Analysis of Self Phase Modulation Effect in 40 Gb/s Optical Fiber Communication System for Various Modulation Formats with Dispersion Compensation

Supreet Singh[1], Kulwinder Singh[2]
[1]Department of Electronics and Communication Engineering, Punjabi University, Patiala, India
[2]Department of Electronics and Communication Engineering, Punjabi University, Patiala, India
[1]supreetldh@gmail.com
[2]ksmalhi@rediffmail.com

Abstract- **In this paper the effect of Self Phase Modulation fiber nonlinearity in 40 Gb/s optical fiber communication system has been compared with different modulation formats such as non return to zero (NRZ), return to zero (RZ), carrier suppressed return to zero (CS-RZ) and modified duo binary return to zero (MDRZ). The effect of SPM fiber nonlinearity has investigated in terms of Q-factor at the receiver output by using different modulation formats with variation in input launched power from -10 to 15 dBm. It has observed that the performance of optical fiber communication system is limit by SPM effect and MDRZ format seems to be best choice for input power 15 dBm. Further, we have analysed the effect of SPM in terms of Q-factor with variation in fiber length from 60 to 360 km and observed that at 360 km fiber length MDRZ format gives better Q-Factor as comparison to other modulation formats. So we proposed that MDRZ modulation format will be used when system should operate at high input power and longer distance**.

***Keywords*—NRZ, RZ, CS-RZ, SPM, EDFA, SSMF and DCF**

I. Introduction

In order to achieve high transmission distance high input power should launched in optical fiber communication system but input launched power has restricted due to the nonlinear effects such as SPM present in the single mode optical fiber [1]. SPM is a scrounging phase modulation caused by signal optical power modulation and fiber nonlinearity that broadens the optical signal spectrum [2]. The SPM effect is measureable at high input powers and high bit rates. The fiber input power that is allowable in long haul transmission link decided by different modulation formats.

Non return to zero (NRZ)

NRZ has been the dominant modulation format for fiber-optical communication systems. There are several reasons for using NRZ in the early days of fiber-optical communication: First, it requires a low electrical bandwidth for the transmitters and receivers (compared to return-to-zero), second it is not sensitive to laser phase noise [2] and it has the simplest configuration for the transmitter and receiver.

Considering recent advancements in optical communication field, NRZ modulation format may not be the best choice for high input power optical communication systems [3]. The schematic of NRZ transmitter is shown in figure 1 (a). In addition, NRZ optical signal has found to be less resistive to SPM effect in transmission compared to its RZ signals.

Return to zero (RZ)

RZ means "return-to-zero", so the width of optical signal is smaller than its bit period. Figure 1 (b) presents the block diagram of a typical RZ transmitter. RZ optical signal has found to be more tolerant to nonlinearity than NRZ optical signal [3]. As we compare the Q-factor of RZ modulation format with NRZ it has found that when the signal is transmitted with high input power RZ modulation format has better Q-Factor than NRZ at higher transmission distance.

Carrier suppressed return to zero (CS-RZ)

CS-RZ modulation format requires a complex transmitter structure as compare to NRZ and RZ but it provides a high tolerance to the effect of self-phase modulation (SPM).

In CSRZ transmitter two Mach-Zehnder modulators (MZMs) are connected in cascade, where first MZM is given input with CW laser and NRZ pulse generator and the second is driven by first and a sine wave generator at the frequency equal to half the bit rate that will introduce a 180-degree phase shift between two any adjacent bits. The schematic of CS-RZ transmitter shown in figure 1 (c)

Modified duobinary return to zero (MDRZ)

The other name of MDRZ is carrier suppressed duo binary format. The MDRZ was created by pseudo random bit sequence generator output given to duobinary precoder which drives the NRZ pulse generator and drives the delay and subtracter circuit which drives the first Mach-Zehnder modulator (MZM) and second mach-zehnder modulator (MZM) drives with the output of the first MZM and sine wave generator having frequency 20 Ghz and -90° phase shift. In MDRZ, the phase of the signal is switched between 0 and Π for the bit '1'. The phase for all the zeros should be kept constant and a variation of 180° phase occurs between all the successive ones [4]. The schematic of MDRZ transmitter as shown in figure 1(d)

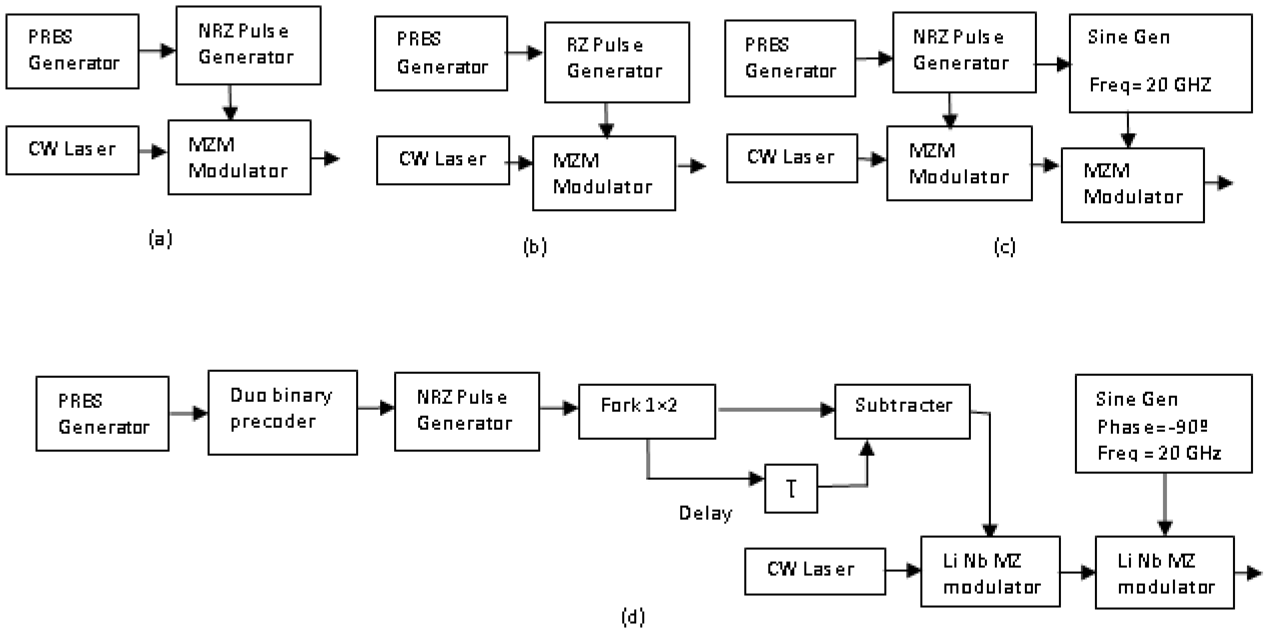

Figure 1.Schematic of optical transmitter different modulation formats (a) NRZ (b) RZ (c) CSRZ and (d)MDRZ [4]

The effect of SPM has been observed at the receiver output in terms of Q-Factor is also calculated by the equation given below. In this the value of Q-Factor is directly proportional to square root of optical input signal launched power [3] as

$$Q = \sqrt{\frac{\lambda P_{in}}{2N\, h\, c\, NF_{eff}\,(G_{eff} - 1)B_e}} \qquad (1)$$

Where P_{in} is the average optical power launched into the communication system, h is the plank constant, c is the speed of light, λ is the signal wavelength, B_e is the receiver bandwidth and N is the total number of amplified fiber spans which consists of a DCF sandwiched between two inline EDFA with the effective noise figure NF_{eff} and effective optical gain G_{eff}.

II. SIMULATION SETUP

The figure 2 shows a simulation setup for analysis of self-phase modulation of the optical fiber link having a single channel. The transmitter section consists of Pseudo Random bit Sequence generator at bit rate of 40 Gbps and NRZ, RZ , CS-RZ and MDRZ modulation formats. The pulse generator is used to convert binary sequence into electrical pulses and used with NRZ, RZ, CS-RZ and MDRZ format to generate different types of optical signal that schematic as shown in figure1The continuous wave lorentzian laser of 1550 nm wavelength is used as optical source to provide input launched power to Mach-Zehnder Modulator has excitation ratio of 30 dB and erbium doped fiber amplifier of gain 5 dB and noise figure 4 dB. The channel consists of two standard single mode fiber (SSMF) of length 25 km and one dispersion compensated fiber (DCF) of length 10 km sandwiched between two SSMF with symmetrical dispersion compensation scheme. The design of transmission link at 40 Gb/s is designed suitably in accordance with [4] considering the fiber parameters of DCF and SSMF for dispersion compensation as shown in Table 1.

$$D_{SMF} L_{SMF} = D_{DCF} L_{DCF} \qquad (2)$$

where, D_{SMF} and L_{SMF} are chromatic dispersion (in ps/km/nm) and length (in Km) of SMMF, D_{DCF} and L_{DCF} are the respective parameters of DCF.

Table 1 Fiber Parameters

Fiber	Attenuation α (dB/Km)	Dispersion D (ps/nm/km)	Dispersion Slope S (ps/km-nm^2)	Effective Core Area A_{eff} (μm^2)
SMF	0.2	17	0.075	70
DCF	0.5	-85	-0.3	22

The receiver section consists of PIN photodiode has responsivity of 1 A/W and dark current of 10 nA for conversion of optical signal into electrical conversion, Low pass electrical filter has cut off frequency 8 GHz and insertion loss of 0 dB and BER analyser to estimate the value of Q-factor.

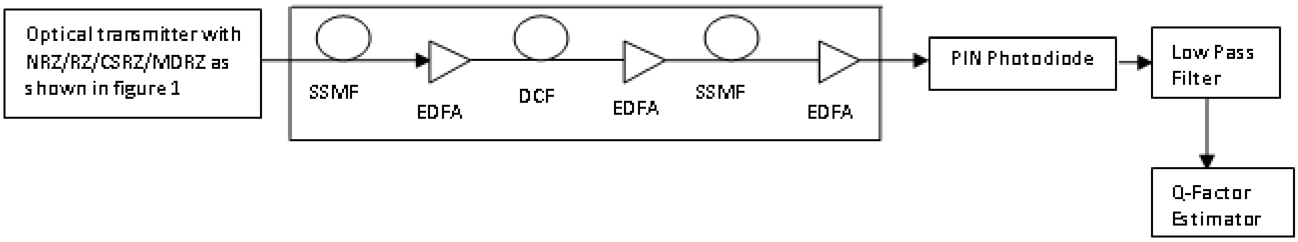

Figure 2 Fiber span 60 km repeated for 6 times

III. RESULTS AND DISCUUSIONS

The laser power is varied from -10 to +15 dBm with various modulation formats NRZ, RZ, CS-RZ and MDRZ to analyse the effect of SPM fiber nonlinearity in terms of Q-factor at the receiver output as shown in Table 2.

Table 2 Q-Factor at the Output by Varying Input Launched Power

S.No.	Input launched power (dBm)	Q-Factor			
		NRZ	RZ	CS-RZ	MDRZ
1	-10	14.09	13.16	10.78	5.22
2	-7.5	20.13	19.56	15.63	7.90
3	-5	27.78	28.39	22.14	11.60
4	-2.5	36.85	40.48	31.78	16.72
5	0	48.45	56.55	42.62	23.10
6	2.5	53.09	76.06	58.05	31.93
7	5	30.82	90.21	69.56	42.41
8	7.5	11.00	82.80	76.24	55.75
9	10	3.64	42.53	79.76	64.35
10	12.5	2.55	13.38	22.24	31.67
11	15	2.82	10.16	17.08	25.24

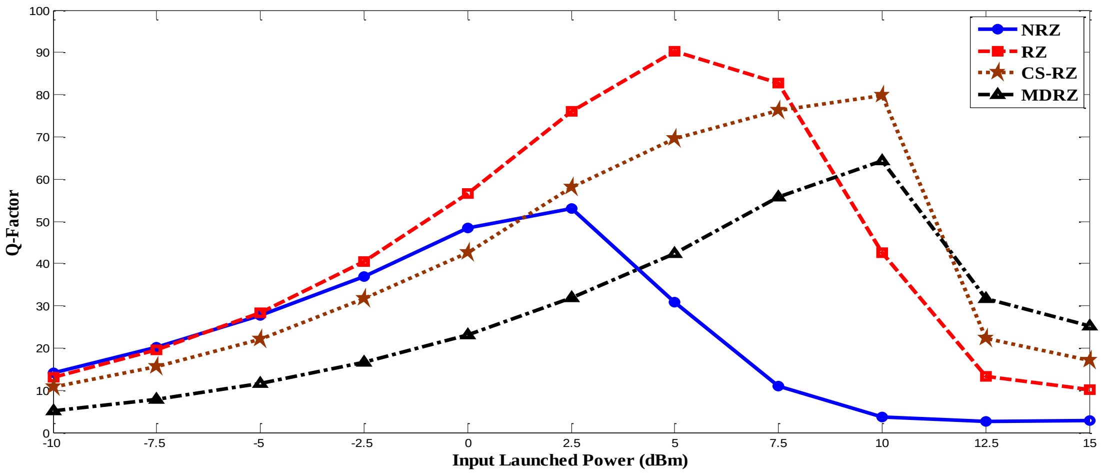

Figure 3.Q-Factor Vs Input Launched Power for Various Modulation Formats

From the figure 3 we have observed that when the laser power is increased from -10 to +15 dBm in optical fiber communication system using single mode fiber the RZ modulation format gives the highest Q- factor up to 5 dBm from the NRZ, CS-RZ and MDRZ modulation format. If we further increase in input launched power, but now the CS-RZ modulation format gives the highest Q-factor up to 10 dBm as compare to NRZ, RZ and MDRZ. It can understood from the fact that the performance of the optical fiber communication system improves with increase in input launched optical power but at high powers when the phase of the light pulse propagating in the optical fiber changes due to fiber nonlinearity such as self-phase modulation (SPM) and the performance of the system degrades. It is observed from the figure 3, that MDRZ format gives higher Q-Factor of 8 as compare to CSRZ at input launched power of 15 dBm. Subsequently we can say that MDRZ modulation format has less affected by SPM fiber nonlinearity.

Further, we have varied the fiber length from 60 to 360 km with different modulation format NRZ, RZ, CS-RZ and MDRZ as shown in Table 3

Table 3 Q-Factor at the Output by Varying Fiber Length

S.No	Fiber length (kms)	Q-Factor			
		NRZ	RZ	CS-RZ	MDRZ
1	60	32.89	95.42	282.16	157.53
2	120	9.38	84.92	128.62	96.20
3	180	4.06	40.01	60.72	60.14
4	240	2.86	23.71	29.35	38.32
5	300	2.67	15.21	17.08	25.24
6	360	2.82	10.16	11.00	17.55

From the figure 4 we have analysed that when the fiber length increases from 60 to 360 km the CSRZ format gives the highest Q-factor as compare to NRZ, RZ and MDRZ when the fiber length is less than 180 km but after the 180 km fiber length the Q–factor value of the MDRZ format higher as compare to NRZ, RZ and CS-RZ as shown in table 3. So we have observed that at the longer distance fiber nonlinearity increases and degrades the performance of the optical communication system. Further it can be observed from the figure 4 the MDRZ modulation format with symmetrical dispersion compensation gives higher Q-factor of 6.55 as compare to CSRZ when the fiber length is 360 km.

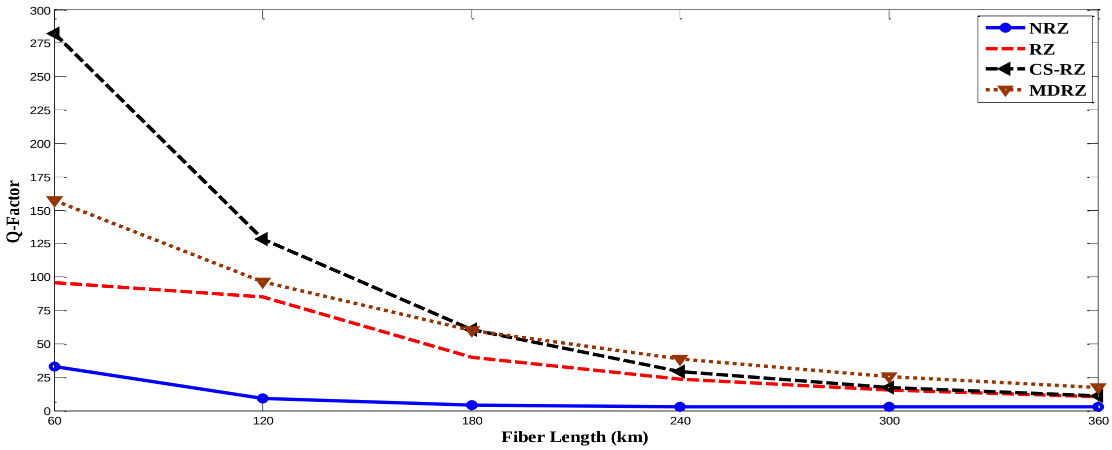

Figure 4.Q-Factor Vs Fiber Length For Different Modulation Formats

IV. CONCLUSIONS

We have investigated the effect of SPM in 40 Gb/s optical fiber communication system for different modulation formats with symmetrical dispersion compensation scheme. The effect of modulation formats NRZ, RZ, CSRZ and MDRZ on the optical fiber communication system with variation in input launched power and fiber length has been analysed. It has observed when the input launched power increases Q-Factor value increases up to 5 dBm after which start decreasing due to the dominance of fiber nonlinearity SPM, but at higher launched powers to the optical fiber the system is less affected by SPM fiber nonlinearity by using MDRZ modulation format as it gives higher Q-factor of 8 as compare to CS-RZ when the input power is 15 dBm. Similarly, when the transmission distance increases the CSRZ gives the highest Q-factor from NRZ, RZ and MDRZ up to a distance of 180 km but when the system was operated at longer distance MDRZ modulation format gives higher Q-factor of 6.55 with comparison to CS-RZ when the transmission distance is 360 km. It has concluded that MDRZ modulation format gives better results in comparison to NRZ, RZ and CSRZ at longer optical fiber transmission links at higher optical power but less than 180 km and 5 dBm optical launched power RZ and CSRZ are good.

References

[1] Agrawal G.P., "*Fiber-Optic Communication Systems"*, John Wile & Sons, New York, 1997

[2] Hayee, M. I., and A. E. Willner."NRZ versus RZ in 10-40-Gb/s dispersion-managed WDM transmission systems." *IEEE photonics technology letters*, volume11 issue8, pp 991-993, 1999

[3] Winzer, Peter J and R J Essiambre. "Advanced optical modulation formats." *Proceedings of the IEEE*, volume 94 issue 5, pp 952-985, 2006.

[4] Sheetal, Anu, Ajay K. Sharma and R. S. Kaler."Impact of optical modulation formats on SPM-limited fiber transmission in 10 and 40Gb/s optimum dispersion-managed lightwave systems." *Optik - International Journal for Light and Electron Optics*, volume121 issue 3, pp 246-252, 2010

[5] Jawla, Shashi. "Intensity Modulation Formats in Optical Communication System." *International journal of scientific & engineering reseach*, volume 12 issue 3, 201

[6] Malti, Meenakshi, and Anu Sheetal."Comparison of CSRZ, DRZ and MDRZ modulation formats for high bit rate WDM-PON system" *International journal of Emerging Technology and Advances Engineering*, volume2 issue6, 2012