International Journal of Advanced Academic Research | Sciences, Technology & Engineering | ISSN: 2488-9849
Vol. 5, Issue 1 (January 2019)

ANALYSIS OF DISPERSION COMPENSATION IN A SINGLE MODE OPTICAL FIBER COMMUNICATION SYSTEM

Sani Abdullahi Mohammed[1], Engr. Yahya Adamu[2] and **Engr. Matthew Kwatri Luka[3]**

[1,2,3] Department of Electrical and Electronics Engineering, School of Engineering and Engineering Technology, Modibbo Adama University of Technology Yola, Adamawa State, Nigeria.

[1]samohd3@yahoo.co.uk, [2]adamuyahya2002@yahoo.com, [3]matthewkl@mautech.edu.ng

Corresponding author's (Sani Abdullahi Mohammed) phone number: +2348034034331

Abstract

The performance of a single-mode optical fiber communication system is significantly affected by chromatic dispersion, which occurs because the index of the glass varies slightly depending on the wavelength of the light, and light from real optical transmitters has nonzero spectral width. Dispersion and fiber attenuation pose a great problem in the detection of optical signals. Dispersion causes pulse broadening which limits the information carrying capacity of the fiber while attenuation limits the maximum transmission distance along the fiber. In this work the technique of analyzing dispersion using a span of dispersion compensation fiber is used to ease the problems of chromatic dispersion and attenuation. An approximate Gaussian pulse propagation model is designed and is obtained from Nonlinear Schrödinger Equation to represent the effects of chromatic dispersion and attenuation which is simulated in Matlab environment using split-step Fourier Method. 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.

1. INTRODUCTION

The development of telecommunications is one of the significant activities nowadays and direct consequence of advances in science and engineering. A virtual real-time communication between entities placed on the opposite sides of the globe, it is potential thanks to a vast physical network able to move information at the speed of light. The core of this structure is composed of the fiber-optic networks, which assume the task of managing the gross amount of data traffic over distances up to thousands of kilometers. 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 tied by many drawbacks, which includes dispersion, attenuation and nonlinear effect. Major studies in recent time compensate dispersion based on Digital Signal Processing (DSP) which lead to the use of digital filters such as bandpass filter, Gaussian filters, Super-Gaussian filters, Butterworth filters and microwave photonic filter. Some researchers examined Coherent Optical-Orthogonal Frequency Division Multiplexing (CO-OFDM) which was used to remove inter symbol interference (ISI) caused by chromatic dispersion at long distances and high data rate. The above mentioned studies lead to the requirement of additional circuit. Nonlinear Schrodinger Equation (NLSE) can be used to analyze the dispersion in the communication system. The combined effect of group velocity dispersion GVD and Self Phase Modulation (SPM) on the propagation pulses can be analyzed through Nonlinear Schrodinger Equation. This method is most economical while having the same level of performance as all other methods. The significant restriction in optical fiber system is the dispersion. Dispersion affects the performance of the system and bit error rate. This research project investigates and analyzes the impact of chromatic dispersion on a single-mode optical fiber communication system.

II. Impairments in Optical Fiber Transmission Systems

The optical fiber is often seen as a perfect transmission medium with almost limitless bandwidth (He et al., 2016). But in practice the propagation through optical fiber is affected with several limitations especially as distance is increased to multi-span amplified systems. As the transmission systems evolved to longer distances and higher bit rates, the linear effect of fibers, which is the attenuation and dispersion, becomes the important limiting factor (Rajana and Suresh, 2016). As for WDM systems that transmit multiple wavelengths simultaneously at even higher bit rates and distances, the nonlinear effects in the fiber begin to present a serious limitation (Xie, 2011). The success of high bit rate long haul point-to-point optical transmission networks depends upon how best the linear and nonlinear effects are managed. The major linear effects include group velocity dispersion (GVD) of standard single-mode fiber, fiber loss, adjacent channel X-talk, polarization mode dispersion (PMD), accumulated ASE noise etc. The nonlinear effects on the other hand include self-phase modulation (SPM), cross phase modulation (XPM), stimulated Brillouin scattering (SBS), stimulated Raman scattering (SRS), and four-wave mixing (PWM) (Osman et al., 2018).

Attenuation in an optical fiber is caused by absorption, scattering, and bending losses (Agrawal, 2010). Attenuation is the loss of optical power as light travels along the fiber. Signal attenuation is defined as the ratio of optical input power (Pm) to the optical output power (Pm). Optical input power is the power injected into the fiber from an optical source (Setiawan et al., 2017). Optical output power is the power received at the fiber end or optical detector. The following equation defines signal attenuation as a unit of length.;

$$Attenuation = 10\log\frac{p_{out}}{p_{in}} \quad ..(1)$$

III. MATERIALS AND METHODS

Dispersion compensating fibers (DCFs) are important elements in today's optical fiber transmission systems; they are used to compensate fiber dispersion which is no longer tolerable by the system after some transmission length. In this chapter it will be presented that mathematical model of an optical pulse propagating in a single mode optical fiber communication system can be obtained from the nonlinear Schrodinger equation (NLSE). The model will be approximated to consider the effects of chromatic dispersion and attenuation. The NLS wave equation is typically derived under a few approximations on the waveguide properties of the guiding medium (Dike, and Ogbe, 2013). The pulse envelope in time t at the spatial position z, $A(z,t)$ propagating from transmitting to the receiving end of an optical fiber communication system is described by the non-linear Schrodinger equation 3.2

$$\frac{\partial}{\partial z}A(z,t) = -\frac{\alpha}{2}A(z,t) - \beta_1\frac{\partial}{\partial t}A(z,t) + j\frac{\beta_2}{2}\frac{\partial^2}{\partial t^2}A(z,t) - \frac{\beta_3}{6}\frac{\partial^3}{\partial t^3}A(z,t) - \mathrm{j}\gamma\left|A(\mathrm{z,t})\right|^2 A(\mathrm{z,t}) + \mathrm{j}\gamma T_R\left|A(\mathrm{z,t})\right|^2 A(\mathrm{z,t}) + \frac{\gamma}{\omega_0}\left|A(\mathrm{z,t})\right|^2 A(\mathrm{z,t}) \quad ..(2)$$

When the pulse width is greater than 1ps, equation 2 can be considerably simplified (as indicated below) because the Raman effect term and the self-steepening effect term are negligible compared to the Kerr effect term.

$$\frac{\partial A}{\partial z} + \frac{\beta_1 \partial A}{\partial t} - i\frac{\beta_2}{2}\frac{\partial^2 A}{\partial t^2} + \frac{\alpha}{2}A = -i\alpha_0 / A/^2 A \quad ..(3)$$

Where the term $\frac{\partial}{\partial z}A(z,t)$ stands for the dynamics of the pulse envelope A in spatial position z and in time t, $-\frac{\alpha}{2}A(z,t)$ stands for the effect of fiber linear attenuation, $-j\frac{\beta_2}{2}\frac{\partial^2}{\partial t}A(z,t)$ represents the effect of second order dispersion, $+\frac{\beta_3}{6}\frac{\partial^3}{\partial t^3}A(z,t)$ represents the effect of Third order dispersion, $-\mathrm{j}\gamma\left|A(\mathrm{z,t})\right|^2 A(\mathrm{z,t})$ represents the Kerr effect, $+\mathrm{j}\gamma T_R\left|A(\mathrm{z,t})\right|^2 A(\mathrm{z,t})$ represents the Stimulated Raman Scattering, $+\frac{\gamma}{\omega_0}\left|A(\mathrm{z,t})\right|^2 A(\mathrm{z,t})$ represents the Self-steepening effect. The terms in the right hand side of the NLSE in equation (3) can be represented as the sum of two parts to yield.

$$\frac{\partial A}{\partial z} = [\mathrm{y}_L + y_N] \quad ..(4)$$

Where y_L represents the linear part and y_N represents the nonlinear part

$$\frac{\partial A_{y_L}}{\partial z} = -\frac{\beta_1 \partial A}{\partial t} + \frac{i}{2}\frac{\beta_2 \partial^2 A}{\partial t^2} - \frac{\alpha}{2} A = Ay_L \quad ..(5)$$

And a non-linear part

$$\frac{\partial A_{y_N}}{\partial z} = -\frac{\alpha_0}{2}|A| = Ay_N \quad ..(6)$$

Considering the effect of chromatic dispersion and fiber attenuation only and that the pulse position is at Zero, center-frequency Equation is obtained as.

$$A_{y_N}(L,\omega) = \exp\left[(\frac{i\beta_2}{2}\omega^2 - \frac{\alpha}{2})\mathrm{L}\right]\mathrm{A}(0,\omega) \quad ..(7)$$

Therefore the fiber frequency response or transfer function in

$$H(\omega) = \exp\left[(\frac{i\beta_2}{2}\omega^2 - \frac{\alpha}{2})\mathrm{L}\right] \quad ..(8)$$

The pulse or signal amplitude decreases as it is propagating along the length of optical fiber; this causes power loss, therefore form Equation (7), considering the effects of attenuation only yields.

$$\mathrm{A}_{y_N}(\mathrm{L},\omega) = \exp(-\frac{\alpha}{2}\mathrm{L})\,\mathrm{A}(0,\omega) \quad ..(9)$$

And α is the attenuation constant in l/km and mostly expressed in dB as α_{dB}

$$\alpha_{dB} = \frac{10}{L}\log_{10}(\frac{p_{out}}{p_{in}}) \quad ..(10)$$

$$\alpha_{dB} = 4.343\alpha \quad ..(11)$$

Considering the effects of chromatic dispersion only in Equation (7) yields an equation representing the effects of chromatic dispersion (CD) on the input pulse.

$$A(L,\omega) = \exp\left[(\frac{i\beta_2}{2}\omega^2)\mathrm{L}\right]\mathrm{A}(0,\omega) \quad ..(12)$$

The time delay between two different spectral components separated by a certain frequency interval is determined using the dispersion coefficient D given by

$$D = -\frac{2\pi c}{\lambda^2}\beta_2 \quad ..(13)$$

The propagation distance after which a Gaussian pulse is broadened by 40% is termed the dispersion length and is given by

$$L_D = -\frac{t_0^2}{|\beta_2|} \quad ..(14)$$

Where t_0 is the pulse full-width at half-maximum (FWHM)
The input is represented by a Gaussian pulse and it is defined as

$$A(t) = \exp\left(-\frac{1}{2}\left(\frac{t}{t_0}\right)^2\right) \quad ..(15)$$

Where t_0 is the pulse full-width at half-maximum (FWHM)

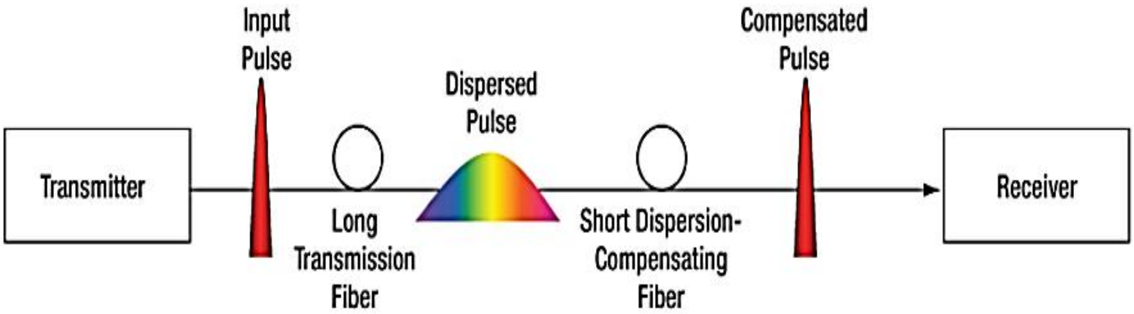


Figure 1. Cascaded dispersion compensation fiber the carrier fiber

The use of DCF provides an all-optical technique that is capable of compensating the fiber dispersion completely if the average optical power is kept low enough that the nonlinear effects inside the optical fibers are negligible. It takes the advantages of linear nature. The condition for perfect dispersion compensation is

$$L_1 D_1 = -\mathrm{LD} \qquad ..(16)$$

Which further yield

$$\beta_{21} = \frac{L}{L_1}\beta_2 \qquad ..(17)$$

$$\alpha_{21} = \frac{L}{L_1}\alpha_2 \qquad ..(18)$$

And similarly, the dispersion coefficient of the right DCF to be used for the compensation can be calculated from equation (13)

IV. RESULTS AND DISCUSSION

Following the theoretical analysis, the performance evaluation of a single mode optical fiber communication systems consisting of cascaded DCF are evaluated. The Gaussian pulse is used because the optical sources have a distribution of power with wavelength that is approximately Gaussian distribution in form, as shown in Figure 2. The power axis is normalized in per unit (p.u.) while the time axis is in s (seconds).

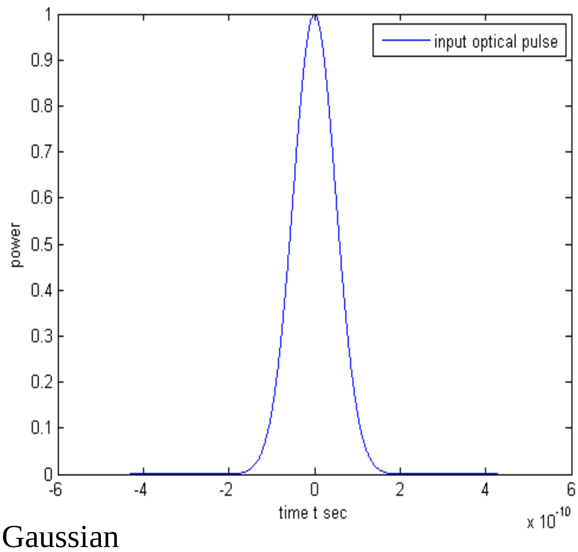
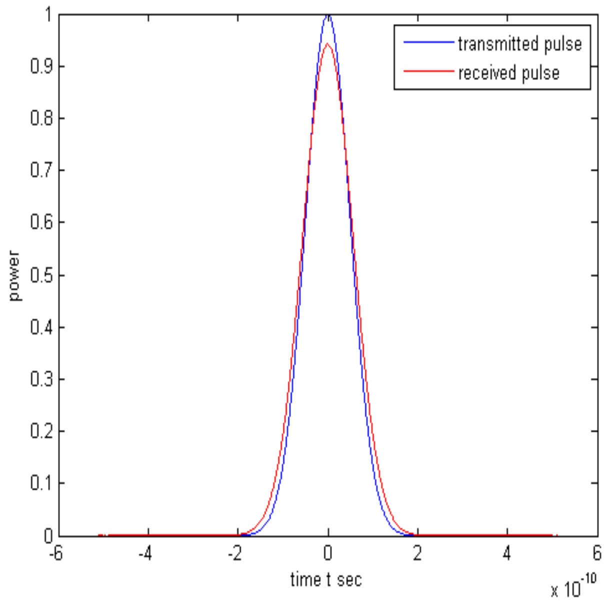
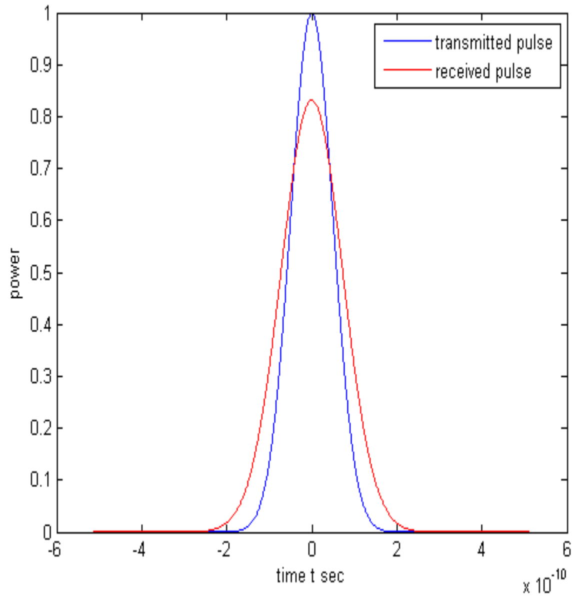


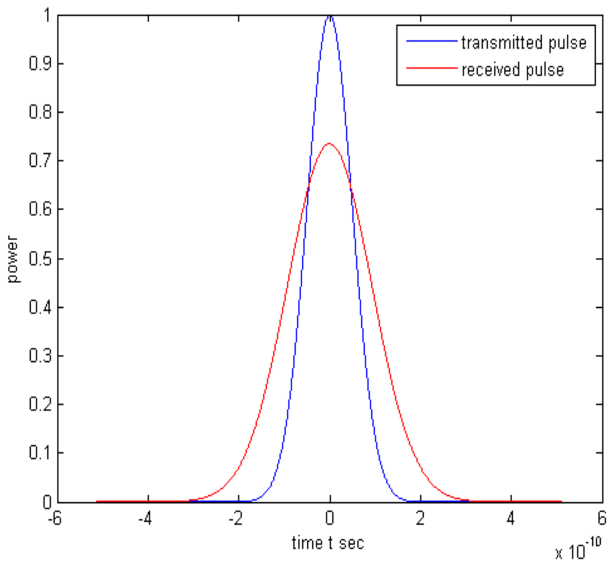
Figure 2. Input Gaussian pulse in time domain



(a)



(b)



(c)

Figure 3. Dispersion effects pulse (a) at 60km (b) at 120km (c) at 180km distance

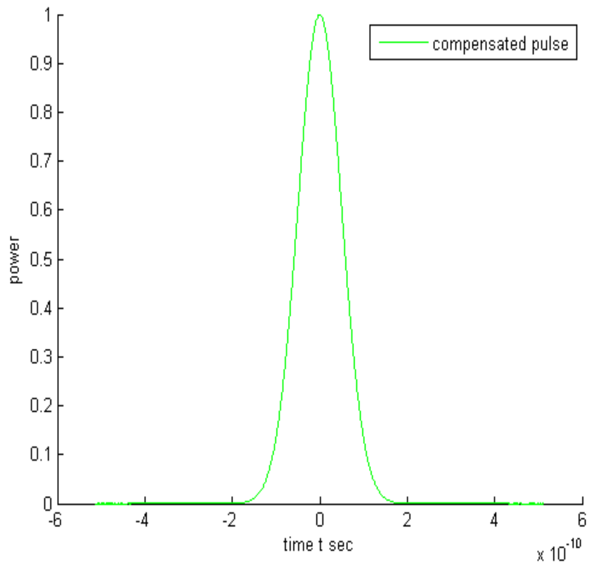


Figure 3. Compensated pulse

The predicted dispersion coefficient of the fiber to be used for the compensation is shown in Table iii below.

Table III. Parameter of the required DCF as predicted by the model

Carrier fiber length L(km)	D (ps/nm/km)	D1 (ps/nm/km)	$\propto_{dB}$	B2	B21	LD
180	-16	80.0000	0.2	2.0393e-23	-1.0197e-22	122.5908
180	-17	85.0000	0.2	2.1668e-23	-1.0834e-22	115.3795
180	-18	90.0000	0.2	2.2942e-23	-1.1471e-22	108.9696

V. CONCLUSION

It is clear from the results that the attenuation and the dispersion effects increase when the distance of communication through the fiber optics increase. Therefore, it is indeed necessary to employ the technique of dispersion compensation in a single mode optical fiber communication system so that these effects causing signal degradation and consequently error in communication can be eliminated.

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. This arrangement perfectly restore the original input signal at the receiver, this is the dispersion compensation in a single-mode optical fiber communication system using dispersion compensation fiber.

REFERENCES

Agrawal, G. P. (2010). *Fiber-Optic Communication Systems.4th edition*, John Wiley & Sons, Inc, New York.

Dike, J. N. and Ogbe, D. A. (2013).Optimizing the Efficiency of Fiber-Optics Technology in Telecommunications Systems.*IEEE International Conference on Emerging & Sustainable Technologies for Power & ICT in a Developing Society (NIGERCON),135-142.*

He, T. Rishoj, L. Demas, J. and Ramachandran,S. (2016). Dispersion compensation using chirped long period gratings, *Conference on Lasers and Electro-Optics (CLEO),San Jose, CA, 1-2.*

Mishra,P. and Tiwari, S. (2017).A Review of Chromatic Dispersion Compensation in Optical Fiber Communication System and its Simulation,*International Advanced Research Journal in Science, Engineering and Technology,Vol.4, Issue 6, 70-73.*

Osman, W. M. Al Nabi, A. B. and Billal, K. H. (2018). Optical Fiber Review.*Journal of Electrical & Electronic Systems 7:249*

Rajana, R. and Suresh, K. (2016). Performance Analysis of Dispersion Compensation using FBG and DCF in WDM Systems.*International Journal of Engineering Technology Science and Research Volume 3, Issue 10, 5-9.*

Setiawan Putra,A. W. Yamada, M. Tsuda, H. andAmbran,S. (2017). Theoretical Analysis of Noise in Erbium Doped Fiber Amplifier, *IEEE Journal of Quantum Electronics, vol. 53, no. 4, 1-8.*

Xie, C. (2011). Fiber nonlinearities in 16QAM transmission systems, in Optical Communication (ECOC).*37th European Conference and Exhibition on optical communication, Geneva, 1-3.*