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Research Article

Performance Analysis of Flat Gain Wideband Raman Amplifier for S+C and C+L Band DWDM System

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Raman amplifier is an open area of research in telecommunication field. This paper discusses the performance of 64 channels of 10 Gbps WDM systems with backward multipump Raman amplifier. The main goal of this paper is the optimization of Raman amplifier to minimize its gain variation without using any gain flattening techniques. To increase the transmission capacity of DWDM system, Raman amplifier with backward multipump configuration is implemented. The optimized parameters such as pump power and frequencies are used to deliver both ground and excited state absorption for amplification in S+C and C+L band region. The pump power and frequencies are optimized through multitarget and multiparameter optimization tool available in OptiSystem software. Gain ripple was achieved <0.5 dB for this simulation setup. The maximum flat gain achieved is 8.6 dB and noise figure of <8 dB was achieved for this wide bandwidth without using gain flattening techniques. This amplifier design will be helpful for CATV applications and telecommunication networks.

1. Introduction

Optical fiber communication supplies the demand of future communication and achieved low attenuation loss as compared to copper and coaxial cable. In the 1980s, the erbium doped fiber amplifier operated as vital role for the amplification in c band [1]. A single wavelength 1310 nm is analyzed with different length as a function of wavelength and the amplifier bandwidth is found 14 nm -16 nm. It was also compared with 1310 nm Raman amplifier with SOA resulting in wavelength as 1310nm with bandwidth 85 nm [2]. We demonstrate C band wavelength Raman amplifier from 1530-1624.4 nm in this paper. The maximum gain and noise figure achieved for C band are 53.3 dB and 9 dB, respectively [3]. In recent years Raman amplifiers are widely used due to wide amplification bandwidth [4]. The paper demonstrated the L band remote pumped EDFA/Raman amplifier using 1480 nm pump utilizing effect of Raman scattering [5]. The performance analysis of EYDFA and Raman amplifier is analyzed with the help of 110×40 Gbps data rate NRZ format. Different pumping schemes are employed with EYDFA+DFA. It is reported that forward pumping scheme is superior to all other experiments [6]. The gain ripple was 2.09 dB and OSNR is 34.23 dB of the work proposed RA with TDM pumps using analytical model. We already reported the performance of hybrid amplifier Raman +EDFA in DWDM system using RZ and NRZ format [7]. Gain flattening filter optimization has been proposed in 320 channels' broadband DWDM system at reduced channel spacing is about 25 GHZ to achieve gain ripple less than 0.5 Db [8]. Optimization tools greatly reduce the design time for required work and fiber Raman amplifier pumped at multiwavelength and frequency reported [9]. Optimization is not done by broad band Raman amplifier [10]. Raman amplifier optimization is done by using particle swarm optimization achieved gain ripple less than 0.5 db [11]. Multiparameter optimization procedure was implemented for the Raman amplifier by particle swarm optimizer [12, 13]. The implementation of Raman amplifier based on genetic algorithm can be found in [14]. Multiparameter optimization of Raman amplifier is essential to improve the gain spectrum of Raman amplifier which is not presented in [15–17]. The Raman amplifier can provide the better amplification and gain flattening in L band to reduce the influence of fiber nonlinearity [18]. The S+C+L band Raman amplifier was

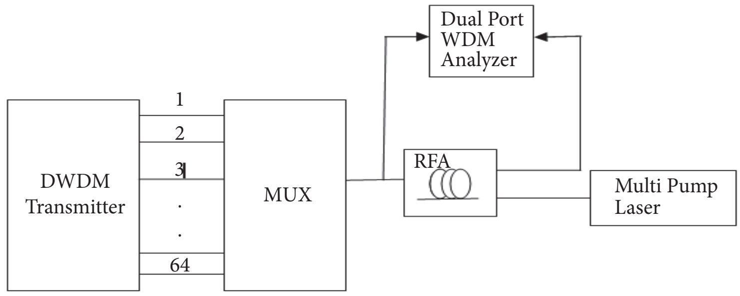


FIGURE 1: Simulation setup of counterpropagation multipump Raman amplifier.

experimented over 100 nm gain bandwidth of 1520-1620 nm with gain ripple 1.1 dB [19]. The wideband Raman amplifier over 98 nm gain bandwidth of 1520-1620 nm has been demonstrated with gain flatness 1 dB [20]. The flat gain wideband cascaded TDFA and Raman hybrid amplifier is the present requirement of DWDM system [21, 22].

For the first time we have reported reduced gain ripple of 0.2 dB and 0.5 dB for S+C band and C+L band, respectively. This new design of optimum gain flattening performance of Raman amplifier will be useful for telecommunication networks.

The rest of the paper is organized as follows: Section 2 explains simulation setup and analysis of Raman amplifier; Section 3 ends with concluding remarks.

2. Characteristics of Multipump Raman Amplifier

The aim behind the optimization of multipump Raman amplifier is to get better gain flatness and reduce ripples instead of utilizing any gain flattening techniques. Gain bandwidth can be improved by Raman amplifier by efficient utilization of DWDM system. In Section 1, we adopted the MPO optimization using OptiSystem simulation software. The optimized four pump powers are utilized to transfer energy from pumps to the signal to provide better gain flatness with less gain variation. MPO tools are available in OptiSystem software to optimize the pump powers and frequencies to achieve the target gain to keep the DWDM system with 0.8 nm channel spacing. This multipump optimization is based on nonlinear least square (LSQ) algorithm. For the initial stage the four types of pumps are randomly chosen with input power -17.4 dBm for 64 channels of DWDM system. The MPO is executed with several iterations for the goal attainment of gain flatness to achieve high gain. The signal power was at length L to amplify the continuous wave signal [23].

$$P_s(L) = P_s(0)\exp\left(\frac{g_R}{a_P}P_0L_{\mathrm{eff}} - \alpha_s L\right) \quad (1)$$

where $L_{\mathrm{eff}} = [1-\exp(-\alpha_P L)]/\alpha_P$ represent the effective length of the Raman fiber amplifier, where g_R represents Raman gain coefficients, a_p is the pump cross-sectional area, α_s is the fiber loss, P_0 is the input power, and $P_s(0)$ is the signal power a L

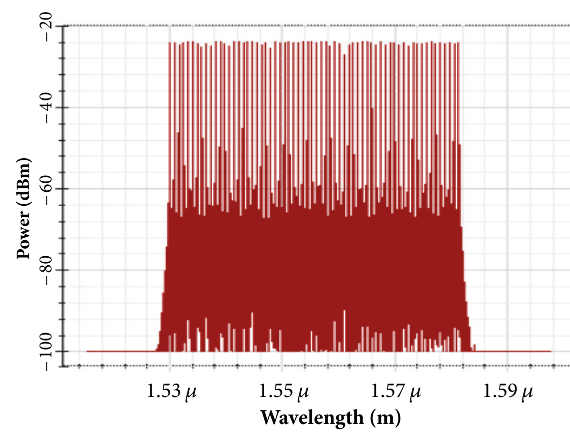


FIGURE 2: Signal of 64-channel WDM system.

= 0. The basic simulation setup in Figure 1 shows 64 channels where each channel is spaced with 0.8 nm and output signal power to the Raman amplifier is -17.4 dBm.

DWDM system transmitting several optical channels on to the single fiber is specially designed with non-zero-dispersion shifted fiber (NZDSF) which is simulated. NZDSF has the zero-dispersion crossing at wavelengths <1530 nm and >1560 nm. We describe the Raman fiber simulation model in detail that enables the shifting of gain band in both S+C band and C+L band region. The simulation setup is established in Figure 1 using OptiSystem software. We have investigated the system with -30 dBm/channel. The simulation setup consists of 64 channels with 10 Gbps data rate/channel in a 100 GHz (0.8 nm) interval shown in Figure 2. Figure 3 shows the RFA flattened gain has length 25 km employing four pump lasers operating at pump powers which are 101 mW, 136.5 mW, 90.1 mW, and 186.07 mW and frequencies are 1406 nm, 1416 nm,1434 nm, and 1461 nm, respectively.

Table 1 summarizes the various simulation parameters applied to the NZDSF fiber. The experiment is carried out with both of 25 km and 50 km of fiber length employing optimized pump power and frequencies.

2.1. Results and Discussion. Here NRZ modulation format is used covering bandwidth starting from 1530 to 1581.3 nm as shown in Figures 4(a) and 4(b) where first channel is 1581.3

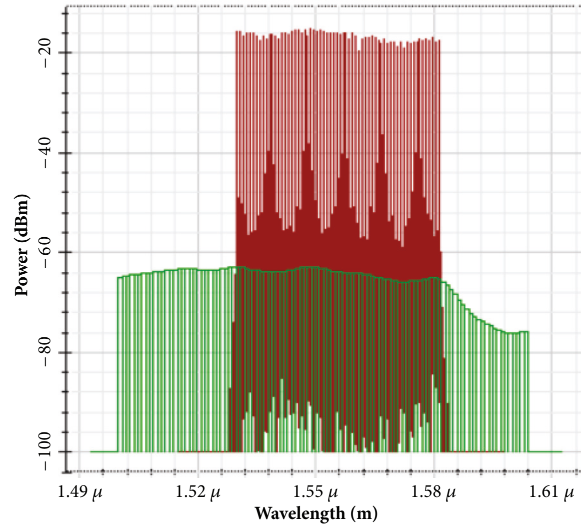
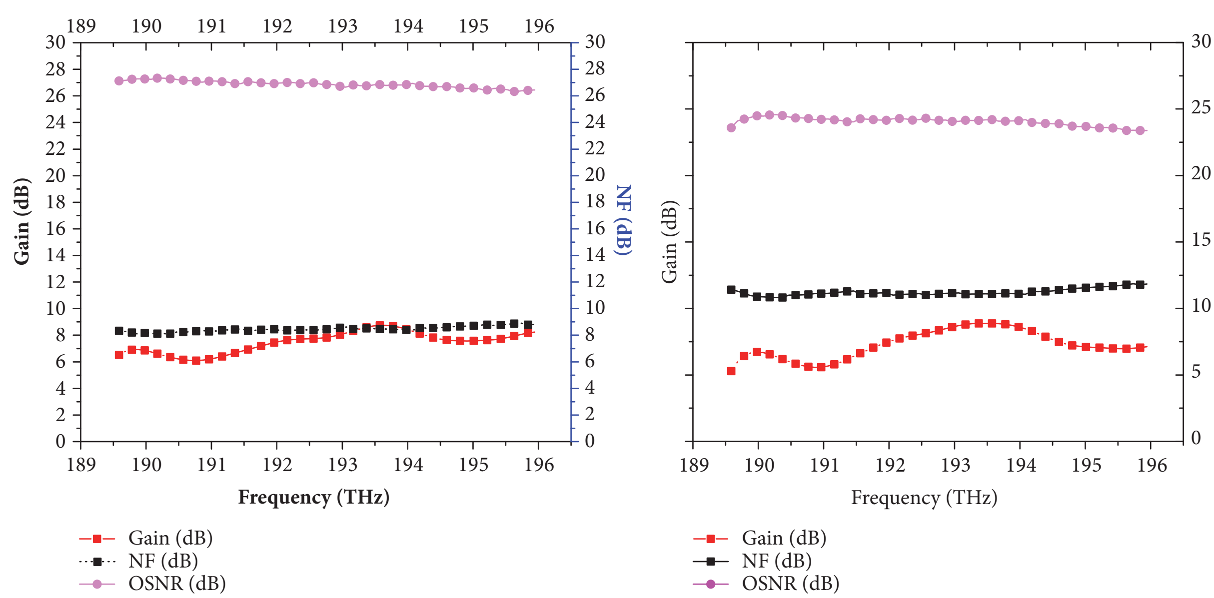


Figure 3: Signal of 64-channel WDM system after 25 km of fiber length.



(a) (b)

Figure 4: (a) Gain, noise figure, and OSNR versus signal wavelength using counterpropagating pumping scheme at 25 km length. (b) 50 km of multipump Raman amplifier in C+L band.

Table 1: Raman fiber amplifier.

Parameter	Value
Length	25 km, 50 km
Attenuation	0.2 dB/km
Dispersion	16.75 ps/nm/km
Dispersion Slope	0.075 ps/nm2/km
Effective Area	55 μm2
Fiber Type	NZDSF

nm (189 THz), second channel is 1578 nm (190THz), and last channel is 1530 nm (196 THz) and also described 1512-1563 nm as shown in Figures 4(a) and 4(b) where first channel is 1563 nm (191 THz), second channel is 1561.4 (192 THz), and last channel is 1512 nm (198 THz).

Figures 4(a) and 4(b) show the values of Raman amplifier for the length of 25 km and 50 km, respectively. The wavelength range is taken from 1530 nm to 1581.3 nm in both cases. The NRZ modulation format is used for both cases. It is evident from Figures 4(a) and 4(b) that bandwidth utilization is 51 nm. The value maximum gain G_{max} is taken as 8.7 dB and minimum gain is taken as G_{min} 5.8 dB and for 25 km of fiber length. The values of G_{max} and G_{min} are taken as 8.7dB and 5.2 dB, respectively, for 50 km of fiber length. The aim of this work is to minimize noise figure (NF) and to maximize OSNR

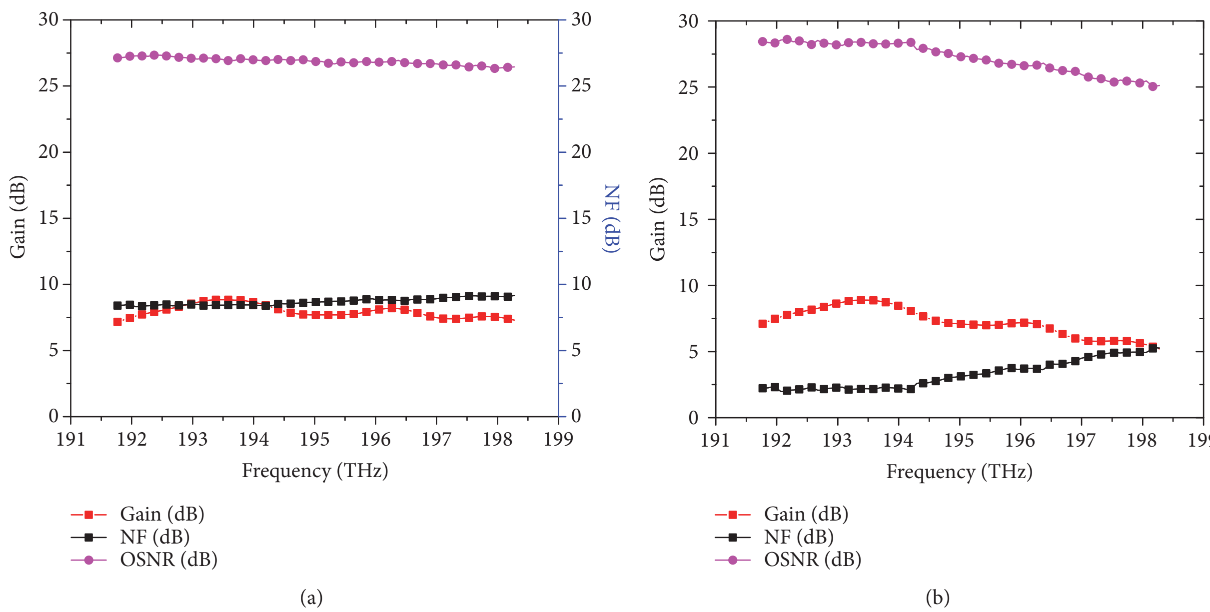


Figure 5: (a) Gain, noise figure, and OSNR versus signal wavelength using counterpropagating pumping scheme at 25 km length. (b) 50 km of multipump Raman amplifier in S+C band.

to optimize the multipump Raman amplifier. The maximum OSNR, noise figure, and gain for 25 km fiber length are found to be 29.9 dB, 8 dB, and 8.7 dB, respectively. The maximum gain ripple is obtained at -17.4 dBm for output power of 0.5 dB and 0.67 dB for 25 km and 50km of fiber length, respectively. This is evident for C+L band as shown in Figures 4(a) and 4(b), respectively. The variations in the power levels are due to the pump signals and do not impart energy to all the channels. From the figures it is clearly observed that a smooth power spectrum is obtained with using any gain flattening filter. The variations of power levels are observed across a wide bandwidth being 1.6 dB and 2.9 dB for S+C and C+L band, respectively.

Figures 5(a) and 5(b) illustrate Raman amplifier for the length of 25 km and 50 km, respectively, for the wavelength range of 1512-1563 nm with NRZ modulation format. The bandwidth of input channel is taken as 51 nm. The simulation is carried out for G_{max} of 8.7 dB and G_{min} as 7.1 dB, respectively, for 25 km of fiber length. For 50 kms length G_{max} and G_{min} are taken as 8.8 dB and 5.1 dB, respectively, for 50 km of fiber length. The maximum OSNR, noise figure, and gain for 25 km fiber length are found as 29.5 dB, 8.3 dB, and 8.7 dB, respectively. The maximum gain ripple is obtained at -17.4 dBm for output power of 0.2 dB and 0.7 dB for 25 km and 50 km of fiber length, respectively, in S+C band as shown in Figures 5(a) and 5(b).

We have considered NRZ modulation format only for 64 channels' DWDM system. Figure 6 shows the graphical representation of Q value as a function of fiber length varies from 10 km to 50 km. The maximum quality factor and maximum output power obtained are 13.4 dB and 5.9 dBm, respectively, in S+C band DWDM system. Due to the fiber nonlinearities the Q factor decreased. Figure 7 shows the graphical representation of BER as a function of signal

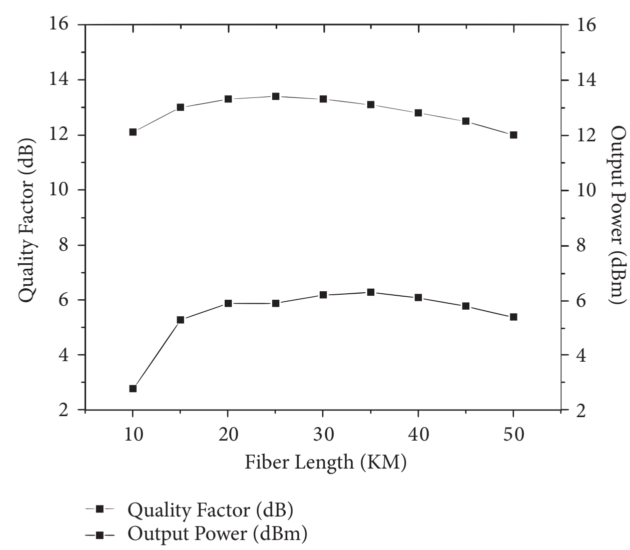


Figure 6: Quality factor and output power versus fiber length of multipump Raman amplifier.

wavelength. As shown in the figure the BER is increased as we increase the signal wavelength. The least BER is obtained (1.93453E-39) by NRZ modulation format and for 1600 nm signal wavelength it becomes 4.53553E-5 dB.

Figure 8 illustrates the graphical representation of BER as a function of transmission distance. The length has lowest BER of $2.2e^{-31}$ for 25 km of fiber length and highest BER is obtained about $7.6e^{-24}$ for 50 km of fiber length. Figures 9(d) and 9(i) show the eye diagrams for 64 channels' DWDM system. The intersymbol interference which is introduced due to transmission loss influenced nonlinear effect in the fiber

Table 2: Response of the multipumping Raman fiber amplifier configuration.

Fiber Configuration	C+L Band		S+C Band	
NZDSF	Length = 25 km	Length = 50 km	Length = 25 km	Length = 50 km
G_{max} (dB)	8.7	8.7	8.7	8.8
G_{min} (dB)	5.8	5.2	7.1	5.1
Noise Figure (dB)	8	10.8	8.3	10
Gain variation (dB)	2.9	3.5	1.6	3.6
Gain Ripple (dB)	0.5	0.67	0.2	0.7
OSNR (dB)	27.1	29.9	29.5	26.8

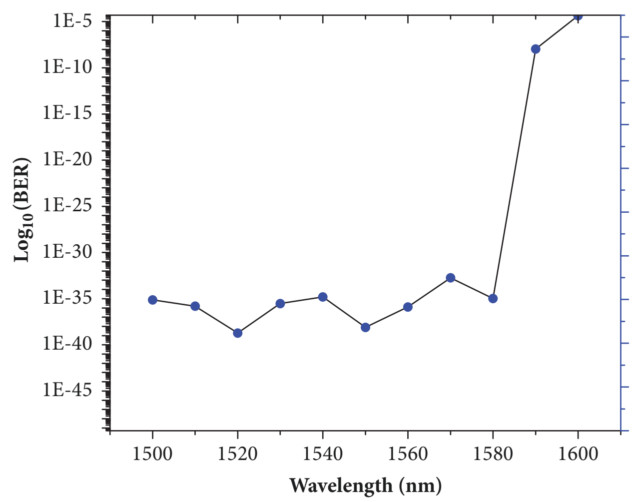


Figure 7: BER versus signal wavelength of multipump Raman amplifier.

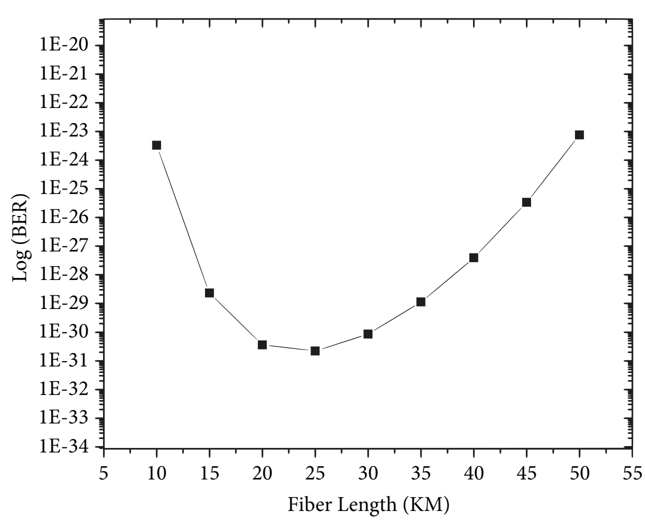


Figure 8: BER versus fiber length of multipump Raman amplifier.

due to impulse width being the largest in NRZ modulation format. The eye is more open in case of 25 km fiber length as compared to all other lengths of fiber with good extinction ratio.

Table 2 shows that Raman amplifier configuration has a ripple of 0.2 dB and 0.5 dB for S+C band and C+L band, respectively. The maximum OSNR is observed at 50 km of fiber length as compared to 25 km of fiber length in case of C+L band for S+C band the maximum OSNR is at 25 km of fiber length than 50 km of fiber length.

3. Conclusion

We present cost effective system with only four utilized pumps (see Table 3). This wideband flat gain amplification is implemented by multipump Raman amplifier without

Table 3: Comparison of the proposed investigation with the previous reported system.

Previous reported System	Operating band	No. of Channels	Channel spacing	Gain ripple	Optimization of amplifier	No. of Pumps
4 backward pumping schemes [3]	C band	45	100 GHz	-	No	4
160 ∗ 10 Gbps DWDM system [4]	L band	160	25 GHz	4.5 dB	No	2
8 backward pumping scheme [10]	S band	14	764.7 GHz	<0.4 dB	Yes	8
64 ∗ 10 Gbps and 96 ∗ 10 Gbps DWDM system [17]	C+L band	96,64	100 Ghz	-	No	1
320 Channel DWDM system [8]	S+C+L band (With Gain Flattening Filter)	320	25 Ghz	<0.5 dB	Yes	2
64 channel DWDM system	S+C and C+L band (Without Gain Flattening Filter)	64	100 GHz	<0.5 dB	Current Investigation	4

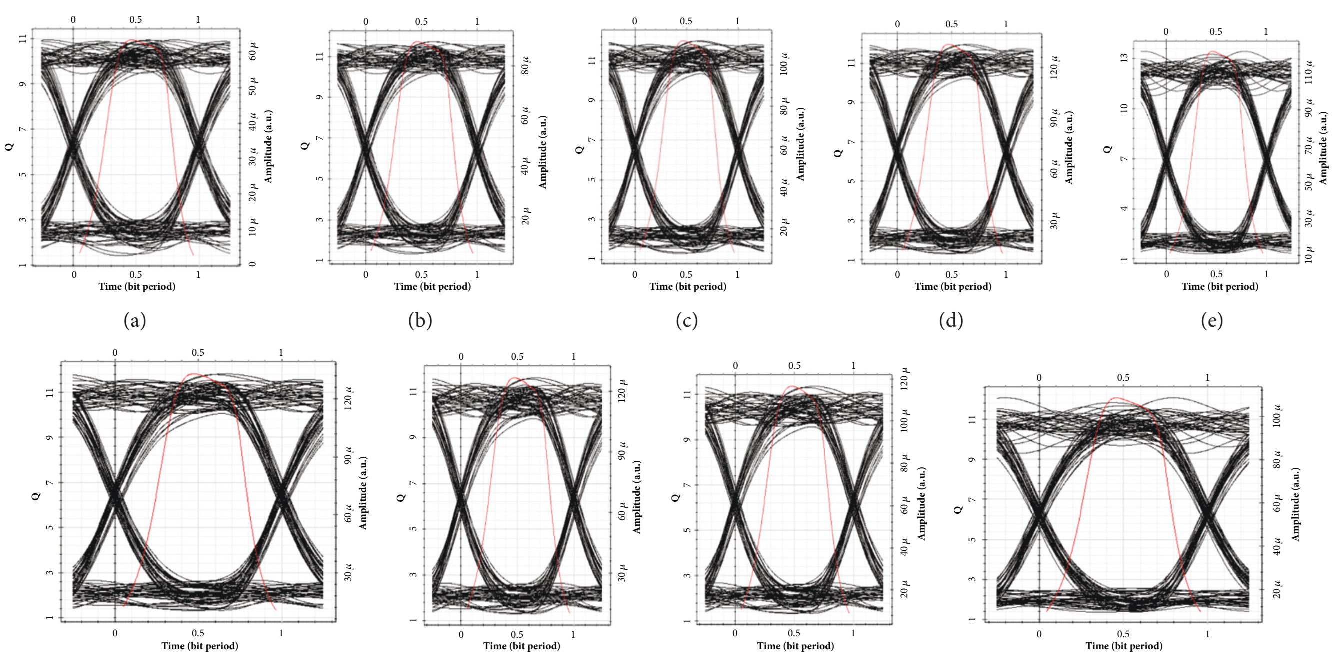


Figure 9: Eye diagram for 64-channel DWDM system. (a) 10 km at 10 Gbps. (b) 15 km at 10 Gbps. (c) 20 km at 10 Gbps. (d) 25 km at 10 Gbps. (e) 30 km at 10 Gbps. (f) 35 km at 10 Gbps. (g) 40 km at 10 Gbps. (h) 45 km at 10 Gbps. (i) 50 km at 10 Gbps.

using gain flattening filter. The optimized parameters are used for counterpropagating Raman amplifier. The S+C band and C+L band with 50 nm wide amplification window cover 1512-1563 nm and 1530-1580.3 nm. The gain ripple for S+C band is found to be 0.2 dB and 0.7 dB for 25 km and 50km length of fiber, respectively. The gain ripple for C+L band is found to be 0.5 dB and 0.67 dB for 25 km and 50 km length of fiber, respectively. Better results are observed for S+C band than C+L bands by Raman amplifier.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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