Reduction of Dispersion in Optical Fiber Communication by Fiber Bragg Grating and Optical Phase Conjugation Techniques

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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. To combat these losses and improve the reliability of fibers introduced many advanced technologies. Here two compensation techniques such as Fiber Bragg Grating and Optical Phase Conjugation are discussed with the help of simulation software "**OPTSIM"** to compensate dispersion**.** We have also analyzed the time delay of the received signal with variation of frequency by using **B4530 trainer** in the "Telecommunication Lab, Rajshahi University of Engineering & Technology, Bangladesh" and proved that when frequency of the transmitted signal increases then time delay i.e. dispersion of the received signal decreases.*

Keywords

Dispersion, Fiber Bragg Gratings, Phase Conjugation, EYE Diagram.

1. INTRODUCTION

Fiber optic communication is a method of transmitting information from one place to another by sending light through an optical fiber [1]. The light forms an electromagnetic carrier wave that is modulated to carry information. The process of communicating using fiber optics involves the following basic steps: Creating the optical signal using a transmitter, relaying the signal along the fiber, ensuring that the signal does not become too distorted or weak, and receiving the optical signal and converting it into an electrical signal [1, 2].

When different wavelengths of light pulses are launched into an optical fiber, these pulses will traveled at different speeds due to the variation of refractive index with wavelength. These light waves tend to get spread out in time after traveling some distance in the optical fiber and this is continued throughout the length of the fiber. This phenomenon of boarding the pulse width is called dispersion [4].

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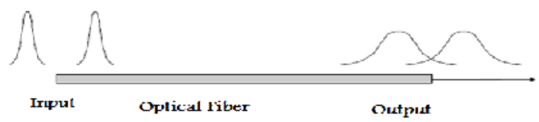

Figure: 1.1: Input pulses are spread out as running along the fiber

There are generally two sources of dispersion: material dispersion and waveguide dispersion. **Material dispersion** comes from a frequency-dependent response of a material to waves. For example, material dispersion leads to undesired chromatic aberration in a lens or the separation of colors in a prism. **Waveguide dispersion** occurs when the speed of a wave in a waveguide (such as an optical fiber) depends on its frequency for geometric reasons, independent of any frequency dependence of the materials from which it is constructed [6].

The dispersion curve is nearly straight line between wavelengths from 1200 nm to 1600 nm. A useful analytic approximation in this range for silica fiber is given by an empirical formula

$$M = -\frac{M_0 \lambda}{4}\left(1 - \frac{\lambda_0^{\ 4}}{\lambda^4}\right)$$

Where the slope M_0 is approximately -0.095 $ps/(nm \cdot km)$, λ_0 is the zero dispersion wavelength which is about 1310 nm.

The material dispersion is plotted as a function of the free space wavelength from above equation in Figure 1.2 for pure silica. For pure silica at wavelengths below 1.3 µm M is positive. When M is negative, the pulse spread is positive and the shorter wavelength travels faster than the longer wavelength. At 1.3 µm, the material dispersion is zero for pure silica. Pulse spreading owing to material dispersion disappears at this wavelength. Silica based glasses used in fiber optics have zero material dispersion near 1.3 µm.

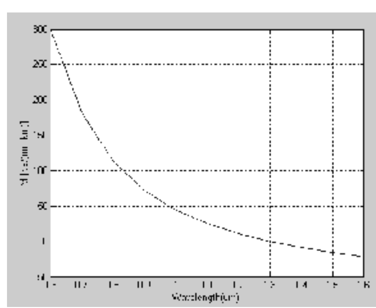

Figure 1.2: Material dispersion vs. wavelength curve

Eye diagram means 1 and 0 signals in an optical system are displayed on an oscilloscope to show how clearly they are defined. If the signals are too long, too short, poorly synchronized with the system clock, too high, too low, too noisy, too slow to change, or have too much undershoot or overshoot, this can be observed from the eye diagram. An open eye pattern corresponds to minimal signal distortion. Distortion of the signal waveform due to intersymbol interference and noise appears as closure of the eye pattern [3].

There are many techniques used in dispersion compensation, out of them two are simulated in "OPTSIM". One is **Fiber Bragg Grating (FBG)** method and another is **Optical Phase Conjugation (OPC).**

2.DISPERSION COMPENSATION BY FIBER BRAGG GRATINGS (FBGS)

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 [5]. 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

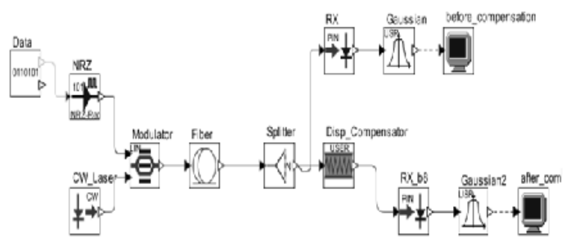

Figure 2.1: Block Diagram of FBG

The topology shown in above figure simulates a 10Gbps NRZ single channel link. The length of the single mode fiber is 100km. The fiber dispersion compensated by user defined FBG model. A digital data consists of '0' and '1' is converted to the NRZ data by a NRZ converter. Then it is fed into the modulator and added with an optical signal from the light source such as laser. Then it is transmitted through the lossless fiber and splitted by a splitter. Finally two outputs are shown with a dispersion compensator and without dispersion compensator [9, 10]. The following four figures are the simulation outcome of FBG method using simulator OPTSIM.

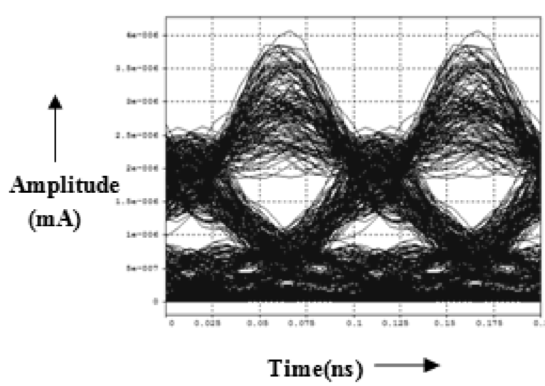

Figure 2.2: EYE Diagram before compensation

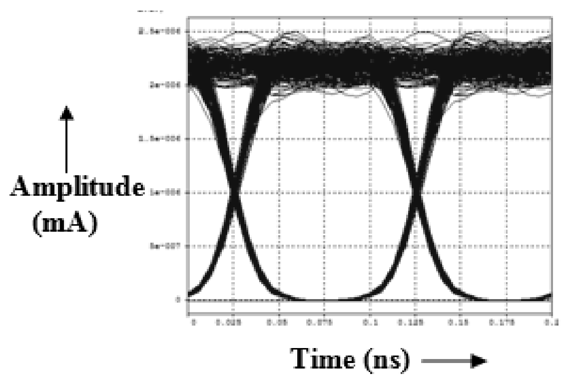

Figure 2.3: EYE Diagram after compensation

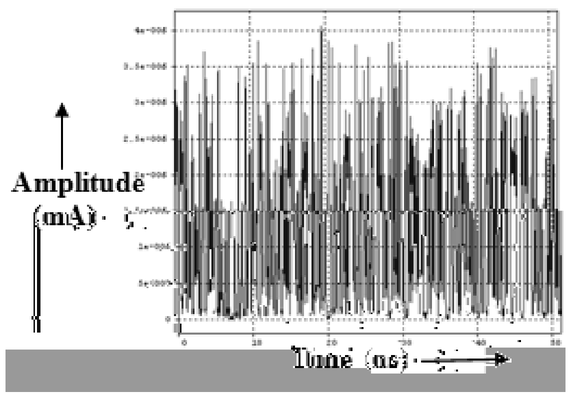

Figure 2.4: Electrical Signal before Compensation

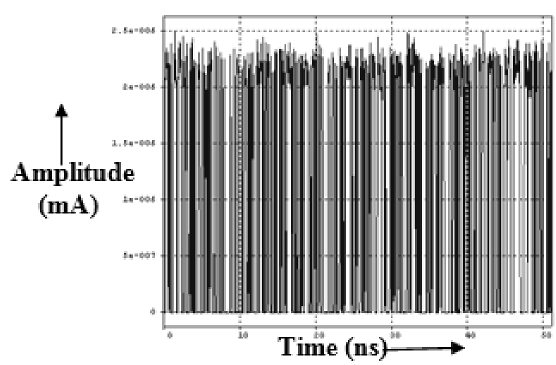

Figure 2.5: Electrical Signal after Compensation

3.DISPERSION COMPENSATION by PHASE CONJUGATION

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 [11]. 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. The principle of operation for OPC block is phase inversion according to—

$$Ein(t)=A(t)\ e^{j\phi(t)}$$

$$E_{out}(t)=A(t)e^{-j\phi(t)}e^{j\phi shift}$$

Where ϕ_{shift} is a extra phase shift. Here it is equal to $\pi/2$.

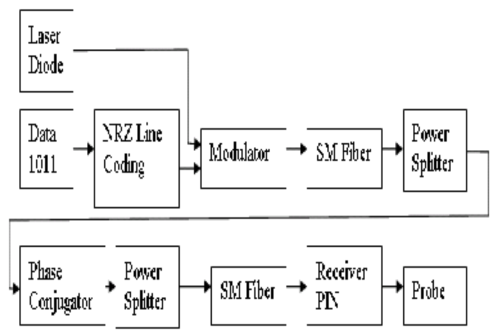

Figure 3.1: Schematic setup for dispersion compensation by phase conjugation

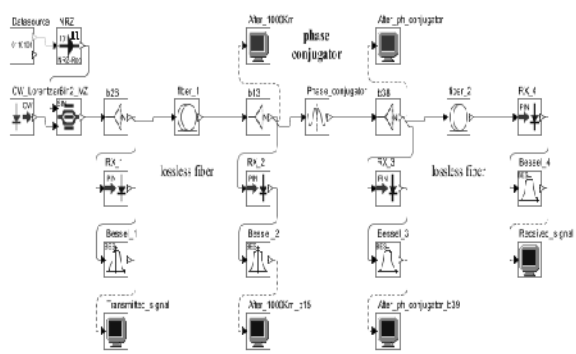

Figure 3.2: Block Diagram of Phase Conjugation

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 four schemes are the result of simulation using OPTSIM.

Figure 3.3 shows the eye diagram of transmitted signal. The binary data are first converted to non-return-to zero and added a light wave in the modulator. Then the signals are filtered and output are measured. So there is no dispersion here because the signal is not passed through the fiber. Here an opening eye exists, so dispersion is so small in the transmitted signal.

But when it is passed through the 1000km fiber a noise is added and dispersion also occurred. So after 1000km eye diagram becomes a closing eye and a huge dispersion occurred. Then a phase conjugator is used to compensate the dispersion but it is not passed. So the dispersion is the same after 1000km. So the eye diagram curve is the same to the curve after 1000km_b15 and it is shown in figure 3.4. When it is passed through a lossless fiber and received and then filtered, a similar curve obtained as transmitted signal. That is the dispersion is compensated by a phase conjugator and a clearly opening eye exist. But after 1000km_b15, the amplitude changes rapidly with time because of the dispersion. At one point amplitude is high but another point it is very low. It is similar after phase conjugator_b39. Finally after phase conjugation a received signal is obtained which is similar to the transmitted signal and it is small because the dispersion is compensated by a phase conjugator and it is shown in Figure 3.6.

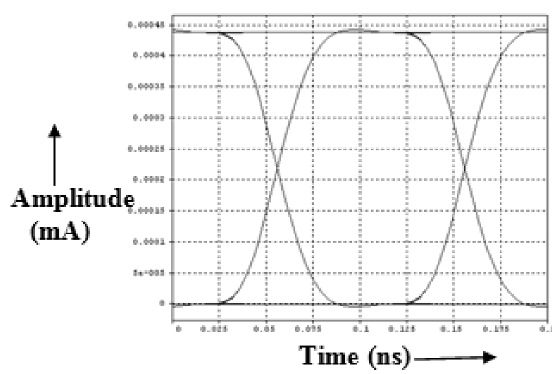

Figure 3.3: EYE Diagram of transmitted signal

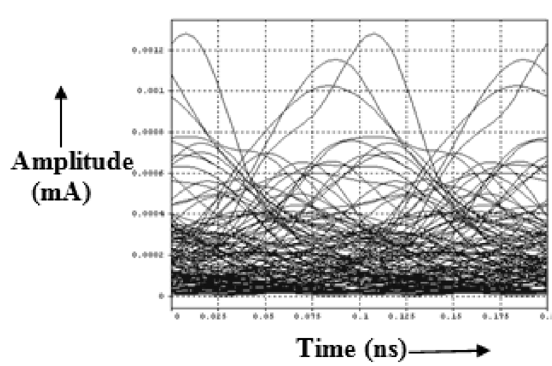

Figure 3.4: EYE Diagram after 1000km_b15

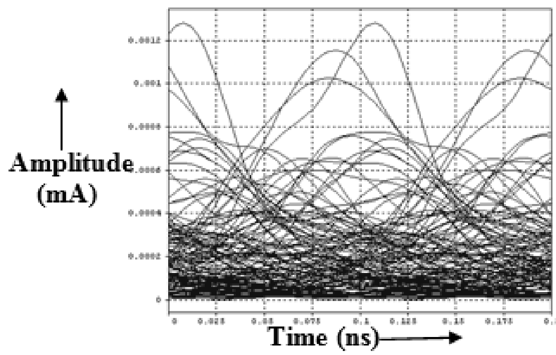

Figure 3.5: EYE Diagram after phase conjugator_b39

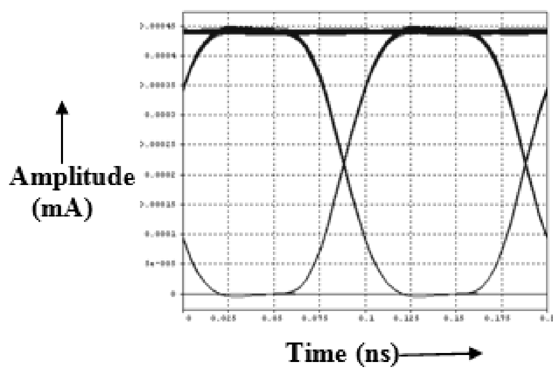

Figure 3.6: EYE Diagram of received signal

4. COMPARISON BETWEEN TWO COMPENSATION TECHNIQUES

The performances of the proposed Phase Conjugation method are investigated and compared to those obtained from the Fiber Bragg Grating (FBG) at various operating conditions, such as, Eye diagram at transmitting and receiving signal. The comparative results show that the Phase conjugation is more reliable and hence, found to be a suitable replacement of the Fiber Bragg Grating (FBG) technique. One important thing is that FBG is very simple and easiest technique to reduce the dispersion but Phase Conjugation is more complex and costly. If we consider the greatest output that is to get the accurate output phase conjugation technique is more reliable than FBG method. On the other hand if we consider the cost then FBG method is more reliable than phase conjugation method. But overall, phase conjugation is the greatest technique to reduce the dispersion in optical fiber communication.

5. PRACTICAL MEASUREMENT by B4530 TRAINER

This trainer includes the means to easily experiment some applications of fiber optics and provides the inherent properties and capabilities of this information transmission medium.
The trainer includes the following- Digital Transmission Channel, Transmitter/Receiver, Digital Receiver Channel, Analog Transmission Channel and Analog Reception Channel.

Digital Transmission Channel accepts digital TTL input signal of variable frequency. The digital channel operates in such a manner that the transmitting F.O. diode is driven in the ON/OFF mode. Transmitter/Receiver are to be linked by one of the two F.O. cables provided which are respectively 50cm and 5m long. Digital Receiver Channel receives the signal from the F.O. receiver. Processing of digital signals consists in amplification and shaping. Analog Transmission Channel receives the analog test signal at its input, typically a sine wave from a test generator, 0.5 to 3V pp amplitude and frequency 0 to at least 70MHz, to conveniently explore the upper frequency cutoff point of the transmission system. Analog Reception Channel must be connected to the receiver's output. The analog amplifier is provided with a variable gain. The gain values affect the output signal amplitude and also the upper cutoff frequency of the transmission system.

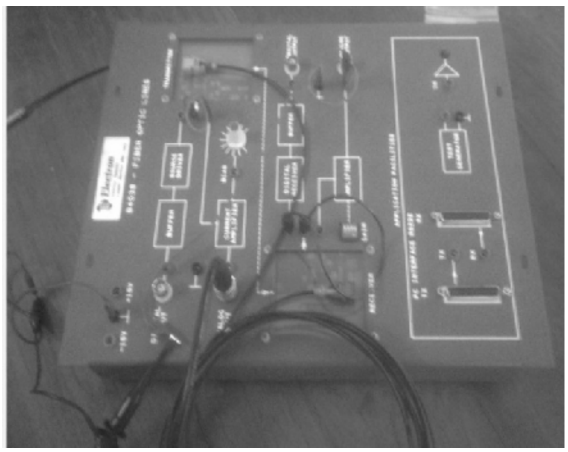

Figure 5.1: B4530 Trainer

Table 5-1: Output Data measured by B4530 trainer

Frequency(f)	**Time Delay(Δt)**
198 kHz	0.17 µs
667 kHz	0.116 µs
945kHZ	0.11 µs
1.96 MHZ	95 ns
1.98 MHZ	85 ns

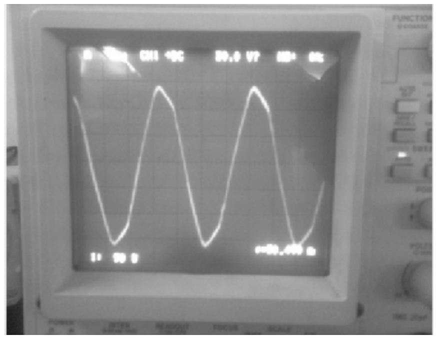

Figure 5.2: Input signal in oscilloscope

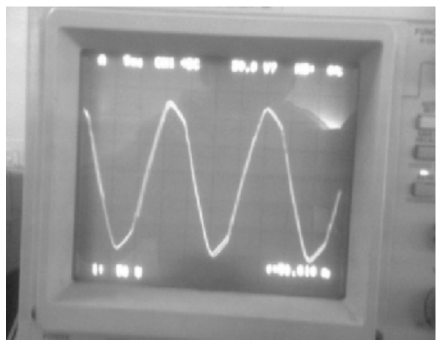

Figure 5.3: Output signal in oscilloscope

6. CONCLUSION

A technique that shows promise for reducing pulse spreading that is dispersion is the production of solitons which travels along a fiber without changing shape. We used two techniques to reduce the dispersion by using OPTSIM. One is the Fiber Bragg Grating(FBG) and another is the Optical Phase Conjugation(OPC) method. But overall optical phase conjugation method (OPC) is the best technique to reduce the dispersion. By using B4530 Trainer we also measured the output signal after a certain distance and found as increasing the frequency of the input signal the output signal remains almost same as like as input which shows dispersion can be reduced by using high frequency input signal.

7. FUTURE WORK

Advanced technologies might be used to reduce the dispersion as like Photonic Crystal Fiber. In future it will be discussed with other techniques by using **OPTSIM.** Moreover improved software can be used such as **COMSOL** which is hand written program software.

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