Estimation of Dispersion Compensation using Dispersion Compensation Fiber (DCF) for Reliable Optical Communication

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Abstract

Dispersion in optical fibers leads to the broadening of optical pulse while propagating in an optical fiber. Pulse spreading due to the dispersion causes the overlapping of the transmitted pulses at the receiver end known as inter symbol interference (ISI). The ISI thus limits transmission of high-speed data. Since the demand of bandwidth and high-speed applications is high, then optical networks form the most important part because of its high bandwidth. In optical networks chromatic dispersion (CD) is one of the main obstacles in high speed transmission. Hence this CD is compensated by various approaches throughout the transmission system. this research work investigates the effect of CD by using a span of dispersion compensation fiber and optical amplifier to relief the problems of CD and attenuation. It was found that pulse broadening and intensity loss in the optical signal is increasing proportionately with the propagation length of the fiber and this is what contributes to the causes of detection errors at the receiver. The predicted dispersion compensation fiber coefficient was used to observed the efficiency of dispersion compensation fiber technique in overcoming the effect of group velocity dispersion in optical fiber transmission system using OptiSystem 16.0 simulator and it was proved that handling the signal to eliminate chromatic dispersion and attenuation was achieved by the use of dispersion compensation fiber cascaded with optical amplifier.

Index Terms— Dispersion, Dispersion Compensated Fibers, optical signals, single mode fiber,

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1. INTRODUCTION

In optoelectronics and optical fiber telecommunication, light is used for data transmission, in optical fiber interferometers, optical fiber lasers, sensors and optical fiber modulators. Optical fiber transmission uses wavelengths that are in the near-infrared portion of the spectrum, just above the visible, and thus undetectable to the unaided eye. Typical optical transmission wavelengths are 850 nm, 1310 nm, and 1550 nm. Both lasers and LEDs are used to transmit light through optical fiber. Lasers are typically used for 1310- or 1550-nm single-mode applications. LEDs are used for 850- or 1300-nm multimode applications. There are ranges of wavelengths at which the fiber operates best. Each range is known as an operating window. Each window is centered on the typical operational wavelength, as shown in Table I. These wavelengths were chosen because they best match the transmission properties of available light sources with the transmission qualities of optical fiber. (Connecticut, 2000)

Table I:
Fiber Optic Transmission Windows

Window	Operating Wavelength
800 – 900 nm	850 nm
1250 – 1350 nm	1310 nm
1500 – 1600 nm	1550 nm

Fig.1.0 Shows the electromagnetic radiation spectrum and allows locating the radiation used in optical fiber transmission. In further parts of this work the terms “light” and “electro-magnetic radiation from near infrared range” will be used interchangeably.

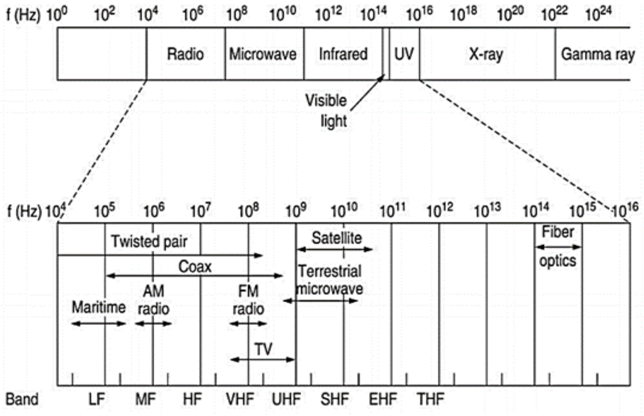


Fig. 1.0 Spectrum of electromagnetic radiation (Keiser, 2013).

2. Fiber Dispersion

Dispersion is defined as spreading of pulse in an optical fiber. As a pulse of light travel through a fiber, elements such as numerical aperture (NA), core diameter, refractive index profile, wavelength (λ), and laser line width cause the pulse to broaden and one more thing about dispersion is that it increases along the fiber length 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. The chromatic dispersion of optical fiber is critical to the design and construction of long-haul and high-speed optical communication systems and to the manufacture of optical fiber. It is important to reduce the accumulated chromatic dispersion after long distance transmission (Warsha & Manish 2013). Each type of dispersion mechanism leads to pulse spreading. As a pulse spreads, energy is overlapped. This condition is shown in figure 2.0.

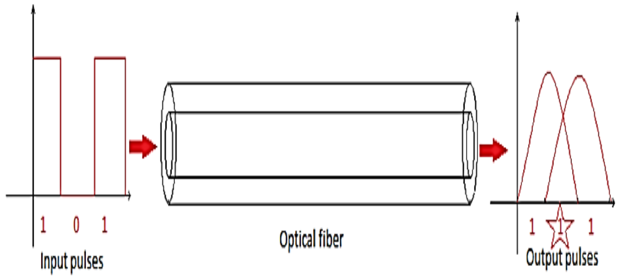


Figure 2.0 Pulse overlap (Keiser, 2013)

chromatic, dispersion depends primarily on fiber materials. There are two types of intramodal dispersion. The first type is material dispersion. The second type is Waveguide dispersion. Intramodal dispersion: occurs because different colors of light travel through different materials and different waveguide structures at different speeds.

Material dispersion occurs because the spreading of a light pulse is dependent on the wavelengths' interaction with the refractive index of the fiber core (Dike and Ogbe 2013). Different wavelengths travel at different speeds in the fiber material. Different wavelengths of a light pulse that enter a fiber at one time exit the fiber at different times. Material dispersion is a function of the source spectral width. The spectral width specifies the range of wavelengths that can propagate in the fiber. Material dispersion is less at longer wavelengths.

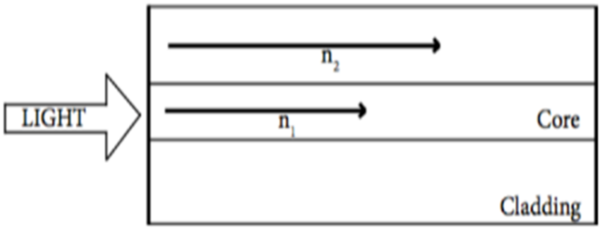


Fig.3.0 Material Dispersion

Waveguide dispersion occurs because the mode propagation constant (β) 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 (Janrao & Janyani, 2011). Dispersion (from all causes) is often grouped under the name Group Velocity Dispersion (GVD) (Robin et al., 2015).

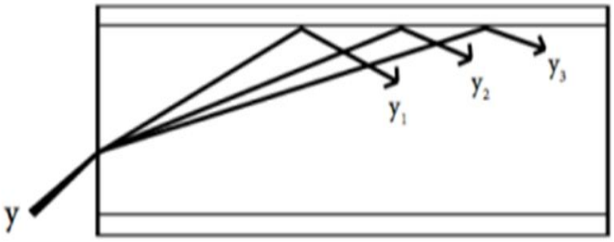


Fig. 4.0 Waveguide Dispersion

3. Dispersion Compensation Techniques

Dispersion compensation is the process of balancing the positive and negative dispersion over the length of the fiber. Several chromatic dispersion compensation techniques exist, with Dispersion Compensation Fiber (DCF), Fiber Bragg Grating (FBG) and Optical Phase Conjugate (OPC) compensation techniques being the most widely employed dispersion compensation techniques (Udayakumar et al., 2013). When the optical pulses reach the receiver the total dispersion is near zero or within an acceptable limit. It should be clear that with the advent of optical amplifiers, fiber losses are no longer a limiting factor for optical communication systems. Indeed, modern light wave systems are often limited by the dispersive and nonlinear effects rather than fiber losses. In some sense, optical amplifiers solve the loss problem but, at the same time, worsen the dispersion problem since, in contrast with electronic regenerators, an optical amplifier does not restore the amplified signal to its original state. As a result, dispersion-induced degradation of the transmitted signal accumulates over multiple amplifiers. In order to achieve high speed, large capacity and long distance communication, it is necessary to use DCF in the optical fiber, thus the total dispersion of the whole optical fiber line is approximately zero (Yue et al., 2016). Dispersion compensating fibers (DCF) are extremely attractive when used in conjunction with standard single mode fibers SMF (Rekha and Mritunjay, 2016). It is possible to construct a fiber profile where the total dispersion is over 100ps/nm/km in the opposite direction to dispersion caused by the material.

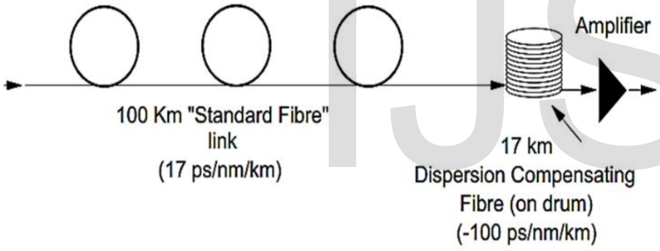


Fig. 5.0 Dispersion Compensation of an Existing Standard Fiber Link (Lucki & Zeman, 2015).

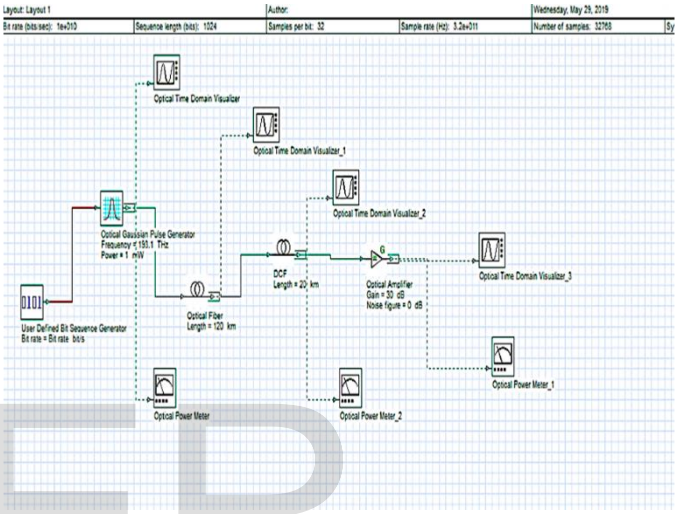
This can be placed in series with an existing fiber link to “undisperse” a signal. Dispersion compensating fiber with dispersion of 100 ps/nm/km is commercially available however it has an attenuation of 0.5 dB/km (Rajana and suresh, 2016).

4. DCF System Simulation:

The dispersion of SMF in the 1550nm window is 17ps/nm/km, therefore the use of dispersion compensating fiber (DCF) is an efficient way to upgrade installed links made of standard single mode fiber (SMF).The simulation model of the DCF based on the Optisystem 16.0 is shown in figure 3.2, in this system the design parameters of SMF and DCF are listed in Table II.

Table II.
Design parameters of SMF and DCF

Fiber	Attenuation in (dB/km)	Dispersion (ps/nm/km)	Dispersion slope (ps/nm²/km)
SMF	0.2	17	0.08
DCF	0.5	-85	-0.3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Wednesday, May 29, 2019
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Number of samples: 32768

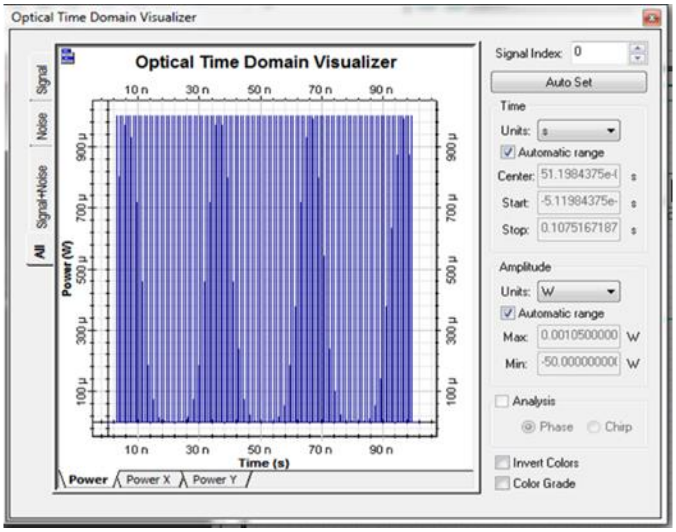
Fig. 6.0 OptiSystem DCF system diagram

Dispersion and Attenuation Effects can be achieved by simulating the optical network and evaluate the results calculated by the mathematical tools embedded in the system. These measurements can be gathered from dedicated optical and electrical visualizer available in this simulator.

5. Results and Discussion

The system in figure **6.0** was implemented and the simulation was run. After generating the original light pulse by optical pulse generator as shown in figure 6.1, the spreading pulse in the time domain due to effect of SMF’s chromatic dispersion was identified and it was shown in Figure 6.2 and because DCF dispersion characteristics is coincides contrary with the SMF the total transmission line dispersion value is close to zero, thus become easy restoring the original light pulse, However, the DCF attenuation is larger, to solve this problem, Optical Fiber Amplifier OFA was added to compensate linear loss after the DCF and near to the receiver.

Figure 6.5 give the ultimate shape of the pulse after amplification, eventually the system has implemented the role of DCF technology by Optisystem simulation



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Amplitude
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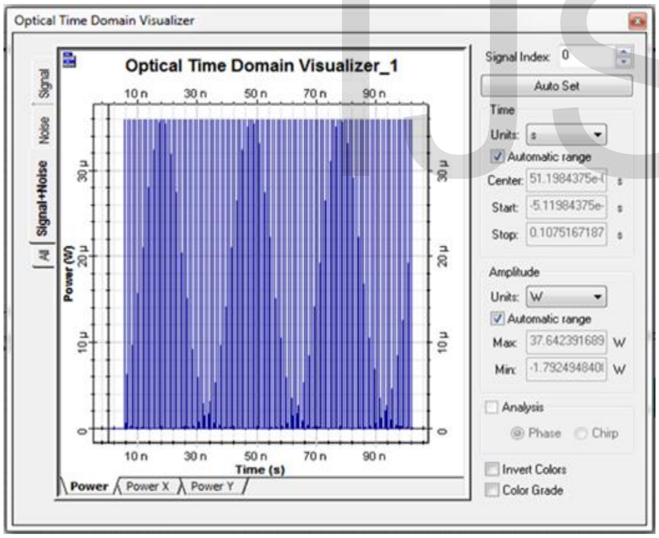
Fig 6.1 initial Gaussian pulse



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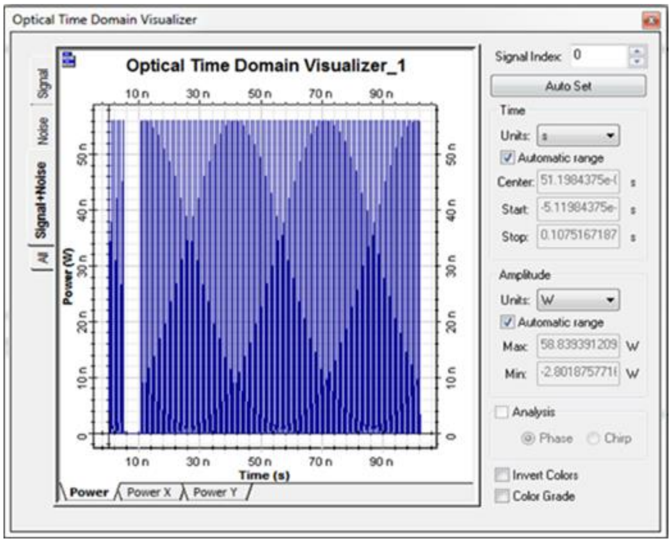

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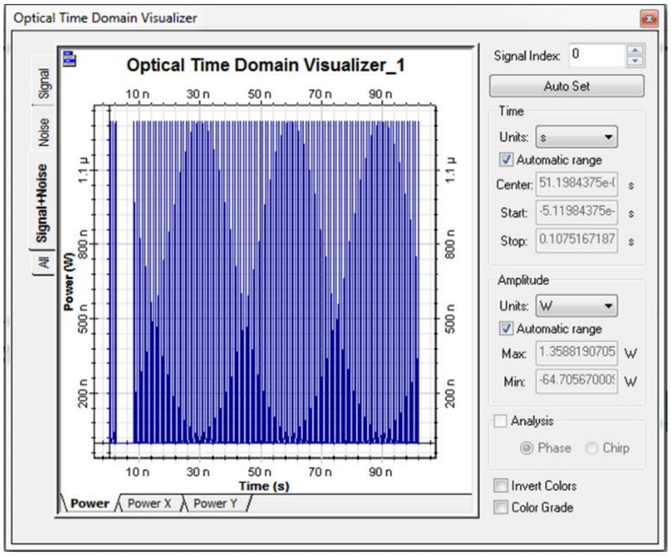

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Fig. 6.2 Dispersion effect pulse at 60km SMF

Fig. 6.3 Dispersion effect pulse at 120km SMF

Fig. 6.4 Dispersion effect pulse at 180km SMF

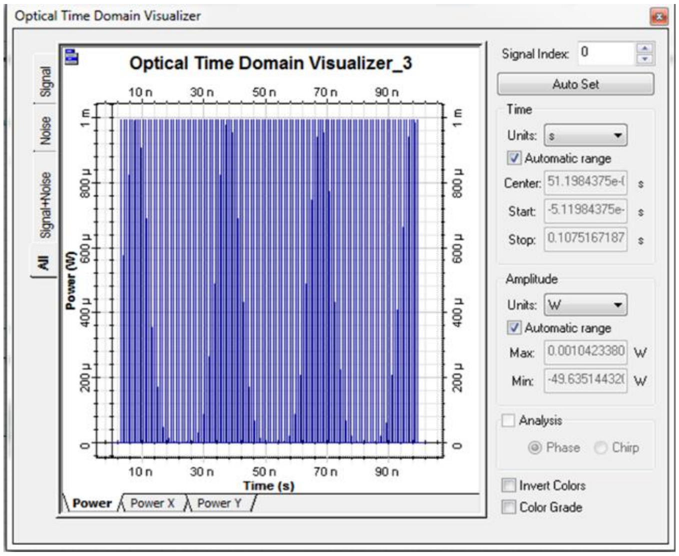

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Fig 6.5 pulse after optical amplifier

The performance of dispersion compensation techniques usind DCF is evaluated by varying the length of the carrier fibre from 60, 120 and 180 Km and the behaviour of the signal was observed from the simulation as follows:-

1. Signal degradation due to chromatic dispersion and fiber attenuation is clearly visible and identifiable
2. Pulse broadening and intensity loss in the optical signal is increasing proportionately with the propagation length of the fiber and this is what contributes to the causes of detection errors at the receiver.
3. compensation of the signal to eliminate chromatic dispersion is achieved by the use of dispersion compensation fiber which was cascaded to the length of the carrier fiber, but this compensating fiber is of shorter length of about one-fifth that of the carrier fiber but with large and opposite dispersion coefficient.
4. The arrangement of DCF and OFA restores the original input signal at the receiver, the designed dispersion compensation technique using DCF and OFA clearly solved the problem of dispersion and attenuation.

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