Analysis of SPM and FWM in Optical Fiber Communication System using Optisystem

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***Abstract*— Focus on development of broadband optical communication systems is incredible since it offers combination of wide bandwidth and low losses unmatched by any other transmission medium. There are some limiting factors related to data rate and capacity in optical fiber communication system. These limiting factors can be linear or non-linear. We can compensate the linear effect such as dispersion and attenuation by using dispersion compensation methods. But the non-linear effect still accumulate with the increase in optical power levels.. When all the input signal frequencies interact due to fiber nonlinearities, the output bit stream may behave in a complicated way giving adverse effects on system performance. In wavelength-division-multiplexing (WDM) systems, inter-channel interference due to fiber nonlinearities may limit the system performance significantly. Therefore, it is crucial to understand fiber nonlinearities and their effects on fiber-optic communication systems. The main motivation of this work was to study theoretical and simulation studies of broad band optical communication systems due to fiber nonlinearities. Here, we investigate power effects on simulation of optical communication systems with Self Phase Modulation (SPM) and Four Wave Mixing(FWM), by using the parametric run feature in Optisystem. The eye diagram highlights the conversion due to the SPM and FWM. Specifically the eye opening decreases with increasing transmitted power.**

***Keywords*—SPM,FWM,Optisystem**

I. INTRODUCTION

Nonlinear optics (NLO) is the branch of optics that describes the behaviour of light in nonlinear media, that is, media in which the dielectric polarization P responds nonlinearly to the electric field E of the light. This nonlinearity is typically observed only at very high light intensities (values of the electric field comparable to inter atomic electric fields, typically 10^8 V/m) such as those provided by pulsed lasers. When an optical signal is transmitted through long haul communication systems (the transmission of a light signal over fiber for distances typically longer than 100 km) of optical fiber, a significant distortion will be seen in the received signal. Distortion could be result of chromatic and polarization mode dispersion in Time Division Multiplexing (TDM) and fiber nonlinearity's in Wavelength Division Multiplexing (WDM) impact transmission performance. Nonlinear effects play a major role in optical fiber with respect to transmission capacity and performance of the system. To achieve maximum transmission rate, combination of TDM and WDM is used and optimized configuration of combination depends on few factors such as dispersion and optical signal power. There are upsides and downsides of using nonlinear effects in optical fiber [4].

II. NON LINEAR EFFECTS

Fiber nonlinearities become a problem when several channels coexist in the same fiber. Nonlinearity effects arose, when optical fiber data-rates, transmission lengths, number of wavelengths, and optical power levels are increased.

- Self Phase Modulation
- Four Wave Mixing

A. *Self Phase Modulation*

Nonlinear effect depends on intensity of light and refractive index. Input pulse travels through fiber, which has high intensity of light inside core resulting in higher refractive index. Signal intensity changes with respect to time leads to variations in refractive index with time, which is similar to intensity dependent refractive index.These variations in refractive index results in time dependent phase changes.

These phase changes are the same as optical signal change with time, so the name Self Phase Modulation (SPM).

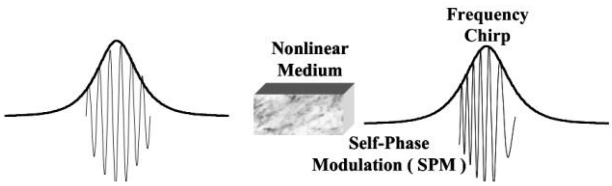

Figure.1. Effect of Cross phase Modulation

Different parts of the input pulse change the phase of the signal randomly, resulting a frequency chirp, which is defined as a signal whose frequency varies with time (increases-up chirp or decreases-down chirp). These variations in frequencies cause pulse broadening, which can be seen significantly high in the systems with high transmission power because the transmission power is directly dependent on frequency chirp. [5] In SPM, pulse broadening is seen in the time domain and spectral characteristics are unaltered.

Phase shift by field over fiber length is given by

$$\varphi = \frac{2\pi nL}{\lambda} \qquad \text{..............(1)}$$

Where n= refractive index of the medium, L= length of the fiber, λ = Wavelength of the optical pulse, nL= Optical path length.

Chirp produced by SPM is used to reduce the effects of dispersion caused by pulse broadening. These effects depend mostly on Input power of the signal transmitted, which can be used as a threshold condition for the frequency chirp to occur. SPM is major limitations in single channel systems. [5]

B. *Four Wave Mixing*

In this nonlinear effect, three optical fields when propagated through fiber will give rise to a new optical field, which depends on the three optical fields $\omega_4 = \omega_1 \pm \omega_2 \pm \omega_3$ [5].

FWM is not dependent on bit rate as the other two nonlinear effects, instead they depend on channel spacing and dispersion of fiber. Dispersion depends on wavelength, so newly generated optical wave and reference signal wave have different group velocities.

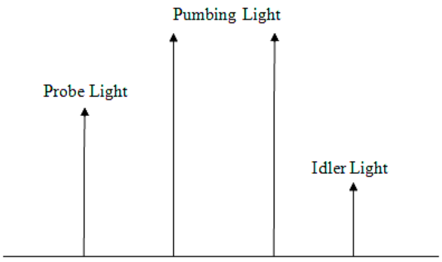

Figure.3. Four Wave mixing phenomena

FWM is not dependent on bit rate as the other two nonlinear effects; instead they depend on channel spacing and dispersion of fiber. Dispersion depends on wavelength, so newly generated optical wave and reference signal wave have different group velocities. With different group velocities, phase matching is not possible, which decrease power transfer to new optical wave. At the same time, if the newly generated wave and original wave has same wavelength, results in interference. The interference of the signals decreases signal to noise ratio. Whenever we observe different group velocities then FWM effect decreases, channel spacing increases and so does dispersion. [5]

III. System Modelling

Ever since the ancient times, one of the principle interest of human beings has been to device a communication systems for sending messages from one distant place to another. When an optical signal is transmitted through long haul communication systems (the transmission of a light signal over fiber for distances typically longer than 100 km) of optical fiber, a significant distortion will be seen in the received signal. The fundamental elements of any communication system are as shown in Fig.4.

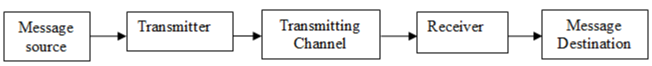

Figure.4. Block diagram of communication system

The role of the optical transmitter is to convert the electrical signal into optical form and to launch the resulting optical signal into the optical fiber. It consists of an optical source, an electrical pulse generator and an optical modulator. The launched power is an important design parameter, as it indicates how much fiber loss can be tolerated. The role of the communication channel is to transport the optical signal from transmitter to receiver without distorting it. Most light wave communication systems use optical fibbers as the communication channel because fibbers can transmit light with a relatively small amount of power loss. An optical receiver converts the optical signal received at the output end of the optical fiber back into the original electrical signal. It consists of a photo detector, filter and a demodulator. The photo detector senses the luminescent power falling upon it and converts the variation of this optical power into a correspondingly varying electric current.

IV. Design and Simulations

The design and analysis of Optical communication systems, which normally include nonlinear devices and non-Gaussian noise sources, are highly complex and extremely time-intensive. As a result, these tasks can now only be performed efficiently and effectively with the help of advanced new software tools such as Optsim and OptiSystem. OptiSystem is an innovative optical communication system simulation package that designs, tests, and optimizes virtually any type of optical link in the physical layer of a broad spectrum of optical networks from analog video broadcasting systems to intercontinental backbones. OptSim is an advanced optical communication system simulation package designed for professional engineering and cutting-edge research of WDM, DWDM, TDM, CATV, optical LAN, parallel optical bus, and other emerging optical systems in telecom, datacom, and other applications.

A. *Analysis of Self Phase Modulation*

In the simulation layout of SPM, consists of a pseudo random generator, NRZ modulator, continuous wave laser, Mach-Zehnder amplitude modulator and EDFA amplifier. Each component block has its own parameters apart from the parameters of the design called as global parameters, which are helpful if we want to use the same parameter for two or more components in the model.

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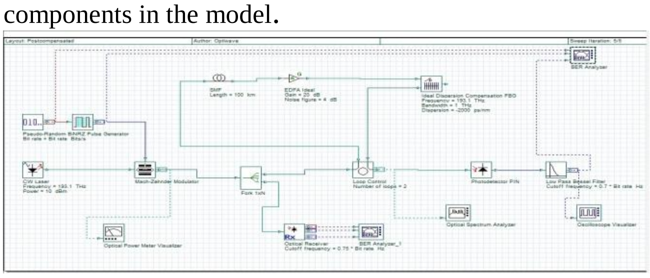

Figure.5. Simulation layout of SPM

Wavelength, frequency, power of the signal is initialized and phase parameter of signal is set to random in CW laser block. We placed electrical and optical oscilloscope to observe waveforms. The transmission rate used is 10 Gbps, power of light wave is 3.98mW, fiber length is 100 km, wavelength is 1550nm and frequency is 193.1THz [11].

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, -2000ps/nm. The receiver consists of EDFA, photodiode, low pass Bessel filter whose cut off frequency is 0.7 * bit rate, BER analyzer and an electrical oscilloscope.

B. Analysis of Four wave Mixing

Four wave mixing effect is also performed with two or more WDM channels. In this design model, there are two WDM channels. Signals generated from these channels are used to generate new signal with the new frequency. Design model of FWM is shown in Figure.

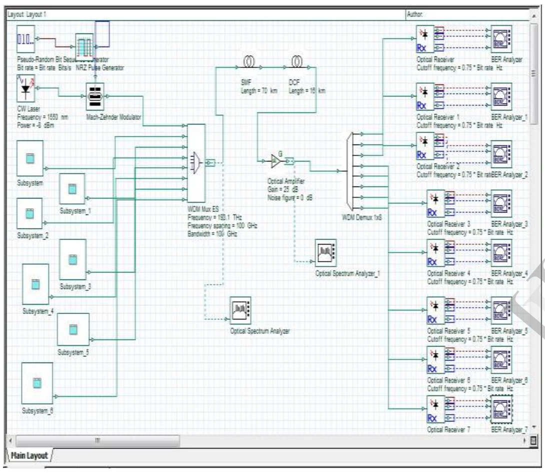

Figure.7. Design of Four Wave Mixing

In the simulation layout of FWM; there are two channels with different laser power to differentiate the input pulses. Design of transmission block and fiber channel of FWM is same as CPM transmission block and fiber channel. The only change in the FWM is the first channel has lower power of light wave than second channel (we can have first channel as high power channel and second as low power channel). These signals sent to optical modulator along with light wave. Input optical signal is observed at output of optical splitter. Receiver block is also similar to CPM except it does not have Gaussian filter after optical splitter. Because the design of FWM receiver does not have any filter and signal is not attenuated to limited frequencies, instead the original output optical signal is sent to the photodiode. The optical signal seen at the output of optical splitter at the receiver side.

V. RESULTS AND DISCUSSIONS

In the simulation, different types of non linearity's are analysed. The result of the block schematic in the previous chapter is provided with the obtained results. Different types of visual parameters are used to obtain the Non Linear analysis. The main analysis tools taken into account are Q factor, BER, Spectrum, Oscilloscope Visualizes etc.

Eye diagram is the methodology used to evaluate the performance of the system. The important parameters of eye diagram are Quality factor and Bit error rate.

A. *Eye Diagram Analysis of Self Phase Modulation*

In the analysis of SPM,the input power is varied from 10dB to 20dB and thus obtained corresponding eye diagrams.

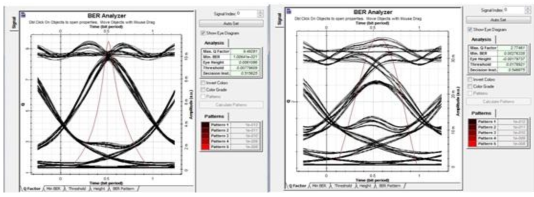

Figure.8. Eye diagrams for Self Phase Modulation for 10dB and 15 dB Input

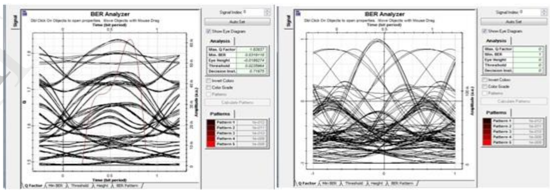

Figure.9. Eye diagrams for Self Phase Modulation for 17dB and 20 dB Input.

A 10 Gb/s NRZ signal is launched over two DS fiber spans (D=0.4 ps/nm/km) of 100 km, each. The power at the input to each span is varied from 10 to 17.5 dbm by using the parametric run feature in OptSim. EDFA noise has been turned off in order to simplify the analysis of SPM. By increasing the power, SPM grows and depletes the signal, and the measured power actually decreases with the increase of the transmitted power. Specifically the eye opening decreases with increasing transmitted power.

B. *Eye Diagram analysis of Four Wave Mixing*

An 8 channel WDM is created to analyse FWM and thus obtained the corresponding Spectrum.

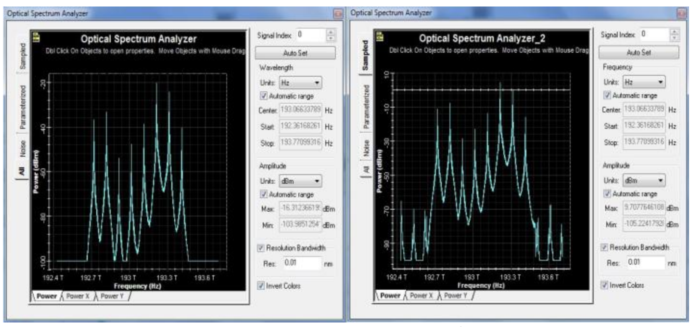

Fig.13. Input and Output optical signal of FWM circuit

Four-wave mixing (FWM) is a type of optical Kerr effect, and occurs when light of two or more different wavelengths is launched into a fiber. Four-wave mixing can be compared to the intermodulation distortion in standard electrical systems. A typical input waveform of 192.77Hz to 193.3 Hz of optical spectrum, shown in the Fig 13 is given to the system. The output values of frequencies obtained due to the FWM effect are as 192.38, 192.528, 192.68, 192.77, 192.83, 192.95, 193.13, 193.18, 193.21, 193.24, 193.3, 193.58, 193.62, 193.69 Hz

VI. CONCLUSIONS

Nonlinear effects arose as optical fiber data rates, transmission lengths, number of wavelengths, and optical power levels increases. This nonlinearity is typically only observed at very high light intensities (values of the electric field comparable to inter atomic electric fields, typically 10^8 V/m) such as those provided by pulsed lasers. The behaviour of SPM versus the optical power for two spans amplified system has been investigated. By increasing the power, SPM grows and depletes the signal, and the measured power actually decreases with the increase of the transmitted power. Specifically the eye opening decreases with increasing transmitted power. Four-wave mixing (FWM) is a type of optical Kerr effect, and occurs when light of two or more different wavelengths is launched into a fiber. Generally speaking FWM occurs when light of three different wavelengths is launched into a fiber, giving rise to a new wave (known as an idler), the wavelength of which does not coincide with any of the others.

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