Dispersion Compensation Techniques: A Review

Kamaldeep Kaur[1], Beant Kaur[2]
[1]*Department of Electronics and Communication Engineering, Punjabi University, Patiala, India*
[2]*Department of Electronics and Communication Engineering, Punjabi University, Patiala, India*
[1]kbrar665@gmail.com
[2]sandhu.beant@gmail.com

***Abstract*— Dispersion compensation plays a very significant role in controlling the overall chromatic dispersion of a system. It is used to avoid excessive temporal broadening of ultra-short pulses or the distortion of signals. Without dispersion compensation, each symbol gets broadened so much that it would strongly overlap with a number of neighbored symbols. Dispersion bound the bandwidth or information carrying capacity of a fiber. The dispersion compensation techniques discussed in this paper are Dispersion compensating fiber (DCF), Electronic dispersion compensation (EDC), Fiber Bragg grating (FBG), Digital filters.**

***Keywords*— equalizer, dispersion, dispersion compensation, dispersion compensating fiber (DCF), digital filters, electronic dispersion compensation (EDC), fiber Bragg grating (FBG).**

I. INTRODUCTION

Fiber optic communication is a technology that uses light pulses to transfer information from source to the destination through an optical fiber [1]. The digital information is generated by telephone systems and computer systems. Electrical signals are converted into light signals. The design of this system is limited by loss, dispersion and nonlinearity of the fiber [1].

As the optical signal pulse travels through a fiber, several factors like attenuation and dispersion of a propagating light can degrade the data transmission. The dispersion effects disfigure the shape of the pulse when the light wave travels down the fiber.. Dispersion compensation in fiber optical communication system is one of the recent topic of great research these days because presence of dispersion lead to pulse broadening which might cause the inter symbolic interference (ISI) which causes signal degradation It is necessary to overcome the dispersion to provide better communication system [1, 2].

II. DISPERSION

Dispersion represents a unique class of phenomenon that the phase velocity of electromagnetic wave depends on the wavelength [1]. Dispersion is the spreading of light pulses when travels down the length of an optical fiber various elements such as numerical aperture, core diameter, refractive index profile, and wavelength cause the pulse to expand. Dispersion increases along the fiber length. The total effect of dispersion on the performance of a fiber optic system is called Intersymbol Interference (ISI) [2].Dispersion limits the bandwidth or information carrying capacity of a fiber. The input pulse is supposed to be composed of three different wavelengths: $\lambda 1$, $\lambda 2$, and $\lambda 3$ travel at different velocities in the fiber. These arrive at the receiver at different intervals of time [3].

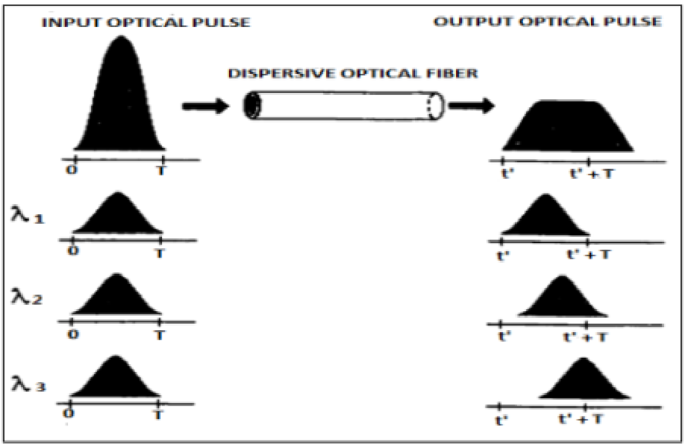


Fig.1 Pulse broadening caused by propagation through optical fiber [3]

The various types of dispersion in a fiber are discussed below:

Chromatic Dispersion

Chromatic dispersion is an important factor of degradation in fiber optic communications which occurs within a single mode fibers and multi mode fibers. It is the result of the different colors, or the wavelengths, in a light beam arriving at same destination at different times. The chromatic dispersion has two contributions: material dispersion and waveguide dispersion [4].

1) *Waveguide Dispersion*

It occurs most significantly in a single- mode fiber, because the light travels at slightly different velocities in the core and cladding, having slightly different refractive indices. The waveguide dispersion to be substantially changed on changing the internal structures of the fiber which leads to change the overall dispersion of the fiber [5].

2) *Material Dispersion*

It arises from the material properties of the fiber in which each wave changes speed differently and refracted differently. In this phenomenon a pulse made up of many wavelengths will spread out in time as it propagates in an optical fiber thus the propagation velocity varies with wavelength. The Index of refraction changes according to the wavelength. Material dispersion sometimes called Intramodal or Color dispersion [5].

Modal Dispersion

The widening of light is called modal dispersion. It occurs in Multimode fibers when rays follow different paths through the fiber and reach the destination at different times. Since the light reflects at different angles for different paths, the path length of different modes are different. It limits the bandwidth of multimode fibers [5].

Polarization Dispersion

It is the special case of mode dispersion. Polarization mode dispersion (PMD) is a phenomenon in which an input pulse excites multiple polarization components. The input Pulse get broadens as the polarization components travel at different speeds (disperse) along the fiber. Thus the time difference in the group delay between two orthogonal polarized modes called differential group delay (DGD), causes pulse spreading. These two local polarization modes travel at different velocities create a pulse spreading leading to a statistical behavior of PMD, both in time and wavelength [5, 7].

III. Dispersion Compensation Techniques

The dispersion compensation technique involves dispersion compensating fibers, electronic dispersion compensation, fiber Bragg grating, and digital filters**.**

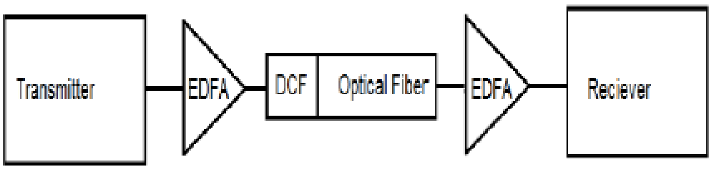
A. *Dispersion Compensating Fibers*

The idea of utilizing dispersion compensating fibers (DCF) introduced in 1980.The components of DCF are not easily affected by temperature, wide bandwidth.DCF has become a one of the most acceptance method for dispersion[6].DCF is a loop of fiber having a negative dispersion equal to the dispersion of the transmitting fiber. It can be put at either beginning or end known as pre compensation, post compensation, and symmetrical compensation. It is the very first compensation technique about the dispersion compensation.

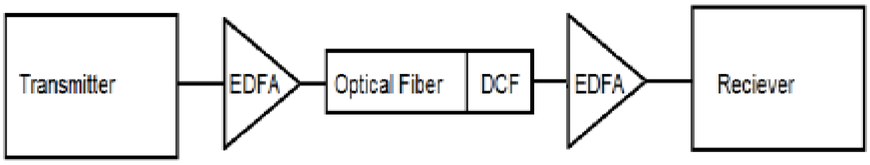
The very first technique was dsf (dispersion shifted fiber) which was used to compensate the dispersion at 1550 nm wavelength but in this window effects such as FWM (four wave mixing) and XPM (cross phase modulation) and FWM adversely affects the transmission. Then a new type of fiber established to compensate all the effects and was strong to nonlinear phase noise. This is known as dispersion compensation fiber (DCF).

This type of fiber can be employed before the optical fiber called pre-compensation or after the optical fiber called post compensation. When the DCF is employed between the amplifiers along with combination of both techniques called symmetrical compensation. The DCF technique is widely used with the WDM systems using single mode fiber having the large effective areas and low bit error rate.

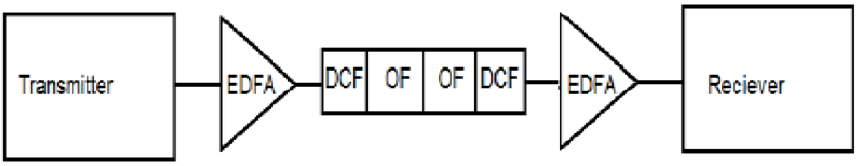
This is a very good and reliable technique but it gives high insertion loss and introduces nonlinear distortion when the input power is high. Other fibers like dispersion managed cables (DM) and reverse dispersion fiber (RDF) are employed which are similar to DCF [8], [9].



a)Pre- Compensation



b)Post- Compensation



(c) Symmetric Compensation

Fig.2 Different dispersion compensation schemes [2]

B. Electronic Dispersion Compensation.

The electronic signal processing used for distortion equalization in optical transmission systems started during 1991. Electronic dispersion compensation technique used the electronics in the optics for chromatic dispersion. There is a direct detection process in the receiver that the chromatic dispersion i.e. the linear distortion becomes nonlinear distortion after optic-electronic conversion. This technique is used in equalization circuits.

Many researchers have implemented different equalization circuits and their combinations. Hui Wu proposed distributed transversal equalizers focusing on delay lines and gain stages stressed on improving ISI. Researcher D.E. Crivelli had proposed the combined adaptive digital equalization for all order PMD and CD. One more technique is by using AMZI with large differential time delay. Another researcher D. Poe proposed feed forward equalizer with an adjustable tap coefficient to reduce the effect of ISI caused by dispersion. A.Gorshtein investigated adaptive lms based equalizer. Also I. Slim presented frequency domain CD compensation based on dft. The simplest technique used for dispersion compensation using EDC is by the use of Feed Forward Equalizer (FFE) and Decision Feedback Equalizers (DFE)[2], [13].

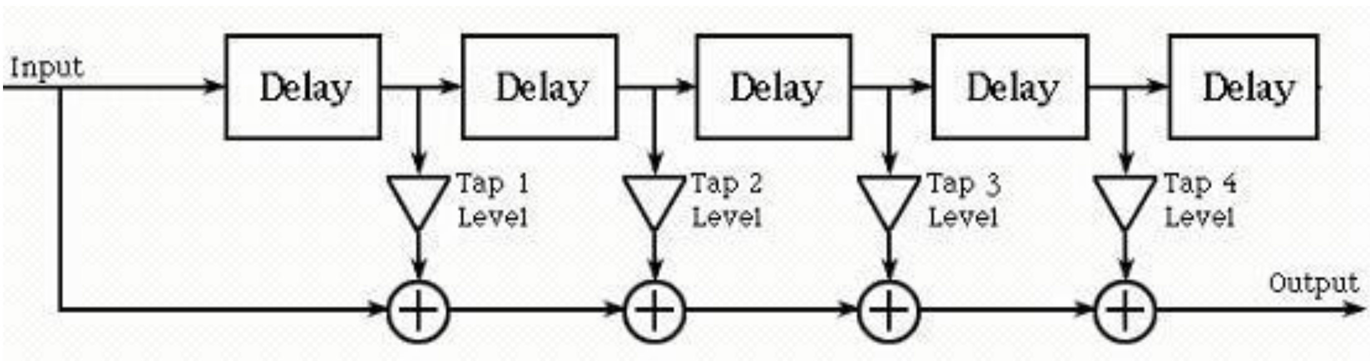


Fig.3 Feed Forward Equalizer [2]

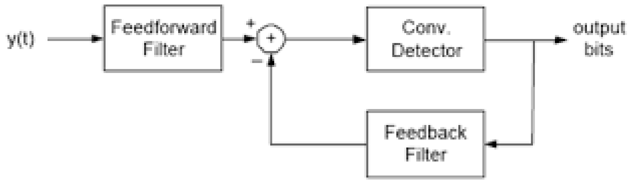


Fig.4 Single stage Decision Feedback structure [2]

C. Fiber Bragg Grating

The purpose of FBG was to provide frequency dependent delays in long haul transmission along with EDFA[10].It has two types i.e. chirped fiber Bragg grating and unchirped fiber Bragg grating. Chirped fiber Bragg grating which is a small all fiber passive device with low insertion loss which is compatible with the transmission system. The main advantage is its small footprint and low insertion loss. CFG must be used to get optimum results. Many researchers have proposed different techniques. One such researcher Y. Aiying proved that the increased interaction of SPM and dispersion in CFG can be used to extend the transmission distance. M.J. Islam concluded that by adjusting fiber length and chirp rate, FBG can be used to compensate GCD by improving BER performance [2], [11], [12].

D. Digital Filters

Digital filters in combination with DSP are effective and efficient method to compensate the chromatic Dispersion. They give fixed as well as tunable compensation for WDM systems. The most commonly used filter is lossless all pass filter. Digital filters are much reliable than FBG for WDM systems. Lossless all pass filter approximate any desired phase response with constant, unity amplitude response. M. H. Zadeh proposed two filters: band pass filter and all pass filter in reference to Q-factor. Y.J.He concluded that super Gaussian filters which can suppress phase jitter and more superior to pert and Gaussian filters. First of all fractional Fourier transform was introduced by Bailey and Swartztrauber. It was reintroduced by many groups in 1993[2], [14]

Conclusion And Future Scope

It has been concluded that dispersion is the main problem in improving the standards of the fiber communication. Researchers have demonstrated many different techniques to compensate the dispersion in the high speed optical fiber transmission. We can improve dispersion by comparing and analyzing different techniques discussed above. Using optical based software's like OPTISIM and OPTYSYS we can operate different parts of the transmission system using DCF technique such as using higher bit rates with complex WDM systems, we can also test upper optimized limits of the DCF fibers as their lengths and other inherent characteristics. So in future, digital filter can be used with digital signal processing for effective compensation of dispersion.

References

[1] en.wikipedia.org/wiki/Fiber-optic communication.
[2] Mehtab Singh, "Different Dispersion Compensation Techniques in Fiber Optic Communication System: A Survey", International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE) , ISSN: 2278 – 909X Volume 4, Issue 8, August 2015.
[3] Prachi Sharma, Rohit Kumar Arora, Suraj Pardeshi, Mandeep Singh, "Fiber Optic Communications: An Overview", International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 5, May 2013.
[4] Shivinder Devra, Gurmeet Kaur "Different Compensation Techniques To Compensate Chromatic Dispersion In Fiber Optics", International Journal of Engineering and Information Technology, Vol 3, 2011
[5] N. Ravi Teja, M.Aneesh Babu, T.R.S.Prasad, T.Ravi, "Different Types of Dispersions in an Optical Fiber", International Journal of Scientific and Research Publications, Volume 2, Issue 12, 1 ISSN 2250-3153, December 2012
[6] N. K. Kahlon and G. Kaur, "Various Dispersion Compensation Techniques for Optical System: A Survey", OPEN JOURNAL OF COMMUNICATIONS AND SOFTWARE, Volume 1, Number 1, MAY 2014
[7] Pawan Kumar Dubey , Vibha Shukla, " Dispersion in Optical Fiber Communication", International Journal of Science and Research (IJSR), ISSN (Online): 2319-7064 Volume 3 Issue 10, October 2014
[8] Manpreet Kaur, Himali Sarangal, Parveen Bagga, "Dispersion Compensation with Dispersion Compensating Fibers(DCF)", International Journal of Advanced Research in Computer and Communication Engineering, Vol. 4, Issue 2, February 2015
[9] Dr. Amit kumar garg, "A comprehensive study of various compensation techniques in high speed single mode optical fiber communication", International Journal of Recent Trends in Engineering & Research, ISSN: 2455-1457, Volume 02, Issue 05; May – 2016.
[10] Er. Abhishek Sharma Er. Sukhbir Singh Er. Bhubneshwar Sharma, "Investigations on Dispersion Compensation using Fiber Braggs Grating **",** International Journal of Computer Applications (0975 – 8887) Volume 73– No.2, July 2013.
[11] R.S. Kaler et al. / Optics Communications 209 (2002) 107–123
[12] N.M. Litchinitser, M. Sumetsky, and P.S. Westbrook, "Fiber-based tunable dispersion compensation", Journal of optical and fiber communications reports, 2007.
[13] Henning Bülow, Fred Buchali, Axel Klekamp, " Electronic Dispersion Compensation", journal of lightwave technology, vol. 26, no. 1, January 1, 2008
[14] Seb J. Savory, "Digital filters for coherent optical receivers", OPTICS EXPRESS 805, Vol. 16, No. 2 , 9 Jan 2008