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Attenuation and Dispersion through Single Mode fiber Optic Simulation

A project
Submitted to the Department Of Communication University Of Diyala-College Of Engineering in Partial Fulfillment Of the Requirement For Degree Bachelor in Communication Engineering

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بِسْمِ اللهِ الرَّحْمنِ الرَّحِيمِ

إِنَّ فِي خَلْقِ السَّمَوَاتِ وَالْأَرْضِ وَاخْتِلَافِ اللَّيْلِ وَالنَّهَارِ وَالْفُلْكِ الَّتِي تَجْرِي
فِي الْبَحْرِ بِمَا يَنْفَعُ النَّاسَ وَمَا أَنْزَلَ اللَّهُ مِنَ السَّمَاءِ مِنْ مَاءٍ فَأَحْيَا بِهِ الْأَرْضَ
بَعْدَ مَوْتِهَا وَبَثَّ فِيهَا مِنْ كُلِّ دَابَّةٍ وَتَصْرِيفِ الرِّيَاحِ وَالسَّحَابِ الْمُسَخَّرِ
بَيْنَ السَّمَاءِ وَالْأَرْضِ لَآيَاتٍ لِقَوْمٍ يَعْقِلُونَ (١٦٤)

صدق الله العلي العظيم

سورة البقرة

Dedication

TO

MY " FAMILY " WITH LOVE

Acknowledgement

First and foremost, I thank God for his guidance and for blessing me. We wish to thank our family for their understanding and support including our parents , siblings , our big family and our friends inside university.

We wish to express our deepest gratitude to ourAss.Lec.Hussein Ahmed Mahmood, Ass.Lec.Omar Abdel- Karim Mahmoud And Dr.Riyadh Khalf Ahmed for his guidance and friendship during our study. And at last we want to thank the head of department of communications Dr.Muntather Abbas Taher for giving us the chance to work on as a fine project as this one.

ABSTRACT

The objective of the project is to study how chromatic dispersion affects the performance of an optical high-speed network. We will use the simulation tool optisystem to calculate common performance parameters in a basic fiber optic link. Thus, we will also learn how to characterize a transmission system**.** Chromatic dispersion and fiber attenuation pose a great problem in the detection of optical signals. Dispersion causes pulse broadening which limits the information carrying capacity of the fiber while attenuation limits the maximum transmission distance along the fiber. It was found that pulse broadening and intensity loss in the optical signal is increasing proportionately with the propagation length of the fiber and this is what contributes to the causes of detection errors at the receiver.

الملخص

يهدف البحث الى دراسة تاثير التشتت والتوهين الناتج من انتقال الاشارة خلال الليف البصري احادي النمط.وقد تم استخدام برنامج (Optisystem) لمحاكاة تاثير هذه العوامل باستخدام اطوال مختلفة لليف البصري وملاحظة تاثير ذلك على عامل الجودة (Q Factor)ومقدار نسبة الخطا(BER) بالاضافة الى حساب مقدار القدرة الخارجة من اليف البصري حيث تم ملاحظة الانخفاض في القدرة الخارجة مع زيادة طول الليف البصري وكذلك بالنسبة الى عامل القدرة اما نسبة الخطا فتزداد بزيادة طول الليف البصري.

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ATM	_	asynchronous transfer mode
EMPS	_	electromagnetic pulses
RFI	_	radio frequencyinterference
EMI	_	electromagnetic interference
IM/DD	_	intensity modulation with direct detection
FMT	–	Fade Mitigation Techniques
ITU	–	International Telecommunication Union
ISI	–	Inter Symbol Interference
LED	_	Light Emitting Diode
GVD	_	Group Velocity Dispersion
BER	_	Bite-Error-Rate
DW	_	Waveguide Dispersion
WDM		Wavelength Division Multiplexing
PMD	_	Phenomenon Dispersion
ZMD	_	Zero Material Dispersion(fiber)
DSFs	_	Dispersion-Shifted Signal mode Fiber
DFFs	_	Dispersion FlattenedSignal mode Fiber
MFD	_	Mode-Field Diameter
TC	_	Triple Clad
QC	_	Quadruple Clad
NDF	_	Negative Dispersion Fiber
DCF	_	Dispersion Compensating Fiber
SSMF	_	Stander Single Mode Fiber
NZ-DSF	_	NonZero-Dispersion Shifted Fiber
Bopt	_	Optical BandWidth

LIST OF SYMBOLS

β	_	Beta describes the time dynamics
A	_	Alpha(Attenuation)
B	_	BandWidth
L	_	Distance
S/N	_	Signal to Noise ratio
$\Delta\omega$	_	Frequency spread
C	_	Speed of light
D	_	Dispersion ps/Km.nm

1.1 General introduction

A communication system transmits information from one place to another, whether separated by a few kilometers or by transoceanic distances. Information is often carried by an electromagnetic carrier wave whose frequency can vary from a few megahertz to several hundred terahertz. Optical communication systems use high carrier frequencies (∼100 THz) in the visible or near-infrared region of the electromagnetic spectrum. They are sometimes called lightwave systems to distinguish them from microwave systems, whose carrier frequency is typically smaller by five orders of magnitude (∼1 GHz). Fiber-optic communication systems are lightwave systems that employ optical fibers for information transmission. Such systems have been deployed worldwide since 1980 and have indeed revolutionized the technology behind telecommunications [1].

Optical transmission systems have been managed to our demands to be able to transfer the required data volumes. Unfortunately, these requirements are increasing, forcing us to deal with problems, which we saw only in theory so far. Specifically, one of these is the chromatic dispersion influence.

Optical transmission system transmits information encoded in optical signal over long distances. The electrical signal in the transmitter at the fiber input is converted into light impulses that are transferred through the fiber to the receiver at the end of the fiber. In the receiver the light impulses are converted back to the original electrical signal.

changes along the fiber as a consequence of light wave speed dependence on various factors. The pulse width gradually increases and peak power of impulse is reduced. This fact limits information capacity at high transmission speeds. Dispersion reduces the effective bandwidth and at the same time it escalates the error rate due to an increasing intersymbol interference.

There are three main types of dispersion: modal dispersion, chromatic dispersion and polarization dispersion.[2]

1.2 Structure of optical fiber

Structure of optical fiber used of communication links. It has inner glass core with an outer cladding. This is covered with apron active buffer and outer jacket.
This design of fiber is light and has very low loss making it ideal for transmission
Of information over long distances.[3]

1-Core is glass high moving the light. .

2-Cladding material surrounding the pulp glass is working on the dimmable back to the center fiber optical.

3-Buffer coating plastic wrap protects the fiber optical of humidity or ported from damage and breakage.

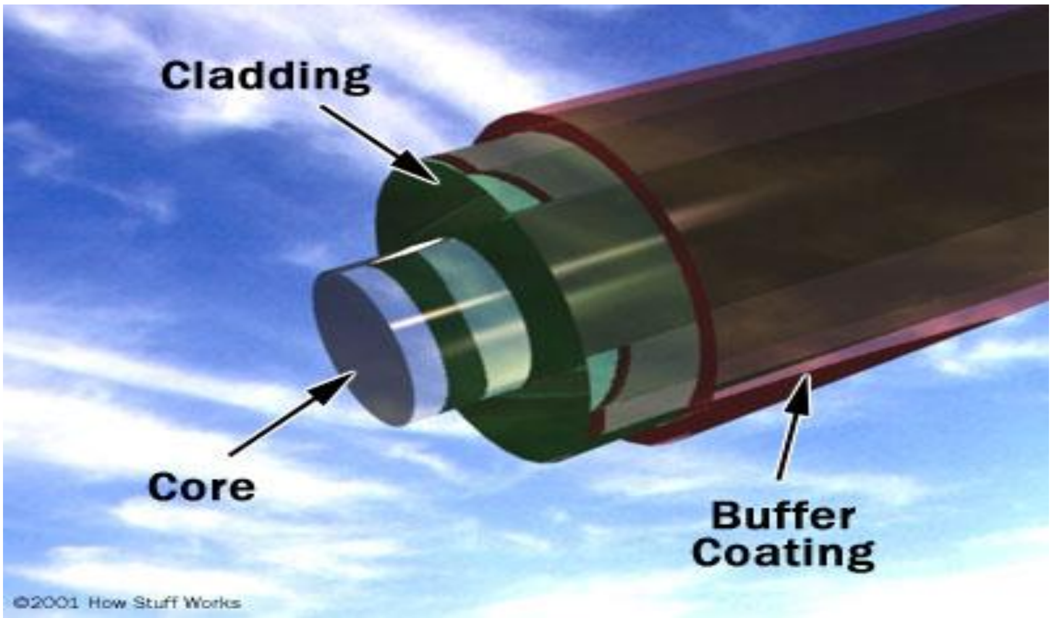


Figure (1.1) Structure of optical fiber.

1.3 Fiber types

1.3.1 Step-Index Fibers

Allow the propagation of a finite number of guided modes along the channel. The number of guided modes is dependent upon the physical parameters (i.e. relative refractive index difference, core radius) of the fiber and the wavelengths of the transmitted light which are included in the normalized frequency V for the fiber. that there is a cutoff value of normalized frequency Vc for guided modes below which they cannot exist. However, mode propagation does not entirely cease below cutoff. Modes may propagate as unguided or leaky modes which can travel considerable distances along the fiber. Nevertheless, it is the guided mode which are of paramount importance in optical fiber communications as these are confined to the fiber over its full length.

Using the ray theory model, the fastest and slowest modes propagating in the step index fiber may be represented by the axial ray and the extreme meridional ray (which is incident at the core–cladding interface at the critical angle φc) respectively. The paths taken by these two rays in a perfectly lows estimation of the pulse broadening resulting from intermodal dispersion within the fiber. [4] As both rays are traveling at the same velocity within the constant refractive structured step index fiber are shown in Figure 1.2.Using Snell's law of refraction the core-cladding interface following:

$$sin\, \emptyset c = \frac{n2}{n1} = cos\, \theta$$

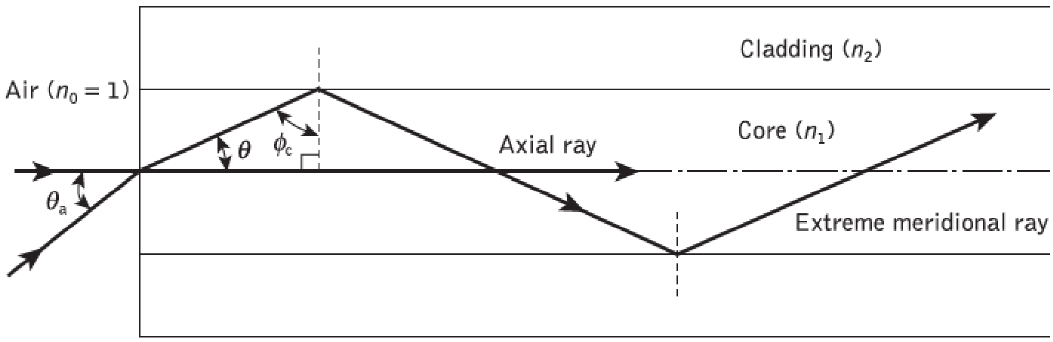


Figure (1.2) The path taken by the axial and an extreme meridional ray in a perfect multimode step index fiber.

1.3.2 Graded-index fiber

The refractive index of the core in graded-index fibers is not constant but decreases gradually from its maximum value n1 at the core center to its minimum value n2 at the core–cladding interface. Most graded-index fibers are designed to have a nearly quadratic decrease and are analyzed by using α-profile, given by

$$n(r) = \begin{cases} n1\left[1 - 2\Delta\left(\frac{\rho}{a}\right)^{\rho}\right]^{0.5} ;\ \rho < a, \\ n1\left[1 - 2\Delta\left(\frac{\rho}{a}\right)^{\rho}\right]^{0.5} = n2] ;\ \rho \geq a, \end{cases}$$

where a is the core radius. The parameter α determines the index profile. A step-index profile is approached in the limit of large α. A parabolic-index fiber corresponds to $\alpha = 2$.

It is easy to understand qualitatively why intermodal or multipath dispersion is reduced for graded-index fibers. Figure 1.6 shows schematically paths for three different rays. Similar to the case of step-index fibers, the path is longer for more oblique rays. However, the ray velocity changes along the path because of variations in the refractive index. More specifically, the ray propagating along the fiber axis takes the shortest path but travels most slowly as the index is largest along this path. Oblique rays have a large part of their path in a medium of lower refractive index, where they travel faster. It is therefore possible for all rays to arrive together at the fiber output by a suitable choice of the refractive-index profile.[5]

1.3.3 Single –mode fiber

The single-mode step index fiber has the distinct advantage of low intermodal dispersion (broadening of transmitted light pulses), as only one mode is transmitted, whereas with multimode step index fiber considerable dispersion may occur due to the differing group velocities of the propagating modes. This in turn restricts the maximum bandwidth attainable with multimode step index fibers, especially when compared with single-mode fibers. However, for lower bandwidth applications multimode fibers have several advantages over

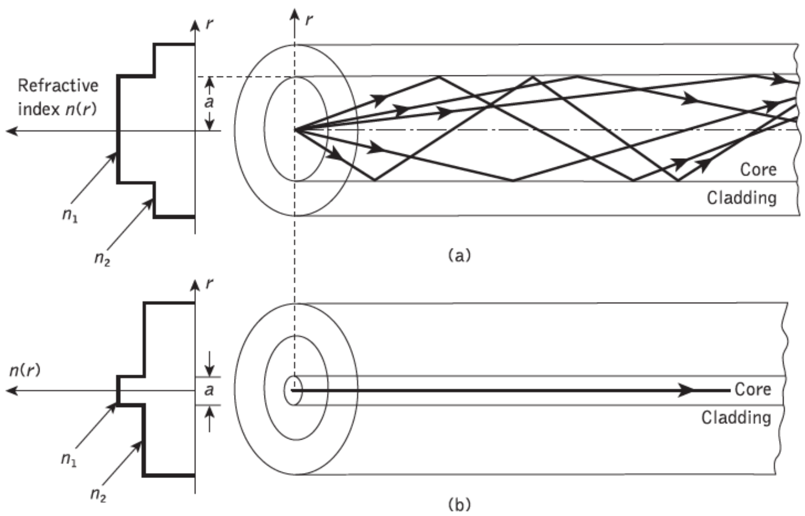


Figure (1.3) The refractive index profile and ray transmission in step index fiber:
(a)multimode step index fiber; (b)single mode step index fiber.

Single mode fibers.These are:(a) multimode step index fiber; the use of spatially incoherent optical sources (e.g. most light-emitting diodes) which cannot be efficiently coupled to single-mode fibers; Optical fiber waveguides .Figure 1.4 The refractive index profile and ray transmission in step index fibers:

(b) single-mode step index fiber larger numerical apertures, as well as core diameters, facilitating easier coupling to optical sources.

(c) lower tolerance requirements on fiber connectors.

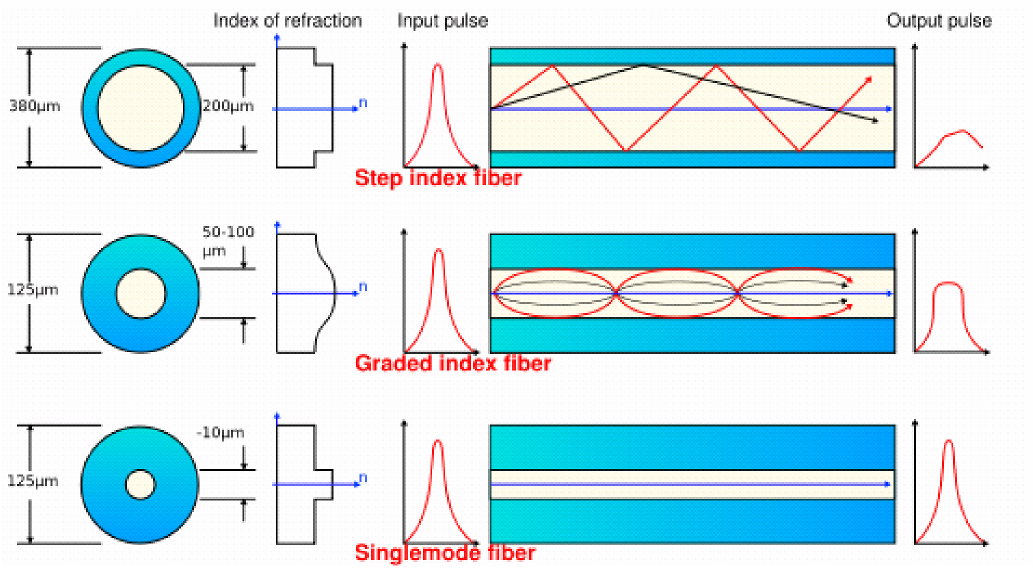


Figure (1.4) types of optical fiber.

1.4 Advantage of optical fiber:

(a) Enormous potential bandwidth.[1]

(b) Small size and weight.

(c) Electrical isolation.

(d) Immunity to interference and crosstalk.

(e) Signal security.

(f) Low transmission loss.

(g) Ruggedness and flexibility.

(h) System reliability and ease of maintenance.

(i) Potential low cost.

1.5 Optical fiber application

The application of optical fiber communications is in general possible in any area that requires transfer of information from one place to another. However, fiber-optic communication systems have been developed mostly for telecommunications applications. This is understandable in view of the existing worldwide telephone networks which are used to transmit not only voice signals but also computer data and fax messages. The telecommunication applications can be broadly classified into two categories, long-haul and short-haul, depending on whether the optical signal is transmitted over relatively long or short distances compared with typical intercity distances (∼100 km). Long-haul telecommunication systems require high-capacity trunk lines and benefit most by the use of fiber-optic lightwave systems. Indeed, the technology behind optical fiber communication is often driven by long-haul applications. Each successive generation of lightwave systems is capable of operating at higher bit rates and over longer distances. Periodic regeneration of the optical signal by using repeaters is still required for most long-haul systems. However, more than an order-of-magnitude increase in both the repeater spacing and the bit rate compared with those of coaxial systems has made the use of lightwave systems very attractive for long-haul applications. Furthermore, transmission distances of thousands of kilometers can be realized by using optical amplifiers.

a large number of transoceanic lightwave systems have already been installed to create an international fiber-optic network. Short-haul telecommunication applications cover intracity and local-loop traffic. Such systems typically operate at low bit rates over distances of less than 10 km. The use of single-channel lightwave systems for such applications is not very cost-effective, and multichannel networks with multiple services should be considered. The concept of a broadband integrated-services digital network requires a high-capacity communication system capable of carrying multiple services. The asynchronous transfer mode (ATM) technology also demands high bandwidths. Only fiber-optic communication systems are likely to meet such wideband distribution requirements. Multichannel lightwave systems and their applications in local-area networks.[1]

1.6 Fiber transmission windows (bands)

Table 1.1 ITU spectral band definitions.

Name	*ITU band*	*Wavelength range (μm)*
Original band	O-band	1.260 to 1.360
Extended band	E-band	1.360 to 1.460
Short band	S-band	1.460 to 1.530
Conventional band	C-band	1.530 to 1.565
Long band	L-band	1.565 to 1.625
Ultralong band	U-band	1.625 to 1.675

1.7 Optical fiber system component:-

1.7.1 Transmitter.

1.7.2 Amplifier.

1.7.3 Receiver.

1.7.1The optical transmitter

The unique properties and characteristics of the injection laser and the LED which make them attractive sources for optical fiber communications. Although both device types exhibit a number of similarities in terms of their general performance and compatibility with optical fibers, striking differences exist between them in relation to both system application and transmitter design. It is useful to consider these differences, as well as the limitations of the two source types, prior to discussion of transmitter circuits for various applications.[1]

1.7.2The Optical amplifier

The transmission distance of any fiber-optic communication system is eventually limited by fiber losses. For long-haul systems, the loss limitation has traditionally been overcome using optoelectronic repeaters in which the optical signal is first converted into an electric current and then regenerated using a transmitter. Such regenerators become quite complex and expensive for wavelength-division multiplexed (WDM) lightwave systems. An alternative approach to loss management makes use of optical amplifiers, which amplify the optical signal directly without requiring its conversion to the electric domain. Several kinds of optical amplifiers were developed during the 1980s, and the use of optical amplifiers for long-haul lightwave systems became widespread during the 1990s. By 1996, optical amplifiers were a part of the fiber-optic cables laid across the Atlantic and Pacific oceans.[1]

1.7.3The optical receiver

The noise performance for optical fiber receivers incorporating both major detector types (the p–i–n and avalanche photodiode). Receiver noise is of great importance within optical fiber communications as it is the factor which limits receiver sensitivity and therefore can dictate the overall system design preamplifier) .the low-level signal as well as the noise sources associated with the optical detector. Also, the possible strategies for the configuration of the preamplifier were considered .as a guide to optimization of the receiver noise performance for a particular application. Following the linear conversion of the received optical signal into an electric current at the detector, it is amplified to obtain a suitable signal level. Initial amplification is performed in the 690 Optical fiber systems 1: intensity modulation/direct detection.[1]

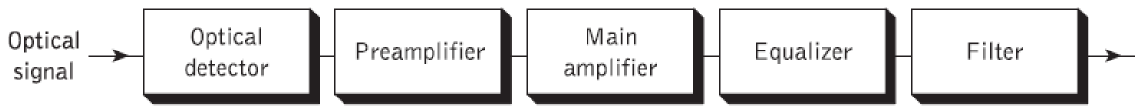


Figure (1.5) Block schematic showing the major element of an optical fiber receiver.

2.1 Introduction

Optical fibers are becoming dominant transmission media in long distance transmission, optical fiber transmission is used from a short distance below 1ft up to transoceanic distances in undersea cable. In fact all currently future plans in transoceanic cables are fiber optic based. Advantages of fiber optic as a medium of transmission are many from unlimited bandwidth, immunity from both radio frequency interference (RFI) and electromagnetic interference (EMI) to excellent attenuation properties, when compared with other transmission media like coaxial cable [6]. Attenuation is the loss of optical power as light travels along the fiber [7]. Signal attenuation is defined as the ratio of optical input power (Pin) to the optical output power (Pout) [1]. Optical input power is the power injected into the fiber from an optical source. Optical output power is the power received at the fiber end or optical detector. An intrinsic limit to the information carrying capacity of optical fibers is set by the wavelength dependence of the propagation constant, resulting in chromatic dispersion and in consequent bandwidth penalty[8]. Hence, the need of an efficient measurement technique to evaluate chromatic dispersion properties of optical fibers in an accurate and possibly simple way [8]. Chromatic dispersion in an optical fiber is the limiting factor in achieving very high bandwidth communication systems. Recent progress in optical fiber amplifier technology makes fiber dispersion the ultimate limiting factor for high-speed long-distance optical fiber transmission. Dispersion is the spreading out of a light pulse in time as it propagates down the fiber [1]. This is the dispersion spread that results in system bandwidth reduction or the fiber information-carrying capacity, it limits how fast information is transferred. The chromatic dispersion of optical fiber is critical to the design and construction of long-haul and high-speed optical communication systems and to the manufacture of optical fiber [9]. it is important to reduce the accumulated chromatic dispersion after long distance transmission. Dispersion in optical fiber includes modal dispersion and chromatic dispersion, chromatic dispersion consist of material dispersion and waveguide dispersion. Material dispersion is the result of the finite linewidth of the light source and the dependence of refractive index of the material on wavelength. Material dispersion is a type of chromatic dispersion. Waveguide dispersion is only important in single mode fibers. It is caused by the fact that some light travels in the fiber cladding compared to most light travels in the fiber core [10]. Since fiber cladding has lower refractive index than fiber core, light ray that travels in the cladding travels faster than that in the core .A major breakthrough came in 1970 when the first fiber with an attenuation below 20 dB km^{-1} was reported .This level of attenuation was seen as the absolute minimum that had to be achieved before an optical fiber system could in any way compete economically with existing communication systems. Since 1970 tremendous improvements have been made, leading to silica-based glass fibers with losses of less than 0.2 dB km−1 in the laboratory by the late 1980s.Hence, comparatively low-loss fibers have been incorporated into optical communication systems throughout the world. Although the fundamental lower limits for attenuation in silicate glass fibers were largely achieved by 1990, continuing significant progress has been made in relation to the removal of the water impurity peak within the operational wavelength range. The investigation of other material systems which can exhibit substantially lower losses when operated at longer wavelengths has, however, slowed down in relation to telecommunication transmission due to difficulties in the production of fiber with both optical and mechanical properties that will compete with silica. In particular, such mid-infrared (and possibly far-infrared) transmitting fibers continue to exhibit both relatively high losses and low strength. The other characteristic of primary importance is the bandwidth of the fiber. This is limited by the signal dispersion within the fiber, which determines the number of bits of information transmitted in a given time period. Therefore, once the attenuation was reduced to acceptable levels, attention was directed towards the dispersive properties of fibers Again, this has led to substantial improvements, giving wideband fiber bandwidths of many tens of gigahertz over a number of kilometers. In order to appreciate these advances and possible future developments, the optical transmission characteristics of fibers must be considered in greater depth. Therefore, in this chapter we discuss the mechanisms within optical fibers which give rise to the major transmission characteristics mentioned previously (attenuation and dispersion).

We begin the discussion of attenuation in section 2.2 and attenuation coefficient in section 2.2.1with the total losses incurred in optical fibers. The various attenuation mechanisms (material absorption, linear scattering, nonlinear scattering, fiber bends). The primary focus within these sections is on silica-based glass fibers. However, material systems which are employed for mid-infrared and far-infrared optical transmission. Dispersion in optical fibers is described later. Sections 2.3.1 and 2.4 deal with chromatic (intramural) and intermodal dispersion mechanisms and included in the latter section is a discussion of the modal noise phenomenon associated with intermodal dispersion.). This is followed in Section 2.5 by a review of the modification of the dispersion characteristics within single-mode fibers in order to obtain dispersion-shifted, dispersion-flattened and nonzero-dispersion-shifted fibers. The polarization within single-mode fibers which includes discussion of both polarization mode dispersion and the salient features of polarization-maintaining fibers. Nonlinear optical effects, which can occur at relatively high optical power levels within single-mode fibers.

2.2 Attenuation

The attenuation or transmission loss of optical fibers has proved to be one of the most important factors in bringing about their wide acceptance in telecommunications. As channel attenuation largely determined the maximum transmission distance prior to signal restoration, optical fiber communications became especially attractive when the transmission losses of fibers were reduced below those of the competing metallic conductors (less than 5 dB km−1).

Signal attenuation within optical fibers, as with metallic conductors, is usually expressed in the logarithmic unit of the decibel. The decibel, which is used for comparing two power levels, may be defined for a particular optical wavelength as the ratio of the input (transmitted) optical power Pi into a fiber to the output (received) optical power Po from the fiber as:

Number of decibels (dB) = $10\, log_{10} \frac{pi}{po}$ (2.1)

This logarithmic unit has the advantage that the operations of multiplication and division reduce to addition and subtraction, while powers and roots reduce to multiplication and division. However, addition and subtraction require a conversion to numerical values which may be obtained using the relationship:

Pi/Po = 10(dB/10) (2.2)

In optical fiber communications the attenuation is usually expressed in decibels per unit length (i.e. dB km−1) following:

$$\alpha dbL = 10\, log_{10} \frac{pi}{po} \qquad (2.3)$$

where αdB is the signal attenuation per unit length in decibels which is also referred to as the fiber loss parameter and L is the fiber length.

A number of mechanisms are responsible for the signal attenuation within optical fibers. These mechanisms are influenced by the material composition, the preparation and purification technique, and the waveguide structure. They may be categorized within several major areas which include material absorption, material scattering (linear and nonlinear scattering), curve and micro bending losses, mode coupling radiation losses and losses due to leaky modes. There are also losses at connectors and splices.[1]

2.2.1 Attenuation coefficient

Under quite general conditions, changes in the average optical power P of a bit stream propagating inside an optical fiber are governed by Beer's law:

$dP/dz = -\alpha P$ (2.4)

where α is the attenuation coefficient. If Pin is the power launched at the input end of a fiber of length L, the output power Pout from Eq. (2.5) is given by

Pout = Pin exp(−αL) (2.5)

It is customary to express α in units of dB/km by using the relation

$\alpha\ (dB/km) = -\frac{10}{L} log_{10}(\frac{po}{pi}) \approx 4.343\alpha$ (2.6)

and refer to it as the fiber-loss parameter. Fiber losses depend on the wavelength of transmitted light. Figure 2.15 shows the loss spectrum α(λ) of a single-mode fiber made in 1979 with 9.4-μm core diameter, $\Delta = 1.9 \times 10^{-3}$, and 1.1-μm cutoff wavelength.[5] The fiber exhibited a loss of only about 0.2 dB/km in the wavelength region near 1.55 μm, the lowest value first realized in 1979. This value is close to the fundamental limit of about 0.16 dB/km for silica fibers.

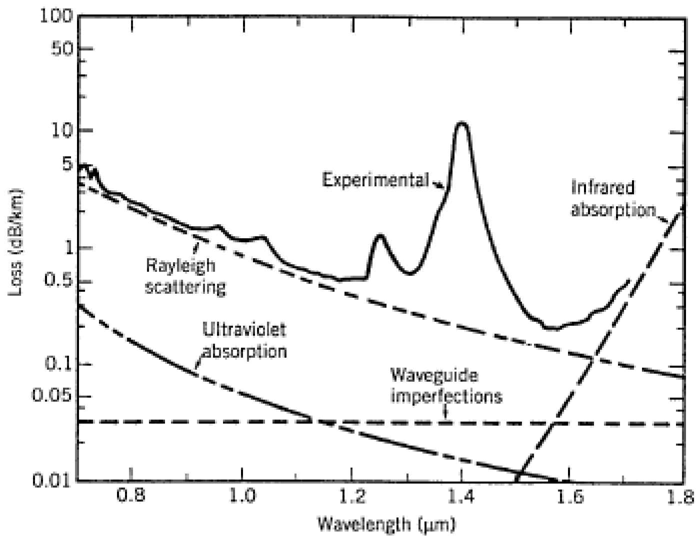


Figure (2.1): Loss spectrum of a single-mode fiber produced in 1979. Wavelength dependence of several fundamental loss mechanisms .

The loss spectrum exhibits a strong peak near 1.39 μm and several other smaller peaks. A secondary minimum is found to occur near 1.3 μm, where the fiber loss is below 0.5 dB/km. Since fiber dispersion is also minimum near 1.3 μm, this low-loss window was used for second-generation light wave systems. Fiber losses are considerably higher for shorter wavelengths and exceed 5 dB/km in the visible region, making it unsuitable for long-haul transmission. Several factors contribute to overall losses; their relative contributions are also shown in Fig. 2.1. The two most important among them are material absorption and Rayleigh scattering.[5]

2.2.2 Material Absorption

Material absorption can be divided into two categories. Intrinsic absorption losses correspond to absorption by fused silica (material used to make fibers) whereas extrinsic absorption is related to losses caused by impurities within silica. Any material absorbs at certain wavelengths corresponding to the electronic and vibrational resonances associated with specific molecules. For silica (SiO_2) molecules, electronic resonances occur in the ultraviolet region ($\lambda < 0.4$ μm), whereas vibrational resonances occur in the infrared region ($\lambda > 7$ μm). Because of the amorphous nature of fused silica, these resonances are in the form of absorption bands whose tails extend into the visible region. Their amount should be reduced to below 1 part per billion to obtain a loss level below 1 dB/km. Such high-purity silica can be obtained by using modern techniques. The main source of extrinsic absorption in state-of-the-art silica fibers is the presence of water vapors. A vibrational resonance of the OH ion occurs near 2.73 μm. Its harmonic and combination tones with silica produce absorption at the 1.39-, 1.24-, and 0.95-μm wavelengths.

The OH ion concentration is reduced to below 10^{-8}in modern fibers to lower the 1.39-μm peak below 1 dB. In a new kind of fiber, known as the dry fiber, the OH ion concentration is reduced to such low levels that the 1.39-μm peak almost disappears[5] .

2.2.3 linear scattering losses

2.2.3.1 Rayleigh Scattering

Rayleigh scattering is a fundamental loss mechanism arising from local microscopic fluctuations in density. Silica molecules move randomly in the molten state and freeze in place during Rayleigh scattering is a fundamental loss mechanism arising from local microscopic fiber fabrication. Density fluctuations lead to random fluctuations of the refractive index on a scale smaller than the optical wavelength λ. Light scattering in such a medium is known as Rayleigh scattering. The scattering cross section varies as λ−4. As a result, the intrinsic loss of silica fibers from Rayleigh scattering can be written as αR = C/λ4 where the constant C is in the range 0.7–0.9 (dB/km)-μm4, depending on the constituents of the fiber core. The contribution of Rayleigh scattering can be reduced to below 0.01 dB/km for wavelengths longer than 3 μm. Silica fibers cannot be used in this wavelength region, since infrared absorption begins to dominate the fiber loss beyond 1.6 μm.

2.2.3.2 Mie scattering

Linear scattering may also occur at inhomogeneities which are comparable in size with the guided wavelength. These result from the nonperfect cylindrical structure of the waveguide and may be caused by fiber imperfections such as irregularities in the core–cladding interface, core–cladding refractive index differences along the fiber length, diameter fluctuations, strains and bubbles. When the scattering inhomogeneity size is greater than λ/10, the scattered intensity which has an angular dependence can be very large.

The scattering created by such inhomogeneities is mainly in the forward direction and is called Mie scattering. Depending upon the fiber material, design and manufacture Mie scattering can cause significant losses. The inhomogeneities may be reduced by:

(a) removing imperfections due to the glass manufacturing process;

(b) carefully controlled extrusion and coating of the fiber;

(c) increasing the fiber guidance by increasing the relative refractive index difference.

By these means it is possible to reduce Mie scattering to insignificant levels.

2.3 Dispersion

Dispersion of the transmitted optical signal causes distortion for both digital and analog transmission along optical fibers. When considering the major implementation of optical fiber transmission which involves some form of digital modulation, then dispersion mechanisms within the fiber cause broadening of the transmitted light pulses as they travel along the channel. The phenomenon is illustrated in Figure 2.3, where it may be observed that each pulse broadens and overlaps with its neighbors, eventually becoming indistinguishable at the receiver input. The effect is known as inter symbol interference (ISI). Thus an increasing number of errors may be encountered on the digital optical channel as the ISI becomes more pronounced. The error rate is also a function of the signal attenuation on the link and the subsequent signal-to-noise ratio (SNR) at the receiver. However, signal dispersion alone limits the maximum possible bandwidth attainable with a particular optical fiber to the point where individual symbols can no longer be distinguished.

For no overlapping of light pulses down on an optical fiber link the digital bit rate BT must be less than the reciprocal of the broadened (through dispersion) pulse duration (2τ).

Hence: $BT \leq \frac{1}{2\tau}$ (2.7)

This assumes that the pulse broadening due to dispersion on the channel is τ which dictates the input pulse duration which is also τ. Hence Eq. (2.8) gives a conservative estimate of the maximum bit rate that may be obtained on an optical fiber link as 1/2τ. Another more accurate estimate of the maximum bit rate for an optical channel with dispersion may be obtained by considering the light pulses at the output to have a Gaussian shape with an rms width of σ. Unlike the relationship given in Eq. (2.8), this analysis allows for the existence of a certain amount of signal overlap on the channel, while avoiding any SNR penalty which occurs when ISI becomes pronounced. The maximum bit rate is given approximately by:

$$D = \frac{d}{d\lambda}\left(\frac{1}{v_g}\right) = -\frac{2\pi c}{\lambda^2}\beta_2. \qquad (2.8)$$

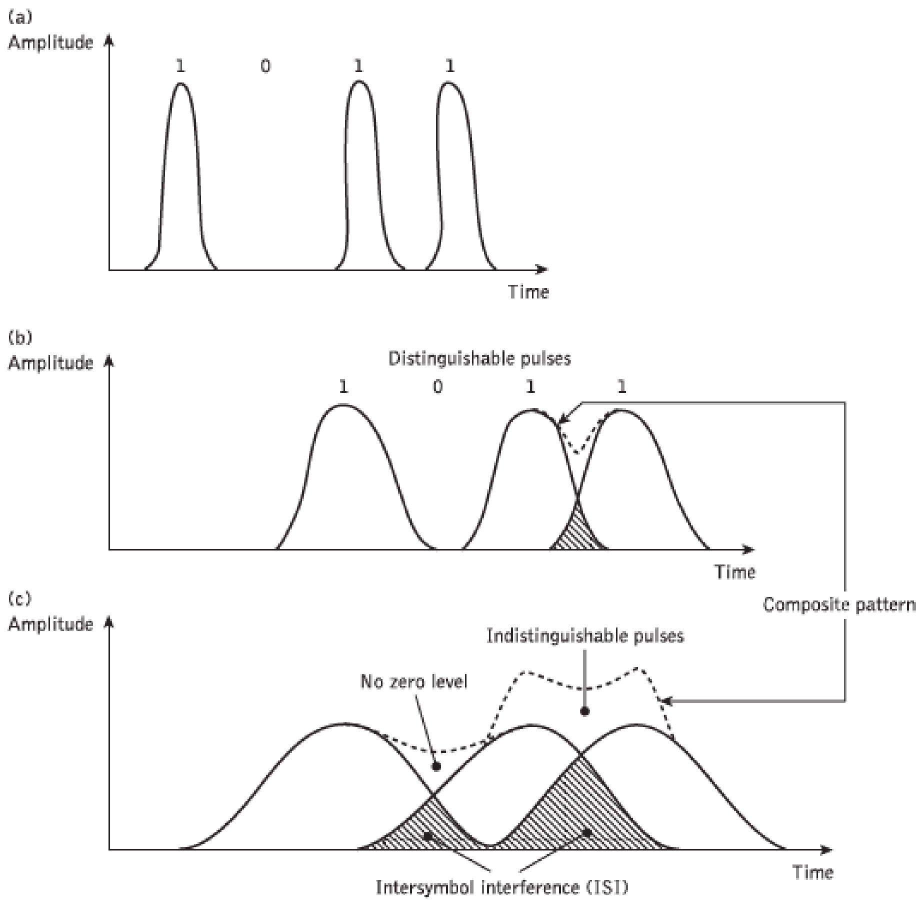


Figure (2.2) An illustration using the digital bit pattern 1011 of the broadening of light pulses as they are transmitted along a fiber: (a) fiber input; (b) fiber output at a distance L1; (c) fiber output at a distance L2 > L1

The conversion of bit rate to bandwidth in hertz depends on the digital coding format used. For metallic conductors when a no return-to-zero code is employed, the binary 1 level is held for the whole bit period τ. In this case there are two bit periods in one wavelength (i.e. 2 bits per second per hertz), as illustrated in Figure 2.3(a).Hence the maximum bandwidth B is one-half the maximum data rate or:

BT(max) = 2B

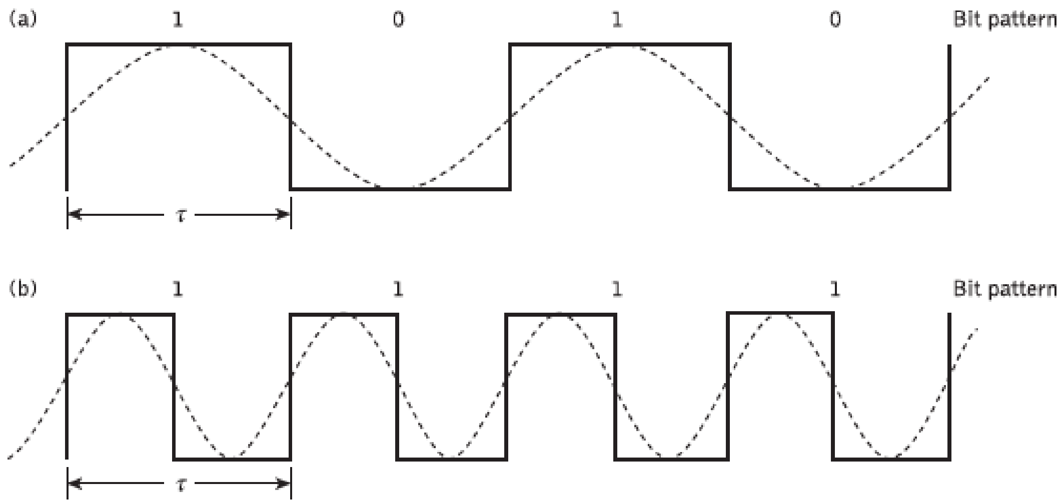


Figure (2.3) Schematic illustration of the relationships of the bit rate to wavelength for digital codes: (a) nonreturn-to-zero (NRZ); (b) return-to-zero (RZ)

data rate is equal to the bandwidth in hertz (i.e. 1 bit per second per hertz) and thus BT = B. The bandwidth B for metallic conductors is also usually defined by the electrical 3 dB points (i.e. the frequencies at which the electric power has dropped to one-half of its constant maximum value). However, when the 3 dB optical bandwidth of a fiber is considered it is significantly larger than the corresponding 3 dB electrical bandwidth. Hence, when the limitations in the bandwidth of a fiber due to dispersion are stated (i.e. optical bandwidth Bopt), it is usually with regard to a return to zero code where the bandwidth in hertz is considered equal to the digital bit rate. Within the context of dispersion the bandwidths expressed in this chapter will follow this general criterion unless otherwise stated., when electro-optic devices and optical fiber systems are considered it is more usual to state the electrical 3 dB bandwidth, this being the more useful measurement when interfacing an optical fiber link to electrical terminal equipment. Unfortunately, the terms of bandwidth measurement are not always made clear and the reader must be warned that this omission may lead to some confusion when specifying components and materials for optical fiber communication systems.

Figure 1.4 shows the three common optical fiber structures, namely multimode step index, multimode graded index and single-mode step index, while diagrammatically illustrating the respective pulse broadening associated with each fiber type. It may be observed that the multimode step index fiber exhibits the greatest dispersion of a transmitted light pulse and the multimode graded index fiber gives a considerably improved performance. Finally, the single-mode fiber gives the minimum pulse broadening and thus is capable of the greatest

transmission bandwidths which are currently in the gigahertz range, whereas transmission via multimode step index fiber is usually limited to bandwidths of a few tens of megahertz. However, the amount of pulse broadening is dependent upon the distance the pulse travels within the fiber, and hence for a given optical fiber link the on usable bandwidth is dictated by the distance between regenerative repeaters.
distance the light pulse travels before it is reconstituted). Thus the measurement of the dispersive properties of a particular fiber is usually stated as the pulse broadening in time over a unit length of the fiber (i.e. ns km−1).

2.3.1 Chromatic dispersion

Chromatic or intramural dispersion may occur in all types of optical fiber and results from the finite spectral line width of the optical source. Since optical sources do not emit just a single frequency but a band of frequencies (in the case of the injection laser corresponding to only a fraction of a percent of the center frequency, whereas for the LED it is likely to be a significant percentage), then there may be propagation delay differences between the different spectral components of the transmitted signal. This causes broadening of each transmitted mode and hence intramural dispersion. The delay differences may be caused by the dispersive properties of the waveguide material (material dispersion) and also guidance effects within the fiber structure (waveguide dispersion).

2.3.2 Material Dispersion

Pulse broadening due to material dispersion results from the different group velocities of the various spectral components launched into the fiber from the optical source. It occurs when the phase velocity of a plane wave propagating in the dielectric medium varies nonlinearly with wavelength, and a material is said to exhibit material dispersion when the second differential of the refractive index with respect to wavelength is not zero (i.e. dn2/dλ2 ≠ 0). The pulse spread due to material dispersion may be obtained by considering the group delay τg in the optical fiber which is the reciprocal of the group velocity υg defined by. Hence the group delay is given by:

$$\tau_g = \frac{d\beta}{d\omega} = \frac{1}{c}\left(n_1 - \lambda \frac{dn_1}{d\lambda}\right) \quad (2.9)$$

where n_1 is the refractive index of the core material. The pulse delay τ_m due to material dispersion in a fiber of length L is therefore:

2.3.3 Waveguide dispersion

The waveguiding of the fiber may also create chromatic dispersion. This results from the variation in group velocity with wavelength for a particular mode. Considering the ray theory approach, it is equivalent to the angle between the ray and the fiber axis varying with wavelength which subsequently leads to a variation in the transmission times for the rays, and hence dispersion. For a single mode whose propagation constant is β, the fiber exhibits waveguide dispersion when $d^2 \beta/d\lambda^2 \neq 0$. Multimode fibers, where the majority of modes propagate far from cutoff, are almost free of waveguide dispersion and it is generally negligible compared with material dispersion (≈0.1 to 0.2 ns km^{-1}).However, with single-mode fibers where the effects of the different dispersion mechanisms are not easy to separate, waveguide dispersion may be significant.[5].

2.4 Intermodal dispersion

Pulse broadening due to intermodal dispersion (sometimes referred to simply as modal or mode dispersion) results from the propagation delay differences between modes within a multimode fiber. As the different modes which constitute a pulse in a multimode fiber travel along the channel at different group velocities, the pulse width at the output is dependent upon the transmission times of the slowest and fastest modes. Thus multimode step index fibers exhibit a large amount of intermodal dispersion which gives the greatest pulse broadening. However, intermodal dispersion in multimode fibers may be reduced by adoption of an optimum refractive index profile which is provided by the near-parabolic profile of most graded index fibers. Hence, the overall pulse broadening in multimode graded index fibers is far less than that obtained in multimode step index fibers (typically by a factor of 100). Thus graded index fibers used with a multimode source give a tremendous bandwidth advantage over multimode step index fibers.

Under purely single-mode operation there is no intermodal dispersion and therefore pulse broadening is solely due to the intermodal dispersion mechanisms. In theory, this is the case with single-mode step index fibers where only a single mode is allowed to propagate. Hence they exhibit the least pulse broadening and have the greatest possible bandwidths, but in general are only usefully operated with single-mode sources.

In order to obtain a simple comparison for intermodal pulse broadening between multimode step index and multimode graded index fibers, it is useful to consider the geometric optics picture for the two types of fiber.[5].

3.1 Introduction

In a fiber-optic transmission, a beam of light, an optical signal, serves as the information carrying vehicle. Both analog and digital information are supported. In operation, the light is launched or fed into the fiber. The fiber itself is composed of two layers, the cladding and the core. Due to their different physical properties, light can travel down the fiber by a process called total internal reflection.

In essence, the light travels through the fiber via a series of reflections that take place where the cladding and core meet, the cladding-core interface. When the light reaches the end of the line, it is picked up by a light-sensitive receiver, and after a series of steps, the original signal is reproduced. To sum up, a video camera's output or other such signal is converted into an optical signal in an FO system. It is subsequently transmitted down the line and converted back following its Reception [1].

Computer-aided modeling and simulation software programs are essential tools to predict how an optical communication component, link, or network will function and perform. These programs are able to integrate component, link, and network functions, thereby making the design process more efficient, less expensive, and faster.

The tools typically are based on graphical interfaces that include a library of icons containing the operational characteristics of devices such as optical fibers, couplers, light sources, optical amplifiers, and optical filters, plus the measurement characteristics of instruments such as optical spectrum analyzers, power meters, and bit error rate testers. To check the capacity of the network or the behavior of passive and active optical devices, network designers invoke different optical power levels, transmission distances, data rates, and possible performance impairments in the simulation programs.

3.2 Simulation Setup:

In this chapter, the simulation program "OPTISYSTEM" used to simulation the design of coming SMF -28 single mode optical fiber.

Table 3.1The transmitter and receiver have the following specifications:

Transmitter	Pseudo random bit sequence	2.5GBit/s
	Optical source	CW laser
	Pulse generator	NRZ
	Modulator	Mach-Zehnder
Fiber	Wave length	1550nm
	Dispersion	16.75ps/nm/km
	Attenuation	0.2db/Km
	Dispersion slope	0.075 ps/nm^2/k
Receiver	Sensitivity	-30 dbm

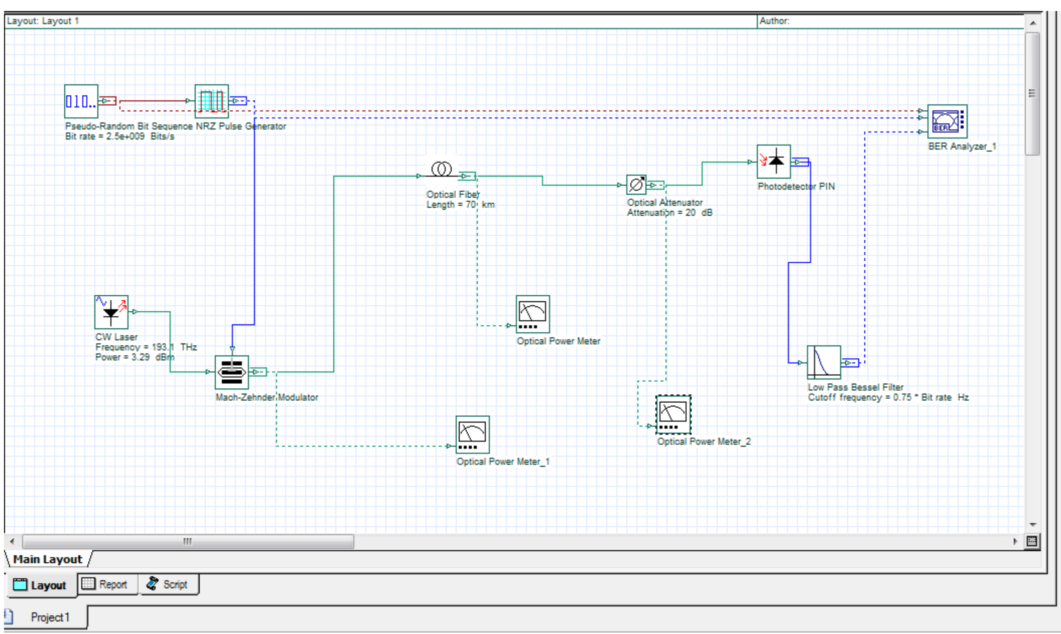


Fig 3.1 simulation setup.

3.3. Attenuation Effects:

Attenuation of a light signal as it propagates along a fiber is an important consideration in the design of an optical communication system, since it plays a major role in determining the maximum transmission distance between a transmitter and a receiver. The attenuation effects at varies distances are shown in figure (3.2), which calculated using equation (2.1) and the values of the output against distances is shown in Table [3,2] . The simulation result of optical signal propagation through SMF refers to: when the distance increase the output power will decrease. This relation is described in fig (3,2).

Table 3.2 attenuation effects at varies distances

Length Fiber	Output Fiber power
1Km	-0.2dB
10Km	-2dB
30Km	-6dB
50Km	-10dB
70Km	-14dB

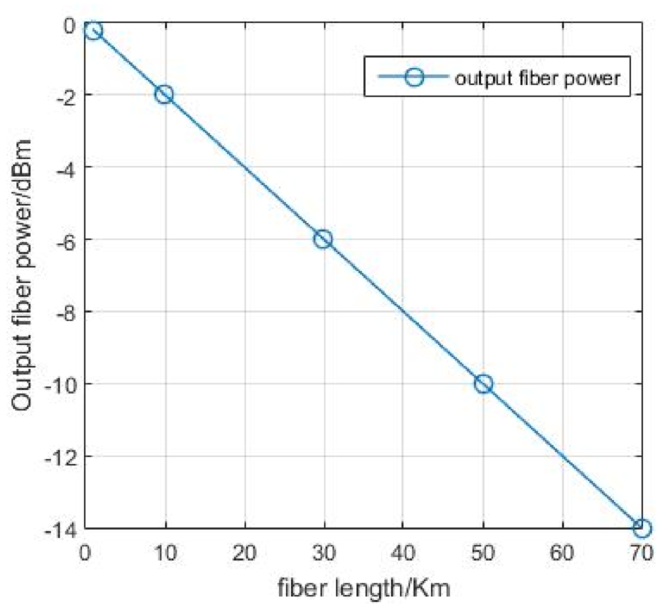


Figure (3.2) The relationship between length fiber and output fiber power.

3.4 Dispersion Effects:

In addition to being attenuated, an optical signal becomes increasingly distorted as it travels along a fiber. This distortion is a consequence of intermodal and intermodal dispersion effects. Intermodal dispersion is pulse spreading that occurs within an individual mode and thus is of importance in single-mode fiber. The dispersion effects on the optical signal at varies distances are shown in figures ((3.3), and (3.4)) .The simulation result of dispersion effects refers to : when the distances increase the pulse width will increase as shown in table [3,3].Thus overlapping between pulses may be occur which causes distortion in information.

Table 3.3 Q- factor and BER effects at varies distances.

Length Fiber	Q Factor	BER
1Km	53.6799	0
10Km	36.1235	$4.849e^{-286}$
30Km	15.4173	$6.151e^{-054}$
40Km	6.7165	$9.289e^{-012}$
50Km	2.909	0.00181

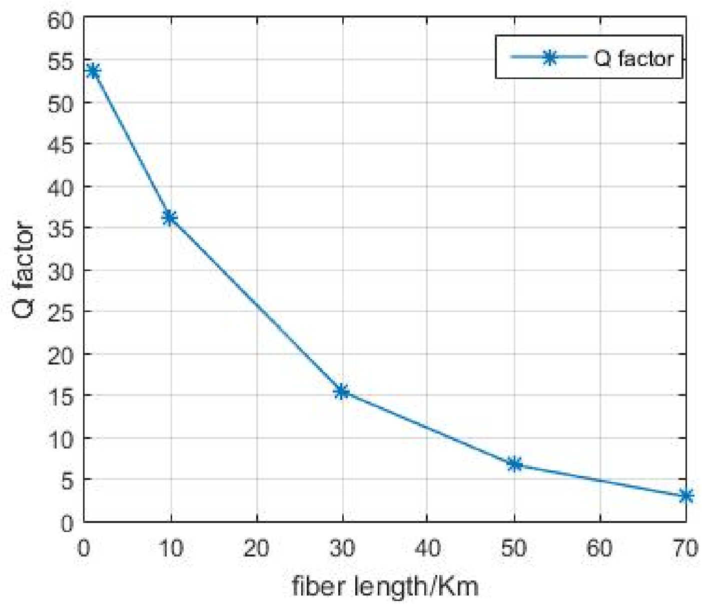


Figure (3.3) The relationship between length fiber and Q factor.

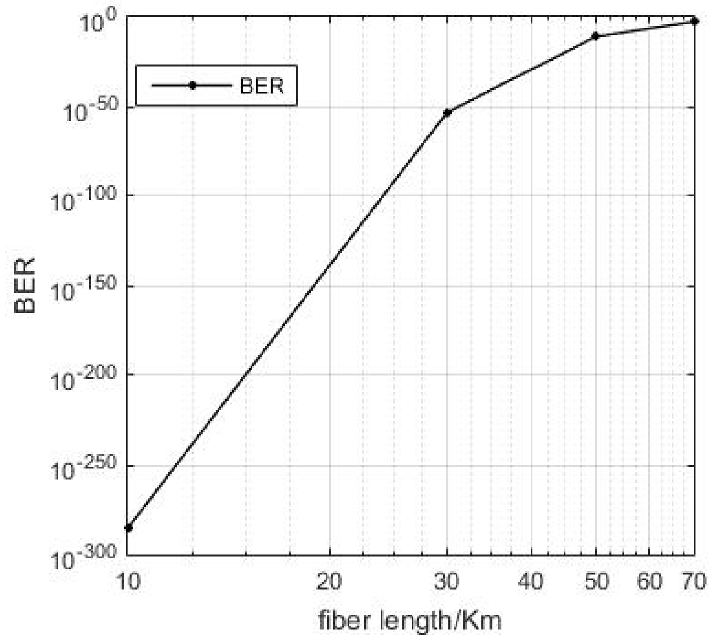
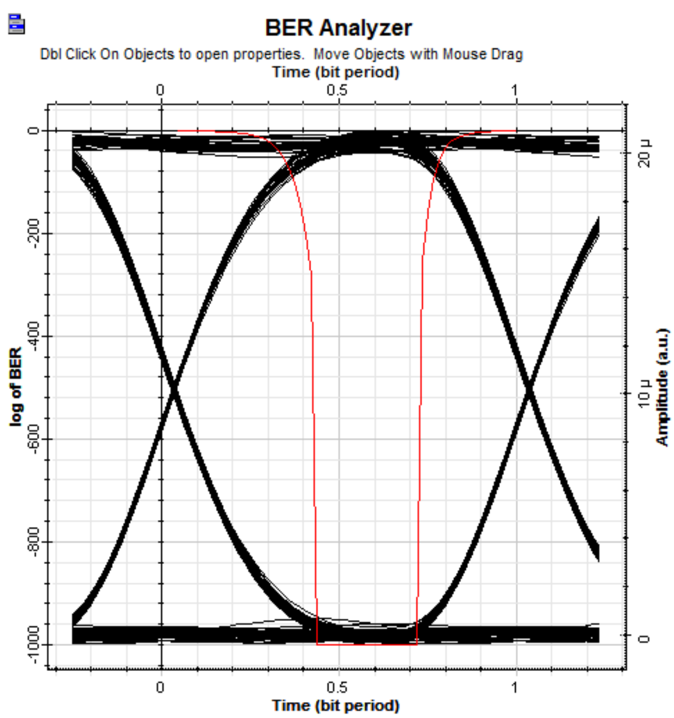
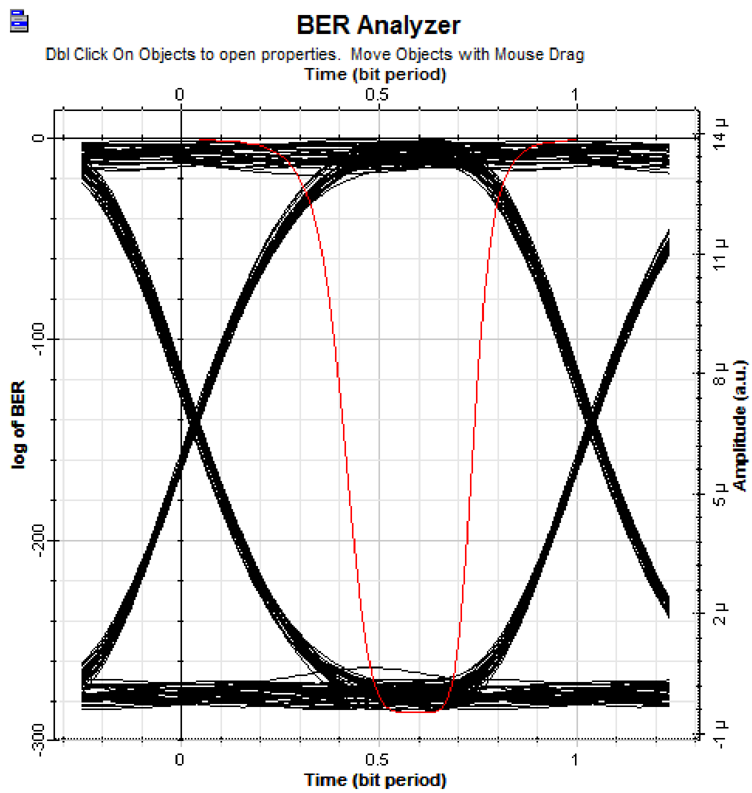


Figure (3.4) The relationship between length fiber and BER.

The relationship between pulse width and distances is shown in fig (3.4). Table 3.3 illustrate the specifications of the coming SMF -28 single mode fibers, the dispersion and total broadening a of an optical pulse over a length of fiber L are calculated from equation (2. 8).

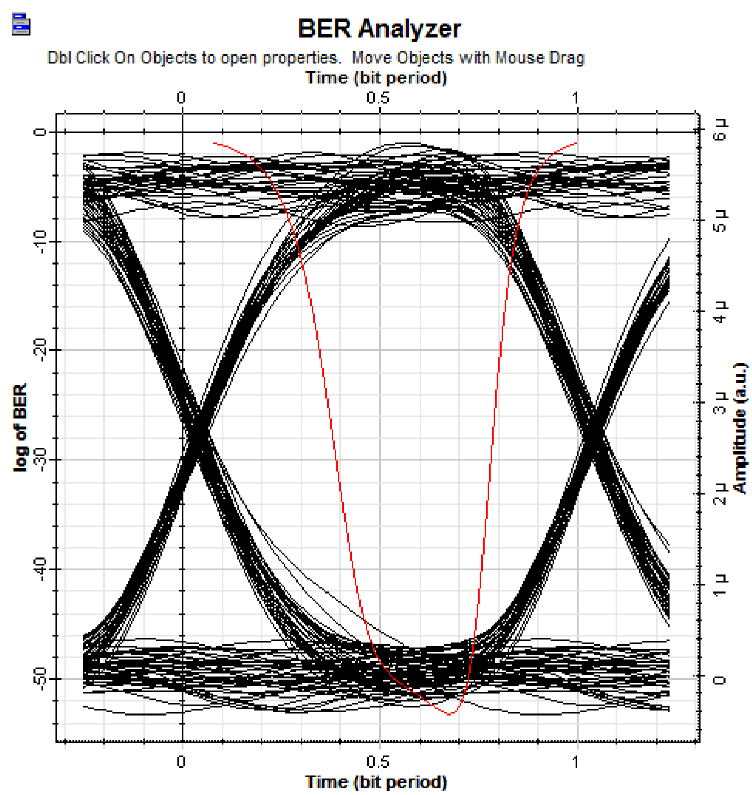


1Km



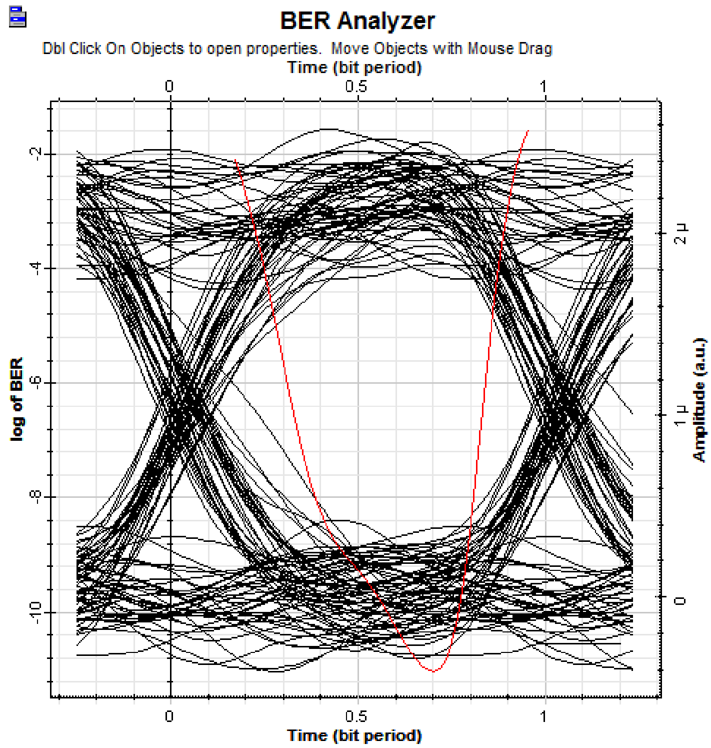
BER Analyzer
Dbl Click On Objects to open properties. Move Objects with Mouse Drag
Time (bit period)
log of BER
Amplitude (a.u.)

10Km

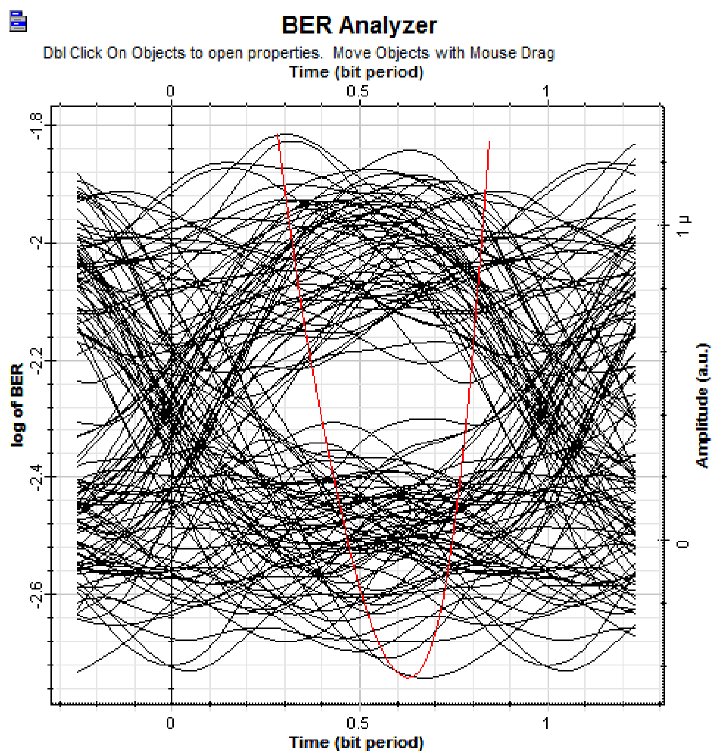


BER Analyzer
Dbl Click On Objects to open properties. Move Objects with Mouse Drag
Time (bit period)
log of BER
Amplitude (a.u.)

30Km



50Km



70Km

Figure 3.5 eye diagram for varies distances optical fiber.

4.1 Conclusion

In this project, simulation methods are presented on a single mode optical fiber link system, using OPTISYSTEM .The signal with wavelength of 1550 nm was used, to study the effects of attenuation and dispersion through the fiber optic length by computer simulations. The results indicate that these effects increase with increasing the distance through the fiber optic length. As propagation continues attenuation increases. Ultimately, the propagating signal is attenuated until it is at some minimal, detectable, level.

4.2 Suggest for future work

1- Study and simulation the noise source in optical receiver.

2- Simulation the non -linear effects in SMF.

3- Simulation of the multimode fiber.