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Simulation And Analysis Of Self Phase Modulation Fiber Non Linearity

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***Abstract*—iber Non-linear effects are just a consequence of increasing need for high data rates, number of wavelengths, transmission lengths and optical power levels. Fiber non-linearities came into picture in 1970's but initially these effects were ignored then, but later studied with the development of LASERS. Reason behind non-linearities is ultra fast third order susceptibility whose real part contributes to self phase modulation (SPM), cross phase modulation (XPM) and four wave mixing (FWM) and imaginary leads to Stimulated Brillioun Scattering (SBS) and Stimulated Raman Scattering (SRS). Earlier some linear effects were faced like optical attenuation and dispersion in fibers, which can now be easily dealt with using a variety of avoidance, regenerative and cancellation techniques, but nonlinearities like SPM, XPM and FWM need special attention while designing a fiber optic transmission system. Here we investigate power effects, bit rate, dispersion, fiber length and laser frequency on simulation of optical communication system with SPM using parametric run feature in Optsim. Increased input power affects the system as it makes SPM grow which eventually degrades the signal. SPM occurs in signal channel configurations, where it basically converts optical power fluctuations into phase fluctuations in the same wave.**

Keywords—Self Phase Modulation (SPM), Cross Phase Modulation (XPM), Four Wave Mixing (FWM), Wavelength Division Multiplexing (WDM), Stimulated Raman Scattering (SRS), Stimulated Brillouin Scattering (SBS), Optsim (5.4 version)

I NTRODUCTION

In optical fiber communication systems, the information is send from one place to another in the form of optical domain. The requirements such as high data rate and large number of transmission channels have made today's fiber optic data systems very complex, and expensive. Spectral broadening in fiber optic is omnipresent regardless of the amount of optical power transmitted. But non-linear effect come into picture when requirements like high data rates, transmission lengths, number of wavelengths and optical power level increases. Fiber non-linearity includes Stimulated Brillouin scattering (SBS), Stimulated Raman Scattering (SRS), Four wave mixing (FWM), self phase modulation (SPM) and cross phase modulation (XPM). If the input optical power increases after certain threshold level, it contributes to intensity of special broadening exponentially. Fundamental difference between SBS and SRS comes with the participating phonons. An optical field modifies its own phase under SPM whereas under XPM an optical pulse changes not only its own phase but also of other co-propagating beams. Though SPM broadens and degrades the performance of a light wave system but on a positive note, it increases optical switching speed. SBS can be controlled by XPM by launching a pseudo random pulse of a different frequency. Otherwise fiber Bragg gratings can suppress SBS. Though XPM leads to inter-channel cross talk in systems employing WDM but can be beneficial for wavelength conversion and pulse compression. FWM also degrades system performance by generating additional noise but can be used for parametric amplification (amplify a weak signal) and pulse conjugation in optical systems.
Now, Kerr effect basically manifests three important non-linear effects; SPM, XPM and FWM. Out of these three only FWM can contribute to gain to one channel at the cost of reducing power from other channels. Both SPM and XPM produce a phase shift in the pulse, broaden the spectrum and increases overall dispersion. This paper studies the impact of SPM non-linearity on NRZ modulation formats.

II SELF PHASE MODULATION – NON LINEAR SPECTRAL BROADENING

Self phase modulation in an optical system is said to occur when the phase of a beam is modulated non-linearly by its own intensity. The portions of beam which carry high intensity have high refractive index compared to those having low intensities. The refractive index of core in an optical fiber is given by equation (optical Kerr effect)

$$n = n_o + n_2 . P A_{\text{efff}} \qquad (1.0)$$

Where
n_0 = linear refractive index of core
n_2 = non linear refractive index
P = optical power (in Watts)

Aeff = effective area of core

Due to the factor n_2, a phase shift is produced, which is in proposition to the intensity of pulse. Further due to non-uniformity in the power along the pulse, there in non uniform distribution of intensity in spectral components. This phase shift changes the central frequency of the pulse and the difference is called frequency chirp. As phase fluctuations are intensity dependent, there is different phase shift in the different parts of the fiber. Hence SPM broadens the optical spectrum non-linearly. As chirping phenomenon increases with increase in input power, SPM grows at high power levels. Furthermore, nowadays EDFA(Erbium-doped fiber amplifiers) are employed to counter attack attenuations and amplify the signal, which increases optical power level and hence contribute to SPM. As can be seen from equation (1.0), the significance of SPM can be reduced by operating the systems at low power levels and by increasing the effective fiber core area. Here, EDFA noise has not been taken into consideration for the ease of analysis. ccording to optical Kerr effect:

$$n(I)=n_0+n_2(I) \qquad (1.1)$$

Where

n(I) = intensity dependent change in refractive index

n_o = linear refractive index

$n_2(I)$ = non linear refractive index (intensity dependent)

As refractive index of fiber core is now power dependent, it affects chromatic dispersion in the fiber, which changes the pulse broadening rate throughout the fiber.

III SETUP

Optimization and simulation consulting (optsim 5.4) is a software tool for designing and simulating optical fiber systems. It has easy to use graphical user interface (GUI) and gives a lab like experience when we talk of measuring instruments. The simulation setup for SPM configuration is shown in Fig 1. For simplicity, the block diagram of the complete system has been split into three sections, i.e. transmitter section, channel and receiver section.

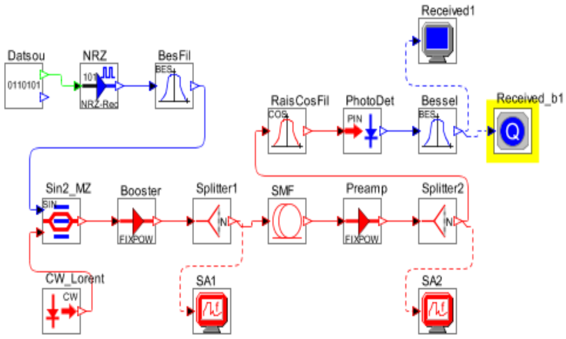

Fig 1. Simulation set up for SPM

IV TRANSMITTER SECTION

The transmitter section of the set up consists Data source or a pseudo random signal generator. Next is the electrical driver to convert binary sequence into electrical pulses. Several mapping techniques can be employed such as rectangular (NRZ, RZ), raised cosine (NRZ, RZ) etc. out of which we have chosen rectangular NRZ. Bessel or “Maximally flat delay” filters are implemented numerically. Here we have employed band pass Bessel electrical filter in transmitter as well as in the receiver section. Minimum value for center frequency (GHz) is zero and maximum is Bo=VBS/4. To plot filter transfer function, amplitude plots are required. Then there is continuous wave (CW) Lorentzian laser with various values of power coming out of it; [CW power (dBm or mW)]. Relaxation oscillator’s peak overshoot sets overshoot of phase noise where as its resonant frequency is set by relaxation oscillation peak frequency. Thermal effects have not been taken into account. Booster is nothing but a fixed output power optical amplifier which stimulates an EDFA (Erbium Doped Fiber Amplifier). Here various values for output power can be assigned in which internally generated ASE noise is also taken into account. Further “No Noise” feature can be selected for comparison with ideal case. Doped fiber length is the length of erbium doped fiber in meters. On the other hand fixed gain Amplifiers are employed where main focus is on fiber transmission properties and not on amplification issues. Then there is first measuring component i.e. optical spectrum analyzer. It estimates the input spectrum by partitioning the total data sequence into various sections each having NP samples where NP is the number of spectrum points over the simulation bandwidth.

V RECEIVER SECTION

Receiver section starts with a fixed EDFA as preamplifier. This model implements a raised cosine optical filter, where main concern is on center frequency and pass band; not on shape of filter. In between pre amplifier and optical filter there is optical spectrum analyzer to access the non-linear output optical spectrum. Next component simulates a photodiode. PIN and APD are two choices, out of which PIN is employed in concerned model. Dark current- shot noise and quantum noise have been taken into account. Photodiode basically does optical to electrical conversion. Further two processing components i.e. electrical scope and quantum estimator employed which actually do not take part in the simulation. Scope is a visualization tool that collects data on various diagrams such as eye diagrams, electrical signal amplitude, histogram and power spectrum. Eye diagrams can be used to effectively analyze the performance of a system. Wide eye opening justifies less crosstalk and vice versa. Quantum estimator estimates quality of received electrical signal. Q factor is calculated using mean and standard deviation of samples considering optimum threshold. Q value is the value that maximizes quality at optimum sampling instant.

VI RESULTS

By parametric variation, the following results have been obtained

(A) Length of fiber variation

Optical signal is one of the most fundamental and complex components of OPTSIM. Via parametric run feature, length of fiber is varied from 20-35k with an increment of 5 km.

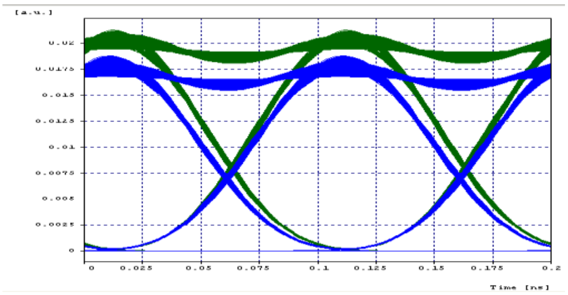

Fig. 2 Eye opening at two different values of fiber length

As length of fiber increases, the power level decreases because of increase in the attenuation level. Output power level goes down from 10.406dBm to 9.790dBm. The reference frequency is taken as 193.415THz. Fiber non linearity coefficient was taken as 1.8 A/V/km. Core refractive area is 67.5m2. Further we see that eye opening decreases with increase in transmitted power. If we compare the two signals eye closure increases from 0.2199dB to 0.2520dB and quality factor decreases from 38.72dB to 30.95dB.

(B) Bit rate variation

Figure 3 shows a comparative simulation of 2 different data rates i.e. 10GBps and 15gbps

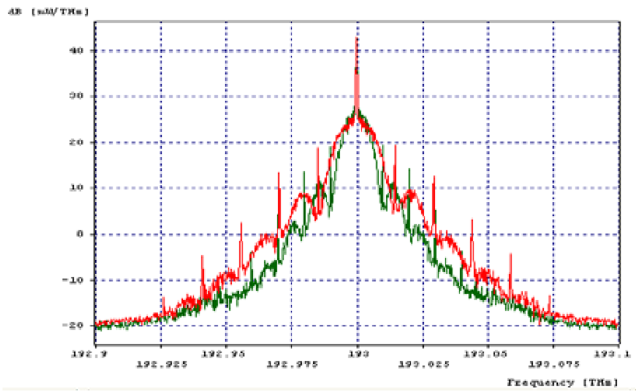

Fig.3 Comparative simulation of 2 different data rates (10GBps and 15GBps)

Baud rate is 10Gbaud/s for 10 Gbps. From figure we see that as bit rate increases spectrum broadens. Further quality factor (Q) decreases from 29.73dB to 29.04dB. Eye closure increases from 0.2614dB to 0.2746dB whereas vice versa happens with eye opening as it goes down from 0.0155dB to 0.0153dB. Further if we compare input and output spectrum for bit rate 20Gbps we get Figure 4.

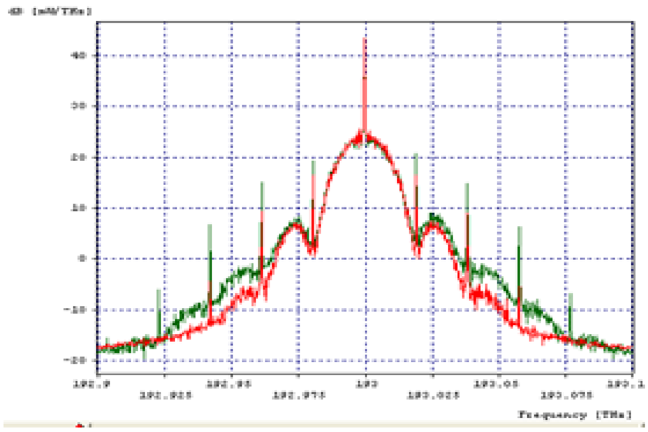

Fig 4. Input and output spectrums at 20Gbps

Spectral broadening is very much visible and hence is the signal degradation. Here 25 samples have been taken per bit and synchronization signal type taken is 'pulse'. Conclusion is that more bit rate means transmitting more symbols which eventually contributes more to cross talk and interference.

(C) Dispersion Variation

As shown in the Fig. 5 spectrum analysis for two different values of dispersion i.e. -5ps/nm/km and +10ps/nm/km. Reference frequency for dispersion is taken as 193.414 THz and corresponding wavelength is 1550nm.

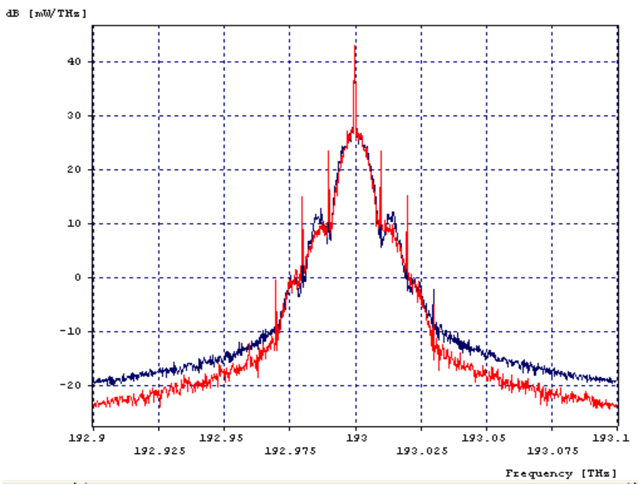

Fig 5. Spectrum analysis for two different values of dispersion i.e. -5ps/nm/km and +10ps/nm/km

Input power is taken as 11dBm. With increase in dispersion, Q factor decreases. It also has adverse effect on eye opening. Output power also decreases with increase in dispersion.

(D) Input/Booster Power Variation

Figure 6 represents spectrum corresponding to input powers 10mW, 13mW and 17mW. Input amplifier is named as booster which is a fixed output power model which takes into account ASE noise.

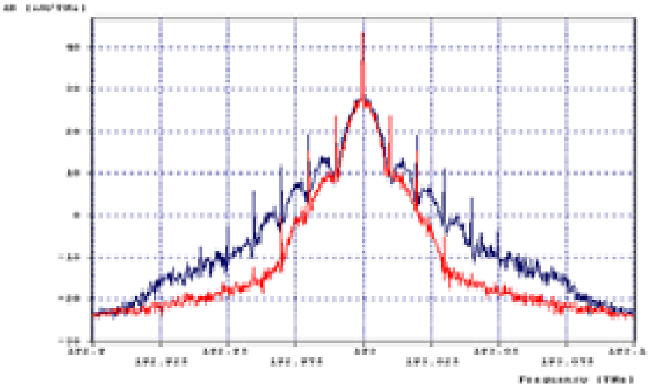

Fig. 6 Spectrum corresponding to input powers 10mW, 13mW and 17mW

Table. 1 Effect of Input Power Variations

Parameter under observation	Input power		
	10mW	**13mW**	**17mW**
Q value (in dB)	32.04	30.31	7.31
Eye closure (in dB)	0.2732	0.428	17.22
Eye opening (in dB)	0.357×10^{-2}	0.256×10^{-2}	0.121×10^{-4}
Output power	9.878	9.415	8.919

By increasing the input power, SPM grows and eventually depletes the signal. On the other hand output measured power decreases with increase in booster power. The eye diagram also highlights PM to AM alteration due to self phase modulation. Specifically, eye opening decreases with increase in transmitted power. Input power is in direct proportion with SPM.

VII CONCLUSION

The behavior of SPM for different lengths of fiber, bit rates, dispersions and booster powers has been investigated in this paper. The parameters are varied with the help of the parametric run feature in Optsim. The following observations have been made
(A) Increasing the length of the fiber causes a decrease in the Q factor.
(B) Increasing Bit rate causes spectral broadening and thus degrades the signal quality.
(C) Increasing dispersion value drastically degrades the Q factor value.
(D) Increasing input power up to some extent causes some degradation which increases considerably if the input power is further increased.

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