Simulation of High Speed and Long-Haul Optical Communication Systems

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Abstract

In high speed optical transmission system, three primary effects limit its speed and transmission distance. These effects are the fiber dispersion, fiber nonlinearities and amplified spontaneous emission (ASE) noise, the last one is introduce in optical amplification process along fiber length. Management of these fiber effects is the key for high bit rate and long haul transmission distance. In this work, methodologies of creating optical communication system is presented, an optical communication link is constructed and simulated, this includes; optical transmitter, the transmitter characteristics of fiber and optical receiver. The interplay effects among various fibers transmissions characteristic is studied and analyze. Results show that and in term of optical amplifier spacing, and for 40Gbps system speed, the system performance degrade obviously at 20km amplifier spacing, this results from that the interaction between amplifier noise and fiber nonlinearity along 20km is enough to degrade system performance. Any increasing of amplifier spacing above 90km, the system performance degrades gradually and the dominant limiting factor is the ASE noise. Using post-compensation dispersion map, non-return to zero (NRZ) signal format and setting optical system parameters to optimal values, makes the optical system capable of transmitting 40Gbps over 1060km of standard single mode fiber length, with 1.2×10^{-12} bit error rate.

Keywords: Modeling of optical communication systems, dispersion and non-linear effect of fiber optic channel, dispersion managements.

الخلاصة

في أنظمة الاتصالات الضوئية ذات السرعة العالية توجد ثلاث مؤثرات أساسية تؤثر في تحديد سرعة هذه الأنظمة ومسافات الإرسال لها. هذه المؤثرات هي ظاهره تقرح الألياف الضوئية و الخواص الغير خطية لها كذاك تأثير الضوضاء المكبرة والتي تنتج من استخدام المكبرات الضوئية على طول مسافة الإرسال. إدارة هذه المؤثرات هو مفتاح الأنظمة السريعة والتي ترسل لمسافات بعيدة. تم في هذا العمل استعراض أساليب لنمذجة نظام اتصالات ضوئي. حيث تم محاكاة هذه الأنظمة والتي تتضمن المرسل الضوئي خواص قناة الإرسال كذلك المستلم الضوئي. من خلال هذه المحاكاة تم تحليل ودراسة مؤثرات الألياف الضوئية. النتائج أشارت وبخصوص اختيار موقع المكبرات الضوئية لنظام بسرعة 40Gbps إلى إن أداء هذه الأنظمة ينخفض بشكل ملحوظ بعد زيادة مواقع المكبرات الضوئية عن 20km. هذا الانخفاض بسبب إن مسافة 20km لموقع المكبرات تعطي مسافة كافية للتداخل ما بين الضوضاء المكبرة مع الخواص الغير خطية لألياف الضوئية والتي تحدد من أداء النظام. أي زيادة في موقع المكبرات بعد مسافة 90km سوف تقلل من أداء النظام تدريجيا ويصبح المؤثر الفعال هي الضوضاء المحفزة. باستخدام تصميم يعتمد على إدارة التقزح بشكل أولي وهيئة الإشارة الغير عائدة إلى الصفر واختيار أفضل قيم لمتغيرات النظام. تم الوصول إلى مسافة 1060km بسرعة نقل بيانات 40Gbps عند معدل خطا للبيانات مقداره 1.2×10^{-12}.

I. Introduction

The key for high speed optical communication system can be met by denser WDM channels and faster TDM channels. On this basis, there is always interest in maximizing speeds of single channel system for long haul transmission distance. In this contest several phenomena limit the transmission performance of long-haul optical transmission systems including fiber nonlinearities, dispersion, and noise [Govind, 2001] and [Ivan, 2005]. For long-haul systems the nonlinear refractive index can couple the signal with noise. In single channel system fiber Self-Phase Modulation (SPM) is dominant nonlinear fiber effect. This effect limits transmitter output power. Because of the degradation of receiver sensitivity due to the noise bandwidth in high speed systems, the power level margin is insufficient for long distance fiber loss. The introduction of optical fiber amplifier repeaters and optical power management along the fibers has dramatically increased the transmission distance. On the other hand fiber chromatic dispersion causes sever transmission waveform distortion in high speed systems and as a results puts limits on the transmission speed and distance. The limits depend on the installed fiber constant, transmission distance and system speed. Management of fiber dispersion can achieve by choosing optimal dispersion map. The technique (known as dispersion mapping [Govind, 2005]) has been used in both single channel systems to reduce nonlinear interaction between signal and noise, as well as in WDM systems. There is a trend in most of the new long-haul systems to be loss-limited. This limitation can be drastically reduced by the use of in-line optical amplifiers, specially erbium doped fiber amplifiers (EDFA’s), allowing long-haul systems to increase their capacity. In other word, optical amplifiers also introduce noise in the system [E. Desurvire, 1994]. The main source of noise in these devices is the amplified spontaneous emission (ASE) noise. Noise accumulation in long amplifier chains reduces the optical signal-to-noise ratio (SNR) and can cause serious impairments to system performance [C. R. Giles, 1991] and [Dietrich, 1999]. It is necessary, then, to investigate the effectiveness of the use of EDFA chains to reduce the loss limitation of system capacity. As system complexity increases, careful design becomes a difficult issue. Using simulation tools can make the design process more efficient, as well as faster and cheaper.

In this work, the performance assessment of 40Gbps system is investigated. An optical communication system is simulated including optical transmitter, transmission characteristics of fiber channel and optical receiver. The interplay effects of fiber dispersion and transmission nonlinearities, as well as the accumulation effects of ASE noise are studied. By setting optical system parameters to optimal value and proper managed fiber effects, an investigation is made to reach longer transmission distance at 40Gbps bit rate with reliable bit error rate.

II. Modeling of Optical Communication System

Computer modeling of the physical optical communication system is a difficult task, due to the large number of system components [Ivan, 2003]. In addition, for the evaluation of the end-to-end system performance, it is necessary to take into account the impact of several transmission impairments, e.g., chromatic dispersion, fiber nonlinearities, amplified spontaneous emission (ASE) noise accumulation, crosstalk, polarization-dependent loss, polarization-mode dispersion (PMD), signal distortion due to filtering, reflections, and so forth. Because of the complexity of the problem, the choice of an adequate computer representation of optical signals and system components is essential. A block diagram of the lightwave system considered is illustrated in Fig. 1. The generated sequence denotes the data values, which are considered independent and identically distributed. The system is represented by models suitable for computer aided analysis.

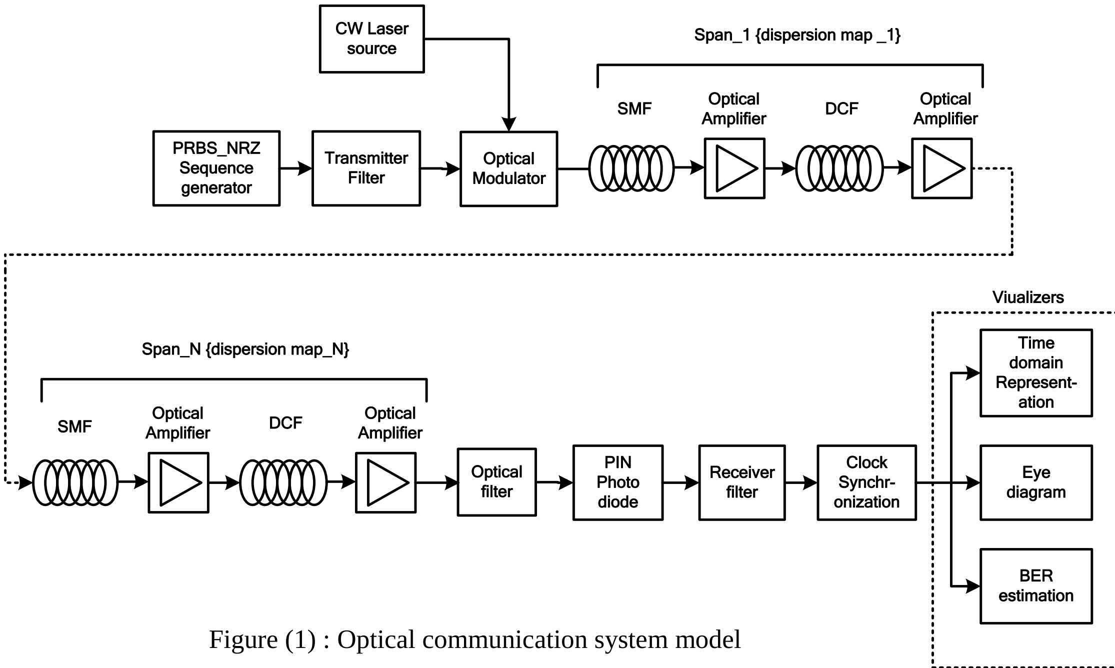


Figure (1) : Optical communication system model

To increase computational efficiency it can assume the waveform over the modeled interval (within a block) is representative of a periodic waveform identical to repeating the interval over and over again. This is called stationary analysis, and allows efficient fast Fourier transform techniques to be used. It also means that data delayed to outside the modeled interval is not lost, but is wrapped around to the beginning of the block. This section presents models, used to describe the optical transmitter, the transmission characteristics of the fiber and the receiver. The detailed of the modeling blocks is explained briefly in this section as follows:

1- Pseudo random binary sequence Generator: A pseudo random binary sequence (PRBS) is usually required when modeling the information source in simulations of digital communication systems. The binary sequence can be generated with the use of a random generator, or, alternatively, can be directly specified or read from a specified file. The PRBS module produces a sequence of N bits (Time Window/Bit Rate) with the numbers m and n of zero bits (spaces) preceding and succeeding the generated bit sequence of length $N\text{-}m\text{-}n$ .The number m and n are used to make the total number of samples always of form 2^k, where k is positive integer, this can reduce the efforts in calculation of Fast Fourier Transform (FFT). The generated bits is encode with an electrical Non Return to Zero (NRZ) coded signal. A NRZ pulse has a single value over the entire bit length, i.e., the “1” is coded by a high level with non-zero amplitude and the “0” by a low level with zero amplitude.

2- Transmitter Filter: This module is used to generate pulses with a pre-defined rise time,suitable for transmission along fiber channel. An electrical rectangular NRZ/RZ preshaped input pulse with pulse duration T is filtered by a linear time-invariant filter with a normalized Gaussian shaped transfer function:

$$H(\omega) = \sqrt{T_o}\, e^{-T_O{}^2 \omega^2 / 4} \qquad \ldots 1$$

Where T_o denotes the *1/e* pulse duration and ω is the angular frequency [Virtual Photonic, 1999].

3- Continuous Wave Laser : The module produces a time dependent field $E_b(t)$, which is normalized to the user specified power P_{ave}. The laser model contains a Gaussian white noise with a variance of $2\pi\Delta f$ corresponding to the optical laser Line width Δf. The output is multiplied with a complex vector considering the state of polarization (SOP). The baseband signal of the optical output CW-wave is therefore determined by

$$E_b(t) = \sqrt{P}\begin{pmatrix}\sqrt{1-K}\\ \sqrt{K}e^{j\delta}\end{pmatrix}.exp(\, j\int \omega(\tau)d\tau.) \qquad \ldots 2$$

Where $\omega(\tau)$ is a Gaussian white noise with variance $2\pi\Delta f$ .The SOP is given by the power splitting parameter K $(0 \le K \le 1)$ and an additional phase δ [Virtual Photonic, 1999]..

4- Optical Modulator: The purposed of the optical modulator is to convert time dependent signal from electrical domain to optical domain with carrier frequency specified by CW-laser source. The optical power P_{out} at the output of Mach-Zehnder Modulator (MZM; is one types of external optical modulators), depends on the phase difference $\Delta\Phi$ between the two modulator branches

$$P_{out}(t) = P_{in}(t)\ \mathrm{d(t)} = \mathrm{P_{in}}(t)\cos^2[\,\Delta\Phi(t)] \qquad \ldots 3$$

$$\Delta\Phi = \frac{\pi}{2}\left(\frac{1}{2} - ext.\left(data(t) - \frac{1}{2}\right)\right)\ \text{with ext} = 1 - \frac{4}{\pi}arctan(1/(\sqrt{\varepsilon}\,))) \qquad \ldots 4$$

Where $d(t)$ is the power transfer function, ε is the power extinction ratio and $\Delta\Phi(t)$ is the phase difference on the electrical input data signal *data(t)* caused by the applied modulation signal data. The electrical field of the output signal can be finally written as [Gerhard, 1996]:

$$E_{out}(t) = \mathrm{E_{in}}(t)\sqrt{\mathrm{d(t)}}\ .\mathrm{e}^{\mathrm{j}\Delta\Phi(\mathrm{t})} \qquad \ldots 5$$

5- Fiber Optic Channel: The module solves the nonlinear Schrödinger (NLS) equation describing the propagation of linearly polarized optical waves in fiber using the split-step Fourier method. The model take into account stimulated Raman scattering (SRS), four-wave mixing (FWM), self-phase modulation (SPM), cross-phase modulation (XPM), first order group-velocity dispersion (GVD), second order GVD and attenuation of the fiber.

Assuming a propagation of optical signals in +z direction and a symmetrical split step algorithm, the mathematical formalism of the procedure can be described according to [Govind, 2001] as follows:

$$E(z_0 + \Delta z, t) = exp\left(\Delta z.\frac{D}{2}\right)[exp(\Delta z N)E(z_0, t))]\,exp\left(\Delta z.\frac{D}{2}\right) \qquad \ldots 6$$

$$\text{where } \mathrm{D} = j\frac{\beta_2}{2}\frac{\partial^2}{\partial t^2} + \frac{\beta_3}{6}\frac{\partial^2}{\partial t^3} + \frac{\alpha}{2} \quad \text{with } \beta_2 = -\frac{\lambda^2}{2\pi c}D_\lambda \ \text{ and } \beta_3 = \frac{\lambda^2}{(2\pi c)^2}(\lambda^2 S_\lambda + 2\lambda D_\lambda)$$

$$N = -j\gamma|E(z,t)|^2 \quad \text{with } \gamma = \frac{2\pi n_2 f_{ref}}{cA_{eff}}$$

Where D is the dispersion operator, N is the nonlinearty operator, β_2 describes the first order Group Velocity Dispersion (GVD), β_3 is the second order GVD , α is the attenuation constant, D_λ is dispersion parameter , S_λ is the dispersion slope, n_2 is the nonlinear index, A_{eff} is the effective core area , f_{fre} is the reference frequency and c is velocity of light in vacuum. The step size in the symmetrical split step algorithm,

$$\Delta z_\phi = \frac{\Delta\phi}{\gamma \left|E(z)\right|_{pk}^{2}} \qquad \ldots 7$$

is determined by a maximum acceptable phase shift $\Delta\phi$ with peak value of optical power $\left|E(z)\right|_{pk}^{2}$

6- Dispersion Map: There are three possible schemes for managing dispersion in long-haul fiber links. In each case, the accumulated dispersion is balance using special fiber type have negative dispersion value called Dispersion Compensation Fiber (DCF). In the first configuration, known as precompensation, the dispersion accumulated over the entire link is compensated at the transmitter end. In the second configuration, known as postcompensation, a DCF of appropriate length is placed at the receiver end. In the third configuration, known as symmetrical dispersion compensation, dispersion is compensated using pre- and post- dispersion compensation in a periodic fashion all along the link. Each of these configurations is referred to as a dispersion map, as it provides a visual map of dispersion variations along the link length. One can construct a variety of dispersion maps by combining several different fibers.

7- Optical Amplifier: In this module the signal is amplified by a gain and then the amplified spontaneous emission (ASE) noise is added. Sometimes an ideal optical filter is placed after each amplifier in order to reduce ASE effect, and the optical isolator avoids the effect of ASE back propagation. As long as only single channel systems are considered, gain and ASE spectra are assumed to be uniform inside the optical filter bandwidth. The ASE power after the optical filter is [Rodolfo, 1997]:

$$P_{ASE} = \eta_{sp}(G-1)h v_s B_o \qquad \ldots 8$$

Where $\eta_{sp} = FG - 1/2(G-1)$ is the amplifier spontaneous emission factor, v_s is the optical frequency of the signal carrier, G is the gain of optical amplifier, h is the Blank constant and B_o is the optical filter bandwidth. The time domain optical field envelope can computed as;

$$E_{out}(t) = \sqrt{G} E_{in}(t) + \sqrt{G_{ASE}(t)} \qquad \ldots 9$$

Where $G_{ASE}(t)$ is Gaussian distribution random variable with zero mean value and P_{ASE} variance.

8- PIN Photodiode: The module converts the incident optical field into an electrical signal. The combined optical field $E(t)$ is then converted into an optical power $P_s(t)$ by taking its modulus squared, and converting to an electrical signal, the process of converting the optical intensity into an electrical current is described by [Gerd, 2002]

$$i(t) = i_s(t) + n_{sh}(t) + n_{th}(t) + i_d \qquad \ldots 10$$

Where $i_s(t)$ is the output current is directly related to the absorbed optical power $P_s(t)$ by $i_s(t) = r.\ P_s(t)$, where r is responsively of photo-diode. $n_{sh}(t)$ denotes the generated Shot

Noise current with the one sided spectral noise density N_{sh} in $A/\sqrt{Hz}$. The spectral density is determined by $N_{sh} = 2q(i_s + i_d)$, $n_{th}(t)$ represents the thermal noise caused by the (usually high) photo-detector's internal resistance. The associated one-sided spectral noise density N_{th} has to be specified in $A/\sqrt{Hz}$ and i_d denotes the PIN dark current.

9- Receiver Filter : An analog fourth order Bessel filter realizes the minimal phase system (linear phase). Therefore, preservation of wave shape of the filtered signal in the passband can be achieved. The transfer function of the filter is described by [Virtual Photonic, 1999].:

$$H(p) = \frac{(105 + 105p + 45p^2 + 10p^3 + p^4)}{105} \quad \text{with} \quad p = \frac{jf}{f_{3dB}} \qquad \ldots 11$$

Where f_{3dB} is the 3dB Cutoff Frequency. This filter is also used to implement in line optical filter with optical filter bandwidth B_o. The function of the optical filter is to remove out of band ASE noise.

10- Clock Recovery: This block synchronizes the incoming electrical signal with the original transmitted signal. The original signal is regenerated from the specified logical information channel attached to the physical signal. From logical information, like the digital bit stream, pulse shape, coding type, modulation type, and bit rate, a copy of the initially sent signal is built. The time delay is calculated from the cross correlation of the incoming electrical signal and the internally regenerated original signal. The incoming signal is then shifted in time, so that the electrical output signal is a time delayed copy of the incoming signal.

11- Visualizers: Visualizers are used to display, measure and processing optical and electrical signal by taped a small quantity of the transmitted signal at any point a long optical communication system such as signal time domain visualization, eye diagram evolution, and bit error rate estimation. Most numerical models investigate a short bit stream in order to avoid excessive computational time. With a few bits it essential to make some assumption about the noise distribution. A bit error estimation assuming a Gaussian noise distribution on both the one and zero levels can compute as follow [Virtual Photonic, 1999].:

$$BER = \frac{p_1}{2(p_0 + p_1)} erfc\left(\frac{|\mu_1 - th|}{\sqrt{2}\sigma_1}\right) + \frac{p_0}{2(p_0 + p_1)} erfc\left(\frac{|\mu_0 - th|}{\sqrt{2}\sigma_0}\right) \qquad \ldots 12$$

Where th is the decision threshold, p_1 and p_0 are the source digital probabilities of zeros and ones, respectively, and $erfc(x)$ denotes the complementary error function. μ_1, μ_0 are the mean values for the ones and zeros, respectively and σ_1, σ_0 are the standard deviation of the ones and zeros, respectively. The optimum value of the decision threshold minimizing the bit error rate is calculated according to

$$\frac{1}{\sigma_0} exp\left(-\frac{(th - \mu_0)}{2\sigma_0^2}\right) = \frac{1}{\sigma_1} exp\left(-\frac{(th - \mu_1^2)}{2\sigma_1^2}\right) \qquad \ldots 13$$

figure (2) shows the flowchart of the optical communication system simulation, in this work Matlab_7.4 language is used to implement this algorithm.

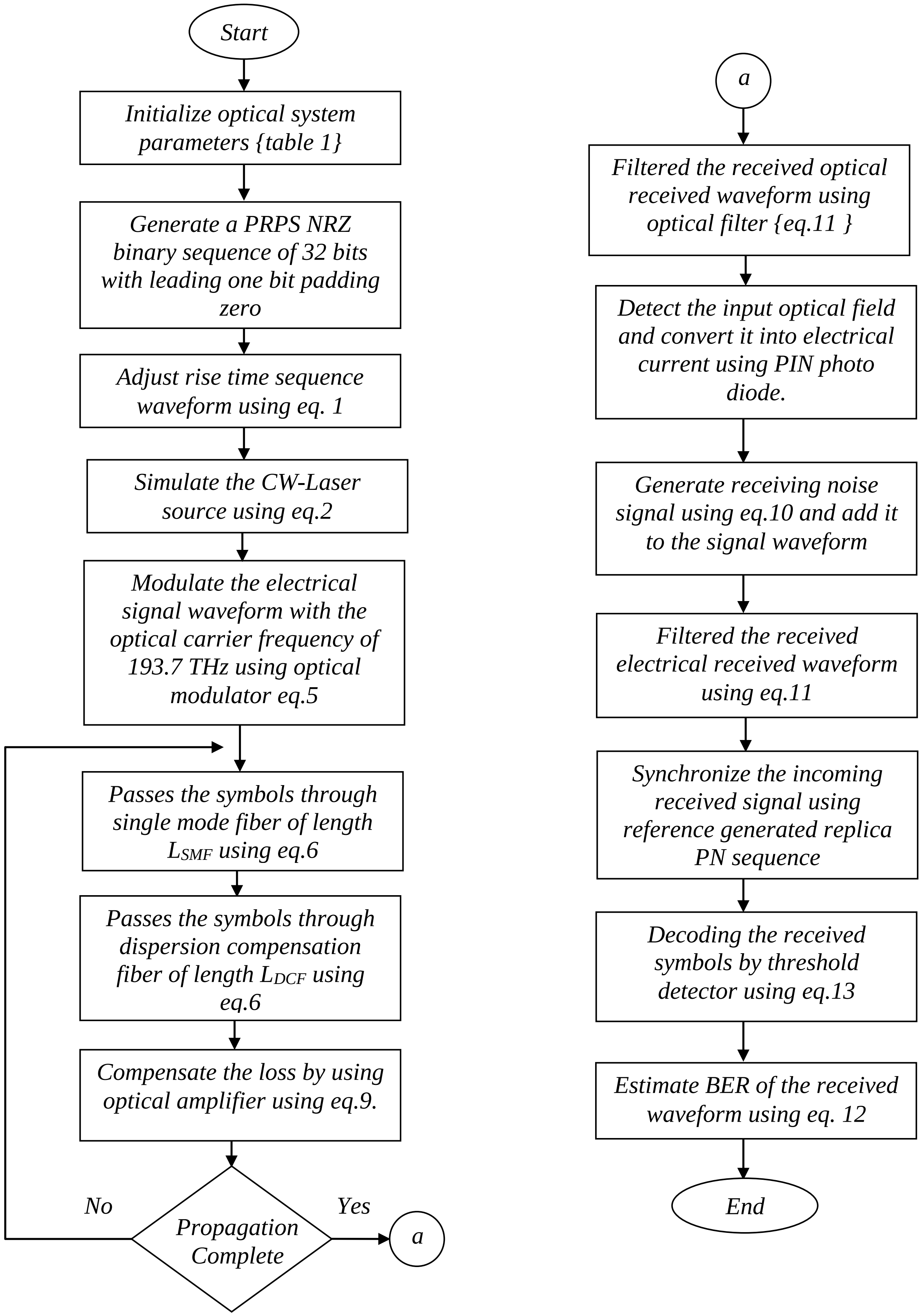


Figure (2) Flow Chart of the Optical Communication System simulation

IV. Results

In this section, 40Gbps optical system is assist in term of computer simulation, the steps of generating and receiving bit sequence as well as typical system parameter values {table (1)} are summarized as following. The input to the optical transmitter is a pseudo-random sequence of electrical pulses, representing 1 and 0 bits. The length N of the pseudo-random bit sequence determines the computing time and should be chosen judiciously. Typically, $N = 2^{k}$', where k is in the range of 5 to 10, in this work we choose $N=32$. A different set of equations governing the dynamics of an external modulator is used to convert the CW laser light into an optical bit stream. Deformation of the optical bit stream during its transmission through the optical fiber is calculated by solving the Non-Linear Schrödinger (NLS) equation. The method most commonly used for solving this equation is known as the spit-step Fourier method. ASE noise added to the signal at the location of each amplifier through. After adding noise at each amplifier, the NLS equation is solved in the following fiber section, and the procedure is repeated until the last amplifier is reached. A suitable receiver model converts optical signal into the electric domain and filters it using a filter whose bandwidth B_e is close to but smaller than the bit rate B (typically B_e/B = 0.6-0.8). The resulting electric bit stream is used to find the instantaneous values of currents, for 0 and 1 bits, respectively, by sampling it at the center of each bit slot. An eye diagram is also constructed using the filtered bit stream. The system performance is quantified through the BER. The calculation of the BER requires that the NLS equation be solved a large number of times with different seeds for the amplifier noise. Such an approach can be used to investigate trade-offs that would optimize overall system performance.

The simulation of the transmission is characterized by a large number of different parameters, most of which did not change from simulation to other. For competence a list of typical parameters set below, and mention deviations from these unless whenever they occur.

Table 1: Simulation Optical System Parameter

System parameter	symbol	value	unit
Bit rate	B	*40*	*Gbps, NRZ*
Number of bit per word	2^k	*32 (k=5)*	*bits*
wavelength	λ	*1.550*	μm
Sample rate	f_s	*32*	*Per bit*
Optical laser power	P	*1*	*mW*
Laser line width	Δf	*10*	*MHz*
Power splitting parameter	k	*0.5*	---
Additional phase shift	δ	*0*	*rad*
Extinction ratio	ε	*30*	*dB*
Fiber attenuation	a (SMF)	*0.2e-3*	*dBm*
Dispersion coefficient	D_λ (SMF)	*16e-6*	s/m^2
Dispersion slope	S_λ (SMF)	*0.08e3*	s/m^3
Nonlinear refractive index	n_2 (SMF)	*2.6e-20*	m^2/W
Effective core area	A_{eff} (SMF)	*80e-12*	m^2
Fiber attenuation	a (DCF)	*0.6e-3*	*dBm*

Dispersion coefficient	D_λ (DCF)	-90e-6	s/m^2
Dispersion slope	S_λ (DCF)	0.21e3	s/m^3
Nonlinear refractive index	n_2 (DCF)	4e-20	m^2/W
Effective core area	A_{eff} (DCF)	30e-12	m^2
Amplifier noise figure	NF	4	dB
Optical Bessel filter bandwidth	B_o	$12\times$ bit rate	Hz
Order of in line optical filter	---	4	---
Responsively of PIN photo diode	r	1	A/W
Thermal noise	N_{th}	10e-12	$A/\sqrt{Hz}$
Shot noise	N_{sh}	$N_{sh}=2q(i_s+i_d)$	$A/\sqrt{Hz}$
Dark current	i_d	0	A
electrical Bessel filter bandwidth	B_e	$0.8\times$ bit rate	Hz
Order of receiver electrical filter	---	4	---

Two standard assessment methodologies are used in this work. The first is the eye opening of the received waveform and the second is the bit error rate, which give us an evolution of satisfactory operation of the system. The bit error rate calculation is based on Gaussian approximation of the received word, where the decision threshold is set to optimum value. Another figure of merit is the Q-factor, which is defined as the differences between the average levels of the pulses and spaces divided by the sum of their standard deviations. However the information gained from Q-factor is less important than bit error rate value, hence it not used in this work.

Figure (3) shows the evolution performance of 40Gbps in term of fiber length in km as a function of bit error rate is studied. It clearly that, the performance .i.e. bit error rate degrade severely as fiber length increase above 5km (BER=1.32e-11 at 5km). This results from accumulation effects of chromatic dispersion and fiber non-linearities along fiber length, especially at 10 km length. The detailed received signal waveform and eye diagram as well as bit error rate is shown in figure (4) and figure (5) for fiber length of 5km and 10km respectively. It noted that from figure (5) that the eye diagram is destroyed completely and the signal waveform is disperse severely due to fiber nonlinear effect, which become more deleterious effect at high system ~40Gbps. It noted from figure (5a) that some pulses in the transmitted waveform remain unchanged, while other spread out. The reason behind this effect is that these unaltered pulses with high peak amplitude satisfy the condition of soliton pulses shape. This type of pulse can travel over long distance without altering its shape.

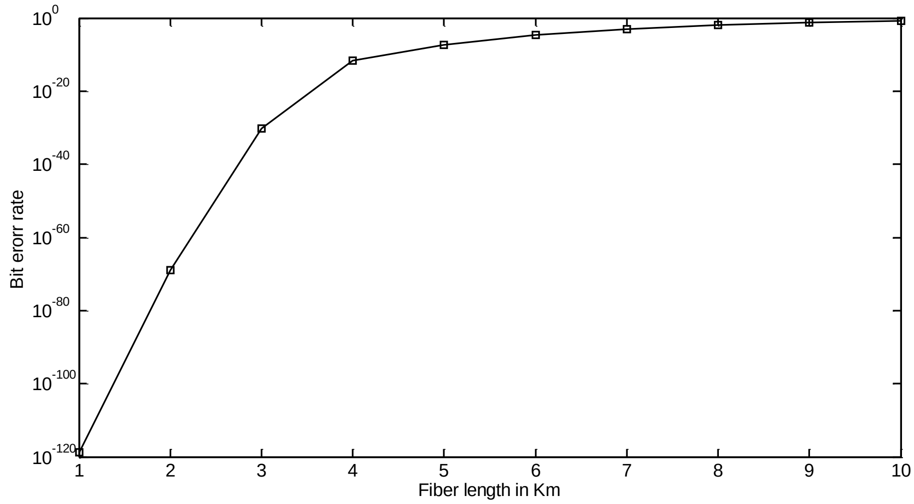
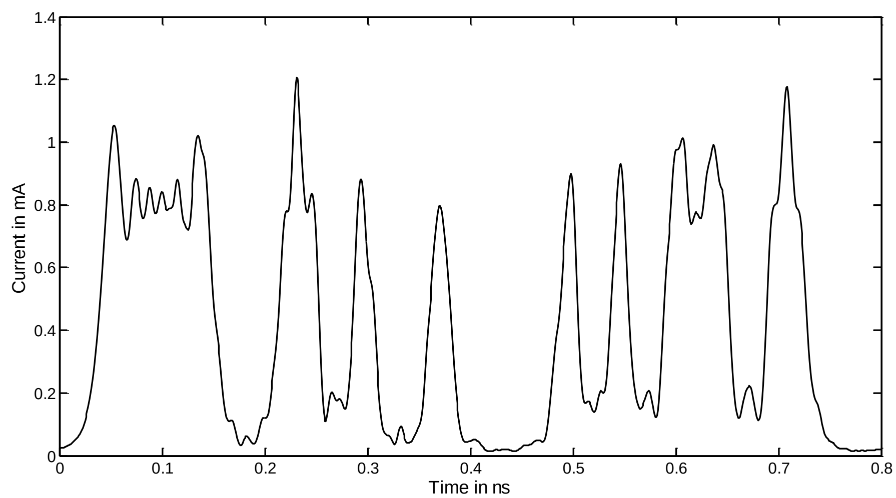


Figure (3): Single Mode Fiber length in km against bit error rate for 40Gbps bit rate.

(a)



(b)

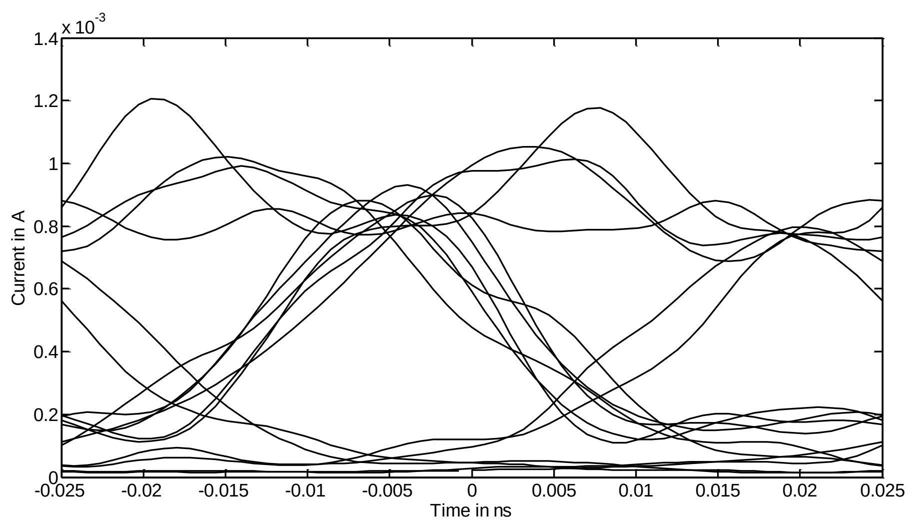


Figure (4): a) Received sequence, b) eye diagram . For 5km fiber length, the measured bit error rate is 1.32×10^{-11}

(a)

(b)

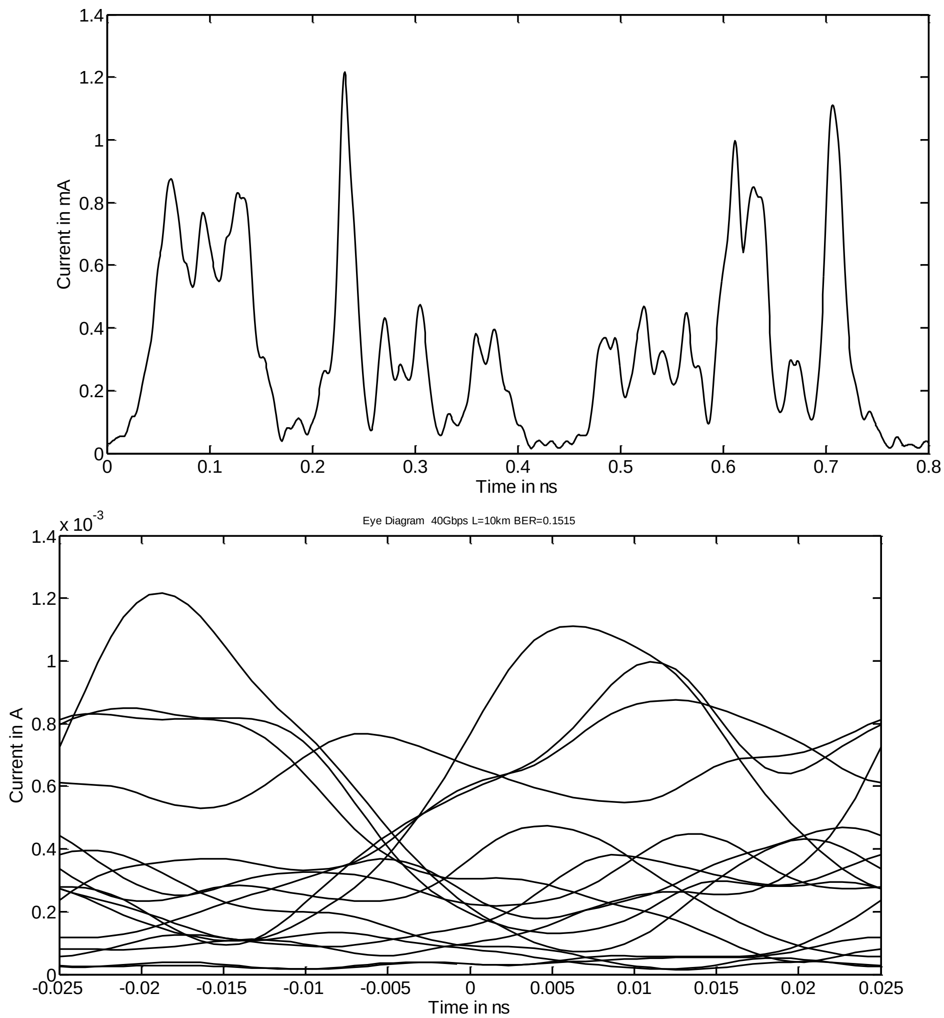
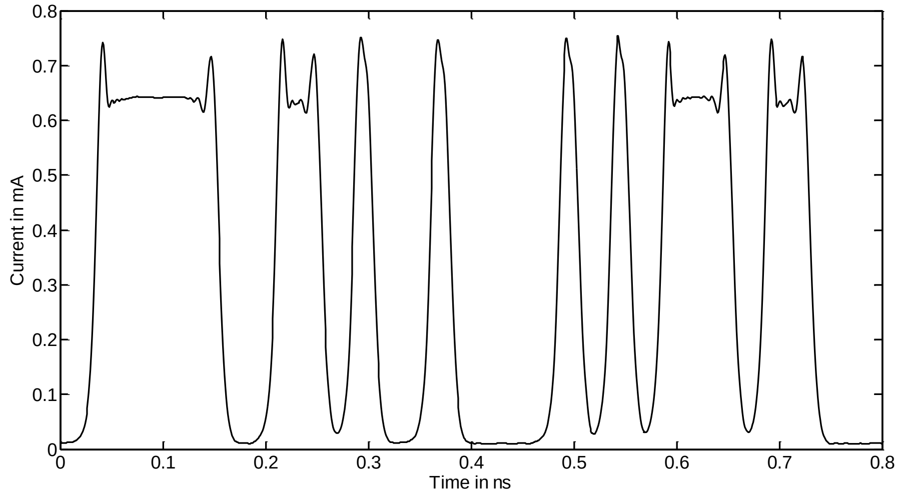


Figure (5): a) Received sequence, b) eye diagram. For 10km fiber length, the measured bit error rate is 0.1515

From the previous discussion, the transmitted optical pulses at 40Gbps are spread out after few kilometer of fiber length. Hence some form of dispersion compensation must apply to increase transmission distance. We first apply the dispersion map for 10km fiber length, to investage the improvement of using dispersion compensation fiber in dispersion management of optical system. Figure (6) shows the transmitted waveform and eye diagram of 10km dispersion managed single mode fiber. The bit error rate is minimizing from 0.1515 in SMF alone to 6.92×10^{-60} in case of dispersion managed section.

(a)


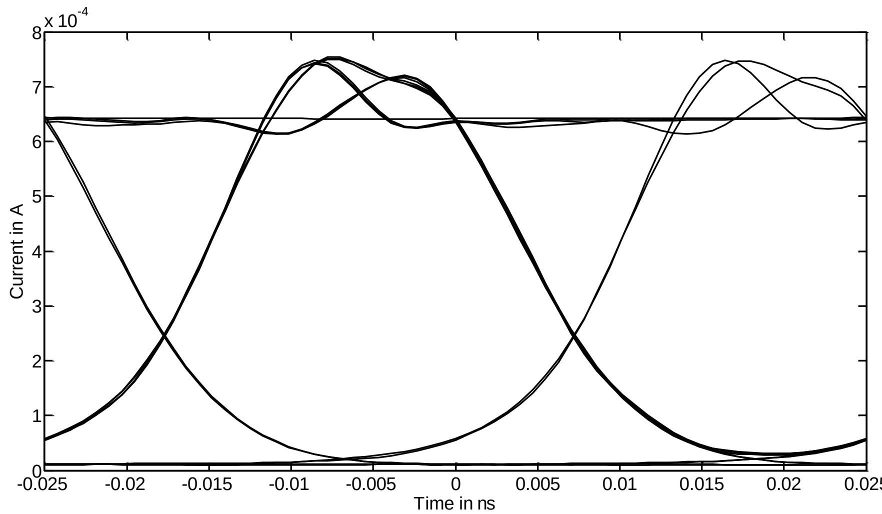
(b)


Figure (6): a) Received sequence, b) eye diagram. For 10km fiber length, dispersion managed using DCF, the measured bit error rate is 6.928×10^{-60}

In optimization of 40Gbps optical system, many system parameters must be set carefully. Among these parameter is the modulation format, adjustment of rise time signal, optimum lunched optical signal power, designing optimal dispersion map including setting optimum amplifier spacing using in line optical filter with appropriate bandwidth. This filter is used to remove out of band ASE optical amplifier noise. At receiver side, setting bandwidth of the electrical receiver filter is an important parameter in optimizing system performance that is help in removing out of band receiver noise (shot and thermal noises). The most key parameters that can be used in optimizing long haul 40Gbps optical system, is the optimum lunching optical power and choosing the optical amplifier spacing.

In this section, the effect of these two parameters is studied in term of computer simulation. Amplifiers not only added ASE noise to the signal but also allow the dispersive and nonlinear effects to accumulate over long lengths. Moreover, amplifier noise required to increase the channel power to be equal or more than 1mW in order to maintain a high SNR (and a high S/N consistent with the BER requirements). Since noise limits the BER at low power levels whereas nonlinear effects limit it at high power levels, it is already known that a lightwave system would have the smallest value of BER at an optimum value of the average power launched into the fiber at the input end. So the interplay effects of optimum optical lunched power and optical amplifier spacing length is displayed in figure (7). Where the bit error rate is plotted as a function of optical amplifier (10km-30km) spacing for reaching distance of 120km fiber length, the lunched optical signal power is 1mW and post-dispersion compensation map design is used. It obvious that the performance of the system degrade as amplifier spacing increase. With the amplifier spacing of 10km, the measured bit error rate is very small value of 1×10^{-110}. As amplifier spacing increase the system performance decrease until reach 20km, where the system performance saturated at specified BER value until reaching 90km, since the interaction between ASE noise and fiber non-linearity take place over long transmission distance (20km). Any increasing above this value, ASE noise will become the limiting factor and destroyed the signal completely, this results from that the power level of the optical signal reach the level of ASE noise that degrade system performance severely

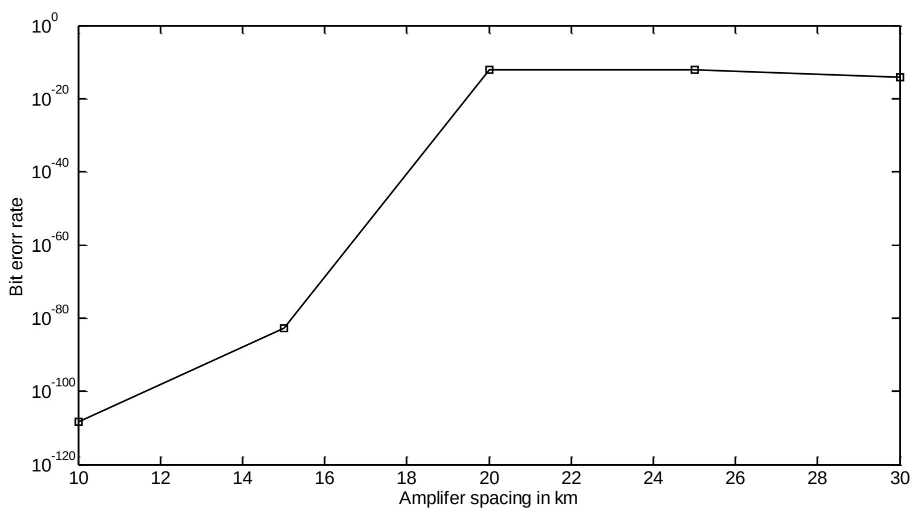


Figure (7): Amplifier spacing against bit error rate for reaching distance of 120 km.

Figure (8) shows the received bit sequence and eye diagram for single channel 40Gbps system bit rate at transmission distance of 1060km, where the post-dispersion compensation map design is used. The dispersion map consists of single mode fiber of length 90 km followed by DCF of length 16km for dispersion compensation. Choosing this length of fibers will diminished the residual dispersion effects. For each transmission section of fiber span, the overall attenuation is compensated at each section end, .i.e. the optical amplifier is placed at dispersion map end. This will prevent the interaction between amplifier noise and fiber dispersion. Bessel in line optical filter is used at fiber transmission end to remove out of band accumulated ASE noise. This procedure makes the optical system capable of transmitting 40Gbps NRZ data over 1060km of standard single mode fiber length, with 1.2×10^{-12} bit error rate. The summarized performance of optical system in term of fiber length as a function of bit error rate is shown in figure (9), again the reaching transmission distance is 1060km (compare with figure(3)). It clearly that the interaction between ASE noise and fiber nonlinearity that accumulate in long transmission distance, is the major limiting factor in long haul transmission optical system.

(a)

(b)

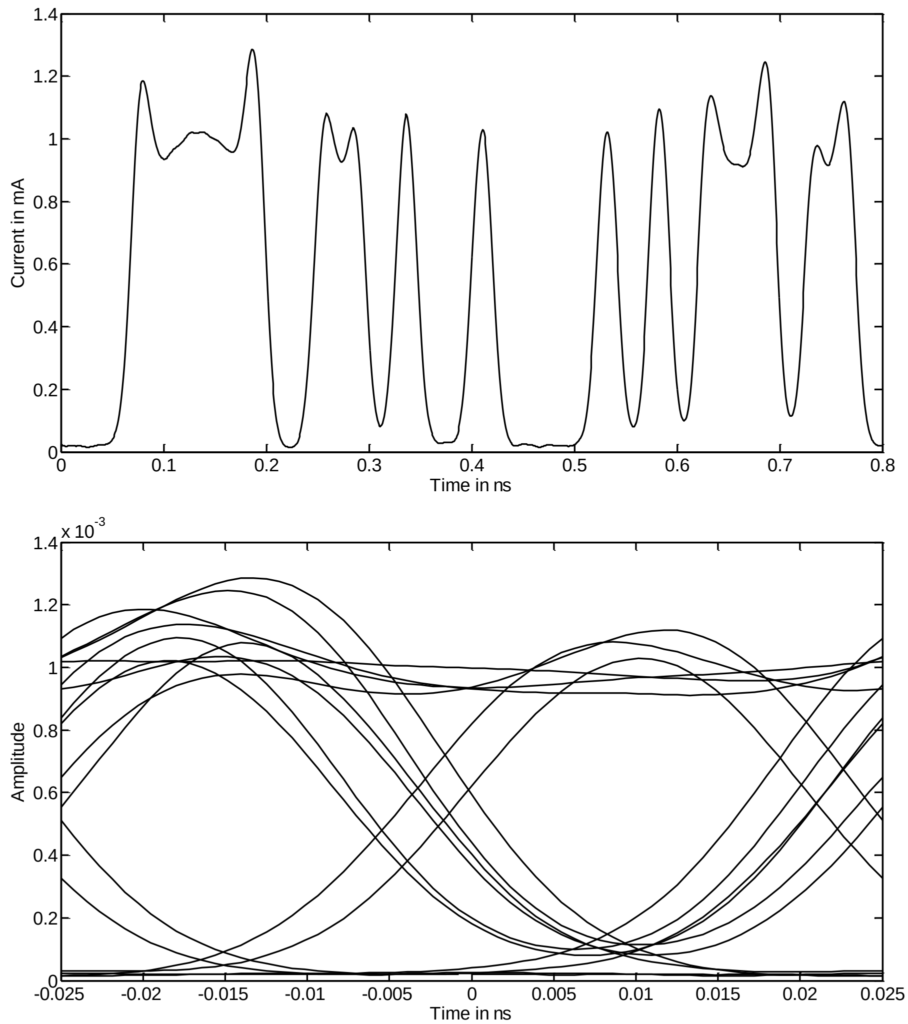


Figure (8): a) Received sequence, b) eye diagram . For 1060km fiber length, dispersion managed using post-dispersion compensation map, the measured bit error rate is 1.12×10^{-12}

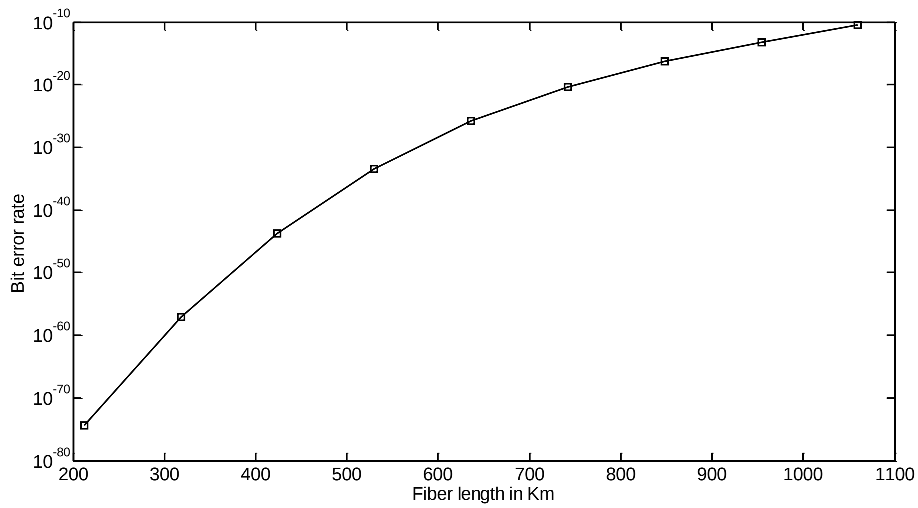


Figure (9): Fiber length in km against bit error rate for long haul optical system

V. Conclusions

In this paper, the behavior of single channel long-haul 40Gbps optical system is estimated using stationary analysis. A 32 bit non-return to zero pseudo random sequence is generated using PRPS module. The generated sequence is transmitted and checked at the output port of each element used along optical simulation link. An overview of simulation of optical link is described, includes configuration of optical transmitter, simulate signal propagation in fiber channel as well as optical receiver. Three optical transmission effects that limit system speed and transmission distance are studied, which are group velocity dispersion, fiber nonlinearity and the accumulation effects of ASE noise over long chain of optical amplifier. Numerical results show that for 40Gbps system speed, the interaction between amplifier noise and fiber nonlinearity along 20km is enough to degrade system performance. Any increasing of amplifier spacing above 90km, the system performance degrades gradually and the dominant limiting factor becomes the ASE noise. Using pre-compensation dispersion map, non-return to zero signal format and in line optical filter, the reaching transmission distance is 1060km at 40 Gbps, and the calculated bit error rate is 1.2×10^{-12}.

VI. References

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