DISPERSION MANAGEMENT IN OPTICAL FIBER

Abstract

Optical fibers are made of glass or plastic and are incredibly thin, are typically employed to transfer signals in the form of light. Broadband services have seen the most improvement thanks to optical fiber because it offers the fastest data transmission speed in long-distance communication. Dispersion is a significant problem in fiber optic communication systems which reduce the performance quality of the sent signal by broadening the signal resulting in pulse distortion, which enhances the rate of bit errors and signal degradation. Another limitation of an optical fiber network is its channel capacity. This book chapter gives a brief idea about optical fiber .Detailed overview of dispersion and work related to dispersion management in optical communication link will also be discussed in this chapter. To prevent the chromatic dispersion of optical elements, dispersion correction is utilized. Avoiding excessive pulse temporal broadening or signal distortion can help you achieve this goal. For fiber optic connections, correction for dispersion is a crucial concern. Therefore, before detecting the signal, the dispersion must be compensated. Here in this chapter we give a brief idea about dispersion management in an optical fiber.

Keywords: Optical fiber; dispersion management; optical communication

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I. INTRODUCTION

A flexible glass filament that is exceptionally transparent and capable of transmitting data by light is known as an optical fiber. Glass rods are formed into pre-forms to create the hair-thin structures known as optical fibers. The core and cladding are the two primary components of an optical fiber. The part of the optical fiber formed of silica glass that transmits light is called the "core," or central component. The "cladding" is the layer that completely covers the core. The distinction in refractive index among cladding and core of a typical silica step index fiber is lower than 0.5 percent.

Due to its many advantages, such as its high bandwidth, as well as long distant transmission, and an excellent level of security, optical fiber is crucial. [1]. Since it is often employed, optical fiber has a variety of drawbacks, including attenuation, nonlinear effect, and dispersion. [2]. When using optical fiber as a medium for DWDM implementation, there are two key considerations that must be made. Dispersion comes first, followed by nonlinear effects. In optical fiber communication, dispersion is the main performance bottleneck [3]. The transmitted signal's pulses are enlarged and deformed, which raises rate of bit errors and signal loss. The amount of channels on an optical fiber network is also hampered. [4]. Since the refractive index varies with wavelength in an optical fiber, light pulses that have different wavelengths will go through it at various rates.

After traversing a given distance in the optical fiber, these light waves have a tendency to spread out over time. This phenomenon lasts the full length of the fiber. [5,6]. The term "dispersion" refers to this enlarging of the light pulses.. Dispersion significantly decreases the efficiency of optical fiber transmission. The fiber length and dispersion are connected. [2]. As an ordinary silica optical fiber's dispersion value rises with wavelength, various channels experience differed broadening. Despite not diminishing the signal's intensity, optical fiber dispersion does shorten the signal's internal travel time and make it fuzzier. As a result, optical fiber dispersion must be reduced or compensated for in long-distance transmission systems such as DWDM. After a suitable length of the fiber, dispersion compensators can be used as an option for reshaping the signal .However, adding a dispersion resolving module enhances the cost of the system, adds reduction that boosts the effectual noise stature of system which causes distinct channels in optical fiber to experience unusual kinds of cumulative dispersion. Finite dispersion fibers with a low dispersion slope have been recommended as a solution to this problem. The narrow effective area of ordinary optical fibers, resulting in nonlinear phenomena such as XPM and SPM is further disadvantage.

The range of wavelengths that can potentially transmit over the fiber is constrained by XPM. Consequently, a suitable transmission medium is necessary for the information transfer at high bit rates. Due to the modulation uncertainty in positive dispersion for distant broadcast, fiber with tiny positive dispersion is appropriate for small distance whereas fibers with low negative dispersion may be employed for long distance communication [3]. Dispersion-compensating fibers (DCFs), which operate at 1.55 µm wavelength, have been effectively employed in long-distance optical communication to correct for the accumulated dispersion. The dispersion coefficient for these transmission routes typically ranges commencing 10-20 ps/nm/km. Since cumulative dispersion reduces the transmitting channel's bandwidth and precludes an accurate replication at the receiver end in the signal, it must be to be remunerated [7].

II. DISPERSION

The broadening of pulses in an optical fiber is referred to as dispersion. A light pulse expands as it travels through a fiber depending on a number of factors, which includes the refractive index characteristics, geometric aperture, wavelength of light, and pulse of laser width. Dispersion increases as fiber length advances. These prolonged pulses may overlap as data rates rise, resulting in crossfire and inter-symbolic interference that affect signal reception at the receiver end of the optical connection. [2]. The transmission bandwidth or information transfer speed of a fiber is decreased by dispersion. Dispersion is often split into two groups: Intermodal dispersion and Intra modal dispersion.

1. **Intermodal Dispersion:** Multiple separate light beams may swiftly pass through multimode fiber because of its many modes. Some rays go faster than others because of different trajectories. Rays having lots of various paths were dispersed out into pulses that formed. The term used to describe this type of pulse widening is intermodal dispersion. A other name for it is modal dispersion. As single mode fibers contain just one mode, intermodal dispersion cannot happen in them. This Particularly relevant with multimode step index fiber.

2. **Intra Modal Dispersion (Chromatic Dispersion):** Dispersion can also happen when two modes are travelling in the same direction through a fiber. As a consequence of being a wavelength-dependent phenomenon, it is also known as chromatic dispersion. The descriptions of waveguide dispersion and material dispersion are provided here.

   - **Material Dispersion**: Although the refractive index of substance varies on behalf of different wavelengths within a group, each of these wavelengths goes through the materials at a different speed. The laser pulse contains a variety of wavelengths as it enters the fiber, and because of each wavelength moves through the fiber at a different speed, the pulse broadens in time at a given distance. As the width of the subsequent pulses widens, the amount of inter-symbol interference grows. In both single mode and multimode fibers, the material dispersion is important. The material dispersion parameter for silica glass is negative to wavelengths below about 1310 nm and positive for all wavelengths over 1310 nm [9].

   - **Waveguide Dispersion:** Wavelength has an impact on how fiber modes are distributed spatially. Because even in the absence of material dispersion, spatial distribution of the mode and wavelength has an impact on the group velocity. This leads to waveguide dispersion, a phenomenon. In single mode fibers alone, waveguide dispersion is crucial. Due to truth that some light travels in fiber cladding but majority of it travels in core of fiber is what causes it. Because fiber cladding and fiber core have different refractive indices, light travelling through the cladding moves more quickly than through the core [9]. Waveguide dispersion is also a sort of chromatic dispersion which relies on the light source's line width, wavelength, V-number, and fiber size [8].Over the majority of the wavelength range, waveguide dispersion is negligible, and material dispersion is the main cause of chromatic dispersion. Some single mode fibers have modified core profiles to increase waveguide dispersion's contribution and move the wavelength at the point where it is equals to zero [9].

III. TECHNIQUE FOR DISPERSION COMPENSATION

One of the most important components of fiber optic communication that may achieve large data speeds is dispersion correction. The following describes electronic dispersion compensation (EDC), DCF and FBG [10].

1. **Dispersion Compensation with DCF:** The fibers which have large negative dispersion can be implemented with a standard fiber in the DCF (dispersion compensating fiber). Using a dispersion compensating fiber with a significantly higher dispersion value which has opposite sign than a regular fiber reduces or eliminates the quantity of light spread by a standard fiber. A link between positive dispersion of conventional single-mode optical fiber, negative dispersion of DCF must exist for the net dispersion to be zero.

$$\mathbf{D_{OF} \times L_{OF} = - D_{DCF} \times L_{DCF}}$$

Where L is the length of each division of fiber, D is dispersion [10]. For adjusting dispersion, one of three systems (fiber-pre, post, or symmetrical) will be employed. Installed 1310nm optimized optical fiber is upgraded to operate at 1550 nm using dispersion compensating fiber. DCF performance is influenced by insertion loss and the DCF module's Mode Field Diameter. To lessen this loss, one can cut the ends of the DCF or add an additional fiber between the DCF and SMF [11]. By altering the fiber refractive index profiles, substantial negative waveguide dispersion is achieved in dispersion compensating fibers.

Fundamental mode as well as modes of high order may be employed for correction of dispersion. The basic mode serves as the foundation for all economically feasible dispersion compensating fiber components. Some dispersion compensating fibers have a flat dispersion slope [12]. Only one channel's dispersion can be fully accounted, due to the transmission fibers ' dispersion slope, and the dispersion of the other channels can either be excessively or inadequately compensated. Broadband compensating fibers having a negative dispersion as well as dispersion slope must be used to modify dispersion of every one of channels in high speed DWDM systems in order to get the best efficiency [13].

Following is a summary of the research that was done by researchers for dispersion compensation**. Faramarz E. Seraji et al**. have done a comparative analysis of fibers and usingoptifiber software, they discovered that a step index fiber having two rings can achieve a negative dispersion -517 ps/nm/km, bending loss 3.3 dB/km on the twisting radius of 20 mm and. On 1550 nm, they obtained an efficient surface area which was 38µm^2 .A DCF that has a triangular index profile and one ring can attain the lowest negative dispersion, which was measured as -120 ps/nm/km with effective area of the 11µm^2 at 1550 nm [14]. **Bikash Kumar Paul et al.** described a modified squared photonic crystal fiber and discovered that it concurrently exhibited high Kerr nonlinearity 74.68 W^{-1} km^{-1} , negative dispersion -2357.54 ps/nm/km using working wavelength of 1550 nm. Veff operates in mono mode for the whole band of interest with minimum and maximum values of 1.7 and 1.37 respectively.

For optical technology based communication systems, this idea of fiber is particularly appealing. If the fiber is actually put up, it will play an important role [15]. Segmented core fiber was reported by **BabitaHooda and Vipul Rastogi .** It has a thin second core, trench-assisted cladding, and a radial multilayered segmented interior. Transfer matrix method was applied to analyzed the fiber's design. They discovered significant non-zero dispersion in flatten fiber simulations that is around +4.5 ps/km/nm in the wavelength range between 1.46 µm and 1.65 µm. In the spectrum of wavelength 1.33 µm -1.56 µm, flatten fibers with non-zero negative dispersion had dispersion of - 6 ps/km/nm. The effective area vary between 114 µm^2 to 325.95 µm^2 in case of flattened fiber with nearly minimal dispersion. Due to these all characteristics of the fiber design may found application for DWDM optical communication link. [3]. Figures 1 and 2 respectively display the fiber profile and dispersion graph.

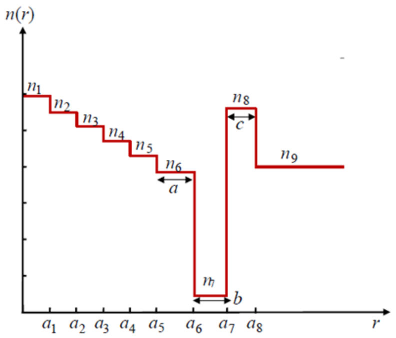

Figure 1: Fiber profile

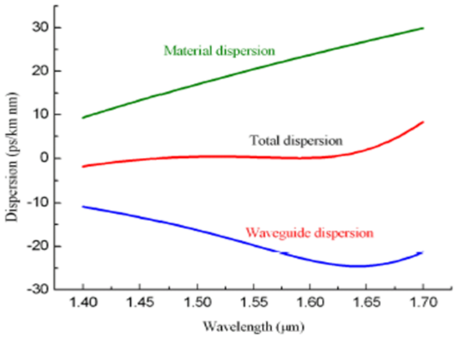

Figure 2: Variation of dispersion with Wavelength

Mahmood Seifouri et al. presented an improvement for dispersion in transmission optical fibers. The C-MOF designs was based on an optical band gap as the light guide technique and has an enormous negative dispersion with value of nonlinearity was 6.2 W^{-1} km^{-1}, negative dispersion at 1.55 µm may be measured to be around -2450 ps/nm/km. This design is unique since its RDS is near to that of a typical transmission optical fiber, at about 0.00332 nm^{-1}.These characteristics allowed to the design's application in wavelength division multiplexing [16]. **Abdelkader Sonne** designed fibers with step and parabolic refractive index and found that DCCF1's single mode has an effective area larger than 65 µm^2 , n_2 minor than 2.4×10^{-16} cm^2/W in the spectrum range from 1.4 µm-1.7 µm, and virtually almost completely flattened dispersion 0.35 ps/nm/km. Contrarily, the DCCF2 can achieve single mode propagation in the 1.4 µm–1.9 µm wavelength range with essentially negligible near zero dispersion 0.45 ps/nm/ km, a small effective area 28 µm^2 along with n_2 is larger than 2.4×10^{-16} cm^2/W at exact equal wavelength [17]. **S. Revathi et al.** stated the highly not linear photonic crystal fiber that has an eight-ring octagonal structure, dispersion between -25 to -28 ps/nm-km, as well as nonlinearity about 13584.5 W^{-1} km^{-1} on 1550 nm. They used the finite element method to complete all of these analysis. The actual confinement loss is in the 10^{-6} dB/km region. From the wavelengths 0.85 µm to 1.95 µm, significant negative dispersion was also obtained, which can be applied to fiber optic communication to compensate dispersion. Optical parametric amplification, supercontinum production, and ultra short soliton pulse transmission are just a few nonlinear uses of this fiber structure. [18].

The finite difference time domain (FDTD) approach was utilized to produce a flattened dispersion of 11.8 ps/nm.km at 1550 nm, a nonlinear coefficient 0.0166 $W^{-1}m^{-1}$, and an effective area of 6.317 µm^2 based on the germanium doped hexagonal photonic crystal fiber that **Y.K. Prajapati et al.** presented. This design has found wide application in the creation of supercontinum because to its high nonlinear coefficient and flat dispersion. [19]. In a spiral-shaped PCF containing an egg-shaped soft-glass rod in its centre area, **Jianfei Liao et al.** obtained significant negative dispersion values for the x/y-polarized modes was -491.16 ps/(nm.km) and -399.98 ps/(nm.km) and 0.32 ps/(nm.km) for the y-polarized mode using full vector finite element method. And x/y-polarized modes exhibit significant nonlinearity which was order of 102 W^{-1}m^{-1} at wavelength 1.55 µm and ultrahigh birefringence up to the amount of 10^{-2} between 1.35 and 1.65 µm. The suggested approach can be helpful for processing wideband signals very effectively [20].Figure3 displays the cross-section image whereas Figure 4 displays the dispersion.

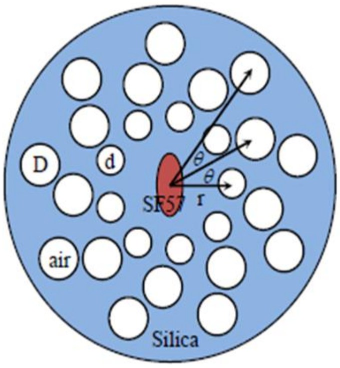

Figure3: Cross-section image of the proposed Fundamental Spiral PCF design

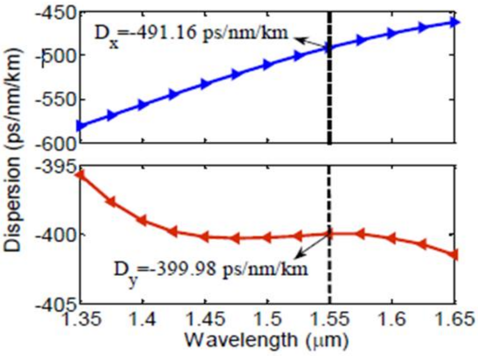

Figure 4: Chromatic dispersion of x and y polarized mode

A dispersion-compensating fiber (DCF) having dual core was designed based on microstructure for long-distant optical communiqué networks was reported by **Gautam Prabhakar et al.** They demonstrated that the proposed fiber has huge mode area 67 µm^2 in the narrowband DCF configuration, as well as a extremely highly negative dispersion of about 42000 ps/nm/km using the full vector finite difference time domain approach. Additionally, they showed that the broadband DCF design for the C band's whole spectrum range has a dispersion between -860 ps/nm/km and -200 ps/nm/km in the wavelength span of 1530 nm–1560 nm, which might be helpful for correction of dispersion in long-distant optical transmission [21]. In the spectral range from 1.3 to 1.8µm **Mahmoud M. A. Eid et al.** designed a dispersion flattened fiber, and after analysis using optifiber software they exhibited flattened dispersion from -4 to 10 ps/km/nm the effective area grows from 38 to 115 µm^2 exponentially. The suggested DFF accomplishes zero dispersion at a particular wavelength 1.3612 µm, and dispersion slope was 0.4569 ps/nm^2.km [22]. A hexagonal-shaped photonic crystal fiber made up of four rings has been established by **Emmanuel Kofi Akowuah et al.**

The results showed adjustable double zero dispersion for the x-polarization mode at the wavelength of 0.99 µm and 1.8 µm as well as birefringence of 1.308*10^{-2} at 1.55 µm. At a communication wavelength of 1.55 µm, dispersion -24.062 ps/km nm along with nonlinear coefficient 30.32 W $^{-1}$km $^{-1}$were also recorded. Due to the fact that photonic crystal fibers with twofold zero dispersion have better power spectral densities than those of only one zero dispersion, they may be useful in nonlinear and supercontinum applications [23]. **John Napari N-yorbe et al**. designed an extremely negative dispersion-compensating fiber .Numerous nil dispersion wavelengths (ZDWs) inside telecommunication bands were found by numerical study, which used the full-vector finite element approach. With many ZDWs occuring in the range from 0. 8μm to 2.0 μm, they also acquired elevated negative dispersion 15089.0 ps/nm/km on 1.55 μm wavelength. Other optical properties include confinement loss, which has a value of 0.059 dB/km, birefringence, which has value $4.11 * 10^{-1}$, and nonlinearity, which has a value 18.92 $W^{-1}km^{-1}$. The PCF will be appropriate for optical sensing, polarization-maintaining applications, soliton pulse transmission, high-speed, long-distance optical communication, systems high-speed. [24]. Using the full-vectorial finite element method, **C. C. Wang et al.** have demonstrated heavily germanium-doped silica fiber exhibiting having refractive index profile of four-layer. They found that flat normal dispersion in fiber may be achieved in wavelength range 1540–2600 nm, with dispersion slope values spanning from 0.0058 to 0.03 ps/nm^2 /km. Due to the simplicity of fiber construction, this fiber profile provides a simple method for producing an fiber coherent SC light source and SC generation that has spectrum width of larger than one octave. [25]. Data from the aforementioned literature analysis of works on dispersion are presented in tables 1 and 2

Table 1: For dispersion compensating fiber

Auther's name	**Dispersion (ps/km/nm)**	**wavelength (nm)**	**Nonlinearity(W^{-1} km^{-1})**	**Effective area (μm^{2})**	**Method/ Technique**	**Reference**
Gautam Prabhakar	-42000	1544	NA	67	finite difference time domain method	21
FaramarzE.Seraji	-517	1550	NA	38	Optifiber software	14
Bikash Kumar Paul	-2357.54	1550	74.68	1.77	Full vector finite element method(FV-FEM)	15
Mahmood Seifouri	-2450	1550	6.2	15.8	Photonoic band gap guiding nechanism	17
Jianfei Liao	-491.6 -399.98	1550	102	NA	Full vectorial finite element method	20
John Napari N-yorbe	−15089.0	1550	18.92	NA	Full vectorial finite element method	24

Table 2: for dispersion flattened fiber

Auther's name	**Dispersion (ps/km/nm)**	**Wavelength (nm)**	**Nonlinearity (W^{-1} km^{-1})**	**Effective area (μm^{2})**	**Method/ Technique**	**Reference**
BabitaHooda	0.0039-0.520	1460-1625	NA	114-325.95	Transfer matrix method	3
S. Revathi	-25 to -28	At 1550	13584.5	NA	Finite element	18

					method	
Y.K Prajapati	11.8	At 1550	0.0166	6.317	finite difference time domain method	19
Abdelkader Sonne	0.35 0.45	1400-1700 1400-1900	NA	65 28	Finite element method	17
Mahmoud M.A Eid	-4 to 10	1300-1800	NA	38-115	Optiwave software	22
Emmanuel Kofi Akowauh	-24.062	At 1550	30.32	NA	NA	23

2. **Dispersion Compensation Using FBG:** Fiber Bragg Grating, a reflecting apparatus used to account for dispersion, is an optical fiber having a changed core refractive index along its length. FBG can greatly lessen the impact of dispersion in gearbox systems with large distances (up to 100 km). When the modulation regularity and the fiber grating's wavelength line up, it reflects light wave moving through the fiber. Due to their low insertion loss, passive optical element fiber compatibility, and affordability, FBGs could be a potential choice for dispersion compensation. The FBG may be utilized like sensors , wavelength stabilizers used for pump lasers, fine band WDM add drop filters, as well as dispersion compensating filters. [26]

   Due to its small size, low insertion loss, relative compatibility with single mode fiber, and high cost-effectiveness, Fiber Bragg Grating is extremely important for dispersion correction. To provide consistent fiber grating over the length of the grating, a period of fiber grating with a constant refractive index is utilized. Chirped grating is another name for ideal dispersion compensation (IDCFBG). The grating time exhibits additive volatility in this form of FBG. It has the benefits of enormous chip parameter, which reduces the power of reflection [10].

3. **Dispersion Compensation with EDC:** An optical communication link's dispersion can be compensated by using electronic filtering, which is known as electronic dispersion compensation (EDC). When a communication channel's medium causes signal deterioration, filtering can be employed to make up for it. Transversal filters are widely employed for implementing EDC, and its output is frequently the weighted average of lots of time-delayed inputs. The EDC system may automatically modify the filter weights in accordance with the properties of the incoming signal, a procedure recognized as adaptation. Electronic dispersion compensation is applicable to both multimode and single-mode fiber networks. On 10-Gbit/s receiver ICs, it may also be combined with other features. [27].

IV. CONLCUSION

This study's goal of discussing the dispersion issue in an optical fiber communication and dispersion reducing technique was successfully accomplished. According to the findings, dispersion lowers the optical fiber system's overall performance, and an increase in communication distance results in an equal rise in dispersion along the communication link.

In light of this, it can be said that dispersion adjustment is strongly advised along a fiber optic communication.

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