Intersymbol Interference Suppression Method Based on the Selective Electric Pulses Shaping Approach

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Abstract

Inter Symbol Interference (ISI) represents one of the most challenging problems in fiber optic communication systems. It causes increase in path loss, degraded performance and delay spread hence; achieving high data rates becomes impossible. However, it is not yet fully explored in terms of electrical pulse shaping and high data rate. In this paper,the Impact of various electrical pulse shapes such as Non-return-to-Zero (NRZ), Return-to-zero (RZ),Gaussian and Raised Cosine (RC) on the optical transmission performance and its characteristics are evaluated, compared and analyzed. Furthermore, the system performance in term of BER was measured for different values of Roll of factor (α) for RC pulse at 100Gb\s data rate. As such, the system performance was figured as a function of received signal power, OSNR, and Roll of Factor. It was found that the Raised cosine pulse offered a better BER for all various transmission distance in comparison with other pulse shapes at the same launch power variation. For instance, for distance of 500 km, the Roll Of factor (α=0.6) appeared better BER and it was 3×10^{-11} compared to other (α) at the same launch power. As well as, for distance of 700 km, the Roll of factor (α=0.8) showed better BER and it was 1.5×10^{-6}.

Keywords: Intersymbol interference, Roll off factor, pulse shaping, Raised Cosine pulse, and BER

الخلاصة:

تداخل الرموز (ISI) يمثل إحدى المشاكل الأكثر تحديا في نظم الاتصالات والألياف البصرية. اذ انه يسبب زيادة في فقدان المسار، تدهور الأداء وتأخير الانتشار وبالتالي؛ تحقيق معدلات عالية للبيانات يصبح من المستحيل. ومع ذلك فان موضوع رموز التداخل لم يتم بعد استكشافها بشكل كامل من حيث شكل النبضة الكهربائية ومعدل البيانات عالية. في هذه الورقة، تأثير مختلف اشكال النبضات الكهربائيه مثل نبض عدم العوده الى الصفر (NRZ)، نبض العوده الى الصفر(RZ)، نبض الكاوسيه (Gaussian) و نبض أثارت جيب التمام (Raised Cosine) على أداء الإرسال االبصري وخواصه تم تقييمه ، مقارنته وتحليله . علاوة على ذلك، تم قياس أداء النظام بدلالة نسبة الخطأ بت (BER) ولقيم مختلفة من عامل اللف (Roll of factor) لنبضة Raised Cosine بمعدل نسبة بيانات 100Gb\s. كذلك تم تقييم اداء النظام بدلالة قدرة الاشارة المستلمة، نسبة الاشارة الى الضوضاء وعامل اللف. النتائج بينت ان شكل النبضة Raised Cosine عرضت اقل نسبة الخطأ بت ولجميع المسافات المستخدمة بالمقارنه مع اشكال النبضات الاخرى ولنفس متغيرات القدرة. كمثال على ذلك، لمسافة نقل 500 km،عامل اللف (0.6) قدم احسن نسبة الخطأ بت وكانت 3×10^{-11} مقارنة مع قيم اللف الاخرى. كذلك لمسافة نقل 700 km،عامل اللف (0.8)اظهر احسن نسبة الخطأ بت وكانت 1.5×10^{-6} مقارنة مع قيم اللف الموجودة.

الكلمات ألمفتاحيه: تداخل الرموز ، عامل اللف، اشكال النبضات، نبض أثارت جيب التمام ، نسبة الخطأ بت.

1. Introduction

The need of high data rate, long transmission distance and high spectral efficiency is the most challenges in optical communication systems. The target of all researchers and designers is how design optimum transmission system can meet all these challenges. Thus, it can introduce efficient system performance. In optical communication, the Inter symbol Interference (ISI) is one of the significant problems that may decrease the efficiency of the optical transmission system (Lathi et al., 2009). The ISI leads to distort the optical signal in which one symbol overlaps with next symbols. The pulse will spread beyond its allotted time interval make it to interfere with neighboring pulses together (Lathi *et. al*., 2009;Lu Zhang *et. al*., 2016; Anderson *et. al*., 2013). The main defect of ISI in the system is producing an error at the receiver. Various techniques have been suggested to overcome ISI such as the traditional techniques like Dispersion Compensating Fibers(DCFs),Fiber Bragg Gratings (FBG),and Electronic Dispersion Compensation (EDC) in optical system (Pizzinat *et. al*., 2002; Konrad and Petermann, 2001; Peucheret *et. al*., 2000).

Nevertheless, all these techniques were not efficient because DCFS have high insertion loss, large foot print and nonlinear effects inside the fiber. For multiple channels present in the optical system, number of DCF's required to be installed, thus the system will be more complicated and costly. EDC is inactive for optical system since it is sophisticated and also not a direct method of compensation.

Furthermore, techniques of equalization were used for a long time to overcome the ISI defect like Feed-Forward Equalizers (FFE), Decision Feedback Equalizers (DFE), and Frequency-Domain Equalization (FDE) (Watts *et. al*.,2005; Ishihara *et. al*.,2008;Ishihara *et. al*.,2011).The main drawback of these techniques that they haven't perfect compensation for the distortions due to the weak performance of the photodiode (PD) detection.Also the nonlinear equalizer is utilized for more improvement to the system quality as Square root operator (SQRT), nonlinear FFE-DFE (NL-FFE-DFE), and maximum- likelihood sequence estimation (MLSE) (Prat *et. al*.,2005; Xia and Rosenkranz, 2007; Färbert *et. al*., 2004;Na Liu *et. al*., 2014). However; limitation of these methods is that the phase information has been lost even after the nonlinear equalizer.

Recently, qualified technique was suggested to suppress the ISI namely the pulse shaping. Basically, propagated of the pulse shape inside the fiber based on the electric pulse applied to the optical transmitter and the dynamic response of the laser beam (Winzer *et. al*., 2010; Alfiad *et. al*., 2010; Nolle *et. al*., 2010; Kikuchi, 2007; Benoit Chatelain *et. al*., 2011;Carmina del Rio Campos *et. al*., 2011).

Lately, to enhance the system quality, a few techniques in term of electrical pulse shape were reviewed. Basically, NZR pulses have a rectangular shape with sudden rise and fall edges. It has been used as electrical modulation of resulting optical bit stream. Nevertheless, it appears low robust to nonlinear effects, and is only appropriate for 10 Gbit/s with transmission distance less than 200 km. The Returns to zero (RZ) pulse has high tolerate to fiber nonlinearity. However, it has a double bandwidth compared to NRZ which producing a poor spectral efficiency (Schvan *et. al*.,2005). Therefore, the solution with electrical pulse shaping selection is still needed to satisfy these requirements. In this work, an effective solution is presented to highlight the electrical pulse shape effect on the performance of optical system for different waveforms and different distances.An evaluation of the transmission performance was made for variety of electrical pulse shape as NRZ,RZ,Gaussian and RC.

The paper is arranged as: Section 2 discusses the characteristics and theory of the pulse shapes with the mathematical model of such pulse implemented. Section 3 covers the simulation system design for 100 Gb\s. Section 4 introduces the findings of optical transmission performance of pulse shapes including various roll of factor and different transmission distance. Section 5 summarizes the findings, and gives a crucial comparison of all the pulse shapes considered.

2. Model of the Pulse shaping

For any data transmission system, the optical signals are modulated in the transmitter and then demodulated and detected by the receiver. At the receiver, the received signals are sampled at an optimum point within pulse interval to increase the binary decision probability. To ensure that the fundamental shapes does not overlap with each other at this optimum point. We have two strategies can do this purpose. Firstly the shape of pulse exhibits a zero crossing at the sampling point of all pulse intervals except its own; else, the residual effect of other pulses will release errors. Secondly the amplitude decays quickly outside of the interval of the pulse.

2.1 NRZ Pulse

Non-Return-to-Zero (NRZ) shown in Fig. (1) has a positive rectangular pulse for binary **1**,else, it has binary **0** (Lathi et al., 2009).

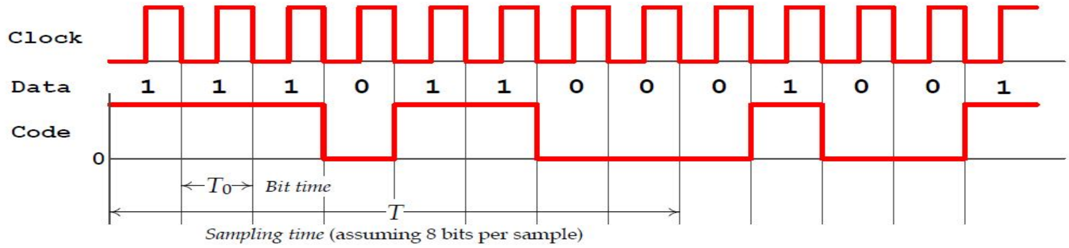


Figure (1): NRZ pulse shape

The NRZ model can generate pulses with Exponential edge shapes as:

$$E(t)=\begin{cases}1-e^{-(t/c_r)}, & 0\le t<t_1\\ 1, & t_1\le t<t_2\\ e^{-(t/c_f)}, & t_2\le t<T\end{cases} \qquad \text{........ (1)}$$

Where (Lathi *et. al*., 2009):

c_r is the rise time coefficient, c_f is the fall time coefficient, t_1 and t_2, together with c_r and c_f, and T is the bit period.

2.2 RZ Pulse

Return-to-Zero (RZ) is a rectangular pulse that drops from logic 1 to logic 0 in the middle of the bit time as shown in Fig. (2) (M. S. Alfiad *et. al*., 2010).

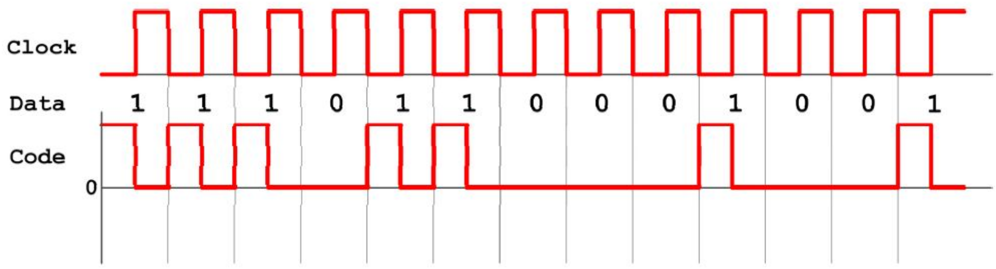


Figure (2): RZ pulse shape

Based on Rectangle shape parameter, the RZ model can generate pulses with **Exponential** edge shapes as (M. S. Alfiad *et. al*., 2010):

$$E(t)=\begin{cases}1-e^{-(t/c_r)}, & 0\le t<t_1\\ 1, & t_1\le t<t_2\\ e^{-(t/c_f)}, & t_2\le t<t_c\\ 0, & t_c\le t<T\end{cases} \qquad \text{........ (2)}$$

t_c is the duty cycle duration

A drawback of (RZ and NRZ) is that its mean value is not zero, which means that significant DC-component will be created at the receiver. A DC-value is unwanted in long-distance communication systems. Another disadvantage of such RZ and NRZ signaling is that they have not clock information especially when the bit stream consists of a long sequence of **0**'s.

2.3 Gaussian Pulse

A Gaussian pulse is shaped in similar form of a Gaussian function and it generates an electrical Gaussian-pulsed signal. It has the features of maximum steepness of transition with minimum overshoot and group delay as in Fig. (3) (Lathi *et. al.*, 2009).

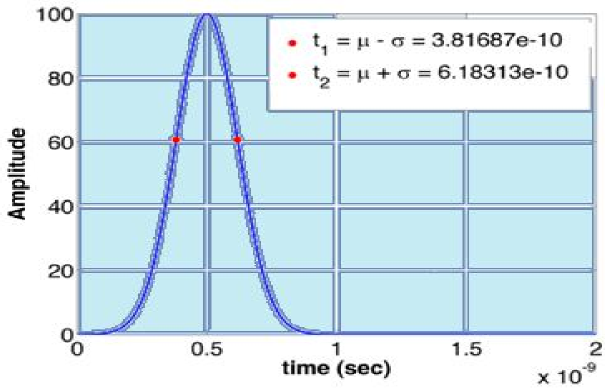


Figure (3): Gaussian pulse shape

The Gaussian pulses model according to the bit sequence at the input, for each bit

$$E(t) = B.\left(A_p.e^{\frac{1}{2}\left(\frac{t.k}{T_{FWHM}}\right)^{\square N}} + A_{bias}\right) \qquad \ldots\ldots. (3)$$

Where:

A_p is the Amplitude parameter, A_{bias} is the bias parameter, B is the bit value (1 or 0) and depends on the input bit sequence, k is the fitting coefficient, T_{FWHM} is the Pulse width, and N is the Gaussian Order (N=1) or super-Gaussian pulses (N>1).

2.4 Raised cosine Pulse(RC)

The raised cosine pulse takes on the shape of a sinc pulse**.** In the fact it refers to the pulse's frequency spectrum, not to its time domain shape (Benoit Chatelain *et. al.*, 2011). The accurate shape of the RC pulse is performed by the parameter α, where its value $0 \le \alpha \le 1$ as in Fig. (4). Precisely, α arbitrates the bandwidth occupied by the pulse and the rate at which the tails of the pulse decay. At α =0, it appears the narrowest bandwidth, but the slowest rate of decay in the time domain. For α = 1, the bandwidth is 1/τ, but the tails of time domain will decay fastly. Therefore, the factor α allows the system designer a trade-off between increased bit rate and time-domain tail suppression.

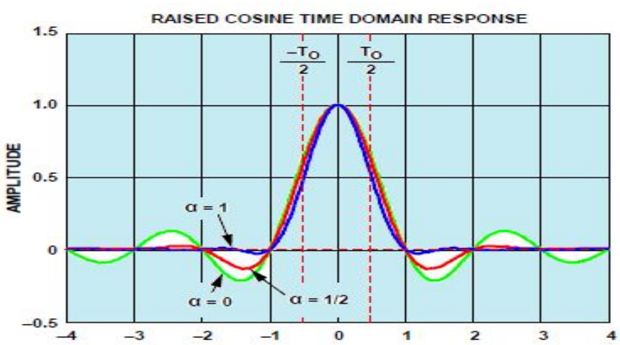


Figure (4): Raised Cosine pulse

$$E(t) = \frac{\sin{\pi t}/_{T}}{{\pi t}/_{T}} \frac{\cos{\pi \alpha t}/_{T}}{1 - \frac{4\alpha^2 t^2}{T^2}} \qquad \ldots\ldots (4)$$

Where α : is Roll of factor

3. System simulation design

Fig.(5) illustrates the proposed simulation design using optical software (Optisystem^{TM} version12). At the transmitter, a continuous wave laser with a centre wavelength of 1550 nm is used to create the carrier signal. The total Bit rate of the suggested system was 100Gb/s. The optical source is linked to an external modulator.

It comprises a Data Bit Sequence (DBS), which is connected to a pulse generator to reshape the optical signals. Then the signal is passed to intensity modulator which is named the Mach-Zehnder modulator (MZM). It consists of two 3 dB couplers connected by two waveguides of equal length. By the electro-optic effect, an applied voltage can be used to change the refractive indices in the waveguide branche.Thus; the different paths can lead to constructive and destructive interference at the output, based on the applied voltage. The output intensity can be modulated according to the voltage.

$$E_{out}(t) = E_{in}(t).\cos\left(\left(\Delta\theta(t)\right)\right).\exp\left(j.\Delta\phi(t)\right) \quad \text{........ (5)}$$

Where Δθ is the phase difference between the two branches and is defined as:

$$\Delta\theta(t) = \frac{\pi}{2}.(0.5 - ER.(Modulation(t) - 0.5)) \quad \text{........ (6)}$$

With

$$ER = 1 - \frac{4}{\pi}.\arctan\left(\frac{1}{\sqrt{ext}}\right) \quad \text{........ (7)}$$

And

$\Delta\varphi$ is the phase change in the signal and defined as:

$$\Delta\phi(t) = SC.\Delta\theta(t).(1+SF)/(1-SF) \quad \text{........ (8)}$$

The parameter SC is -1 if negative signal chirp is true, or 1 if negative signal chirp is false, ext: is the extinction ratio, SF is the symmetry factor, and modulation (t) is the electrical input pulse. Then the output optical signal behavior depends on the electrical pulse shape.

The optical signal is passed to the optical channel which consists of number of span. Each span has two stage erbium doped fiber amplifiers (EDFA) that are used to compensate the total fibre loss in each span, and are placed before and after the dispersion compensation fibre (DCF).Two kinds of fiber optic have been used namely SMF and DCF. The standard parameters of proposed optical system shown in Table 1.

At the receiver, the signal is demultiplexed and then detected by a PIN photodiode and then passed through the low-pass Bessel filter to suppress the electrical noise. Finally, the received signal is passed to the BER analyzer tester, which is used to figure the eye diagram.

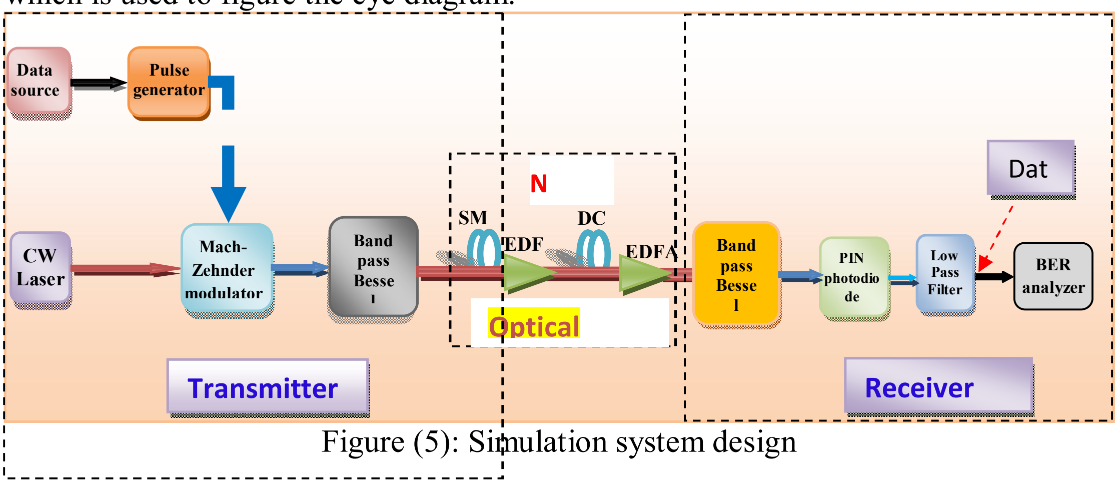


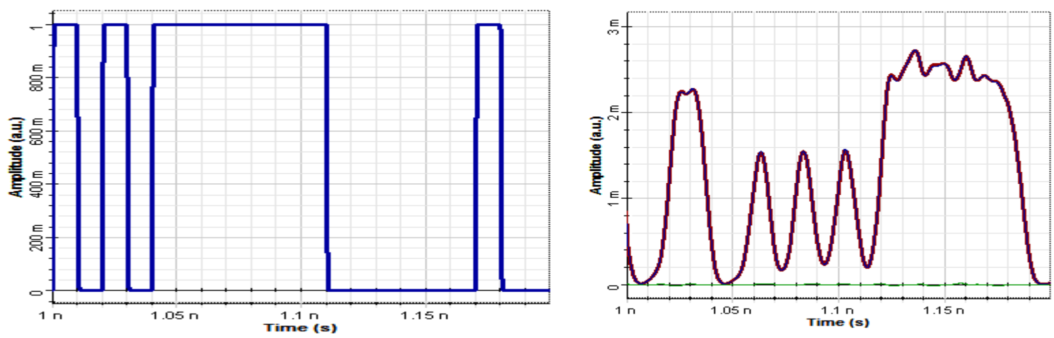
Figure (5): Simulation system design

4. Simulation results and discussions

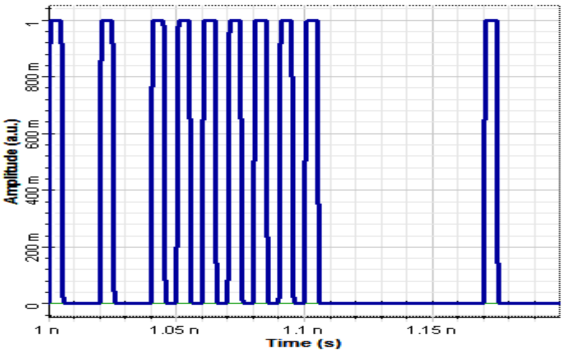
Four pulse shaping types are used based on the optical system design of Fig. 5. The waveform analyzed illustrates the pulse waveform of different pulse shapes (see Fig.6). Figures from 6.a to 6.h represent the transmitting and receiving signal for all pulses used for 600km transmission distance. From these figures, it can be seen that the RC offered better response than other current pulse shapes. The RC has a little sensitivity to ISI in comparison to other pulse shaping which suffer from the pulse broadening due to the inter symbol interference phenomena. The receiving RC pulse wave form seems clearly and not distorted as shown in Fig 6.h. In the case of NRZ and Gaussian, the receiving pulses are so distorted which means that the both pulses have a high sensitivity to ISI in as in Fig 6.b and Fig 6.f respectively.

Table (1) Stander parameters of optical transmission system

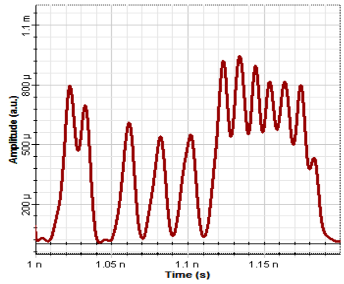
Parameter	unit	Values
Fiber length, L	km	50 for SMF and 10 for DCF
Number of span		10,12 and 14
Launch power, Pi	dBm	-10 to 4 dBm
Dispersion, Dc	ps/nm.km	16.8 for SMF and -80 for DCF
Cross effective area, Aeff	μm^2	80 for SMF and 22 for DCF
Third order Susceptibility, X_{111}	m^3/w.s	6×10^{-15}
Refractive index, n	-	1.48
Speed of light, c	(m/s)	3×10^8
Operating wavelength, λ	(nm)	1550
Attenuation factor,	(dB/ km)	0.2 for SMF and 0.5 for DCF
b, detector responsively	A/ W	0.8
Data Rate	Gb/s	100
Bandth Bessel Optical	GHz	150



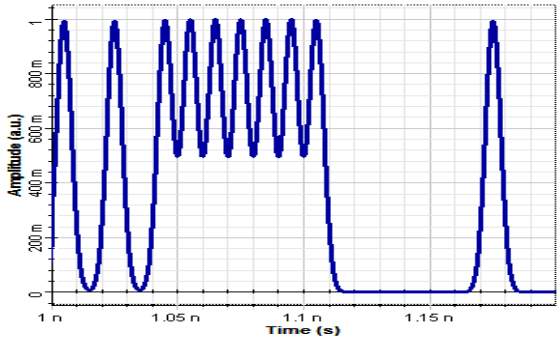
(a) (b)



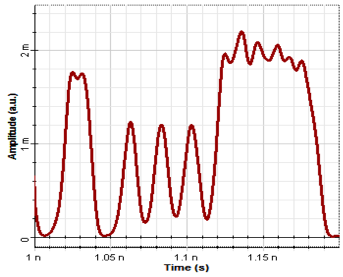
(c)



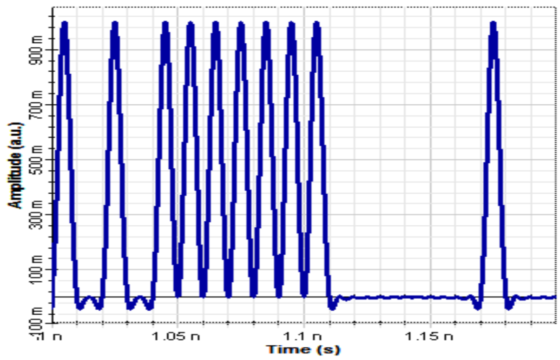
(d)



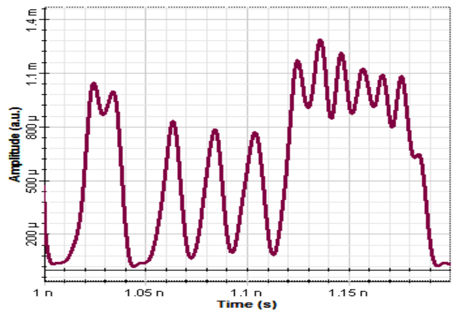
(e)



(f)



(g)



(h)

Figure (6): Time waveform of different pulse shape. a) NRZ transmitting. b) NRZ receiving. c) RZ transmitting. d) RZ receiving. e) Gaussian transmitting. f) Gaussian receiving. g) Raised Cosine transmitting. h) Raised Cosine receiving.

The simulation results were performed under the impact of three various transmission distances 500, 600 and 700 km which explains in cases (A, B, and C). In all cases, a variation in launch power between -10 dBm to 4 dBm was considered.

Case A: System performance of 500Km fiber length

The system performance in term of BER has been analyzed for variable launch power and different pulse shape. Moreover, the performance was figured and analyzed after transmission distance of 500 km. Fig. (7) shows the relationship between the BER and OSNR under Raised Cosine shape effect at different α values (0.5: 0.1:1). At 4dBm launch power, and at Roll of factor (α= 0.6), the BER was better compared to other (α) and it was 3×10^{-11} at OSNR of 21.8 dB, while for (α=1), the BER was 4×10^{-10} at OSNR of 20.7 dB. Here, it can be seen that for 500 km distance, the optimum Roll of factor was 0.6 which offers lower BER.

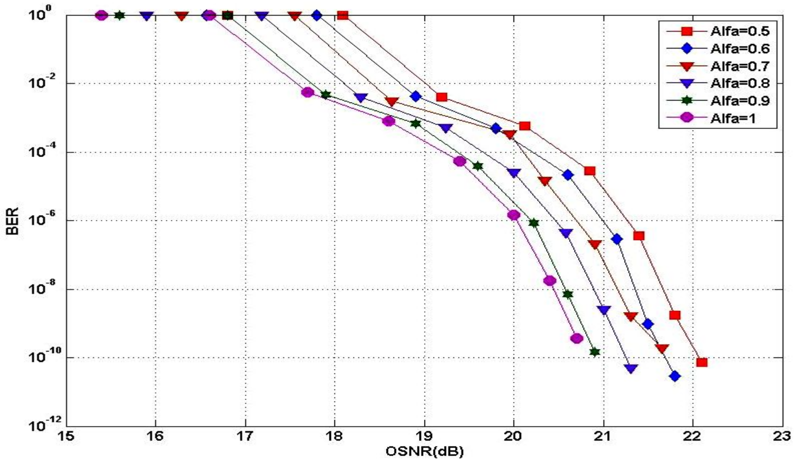


Figure (7): OSNR versus BER for different Roll of factor values

To confirm that at 500 km, the optimum Roll of factor was 0.6 that appears better performance, this factor is tested in term of RC with various pulse shapes as in shown Fig.(8) Observation of the results shows that the RC of (α= 0.6) gives best system performance than other pulse shapes. The RZ showed less system performance from raised Cosine where the BER was 6×10^{-10}. In the case of NRZ and Gaussian pulse, the performance was the worst case where the BERs were $2\times10^{-4}$and 3×10^{-5} respectively.

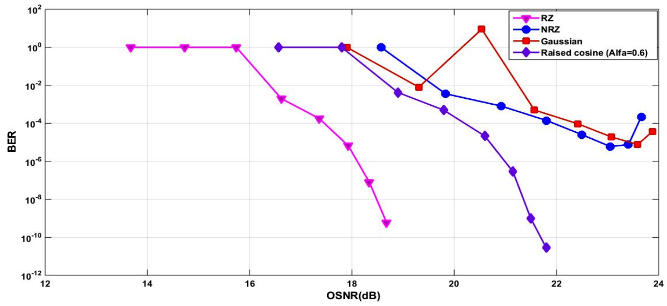
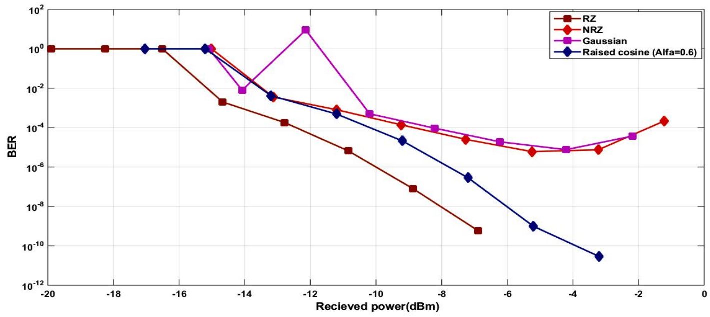


Figure (8): OSNR Versus BER for different pulse shaping types

Fig. (9) depicts the relationship between the received power and BER at the current pulse shaping shown. The results reveal that the raised cosine at received power -3.2 dBm, offered a BER of 3×10^{-11} while NRZ introduced at -1.21 dBm received power a worse value of BER and it was 2×10^{-4}. To explain this behavior, it can notice that the RC pulse more immunity to ISI than NRZ pulse.

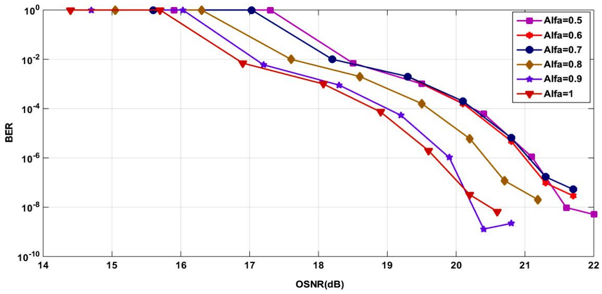


Figure(9): Received power Versus BER for different pulse shaping types

Case B: System performance of 600Km fiber length

According to the (Case A) finding, other investigation was considered using transmission distance of 600 km. The simulation system also was carryout with same assumption of transmission distance of 500 km and 100 Gb\s data rate. At 4dBm launch power, and at Roll of factor (α= 0.9), the BER was better compared to otherα, and it was 2×10^{-9} at OSNR of 20.8 dB, while for (α= 0.7), the BER was 5.5×10^{-8} at

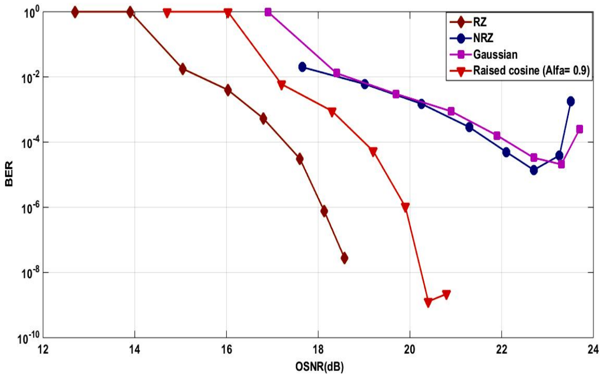
OSNR of 21.7 dB. Here, it can be seen that for 600 km distance, the roll of factor (α= 0.9) offered optimum BER as shown in Fig. (10).



Figure(10): OSNR versus BER for different Roll of factor values

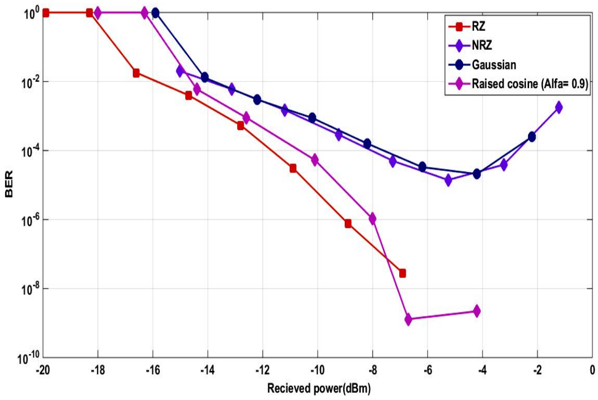
For the same procedure for 500 km distance, the optimum Roll of factor was 0.9; it is tested in term of RC with different pulse shape as in Fig. (11)

Fig. (11) shows also the relation between the BER and OSNR in the presence of various pulse shapes. It is clearly shown from the results that the RC of (α=0.9) presented best system performance to other pulse shape. As mentioned before, the RZ is still showed less system performance than RC where the BER was 2.8×10^{-8} at 18.5 dB of OSNR. Also the NRZ and Gaussian pulse, have the worst performance.



Figure(11): OSNR Versus BER for different pulse shaping types

Fig. (12) explains the relationship between the received power and BER for the available pulse shaping shown. The results displayed that the raised cosine at received power -4.2 dBm , offered BER of 2×10^{-9} while NRZ introduced at -3.7 dBm received power a worse value of BER and it was 1.8×10^{-3}. This means that at this launch power, the RC is more tolerant to the ISI than the NRZ and other pulse shape used.

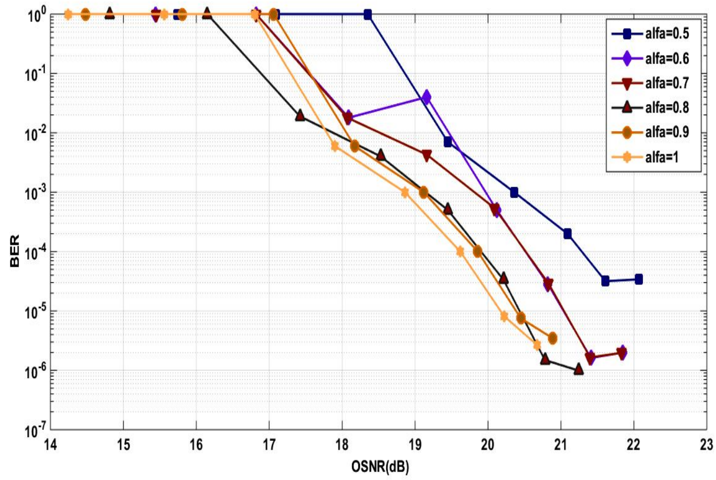


Figure(12): Received power Versus BER for different pulse shaping types

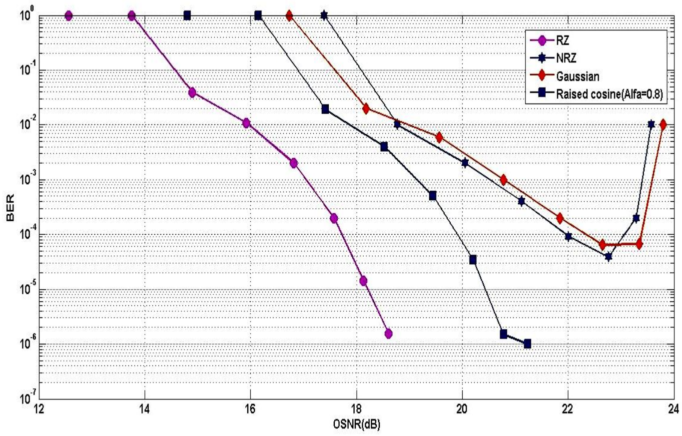
Case C: System performance of 700Km fiber length

As mentioned before the factor α strongly affects on the performance of the transmission distance and BER. Fig. (13) shows the relationship between the BER and OSNR under Raised Cosine shape effect at different α. It can be seen that the roll off factor which gives better BER (1.5×10^{-6}) is 0.8 compared with other factor values for transmission distance 700km.

By compare the raised cosine with roll off factor 0.8 and the other pulse shape as in Fig. (14). As seen from the figure the raised cosine shows better performance with respect to the other pulses. In addition, for the RZ showed less system performance from raised Cosine where the BER was 1.5×10^{-6} at 21.3 dB of OSNR. In the case of NRZ and Gaussian pulse, the worst performance was appearing, the BERs were 10^{-2} for both pulse at OSNR 23.5, 23.7dB respectively.

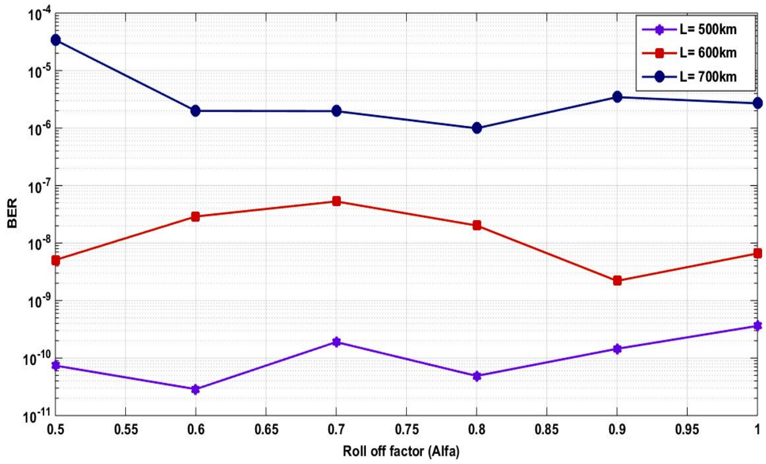


Figure(13): OSNR versus BER for different Roll of factor values



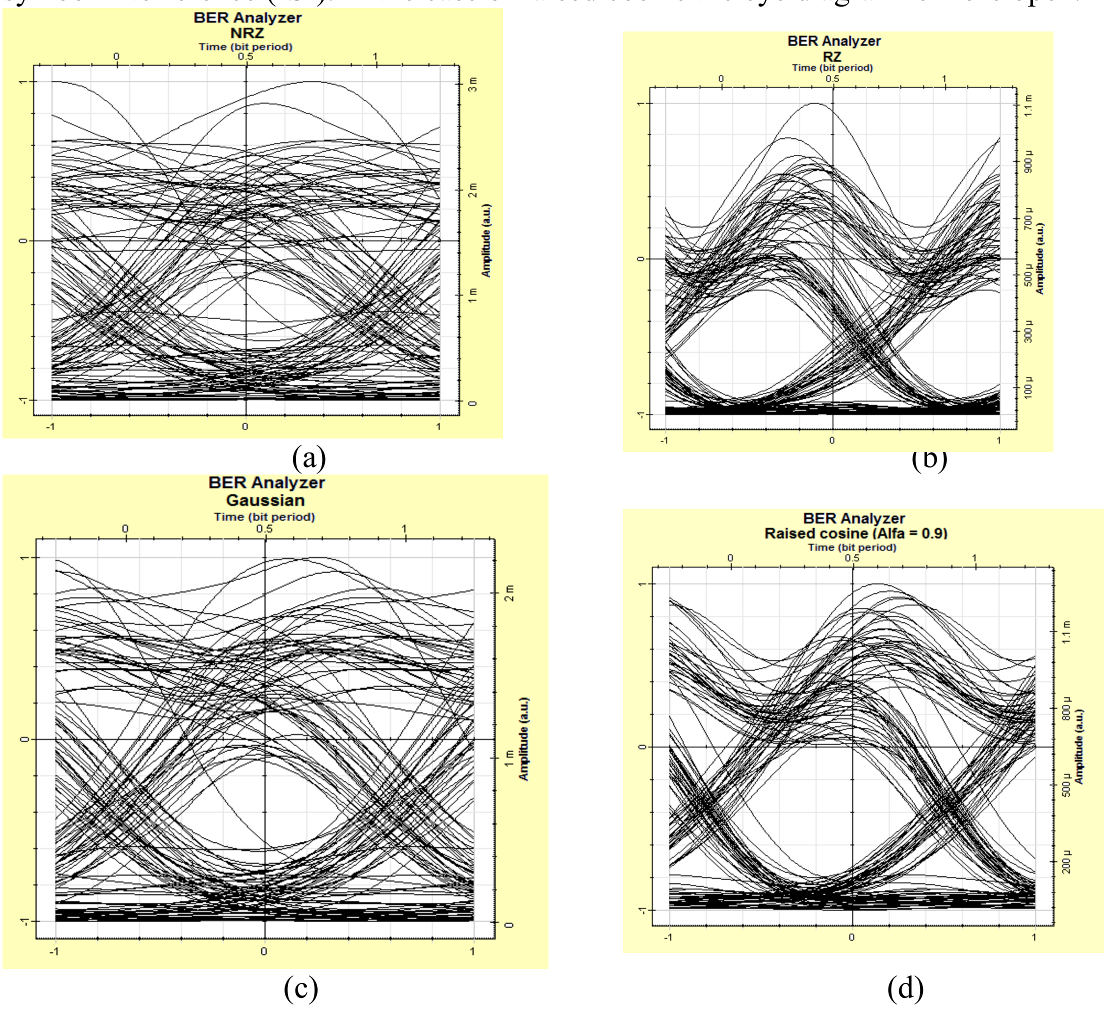
Figure(14): OSNR Versus BER for different pulse shaping types

Fig. (15) shows the relation between roll off factors for raised cosine and the BER with different distances. The effect of roll off factor on transmission performance is varied and depended on the transmission distance, such as for 500 km distance, the 0.6 factor gives minimum BER, for distance 600 km, the 0.9 factor appears best BER and for 700 km distance the best Roll of factor is 0.8.



Figure(15): Roll off factor versus BER for different transmission distances

Fig. (16) explains the eye diagrams of various signal over a distance of 600 km. The eye corresponding to the transmission using NRZ and Gaussian is more defaced than the eye diagram using Raised cosine because of the high value of inter symbol interference (ISI). In the case of raised cosine the eye diagram is more open.



Figure(16): Optimum Eye diagram performance of 600 km fiber length for different pulse shaping. a) NRZ. b) RZ. c) Gaussian. d) Raised cosine(Alfa=0.9)

5. Conclusion

An active and efficient approach for ISI suppression was simulated. In this work, a Realistic simulation was done to investigate the impact of various electrical pulse shapes such as NRZ, RZ, Gaussian and RC on transmission system performance at 100Gbit/s data rate. In addition, the effect of RC pulse shape on the system performance with various Roll of factor values (α) were investigated and compared for different transmission distances. The findings show that the RC pulse shape revealed better BER than other pulse shapes available with all transmission distances used. Moreover, the improvement in system performance differs from Roll of factor value to another and based on the transmission distance utilized. As, for 500 km transmission distance, the RC with α=0.6 showed better BER of 3×10^{-11} compared to other (α) at the same launch power . For 700 km, the RC with α=0.8 appeared better BER of 1.5×10^{-6}. Above all of that, it can conclude that the transmission system performance (distance and data rate) is more influenced by the pulse shaping of the electrical signal.

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