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Improving Signal Strength Through Higher-Order Dispersion And Phase Modulation for nCRZ Modulation

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Abstract

Fiber nonlinearity and dispersion are among those factors that play a significant role in degrading the performance of a system. Modulation format may be suggested as a way out in this regard whereby a signal can be transmitted over a long distance thereby improving the performance of a system. Considering one particular optical format that will help in this manner is a tough job to do. Thus it has inspired us to go deep through the root to study the various aspects of Wave-Division Multiplexing System (WDM) or more precisely Optical WDM (OWDM) or Dense WDM (DWDM). In this short version, we have analysed how the performance of an optical system changes when higher order dispersion effects are compensated along with phase modulation. Here based on our some results, we have graphically explained the impact of higher order dispersion on our modulation format. For different values of phase modulation, graphical representation shows a significant change in the signal strength of the system.

Keywords- nCRZ, RZ Modulation Format, GVD, SPM, SSMF.

1. Introduction

With the emerging technology, the need for proper transmission of signal, without any disruption has effectively increased. [1] Now with the help of a phase modulator at the transmitter side, it has become almost possible to form a narrower signal spectrum of Return-to-Zero (RZ) pulses. Thus enabling the increment of spectral efficiency to a much higher level. With this effort it has also been observed that the nonlinear tolerance which plays an important role in signal transmission is increased to a great extent. The chirping of the RZ signal is realized by a phase modulation and the higher order harmonics are suppressed by significantly choosing an optimal value of the phase modulation index.[2], [3]. This makes the signal spectrum formed with only two side bands and a carrier component, which causes less spectral broadening of the signal. The Novel Chirped RZ (nCRZ) spectrum is narrower by a factor of 2 when compared to that of a conventional RZ signal, while the carrier peak possesses equal amplitude as the peaks of both side bands. Thus the nCRZ modulation has an increased dispersion tolerance and the signal form reduces Self-Phase Modulation-Group-Velocity Dispersion (SPM-GVD) impairment in Standard Single Mode Fiber (SSMF) based transmission systems when compared to RZ modulation. [4]. in this paper we have evaluated the effect on output electric field in the presence of higher order dispersion and for various values of phase modulation index. [5].

1.1Basic Description of nCRZ Modulation

The generation of alternate chirped RZ pulses can also be done by using a much more modified modulation format named Novel Chirped Modulation Format. By using a phase modulator at the transmitter end it is possible to achieve a much narrower signal spectrum of RZ pulses. This enhances to produce higher spectral efficiency and an increased nonlinear tolerance. [6] The light of the continuous wave (CW) pump is modulated externally in a LiNbO3 MZM with a RZ encoded electrical signal. The 40 GB/s RZ optical pulses are additionally phase-modulated in a phase modulator (PM). It is then driven by a sine-clock signal at half the bit-rate. [8] This leads to a spectral form which is compact in nature. It also provides a better concentration of the signal spectrum around the wavelength of the carrier. Thus the signal spectrum formed here is quite similar to that of alternate chirped RZ pulses but there lies significant differences between the two: the chirping of the RZ signal is realized by a phase modulation and the higher harmonics are suppressed by choosing an optimal value of phase modulation index. [9], [10]. This enables a signal spectrum with only two side bands and a carrier component that causes less broadening of the signal. Moreover in nCRZ, no additional optical filtering has to be at the transmitter side. [11], [12]. The basic description of this method is illustrated below with a block diagram as given in figure 1.

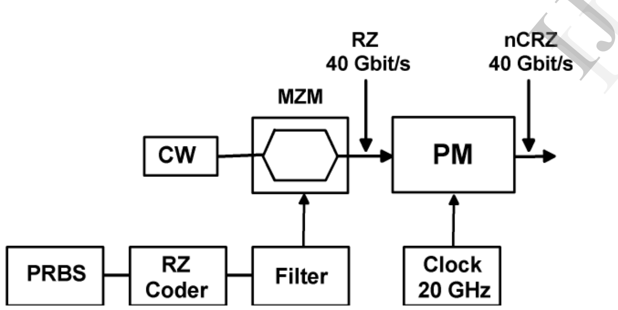

Figure 1. Generation of 40 Gb/s nCRZ signal [8]

1.2. Dispersion and its sources

Dispersion may be defined as the phenomenon in which the phase velocity of a wave depends on its frequency or in other words, when the group velocity depends on the frequency. Dispersion is sometimes called as *chromatic* dispersion to emphasize on its wavelength dependent nature, or *group velocity* dispersion to emphasize on the importance of group velocity. Dispersion plays a very important role in the transmission of an optical signal. Pulse gets broadened due to dispersion as shown in figure 2. There are generally two sources of dispersion: [13]

Material Dispersion is caused by the wavelength dependence of silica's refractive index. It comes from a frequency-dependent response of a material to waves. In single mode fiber amount of pulse spreading caused by material dispersion per unit length is given by [14]:-

$$\frac{\Delta t_m}{L(ps/Km)} = D_m(\lambda)\Delta\lambda \qquad (1.1)$$

Where, Δt_m is material dispersion D_m is material dispersion parameter and L is fiber length, $\Delta\lambda$ is spectral width of the source.

Wave Guide Dispersion occurs because the light signal is guided by a structure i.e. optical fiber. It usually occurs when the speed of a wave in a waveguide like an optical fiber depends on its frequency for geometric reasons, independent of any frequency dependence of the materials from which it is constructed. The information pulse is distributed in core and cladding. The pulse spreading per unit length is given by [14]:-

$$\frac{\Delta t_{wg}}{L(ps/Km)} = D_{wg}(\lambda)\Delta\lambda \qquad (1.2)$$

Where Δt_{wg} is pulse broadening due to dispersion and D_{wg} is wave guide dispersion parameter L is the fiber length and $\Delta\lambda$ is the spectral width of the source.

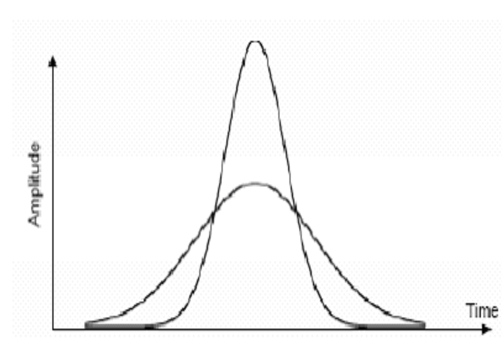

Figure 2. Pulse broadening due to dispersion [15]

2. Analytical Dispersion of nCRZ Modulation

The complex amplitude of the generated nCRZ pulses is given by: [8], [16], and [17]

$$E_{nCRZ} = \sqrt{P_{RZ}} \times \exp\left(i \times m \times \left(\sin(2\pi ft)\right)\right) \tag{2}$$

Here i is the current in amperes, m is the phase modulation index in radians, f is the clock frequency in GHz, t is the time period in seconds

To insert dispersion into equation number (2), we can multiply it with $e^{-j\beta L}$

$$E_{nCRZ} = \sqrt{P_{RZ}} \times \exp\left(i \times m\left(\sin(2\pi ft)\right)\right) \times e^{-j\beta L} \tag{3}$$

Propagation constant β can be expanded in terms of Taylor's series around $\omega = \omega_0$, then (3) can be written as:

$$\beta = \beta_0 + (\omega - \omega_0)\frac{d\beta}{d\omega} + \frac{1}{2}(\omega - \omega_0)^2 \frac{d^2\beta}{d\omega^2} + \frac{1}{6}(\omega - \omega_0)^3 \frac{d^3\beta}{d\omega^3} + \frac{1}{24}(\omega - \omega_0)^4 \frac{d^4\beta}{d\omega^4} \ldots \tag{4}$$

Now as we know that $\frac{d\beta}{d\omega} = \tau$ is the group delay for unit length and L denotes fiber length by putting the value of β from equation in $\exp(-j\beta L)$, we will get [10], [11], [12], and [17].

$$E_{nCRZ} = -j\left[1 - jF_2 \frac{\partial^2}{\partial t^2} + F_3 \frac{\partial^3}{\partial t^3} - jF_4 \frac{\partial^4}{\partial t^4}\right] \sqrt{P_{RZ}} \times \exp\left(i \times m\left(\sin(2\pi ft)\right)\right) \tag{5}$$

Here the values of F_2, F3, and F4 are the higher order dispersion parameters

$$F_2 = \frac{\lambda^2 L}{4\pi c}\frac{\partial \tau}{\partial \lambda} \tag{6}$$

Is the second order dispersion term

$$F_3 = -\frac{L}{6}\frac{\lambda^2}{(2\pi c)^2}\left[\lambda^2 \frac{\partial^2 \tau}{\partial \lambda^2} + 2\lambda \frac{\partial \tau}{\partial \lambda}\right] \tag{7}$$

Is the third order dispersion term

Similarly the value of F_4 can be taken as the fourth order dispersion term

$$F_4 = \frac{L}{24}\frac{\lambda^3}{(2\pi c)^3}\left[\lambda^3 \frac{\partial^3 \tau}{\partial \lambda^3} + 6\lambda^2 \frac{\partial^2 \tau}{\partial \lambda^2} + 6\lambda \frac{\partial \tau}{\partial \lambda}\right] \tag{8}$$

In order to simplify the equation (5)

Let $$E = \sqrt{P_{RZ}} \times \exp\left(i \times m\left(\sin(2\pi ft)\right)\right) \tag{9}$$

$$E_{nCRZ} = -j \times \sqrt{P_{RZ}} \left[E - jF_2 \frac{\partial^2 e}{\partial t^2} + F_3 \frac{\partial^3 e}{\partial t^3} - jF_4 \frac{\partial^4 e}{\partial t^4} + \ldots\right] \tag{10}$$

$\frac{\partial^2 e}{\partial t^2} = E_2$, $\frac{\partial^3 e}{\partial t^3} = E_3$, and $\frac{\partial^4 e}{\partial t^4} = E_4$ respectively.

By using the above equation, (9) becomes

$$E_{nCRZ} = -j \times \sqrt{P_{RZ}} \begin{bmatrix} E - jF_2 E_2 + F_3 E_3 \\ - jF_4 E_4 + \ldots \end{bmatrix}$$

(11)

Now, let us consider our original equation which is given by

$$E_{nCRZ} = \sqrt{P_{RZ}} \times \exp\left(i \times m(\sin(2\pi ft))\right)$$

It is now required to find up to fourth order derivative of the above expression. From (10) it is clear that the first order derivative is expressed as E_1, second order as E_2, third order as E_3 and fourth order as E_4 respectively.

Since P_{RZ} is a constant as well as a common term involved in all the derivatives expression, its value will be put at the expression of the fourth order derivative, i.e. E_4

Now,

$$E = E_{nCRZ} = \sqrt{P_{RZ}} \times \exp\left(i \times m(\sin(2\pi ft))\right) \quad (12)$$

To find the first order derivative

$$E_1 = \exp\left(i \times m(\sin(2\pi ft))\right)\left[i \times m \times (2\pi f)\cos(2\pi ft)\right] \quad (13)$$

$$E_1 = i \times 2 \times m \times \pi \times f\left[E\cos(2\pi ft)\right] \quad (14)$$

To find the second order derivative

$$E_2 = 2im\pi f\left[E_1\cos(2\pi ft) - 2\pi f E\sin(2\pi ft)\right] \quad (15)$$

To find the third order derivative

$$E_3 = 2im\pi f \begin{bmatrix} E_2\cos(2\pi ft) - 2\pi f E_1\sin(2\pi ft) \\ - 2\pi f E_1\sin(2\pi ft) - 4\pi^2 f^2 E\cos(2\pi ft) \end{bmatrix} \quad (16)$$

$$E_3 = 2im\pi f \begin{bmatrix} E_2\cos(2\pi ft) - 4\pi f E_1\sin(2\pi ft) \\ - 4\pi^2 f^2 E\cos(2\pi ft) \end{bmatrix} \quad (17)$$

To find the fourth order derivative, we get

$$E_4 = 2im\pi f \begin{bmatrix} E_3\cos(2\pi ft) - 2\pi f E_2\sin(2\pi ft) - \\ 4\pi f E_2\sin(2\pi ft) - 8\pi^2 f^2 E_1\cos(2\pi ft) \\ - 4\pi^2 f^2 E_1\cos(2\pi ft) \\ + 8\pi^3 f^3 E\sin(2\pi ft) \end{bmatrix} \quad (18)$$

$$E_4 = 2im\pi f \begin{bmatrix} E_3\cos(2\pi ft) - 6\pi f E_2\sin(2\pi ft) \\ - 12\pi^2 f^2 E_1\cos(2\pi ft) + \\ 8\pi^3 f^3 E\sin(2\pi ft) \end{bmatrix} \quad (19)$$

Now putting P_{RZ} in (18) we have

$$E_4 = 2im\pi f \times P_{RZ} \begin{bmatrix} E_3\cos(2\pi ft) - 6\pi f E_2\sin(2\pi ft) \\ - 12\pi^2 f^2 E_1\cos(2\pi ft) \\ + 8\pi^3 f^3 E\sin(2\pi ft) \end{bmatrix} \quad (20)$$

Putting the values of E_2, E_3 and E_4 from (14), (16) and (18) in equation number (10) we have

$$E_{nCRZ} = -j \times \sqrt{P_{RZ}} \begin{bmatrix} E \\ -jF_2 \begin{bmatrix} 2im\pi f \\ \begin{pmatrix} E_1 \\ \cos(2\pi ft) \\ -2\pi fE \\ \sin(2\pi ft) \end{pmatrix} \end{bmatrix} \\ +F_3 \begin{bmatrix} 2im\pi f \\ \begin{pmatrix} E_2 \\ \cos(2\pi ft) \\ -4\pi fE_1 \\ \sin(2\pi ft) \\ -4\pi^2 f^2 E \\ \cos(2\pi ft) \end{pmatrix} \end{bmatrix} \\ -jF_4 \begin{bmatrix} 2im\pi f \\ \begin{bmatrix} E_3 \\ \cos(2\pi ft) \\ -6\pi fE_2 \\ \sin(2\pi ft) \\ -12\pi^2 f^2 E_1 \\ \cos(2\pi ft) \\ +8\pi^3 f^3 E \\ \sin(2\pi ft) \end{bmatrix} \end{bmatrix} \end{bmatrix} \quad (21)$$

This equation can be further simplified by putting the value of higher-order derivatives in detail. Putting the different values of all the constant terms used (i, m, f, P_{RZ}) in equation number (21) we will plot our required graphs accordingly.

3. Results and Discussion

Here we have assumed the wavelength $\lambda = 1.55\mu m$, change of group delay with respect to wavelength as $\frac{\partial \tau}{\partial \lambda} = 20\, ps / nm.km$ and L denotes fiber length [18].

Using these values we have obtained the following dispersion parameters using equation (6), equation (7) and equation (8) respectively.

$$F2 = -12.72(ps)^2 L, \quad F3 = \frac{d^3\beta}{d\omega^3} = 0.00298(ps)^3 L$$

$$F4 = \frac{d^4\beta}{d\omega^4} = -5.32x10^{-5}(ps)^4 L .$$

The modified mathematical relationship for the nCRZ modulation format in the presence of higher order dispersion terms is given in equation (21). Accordingly we have visualized the effect of higher-order dispersion compensation that has led to a quantitative change in the strength of the signal with the signal distance covered, as shown in the following figure (3). To be more clear, the effect of higher-order dispersion has been considered individually in our results with F3=0, F4=0 and F4=0 in figure (4) and (5) respectively. It is realized that the signal strength is found to be improved when all of the higher order dispersion parameters are considered together, as shown in figure (6). The result is not limited to only higher order dispersion compensation but also shows the effect for different values of phase modulation on nCRZ. Here the signal strength is plotted against with phase modulation index m=1, m=2 and m=3 in figure (7), (8) and (9) respectively. Effect of all the phase modulation index has been shown together in figure (10) where a steady curve depicts that the signal strength enhances with distance.

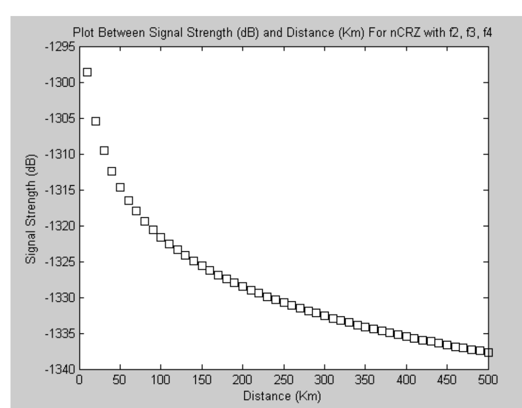

Figure 3. Signal Strength is plotted against distance with F2, F3 and F4

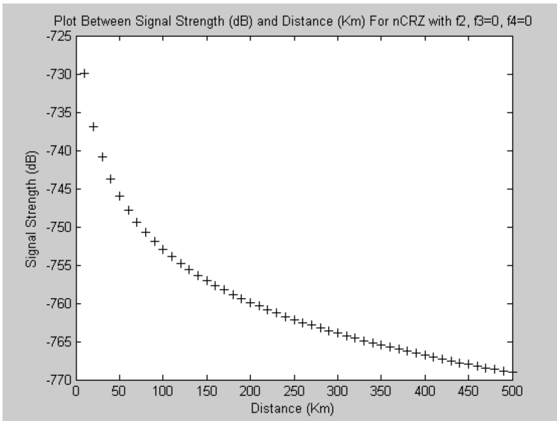

Figure 4. Signal Strength is plotted against distance with F2, F3=0 and F4=0.

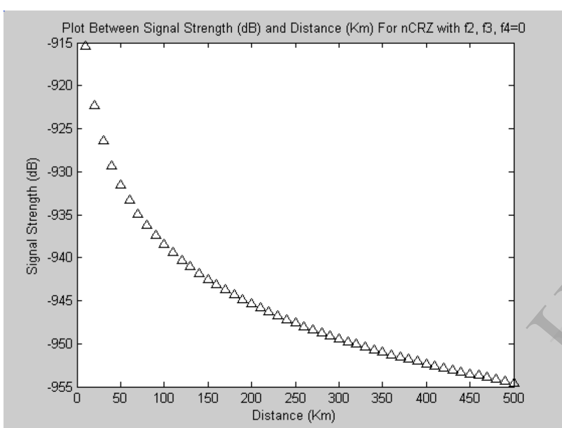

Figure 5. Signal Strength is plotted against distance with F2, F3 and F4=0.

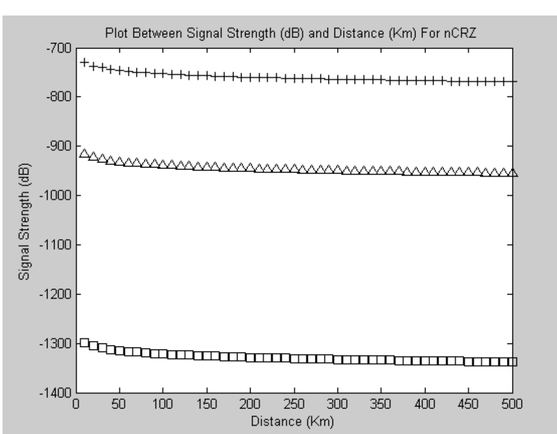

Figure 6. Signal Strength is plotted against distance with higher-order dispersion.

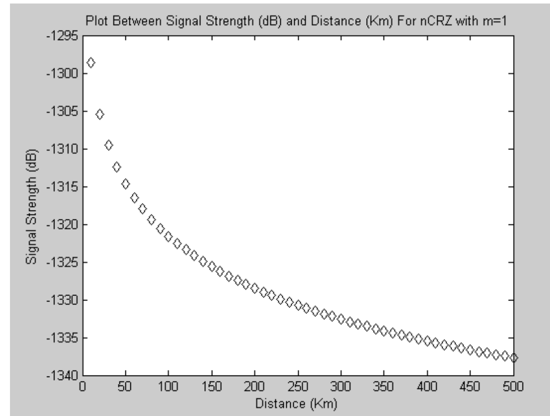

Figure 7. Signal Strength is plotted against distance with m=1.

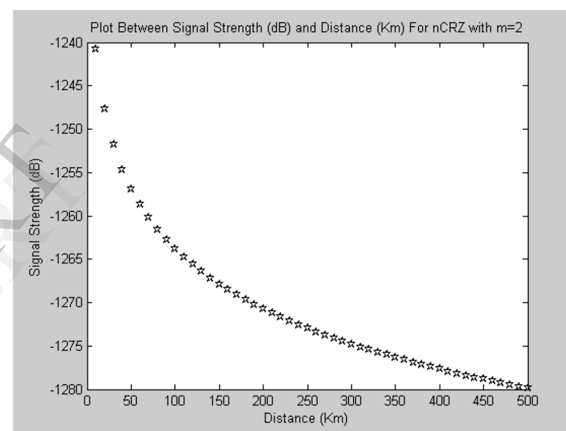

Figure 8. Signal Strength is plotted against distance with m=2.

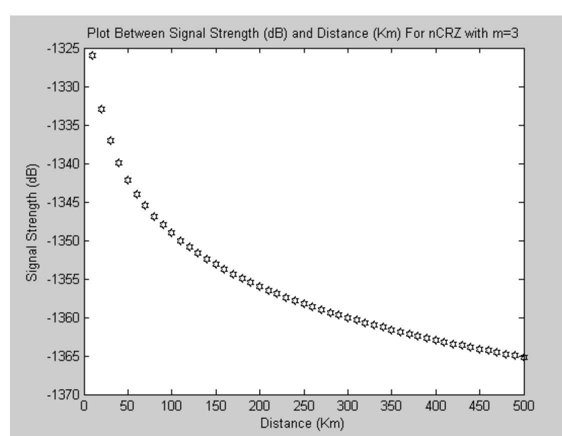

Figure 9. Signal Strength is plotted against distance with m=3.

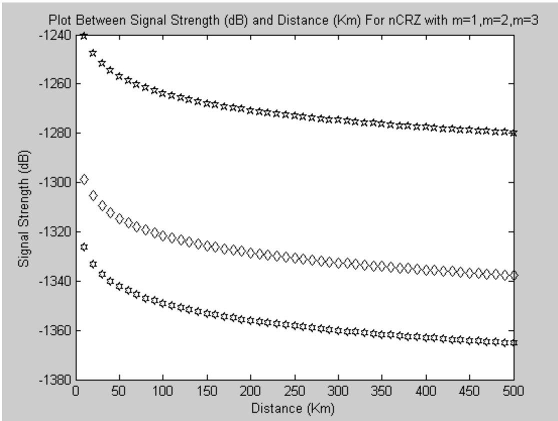

Figure 10. Signal Strength is plotted against distance with m=1, m=2 and m=3.

4. Conclusion

The equation number (20) presents a modified relationship for the signal strength including the higher order dispersion effect and the phase modulation for optical nCRZ based communication system. At an operating wavelength of 1.55 μm the effect of higher order dispersion has been evaluated. It has been observed from the graphical representation that the signal strength is enhanced when the higher order dispersion compensation is considered together. Here we have just added dispersion compensation and phase modulation in our existing model to find out the effect of these parameters on the signal. Also to find out how these factors helps in enhancing the strength of a signal when passed over a long distance. This method can also helps in cost saving in an OFC link. Thus after making a detailed comparison between the existing model and the modified model, we can conclude that signal strength can increase as well as improve if higher order dispersion compensation and phase modulation are equally considered for that particular signal.

5. Future Scope

The results presented in this work can be used for the future research purpose in the following areas as mentioned below:

a) The work can be extended to study the impacts of other non linearity's like Four Wave Mixing (FWM), Self Phase Modulation (SPM) and Cross Phase Modulation (XPM) etc.

b) The results obtained in this paper also encourage the multimedia and personnel communication applications as it requires large bandwidth.

c) Due to the Polarization Mode Dispersion (PMD) impact of data transfer at higher bit rate proper choice of PMD coefficient influences the design of today's DWDM networks. So this work can be extended in this direction also.

d) This work can also be extended for use in WDM systems.

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