Chapter 1

INTRODUCTION

1.1 Historical development

The use of visible optical carrier waves or light for communication has been common for many years. Simple systems such as signal fires, reflecting mirrors and, more recently, signaling lamps have provided successful, if limited, information transfer. Moreover, as early as 1880 Alexander Graham Bell reported the transmission of speech using a light beam . The photophone proposed by Bell just four years after the invention of the telephone modulated sunlight with a diaphragm giving speech transmission over a distance of 200 m. However, although some investigation of optical communication continued in the early part of the twentieth century its use was limited to mobile, low-capacity communication links. This was due to both the lack of suitable light sources and the problem that light transmission in the atmosphere is restricted to line of sight and is severely affected by disturbances such as rain, snow, fog, dust and atmospheric turbulence. Nevertheless lower frequency and hence longer wavelength electromagnetic waves* (i.e. radio and microwave) proved suitable carriers for information transfer in the atmosphere, being far less affected by these atmospheric conditions. Depending on their wave-lengths, these electromagnetic carriers can be transmitted over considerable distances but are limited in the amount of information they can convey by their frequencies (i.e. the information-carrying capacity is directly related to the bandwidth or frequency extent of the modulated carrier, which is generally limited to a fixed fraction of the carrier frequency). In theory, the greater the carrier frequency, the larger the available transmission bandwidth and thus the information carrying capacity of the communication system. For this reason radio communication was developed to higher frequencies (i.e. VHF and UHF) leading to the introduction of the even higher frequency microwave and, latterly, millimeter wave transmission. The relative frequencies and wavelengths of these types of electro-magnetic wave can be observed from the electromagnetic spectrum shown in Figure 1.1. In this context it may also be noted that communication at optical frequencies offers an increase in the potential usable bandwidth by a factor of around 104 over high-frequency microwave transmission. An additional benefit of the use of high carrier frequencies is the general ability of the communication system to concentrate the available power within the transmitted electromagnetic wave, thus giving an improved system performance .

A renewed interest in optical communication was stimulated in the early 1960s with the invention of the laser . This device provided a powerful coherent light source, together with the possibility of modulation at high frequency. In addition the low beam divergence of the laser made enhanced free space optical transmission a practical possibility. However, the previously mentioned constraints of light transmission in the atmosphere tended to restrict these systems to short-distance applications. Nevertheless, despite the problems some modest free space optical communication links have been implemented for applications such as the linking of a television camera to a base vehicle and for data links of a few hundred meters between buildings. There is also some interest in optical communication between satellites in outer space using similar techniques.

Although the use of the laser for free space optical communication proved somewhat limited, the invention of the laser instigated a tremendous research effort into the study of optical components to achieve reliable information transfer using a lightwave carrier. The proposals for optical communication via dielectric waveguides or optical fibers fabricated from glass to avoid degradation of the optical signal by the atmosphere were made almost simultaneously in 1966 by Kao and Hockham and Werts . Such systems were viewed as a replacement for coaxial cable or carrier transmission systems. Initially the optical fibers exhibited very high attenuation (i.e. 1000 dB km−1) and were therefore not comparable with the coaxial cables they were to replace (i.e. 5 to 10 dB km−1). There were also serious problems involved in jointing the fiber cables in a satisfactory manner to achieve low loss and to enable the process to be performed relatively easily and repeatedly in the field. Nevertheless, within the space of 10 years optical fiber losses were reduced to below 5 dB km−1 and suitable low-loss jointing techniques were perfected.

In parallel with the development of the fiber waveguide, attention was also focused on the other optical components which would constitute the optical fiber communication system. Since optical frequencies are accompanied by extremely small wavelengths, the development of all these optical components essentially required a new technology. Thus semiconductor optical sources (i.e. injection lasers and light-emitting diodes) and detectors (i.e. photodiodes and to a lesser extent phototransistors) compatible in size with optical fibers were designed and fabricated to enable successful implementation of the optical fiber system. Initially the semiconductor lasers exhibited very short lifetimes of at best a few hours, but significant advances in the device structure enabled lifetimes greater than 1000 h and 7000 h to be obtained by 1973 and 1977 respectively. These devices were originally fabricated from alloys of gallium arsenide (AlGaAs) which emit-ted in the near infrared between 0.8 and 0.9 μm.

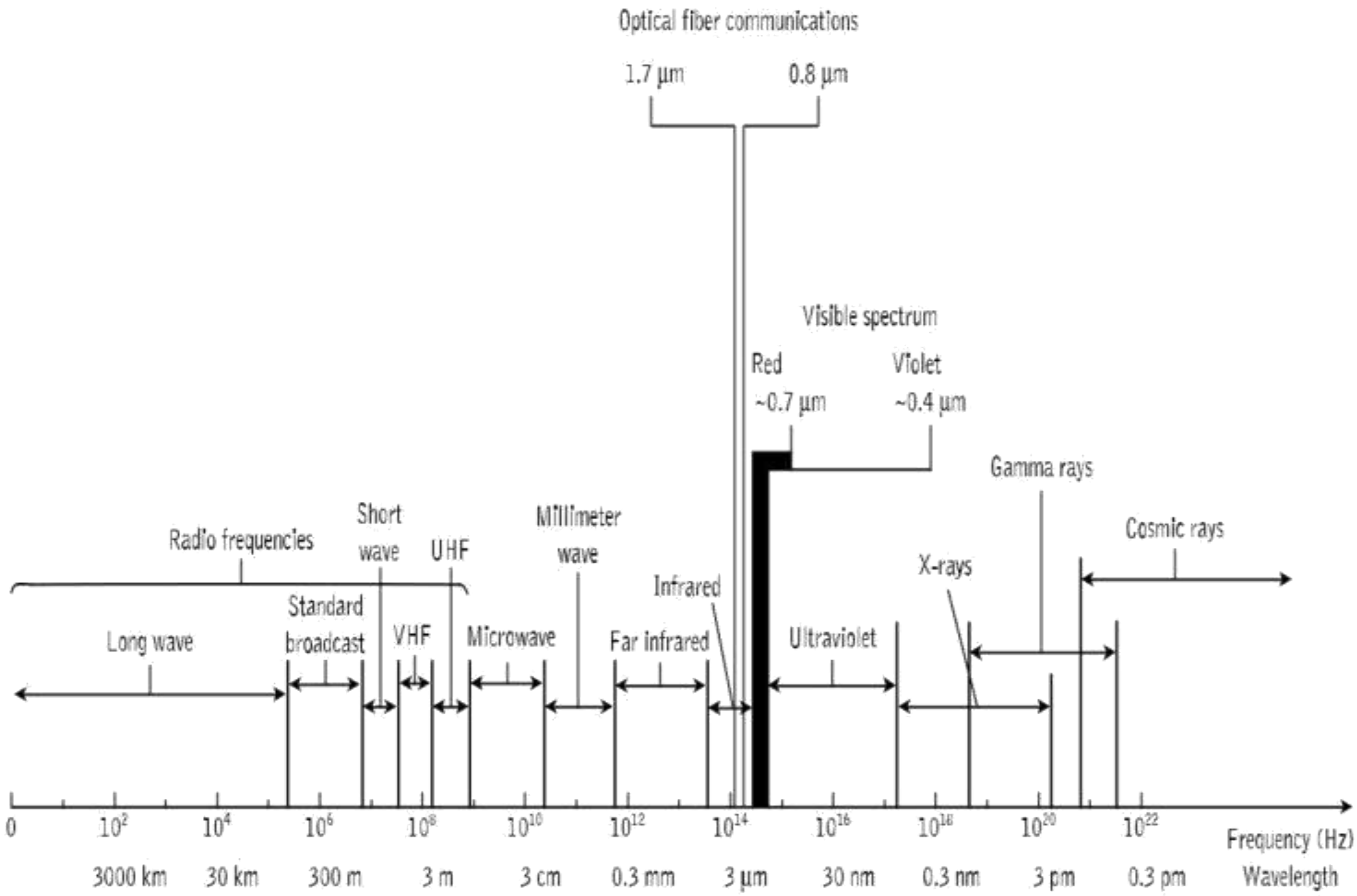


Figure 1.1 The electromagnetic spectrum showing the region used for optical fiber communications.

1.2. The general system

An optical fiber communication system is similar in basic concept to any type of communication system. A block schematic of a general communication system is shown in Figure 1.2(a), the function of which is to convey the signal from the information source over the transmission medium to the destination. The communication system therefore consists of a transmitter or modulator linked to the information source, the transmission medium, and a receiver or demodulator at the destination point. In electrical communications the information source provides an electrical signal, usually derived from a message signal which is not electrical (e.g. sound), to a transmitter comprising electrical and electronic components which converts the signal into a suitable form for propagation over the trans-mission medium. This is often achieved by modulating a carrier, which, as mentioned previously, may be an electromagnetic wave. The transmission medium can consist of a pair of wires, a coaxial cable or a radio link through free space down which the signal is trans-mitted to the receiver, where it is transformed into the original electrical information signal (demodulated) before being passed to the destination. However, it must be noted that in any transmission medium the signal is attenuated, or suffers loss, and is subject to degradations due to contamination by random signals and noise, as well as possible distortions imposed by mechanisms within the medium itself. Therefore, in any communication system there is a maximum permitted distance between the transmitter and the receiver beyond which the system effectively ceases to give intelligible communication. For long-haul applications these factors necessitate the installation of repeaters or line amplifiers at intervals, both to remove signal distortion and to increase signal level before transmission is continued down the link.

For optical fiber communications the system shown in Figure 1.2(a) may be considered in slightly greater detail, as given in Figure 1.2(b). In this case the information source pro-vides an electrical signal to a transmitter comprising an electrical stage which drives an optical source to give modulation of the lightwave carrier. The optical source which pro-vides the electrical–optical conversion may be either a semiconductor laser or light-emitting diode (LED). The transmission medium consists of an optical fiber cable and the receiver consists of an optical detector which drives a further electrical stage and hence provides demodulation of the optical carrier. Photodiodes (p–n, p–i–n or avalanche) and, in some instances, phototransistors and photoconductors are utilized for the detection of the optical signal and the optical electrical conversion. Thus there is a requirement for electrical interfacing at either end of the optical link and at present the signal processing is usually performed electrically.*

The optical carrier may be modulated using either an analog or digital information signal. In the system shown in Figure 1.2(b) analog modulation involves the variation of the light emitted from the optical source in a continuous manner. With digital modulation, however, discrete changes in the light intensity are obtained (i.e. on–off pulses). Although often simpler to implement, analog modulation with an optical fiber communication sys-tem is less efficient, requiring a far higher signal-to-noise ratio at the receiver than digital modulation. Also, the linearity needed for analog modulation is not always provided by semiconductor optical sources, especially at high modulation frequencies. For these reasons, analog optical fiber communication links are generally limited to shorter distances and lower bandwidth operation than digital links.

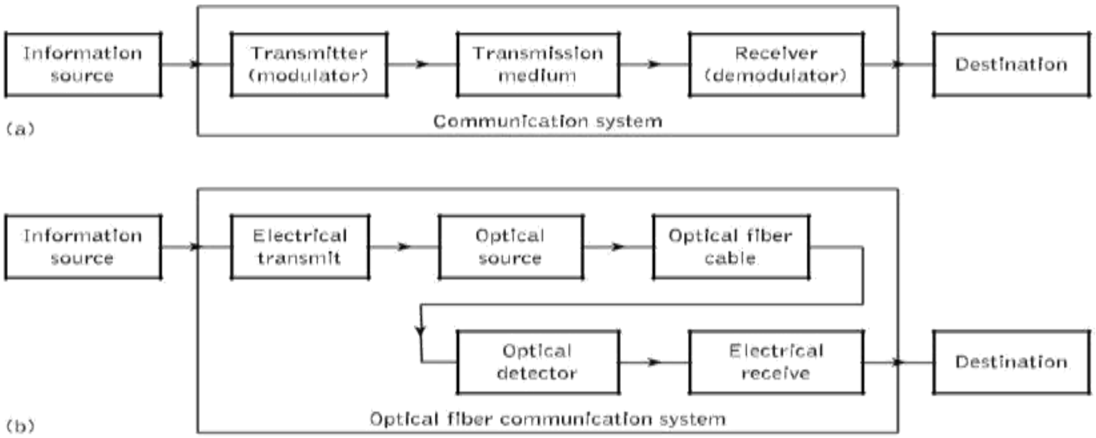


Figure 1.2 (a) The general communication system. (b) The optical fiber communication system.

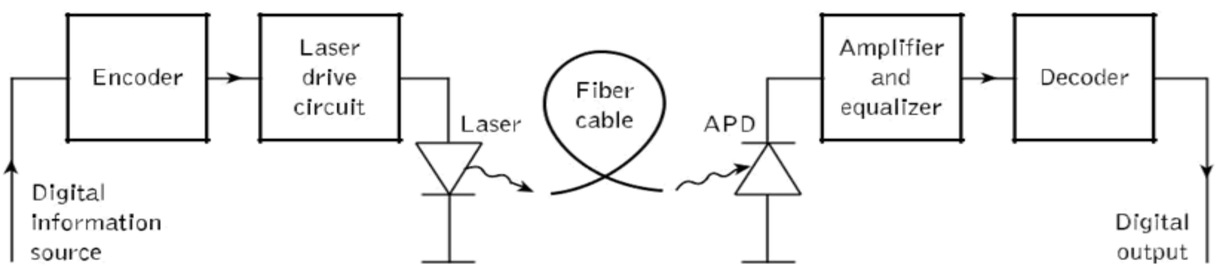


Figure 1.3 A digital optical fiber link using a semiconductor laser source and an avalanche photodiode (APD) detector.

Figure 1.3 shows a block schematic of a typical digital optical fiber link. Initially, the input digital signal from the information source is suitably encoded for optical transmission. The laser drive circuit directly modulates the intensity of the semiconductor laser with the encoded digital signal. Hence a digital optical signal is launched into the optical fiber cable. The avalanche photodiode (APD) detector is followed by a front-end amplifier and equalizer or filter to provide gain as well as linear signal processing and noise band-width reduction. Finally, the signal obtained is decoded to give the original digital information. The various elements of this and alternative optical fiber system configurations are discussed in detail in the following chapters. However, at this stage it is instructive to consider the advantages provided by light wave communication via optical fibers in com parison with other forms of line and radio communication which have brought about the extensive use of such systems in many areas throughout the world.

1.3 Advantages of optical fiber communication

Communication using an optical carrier wave guided along a glass fiber has a number of extremely attractive features, several of which were apparent when the technique was originally conceived. Furthermore, the advances in the technology to date have surpassed even the most optimistic predictions, creating additional advantages. Hence it is useful to consider the merits and special features offered by optical fiber communications over more conventional electrical communications. In this context we commence with the originally foreseen advantages and then consider additional features which have become apparent as the technology has been developed.

(a) **Enormous potential bandwidth-** The optical carrier frequency in the range 1013 to 1016 Hz (generally in the near infrared around 1014 Hz or 105 GHz) yields a far greater potential transmission bandwidth than metallic cable systems (i.e. coaxial cable bandwidth typically around 20 MHz over distances up to a maximum of 10 km) or even millimeter wave radio systems (i.e. systems currently operating with modulation bandwidths of 700 MHz over a few hundreds of meters). Indeed, by the year 2000 the typical bandwidth multiplied by length product for an optical fiber link incorporating fiber amplifiers (see Section 10.4) was 5000 GHz km in comparison with the typical bandwidth length product for coaxial cable of around 100 MHz km. Hence at this time optical fiber was already demonstrating a factor of 50000 bandwidth improvement over coaxial cable while also providing this superior information-carrying capacity over much longer transmission distances .

(b) **Small size and weight-** Optical fibers have very small diameters which are often no greater than the diameter of a human hair. Hence, even when such fibers are covered with protective coatings they are far smaller and much lighter than corresponding copper cables. This is a tremendous boon towards the alleviation of duct congestion in cities, as well as allowing for an expansion of signal transmission within mobiles such as aircraft, satellites and even ships.

(c) **Electrical isolation-** Optical fibers which are fabricated from glass, or sometimes a plastic polymer, are electrical insulators and therefore, unlike their metallic counterparts, they do not exhibit earth loop and interface problems. Furthermore, this property makes optical fiber transmission ideally suited for communication in electrically hazardous environments as the fibers create no arcing or spark hazard at abrasions or short circuits.

(d) **Immunity to interference and crosstalk-** Optical fibers form a dielectric waveguide and are therefore free from electromagnetic interference (EMI), radio-frequency interference (RFI), or switching transients giving electromagnetic pulses (EMPs). Hence the operation of an optical fiber communication system is unaffected by transmission through an electrically noisy environment and the fiber cable requires no shielding from EMI. The fiber cable is also not susceptible to lightning strikes if used overhead rather than under-ground. Moreover, it is fairly easy to ensure that there is no optical interference between fibers and hence, unlike communication using electrical conductors, crosstalk is negligible, even when many fibers are cabled together.

(e) **Signal security-** The light from optical fibers does not radiate significantly and there-fore they provide a high degree of signal security. Unlike the situation with copper cables, a transmitted optical signal cannot be obtained from a fiber in a noninvasive manner (i.e. without drawing optical power from the fiber). Therefore, in theory, any attempt to acquire a message signal transmitted optically may be detected. This feature is obviously attractive for military, banking and general data transmission (i.e. computer network) applications.

(f) **Low transmission loss-** The development of optical fibers over the last 20 years has resulted in the production of optical fiber cables which exhibit very low attenuation or transmission loss in comparison with the best copper conductors. Fibers have been fabricated with losses as low as 0.15 dB km−1 and this feature has become a major advantage of optical fiber communications. It facilitates the implementation of communication links with extremely wide optical repeater or amplifier spacings, thus reducing both system cost and complexity. Together with the already proven modulation bandwidth capability of fiber cables, this property has provided a totally compelling case for the adoption of optical fiber communications in the majority of long-haul telecommunication applications, replacing not only copper cables, but also satellite communications, as a consequence of the very noticeable delay incurred for voice transmission when using this latter approach.

(g) **Ruggedness and flexibility-** Although protective coatings are essential, optical fibers may be manufactured with very high tensile strengths (see Section 4.6). Perhaps surprisingly for a glassy substance, the fibers may also be bent to quite small radii or twisted without damage. Furthermore, cable structures have been developed (see Section 4.8.4) which have proved flexible, compact and extremely rugged. Taking the size and weight advantage into account, these optical fiber cables are generally superior in terms of storage, transportation, handling and installation to corresponding copper cables, while exhibiting at least comparable strength and durability.

(h) **System reliability and ease of maintenance-** These features primarily stem from the low-loss property of optical fiber cables which reduces the requirement for intermediate repeaters or line amplifiers to boost the transmitted signal strength. Hence with fewer optical repeaters or amplifiers, system reliability is generally enhanced in comparison with conventional electrical conductor systems. Furthermore, the reliability of the optical components is no longer a problem with predicted lifetimes of 20 to 30 years being quite common. Both these factors also tend to reduce maintenance time and costs.

(i) **Potential low cost-** The glass which generally provides the optical fiber transmission medium is made from sand – not a scarce resource. So, in comparison with copper con-ductors, optical fibers offer the potential for low-cost line communication. Although over recent years this potential has largely been realized in the costs of the optical fiber trans-mission medium which for bulk purchases has become competitive with copper wires (i.e. twisted pairs), it has not yet been achieved in all the other component areas associated with optical fiber communications. For example, the costs of high-performance semi-conductor lasers and detector photodiodes are still relatively high, as well as some of those concerned with the connection technology (demountable connectors, couplers, etc.).

Chapter 2

Optical fibers and cables

2.1 Introduction

we have yet to discuss the practical considerations and problems associated with the production, application and installation of optical fibers within a line transmission system. These factors are of paramount importance if optical fiber communication systems are to be considered as viable replacements for conventional metallic line communication systems. Optical fiber communication is of little use if the many advantages of optical fiber transmission lines outlined in the preceding chapters may not be applied in practice in the telecommunications network without severe degradation of the lines' performance.

It is therefore essential that:

Optical fibers may be produced with good stable transmission characteristics in long lengths at a minimum cost and with maximum reproducibility.

A range of optical fiber types with regard to size, refractive indices and index profiles, operating wavelengths, materials, etc., be available in order to fulfill many different system applications.

The fibers may be converted into practical cables which can be handled in a similar manner to conventional electrical transmission cables without problems associated with the degradation of their characteristics or damage.

The fibers and fiber cables may be terminated and connected together (jointed) without excessive practical difficulties and in ways which limit the effect of this process on the fiber transmission characteristics to keep them within acceptable operating levels. It is important that these jointing techniques may be applied with ease in the field locations where cable connection takes place.

2.2 Optical fibers

In order to plan the use of optical fibers in a variety of line communication applications it is necessary to consider the various optical fibers currently available. The following is a summary of the dominant optical fiber types with an indication of their general characteristics. The performance characteristics of the various fiber types discussed vary consider-ably depending upon the materials used in the fabrication process and the preparation technique involved. The values quoted are based upon both manufacturers’ and suppliers’ data, and practical descriptions for commercially available fibers, presented in a general form rather than for specific fibers. Hence in some cases the fibers may appear to have somewhat poorer performance characteristics than those stated for the equivalent fiber types produced by the best possible techniques and in the best possible conditions which were indicated . It is interesting to note, however, that although the high-performance values quoted in were generally for fibers produced and tested in the laboratory, the performance characteristics of commercially available fibers in many cases are now quite close to these values. This factor is indicative of the improvements made over recent years in the fiber materials preparation and fabrication technologies.

This section therefore reflects the maturity of the technology associated with the production of both multicomponent and silica glass fibers, and also plastic optical fibers. In particular, a variety of high-performance silica-based single-mode fibers for operation over the 1.260 to 1.625 μm wavelength range (O to L spectral bands; see Section 3.3.2) are now widely commercially available. A number of these fibers have found substantial application within the telecommunications network while the more specialized polarization-maintaining fibers are also commercially available, but do not at present find widespread application, and therefore these fibers are not dealt with in this section. Moreover, fibers developed for both mid- and far-infrared transmission can also be obtained commercially but they continue to exhibit limitations in relation to relatively high losses and low strength (see Section 3.7) which negates their consideration in this section.

Finally, it should be noted that the bandwidths quoted are specified over a 1 km length of fiber (i.e. Bopt × L). These are generally obtained from manufacturers' data which does not always indicate whether the electrical or the optical bandwidth has been measured. It is likely that these are in fact optical bandwidths which are significantly greater than their electrical equivalents .

2.2.1 Multimode step index fibers

Multimode step index fibers may be fabricated from either multicomponent glass com-pounds or doped silica. These fibers can have reasonably large core diameters and large numerical apertures to facilitate efficient coupling to incoherent light sources such as LEDs. The performance characteristics of this fiber type may vary considerably depending on the materials used and the method of preparation; the doped silica fibers exhibit the best performance. Multicomponent glass and doped silica fibers are often referred to as multi-component glass/glass (glass-clad glass) and silica/silica (silica-clad silica), respectively, although the glass-clad glass terminology is sometimes used somewhat vaguely to denote both types. A typical structure for a glass multimode step index fiber is shown in bellow fig .

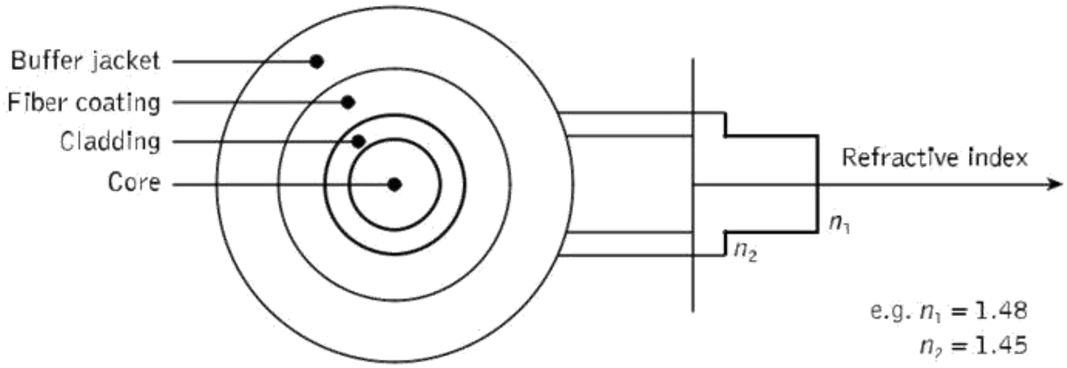


Figure 2.1. Typical structure for a glass multimode step index fiber.

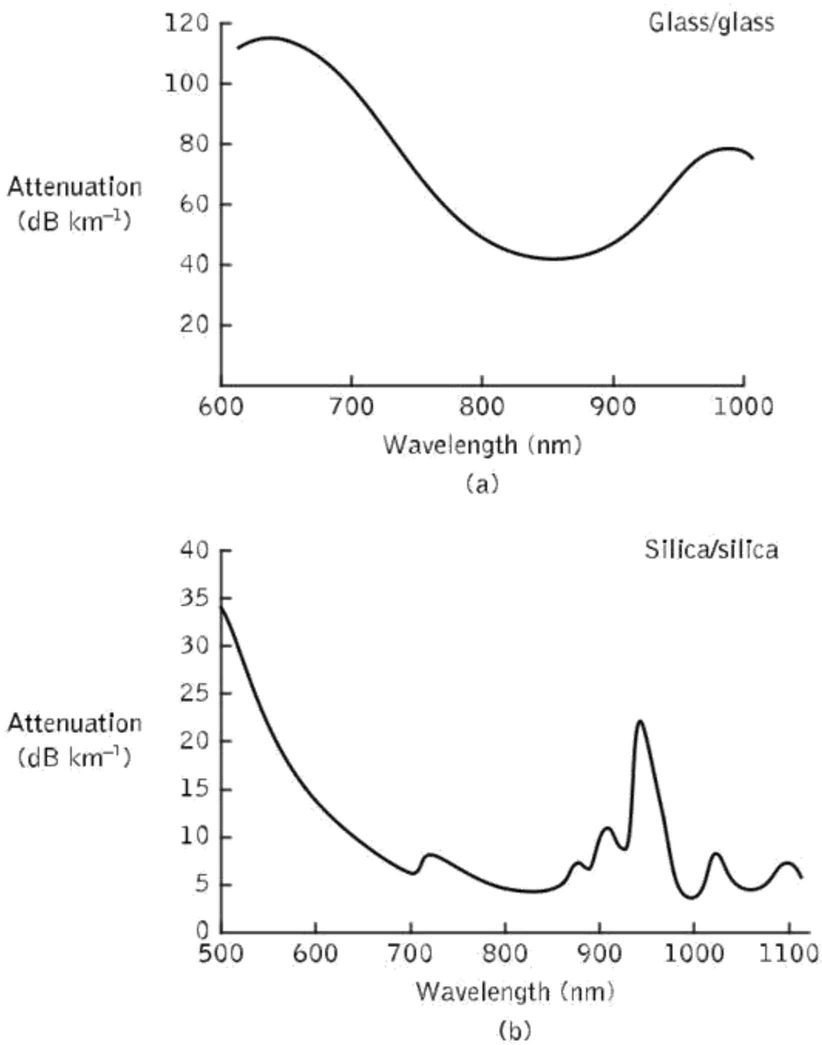


Figure 2.2. Attenuation spectra for multimode step index fibers: (a) multicomponent glass fiber; (b) doped silica fiber.

Table 1. Structure of multimode step index fiber

Structure	
Core diameter:	100 to 300 μm
Cladding diameter:	140 to 400 μm
Buffer jacket diameter	400 to 1000 μm
Numerical aperture :	0.16 to 0.5

2.2.2 Single-mode fibers

Single-mode fibers can have either a step index or graded index profile. The benefits of using a graded index profile are to provide dispersion-modified single-mode fibers . The more sophisticated single-mode fiber structures used to produce polarization-maintaining fibers make these fibers quite expensive at present and thus they are not generally utilized within optical fiber communication systems. Therefore currently commercially available single-mode fibers are designed to conform with the appropriate ITU-T recommendations, being fabricated from doped silica (silica-clad silica) to produce high-quality, both medium- and long-haul, wideband transmission fibers suit-able for the full range of telecommunication applications.

Although single-mode fibers have small core diameters to allow single-mode propagation, the cladding diameter must be at least 10 times the core diameter to avoid losses from the evanescent field. Hence with a coating and buffer jacket to provide protection and strength, single-mode fibers have similar overall diameters to multimode fibers.

2.2.2.1 Standard single-mode fiber

A typical example of the standard single-mode fiber (SSMF) which usually comprises a step index profile and is specified in the ITU-T Recommendation G.652.A is shown in Figure . Such fiber is also referred to as nondispersion shifted as it has a zero-dispersion wavelength at 1.31 μm and is therefore particularly suited to single-wavelength transmission in the O-band. Although SSMF can be utilized for operation at a wavelength of 1.55 μm, it is not optimized for operation in the C- and L-bands where it exhibits high dispersion in the range 16 to 20 ps nm−1 km−1. A commercially available example of this fiber type is the Corning SMF-28.

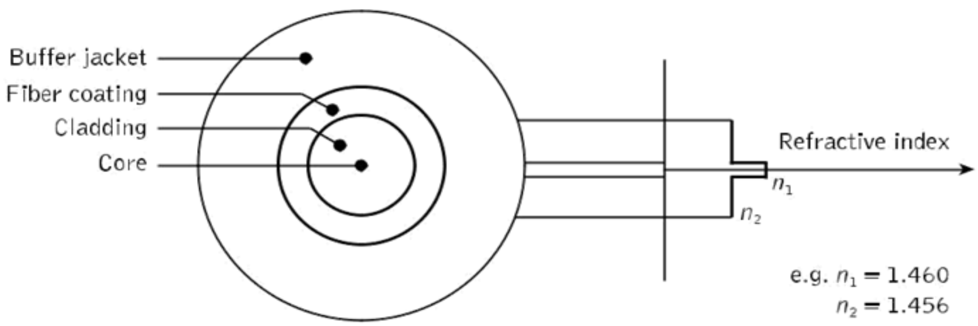


Figure 4.14 Typical structure for a standard single-mode step index fiber.

Table 2. Structure of standard single-~~mode step in~~dex fiber.

Mode-field diameter	7 to 11 μm ,
Lading diameter	Generally 125 μm
Coating diameter	200 to 300 μm
Buffer jacket diameter	500 to 1000 μm
Numerical aperture	0.08 to 0.15

Chapter 3

Wavelength Division Multiplexing

3.Introduction

In this digital era, the communication demand has increased from previous eras due to introduction of new communication techniques. As we can see there is increase in client's day by day, so we need huge bandwidth and high speed networks to deliver good quality of service to clients. Fiber optics communication is one of the major communication systems in modern era, which meets up the above challenges. This utilizes different types of multiplexing techniques to maintain good quality of service without traffic, less complicated instruments with good utilization of available resources. Wavelength Division Multiplexing (WDM) is one of them with good efficiency. It is based on dynamic light-path allocation. Here we have to take into consideration the physical topology of the WDM network and the traffic. We have taken performance analysis as parameter to analyse which type of topology is best suited to implement in real life application without degrading quality of service (QoS).

3.1. Wavelength Division Multiplexing (WDM)

In optical communication, wavelength division multiplexing (WDM) is a technology which carries a number of optical carrier signals on a single fiber by using different wavelengths of laser light. This allows bidirectional communication over one standard fiber with in increased capacity. As optical network supports huge bandwidth; WDM network splits this into a number of small bandwidths optical channels. It allows multiple data stream to be transferred along a same fiber at the same time. A WDM system uses a number of multiplexers at the transmitter end, which multiplexes more than one optical signal onto a single fiber and demultiplexers at the receiver to split them apart. Generally, the transmitter consists of a laser and modulator. The light source generates an optical carrier signal at either fixed or a tuneable wavelength. The receiver consists of photodiode detector which converts an optical signal to electrical signal. This new technology allows engineers to increase the capacity of network without laying more fibre. It has more security compared to other types of communication from tapping and also immune to crosstalk

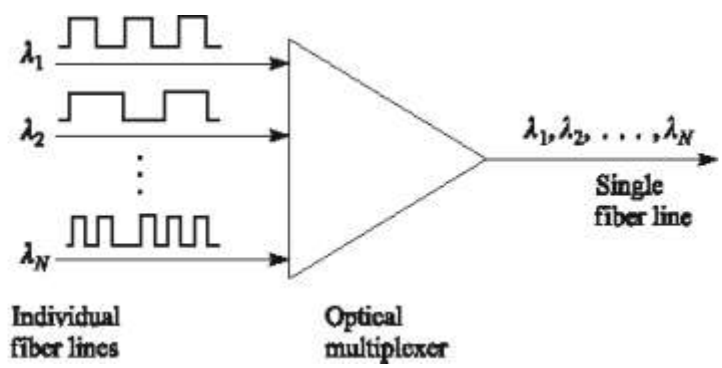


Fig 3.1. **Wavelength Division Multiplexing**

3.2. Different types WDM network

The optical network has huge bandwidth and capacity can be as high as 1000 times the entire RF spectrum. But this is not the case due to attenuation of signals, which is a function of its wavelength and some other fibre limitation factor like imperfection and refractive index fluctuation. So 1300nm (0.32dB/km)-1550nm (0.2dB/km) window with low attenuation is generally used.

According to different wavelength pattern there are 3 existing types as:-

- WDM (Wavelength Channel Multiplexing)
- CWDM (Coarse Wavelength Division Multiplexing)
- DWDM (Dense Wavelength Division Multiplexing)

Table 3. Types of WDM Networks

Parameters	**WDM**	**CWDM**	**DWDM**
Channel Spacing	1310nm & 1550nm	Large,1.6nm-25nm	Small,1.6nm or Less
No of base bands Used	C(1521-1560 nm)	S(1480-1520 nm)C(1521-1560 nm),L(1561-1620 nm)	C(1521-1560 nm),L(1561-1620 nm)
Cost per Channel	Low	Low	High
No of Channels Delivered	2	17-18 most	hundreds of channel possible
Best application	PON	Short haul, Metro	Long Haul

3.3. Benefits of WDM

Wavelength Channel Multiplexing (WDM) is important technology used in today's telecommunication systems. It has better features than other types of communication with client satisfaction. It has several benefits that make famous among clients such as:

3.3.1. Capacity Upgrade

Communication using optical fibre provides very large bandwidth. Here the carrier for the data stream is light. Generally a single light beam is used as the carries. But in WDM, lights having different wavelengths are multiplexed into a single optical fibre. So in the same fibre now more data is transmitted. This increases the capacity of the network considerably.

3.3.2. Transparency

WDM networks supports data to be transmitted at different bit rates. It also supports a number of protocols. So there is not much constraint in how we want to send the data. So it can be used for various very high speed data transmission applications.

3.3.3. Wavelength Reuse

WDM networks allows for wavelength routing. So in different fibre links the same wavelength can be used again and again. This allows for wavelength reuse which in turn helps in increasing capacity.

3.3.4. Scalability

WDM networks are also very flexible in nature. As per requirement we can make changes to the network. Extra processing units can be added to both transmitter and receiver ends. By this infrastructure can redevelop to serve more number of people.

3.3.5. Reliability

WDM networks are extremely reliable and secure. Here chance of trapping the data and crosstalk is very low. It also can recover from network failure in a very efficient manner. There is provision for rerouting a path between a source-destination node pair. So in case of link failure we will not lose any data .

3.4. QoS in WDM Network

Quality of Service (QoS) parameters refers to certain parameters which are used to determine performance of a WDM network. To determine QoS first all the possible light paths are found out. Then a number of measurements are performed on these light paths using simulation software, whose results are called performance matrices. From these performance matrices QoS is determined.

Few QoS parameters are Delay, Network Congestion, and Single Hop Traffic/Offered Traffic. For better performance, delay should be low, Network Congestion should be less and Single Hop Traffic/Offered Traffic should be more. So while designing the network, these conditions should be taken into account.

Chapter 4

LITERATURE REVIEW

4 .LITERATURE REVIEW

Nonlinear effects in optical fibers have become an area of academic research and of great importance in the optical fiber based systems. Optical duobinary coding is an effective method in high speed optical transmission systems to increase dispersion tolerance, to improve spectral efficiency and to reduce the sensitivity to non linear effects . Optical duo-binary has attracted great attention in recent years. The term 'duo' means doubling the bit capacity of a straight binary system. The main advantages attributed to this modulation format are increased tolerance to the effects of chromatic dispersion. The fundamental idea of duo binary modulation (electrical or optical) that were first described by Lender in 1964 is to deliberately introduce Inter Symbol Interference (ISI) by overlapping data from adjacent bits. This correlation between successive bits in a binary signal leads the signal spectrum to be more concentrated around the optical carrier. This is accomplished by adding a data sequence to a 1-bit delayed version of itself, which can be obtained by passing the binary signal through the delay-and-add filter . Binary signal is a two level signal but duo binary is a three level signal. Binary has information capacity 1, but duobinary has that of 2 also speed of duobinary is twice than that of Binary. For duobinary system, degree of complexity and amount of circuitry required are low.

In order to meet the huge capacity demands imposed on the core transmission network by the explosive growth in data communications the number of optical channels in dense-WDM optical networks is being increased. Since the gain bandwidth of EDFAs is limited, these requirements for a very large number of channels mean that the channel spacing will have to be small. The current ITU grid specifies 100 GHz channel spacing, but systems are being considered with 50 GHz to 25GHz channel spacing. At these spacing, the non-linear effects of the optical fibre can induce serious system impairments and modulation schemes are now being developed which are robust to both the linear and non-linear behaviour of fibre. Duobinary modulation techniques are known to compress the optical spectrum, thereby facilitating the tighter packing of channels into the EDFA gain window. It has also been reported that the 2-level variant of duobinary signalling almost eliminates the impact of SBS since the optical carrier component is suppressed . Four-Wave-Mixing (FWM) is another non linear effect that can limit the performance of WDM systems .For long distance light wave communication larger information transmission capacity and longer repeater-less distance are required formers requires high bit rate and wavelength division multiplexing for increasing bit rate. When high power optical signal is launched into a fiber linearity of optical response is lost. Four wave mixing is due to changes in the refractive index with optical power called optical Kerr effect. In FWM effect, two co-propagating wave produce two new optical sideband wave at different frequencies. When new frequencies fall in the transmission window of original frequency it causes severe cross talk between channels propagating through an optical fiber. Degradation becomes very severe for large number of WDM channels with small spacing. Optical duobinary modulation has attracted much attention as a transmission technique that can mitigate fiber chromatic-dispersion effects in high capacity optical transmission system. The technique was first described by Lender in 1963 . The simulation setup is validated using simulation software Optsim**.**

Chapter 5

PROBLEM

STATEMENT &

NETWORK DESIGN

5. Simulation Setup

For high bit rate, long-haul communications supported by optical fiber, high quality light sources serving as transmitters are essential. Lasers operating in continuous wave (CW) mode provides a beam of light to an electro- optical modulator that

is controlled to switch the light ON and OFF at the desired bit rate.

Two alternate ways to generate a modulated optical signal namely direct modulation and external modulation. In direct modulation, the laser is completely ON at all times and so called CW laser . External modulation can pro- duce higher quality optical pulses permitting extended reach and higher bit rates. Both direct and external modulation can produce NRZ or RZ modulated optical signals.

5.1 Simulation Block Diagrams

This work includes the simulation of a two channel WDM optical communication system in order to compare the BER and Q factor of both Binary and Duobinary modulation schemes. For the simulation purpose, here used optical software "OPSIM". Here we used Optsim 5.0. An optical fiber of 100km long is used & two CW semiconductor lasers externally modulated by Duo-binary & binary modulation format like NRZ Rectangular.

5.1.1 Using Binary Modulation Scheme

In Binary modulation scheme, there are only two possible states- an ON state and an OFF state. Here ON state corresponds to logic ONE and OFF state corresponds to logic ZERO. Two 10 Gbps data sources and CW Lasers are used. Figure 2 shows the block diagram of 2 channel optical WDM system employing Binary modulation scheme. Signals coming from the two channels are modulated by using optical modulators. These modulated signals are then combined in an optical combiner.

Combined signal is then fed to an optical amplifier and in this work here used an Erbium Doped Fiber Amplifier (EDFA). Amplified signal is then passed through a 100km single mode fiber. At the receiving section a PIN photo- diode is employed in order to convert optical signal into electrical form. Bessel electrical filter is also used for proper filtering.

5.1.2 Using Duobinary Modulation Scheme

In Duo binary modulation scheme, there are two ON states and one OFF state. In both the ON states, the light is ON continuously with equal intensity but each ON state is 'π' radians out of phase. Duo binary modulation format is obtained by driving an external dual arm Mach-Zhender modulator with opposite phase signal.

A Dual arm Mach-Zehnder modulator is based on Mach-Zhender Interferometer (MZI) andis fabricated from $LiNbO_3$. Two 10 Gbps data sources and CW Lasers are used. An EDFA is used to amplify the signal coming from the optical combiner. Amplified signal is then transmitted through a 100 km standard single mode fiber. Figure 3 shows the block diagram 2 channel optical WDM using Duobinary modulation scheme.

While traveling through the fiber, the signal may be distorted due to dispersion or FWM. So in order to boost this signal an EDFA is again placed before detection. After amplification signal enters an optical splitter, which performs the function of an optical DMUX. A PIN photodiode is placed at the receiver section for optical to electrical conversion. A Duo binary transmitter mainly consists of two NRZ rectangular drivers, Bessel electrical filters and a NOT gate. Here the NOT gate is used to invert the signal. NRZ rectangular driver is the modulator drive. Bessel electrical filter is a type of linear filer which preserves he wave shape. Bessel filter is also called Bessel-Thompson filter and it has maximally flat group delay.

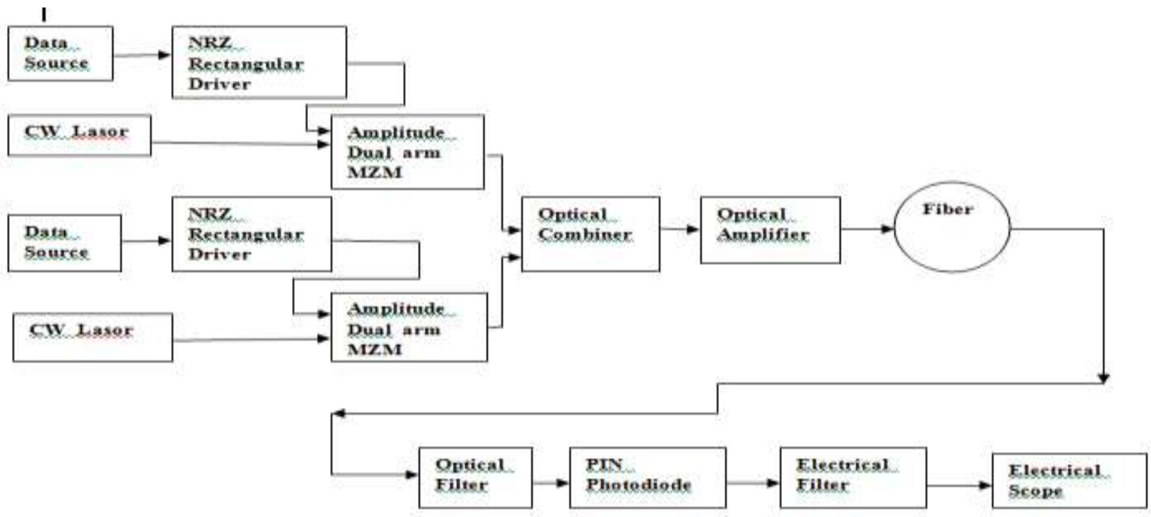


Figure 5.1 **Block diagram of binary modulation scheme for 2 channel WDM system.**

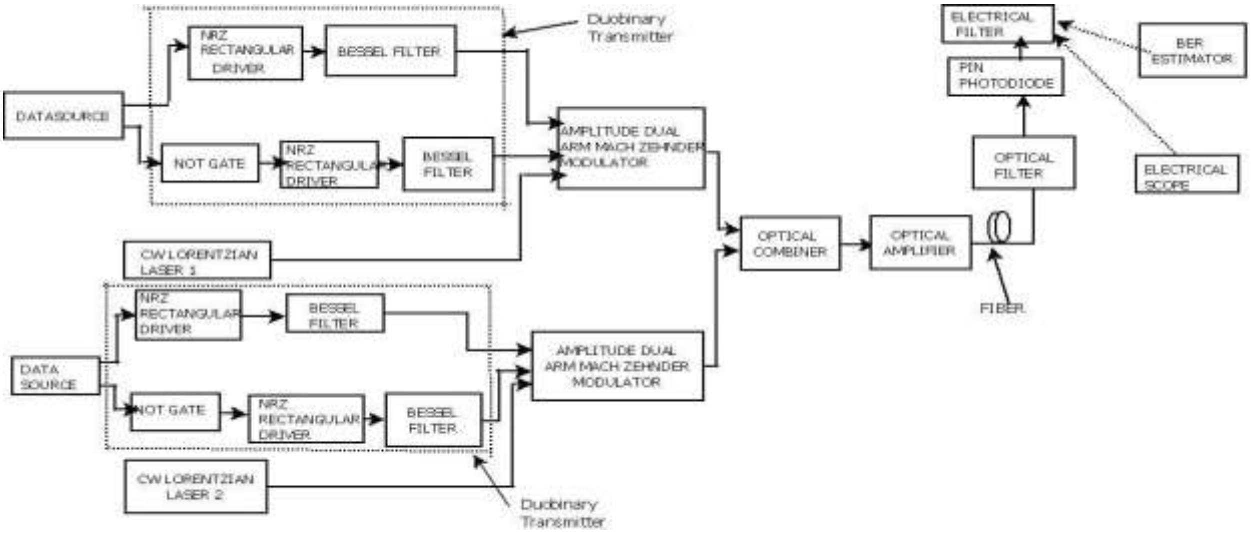


Figure 5.2 Block diagram of Duo binary modulation scheme for 2 channel WDM system.

5.2 Simulation Schematics

Optsim software was developed by RSoft Design Group. Optsim is an advanced optical communication system simulation package designed for professional engineering and cutting-edge research of WDM, DWDM, TDM, CATV, optical LAN, parallel optical bus, and other emerging optical systems in telecom, datacom, and other applications. It can be used to design optical communication systems and simulate them to determine their performance given various component parameters.

Optsim layouts of a two channel WDM optical communication system using both Binary and Duobinary modulation schemes are shown below. This simulation work is done in the Sample mode approach. In the sample mode simulation approach a component model will pass new sample data to another component model at each time step in the simulation.

5.2.1 Optsim Layout of Binary Modulation

Figure 4 shows the Optsim layout of Binary modulation format.

CW laser1 have central emission frequency 193.41449 THz (1550nm), optical power 3dBm & FWHM line width 10 MHz. CW Laser 2 have central emission frequency 193.45817 THz (1549.65nm) . Optical spectrum can be viewed through OSA and eye diagrams through electrical scopes.

5.2.2 Optsim Layout of Duo Binary Modulation

Figure 5 shows the Optsim layout of Duobinary modulation format.

Data source generate data of various bit rates in Gbps.

The duo binary encoder used consists of a one-bit delay line. The output of the delay line is added to the original signal to generate a zero mean, three-level signal.

Here external modulation is carried out by amplitude dual arm Mach Zehnder modulator (MZM). The Mach Zehnder modulator has maximum transmissivity offset voltage of 0.5V & extinction ratio of 20dB. Same external modulator is used for both duo binary & binary signal with same parameter as mentioned above. Duo binary modulation format is obtained by driving an external dual arm modulator with opposite phase signal.

Optical spectrum can be viewed through OSA and eye diagram through electrical scope. From the eye diagrams, BER, Q values etc. can be determined. Optical spectrum gives both frequency and peak power of the optical signals.

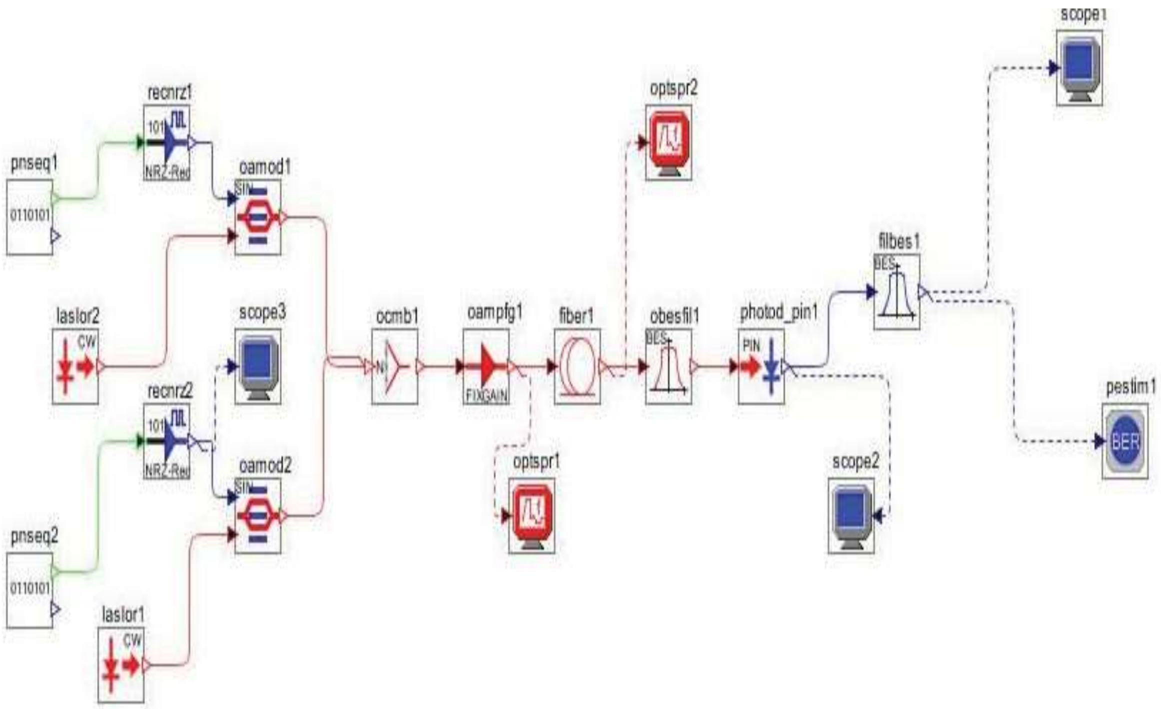


Figure 5.3. **Binary modulation schematic.**

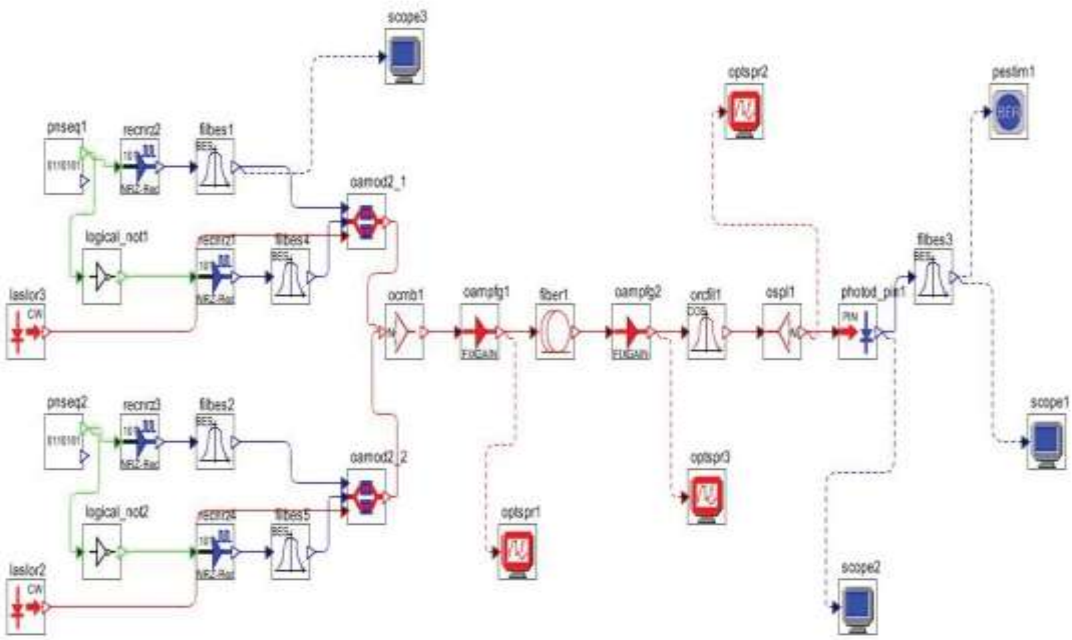


Figure 5. **Duo binary modulation schematic**.

Chapter 6

SIMULATION RESULTS AND DISCUSSIONS

6. Simulation Results and Discussions

Simulation results can be obtained through the various measurement components like Optical Spectrum Analyzer (OSA) and Electrical scope which provides Eye diagrams, BER Estimator, Electrical probes etc. The spectrum after propagation through the fiber is viewed on an OSA. At receiver side, electrical scope is connected to electrical filter output to view eye diagram, to calculate BER, Q factor. Eye diagrams can be used o effectively analyze the performance of an optical system. If the eye opening is very wide here is no crosstalk. Eye height is an indicator of noise. Signal width at the centre of an eye diagram represents a measure of timing jitter.

6.1 Results from Binary Modulation

6.1.1 Optical Spectra

When we analyze the above spectra, two highest peaks are appeared which corresponds to two channels of different wavelengths used in this work.

At the fiber output, the highest peak power is reduced after travelling through a 100 km long optical fiber cable due to some linear and non linear effects.

6.1.2 Eye Diagrams

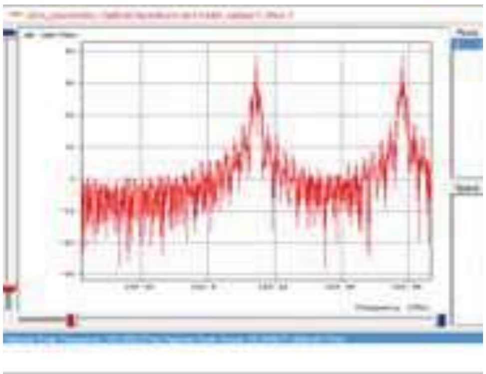
Eye diagrams obtained for different bit rates in Duobinary modulation scheme are shown in Figure 7. These eye diagrams are obtained at the receiving section after PIN photodiode (before and after filtering).

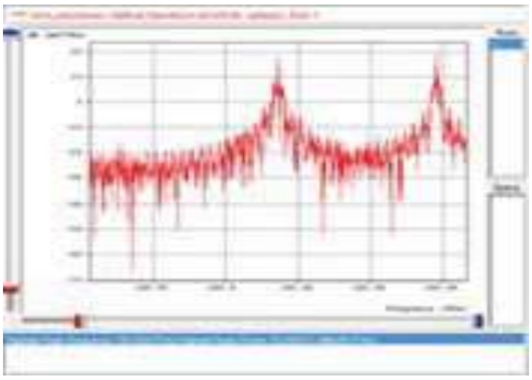
Eye opening becomes wider while reducing the bit rates. For a bit rate of 2.5

Gbps, a clear eye opening is obtained and BER is reduced which results in better Q facor. There is no eye opening is present when bit rate is 20 Gbps and eye diagram is completely distorted.

BER and Q factor values for different bit rates are summarized (Table 1, Figure 8).

As bit rate is increased, BER is also increased which results in poor Q factor.

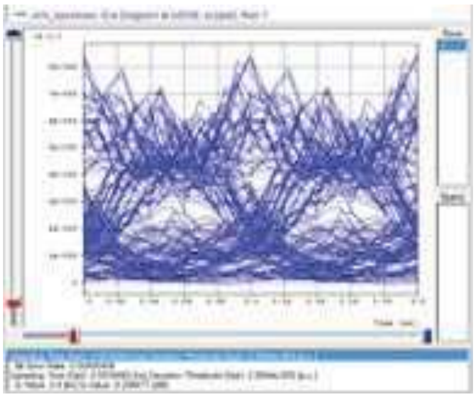


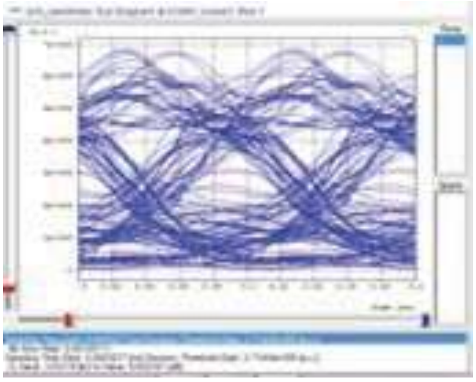


(a) **(b)**

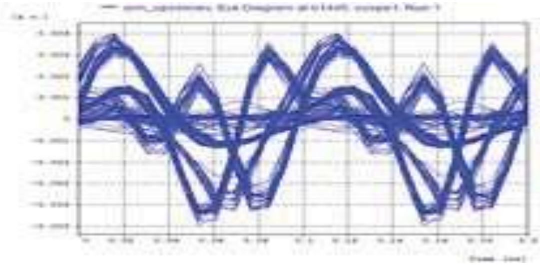
Figure 6.1. Optical spectra obtained from (a) fiber input and (b) fiber output in Binary modulation scheme.

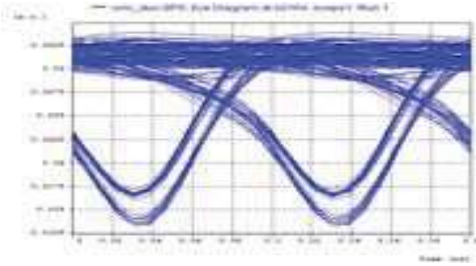
For Bit rate = 10 Gbps



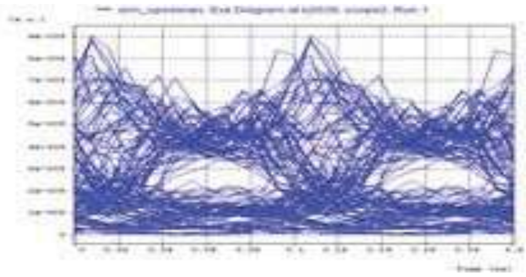


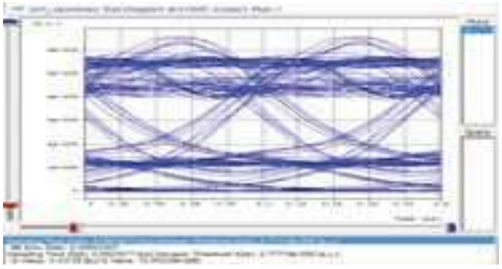
For Bit rate =7.5 Gbps.



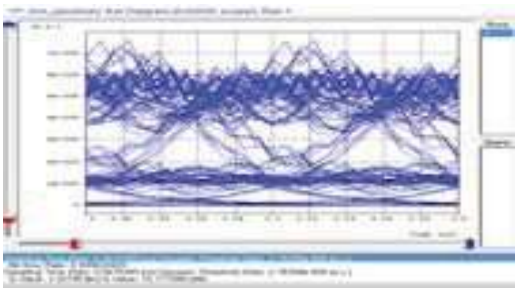


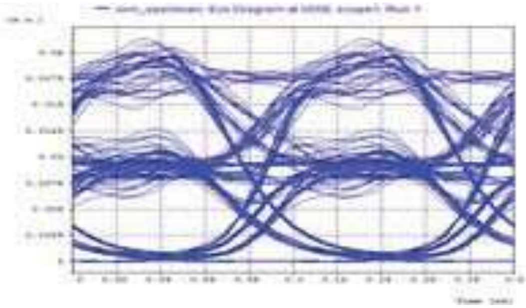
For Bit rate = 5Gbps.



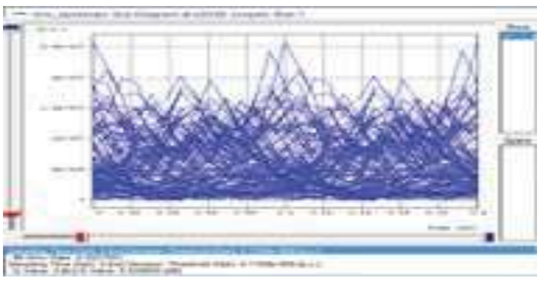


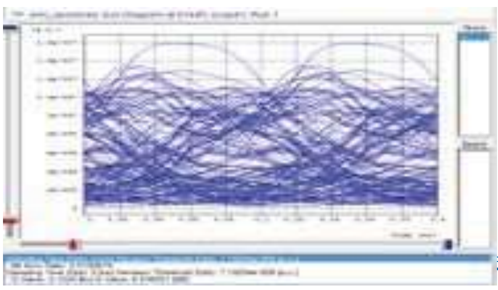
For Bit rate = 2.5 Gbps





For Bit rate = 20Gbps





6.2. Eye diagrams for different bit rates obtained in Binary modulation.

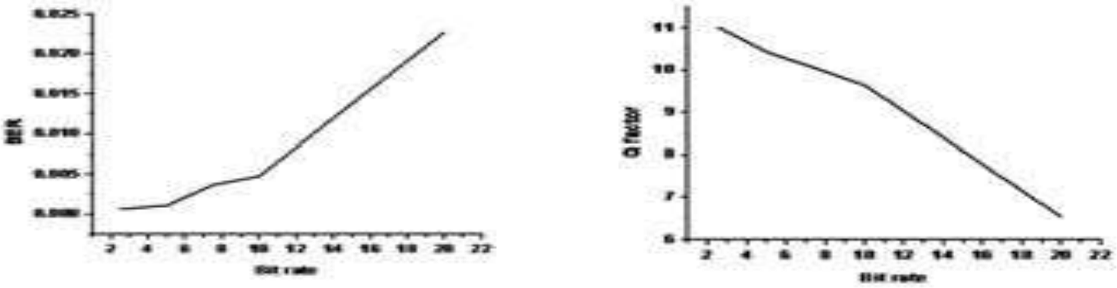


Figure 6.3. **Variation of BER and Q factor with Bit rate of Binary modulation.**

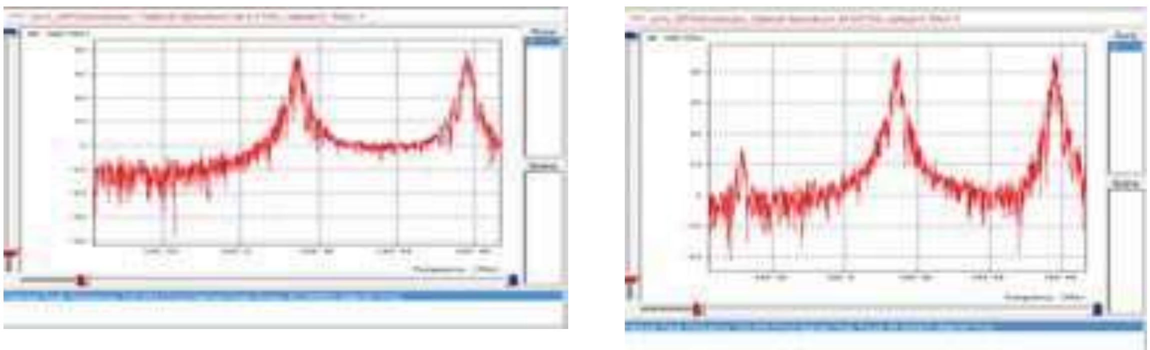
Table 4 . **Results from Eye diagrams of Binary modulation**

Bit rate (Gbps)	Scope 1		Scope2	
	BER	Q Value (dB)	BER	Q Value (dB)
20	0.0199879	6.536551	0.0227501	6.020600
10	0.00125111	9.632181	0.00480456	8.299471
7.5	0.0021753	10.03865	0.0036921	9.73924
5	0.00043307	10.45239	0.00113719	9.737243

6.2 Results from Duo Binary Modulation

6.2.1 Optical Spectra

9 represents the optical spectra obtained in Duo Binary modulation.



(a) (b)

Figure 6.4. **Optical spectra obtained from (a) fiber input and (b) fiber output in Duo Binary modulation scheme.**

When we analyze the above spectra, an additional optical side band (small peak) along with two highest peaks is appeared which corresponds to the Four Wave Mixing (FWM) product. At the fiber output, the highest peak power is reduced after travelling through a100 km long optical fiber cable due to FWM effects. But it is increased a little after amplification by EDFA.

6.2.2 Eye Diagrams

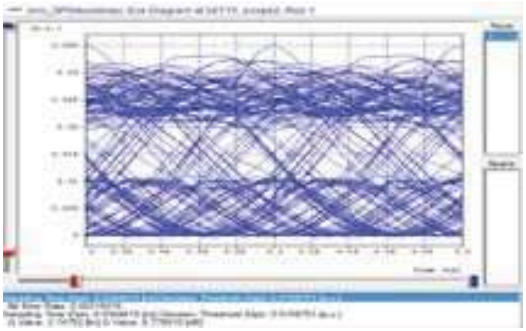
Eye diagrams obtained for different bit rates in Duobinary modulation scheme are shown (Figure 10). These eye diagrams are obtained at the receiving section after PIN photodiode (before and after filtering).

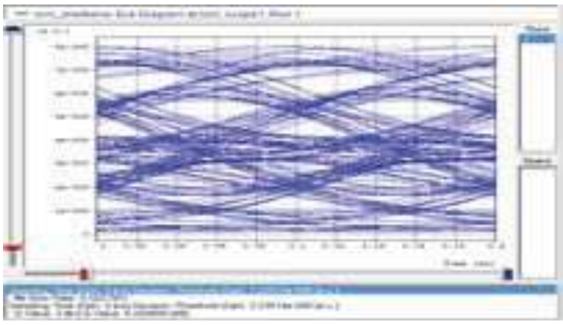
Eye opening becomes wider for lower bit rates. For a bit rate of 2.5 Gbps, a clear eye opening is obtained and BER is reduced which results in better Q facor. There is no eye opening is present when bit rate is 20 Gbps and at his rate, eye diagram is completely distorted. While comparing the eye diagrams, it is revealed that eye diagrams obtained in Duo binary modulation scheme are better than that obtained in Binary modulation.

BER and Q factor values for different bit rates are summarized in Table 2, Figure 11.

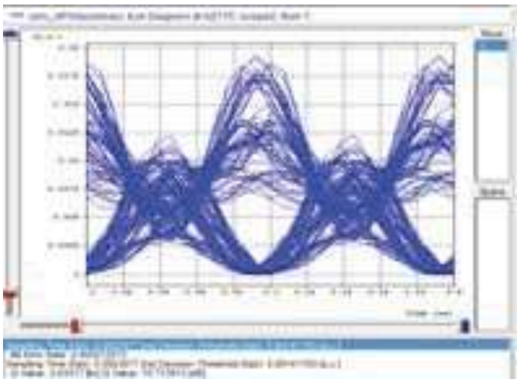
As bit rate is increased, BER is also increased which results in poor Q factor.

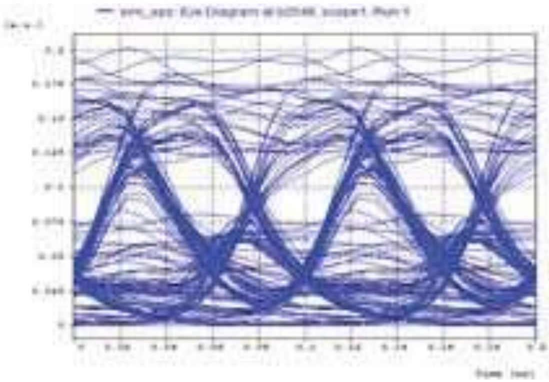
For Bit rate =10 Gbps.



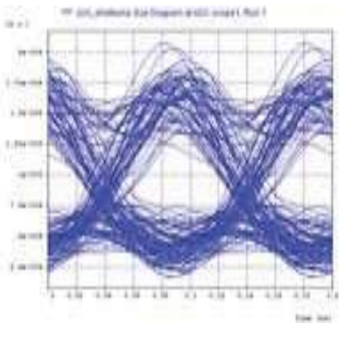


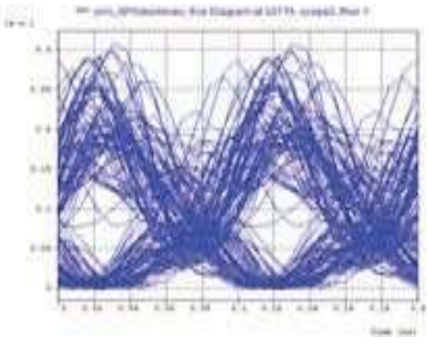
For Bit rate = 7.5Gbps.



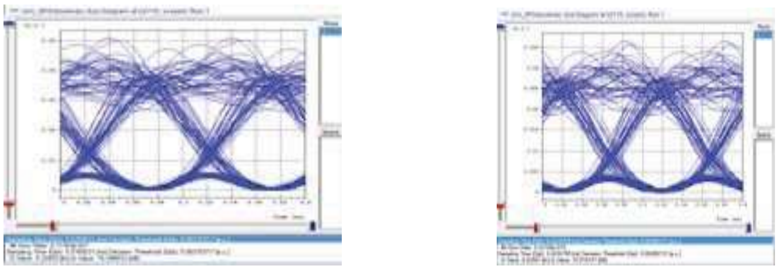


For Bit rate = 5 Gbps.





For Bit rate = 2.5Gbps.



For Bit Rate = 20Gbps.

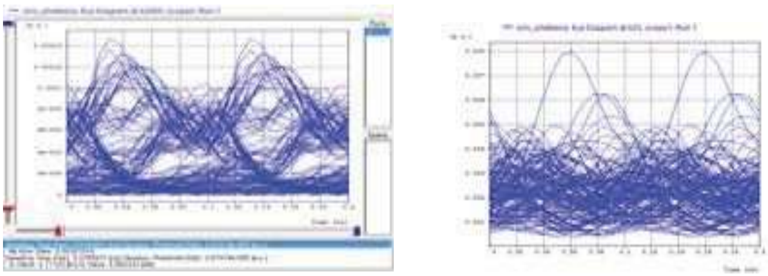


Figure6.5 . Eye diagrams for different bit rates obtained in Duo Binary modulation.

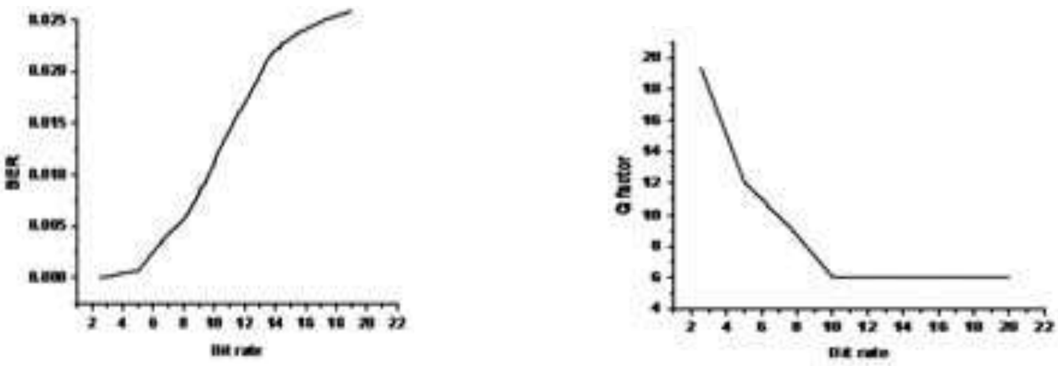


Figure 6.6. Variation of BER and Q factor with Bit rate of Duo Binary modulation.

Table 5. Results from Eye diagrams of Duo Binary modulation.

Bit rate (Gbps)	**Scope 1**		**Scope2**	
	BER	Q Value (dB)	BER	Q Value (dB)
20	0.00359216	6.020600	0.00307019	8.663333
10	0.0227501	6.052317	0.00315016	8.778810
7.5	0.0053869	9.362857	0.00021257	10.713913
5	0.0007256	12.0053683	0.0019379	11.020758
2.5	4.7135e-021	19.396633	5.2218e-019	18.915147

6.3Binary vs. Duobinary

Figure 12 shows the comparison of Q factor vs. Bit rate in Binary and Duo binary modulation formats for different bitrates.

From the above graph, it is concluded that Q factor of Duo binary modulation format is better than Binary modulation for various bit rates. Better Q factors are obtained at a bit rate of 2.5Gbps for both Binary and Duobinary modulation schemes. For 5Gbps, obtained Q factors are 11 dB and 19 dB in binary and Duo binary modulation formats respectively.

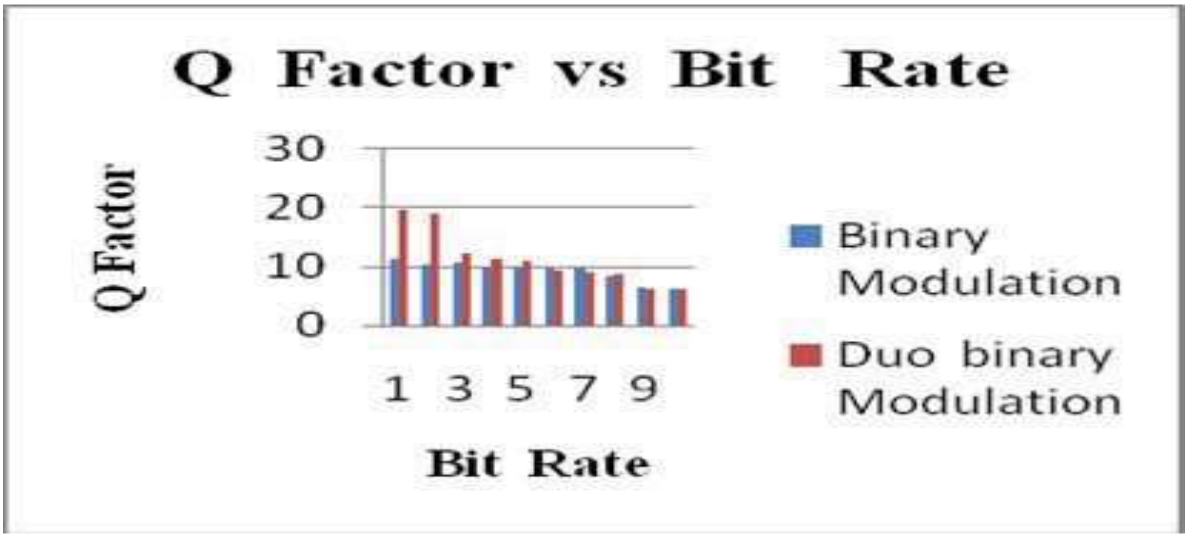


Figure 6.7. **Comparison of Q factor in Binary and Duo binary modulation schemes.**

Chapter 7

CONCLUSION

7. Conclusion

Recent advances in the field of optical communication have opened the way for the practical implementation of WDM networks. After going through several papers we have found out that for determining Quality of Service the effect of network architecture is not taken into account. So we have designed four different networks and simulated them with different scenario to determine the performance matrices, which are called QoS (Quality Of Service) parameters.

In this work, the simulation of a 2 channel WDM optical communication system for different modulation formats is presented in order to analyze the variations in BER and Q factor with different bit rates. Here used both Binary and Duo binary modulation formats for this purpose. From the obtained results it is concluded that BER is got improved with duo binary modulation format than a binary scheme for different values of bit rates which will offer a significant performance benefit in digital sys- tems. For the bit rates of 5 Gbps and 2.5 Gbps, Duo binary modulation scheme gives highest Q factor than Binary modulation scheme.

7.1 SCOPE OF FUTURE WORK

Optsim WDM is a good simulation tool to analyse different network topologies and performance matrices. With this we can use different types of designing algorithm like MILP (Mixed integer Linear Programming). For this we need Optsim (require registration) which allows many more functions like wavelength conversion/without wavelength conversion, with traffic losses/without traffic losses, losses cost per Gbps, cost per electronically switched Gbps, maximum light path distances.

Its GUI (Graphic User Interface) allows the user to carry out full multi-hour test for a pre-built or user defined multi-hour planning algorithm and virtual topology analysis. We can work towards dynamic Analysis which allows GUI (Graphic User Interface) to test online optimization algorithms to react to high level traffic connections arrivals, terminations and to do high level of performance analysis with good accuracy.