DISPERSION COMPENSATION IN A SINGLE MODE OPTICAL FIBRE COMMUNICATION SYSTEM

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M.Eng. Thesis, 2015

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M.ENG. (ELECTRICAL)

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M.Eng. Thesis, 2015

DECLARATION

I hereby declare that this work is the product of my own research efforts, undertaken under the supervision of Dr. A.U. Jibia and has not been presented and will never be presented elsewhere for the award of a degree or certificate. All sources have been duly acknowledged.

Signature………………………………………………

Date…………………………..

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CERTIFICATION

This is to certify that the research work for this thesis “Dispersion compensation in a single-mode optical fibre communication system” and subsequent preparation of this thesis by Muyideen Jimoh (SPS/11/MEE/00027) were carried out under my supervision.

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APPROVAL

This is to certify that the thesis titled "**Dispersion compensation in a single mode optical fibre communication system"** by Muyideen Jimoh, meets the requirements and regulations governing the award of the Master of Engineering(Electrical) degree of Bayero University and is approved for its contribution to knowledge and literary presentation.

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My profound appreciation goes to my parents, my family and friends for their full support, contributions and prayers toward the success of my carrier. May Almighty Allah reward them, Ameen.

DEDICATION

This dissertation is dedicated to my parents, brothers and sisters for their support, love and prayers.

ABSTRACT

This work is on dispersion compensation in a single mode optical fibre communication system. Dispersion and fibre attenuation pose a great problem in detection of optical signals. Dispersion causes pulse broadening and signal distortion that ultimately limits the bandwidth and usable length of the fibre cable. In this work, the technique of dispersion compensation using Fibre Bragg Grating (FBG) is used to mitigate the problems of dispersion and attenuation. OPTISYS (optical simulator) simulation environment is used to create a model for dispersion compensation using single mode fibres. A 10Gb/s NRZ (non-return-to-zero) signal is launched onto 100km long standard single mode fibre . Input power values have been varied from 10 to 30dBm by using the parametric run feature in Optisys. It was observed that after the transmission of the signal, the pulse broadening tends to increase significantly immediately before the compensation as a result of dispersion effects. But, after the compensation has been achieved, the received signal tends to regain its original form. This arrangement perfectly restores the original input signal at the receiver. Between 10dBm and 20dBm input power, the received signal tends to perfectly regain its original form, but between 25dBm and 30dBm, the received signal was a little bit distorted as a result of the high input power. This clearly shows that dispersion effects can be best compensated at low input power. All results are analysed using OPTSIM simulation at 10Giga bits per second (Gb/s) transmission systems. Therefore, in most of the previous works reviewed above, there are some limitations in the compensation ranging from the use of 'DCF or FBG alone as a compensator' to the use of 'eye diagram analyzer to display the nature of the

signals'. Thus, this work uses not only FBG as a dispersion compensator but combines it with optical attenuator and optical Bessel filter which makes the compensation changeable. It also uses optical spectrum analyzer(OSA) to display the nature of the signal being transmitted so that the nature of the signal before and after compensation can easily be seen and understood. This helps to show how accurate the signal is being compensated.

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LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

V	Normalized frequency parameter
λ	Wavelenght
c	Speed of light
f	Frequency of light
n	Refractive index
β	Periodic frequency of the plane wave
β	propagation constant along the fibrelenght
□*1*	Refractive index of core
□*2*	Refractive index of cladding
□□□□	Output power
□□□	Input power
L	Length
A	Pulse complex envelope
□*1*	Group velocity dispersion
□*2*	Second order dispersion
α	Attenuation coefficient
□*0*	Non-linearity constant
Ď	Linear part of the non-linear Schrodinger equation
□□	Complex envelope propagating through the linear part of the Schrodinger Equation
□□	Complex envelope propagating through the nonlinear part of the Schrodinger

	Equation
H(ω)	Frequency response of the filter
ω	Angular frequency
ω*0*	Center frequency
D	Dispersion coefficient
□□	Dispersion Length
□*0*	Full width at half maximum
t	Time
□′	Length of disersion compensation fibre
□′	Dispersion coefficient of the dispersion compensation fibre
□*2′*	Propagation constant of the dispersion compensation fibre
Dt	Sampling period
□□	Sampling frequency
□□	Time unit
i	Complex vector notation
dB	Decibel
Km	Kilometer
nm	Nanometer
Mbps	Mega bytes per seconds
Gbps	Giga bytes per seconds
MHz	Mega hertz
THz	Tera hertz
GHz	Giga hertz
ps/nm-km	Pico-seconds per nanometer-kilometer
TE	Transverse electric
TM	Transverse magnetic

TE0	Transverse electric with one field maxima
NA	Numeric aperture
LED	Light emiting diode
WDM	Wavelenght division multiplexing
GVD	Group velocity dispersion
X-talk	Cross talk
PMD	Polarization mode dispersion
ASE	Amplified spontaneous emission
SPM	Self phase modulation
XPM	Cross phase modulation
SBS	Simulated Brillouin scattering
SM	Single mode
MM	Multimode
FWHM	Full width at half maxima
FFT	Fast Fourier transform
IFFT	Inverse fast Fourier transform
EDFA	Erbium doped fibre amplifier
DSF	Dispersion shifted fibre
FBG	Fiber Bragg Gratings
DCG	Dispersion compensation gratings
NLSE	Non-linear Schrodinger equation
OOK	On-off keying
MSSI	Mid-span spectral inversion

CHAPTER ONE

INTRODUCTION

1.1 DISPERSION

The broadening of light pulses, called dispersion, is a critical factor limiting the quality of signal transmission over optical links. Dispersion causes signal distortion that ultimately limits the bandwidth and the transmission distance of the signal. Dispersion compensation is used to avoid the chromatic dispersion of optical element. This goal can be achieved by avoiding excessive temporal broadening of the pulse or the distortion of signals. Dispersion compensation is an important issue for fiber–optic links[1]. Strong dispersive broadening of modulated signal can occur in cases with higher data rates. Without dispersion compensation, each signal would be broadened so much that it would strongly overlap with a number of neighboured symbols. Even for moderate broadening, significant inter-symbol interference can strongly distort the detected signal. Therefore, it is essential to compensate the dispersion before detecting the signal. Operating companies need to measure the dispersion of their networks to assess the possibility of upgrading them to higher transmission speeds, or to evaluate the need for compensation. Dispersion in optical fibre include modal dispersion and chromatic dispersion, chromatic dispersion consist of material dispersion and waveguide dispersion[2,3]. Chromatic type are discussed as :

1.1.1 Material Dispersion

Material dispersion is the result of the finite linewidth of the light source and the dependence of the refractive index of the material on wavelength. Material dispersion is a type of chromatic dispersion. Chromatic dispersion is the pulse spreading that arises because the velocity of light through a fibre depends on its wavelength.

1.1.2 Waveguide Dispersion

Waveguide dispersion is only important in single mode fibres. It is caused by the fact that some light travels in the fibre cladding compared to most light travelling in the fibre core. Since fibre cladding has lower refractive index than fibre core, light ray that travels in the cladding travels faster than that in the core. Waveguide dispersion is also a type of chromatic dispersion. It is a function of fibre core size, normalized frequency parameter, wavelength and light source linewidth. While the difference in refractive indices of single mode fibre core and cladding are minuscule, they can still become a factor over great distances. It can also combine with material dispersion to create a nightmare in single mode chromatic dispersion. Various tweaks in the design of single mode fibres can be used to overcome waveguide dispersion, and manufacturers are constantly refining their processes to reduce its effects[4,5].

1.2 MOTIVATION AND SIGNIFICANCE OF THE STUDY

Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. [6]. Optical fiber is used by many telecommunications companies to transmit telephone signals, internet communication, and cable television signals. Due to its much lower attenuation and interference, optical fiber has large advantages over existing copper wire in long-distance and high-demand applications. The evolution of optical technologies makes the transmission of Gbits information possible over considerable distance compared with conventional copper cable. Today, with the advent of multimedia services, the demand of high data rates is high. Higher data rate optical technologies that would transmit up to 500 Gbits/s or more are required[7].

1.3 AIM AND OBJECTIVES

The aim of this project is to achieve dispersion compensation in a single-mode optical fibre communication system. The aim of the project would be achieved through the following objectives:

1. Development of a dispersion compensation model using optisystem design environment to minimize the effects of dispersion in the system.
2. Running of the dispersion compensation model using optisystem design environment.

1.4 METHODOLOGY

A flow chart diagram for dispersion compensation of a single mode fibre link is designed. Optisys (optical simulator) simulation environment is used to create a model for dispersion compensation using single mode fibres to minimize the effects of dispersion in the system. Optisys simulation environment is then used to run the developed model. The technique of dispersion compensation using a Fibre Bragg Grating (FBG), optical attenuator and optical Bessel filter is used to minimize the problems of dispersion in the system.

1.5 SCOPE AND LIMITATION

The research focuses on dispersion compensation in a single mode optical fibre communication system. This work limits dispersion compensation at 10Gb/s transmission system.

1.6 THESIS ORGANISATION

Chapter one of the research gives the introduction of the research work. Chapter two presents a detailed literature review of dispersion. Chapter three presents the research methodology.

Chapter four focuses on the simulation results and discussion, and finally chapter five highlights the conclusion.

CHAPTER TWO

LITERAURE REVIEW

2.1 INTRODUCTION

This chapter covers the theoretical background of Dispersion. In the following paragraphs, dispersion will be reviewed. A brief background will be given and the process will be described from a theoretical point of view. The basic structure of optical fibre, types and effects of dispersion and the impairments in optical fibre transmission systems such as attenuation and dispersion will be discussed. Several management techniques will be briefly mentioned with their limitations.

2.2 THEORY

Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. Information is modulated and sent as a series of pulses representing binary encoded data. Data can be transmitted with few errors, as long as these pulses travel through the fiber without changing their shape. But usually, as they travel through the fiber, the pulses start to spread, losing their original shape and overlap each other becoming indistinguishable at the receiver input. Dispersion is the general term applied to this cause and this effect is known as inter-symbol interference[8].

Dispersion was initially a problem when multimode step index fiber were introduced. Multimode graded-index fiber improved the situation, but when they are well graded some limitations are added to the information capacity of multimode fibers. Single-mode fiber eliminated the multipath dispersion and left only chromatic dispersion and polarization mode dispersion to be dealt with by engineers. Both of them causes distortion and broadening of pulse[9,10].

2.3 DISPERSION TYPES

There are two different types of dispersion in optical fibers. The types are intramodal and intermodal dispersion. Intramodal, or chromatic, dispersion occurs in all types of fibers. Intermodal, or modal, dispersion occurs only in multimode fibers. Each type of dispersion mechanism leads to pulse spreading. As a pulse spreads, energy is overlapped[11]. This condition is shown in figure 2.1. The spreading of the optical pulse as it travels along the fiber limits the information capacity of the fiber.

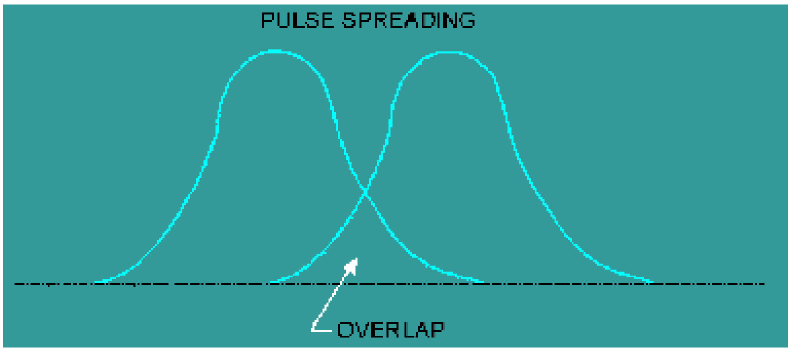

Figure 2.1 pulse overlap

- **Chromatic Dispersion:** Chromatic dispersion depends primarily on fiber materials. There are two types of chromatic dispersion. The first type is material dispersion. The second type is waveguide dispersion[11]
- **Material dispersion:** Is a phenomena whereby material cause a bundle of light to spread out as it propagates.A laser pulse, while almost monochromatic, contains a continuum of wavelengths in a small range. The index of refraction of a material is dependent on the wavelength, so each frequency component actually travels at a slightly different speed. As the distance increases, the pulse becomes broader. This phenomena is not helpful in optical communications. On the contrary, material dispersion limits how much data can

be sent, as the pulse will overlap and information will be lost. Ongoing research is attempting is attempting to reduce the effects of material dispersion. Promising method include greaded-index fibres and optical temporal solitons. [11,12]

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

  Modal dispersion causes the input light pulse to spread. The input light pulse is made up of a group of modes. As the modes propagate along the fiber, light energy distributed among the modes is delayed by different amounts. The pulse spreads because each mode propagates along the fiber at different speeds. Since modes travel in different directions, some modes travel longer distances. **Modal dispersion** occurs because each mode travels a different distance over the same time span, as shown in figure 2.2. The modes of a light pulse that enter the fiber at one time exit the fiber a different times[12]. This condition causes the light pulse to spread. As the length of the fiber increases, modal dispersion increases

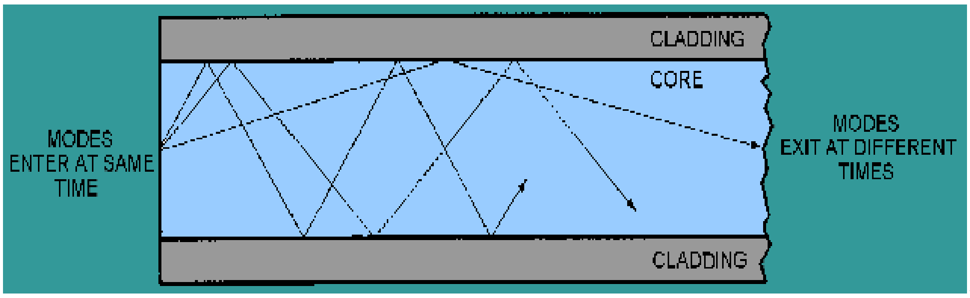

Figure 2.2 Distance traveled by each mode over the same time span

Modal dispersion is the dominant source of dispersion in multimode fibers. Modal dispersion does not exist in single mode fibers. Single mode fibers propagate only the fundamental mode. Therefore, single mode fibers exhibit the lowest amount of total dispersion. Single mode fibers also exhibit the highest possible bandwidth.

2.4 BASIC STRUCTURE OF AN OPTICAL FIBRE

The basic structure of an optical fiber consists of three parts; the **core**, the **cladding**, and the **coating** or **buffer**. The basic structure of an optical fiber is shown in figure 2.3. The **core** is a cylindrical rod of dielectric material. Dielectric material conducts no electricity. Light propagates mainly along the core of the fiber. The core is generally made of glass. The **core** is described as having a radius of (a) and an index of refraction n_1. The core is surrounded by a layer of material called the **cladding**. Even though light will propagate along the fiber core without the layer of cladding material, the cladding does perform some necessary functions[13].

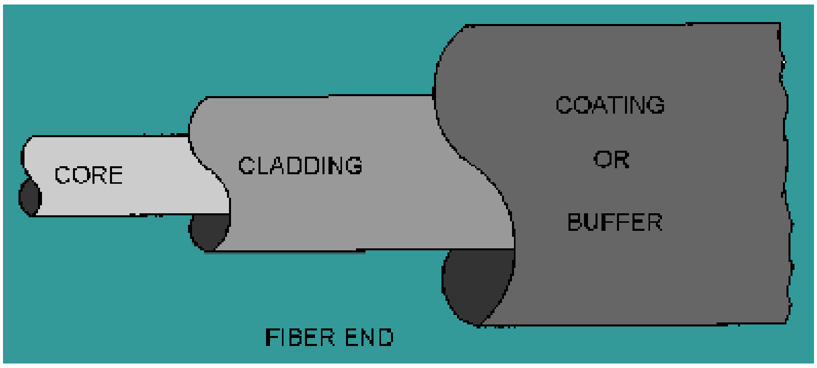

Figure 2.3. Basic structure of an optical fibre

The **cladding** layer is made of a dielectric material with an index of refraction n_2. The index of refraction of the cladding material is less than that of the core material. The cladding is generally made of glass or plastic. The cladding performs the following functions:

- Reduces loss of light from the core into the surrounding air
- Reduces scattering loss at the surface of the core
- Protects the fiber from absorbing surface contaminants
- Adds mechanical strength

For extra protection, the cladding is enclosed in an additional layer called the **coating** or **buffer**. The **coating** or **buffer** is a layer of material used to protect an optical fiber from physical damage. The material used for a buffer is a type of plastic. The buffer is elastic in nature and prevents abrasions The buffer also prevents the optical fiber from scattering losses caused by microbends. Microbends occur when an optical fiber is placed on a rough and distorted surface[13].

2.5 OPTICAL FIBRE TYPES

Optical fibres are characterized by their structure and by their properties of transmission. Basically, optical fibres are classified into two types. The first type is single mode fibres. The second type is multimode fibres. As each name implies, optical fibres are classified by the number of modes that propagate along the fibre. As previously explained, the structure of the fibre can permit or restrict modes from propagating in the fibre. The basic structural difference is the core size. Single mode fibres are manufactured with the same materials as multimode fibres. Single mode fibres are also manufactured by following the same fabrication process as multimode fibres.

2.5.1 Single Mode Fibres

In fiber-optic communication, a **single-mode optical fiber** (**SMF**) is an optical fiber designed to carry light only directly down the fiber - the transverse mode. Modes are the possible solutions of the Helmholtz equation for waves, which is obtained by combining Maxwell's equations and the boundary conditions. These modes define the way the wave travels through space, i.e. how the wave is distributed in space. Waves can have the same mode but have different frequencies. This is the case in single-mode fibers, where we can have waves with different frequencies, but of the same mode, which means that they are distributed in space in the same way, and that gives us a single ray of light. Although the ray travels parallel to the length of the fiber, it is often called transverse mode since its electromagnetic vibrations occur perpendicular (transverse) to the length of the fiber. The 2009 Nobel Prize in Physics was awarded to Charles K. Kao for his theoretical work on the single-mode optical fiber [14].

Like multi-mode optical fibers, single mode fibers do exhibit modal dispersion resulting from multiple spatial modes but with narrower modal dispersion. Single mode fibers are therefore better at retaining the fidelity of each light pulse over longer distances than multi-mode fibers. For these reasons, single-mode fibers can have a higher bandwidth than multi-mode fibers. Equipment for single mode fiber is more expensive than equipment for multi-mode optical fiber, but the single mode fiber itself is usually cheaper in bulk. A typical single mode optical fiber has a core diameter between 8 and 10.5 µm and a cladding diameter of 125 µm. There are a number of special types of single-mode optical fiber which have been chemically or physically altered to give special properties, such as dispersion-shifted fiber and nonzero dispersion-shifted fiber. Data rates are limited by polarization mode dispersion and chromatic dispersion. As of 2005, data rates of up to 10 gigabits per second were possible at distances of over 80 km (50 mi) with commercially available transceivers (Xenpak). By using optical amplifiers and dispersion-compensating devices, state-of-the-art DWDM optical systems can span thousands of kilometers at 10 Gbit/s, and several hundred kilometers at 40 Gbit/s. The lowest-order bounds mode is ascertained for the wavelength of interest by solving Maxwell's equations for the boundary conditions imposed by the fiber, which are determined by the core diameter and the refractive indices of the core and cladding. The solution of Maxwell's equations for the lowest order bound mode will permit a pair of orthogonally polarized fields in the fiber, and this is the usual case in a communication fiber [14.15].

2.5.2 Multimode Fibres

Multimode fibers are optical fibers which support multiple transverse guided modes for a given optical frequency and polarization. The number of guided modes is determined by the wavelength and the refractive index profile. For step-index fibers, the relevant quantities are the core radius and the numerical aperture, which in combination determine the V number. For large V values, the number of modes is proportional to V^2. Particularly for fibers with a relatively large core (Figure 2.4), the number of supported modes can be very high. Such fibers can guide light with poor beam quality (e.g. generated with a high-power diode bar), but for preserving the beam quality of a light source with higher brightness it can be better to use a fiber with smaller core and moderate numerical aperture, even though efficient launching can then be more difficult. Compared with standard single-mode fibers, multimode fibers usually have significantly larger core areas, but also generally a higher numerical aperture of e.g. 0.2–0.3. The latter leads to robust guidance, even under conditions of tight bending, but also to higher propagation losses without bending, as irregularities at the core–cladding interface can scatter light more effectively[15]. A basic specification of a multimode fiber contains the core diameter and the outer diameter of a multimode fiber.

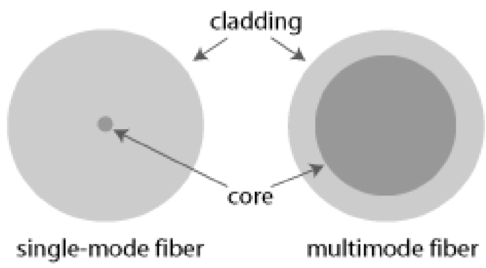

Figure 2.4: A single-mode fiber (left) has a core which is very small compared with the cladding, whereas a multimode fiber (right) can have a large core.

2.6 PROPERTIES OF OPTICAL FIBRE TRANSMISSION

Signal loss and system bandwidth describe the amount of data transmitted over a specified length of fiber. Many optical fiber properties increase signal loss and reduce system bandwidth. The most important properties that affect system performance are fiber attenuation and dispersion. Attenuation reduces the amount of optical power transmitted by the fiber. Attenuation controls the distance an optical signal (pulse) can travel as shown in figure 2.5. Once the power of an optical pulse is reduced to a point where the receiver is unable to detect the pulse, an error occurs. Attenuation is mainly a result of **light absorption**, **scattering**, and **bending losses**. Dispersion spreads the optical pulse as it travels along the fiber. This spreading of the signal pulse reduces the system bandwidth or the information-carrying capacity of the fiber[15]. Dispersion limits how fast information is transferred as shown in figure 2.5. An error occurs when the receiver is unable to distinguish between input pulses caused by the spreading of each pulse. The effects of attenuation and dispersion increase as the pulse travels the length of the fiber as shown in figure 2.6.

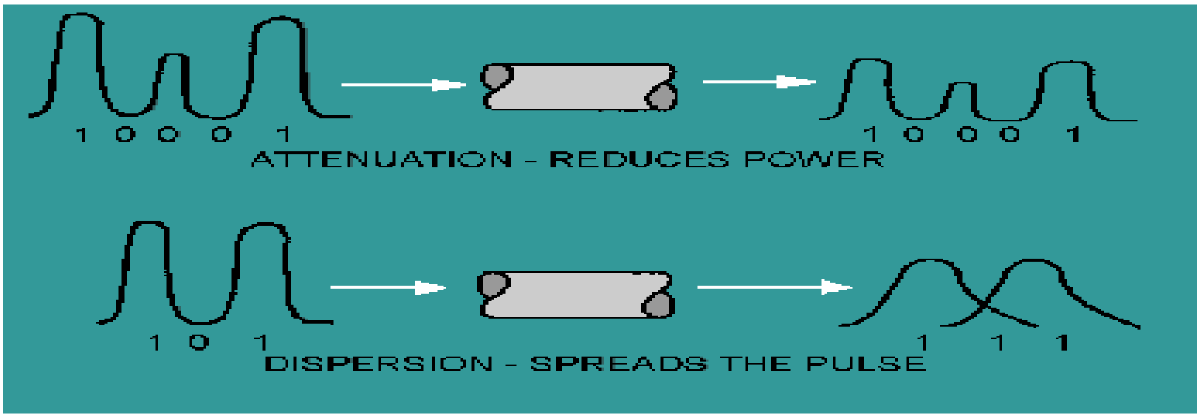

Figure 2.5 Fibre transmission properties

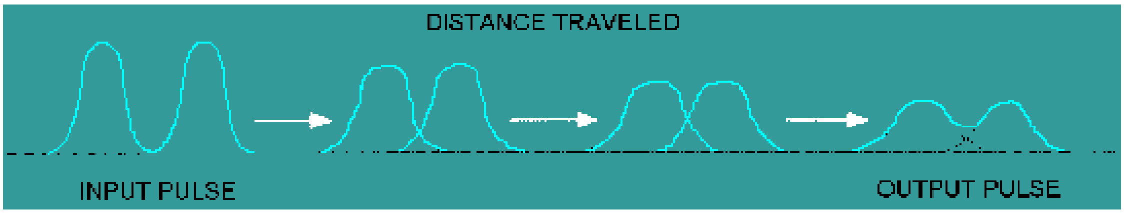

Figure 2.6 Pulse spreading and power loss along an optical fibre

In addition to fiber attenuation and dispersion, other optical fiber properties affect system performance. Fiber properties, such as modal noise, pulse broadening, and polarization, can reduce system performance. Modal noise, pulse broadening, and polarization are too complex to discuss as introductory level material. However, you should be aware that attenuation and dispersion are not the only fiber properties that affect performance.

2.7 IMPAIRMENTS IN OPTICAL FIBRE TRANSMISSION SYSTEMS

The optical fiber is often seen as a perfect transmission medium with almost limitless bandwidth, but in practice the propagation through optical fiber is beset with several limitations especially as distance is increased to multi-span amplified systems. As the transmission systems evolved to longer distances and higher bit rates, the linear effect of fibers, which is the attenuation and dispersion, becomes the important limiting factor. As for WDM systems that transmit multiple wavelengths simultaneously at even higher bit rates and distances, the nonlinear effects in the fiber beginning to present a serious limitation. The success of high bit rate long haul point-to-point optical transmission networks depends upon how best the linear and nonlinear effects are managed. The present chapter briefly highlights the various fiber induced impairments and their negative influence in restricting the achievable capacity of the transmission link. The major linear effects include group velocity dispersion (GVD) of standard single-mode fiber, fiber loss, adjacent channel cross-talk, polarization mode dispersion (PMD), accumulated ASE noise etc.

The nonlinear effects on the other hand include self phase modulation (SPM), cross phase modulation (XPM), stimulated Brillouin scattering (SBS), stimulated Raman scattering (SRS), and four-wave mixing (FWM)[16].

2.7.1 Attenuation

Attenuation in an optical fiber is caused by absorption, scattering, and bending losses. **Attenuation** is the loss of optical power as light travels along the fiber. Signal attenuation is defined as the ratio of optical input power (P_i) to the optical output power (P_o). 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. The following equation defines signal attenuation as a unit of length:

10□□□□*10*□□□□□□□

Signal attenuation is a log relationship. Length (L) is expressed in kilometers. Therefore, the unit of attenuation is decibels/kilometer (dB/km). As previously stated, attenuation is caused by absorption, scattering, and bending losses. Each mechanism of loss is influenced by fiber-material properties and fiber structure. However, loss is also present at fiber connections due to fibre connector, splice, and coupler losses. There are different values of attenuation depending on the optical frequency range that can be divided in three windows.

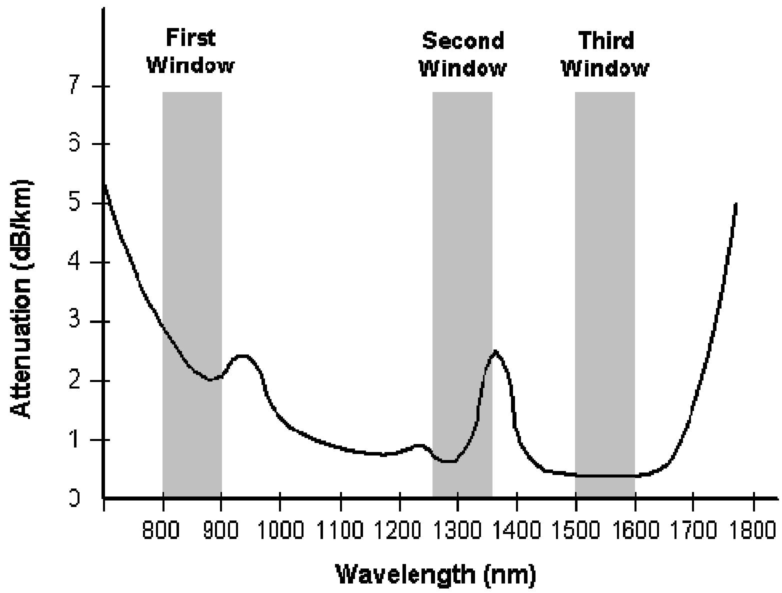

Figure 2.7 The Attenuation-Wavelength Curve and the Transmission Windows of an Optical Fiber

From Figure 2.7 and Table 1, Infrared Light with Wavelengths of 850 nm, 1,310 nm and 1,550 nm is mostly used. Therefore, the most common devices used as the Light Source in Optical Transmitters are the Light Emitting Diode (LED) and the Laser Diode (LD). They operate in the Infrared Radiation (750nm to 1mm) of the Electromagnetic Spectrum so that their Light Output is usually invisible to the human eye[17].

Table 1: Transmission Windows Ranges and Operating Wavelengths of the Optical Fiber

	Window Range	Operating Wavelenght
First Window	800 nm – 900 nm	850 nm
Second Window	1,260 nm – 1,360 nm	1,310 nm
Third Window	1,500 nm – 1,600 nm	1,550 nm

Optical Fibers are replacing Copper Wires to become an important Transmission Medium. Optical Fibers offer over 1,000 times as much Bandwidth as a Copper Wire, and can support Transmission at Gigabits per second.

2.8 DISPERSION IN OPTICAL FIBRES

An information signal becomes distorted due to attenuation and dispersion as it travels in an optical fiber. Attenuation is the loss of signal power and is governed by different mechanisms, including absorption, scattering, and radiation. Since optical fibers were introduced for communication applications three decades ago, great progress has been accomplished in producing optical fibers that exhibit very low signal attenuation. On the other hand, dispersion is the spreading in the time domain of a signal pulse as it travels through the fiber. Spectral components of a pulse propagating down an optical fiber reach their destination at slightly different times. This translates into a wider pulse at the receiving end of the fiber. Both attenuation and dispersion affect repeater spacing in a long distance fiber-optic communication system. Dispersion affects the bandwidth of the system, hence maintaining low dispersion is of equal importance for ensuring increased system information capacity, versatility and cost effectiveness.

2.8.1 DISPERSION IN SINGLE-MODE FIBERS

Dispersion in single-mode fibers is an intramodal effect and is a result of group velocity dependence on wavelength. Because of that, the amount of signal distortion depends on the spectral width of the optical source used. Three mechanisms contribute to intramodal dispersion: material dispersion, waveguide dispersion, and polarization-mode dispersion.

2.8.2 POLARIZATION-MODE DISPERSION

Single-mode fibers, in reality, support two orthogonally-polarized fundamental modes. In perfectly circular fibers, these two modes have identical propagation constants and pulse spreading due to polarization-mode dispersion does not exist. In practical fibers, however, there is a small difference between the propagation constants of these two modes due to the slight ellipticity of the core. In other words, common single-mode fibers actually support two modes and thus are not truly single-mode. The presence of two fundamental modes contributes to pulse spreading. This phenomenon is known as polarization-mode dispersion.

2.8.3 DISPERSION IN MULTIMODE FIBERS

In applications where two or more modes travel simultaneously though the fiber, intermodal as well as intramodal dispersions exist. Intermodal dispersion does not occur in single-mode fibers, but is a significant effect in multimode fibers. It occurs as a result of different modes having different group velocities at the same frequency. Graded-index fibers with nearly parabolic-index profile were developed mainly to reduce the effect of intermodal dispersion. Here, bound rays deviating from the axis of the fiber travel a longer distance but at larger velocities, reaching the receiving end of the fiber at about the same time with the other rays, thus in graded-index fibers pulse spreading is significantly reduced.

Although all forms of dispersion present in single-mode fibers exist in multimode fibers too, the material dispersion is the only significant intramodal effect which should be considered. Thus, pulse spreading in multimode fibers is largely due to material dispersion and intermodal delay distortion. Polarization-mode dispersion is a much weaker effect than material dispersions and intermodal delay, and is often neglected in the analysis and design of fiber-optic links.

Apart from the three dispersion effects described above, there is yet another kind of dispersion referred to as profile dispersion. This effect is attributed to core and cladding materials having slightly different material dispersions. In this thesis, the profile dispersion is accounted for as part of material dispersion and thus does not require a separate analysis.

2.8.4 DISPERSION COMPENSATION SCHEMES

(1) Precompensation Scheme: To avoid the effect of dispersion this scheme modifies the characteristics of input pulses at the transmitter before they are sent into the fiber link. Precompensation techniques are:

a) Prechirp Technique.

b) Novel Coding Technique.

a) Prechirp Technique:- It modifies the characteristics of input pulse before sending into the fiber link. If input pulse is Gaussian then by prechirping (chainging amplitude) the amplitude of this pulse is given by [36]

A0 exp *1*+□□*2*□□*02* where C is the chirp parameter.

□*2*□ *<0*) can propagate over longer distances before it broadens outside its allocated bit slot.

then the transmission distance is given by

1√(1+2C2)1+C2LD

LD= T02|β2| is the dispersion length

2 occurs.

Prechirp technique was used in 1980s with directly modulated semiconductors lasers [18]-[20]. These lasers have chirp parameter which is negative. Also chirp parameter is negative for β2C<0) [18]. The chirp induced during the direct modulation increases GVD(Group Velocity

Dispersion) induced pulse broadening and due to this transmission distances decreases. To increase the transmission distance without affecting the current pulse shape several technique were used in 1980s. By using external modulator at the transmitter side for prechirping , then optical pulse are nearly chirp-free and prechirp technique in this case uses positive value of chirp $\beta 2C<0$). Many techniques used for this purpose.

b) Novel Coding Technique (FSK):-In novel coding technique, frequency shifted keying (FSK) format is used for transmission of signal. The FSK signal is generated by switching the

.The 1 and 0 are transmitted with different carrier wavelengths. Two wavelengths travel at

determines the time delay between 1 and 0. The time delay is given by-

where D is the dispersion coefficient and L is the length of optical fibre.

1β where is the propagation constant along the fibre length.

This scheme is known as dispersion-supported transmission. Because of fiber dispersion FSK signal is converted into the amplitude modulated signal. At the receiver side this signal is decoded using an electrical integrator with decision device [17]. If the system is properly designed then FSK technique is used for longer distance transmission with better performance [21]. The transmission distance can also be increased by using **Duobinary Coding**. Dispersive effects are reduced for smaller bandwidth signal. And Duobinary Coding reduces the signal bandwidth by 50%. Therefore it increases the transmission distance. Two successive bits in the digital bit stream summed to form a three level duobinary code at half bit rate.

1+1=10; 0+0=0; 0+1=1; 1+0=1

At the reciever side, phase information is used to distinguish the two. By using duobinary coding in optical communication system instead of using binary coding then 10Gbps signal was transmitted over 30km to 40 km [16]. Also by duobinary coding with an external modulator (frequency chirp with C>0) then 10Gbps signal was transmitted over 160km of a standard fiber.

c) Nonlinear Prechirp Techniques: In this technique transmitter output is amplified by using a semiconductor optical amplifier (SOA). SOA operates in gain saturation region. Due to gain saturation region time dependent variation takes place in carrier density, which chirps the amplified pulse. SOA not only amplifies the input pulse but also chirp (chirp parameter C>0) it. □*2*<0. An input pulse of 40-ps is compressed to 23-ps and it can propagate over 18 km of standard fiber. This technique is used for transmitting a 16Gb/s signal, obtained from a mode-locked external cavity semiconductor laser, over 70km of fiber [18]. This technique is used for simultaneous compensation of fiber loses and GVD(Group Velocity Dispersion) if SOAs are used as in-line amplifiers [19]. A nonlinear medium is also used to prechirp the pulse by self phase modulation of pulse.

SPM Induced Prechirping – It uses self phase modulation for chirping the pulse.The transmitter output is passed through a fiber of suitable length before passing into the fiber link. The input signal at the fiber input is given by [22]

□□□□*1* (1)

□□ is the length of nonlinear medium, □ is the nonlinear parameter.

□*0*□□□−□*2*□*02*

Then equation (1) can be written as

□*0*□□□−*1*+□□*2*□*2*□*02*exp□*(−*□□□□□*0)*

□□□*0* is the chirp parameter, C is positive and suitable for dispersion compensation.

(2) Postcompensation Technique:- This technique is used to manage the GVD(Group Velocity Dispersion) at the receiver side .It uses an electronic technique at the receiver side. It is an easy technique for dispersion compensation with the use of heterodyne receiver for signal detection. Heterodyne receiver first converts data (optical signal) into microwave signal, it preserves both amplitude and phase information. A microwave filter cancels the effects of GVD. This technique has a great importance for dispersion compensation in coherent light wave system. A 31.5cm long microstrip line is used for dispersion equalization [22]. By using this 8-Gbps signal was transmitted over 188 km of standard fiber having dispersion of 18.5ps/km-nm. To avoid the GVD of light wave system using fiber length of 4900km having bit rate 2.5Gbps microstrip lines were used [23]. If the phase information of the optical signal is lost then it is difficult to avoid the effect of GVD in this technique.

An **optoelectronic equalization** technique is also used to compensate the GVD which is based on transversal filter [24]. In this technique power splitter used at the receiver splits the received signal into several branches. Fiber optic delay line introduces delays in different branches. A variable- sensitivity photodetector converts the optical signal of each branch into photocurrent and the summed photocurrent is used by the decision circuit. The transmission distance of light wave system operating at 5Gbps is extended by a factor 3 by using this technique.

(3) Dispersion Compensating Fibers:-The precompensation and postcompensation scheme extends the transmission distance of dispersion limited system by a factor of 2 and these schemes are not suitable to avoid the GVD dispersion of long hall system. To avoid these limitations a special kind of fiber is used, known as Dispersion Compensating Fiber (DCF). The dispersion

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