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Original Research Article

Assessment of WDM Based RoF Passive Optical Network

Muhammad Towfiqur Rahman[1*], Roni Ahmed[2], Md. Kamal Hossain[2], Md. Asadul Haque[2], Raduyan Ahmed[2], Naznin Sultana[2], Md. Nasir Uddin[2]

[1]Department of Computer Science & Engineering, University of Asia Pacific (UAP)
[2]Department of Electrical and Electronics Engineering, Northern University Bangladesh

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***Corresponding author:** Muhammad Towfiqur Rahman
Department of Computer Science & Engineering, University of Asia Pacific (UAP)

Abstract

In this research, alternative Raman amplifier configuration were used in a wavelength division multiplexing (WDM)-passive optcal network (PON) system to investigate their effects on channel capacity and signal quality. Because of its scalability, energy efficiency, high capacity, low cost, and flexibility of data transfer ability, various Raman configurations are applied in different position to measure the output power. We used various techniques to evaluate the system performance such as varying the length of an optical fiber from 10 to 100 kms, number of users by increasing 8 to 16 channels. Various channel spacings are utilized in an 8 and 16 channels WDM system to calculate the system's bit error rate (BER) and signal-to-noise ratio (SNR). Another key concern is the high data rate and to achieve the maximum transmission speed. We get the maximum data rate of 128 Gb/s by 8 channels and 192 Gb/s by 16 channels. The maximum BER was $10^{-9}$and noise level was -6.35 dBm associated with the distance which was 70 kilometers long fiber channel. Finally, maximum data rate and its related eye diagrams was evaluated.

Keywords: passive optical network, Radio over fibre, WDM, Raman amplifier.

1. INTRODUCTION

Due to the growing number of internet users and the numerous requirements of huge data traffic in our daily lives. Bandwidth demand has been increasing enormously [1] for using social networking, IoT applications, online audio/video conferencing, live broadcasting, and e-health services. As a result, next-generation optical networks are expected to provide broad coverage, extended length, and high capacity to accommodate a huge number of users at high speeds [2]. WDM PONs should be able to deliver cost-effective scalable schemes customized to the requirements of the consumers [3]. Ref. [4] proposes a survivable WDM-PON architecture based on producing different wavelengths from a single laser for multicast data delivery to the subscribers [5].

Radio over fiber (RoF) technology is deployed to reduce noise and increase data transmission speed. With an optical amplifier, RoF can efficiently transmit long-distance signals. Optical amplifiers are an important component of any fiber optic communication system. Despite those modern optical fibers have losses of less than 0.2 dB/km, the signal amplifies to deliver its original power over long distances. In recent years, Raman amplifiers have gained a lot of interest as a potential contributor for future high-speed optical transmission. Raman scattering effect is used to generate power to the Raman amplifier and a nonlinear optical process in which a photon is absorbed by the material and then emitted as a different energy photon. The photon energy is changes with the vibrational state of the material [6]. A hybrid amplifier (EDFA and Raman) is employed in RoF communication systems for both long distances as well as long wavelengths [7]. Multiple amplifiers were chosen because it reduced signal noise, channel cross talk, coupling loss, and, made the system a better candidate for DWDM or CWDM [8].

Our model has been designed using the "Optisystem" software. The configuration of raman amplifiers with WDM transmission systems, as well as simulation and framework models were discussed and the simulation model framework was conducted. Consequently, WDM-PON is used to prepare the structure to convey signals from transmission to receiver end. Finally, BER analyser and eye diagram results were recorded. We studied 8 and 16 WDM channels up to 20 Gbps/channel data rate maintain standard channel spacing by 100 GHz or 0.8 nm. We also evaluated the system's BER, SNR, and related eye diagrams from 10 to 100 kms of fiber length.

2. RELATED LITERATURES

RoF is a technique that modulates light signal with a radio frequency and transmits it through an optical fiber link compared to electrical signal. The main technological advantages of fiber optical networks are lower transmission losses and less sensitivity to noise and electromagnetic interference. It has wide applications such as radio transmission (3G, 4G, 5G, and WiFi), cable television signal transmission (CATV) and RF L-Band signal for satellite communications. RoF technology realizes the convergence of fixed and mobile networks. RoF transmission radio is used in various modules, such as cable television networks, satellite base stations, etc. [9]. RoF structure has implemented as Wi-Fi alarms which are transmitted optically between important nodes and (BS) base stations [10]. It reduces the equipment and maintenance cost of the communication system [11]. Based on the frequency limitation of the carrier signal transmitted on the channel, the classification of RoF systems is divided into two sub-parts [12]. Wavelength division multiplexing (WDM) is an effective technology that can use the large bandwidth of optical fiber to meet the rapid growth of Internet bandwidth requirements owing the extremely high limit of optical filaments, Fiber-To-The-Home (FTTH) can convey more prominent limit when contrasted with copper-based innovations [13]. FTTH innovation utilizing aloof optical organization (PON) with P2MP design or tree geography is the most encouraging approach to give excellent broadband access [15]. Dense wave division multiplexing (DWDM) is multiplexing optical enhancers, and it permits growing limit of a current optical fiber. Coarse frequency division multiplexing (CWDM) and DWDM share the equivalent multiplexing instrument however contrast in number of channels, channel dispersing, and the capacity to intensify the multiplexed signals in the optical space.

All local, metro, and transcontinental telecommunications networks are built on WDM systems. Optical amplifiers (OAs) boost the optical signals passing through fiber by giving the laser's photons. Erbium-doped fiber amplifier (EDFA) is the most extensively used fiber amplifier because it uses silica-based optical fiber for amplification.

3. SYSTEM DESIGN

Our proposed system configuration using Raman amplifier with WDM consists of transmitter, channel and receiver. C band optical laser is initially turned on with the input signal power using 0 dB. After PRBS generator, each channel utilizes non-return-to-zero (NRZ) OOK modulation. Eight and sixteen modulated signals are multiplexed onto each channel. A Raman amplifier is installed before and after the fiber channel, and the optical fiber length has been set between 10 and 100 kilo meters. The pump laser's power has been set between 50 and 180 milli watts, and the signal is pushed into the fiber for amplifying. On the receiver side, a WDM demultiplexer is used to separate the signal received by different receivers, a photodiode is used to receive optical signal and the received signal is cleaned up by a low-pass filter. Figure 1 show the basic simulation setup that showing forward and back word pumping to prove of concept our proposed WDM system. If the pump power reaches a specified threshold, Raman scattering occurs in both forward and backward directions in optical fibers [16], i.e.

$$Pp\ (\omega) \geq \frac{\alpha p\ Aeff}{gR(\omega)} \qquad (1)$$

Where gR(ω), αp, and Aeff are the gain coefficient, the fiber loss coefficient inside the signal wavelength and its effective area.

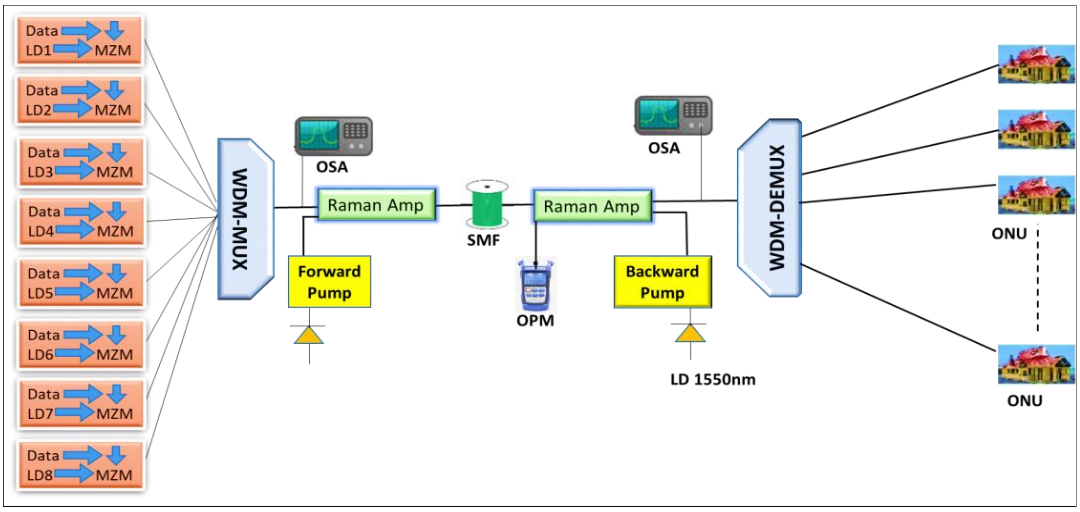


Fig. 1: Simulation setup of the Proposed System Architecture

We consider the pulse modulated signal for both forward and backward Raman pumping, while the pump laser could be used as continuous wave. We examine a single mode fiber with a Pp(0) pump injected at z = 0 and traveling in the +z direction. Because the signal and pump wavelengths in extremely low-loss and working around the 1.55m wavelength range. The signal power and forward pump power are consistent with the equations explained by Mochizuki [17].

$$\text{N Ps (z)} = \frac{\text{Ps (0).exp}[\frac{gR.Pp(0)}{\propto}(1-e^{-\propto z})-\alpha.z\,]}{1+\frac{\text{vp}}{\text{vs}}.\frac{\text{Ps(0)}}{\text{Pp (0)}}exp[\frac{gR.Pp(0)}{\alpha}(1-e^{-\alpha z})]} \qquad (2)$$

And

$$\text{Pp (z)} = \frac{Ps\,(0)\cdot e^{-\propto z}}{1+\frac{vp}{vs}\cdot\frac{Ps(0)}{Pp\,(0)}exp[\frac{gR\cdot Pp(0)}{\propto}(1-e^{-\propto z})]} \qquad (3)$$

When the input is restricted and shot-noise limitation of a hypothetical power detection, the spectral density of the output optical noise. Pp and Ps represent the pump power and signal power at selected frequencies vp and vs and propagation distance are z.

$$\frac{\text{vp}}{\text{vs}}\cdot\frac{\text{Ps(0)}}{\text{Pp (0)}}exp[\frac{gR\cdot Pp(0)}{\propto}(1-e^{-\propto z})] \ll 1 \qquad (4)$$

The signal power becomes [17] [18]

$$\text{Ps (z)} = \text{Ps (0)}\cdot e^{\{\frac{gR\cdot Pp(0)}{\alpha}(1-e^{-\alpha z})-\alpha z\}} \qquad (5)$$

Raman gain is optical amplification arising from stimulated Raman scattering. It can occur in transparent solid, liquids and gases under the influence of laser pump light. This lost optical energy is converted into heat. The maximum unrepeated transmission distance Lu (fw) is often evaluated and is simply adequate to get closer to fiber losses. Lu (fw) is obtained from Eq. (2) when signal power, Ps (Lu (fw)) = Ps(0), as

$$\text{Lu (fw)} = \frac{-1}{\propto}\cdot ln\left[e^{\frac{gR\cdot Pp(0)}{\propto}}+\frac{vp}{vs}\cdot\frac{Ps(0)}{Pp\,(0)}\right], \qquad \alpha L \gg 1$$
(6)

Where, the amplifier gain, G, due to stimulated Raman amplification is defined by

G = Ps (L)/Ps(0) [26].

When pump reduction is considered as gain extension which is obtained as follows [17]

$$G = \frac{\exp[\frac{gR\cdot Pp(0)}{\propto}(1-e^{-\propto L})-\alpha\cdot L\,]}{1+\frac{\text{vp}}{\text{vs}}\cdot\frac{\text{Ps(0)}}{\text{Pp (0)}}exp[\frac{gR\cdot Pp(0)}{\alpha}(1-e^{-\alpha z})]} \qquad (12)$$

In case of negligible pump depletion, amplification gain becomes [19]

$$G = \exp[\frac{gR\cdot Pp(0)}{\alpha}(1-e^{-\alpha L})-\alpha L\,] \qquad (13)$$

Under the condition that pump power degradation due to the stimulated model is ignored, equation (13) is the same as that obtained by Bindal *et al*, [20]. As a result, the pump failure can be overlooked. For a backward traveling wave, the pump and signal powers are given by [21]

$$\text{Ps (z)} = \text{Ps (0)}\cdot exp[\frac{gR\cdot Pp(L)}{\alpha}e^{-\alpha L}(e^{-\alpha z}-1)-\alpha\cdot z]$$
(14)

And

$$\text{Pp(Z)} = \text{Pp(L)e}^{-\alpha(\text{z}-\text{L})} \qquad (15)$$

The influence of these parameters in the WDM transmission system, Raman amplification has performance in terms of gain, signal-to-noise ratio, received signal power, BER, and attenuation level. The pump power of the signal emitted into the fiber using a laser diode to perform the stimulated Raman scattering (SRS) effect. OSA traces the power on the vertical scale and wavelength on the horizontal scale and an eye diagram provide a simple and useful tool to visualize inter-symbol interference between data bits. According to ITU grid our proposed system specifies 100 GHz (0.8nm), 88 GHz (0.7nm), 75 GHz (0.6nm), 50 GHz (0.4nm) and 25 GHz (0.2nm) channel spacing, but the shows best BER with 100 GHz spacing.

Table 1: Simulation Parameters

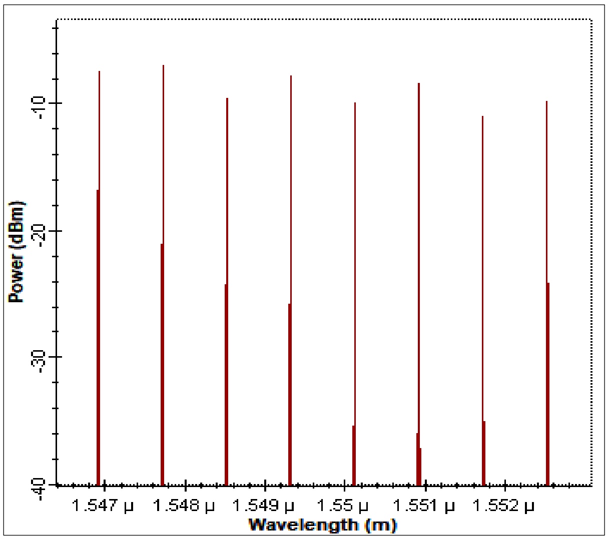
Component	Parameter	Value
Global Parameter	Bit rate	2.5 Gb/s
	Sample rate	
	Samples per bit	900^{e-6} Hz
	Time window	5.12e-006s
	Sequence length	128 bits
WDM-MUX Wavelength	0.8nm spacing	1549 nm-1554 nm
Input Power		20 mW
Raman Fiber length		10-100 km
Pump power		Up to180 mW
Operating temperature		300 K

Component	Parameter	Value
Receiver PD	Responsivity	1 A/W
	Bandwidth	3 GHz
	Dark current	10 nA
	Rx Load resistance	50 Ohm
SMF Channel	Fiber Length	10-100 km
	Wavelength Ref	C band
	Attenuation	0.2 dB/km
Pump LDs	LDs frequencies	Ref. freq.
	Bit rate	2.5 GHz
	Modulation type	OOK
	Laser power	-3 dB

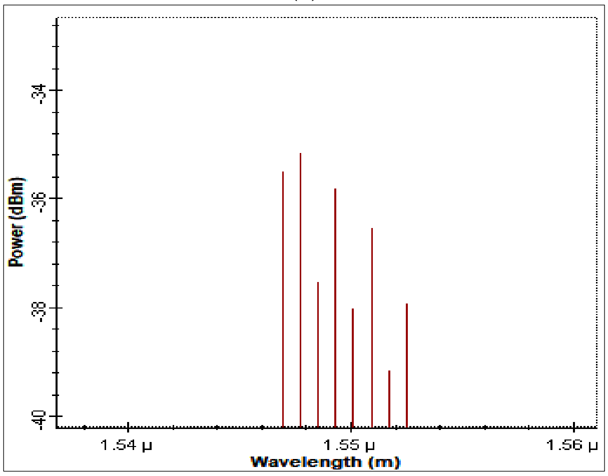
This proposed model consists of a multiplexer in the transmitter side to combine several laser signals by multiple channels and then transmit them through one fiber link. All the global parameters of the simulation are tabulated in Table 1. The Raman amplifier can be placed at different points of the communication link, or at the transmitting end, it is called a power amplifier, Hence, WDM is utilized to make the framework ready to communicate signals from many sending channels to many getting channels simultaneously.

4. RESULTS AND DISCUSSION

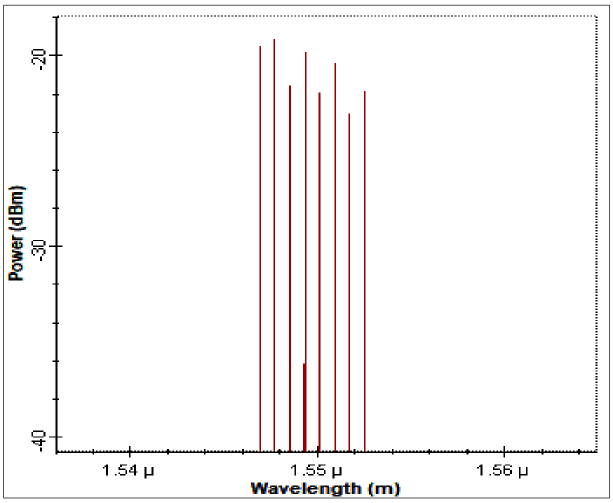
In this simulation, we used 8 and 16 channels WDM system with spacing of 100 GHz. The wavelength ranges have used in the laser sources from 1546.92 nm to 1552.52 nm. Here OSA was used to examine the output signal of the Raman amplifier, and system BER was measured the distances from 10 km to 100 kms which indicates in Fig 3. The best BER was recorded at 10km, where system noise level was -6.023 dBm.



(a)



(b)



(c)

Fig 2: a) Transmitter input signal b) Output before Raman pump laser c) Output after pump laser

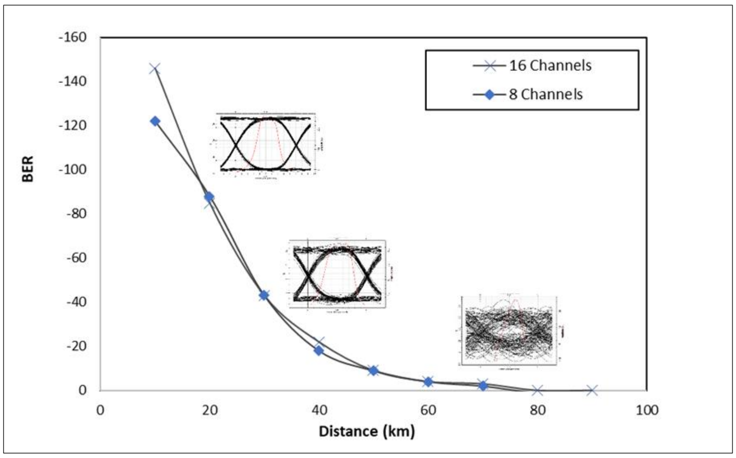


Fig 3: Fiber length Vs BER of 8 &16 channels

We set bit rate 1 Gb/s up to 20 Gb/s where the fiber length was 10km and we have found the total data using Raman amplifier power meter 5.574 dBm, frequency range from 1546.92 nm to 1552.52nm. At the receiver end, 16 and 8 channel's BER was calculated 10^{-9} for better quality of optical signal we can consider 10^{-9}. To maintain standard BER, maximum data can transmit 16 Gb/s x8 = 128 GB/s using 8 channels and 12 Gb/s x16= 192 Gb/s which has explained in Fig 4. However, we could have successfully transmitted data over 70 km with this data rate. When fiber length 5 km, CW laser power 1~30 mW and when the pump laser power 80 mW the maximum Q-factor 24.10 ~35.97 and minimum BER 9.52×10^{-12} ~ 6.72×10^{-28} at BER analyser. When the fiber length 10km, the global bit rate 5 Gb/s, CW laser power 0dBm and after varied the pump laser power 50mW~150mW, maximum Q-factor 24.01 and minimum BER result 8.24×10^{-12}.

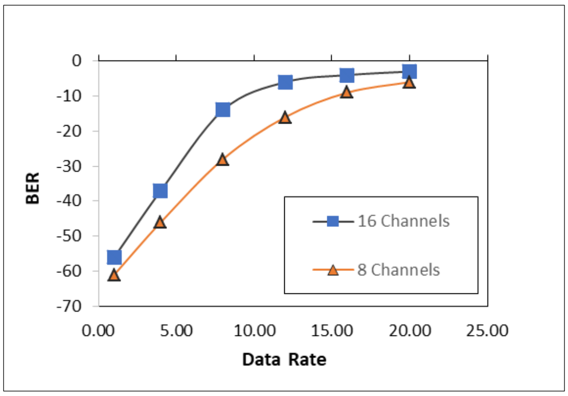
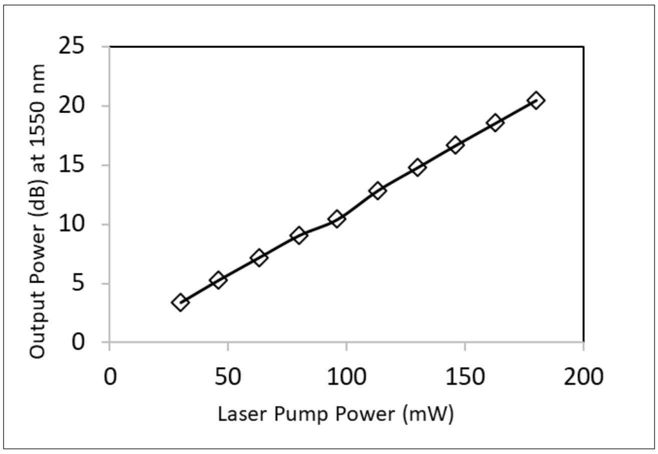
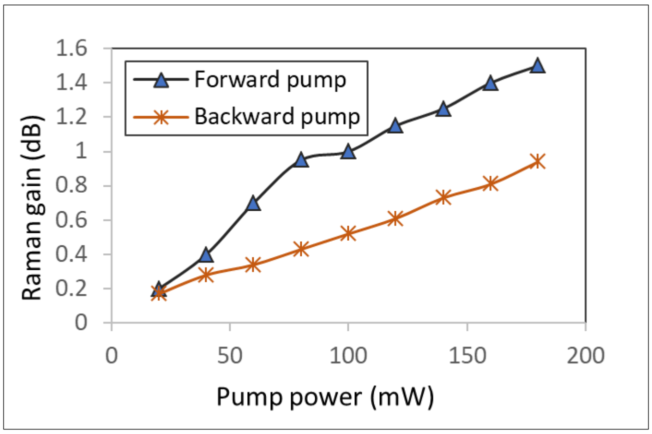


Fig 4: Data rate Vs BER of 8 &16 channels

With the changing of the spacing, the non-linear effects of the optical fibre can induce and signal BER of the system. To validate the previous study, we have compared the BER and the quality factor as a function of channel spacing [22]. According to linewidth Table [23], BER was found in table 2 of the system where the value of Raman amplifier at 70 km and the data rate was 5 Gb/s.



(a)



(b)

Fig 5: a) Laser pump power (mW) vs output power and b) Forward and backward Raman pump power vs gain

The input and output signal of Raman amplifier has been tested using OSA shown in Fig 5 (a) and Fig 5 (b). Table 3 and 4 shows a BER related eye diagram with varied fiber lengths of 30km, 50km, 70km, and 90km. Over 80km was the worst for this model.

Table 2: Channel Spacing effects on BER

Channel Spacing nm	GHz		BER
0.8	100	10^{-11}
0.7	88	10^{-9}
0.6	75	10^{-8}
0.4	50	10^{-7}
0.2	25	10^{-5}

5. CONCLUSIONS

We designed WDM RoF model and measured the system performance using different data rate, changing length of the fiber, shifting channel spacing and using Raman amplifier is set before and after optical fiber channel to amplify the signal. Received total data rate of 20 Gb/s and 40 Gb/s using 8 and 16 WDM channels. The maximal OSNR is observed using a WDM analyser using C band laser and getting reasonable eye with a WDM-PON network. 100 GHz channel spacing used getting most variable output by optical simulator OptiSystem in this paper. The best BER has been recorded at 70 km, with low noise level of -60 db and after 70 km eye diagram of the signal becoming worse. Maximum 128 Gb/s data can transmit by 8 channels and and 192 Gb/s data can transmit by maintaining BER 10^{-9}. The input power always maintains below 180mW, the output power was ~20 dBm using RA. Finally, proposed system can be enhanced using more channels and higher order modulation scheme.

Table 3: 16 Channel using Raman amplifier before and after fiber channel

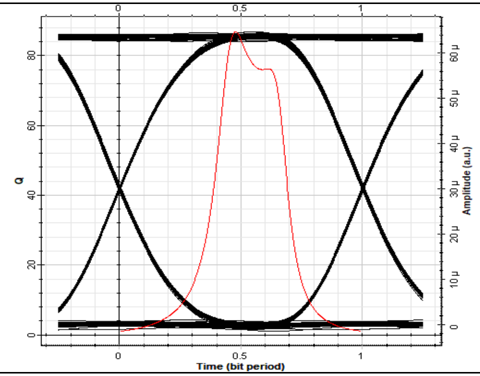
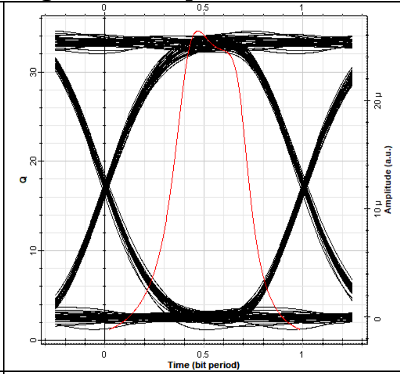
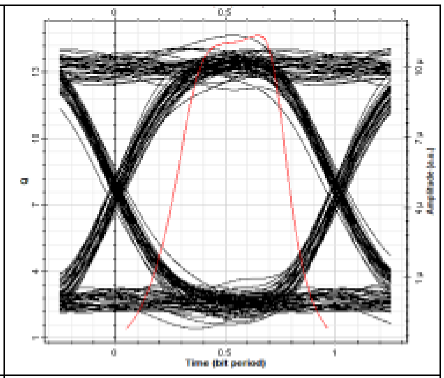
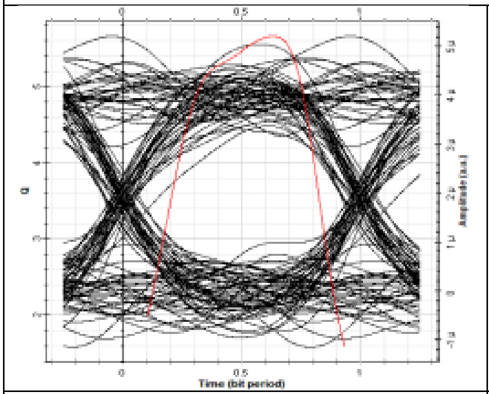
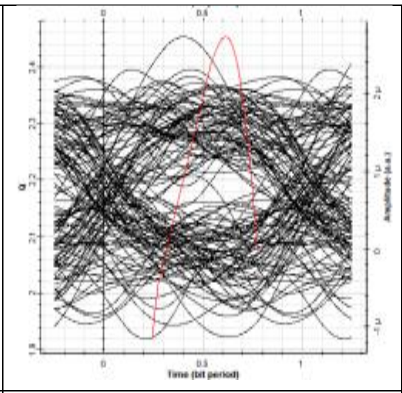
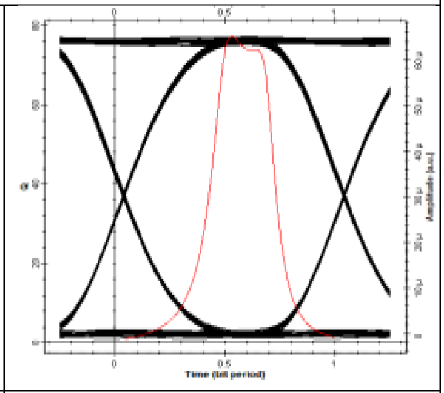
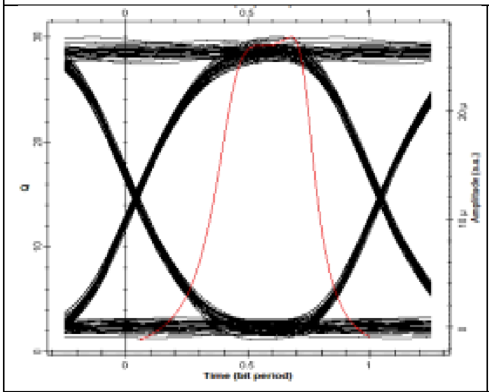
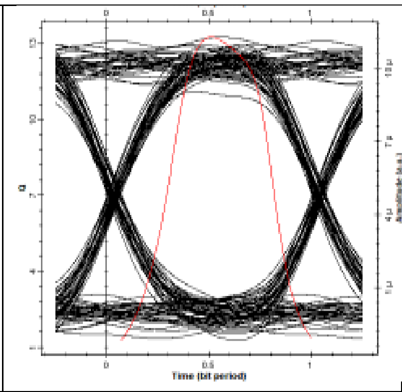
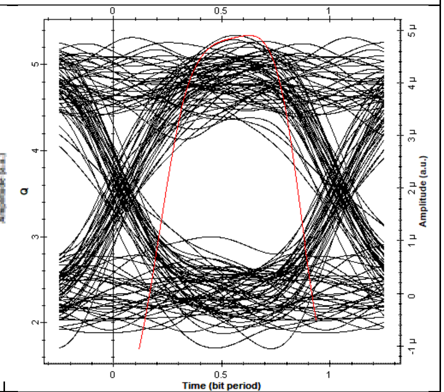
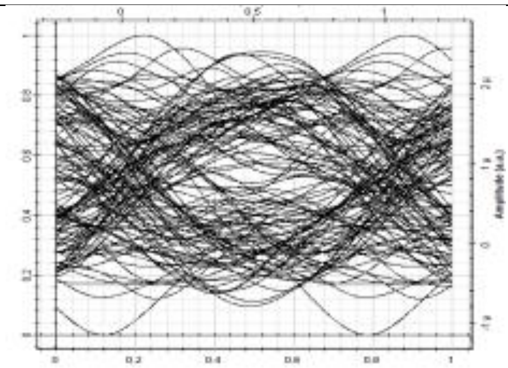
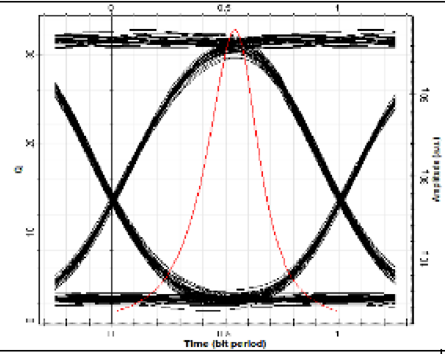
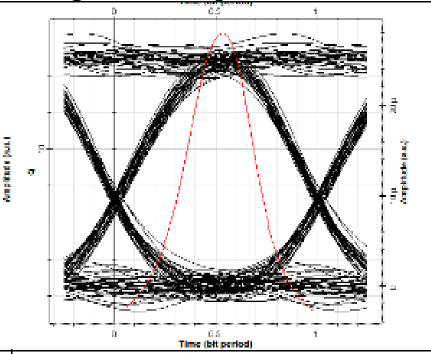
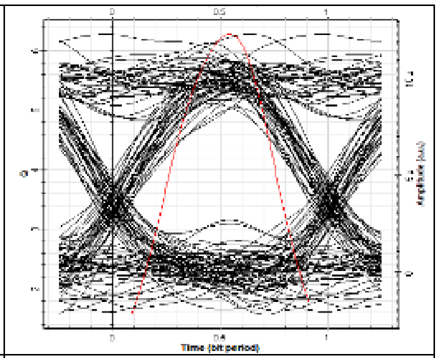
		
Fiber length 10km	Fiber length 30km	Fiber length 50km
		
Fiber length 70km	Fiber length 90km	Fiber length 10km
		
Fiber length 30km	Fiber length 50km	Fiber length 70km
		
	Fiber length 90km	

Table 4: 8 Channel using Raman amplifier before and after fiber channel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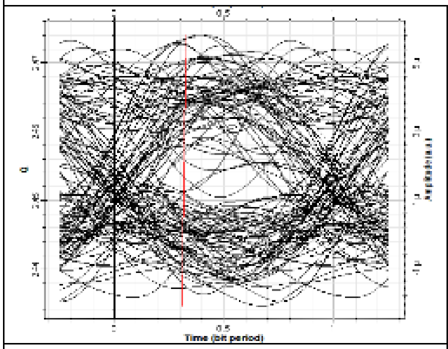
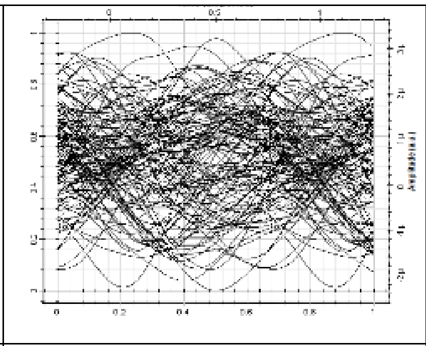
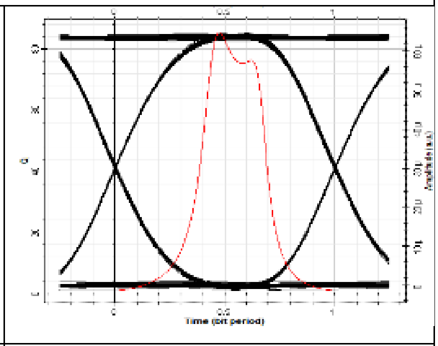
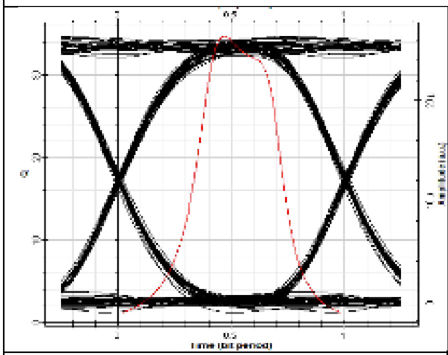
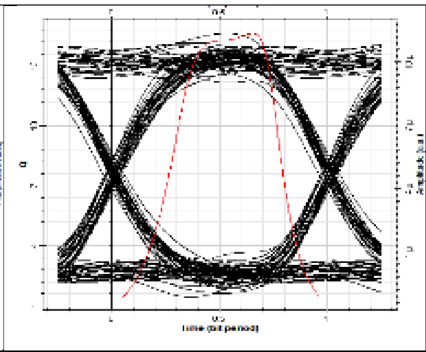
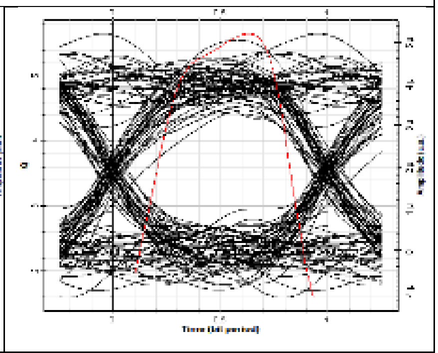
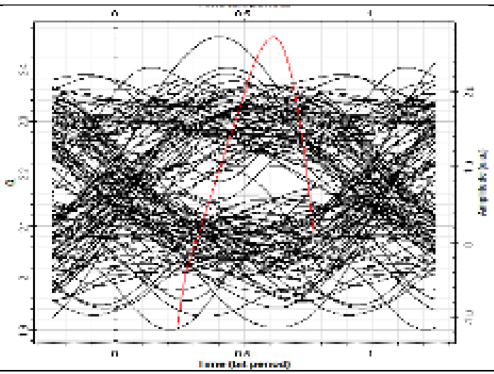
		
Fiber length 70km	Fiber length 90km	Fiber length 10km
		
Fiber length 30km	Fiber length 50km	Fiber length 70km
		
	Fiber length 90km	

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