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Impact of Residual Dispersion and Power in The Presence of Nonlinearities in RZ Optical Link

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Abstract: Intensity dependence of the refractive index is known to be the major cause of nonlinear effects in optical fibers. These non-idealities' effects are insignificant in the low power regime but become prominent when launch powers exceeds the threshold values. This seems to add to performance degradation due to the already present dispersion-induced pulse spreading. However, since fiber nonlinearities and dispersion present in the link tend to balance each other, complete dispersion-compensation results in low Q-parameter and high BER. The system can be significantly improved by optimizing the launch power and dispersion residue. In this work, extensive simulations have been performed to study the impact of launch power and dispersion residue on the performance of optical link to arrive at the optimal values. Main objective of the study is to minimize the BER at the receiver while optimizing the power and dispersion residue. A 100km optical link is established using 10Gbps-RZ transmission at an operating wavelength of 1552.5nm. Simulations show that in the low power regime, complete compensation (dispersion residue is zero) resulted in very low BER. Maximum Q parameter of 18 is achieved when the launch power is around 19dBm and DCF length is 12.5km i.e., dispersion residue is around 800ps/nm.

Keywords: Nonlinear effects, residual dispersion, Launch power, BER, DCF.

I. INTRODUCTION

Long haul and high speed optical communication systems require high launch power for error free transmission and reception. For the systems operating in the high power regime, nonlinear effects are the major performance limiting phenomenon [1]. These effects arise in optical fibers due to intensity dependence of the refractive index and accumulate along the fiber length. Different types of fiber nonlinearities are Self phase modulation (SPM), Cross phase modulation (CPM) and Four-wave mixing (FWM). In a single channel optical link, SPM is the major limitation [2]. The other performance limiting factors are known to be pulse broadening (dispersion) and attenuation. Pulse broadening can be reduced by incorporating DCF into the optical link at optimal positions. Hence, the bandwidth-distance product is not limited by pulse broadening [4].
The primary effect of SPM is to broaden the pulse in the frequency domain while maintain the temporal shape [5].

This spectral broadening results in frequency chirping of the pulse. For silica optical fibers, the frequencies in the trailing edge are upshifted and those in the leading edge are downshifted with reference to the center frequency of the pulse launched. This process generates new wavelengths in the pulse resulting in pulse broadening.
When the operating wavelength is above the zero-dispersion wavelengths, lower wavelengths travel faster relative to the higher wavelengths. This results in a chirp within the pulse and pulse broadening in the absence of nonlinear effects or in the low power regime [9-10]. SPM results in chirping, with higher wavelengths in the leading edge and lower wavelengths in the trailing edge. This chirping phenomenon is just opposite to the chirping introduced by dispersion in the mentioned wavelength region. Therefore, complete compensation of dispersion present in optical link degrades the system performance. Thus, by a proper choice of launch power and dispersion residue, chirping introduced by SPM can be compensated through chirping caused by dispersion [2-3]. By this mutual compensation of dispersion and SPM, pulse will be propagated longer distances without distortion resulting in improved bit rate-distance product.

The rest of this paper is organized as follows. Section 2 describes the Self-phase modulation in detail, while section 3 describes the system model. In section 4 implementation and results are discussed followed by conclusion in the Section 5.

II. SELF-PHASE MODULATION

If the power carried by a mode in optical fiber is 'P', then the effective intensity within the fiber can be written as

$$I \simeq \frac{P}{A_{eff}} \qquad (1)$$

where A_{eff} represents the effective area of the fiber mode. Assuming Gaussian approximation for the fundamental mode, the effective area is given by

$$A_{eff} = \pi \omega_o{}^2 \qquad (2)$$

where ω_o is the Gaussian spot size. Therefore, for an optical fiber we write [6]

$$n = n_o + n_2 \frac{P}{A_{eff}} \qquad (3)$$

This intensity dependence of the refractive index results in mode effective index change. If β_o is the propagation

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constant in linear regime, then new propagation constant is approximately given by

$$\beta \simeq \beta_o + \frac{k_o n_2 P}{A_{eff}} \qquad (4)$$

Hence, incident wave of the form $Ae^{i\omega_o t}$ can be written as

$$Ae^{i(\omega_o t-\beta z)} = A\exp\left[i\left(\omega_o t-\beta_o z-\frac{k_o n_2 P}{A_{eff}} z\right)\right] \quad (5)$$

If the input wave is a pulse with a power variation given by P(t), then the output phase dependence would be

$$\exp\left[i\left(\omega_o t-\frac{k_o n_2 P(t)}{A_{eff}} z-\beta_o z\right)\right] \qquad (6)$$

Since P(t) is a function of time, the output pulse is chirped and results in SPM.
Now, consider an input Gaussian pulse given by

$$E(z=0,t) = E_o e^{-t^2/\tau_o{}^2} e^{i\omega_o t} \qquad (7)$$

After propagating through a fiber of length L, the pulse becomes

$$E(z=L,t) = E_o e^{-\left(t-\frac{L}{v_g}\right)^2/\tau_o{}^2} \times \exp\left[i\left(\omega_o t-\beta_o L-\right.\right.$$

kon2P(t)AeffL (8)

where β_o, υ_g and A_{eff} represent the propagation constant, group velocity and effective area of the fundamental mode of the fiber respectively. P(t) represents the temporal variation of the power in the pulse and is given by

$$P(z,t) = P_o \exp\left[-\frac{2\left(t-\frac{L}{v_g}\right)^2}{\tau_o{}^2}\right] \qquad (9)$$

Thus, the instantaneous frequency is given by

$$\omega(t) = \omega_o + \frac{k_o n_2 z}{A_{eff}}\left[4\frac{t-z/v_g}{\tau_o{}^2} P_o \exp\left\{-\frac{2\left(t-\frac{z}{v_g}\right)^2}{\tau_o{}^2}\right\}\right]$$

$$= \omega_o + \frac{k_o n_2 z}{A_{eff}}\frac{4T}{\tau_o{}^2} P_o e^{-2T^2/\tau_o{}^2} \qquad (10)$$

Where $T = t - \frac{z}{v_g}$ represents the time in the moving frame.

Thus, nonlinearity leads to spectral broadening and does not alter pulse envelope where as GVD results in broadening of the pulse in time domain and does not affect the spectral content [9-10].

III. SYSTEM MODEL

To facilitate the analysis, an end-to-end optical link is modeled using OptiSystem tool. As shown in figure (1), the transmitter section consists of CW laser operating at 1552.5 nm, Mach-Zehnder modulator, RZ pulse generator and the Pseudo-Random Bit Sequence Generator that generates data at the rate of 10Gbps.
Return-to-zero (RZ) is preferred over NRZ because of its better tolerance to fiber nonlinear effects. Fiber section consists of standard single mode fiber (SSMF) of 100km, DCF and EDFA. Single mode fiber has a dispersion coefficient of 17.8ps/nm.km and attenuation coefficient of 0.17dB/km at 1552.5nm.
The total accumulated dispersion is about 1700ps/nm. DCF is designed with a dispersion coefficient of -80ps/nm.km. Receiver section consists of PIN photo

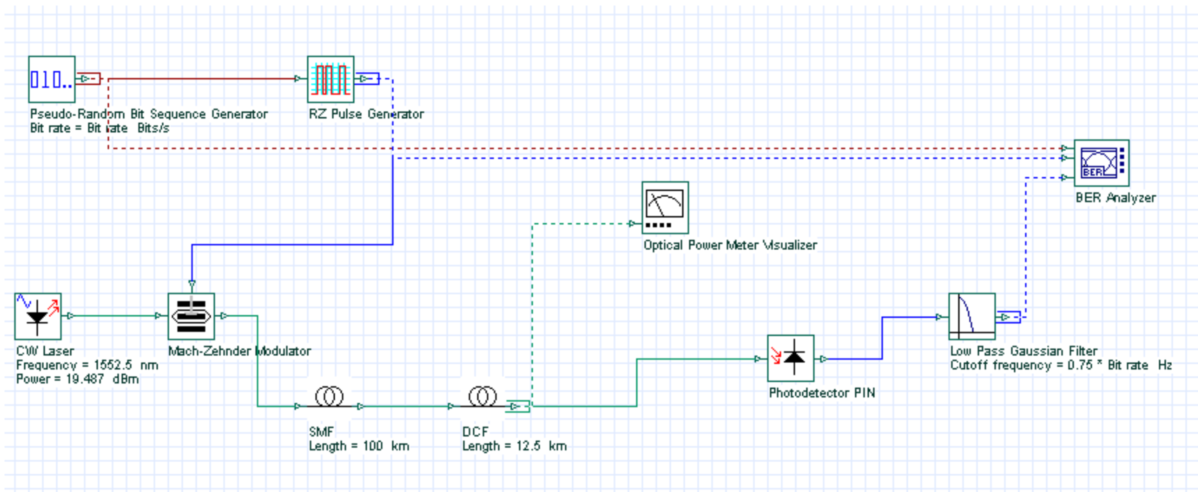


Fig. 1 An end-to-end optical fiber link modeled in OptiSystem

detector followed by a low-pass Bessel filter that removes noise from the electrical signal. Finally, the output of filter is fed to BER analyzer. The receiver sensitivity is kept at -18dBm.

Parameters used for DCF

- Dispersion at 1550 nm : -80ps/nm.km
- Dispersion Slope at 1550 nm : -0.075 ps/nm^2.km
- Effective Area : 30μm^2
- Polarization Mode Dispersion : ≤ 0.05 ps/√km
- Attenuation : ≤ 0.4dB/km

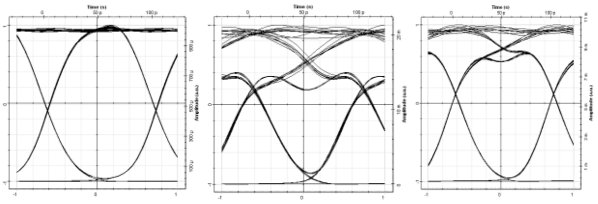
Performance evaluation is done by launching data at 10Gbps through the SMF and measuring the Q-factor and the BER at the receiver side.

IV. RESULTS AND DISCUSSION

Simulations are carried out in two phases. In the first phase, simulations are performed at three different power levels of 0, 10 and 15dBm, under the two cases of with and without complete dispersion compensation. Fig 2.1 and 2.2 show that, in the low power regime, complete

compensation of the dispersion yields better performance due to the absence of nonlinear effect where as in the high power regime complete compensation degrades the system performance. For higher launch powers, Q-factor is improved by leaving some dispersion in the channel that is used to compensate the SPM effect.
First phase results show that the effect of SPM can be compensated by effectively managing the dispersion residue. In order to achieve better performance from the existing optical link; dispersion residue must be optimized along with the launch power. Hence, second phase simulations deal with maximizing the Q-factor by optimizing the launch power and dispersion residue.

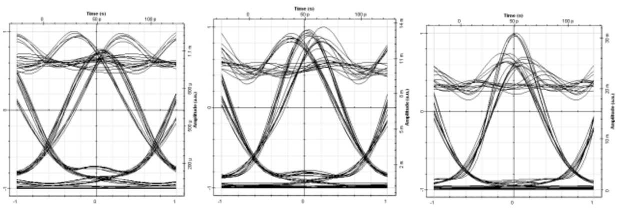
Dispersion residue: 0ps/nm (complete compensation)



(a) Pin = 0dBm (b)Pin = 10dBm (c)Pin = 15dBm Max. Q Factor: 80 Max. Q Factor: 10.8 Max. Q Factor: 5.1

Fig. 2.1 Eye diagrams for different power levels when the dispersion residue is 0ps/nm

Dispersion residue: 180ps/nm



(a) Pin = 0dBm (b)Pin = 10dBm (c)Pin = 15dBm Max. Q Factor: 11.10 Max. Q Factor: 7.44 Max. Q Factor: 7.34 Fig. 2.2 Eye diagrams for different power levels when the dispersion residue is 180ps/nm

SPO optimization tool of OptiSystem has been utilized in implementing the second phase simulations. The length of DCF is varied through 0km (no compensation) to 22.125 km (complete compensation). For each of these lengths, the power launched in to the SMF is varied through 10dBm to 25dBm.

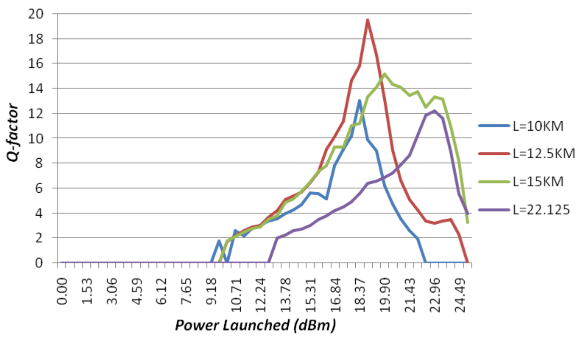


Fig. 3 Launch Power Vs Q-factor for different lengths of DCF

The number of sweep iterations is kept at 50 and the power is varied linearly in steps of 0.5dBm for a fixed length of DCF. Fig. 3 depicts the outcome of the simulation for four different lengths. Results show that maximum Q factor of 18 is achieved at a DCF length of 12.5km and the power launched at this length is around 19dBm.

On the other hand, Fig. 4 depicts the dependency of Q factor on the dispersion residue in the presence of nonlinearities. It is clearly shown in the graph that both complete compensation (to the left of the horizontal axis) and no compensation (to the right of the horizontal axis) result in very low Q-parameter and the received signal does not convey any information.
Dispersion residue of about 800ps/nm results in the maximum Q factor of 18 and that matches with the earlier discussion of length being 12.5km.

Fig. 4 Dispersion residue Vs Q factor for P_{in} = 19dBm

Therefore, for a100km single channel SMF operating at 10Gbps in the presence of nonlinearities, the optimal values of residual dispersion and launch power are 800ps/nm and 19dBm respectively. At these optimum values, the performance of the link is analyzed through eye diagram and is depicted in Fig.5. BER of 1.10381e-074 is obtained and the eye opening is very good.

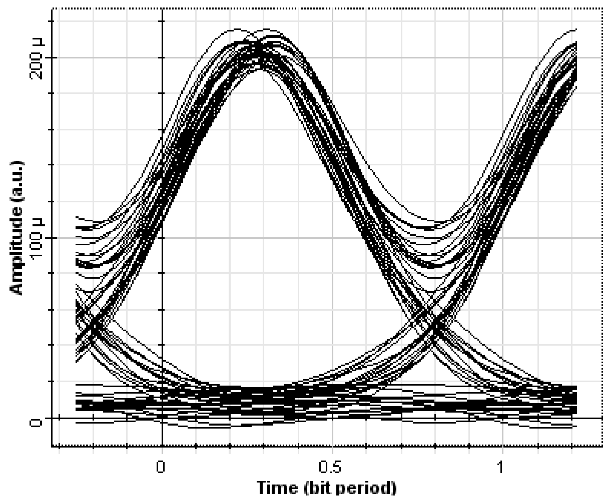


Fig. 5. Eye diagram for the optimized parameters (Max. Q factor : 18.51)

V. CONCLUSION

In this paper, we have demonstrated the effect of SPM on the performance of single channel optical link. Results show that dispersion present in the optical link and SPM compensate each other. Investigations are made to study the impact of launch power and dispersion residue on the system performance. These two parameters are optimized through extensive simulations so as to obtain the Maximum Q parameter. System performance is evaluated using these optimal parameters and the results are reported. Data rates and the transmission distance can be further increased as the Q factor obtained is very well above the min Q factor needed to achieve the required BER. Therefore, in a single channel system, optimization of dispersion compensation is recommended in the presence of nonlinearities for a better performance. To continue further, simulations can be carried out to study the impact of nonlinearities on the performance of WDM link.

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BIOGRAPHIES

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