

Qualitative Analysis of Self Phase Modulation (SPM)

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Abstract - Optical fiber changed the way of communication. In comparison with wireless communication, optical fiber communication is very fast and reliable. It is more secure but costly. Optical fiber uses the principle of total internal reflection for transmission. Optical fiber has core and cladding with different refractive index and major portion of the signal goes through the core. But due macro and micro bending, chromatic dispersion is observed. In this paper, we have analyzed self phase modulation in an optical fiber system and discussed how it causes dispersion in input signal. These effects are simulated using OPTISYSTEM tool at a bit rate of 10Gbps and analysed using eye pattern method with respect to bit error rate and Q factor. Simulation results from the OPTISYSTEM tool are also compared with the numerical analysis of nonlinear Schrodinger equation, which is simulated in MATLAB.

Keywords - Self Phase Modulation, Bit Error Rate, Fiber Nonlinearities, Optisystem Tool.

I. INTRODUCTION

The development of low loss optical fiber, optical transmitter, optical detector and optical amplifier with compact size and high efficiency has dominated the field of telecommunication. When optical signal is transmitted at distances longer than 100km, they suffer from attenuation, temporal broadening and even interact with each other through non linear effects in the optical fiber. The performance of the system is greatly affected by the non linear effects. The main requirement of the optical system is to increase the higher optical power to achieve the desired signal to noise ratio(SNR). With the increase in optical power, bit rate, and number of Wavelengthchannels, the total optical power propagating through the optical fiber increases and hence, results in non linear effects. These non- linear effects include self phase modulation (SPM), cross phase modulation (XPM), four wave mixing (FWM), stimulated brillouin, stimulated Raman scattering (SRS). Although, these effects have several disadvantages but there are certain advantages also, such as , formation of dispersionless pulses(solitons) with the help of SPM; realization of low noise optical amplifier using SRS; in signal processing using XPM; or in the realization of wavelength converter using FWM.

This paper deals with the analysis of reducing non linear dispersion, induced distortion in single mode, non linear fiber and erbium doped fiber amplifier (EDFA). Also, analysis of various fiber non linear designs are done and compared with each other over long haul distance of 100 km.

A. Self-phase modulation

Nonlinear phase modulation of beam, caused by its own intensity by the kerr effect. Due to kerr effect high optical intensity in medium causes a non linear phase delay which has same temporal shape as optical intensity. This can be

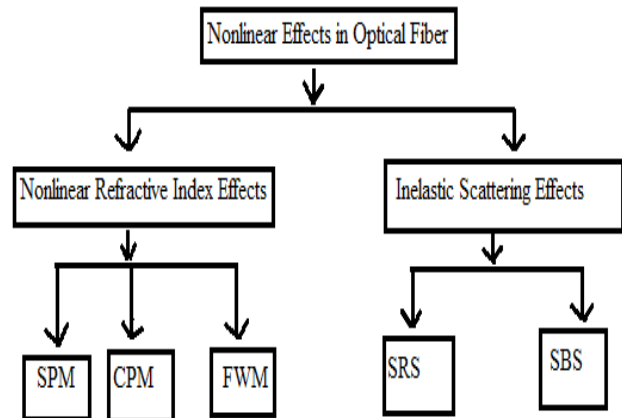


Fig.1.Types of non linearity effects

described as a non linear change in refractive index [1]. Phase modulation of an optical signal by itself is known as SPM. SPM generally occurs in single wavelength system. It occurs through interaction of rapidly varying and time dependent laser pulse with non linear intensity dependent change in refractive index of an optical material. At high bit rate SPM tends to cancel dispersion, but it increases with signalpower level.

Phase shift by field over fiber length is given by: [5]

$$\phi = \frac{2\pi nL}{\lambda}$$

Where, n = refractive index of the medium; L= length of the fiber; λ = Wavelength of the optical pulse

The design of SPM is stimulated using Optisystem tool. Coding of nonlinearSchrodinger equation is done in Matlab and analysis of Eye diagram, bit error rate (BER), and Q factor is done.

II. SIMULATION AND RESULTS

A. Self Phase Modulation Using Optisystem Tool

a) Simulation Model of SPM

Conceptual design of SPM consists of an optical transmitter, channel and receiver.

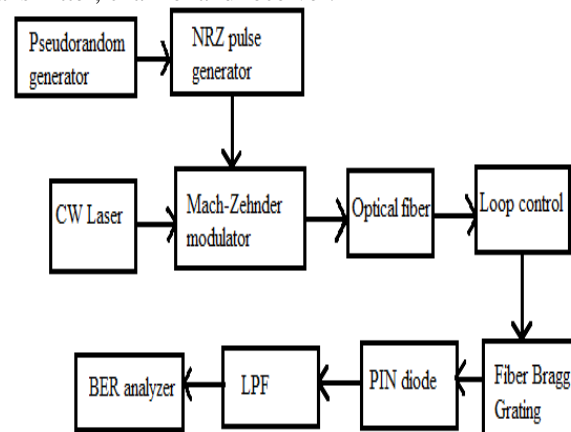


Fig.2. Conceptual model of SPM

1) Transmitter block

Transmitter comprises of a pseudo random generator, continuous wave laser, NRZ modulator, EDFA amplifier and Mach-Zehnder amplitude modulator. Each component block has its own global parameters that are very useful if we use the same parameters for two or more components in the model. Wavelength, power and frequency of the signal is initialized. The waveforms are observed through an electrical and optical oscilloscope. The transmission rate used is 10 Gbps, power of light wave is 3.98mW, wavelength is 1550nm, frequency is 193.1THz and fiber length is 100 km.

2) Fiber channel

It is shown as iterative loop component. The iterative loop component consists of an optical fiber, fiber compensating techniques and a pre-amplifier. Output of fiber is sent to fiber Bragg grating which is used to compensate the distortion of signal by inducing dispersion after each stage. Dispersion coefficients used are 0ps/nm, -500ps/nm, -1000ps/nm, -1500ps/nm and -2000ps/nm.

3) Receiver block

It consists of EDFA, photodiode, low pass Bessel filter whose cut off frequency is $0.7 \cdot \text{bit rate}$, BER analyzer and an electrical oscilloscope.

b) Result analysis

Input signal is shown in figure 3(a) which is visualized as almost a sinusoidal waveform. The output of CW laser is sent to Mech-Zehnder modulator which is an electro-optical modulator, used to modulate the light wave with respect to transmitted electrical signal and generate an optical signal at output of modulator. The optical signal before and after the booster block with factor 10 is shown in figure 3(c) and figure 3(d) respectively.

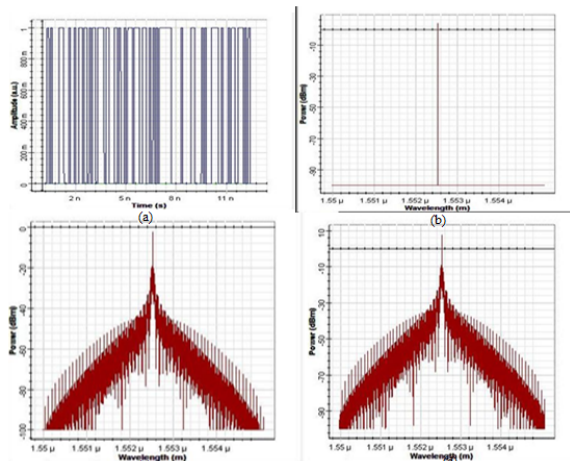


Fig.3. signal after (a) NRZ modulator; (b) CW laser block; (c) Output of Mach-Zehnder modulator; (d) Output signal after EDFA

B. Split step algorithm in Matlab

The numerical analysis of the nonlinear effects is done by Nonlinear Schrödinger equation. The equation is solved using an algorithm called "Split-step algorithm", which is coded in Matlab. Split step algorithm separates linear and nonlinear parts of the equation as shown below and solves it separately.

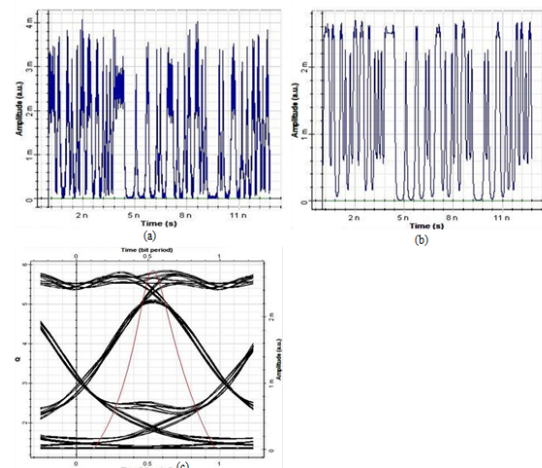


Fig.4. (a) Output of PIN diode; (b) Output of Low Pass Bessel filter; (c) BER waveform and EYE diagram

The nonlinear Schrodinger equation is given by

$$\frac{\partial A}{\partial Z} + \frac{i\beta_2}{2} \frac{\partial^2 A}{\partial t^2} = i\gamma |A|^2 A - \frac{\alpha}{2} A$$

We can rewrite the above equation as

$$\frac{\partial A}{\partial Z} = -\frac{i\beta_2}{2} \frac{\partial^2 A}{\partial t^2} - \frac{\alpha}{2} A + i\gamma |A|^2 A$$

Representation of above equation after dividing into linear and nonlinear parts is

$$\frac{\partial A}{\partial Z} = -\frac{i\beta_2}{2} \frac{\partial^2 A}{\partial t^2} - \frac{\alpha}{2} A + i\gamma |A|^2 A = [D+N]A$$

When $\gamma=0$, results in linear part of nonlinear Schrödinger equation

$$\frac{\partial A_D}{\partial Z} = -\frac{i\beta_2}{2} \frac{\partial^2 A}{\partial t^2} - \frac{\alpha}{2} A = DA$$

Consider $\beta_2=0$, $\alpha=0$, results in nonlinear part of nonlinear Schrödinger equation

$$\frac{\partial A_N}{\partial Z} = i\gamma |A|^2 A = NA$$

Added a small step "h" simulation parameter is added to separate the linear and nonlinear terms of the equation with minimal error. If we solve nonlinear part of equation in time domain will result as

$$A_N(t, Z+h) = \exp\left[i\gamma |A|^2 h\right] A(t, Z)$$

In the same way, solving the equation of linear part gives:

$$A(\omega, Z+h) = \exp\left[\frac{i\beta_2}{2} (\omega)^2 h - \frac{\alpha}{2} h\right] A_D(\omega, Z)$$

This linear function and the inverse Fourier transform of this function multiplied with the nonlinear function is solved using Matlab. The code is simulated in order to compare the ideal behavior of the input pulse with practically generated dispersed pulse with the same parameters used in the optisystem design model of Self phase modulation. The parameters are P_i (input power) = 3.98mw, Time period of input pulse= 200ps, area of effective core = 67.56, Fiber losses in db/km= 0.25, Chirp

factor =0, dispersion coefficient= -500 ps/nm/km, Wavelength= 1550nm, and length of the fiber = 100km. The input pulse is shown in Figure5 (a) and figure5 (b) shows the Full Width at Half Maximum (FWHM) points on the input pulse. At half of the power the FWHM points are observed. FWHM points are equal to $0.707 \times \text{Voltage}$ if the amplitude is calculated with voltage. With the help of FWHM's generated from the code, pulse broadening ratio is plotted. Figure5 (c) indicates the pulse broadening ratio plot and explains how the input pulse is broadened with respect to the distance travelled. The spectral output pulse waveform as shown in figure5 (d) indicates that the pulse broadening is zero for ideal case. Ideally, there is no pulse broadening when the input pulse is transmitted through zero dispersion and zero chirp factor in the fiber calculated by the numerical values but when an input pulse is sent through the fiber, dispersion occurs and is analyzed using the simulation results. Practical implementation gives the virtual experience of the dispersion due to its propagation in the fiber and it is observed in the received signal.

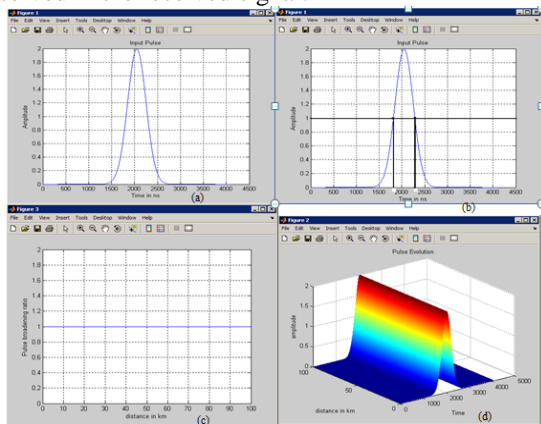


Fig.5. (a) Input pulse from Matlab (ideal); (b) FWHM points on input pulse; (c) Pulse broadening plot (ideal); (d) Output spectrum of input pulse (ideal)

From Figure 6 (a), when there is no pulse broadening the received signal will be replicate of input signal considering zero losses. Parameters shows dispersion of the input pulse with respect to distance of fiber in the output spectrum. $P_i=0.00064\text{mw}$, $\gamma=0.003$, dispersion coefficient= $1.5684e-5$, Chirp factor= -2, wavelength=1550nm, time period of pulse is 125ps, fiber losses=0 db/km. Waveforms of input pulse, dispersed pulse and pulse broadening ratio are shown in Figure6 (b) and Figure6 (c).

Figure6 (c) shows the broadening of the pulse with distance travelled by input pulse.

Output spectrum is a three dimensional plot, which has X, Y and Z axis. In the plots shown above, X axis represents "time", Y axis represents "distance" and Z axis represents "amplitude". The colors represent the amplitude value of the signal. We generalized and optimized the algorithm to take wide varieties of inputs and see the behavior of input signal with respect to those inputs. Output spectrum shown in Figure15 lower frequency components are attenuated using a band pass filter as discussed earlier in simulations.

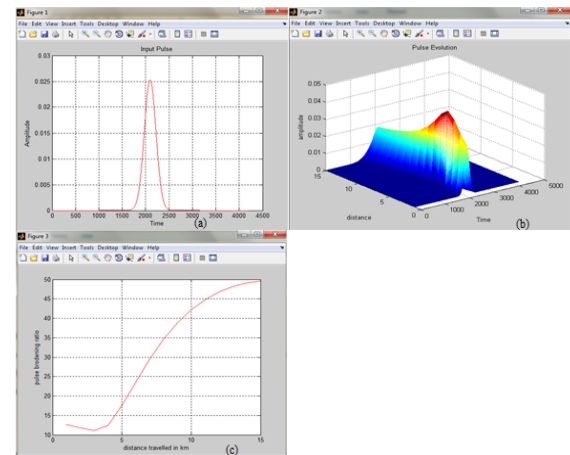


Fig.6. (a) Input pulse from Matlab (with dispersion); (b) Output spectrum of input pulse with dispersion; (c) Pulse broadening plot (with dispersion)

C. Comparative Analysis of Calculated Parameters

Q factor is known as digital SNR and it is defined as ratio of signal current to noise current. Optical communication system bit error rate less than 10^{-12} is to be achieved which corresponds for obtaining $Q > 7$. If $BER < 10^{-9}$ then $Q > 6$.

Table 1: Comparison of BER

S.No.	Parameters	In optisystem	In matlab
1.	Q factor (in db)	7.6708	7.6708
2.	BER	2.41907×10^{-9}	8.6870×10^{-15}

By theoretical implementation of SPM in Matlab bit error rate obtained is 8.6870×10^{-15} , but by practical analysis of SPM in optisystem BER obtained is 2.41907×10^{-9} . This difference is due to the interference of noise in optical components. In this project, we have tried to minimize noise by increasing the Q factor, thereby reducing the BER.

III. CONCLUSION

This paper deals with the analysis of self-phase nonlinear effects in optical system. Non-linear effects have disadvantages in limiting the transmission rate but the main advantage of this effect is to improve performance of the transmitted signal. The simulation is performed in optisystem to analyze the Q factor and BER of the system and numerical analysis of the nonlinear Schrodinger equation is done in matlab using the Split step algorithm in order to analyze the effects of nonlinearity in fiber.

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