# A SURVEY: DISPERSION COMPENSATION TECHNIQUES FOR OPTICAL FIBER COMMUNICATION

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**ABSTRACT:**

**In the modern day industries, Fiber optic transmission and communication are technologies that are constantly growing and support more challenges. Three properties of optical fibers are dispersion, absorption and scattering which cause attenuation and also decreased in transmitted power. Dispersion compensation is the most important feature required in optical fiber communication system because absence of it leads to pulse spreading that causes the output pulses to overlap. If an input pulse is caused to spread such that the rate of change of the input exceeds the dispersion limit of the fiber, the output data will become indiscernible. In this paper various dispersion compensation techniques are discussed like- Dispersion Compensating Fibers (DCF), Fiber Bragg Grating (FBG), Electronic Dispersion Compensation (EDC), Optical Phase Conjugation and digital filters.**

**Keywords: Fiber Communication, DCF, FBG, EDC, OPC, Losses, Dispersion.**

## 1. INTRODUCTION

Fiber optic communication is a method of transmitting information from one place to another by sending pulses of light trough optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. The potential bandwidth of optical communication systems is the driving force behind the worldwide development and deployment of light wave system.

Like other communication systems optical communication system also faces problems like dispersion, attenuation and non-linear effects that lead to deterioration in its performance. Among them dispersion affects the system the most and it is tougher to overcome it as compared to other two problems. Thus it is important to work out an effective dispersion compensation technique that leads to performance enhancement of the optical system.

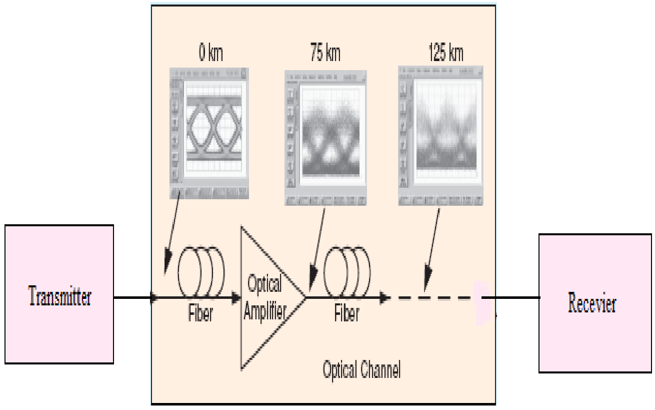


**Figure. I. Block diagram of an optical fiber link**

As shown in above Figure the link can be broken into three key components: the transmitter, the optical channel, and the receiver. The transmitter contains a laser source that is modulated by an information bearing sequence, the channel consists of potentially repeated spans of optically amplified single-mode fiber, and the detector contains optical filtering, a photo-detector, electrical filtering, and subsequent electrical processing for clock and data recovery. For shorter reach links, the fiber may be unamplified and for very short reach applications, multimode fiber may be used. Also shown are data eye diagrams, which illustrate the transmitted and received symbol patterns as they would appear on an oscilloscope at various stages through the optical fiber.

## 2. DISPERSION

Dispersion is defined as pulse spreading in an optical fiber. As a pulse of light propagates through a fiber, elements such as numerical aperture, core diameter, refractive index profile, wavelength, and laser line width cause the pulse to broaden. Dispersion increases along the fiber length. The overall effect of dispersion on the performance of a fiber optic system is known as Inter symbol Interference (ISI). Inter symbol interference occurs when the pulse spreading caused by dispersion causes the output pulses of a system to overlap, rendering them undetectable.

Dispersion is generally divided into three categories: modal dispersion, chromatic dispersion and polarization mode dispersion.

**2.1 Modal Dispersion**

Modal dispersion is defined as pulse spreading caused by the time delay between lower-order modes and higher-order modes. Modal dispersion is problematic in multimode fiber, causing bandwidth limitation.

**2.2 Chromatic Dispersion**

Chromatic Dispersion (CD) is pulse spreading due to the fact that different wavelengths of light propagate at slightly different velocities through the fiber because the index of refraction of glass fiber is a wavelength-dependent quantity; different wavelengths propagate at different velocities.

Chromatic dispersion consists of two parts: material dispersion and waveguide dispersion.

**2.2.1 Material Dispersion**

It is due to the wavelength dependency on the index of refraction of glass i.e. refractive index of the core varies as a function of wavelength.

**2.2.2 Waveguide Dispersion**

It is due to the physical structure of the waveguide. In a simple step-index profile fiber, waveguide dispersion is not a major factor, but in fibers with more complex index profiles, waveguide dispersion can be more significant.

**2.3 Polarization Mode Dispersion**

Polarization Mode Dispersion (PMD) occurs due to birefringence along the length of the fiber that causes different polarization modes to travel at different speeds which will lead to rotation of polarization orientation along the fiber.

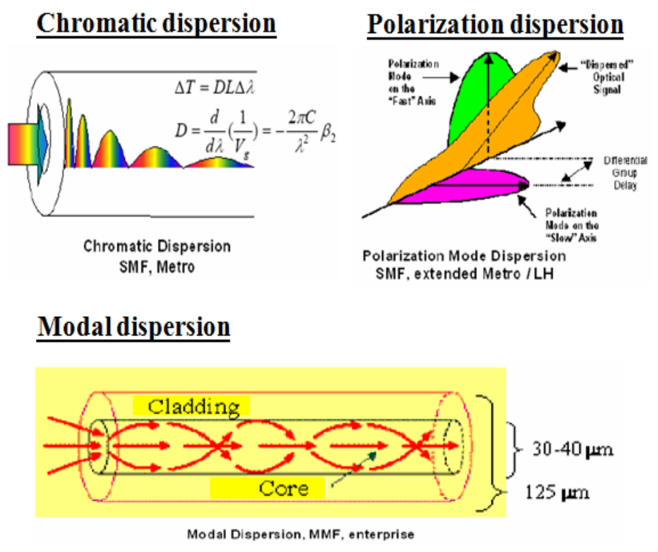


**Figure. II. Types of Dispersion**

**3. DISPERSION COMPENSATION TECHNIQUES**

In order to remove the spreading of the optical or light pulses, the dispersion compensation is the most important feature required in optical fiber communication system.

The most commonly employed techniques for dispersion compensation are as follows:

**3.1 Dispersion Compensating Fibers (DCF)**

DCF is a loop of fiber having negative dispersion equal to the dispersion of the transmitting fiber. It can be inserted at either beginning (pre-compensation techniques) or end (post-compensation techniques) between two optical amplifiers. But it gives large footprint and insertion losses.

**3.2 Fiber Bragg Grating (FBG)**

Optical Fiber Bragg Grating (FBG) has recently found a practical application in compensation of dispersion-broadening in long-haul communication. In this, Chirped Fiber Grating (CFG) is preferred.CFG is a small all-fiber passive device with low insertion loss that is compatible with the transmission system and CFG's dispersion can be easily adjusted. CFG should be located in-line for optimum results. This is a preferred technique because of its advantages including small footprint, low insertion loss, dispersion slope compensation and negligible non-linear effects. But the architectures using FBG is complex.

**3.3 Electronic dispersion compensation (EDC)**

Electronic equalization techniques are used in this method. Since there is direct detection at the receiver, linear distortions in the optical domain, e.g. chromatic dispersion, are translated into non linear distortions after optical-to-electrical conversion. It is due to this reason that the concept of nonlinear cancellation and nonlinear channel modeling is implemented. For this mainly feed forward equalizer (FFE) and decision feedback equalizers (DFE) structures are used. EDC slows down the speed of communication since it slows down the digital to analog conversion.

**3.4 Optical Phase Conjugation Techniques**

Phase conjugation is a fascinating phenomenon with very unusual characteristics and properties. The effective compensation of waveform distortion due to chromatic dispersion in a single mode fiber was demonstrated using an optical phase conjugate (OPC) wave generated by no degenerate forward four waves mixing in a zero dispersion single mode fiber.

**3.5 Digital Filters**

Digital filters using Digital Signal Processing (DSP) can be used for compensating the chromatic dispersion. They provide fixed as well as tunable dispersion compensation for wavelength division multiplexed system. Popularly used filter is lossless all-pass optical filters for fiber dispersion compensation, which can approximate any desired phase response while maintaining a constant, unity amplitude response. Other filters used for dispersion compensation are bandpass filter, Gaussian filters, Super-Gaussian filters, Butterworth filters and microwave photonic filter.

## 4. TECHNQUES

### 4.1 Dispersion Compensating Fibers (DCF)

As the transmission bandwidth is fixed, allowable dispersion values are in inverse proportion to the square of transmission speed and therefore the faster the transmission bit rate speed, the more important the compensation of accumulated chromatic dispersion over transmission bandwidth. In the case of non-return-to-zero method, the allowable residual dispersion is about 100 ps/nm for a signal of 40 Gbit/s overall transmission bandwidth. Dispersion compensating fiber (SC-DCF) has been the most advantageous and widely used method as dispersion compensation devices.

Figure III shows schematic diagram of chromatic dispersion compensation in optical transmission system. SC-DCF modules are inserted into the transmission line at uniform intervals and compensate the accumulated chromatic dispersion so that optical signals are adjusted within small residual dispersion required by the transmission channel so as not to cause any distortion of optical signal.

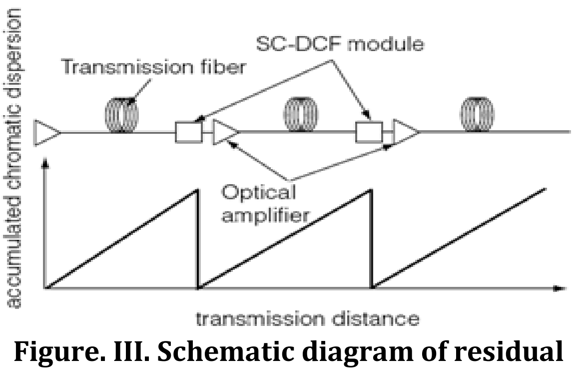


**Figure. III. Schematic diagram of residual chromatic dispersion compensation**

One of the reference indexes of dispersion and dispersion slope compensation ability of SC-DCF is relative dispersion slope (RDS). The RDS is given by

RDS =S/D……………… (1)

where S is the dispersion slope and D is the chromatic dispersion of SC-DCF and SSMF at operation wavelength.

When the RDS of SC-DCF equals the RDS of SSMF, the chromatic dispersion and the dispersion slope of SSMF are compensated simultaneously.

As shown in Figure IV, SC-DCF has negative dispersion and dispersion slope so as to compensate for the chromatic dispersion of SSMF over a wide wavelength range.

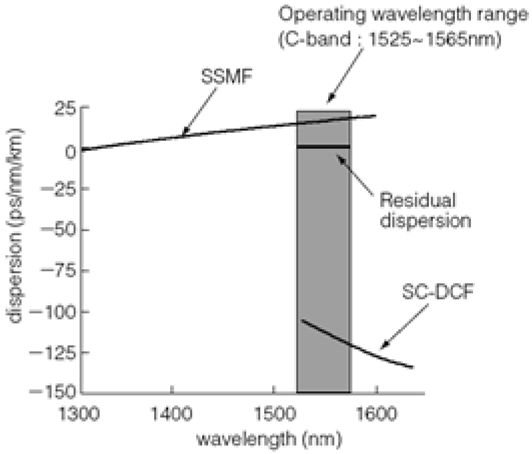


**Figure. IV. Chromatic dispersion of fiber and residual dispersion**

To impel the progress of DWDM transmission system, there are two requirements for improving the performance of SC-DCF modules. The first requirement is a lowering of insertion loss of the SC-DCF module in optical fiber transmission systems. Low-loss SC-DCF module contributes to the relaxation in optical gain requirement for an optical amplifier, which improves the noise Figureure of the optical amplifier as well as the overall performance of the optical fiber transmission systems. Downsizing of the SC-DCF module is the other requirement. DWDM transmission system consists of a large number of devices, and therefore downsizing each device is one of the major developmental challenges. Particular features of each SC-DCF are demanded; thus, it is difficult to achieve both demands simultaneously

### 4.2 Fiber Bragg Grating (FBG)

A FIBER Bragg grating (FBG) is a periodic perturbation of the refractive index along the fiber length which is formed by exposure of the core to an intense optical interference pattern. They launched intense Argon-ion laser radiation into a germania-doped fiber and observed that after several minutes an increase in the reflected light intensity occurred which grew until almost all the light was reflected from the fiber. Spectral measurements, done indirectly by strain and temperature tuning of the fiber grating, confirmed that a very narrowband Bragg grating filter had been formed over the entire 1-m length of fiber. This achievement, subsequently called "Hill gratings," was an outgrowth of research on the nonlinear properties of germania-doped silica fiber. It established an unknown photosensitivity of germania fiber, which prompted other inquires, several years later, into the cause of the fiber photo-induced refractivity and its dependence on the wavelength of the light which was used to the form the gratings. Detailed studies showed that the grating strength increased as the square of the light intensity, suggesting a two-photon process as the mechanism.

In the original experiments, laser radiation at 488 nm was reflected from the fiber end producing a standing wave pattern that formed the grating. A single photon at one-half this wavelength, namely at 244 nm in the ultraviolet, proved to be far more effective. This article contains an introduction to the fundamentals of FBG's, including a description of techniques for grating fabrication and a discussion of those fiber photosensitivity characteristics which underlie grating formation. By applying FBGs, the dispersion effects can be dramatically decreased in long transmission systems. Fiber gratings are a periodic variation in the refractive index of the core as measured along its axis. For an input wavelength equal to one half the repetition period Λ, the waves reflected at each periodic refractive index change add up in phase. The grating acts as a reflector as all the reflected beams add up in phase with each other. The reflected wavelength obeys
Bragg's law,

$$\Lambda = \lambda/2$$

Where, λ is measured in the fiber core.
The following Figure are the simulation outcome of FBG method using simulator OPTSIM.

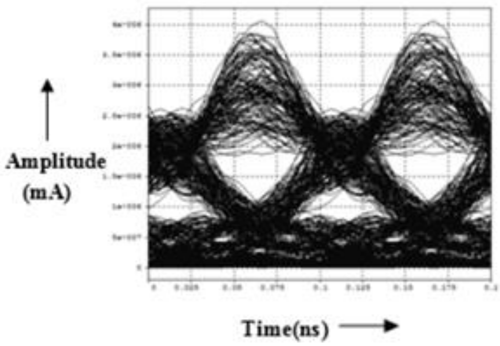


**Figure. V. EYE Diagram before compensation**

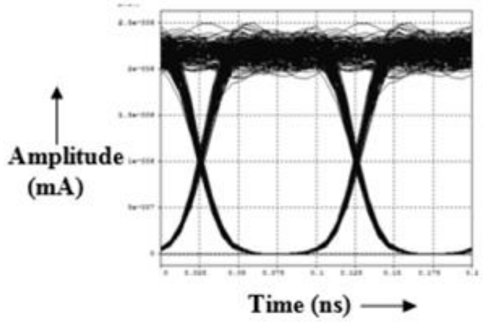


**Figure. VI. EYE Diagram after compensation**

## 4.3 Electronic Dispersion Compensation (EDC)

A schematic of the EDC receiver is shown in Figure.VII. Block A contains the optical components, as described above. An AMZI biased at quadrature with a delay of 5 ps acts as a 200 GHz periodic filter, which is compatible with the ITU frequency grid. The outputs are detected by two 12GHz-bandwidth photodiodes, which generate the two different electrical signals V1 and V2 ( of equations (3) and (4) respectively), each dependent on the instantaneous frequency (Δω) and amplitude (A) of the received optical field The functionality of blocks B, C and D may each be implemented using either analogue or digital electronics. Block B produces the two electrical signals VA=V1+V2 and VF= (V1-V2)/(V1+V2) which are proportional to the power and instantaneous frequency of the received optical field as in (3) and (4) above. In Block C, a local oscillator is modulated in power and frequency using VA and VF respectively to give a replica of the received signal. Finally a dispersive transmission line equalizes the group delay [3]. This is followed by square law detection and EFEC decoding which are used to recover the original signal from the electronic replica of the received signal.


**Figure. VII. Schematic diagram of EDC**

Upon entering the receiver, the signal was pre-amplified and filtered using a 42GHz-bandwidth third-order Gaussian optical filter. The amplified signal passed through the optical part of the receiver and the two voltages VA and VF were produced in blocks A and B. Block C comprised a high frequency oscillator within the simulation bandwidth and ideal power and frequency modulators were used to generate the down-shifted signal. Linear dispersion and the overall circuit frequency response were implemented in Block D with a total single sided bandwidth of 8GHz.

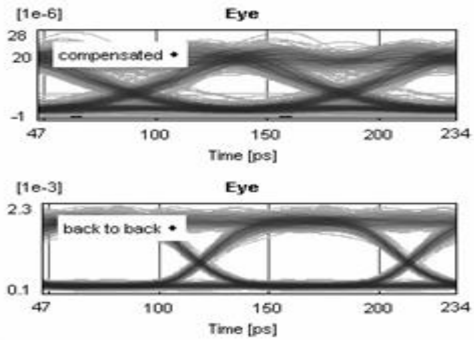


**Figure. VIII. Eye Diagram of EDC**

ISSN: 2394-3696

### 4.4 Optical Phase Conjugation Techniques

Phase conjugation is a fascinating phenomenon with very unusual characteristics and properties. The effective compensation of waveform distortion due to chromatic dispersion in a single mode fiber was demonstrated using an optical phase conjugate (OPC) wave generated by no degenerate forward four waves mixing in a zero dispersion single mode fiber. After transmission of 5 Gb/s and 6 Gb/s continuous phase FSK (CPFSK) signal through a dispersive single mode fiber, distortion compensation was confirmed by measuring bit error rate characteristics and observing heterodyne detected eye patterns.

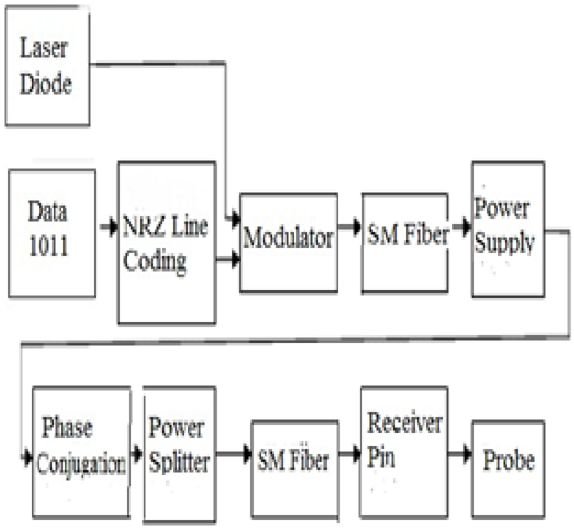


**Figure. IX. Schematic diagram of Optical phase conjunction techniques**

The schematic setup is combines transmitter, a fiber span consisting of two links, a mid span phase conjugator, and receiver. A 10 Gb/s NRZ data stream is sent over a first lossless fiber link where dispersion is set to D = 16 ps/nm/km. The peak power is set to -3 dBm. After 1000 km the eye diagram shows a completely closed eye, due to the accumulation of chromatic dispersion.

Then the signal goes through an OPC, and then to another 1000 km long fiber link. At the output of the second link the received eye is completely open. It is known from theory that a phase conjugator placed between two identical spools of fiber can completely compensate second order dispersion. In detail, the signal is being dispersed in the first half of the span resulting in distorted pulse shapes with the blue light leading the red light. This dispersed signal is then being phase conjugated. The OPC reverses or inverts the optical spectrum of the signal so that red becomes blue and blue becomes red. The below two schemes are the result of simulation using OPTSIM.

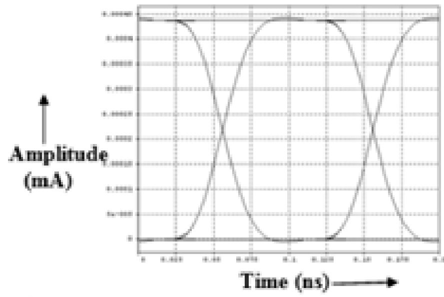


**Figure. X. Eye diagram of transmitted signal**

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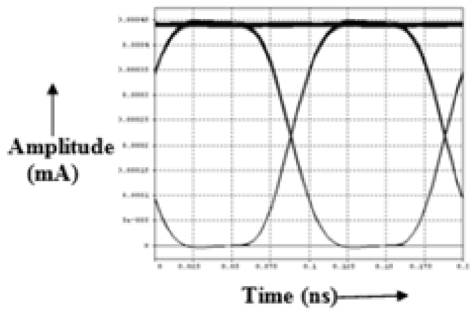



**Figure. XI. Eye diagram of received signal**

### 4.5 Digital Filters

The system of interest, as shown in Figure. XII, is based on a 10 Gb/s, non return to zero (NRZ) on off keying (OOK) pulse, optical source ( $\lambda_0$) 1.55 µm, length of SMF (L) is 160 km with dispersion (D) is 17 ps/nm-km, square law detector and second order of Butterworth low pass filter. All pass filter (APF) can be used to equalize a phase of a signal without introducing any amplitude distortion. The design of an optical all pass filter (OAPF) is based on APF. From the transfer function of OAPF, the phase response of the OAPF can be made arbitrarily close to any desired phase response. If designed correctly, are potentially very important devices in optical transmission systems since they can be compensate any dispersion in very small structures with very low loss.

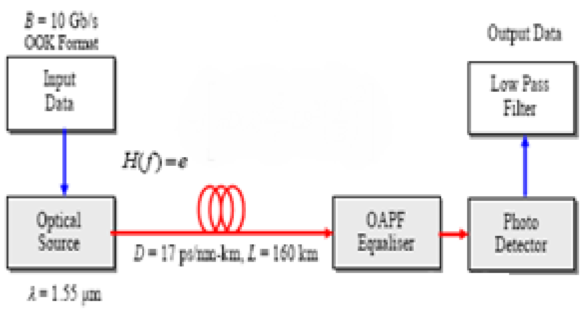
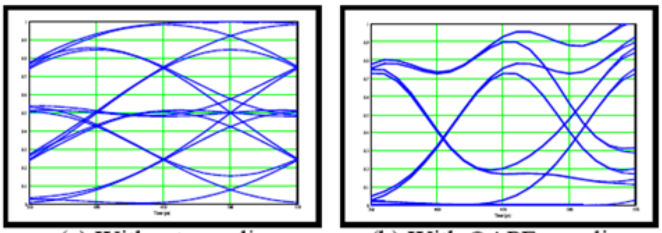



**Figure. XII. Optical communication system using OAPF**

Since the OAPF response is periodic, the free spectral range (FSR) of OAPF can be chosen so that the OAPF response coincides with each channel passband providing dispersion compensation for multiple channels in a WDM system. OAPFs have the potential for providing the highly stable third order dispersion compensation in optical fibre transmission systems. However, there is a tradeoff between the maximum group delay and the bandwidth as well as the FSR. Performance may be improved by increasing the number of stages or designing the poles and zeros of OAPF closer to the unit circle, however this poses practical problem such as increased in fibre complexity, unacceptable losses and unacceptable ripple of GVD which OAPF produces. OAPF is a lossless device, but in cases where several stages are used the finite insertion loss in practical devices needs to be considered. In practice there will be loss associated to the OAPF in the form of coupling losses, however if the loss is small over the bandwidth of interest, then the degradation in the performance will be minimal. This paper considered the ideal lossless case. OAPFs are linear systems which have a unity magnitude response over all frequencies. The phase response of OAPFs varies with frequency.

Figure. XII (a) and (b) shows the eye diagram at the receiver, at 160 km of SMF. The eye diagram of the system without the OAPF has an eye opening of 2% compared to a fully opened eye. The small eye opening will result in higher bit error rate (BER).



(a) Without equaliser. (b) With OAPF equaliser.

**Figure. XIII. Eye Diagram at 160km**

## 5. CONCLUSION

Fiber-optic communication because of its advantages over electrical transmission, have largely replaced copper wire communications in core networks in the developed world. But it is also marred by many drawbacks: dispersion, attenuation and non linear effect.

From this study it is clear that different researchers have used different techniques for dispersion compensation in optical system.

We consider five techniques in our consideration, but Phase conjugation technique is the best technique to reduce the dispersion.

## 6. ACKNOWLEDGE

All the authors would like to express a deep gratitude to, Principal, A.G. Patil Institute of Technology, Solapur for providing platform for research work. Authors are also grateful to anonymous reviewers for providing valuable feedback to improve upon the quality of the research paper.

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