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Performance of a 32 Channels WDM System using Gain Flattened EDFA

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Abstract
The gain flattening of erbium doped fiber amplifier (EDFA) is essential for their application in wavelength division multiplexing (WDM) system. This paper attempts to design and analyse a 32 channels WDM system using EDFA in the wavelength range of 1546 to 1560 nm with channel spacing of 0.4 nm. The analysis is made for the data rate of 10 Gb/s of NRZ signal. The gain flattening of EDFA in such system is achieved through EDFA's pump power and input power variation. Results show that the gains are flattened within 43.6 ± 0.8 dB with noise figure about 7.38 dB at pump power of 600 mW and input power of -34 dBm using optimized erbium doped fiber of 6.2 m length. The performance analysis in terms of BER, eye diagram and Q factor shows satisfactory results.
Keywords- Gain flattening, WDM system, EDFA

1. Introduction

Optical fiber communication is undoubtedly a very high capacity, reliable and secure system for present and future communication needs. Wavelength division multiplexing (WDM) technique has made the transmission bit rate to grow exponentially since the advent of erbium doped fiber amplifier (EDFA) in 1980s. EDFAs are preferred as optical amplifier in multichannel WDM system for their wide gain bandwidth, capable of simultaneously amplifying a large number of channels especially in C-band (1530 to 1570 nm) [1-4].

EDFA is Er^{+3} ions doped optical fiber acts as a gain medium to amplify an optical signal when pump signal either at 980 nm or 1480 nm is used for excitation of Er^{+3} ions. The output signal is characteristically amplified in the lowest loss 1550 nm wavelength window covering L- and C-band and hence EDFAs are the inevitable choice for dense wavelength division multiplexing (DWDM) system.

The important characteristics of EDFA are efficient pumping, high gain and low noise. However EDFA gains are widely wavelength dependent and needs gain flattening for DWDM system involving multiple channels with channel spacing of the order of 0.5 nm or even lower.

Several methods exist for EDFA gain flattening [5-8]. By using high pump powers or by changing erbium doped fiber length or by varying input power one can achieve flat gains [9-12]. One can also achieve it by properly choosing optical notch filter characteristics [13].

In this work, the EDFA gain flattening is achieved by variation of pump power and input power for optimized erbium doped shorter fiber length of 6.2 m only using optisystem.

2. System Layout

The system layout for simulation in optisystem is shown in Fig. 1. A 32 channels WDM transmitter, dual port WDM analyzer, EDFA and BER analyzer are the key components used for 32 channels WDM system in the wavelength range between 1546 to 1560 nm with 0.4 nm channel spacing. Table 1 shows the WDM and EDFA parameters used for simulation.

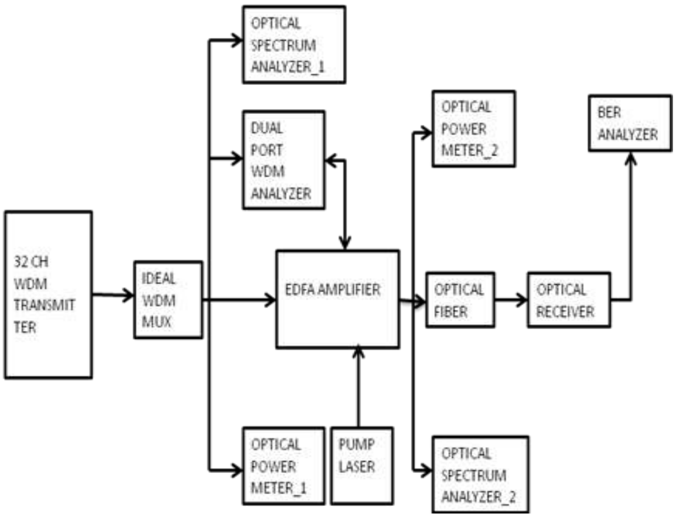


Fig. 1. Simulation Layout of 32 channels WDM System

Table 1. WDM and EDFA Parameters used

Parameters	Values
WDM transmitter frequency range	1546-1560 nm
Frequency spacing	0.4 nm
Number of WDM Channels	32
Bit rate, Modulation type	10 Gb/s, NRZ
Optimized EDFA length	6.2 m
EDFA core radius	2.2 µm
Er^{+3} ion density	$1.425e^{+25}$ m^{-3}
EDF numerical aperture	0.24

3. Gain and Noise Figure Analysis

In the simulation model, pump power is varied from 200 to 600 mW and the input signal power is varied from -22 to -34 dBm. Fig. 2 shows the output signal and noise spectra where an average gains of 43.6 dBm and a gain flatness of about 0.8 dBm are achieved. The output power of about 25 dBm and noise figure of about 7.38 dBm are obtained. These values are taken from WDM analyzer when input signal power of -34 dBm and pump power of 600 mW are used at the optimized EDF length of 6.2 m. The gain and noise figure variations across the complete frequency range for different pump powers are shown in Fig. 3 and Fig. 4 respectively at fixed input signal power of -34 dBm. The same variations for different input powers are shown in Fig. 5 and Fig. 6 respectively at fixed pump power of 600 mW.

It is observed from Fig. 3 and Fig. 4 that high average gain and low average noise figure is found at maximum pump power of 600 mW with gain flatness of about 0.80 dBm and to achieve even better flatness (0.72 dBm) both gain and noise figure has to be sacrificed a bit as shown in Table 2, where a pump power of 500 mW is sufficient.

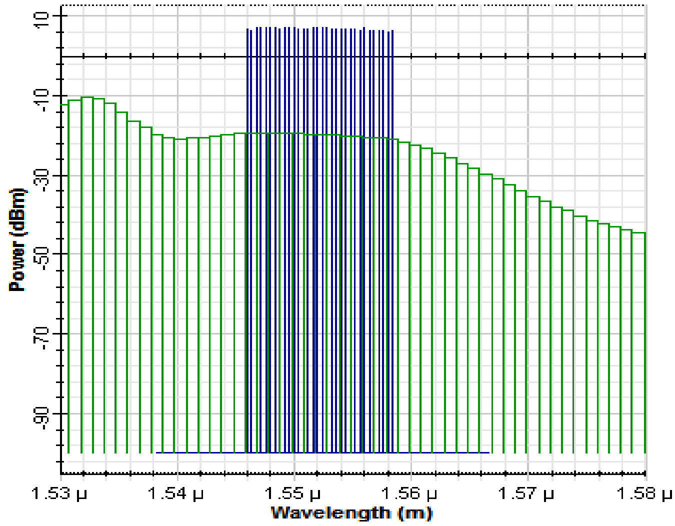


Fig. 2. output signal and noise power variation

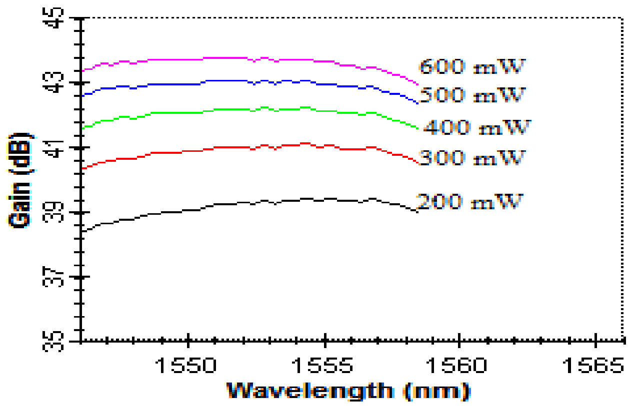


Fig. 3. Gain variation for different pump powers at fixed input power of -34 dBm

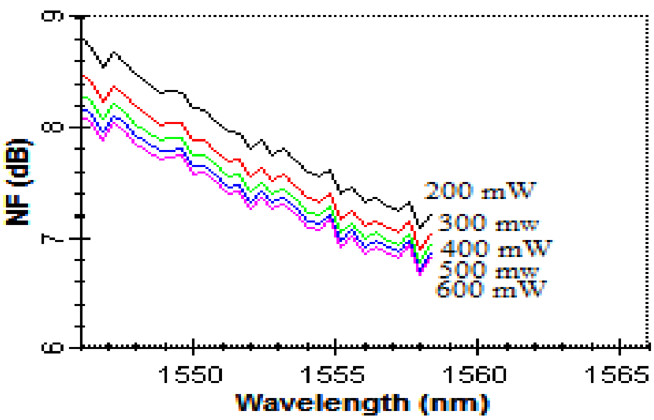


Fig. 4. Noise Figure (NF) variation for different pump powers at fixed input power of -34 dBm

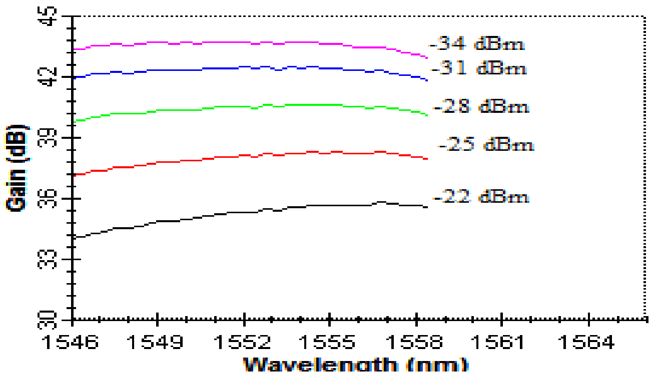


Fig. 5. Gain variation for different input powers at fixed pump power of 600 mW

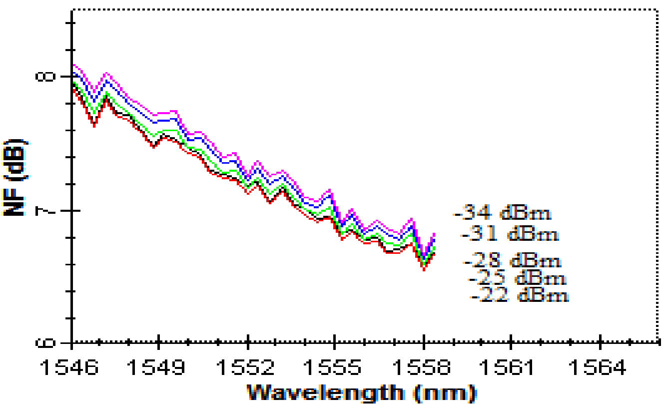


Fig. 6. Noise Figure (NF) variation for different input powers at fixed pump power of 600 mW

Fig. 5 and Fig. 6 also show that high average gain and low average noise figure is found at pump power of 600 mW with gain flatness of about 0.80 dBm and to achieve even better flatness (0.66 dBm) in this case both gain and noise figure has to be sacrificed a bit again as shown in Table 3, where a input power of -31 dBm is required. Table 4, 5 and 6 shows the numerical values of Gains and NFs at different pump powers for all 32 channels for three pump powers 200, 300 and 600 mW respectively. Here typical input signal power of -26 dBm is considered. These findings are useful for designing such system having predefined system requirements in terms of average gain, noise figure or gain flatness.

Table 2. Gain and NF values at different Pump Power and fixed input power of -34 dBm

Parameters	Pump Power (mW)				
	200	300	400	500	600
Avg. Gain (dB)	39.13	40.87	42.03	42.90	43.60
Gain Flatness (±dB)	1.05	0.78	0.63	0.72	0.80
Avg. NF (dB)	7.95	7.68	7.54	7.45	7.38

Table 3. Gain and NF values at different input power and fixed pump power of 600 mW

Parameters	Input Power (dBm)				
	-22	-25	-28	-31	-34
Avg. Gain (dB)	35.24	37.99	40.43	42.33	43.60
Gain Flatness (±dB)	1.79	1.24	0.85	0.66	0.80
Avg. NF (dB)	7.27	7.23	7.29	7.34	7.38

4. Eye Diagram, Q-Factor And Ber Analysis

This analysis is made for data rate of 10 Gb/s with NRZ modulation to understand the performance of the gain flattened amplifier. Results for pump power of 200, 300 and 600 mW and 1^{s}, 16^{th} and 32^{nd} channels are considered for discussion here. Fig.7 shows the eye diagrams for fixed input power of -26 dBm and three pump powers of 200, 300 and 600 mW for each of 1^{st}, 16^{th} and 32^{nd} channel. Fig. 8, 9 and 10 shows Q-factor and minimum bit error rate (BER) at different pump powers and fixed input power of -26dBm for 1^{st}, 16^{th} and 32^{nd} channel respectively. Table 7, 8 and 9 shows the numerical system parameters achieved in the simulation. From the figures and the tables it is clear that the Q-factor and Eye opening increases and BER decreases with the increase in pump power. It is also seen that these values are approximately equal for the channels under consideration. The extreme channels (1^{st} and

32nd) have slightly higher values in case of Q-factor and Eye opening and slightly lower value in case of minimum BER for intermediate channel (16th). This establishes satisfactory system performance for all 32 channels. Here the effect of inter-channel interference is assumed to be zero.

Table 4. Gains and NF at pump power 200mW & input power -26 dBm

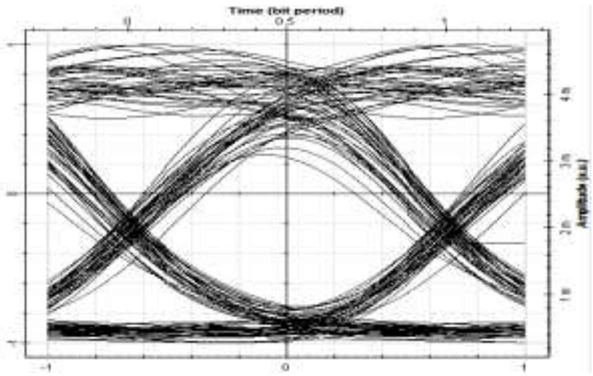
Wavelength (nm)	Gains (dB)	Noise Figure(dB)
1558.40	38.96	7.20
1558.00	39.08	7.08
1557.60	39.16	7.35
1557.20	39.24	7.28
1556.80	39.34	7.28
1556.40	39.26	7.36
1556.00	39.29	7.33
1555.60	39.28	7.47
1555.20	39.34	7.41
1554.80	39.31	7.61
1554.40	39.37	7.56
1554.00	39.31	7.61
1553.60	39.31	7.69
1553.20	39.19	7.81
1552.80	39.28	7.75
1552.40	39.16	7.87
1552.00	39.22	7.81
1551.60	39.17	7.96
1551.20	39.16	7.97
1550.80	39.11	8.06
1550.40	39.01	8.15
1550.00	38.98	8.18
1549.60	38.94	8.31
1549.20	38.92	8.33
1548.80	38.89	8.32
1548.40	38.79	8.42
1548.00	38.70	8.51
1547.60	38.70	8.58
1547.20	38.60	8.67
1546.80	38.57	8.55
1546.40	38.39	8.72
1546.00	38.30	8.81

Table 5. Gains and NF at pump power 300mW & input power -26 dBm

Wavelength (nm)	Gains (dB)	Noise Figure(dB)
1558.40	40.51	7.01
1558.00	40.64	6.87
1557.60	40.74	7.16
1557.20	40.83	7.07
1556.80	40.94	7.08
1556.40	40.87	7.15
1556.00	40.92	7.10
1555.60	40.92	7.26
1555.20	40.99	7.18
1554.80	40.98	7.40
1554.40	41.04	7.33
1554.00	41.00	7.37
1553.60	41.01	7.46
1553.20	40.90	7.57
1552.80	41.01	7.51
1552.40	40.89	7.63
1552.00	40.97	7.55
1551.60	40.93	7.71
1551.20	40.94	7.70
1550.80	40.90	7.80
1550.40	40.81	7.89
1550.00	40.80	7.90
1549.60	40.77	8.04
1549.20	40.76	8.05
1548.80	40.75	8.04
1548.40	40.66	8.13
1548.00	40.58	8.20
1547.60	40.60	8.28
1547.20	40.52	8.36
1546.80	40.49	8.24
1546.40	40.32	8.41
1546.00	40.25	8.48

Table 6. Gains and NF at pump power 600mW & input power -26 dBm

Wavelength (nm)	Gains (dB)	Noise Figure(dB)
1558.40	42.94	6.80
1558.00	43.09	6.64
1557.60	43.21	6.95
1557.20	43.32	6.84
1556.80	43.46	6.86
1556.40	43.40	6.92
1556.00	43.47	6.85
1555.60	43.49	7.02
1555.20	43.58	6.92
1554.80	43.59	7.16
1554.40	43.68	7.07
1554.00	43.65	7.09
1553.60	43.68	7.21
1553.20	43.59	7.30
1552.80	43.72	7.25
1552.40	43.62	7.35
1552.00	43.72	7.25
1551.60	43.70	7.43
1551.20	43.73	7.40
1550.80	43.71	7.52
1550.40	43.64	7.59
1550.00	43.65	7.58
1549.60	43.63	7.74
1549.20	43.65	7.72
1548.80	43.66	7.73
1548.40	43.59	7.80
1548.00	43.54	7.85
1547.60	43.58	7.95
1547.20	43.51	8.01
1546.80	43.52	7.89
1546.40	43.36	8.05
1546.00	43.30	8.10



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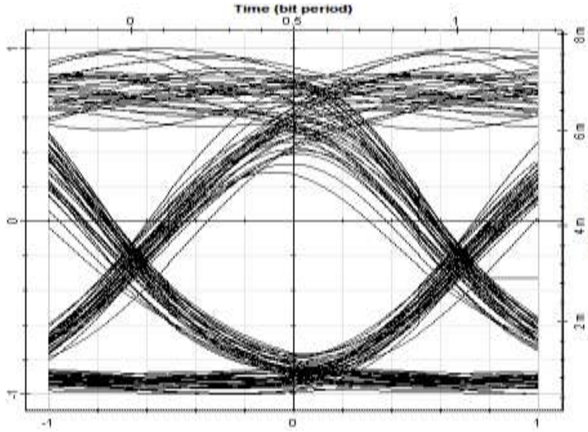

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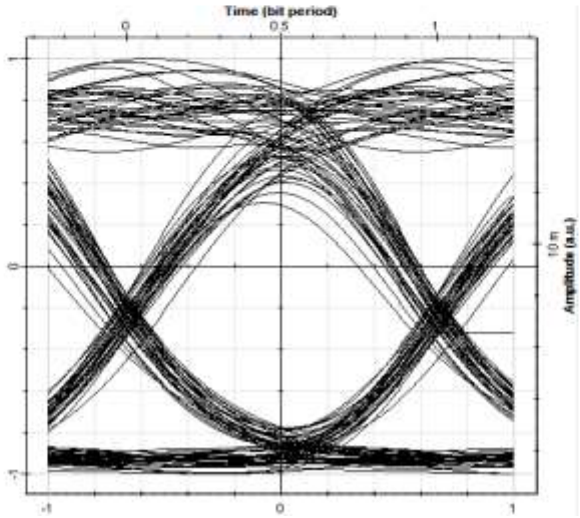

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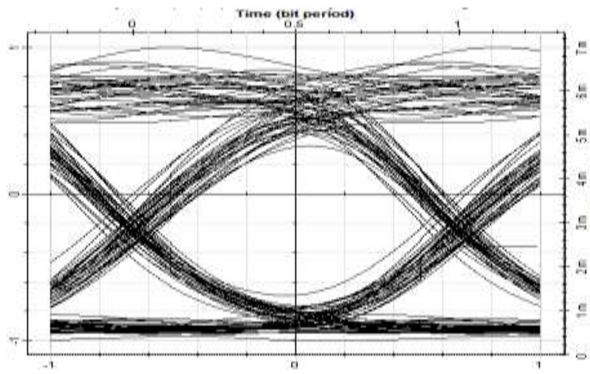

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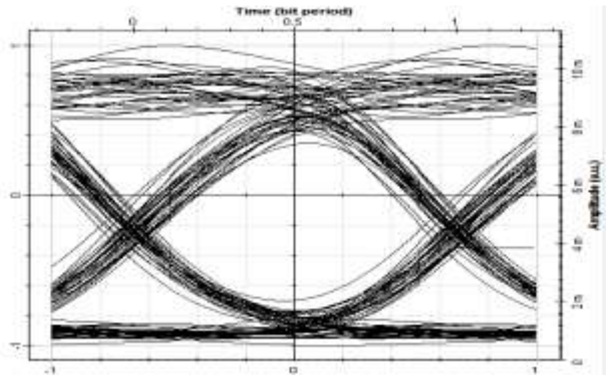

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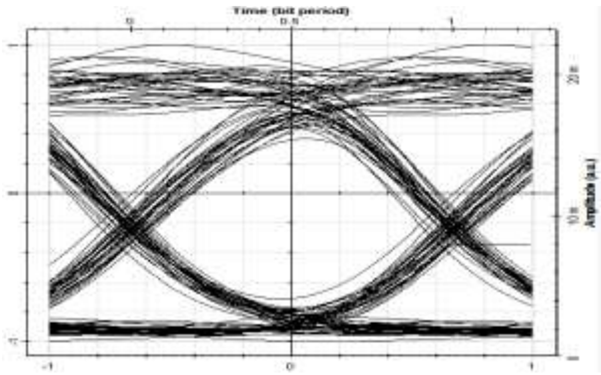

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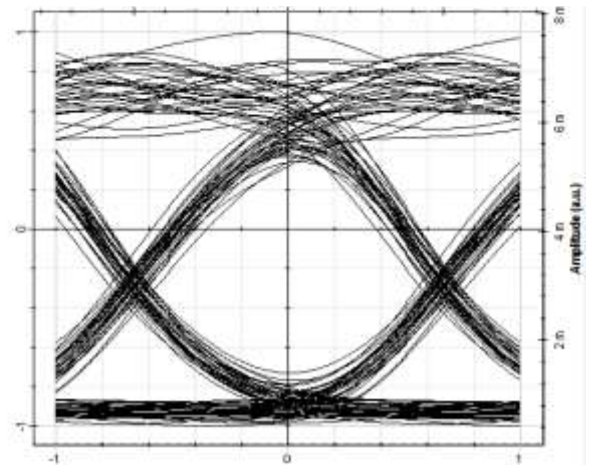

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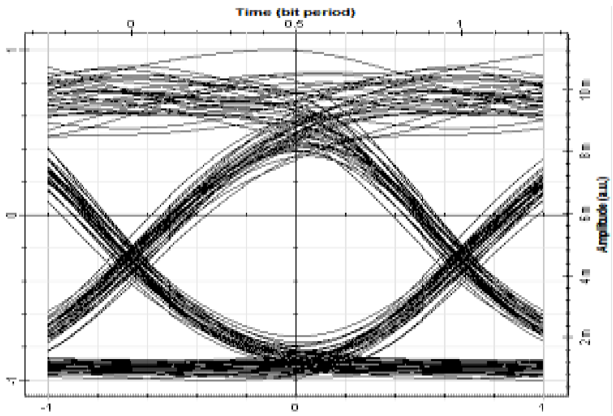

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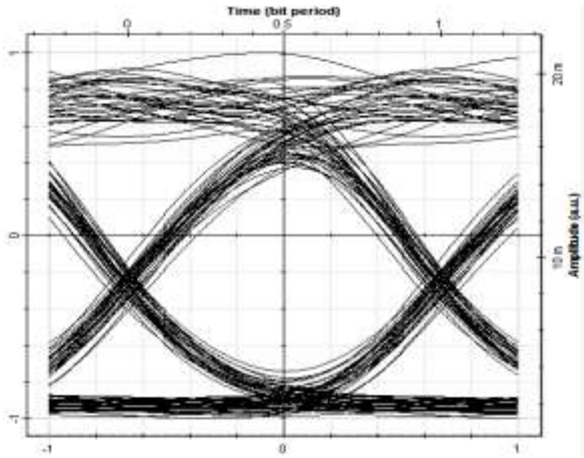
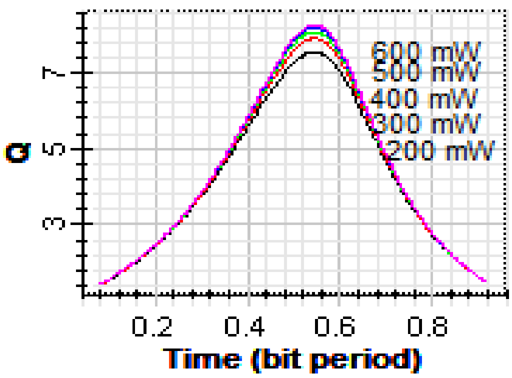


(i)

Fig. 7. Eye Diagrams for fixed input power of -26 dBm and different pump powers at
(a) 200mW (1st channel), (b) 300mW (1st channel),
(c) 600mW (1st channel)
(d) 200mW (16th channel), (e) 300mW (16th channel), (f) 600mW (16th channel)
(g) 200mW (32nd channel), (h) 300mW (32nd channel), (i) 600mW (32nd channel)



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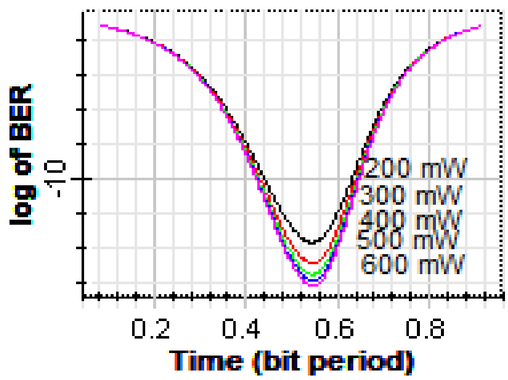
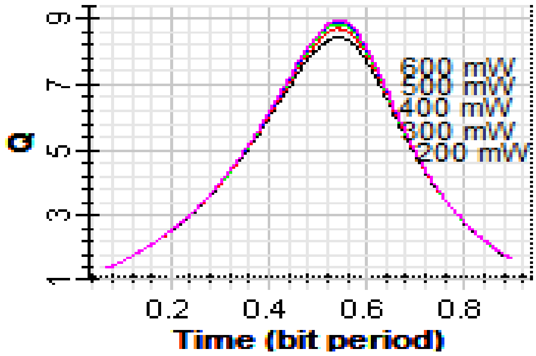


(b)

Fig. 8. (a) Q-Factor and (b) Minimum BER at different pump powers and fixed input power at -26dBm (Channel 1)



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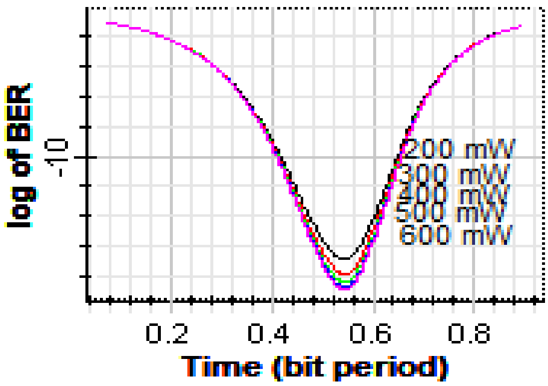
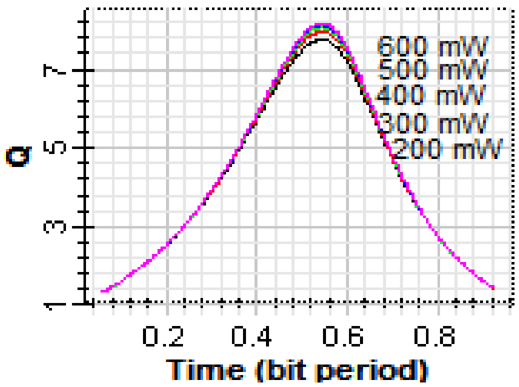


(b)

Fig. 9. (a) Q-Factor and (b) Minimum BER at different pump powers and fixed input power at -26dBm (Channel 16)



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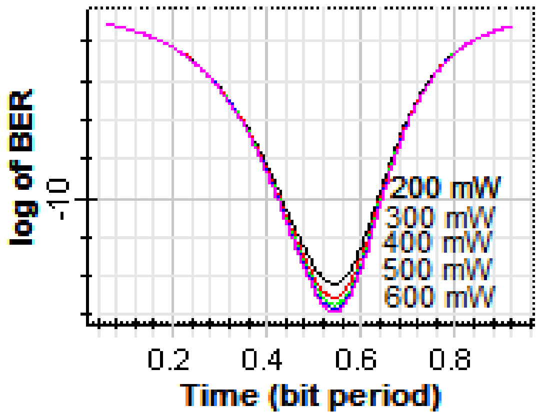

(b)

Fig. 10. (a) Q-Factor and (b) Minimum BER at different pump powers and fixed input power at -26dBm (Channel 32)

5. Conclusion

A 32 channels WDM system using EDFA in the wavelength range of 1546 to 1560 nm with channel spacing of 0.4 nm is designed and analysed for data rate of 10 Gb/s. The gain flattening of EDFA in such system is achieved through EDFA's pump power and input power variation. Results show that the gains are flattened within 43.6 ± 0.8 dB with noise figure about 7.38 dB at pump power of 600 mW and input power of -34 dBm using optimized erbium doped fiber of 6.2 m length. The performance evaluation in terms of BER, eye diagram and Q factor are also made considering three pump powers at 200, 300 & 600 mW. The simulation results show satisfactory system parameters to work with for a 32 channel DWDM system. The performance analysis can be extended using more channels and higher bit rate cases of practical importance. Channel interference issues can also be addressed in future.

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Table 7. System Parameters achieved for 1st Channel

Parameters	Pump Power 200 mW	Pump Power 300 mW	Pump Power 400 mW	Pump Power 500 mW	Pump Power 600 mW
Max. Q Factor	7.90	7.90	8.08	8.19	8.26
Min. BER	1.26E-15	1.26E-15	2.92E-16	1.18E-16	6.36E-17
Eye Height(a.u.)	0.00339	0.00339	0.00482	0.00629	0.00778
Threshold(a.u.)	0.00241	0.00241	0.00339	0.00438	0.00539
Decision Inst.(bit period)	0.54297	0.54297	0.54297	0.54297	0.54688

Table 8. System Parameters achieved for 16th Channel

Parameters	Pump Power 200 mW	Pump Power 300 mW	Pump Power 400 mW	Pump Power 500 mW	Pump Power 600 mW
Max. Q Factor	8.44	8.70	8.84	8.92	8.97
Min. BER	1.47E-17	1.47E-18	4.50E-19	2.17E-19	1.32E-19
Eye Height(a.u.)	0.00312	0.00494	0.00675	0.00855	0.01034
Threshold(a.u.)	0.00235	0.00366	0.00497	0.00626	0.00754
Decision Inst.(bit period)	0.54297	0.54297	0.54297	0.54297	0.54297

Table 9. System Parameters achieved for 32nd Channel

Parameters	Pump Power 200 mW	Pump Power 300 mW	Pump Power 400 mW	Pump Power 500 mW	Pump Power 600 mW
Max. Q Factor	7.75	7.95	8.06	8.12	8.16
Min. BER	3.98E-15	8.00E-16	3.45E-16	2.05E-16	1.43E-16
Eye Height(a.u.)	0.00323	0.00486	0.00640	0.00789	0.00933
Threshold(a.u.)	0.00229	0.00337	0.00441	0.00540	0.00637
Decision Inst.(bit period)	0.54297	0.54297	0.54297	0.54297	0.54297