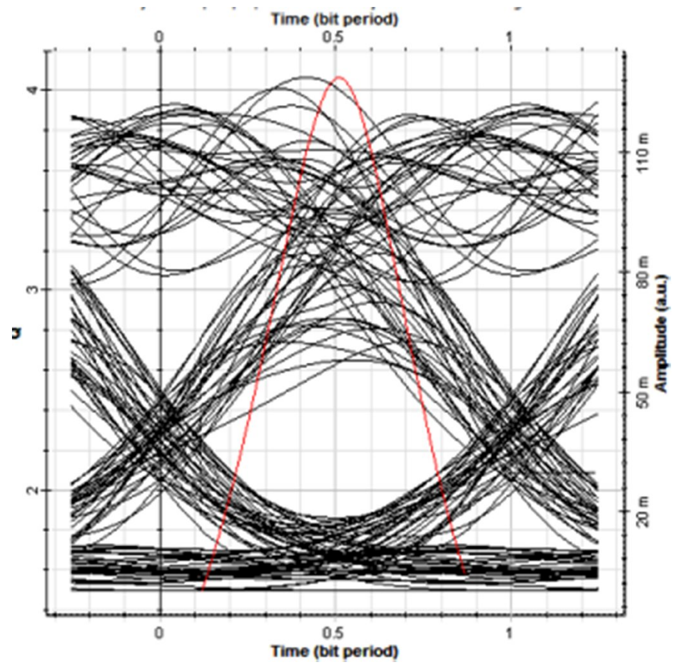


Fig.6.3 Result of 8×40Gb/s BER measurement for channel-3 (195.90 THz).

Table-6.9

Max. Q Factor	Min. BER	Eye Height
4.06476	2.03473×10^{-5}	0.021149

Table-6.9 Q factor, Min BER, Eye Height of channel-3.

6.3.4 Result of Channel-4 (195.85 THz)

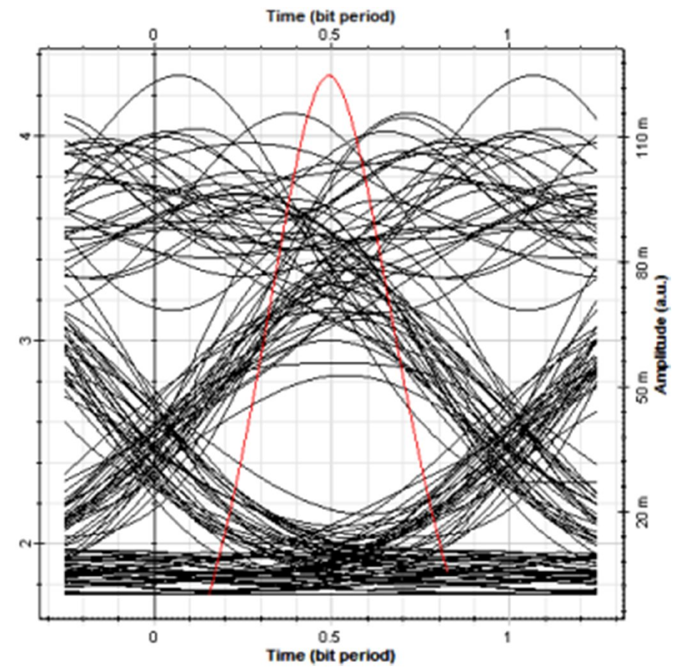


Fig.6.4 Result of 8×40Gb/s BER measurement for channel-4 (195.85 THz).

Table-6.10

Max. Q Factor	Min. BER	Eye Height
4.29797	7.58675×10^{-6}	0.0222047

Table-6.10 Q factor, Min BER, Eye Height of channel-4.

6.3.5 Result of Channel-5 (195.80 THz)

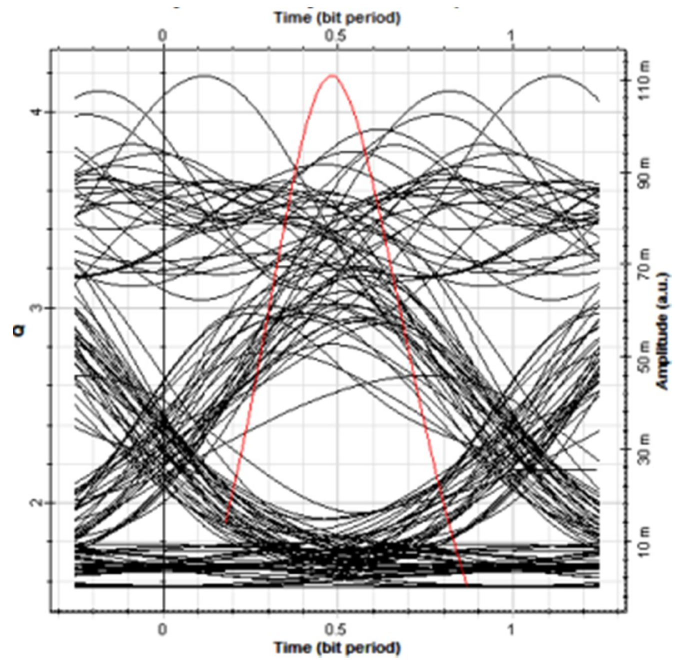


Fig.6.5 Result of 8×40Gb/s BER measurement for channel-5 (195.80 THz).

Table-6.11

Max. Q Factor	Min. BER	Eye Height
4.18652	1.17177×10^{-5}	0.0182808

Table-6.11 Q factor, Min BER, Eye Height of channel-5.

6.3.6 Result of Channel-6 (195.75 THz)

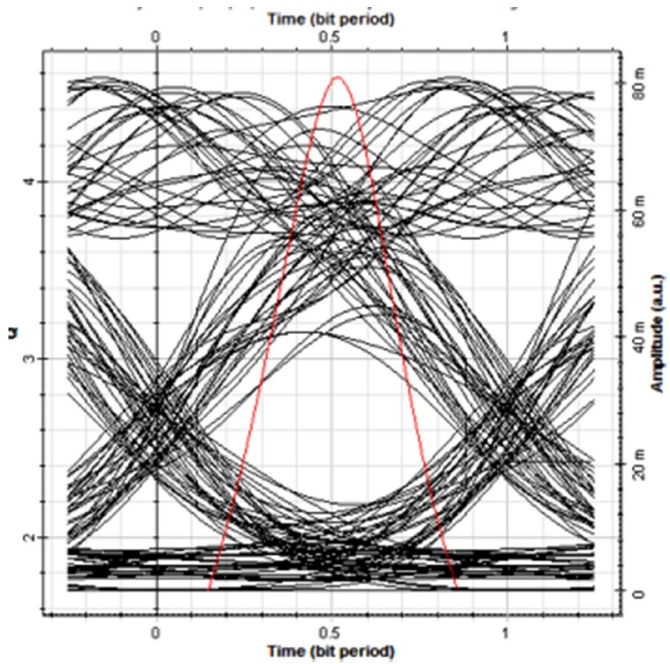


Fig.6.6 Result of 8×40Gb/s BER measurement for channel-6 (195.75 THz).

Table-6.12

Max. Q Factor	Min. BER	Eye Height
4.57969	2.08206×10^{-6}	0.0179573

Table-6.12 Q factor, Min BER, Eye Height of channel-6.

6.3.7 Result of Channel-7 (195.7 THz)

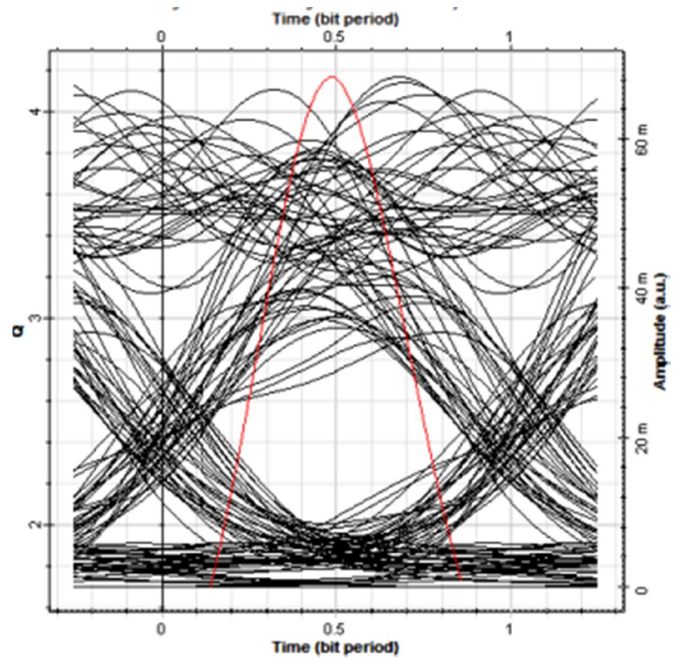


Fig.6.7 Result of 8×40Gb/s BER measurement for channel-7 (195.70 THz).

Table-6.13

Max. Q Factor	Min. BER	Eye Height
4.16977	1.26103×10^{-5}	0.0121088

Table-6.13 Q factor, Min BER, Eye Height of channel-7.

6.3.8 Result of Channel-8 (195.65 THz)

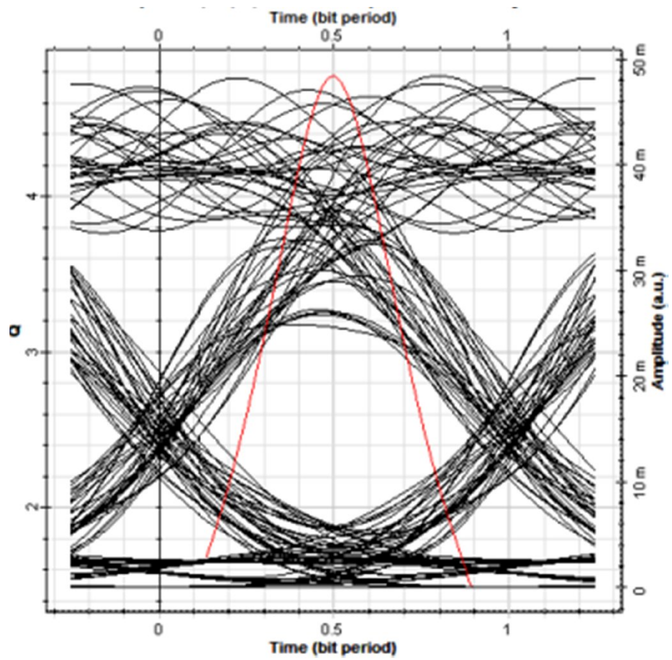


Fig.6.8 Result of 8×40Gb/s BER measurement for channel-8 (195.65 THz).

Table-6.14

Max. Q Factor	Min. BER	Eye Height
4.77647	7.69413×10^{-7}	0.0121801

Table-6.14 Q factor, Min BER, Eye Height of channel-8.

6.4 Conclusion

When we compare the result of Chapter-6 in terms of eye opening, BER, Q factor with the result of Chapter-5, we found that DWDM system with DCF technique whose all fiber parameter is shown in Chapter-4 shows the better result than the DWDM system designed in Chapter-6.

CHAPTER-7
SUMMARY AND SCOPE FOR FUTURE WORK

Thus, in this designed system, we demonstrated an ultra high capacity 8×40 Gb/s DWDM system over 90km distance in 1550-nm wavelength domain using dispersion compensation technique. The proposed system showed the excellent performance in terms of BER, Q-factor ,eye opening etc. The BER obtained from proposed system is from 1.23×10^{-11} to 2.18×10^{-15} and Q-value is from 6.6 to 7.7. The proposed system is analysed for 50GHz channel spacing which show better performance for this small channel spacing .It can also be analysed for another channel spacing like 25 GHz . This system can also be extend over a very large distance upto thousands of kilometres by increasing channel spacing upto 100 GHz, 200 GHZ .AS channel spacing is decreased and input power is increased fiber non-linearity phenomenon dominating which degrade the signal quality .By decraesing these non-linearity effect Ultra High data rate upto several Tb/s can be obtained by these proposed system.

In DWDM system how many wavelengths can be multiplexed in single mode fiber is important issue. Currently, commercial systems with 16, 40, 80, and 128 channels (wavelengths) per fiber have been announced. Those with 40 channels have channel spacing of 100 GHz, and those with 80 channels have channel spacing at 50 GHz. This channel separation determines the width of the spectral (wavelength) narrowness of each channel, or how close (in terms of wavelength) the channels are. Forty channel DWDM systems can transmit over a single fiber an aggregate bandwidth of 400 Gb/s (10 Gb/s per channel). It is estimated that at 400 Gb/s, more than 10,000 volumes of an encyclopedia can be transmitted in 1 second.

Although DWDM technology is still evolving and technologists and standards bodies are addressing many issues, systems are being offered with few tens of wavelengths in the same fiber. However, it is reasonable to assume that in the near future we will see DWDM systems with several hundred wavelengths in a single fiber. Theoretically, more than 1000 channels may be multiplexed in a fiber. DWDM technology with more than 200 wavelengths has already been demonstrated. Devices with 200 wavelengths per fiber at 40 Gb/s per wavelength with an aggregate bandwidth of 8 Tb/s per fiber are feasible. Eight Tb/s per fiber is an aggregate bandwidth that exceeds all needs today. Nevertheless, this bandwidth may become tomorrow's norm if we extrapolate from the explosion in data traffic now in progress.

REFERENCES

[1] Djafar K. mynbaev, Lowell L.Scheiner, Fiber Optic Communication Technology Pearson Education ,2003.

[2] Roger L.Freeman, Fiber-Optic Systems for Telecommunications, John Wiley & Sons, 2002.

[3] Rajiv Ramaswami, Kumar N. Sivrajan, Galen A. Sasaki, Optical Networks, 3'rd edition, Morgan Kaufmann.

[4] The IEEE Standard Dictionary of Electrical and Electronic Terms, 6th ed., IEEE, NewYork, 1996.

[5] Vivek Alwayn, CCIE No. 2995, Optical Network Design and Implementation.

[6] ITU-T, G.694.1(02/2012), Spectral grid for WDM applications: DWDM frequency grid. [Online]. Available: http:// www.itu.int/rec/T-REC-G.694.1-201202-I.

[7] Shardha Gupta, N.K.Shukla and Shikha Jaiswal,Efficient Modulation Formats for Higher Bit Rates Fiber Transmission, Int'l Conf. on Computer & Communication Technology ICCCT'10.

[8] Bijayananda Patnaik,P.K. Sahu, Ultra high capacity 1.28 Tbps DWDM system design and simulation using optimized modulation format, Optik 124 (2013) 1567–1573.

[9] Y. Malhotra, R.S. Kaler, Compensating spectral loss variations in EDFA amplifiers for different modulation formats, Optik 122 (2011) 435–439.

[10] Mohammed Sirajul Islam; Sk Md. Mizanur Rahman; Salahuddin Mohammad Masum; Sharmeen Purveen and Prof: DZ Shahida Rafique,DWDM Technology: Implemation on a Unidirectional System Throught Algorithmic Apporach, 0-7803-7840-7/2003 IEEE.

[11] G. P. Agrawal, Nonlinear Fiber Optics. New York: Academic, 1989.

[12] Chaloemphon Lorattanasane and Kazuro Kikuchi, Design Theory of Long-Distance Optical Transmission Systems Using Midway Optical Phase Conjugation, JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 15, NO. 6, JUNE 1997.

[13] K. Kikuchi and C. Lorattanasane, "Design of highly efficient four-wave mixing devices using optical fibers," IEEE Photon. Technol. Lett., vol.6, pp. 992–994, 1994.

[14] K. Kikuchi, C. Lorattanasane, and K. Saito, “Phase-conjugation characteristics of semiconductor optical amplifiers,” in Proc. European Conf. Opt. Commun. (ECOC’96), Oslo, Norway, Sept. 15–19, 1996, paper WeP.15.

[15] A.R. Chraplyvy, A.H. Gnauck, R.W. Tkach, R.M. Derosier, IEEE Photonics Technology Letters 5 (1993) 1233.

[16] K.O. Hill, D.C. Johnson, B.S. Kawasaki, R.I. MacDonald, Journal of Applied, Physics 49 (10) (1978) 5098.

[17] Amarpal Singh, Ajay K. Sharma , T.S. Kamal, Investigation on modified FWM suppression methods in DWDM optical communication system, Optics Communications 282 (2009) 392–395.

[18] Bijayananda Patnaika, P.K. Sahub, Ultra high capacity 1.28 Tbps DWDM system design and simulation using optimized modulation format, Optik 124 (2013) 1567– 1573.

[19] Simranjit Singh, R.S. Kaler, Performance evaluation of 64×10 Gbps and 96×10 Gbps DWDM system with hybrid optical amplifier for different modulation formats, Optik 123 (2012) 2199– 2203.

[20] Bijayananda Patnaika, P.K. Sahub, Ultra high capacity 1.28 Tbps DWDM system design and simulation using optimized modulation format, Optik 124 (2013) 1567– 1573.

[21] P. Nouchi, Maximum effective area for non-zero dispersion-shifted fiber,OFC '98 Technical Digest, Alcatel Cable France, 53 rue Jean Broutin, 78 700 Conflans Saint Honorine.

[22] Guide to WDM Technology Testing, 2nd ed., EXFO Electro-Optical Engineering, Inc., Quebec City, Canada, 2000.

[23] S. Pazi, C. Chatwin, R. Young, P. Birch, W. Wang, Performance of Tanzanian optical DWDM system, Eur. J. Sci. Res. 36 (4) (2009) 606–626.

[24] D. Dahan, G. Eisensteinb, Numerical comparison between distributed and discrete amplification in a point-to-point 40-Gb/s 40-WDM-based transmission system with three different modulation formats, J. Lightwave Technol. 20 (3) (2002) 379–388.