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Comparative Analysis of different Configurations of Optical Amplifiers (EDFA, RAMAN and EDFA+RAMAN) for Intensity Modulated WDM System

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Abstract—*As it happens, Wavelength Division Multiplexing (WDM) makes the signal travel in optical domain so in order to directly amplify the signal in optical domain rather than converting it into electrical signal, an optical amplifier is required. Various kind of optical amplifiers have been introduced consisting of: Erbium Doped Fiber Amplifier, RAMAN amplifier and Semiconductor Optical Amplifier. To elevate the capacity Hybrid optical amplifiers like EDFA+RAMAN are more popular these days. This paper helps as a tool to present the comparison of different configurations of optical amplifiers (EDFA, EDFA and RAMAN +RAMAN) for intensity modulated WDM systems. To execute the comparison between these, the received optical power is kept approximately same at receiver's end and the total span distance between transmitter and receiver is also kept constant.*

Keywords*: Erbium Doped Fiber Amplifier(EDFA), Single Mode Fiber(SMF), Dispersion Compensating Fiber(DCF), Qualtiy Factor(Q), Bit Error Rate(BER), Carrier Suppressed Return-To-Zero(CSRZ), Non-Return-To-Zero(NRZ), Return-To-Zero(RZ)*

1. INTRODUCTION

Nowadays the use of internet is increasing by leaps and bounds so a method of transmission is needed to cater large bandwidth requirements. One of the methods to achieve this is Wavelength division multiplexing(WDM) . It is a technology that enhances the capacity and enables bidirectional communication by transmitting the whole information through multiple channels using a single fiber. The best feature of WDM is that the rate of transmitted signals is always relatively high and loss of signal integrity is very less. In WDM large amount of data is transmitted over different wavelengths on a single fiber which makes it capable of utilizing the large bandwidth of optical fiber [1-2]. Hence WDM makes optical fiber communication system an efficient system with a large channel capacity.The process of WDM is shown in fig. 1.

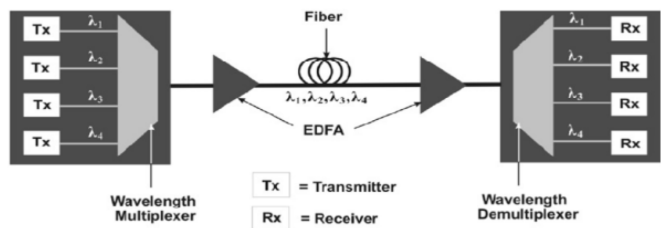

Fig. 1: Wavelength Division Multiplexing

As in WDM, an optical signal is transmitted so an amplifier is needed which can directly amplify the signal in optical domain rather than first converting into electrical signal. This type of amplifier is known as optical amplifier. In other words optical amplifier is like a laser without an optical cavity [3]. Different optical amplifiers and their Hybrid configurations are used as an emerging solution for extending the bandwidth capacity of WDM system [8]. These configurations are: EDFA, RAMAN and Hybrid of EDFA and RAMAN [4].

A device which amplifies an optical signal passes through an optical fiber is known as EDFA. The optical properties of optical fiber are changed by inserting, a small quantity of impurity in the form of a trivalent erbium ion, in the optical fiber's silica core. Dopants are inserted into silicon fiber at 980 nm or 1480 nm wavelength, using pump laser also known as pump bands, as a result amplification in 1550 nm range or we can say pump energy is transferred to the signal by stimulated emission within the length of dopant fiber. Pump laser operates bi-directionally [6]. The optical wavelength range of amplification is the factor on which the EDFA rate depends. The energy level spreads when ions are sent into the optical fiber glass which give amplification. The EDFA is provided with optical isolators on either of its sides and serve as diodes. EDFA gives better performance if amplification is to be done for ranges of 60 km [4-5].

Raman amplification is based on the principle of stimulated Raman scattering (SRS). This type of scattering is inelastic in nature. In this a Stokes wave is to be generated in the same direction as the pump wave down-shifted in frequency by 13.2 THz but the signal is amplified if it is lower in frequency than the pump. Optimal amplification occurs when the difference in wavelengths is around 13.2 THz. Raman effect is dominant in silica glass due to bending motion of Si-O-Si bond [9].

In RAMAN amplifier, the signal and pump power interact nonlinearly to achieve amplification. Two types of RAMAN amplifier are there: Distributed amplifier and Lumped amplifier. In Distributed amplifier raman fiber is the gain medium where signal and pump wavelength are multiplexed whereas in case of Lumped amplifier non linear fiber of small core size is used which causes more interaction between signal and pump wavelength [7]. It results in reduction of fiber length.

HOA is a multistage amplifier in which two or more amplifiers are cascaded. It is a promising technology for high speed broadband applications to enhance the system performance without using costly techniques. HOA increases the gain bandwidth of WDM system with least gain variation over the effective bandwidth, reduces the losses due to induced nonlinearities and avoid the constraint of high cost gain flattening filters and multi-pumps for large gain flatness

2. SYSTEM DESCRIPTION

All the simulations is performed in opti-system simulator with bit rate of 10 Gb/s. The process of WDM is shown in fig. 1. An 8 channel WDM system with 193.1 THz as first channel and 193.8 THz as last channel with frequency spacing of 0.1 THz is used. This transmitter transmits the signal with power of 2 dBm. Two different analysers are used to obtain results and graphs. These are BER analyser and optical power meter.

BER Analyzer is used to visualize results such as Q factor, BER etc. Optical power meter is used to measure the power at receiver's end.

Three different configurations of optical amplifiers: EDFA, EDFA and RAMAN +RAMAN for NRZ and RZ modulated WDM system. Some parameters of these configurations are shown in Table 1.

Table 1: Parameters used in different configurations

S. No.	Parameters	EDFA	RAMAN	EDFA+RAMAN
1.	Bit rate	10 Gb/s	10 Gb/s	10 Gb/s
2.	Length(DCF)	10 km	10 km	5 km
3.	Attenuation(SMF)	0.2 dB/km	0.2 dB/km	0.2 dB/km
4.	Attenuation(DCF)	0.5 dB/km	0.5 dB/km	0.5 dB/km
5.	Effective area(SMF)	80 µm2	80 µm2	80 µm2
6.	Effective area(DCF)	22 µm2	22 µm2	22 µm2
7.	Threshold Q factor	6	6	6
8.	Min Acceptable BER	10-9	10-9	10-9

System configuration of these three configurations is described as below:

A. EDFA

As shown in the fig.2, a WDM transmitter transmits eight different wavelengths and then the multiplexer multiplexes these wavelengths into one and transmits it on a single channel.

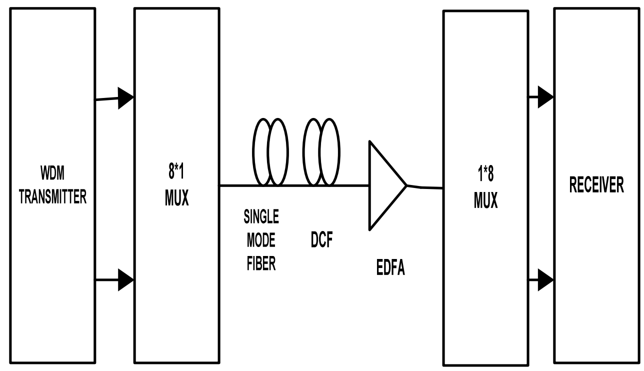

Fig. 2: Gain compensation using EDFA

It is further followed by SMF and DCF through which this multiplexed signal passes. There are different parameters like dispersion, dispersion slope, effective area, attenuation factor etc. which need to be set, some of the parameters are constant like the value of dispersion for SMF is always 16.75, dispersion slope is .75, attenuation factor is 0.2 and effective area is 80 μm^2 where as for DCF attenuation factor is 0.5 and effective area is 22 μm^2 but for DCF dispersion and dispersion slope is set according to the following formulae :

$$L_{SMF} * Disp_{SMF} = L_{DCF} * D_{DCF}$$

$$Slope_{DCF} = Slope_{SMF} * (Disp_{DCF}/Disp_{SMF})$$

After this an EDFA amplifier is applied which is used to amplify the attenuated signal and transmits it into a demultiplexer, which demultiplexes it into 8 different signals. It is followed by a receiver where output is recovered. This receiver consists of Photodetector PIN followed by a low pass filter, a 3R regenerator and a BER analyser.

B. RAMAN Amplifier

As in fig. 3 it is shown, a WDM transmitter is needed to transmit eight different wavelengths and then the multiplexer multiplexes these wavelengths into one and transmits it on a single channel. Further it is followed by RAMAN amplifier which amplifies the attenuated signal. For RAMAN amplification a pump is needed to achieve population inversion. After amplification, signal is passed through DCF. Some parameters of DCF are kept constant and others are set according to the formula discussed in system description of EDFA. Through DCF signal is transmitted into a demultiplexer which demultiplexes it into 8 different signals. At the end there is a receiver where output is recovered. This receiver consists of Photodetector PIN followed by a low pass filter, a 3R regenerator and a BER analyser.

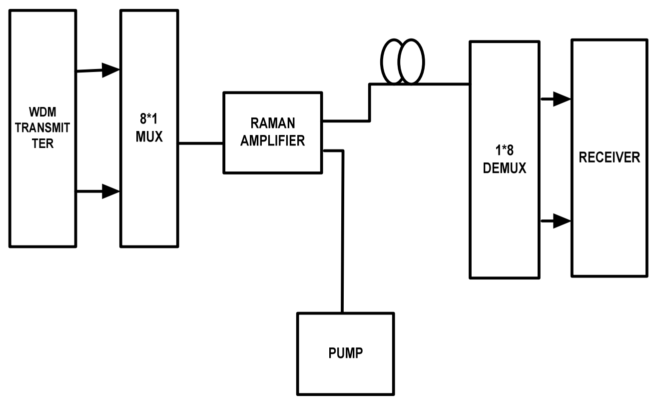

Fig. 3: Gain compensation using RAMAN

C. Hybrid of EDFA and RAMAN Amplifier

In fig. 4 it is shown a WDM transmitter transmits eight different wavelengths and then the multiplexer multiplexes these wavelengths into one and transmits it on a single channel and it is further followed by a SMF and DCF through which this multiplexed signal passes.

The parameters of SMF and DCF are set similarly as in above sections. After this the HYBRID of EDFA and RAMAN amplifies the attenuated signal and transmits it into a demultiplexer which demultiplexes it into 8 different signals. At the end there is a receiver where output is recovered. This receiver consists of Photo detector PIN followed by a low pass filter, a 3R regenerator and a BER analyser.

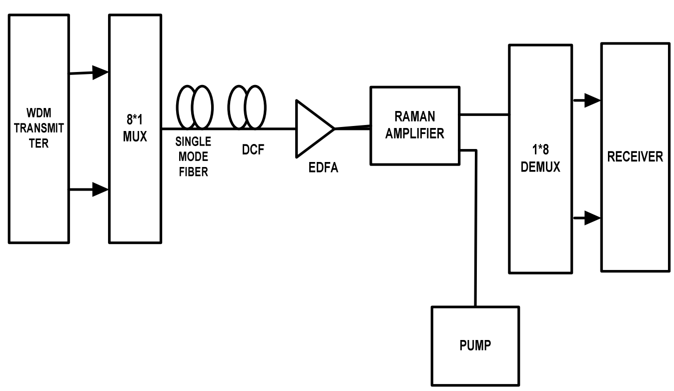

Fig. 4: Gain compensation using EDFA+RAMAN

3. RESULTS AND DISCUSSIONS

In this paper, three different configurations of optical amplifiers are compared on the basis of Q factor and BER for NRZ, RZ, CSRZ and Duobinary modulated WDM system. For this comparison we consider a constant span distance of 100 km and power at the receiver end of every configuration is approximately same and then we analyse Q factor and BER at the worst effected channel in all the configurations. We will discuss these results using both the modulation formats as follows:

A). NRZ(Non-return-to zero)

This modulation format is a binary code in which 1's are represented by a positive value and 0's are represented by a negative value. There is no rest state in this format. Different configurations for NRZ modulated WDM system are as below:

I). EDFA. SMF of length 90km, DCF of 10 km and EDFA of 1.5m is considered in this configuration. The dispersion of SMF is 16.75 and dispersion slope is .075 whereas for DCF dispersion is –150.75 and dispersion slope is -0.675 as calculated by the formula. Then power at the demultiplexer is 1.815dBm. After this fig. 5 shows the results of BER analyzer at the output for the worst effected channel and it is found that the 7th channel had the worst output resulting in a Q factor of 26.8767 and BER 1.80698e^{-159} .

II). RAMAN Amplifier. RAMAN of length 90 km and DCF of 10 km is considered in this configuration. The dispersion of SMF is 16.75 and dispersion slope is .075 whereas for DCF dispersion is -150.75 and dispersion slope is -0.675 as calculated by the formula. A a pump is required for RAMAN amplification so an array of four frequencies 1405nm, 1415nm, 1435nm, 1460nm and powers

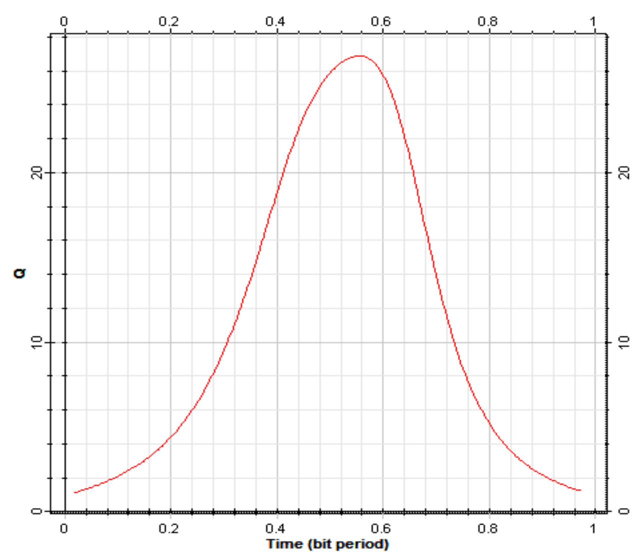

Fig. 5: Q factor at worst effected channel 7(193.7 THz) for EDFA

corresponding to these frequencies 70mw, 70mw, 160mw, 160mw respectively are taken in account. Then power at the demultiplexer is 1.304dBm. After this fig. 6 shows the results of BER analyzer at the output for the worst effected channel and it is found that the 7th channel had the worst output resulting in a Q factor of 47.7217 and BER 0.

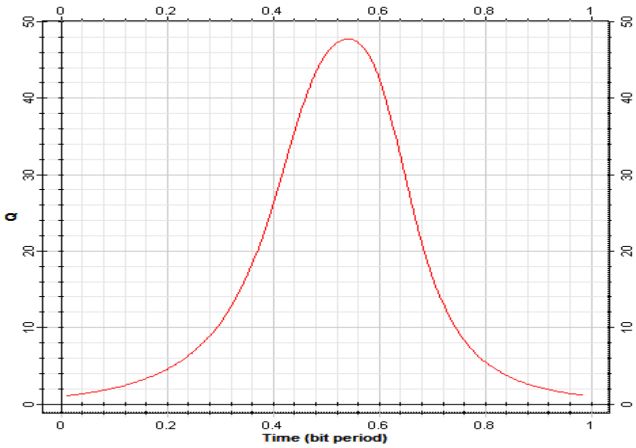

Fig. 6: Q factor at worst effected channel 7(193.7 THz) for RAMAN

III). HYBRID. SMF of length 35km, RAMAN of length 60 km, DCF of 5 km and EDFA of 1m is considered in this configuration. The dispersion of SMF is 16.75 and dispersion slope is .075 whereas for DCF dispersion is -117.25 and dispersion slope is -0.525 as calculated by the formula. A pump is required for RAMAN amplification. An array of four frequencies that are 1405 nm, 1415 nm, 1435 nm, 1460 nm and powers 20 mw, 20 mw, 60 mw and 60 mw respectively were taken in account. Then power at the demultiplexer is 1.866 dBm. After this fig. 7 shows the results of BER analyzer at the output for the worst effected channel and it is found that the 6th channel had the worst output resulting in a Q factor of 54.74 and BER 0.

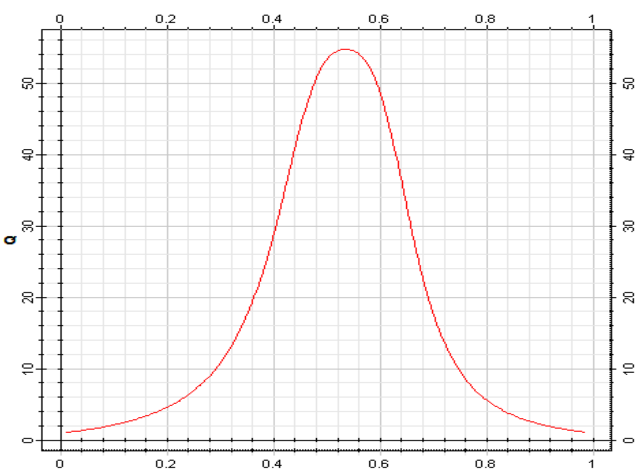

Fig. 7: Q factor at worst effected channel 6(193.6 THz) for EDFA+RAMAN

Table 2: Comparison of different configurations of optical amplifiers for NRZ modulated WDM system

Configuration	Modulation Format	Quality Factor of worst effected channel	Power at Receiver
EDFA	NRZ	26.8767	1.815 dBm
RAMAN	NRZ	47.7217	1.304 dBm
EDFA and RAMAN	NRZ	54.74	1.866 dBm

From the above table no.2 and graphs it is analysed that the Hybrid combination of EDFA and RAMAN amplifier gives better results on the basis of Q factor and BER as compared to EDFA and RAMAN amplifiers. It is also observed that RAMAN amplifier gives better result than EDFA amplifier.

B). RZ(Return-to-zero)

In this type of line code all 1's are represented by a positive value and 0's by a negative value. In between each pulse the signal returns to zero even if there are consecutive 0's or 1's in a pulse. Different configurations for NRZ modulated WDM system are as below:

I). EDFA. SMF of length 90km, DCF of 10 km and EDFA of 1.7m is considered in this configuration. The dispersion of SMF is 16.75 and dispersion slope is .075 whereas for DCF dispersion is -150.75 and dispersion slope is -0.675 as calculated by the formula. Then power at the demultiplexer is 1.843 dBm. After this fig. 8 shows the results of BER analyzer at the output for the worst effected channel and it is found that the 6th channel had the worst output resulting in a Q factor of 21.8607 and BER 2.736038e^{-106}.

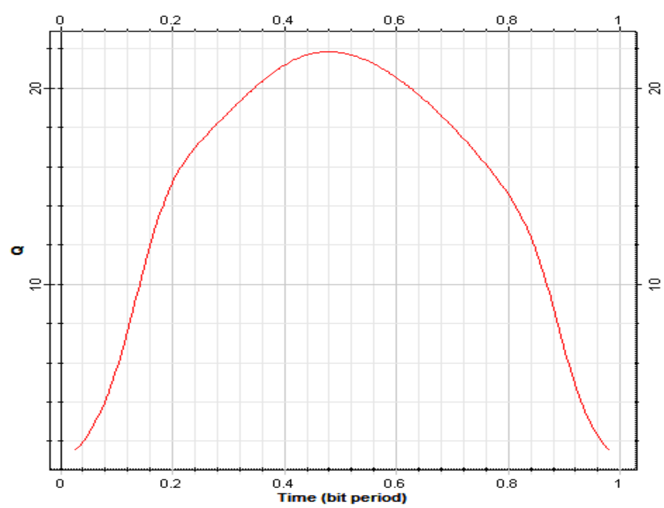

Fig. 8: Q factor at worst effected channel 6(193.6 THz) for EDFA

II). RAMAN. RAMAN of length 90 km and DCF of 10 km is considered in this configuration. The dispersion of SMF is 16.75 and dispersion slope is .075 whereas for DCF dispersion is -150.75 and dispersion slope is -0.675 as calculated by the formula.

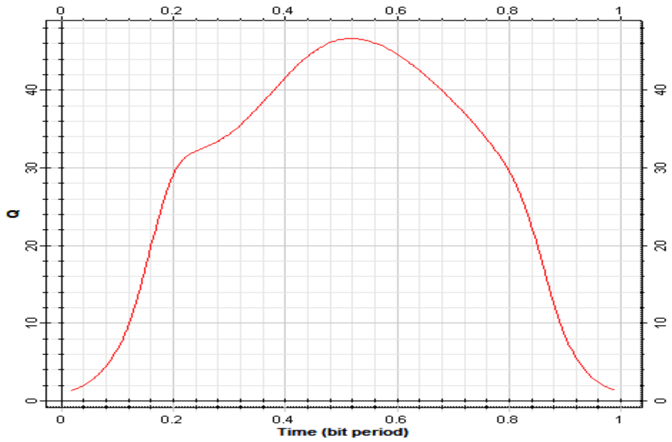

Fig. 9: Q factor at worst effected channel 6(193.6 THz) for RAMAN

A pump is required for RAMAN amplification so an array of four frequencies 1405 nm, 1415 nm, 1435 nm, 1460 nm and power corresponding to these frequencies 140 mw, 140 mw, 140 mw, 160 mw respectively are taken in account. Then power at the demultiplexer is 1.757 dBm. After this fig. 9 shows the results of BER analyzer at the output for the worst effected channel and it is found that the 6th channel had the worst output resulting in a Q factor of 46.6809 and BER 0.

III). HYBRID. SMF of length 35km, RAMAN of length 60 km, DCF of 5 km and 1m is considered in this configuration. The dispersion of SMF is 16.75 and dispersion slope is .075 whereas for DCF dispersion is-117.25 and dispersion slope is -.525 as calculated by the formula.

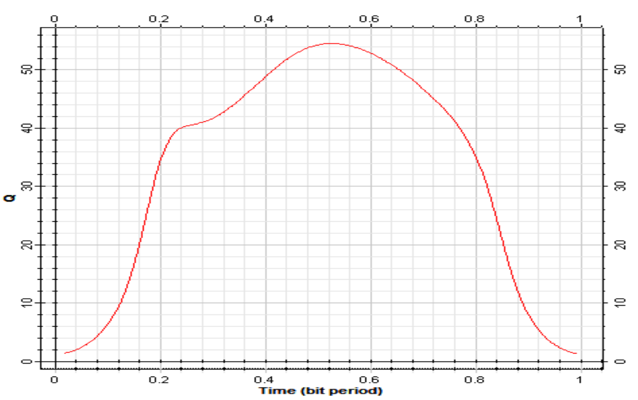

Fig. 10: Q factor at worst effected channel 6 (193.6 THz) for EDFA+RAMAN

A pump is required for RAMAN amplification. An array of four frequencies that are 1405 nm, 1415 nm, 1435 nm, 1460 nm and powers 60 mw, 60 mw, 60 mw, 60 mw respectively were taken in account. Then power at the demultiplexer is 1.027 dBm. After this fig. 10 shows the results of BER analyzer at the output for the worst effected channel and it is found that the 6th channel had the worst output resulting in a Q factor of 54.5309 and BER 0.

Table 3: Comparison of different configurations of optical amplifiers for RZ modulated WDM system

Configuration	Modulation Format	Quality Factor of worst effected channel	Power at Receiver
EDFA	RZ	21.8607	1.843 dBm
RAMAN	RZ	46.6809	1.757 dBm
EDFA and RAMAN	RZ	54.5309	1.027 dBm

From the above table no.3 and graphs it is analysed that the Hybrid combination of EDFA and RAMAN amplifier gives better results on the basis of Q factor and BER as compared to EDFA and RAMAN amplifiers. It is also observed that RAMAN amplifier gives better result than EDFA amplifier.

C). CSRZ(Return-to-zero)

CSRZ is an optical signal format. In this the field intensity drops to zero between consecutive bits and the field phase alternates by π between neighbouring bits, that means the phase of the signal in even bits (bit number $2n$) and odd bit slots (bit number $2n+1$) differ by π. Different configurations for CSRZ modulated WDM system are as below:

1).EDFA. SMF of length 90km, DCF of 10 km and EDFA of 1.7m is considered in this configuration. The dispersion of SMF is 16.75 and dispersion slope is .075 whereas for DCF dispersion is -150.75 and dispersion slope is -0.675 as calculated by the formula. Then power at the demultiplexer is 1.839 dBm. After this fig. 11 shows the results of BER analyzer at the output for the worst effected channel and it is found that the 7th channel had the worst output resulting in a Q factor of 33.8946 and BER 2.78964e^{-252}.

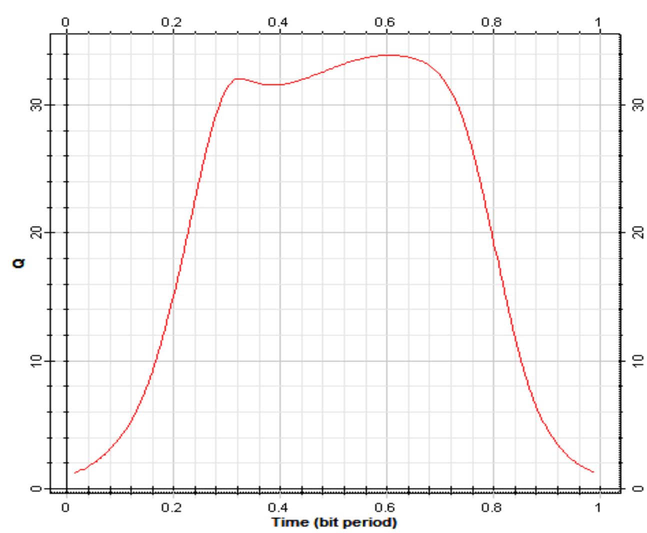

Fig. 11: Q factor at worst effected channel 7(193.7 THz) for EDFA

II). RAMAN. RAMAN of length 90 km and DCF of 10 km is considered in this configuration. The dispersion of SMF is 16.75 and dispersion slope is .075 whereas for DCF dispersion is -150.75 and dispersion slope is -0.675 as calculated by the formula. A pump is required for RAMAN amplification so an array of four frequencies 1405 nm, 1415 nm, 1435 nm, 1460 nm and power corresponding to these frequencies 140 mw, 140 mw, 150 mw, 150 mw respectively are taken in account. The power at the demultiplexer is 1.297 dBm. After this fig. 12 shows the results of BER analyzer at the output for the worst effected channel and it is found that the 7th channel had the worst output resulting in a Q factor of 67.0398 and BER 0.

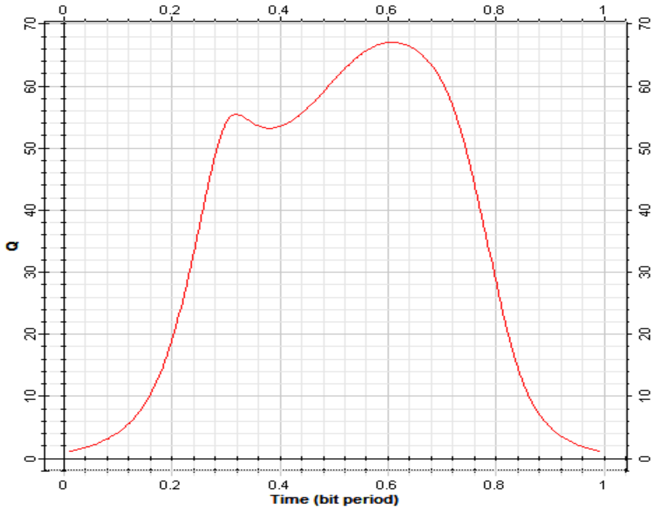

Fig. 12: Q factor at worst effected channel 7(193.7 THz) for RAMAN

III). HYBRID. SMF of length 35km, RAMAN of length 60 km, DCF of 5 km and 1m is considered in this configuration. The dispersion of SMF is 16.75 and dispersion slope is .075 whereas for DCF dispersion is-117.25 and dispersion slope is -.525 as calculated by the formula.

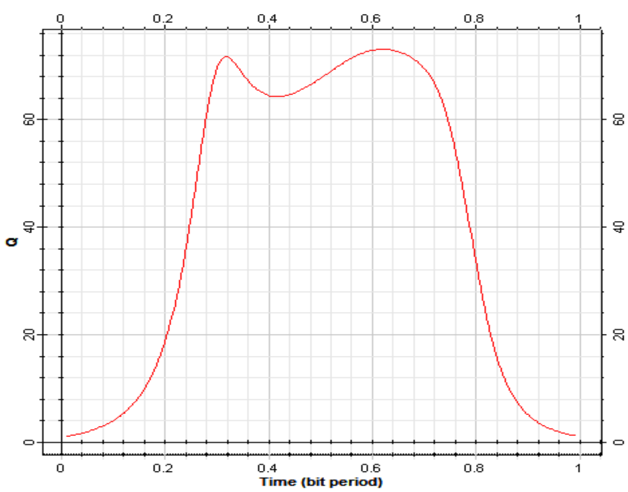

Fig. 13: Q factor at worst effected channel 1(193.1 THz) for EDFA+RAMAN

A pump is required for RAMAN amplification. An array of four frequencies that are 1405 nm, 1415 nm, 1435 nm, 1460 nm and powers 60 mw, 60 mw, 60 mw, 60 mw respectively were taken in account. The power at the demultiplexer is 1.024 dBm. After this fig. 13 shows the results of BER analyzer at the output for the worst effected channel and it is found that the 1st channel had the worst output resulting in a Q factor of 73.0937 and BER 0.

Table 4: Comparison of different configurations of optical amplifiers for CSRZ modulated WDM system

Configuration	Modulation Format	Quality factor of Worst effected Channel	Power at Receiver (dBm)
EDFA	CSRZ	33.8946	1.839
RAMAN	CSRZ	67.0398	1.297
EDFA and RAMAN	CSRZ	73.0937	1.024

From the above table no.4 and graphs it is analysed that the Hybrid combination of EDFA and RAMAN amplifier gives better results on the basis of Q factor and BER as compared to RAMAN amplifer and EDFA amplifier. It is also observed that RAMAN amplifier gives better result than EDFA amplifier.

D). Duobinary

Duobinary is a type of line code, where two nonzero values are used. In this code, a binary 0 is encoded as zero volts, as in unipolar encoding, whereas a binary 1 is encoded alternately as a positive voltage or a negative voltage. Hence in Duobinary there is a balance of positive and negative voltages. Different configurations for Duobinay modulated WDM system are as below:

I). EDFA. SMF of length 90km, DCF of 10 km and EDFA of 1.75 m is considered in this configuration. The dispersion of SMF is 16.75 and dispersion slope is .075 whereas for DCF dispersion is -150.75 and dispersion slope is -0.675 as calculated by the formula. Then power at the demultiplexer is 1.502 dBm. After this fig. 14 shows the results of BER analyzer at the output for the worst effected channel and it is found that the 7th channel had the worst output resulting in a Q factor of 28.1084 and BER 2.7826e^{-174}.

II). RAMAN. RAMAN of length 90 km and DCF of 10 km is considered in this configuration. The dispersion of SMF is 16.75 and dispersion slope is .075 whereas for DCF dispersion is -150.75 and dispersion slope is -0.675 as calculated by the formula. A pump is required for RAMAN amplification so an array of four frequencies 1405 nm, 1415 nm, 1435 nm, 1460 nm and power corresponding to these frequencies 135 mw, 140 mw, 160 mw, 160 mw respectively are taken in account. Then power at the demultiplexer is 1.097 dBm. After this fig. 15 shows the results of BER analyzer at the output for the worst effected channel and it is found that the 5th channel had the worst output resulting in a Q factor of 62.2196 and BER 0.

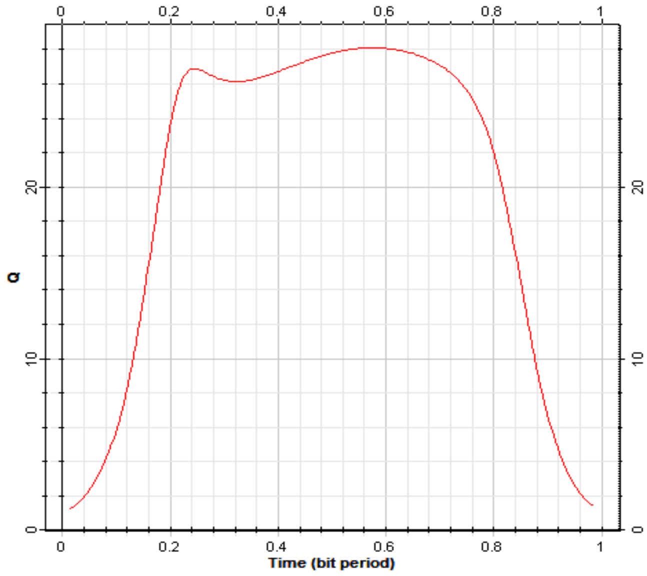

Fig. 14: Q factor at worst effected channel 7(193.7 THz) for EDFA

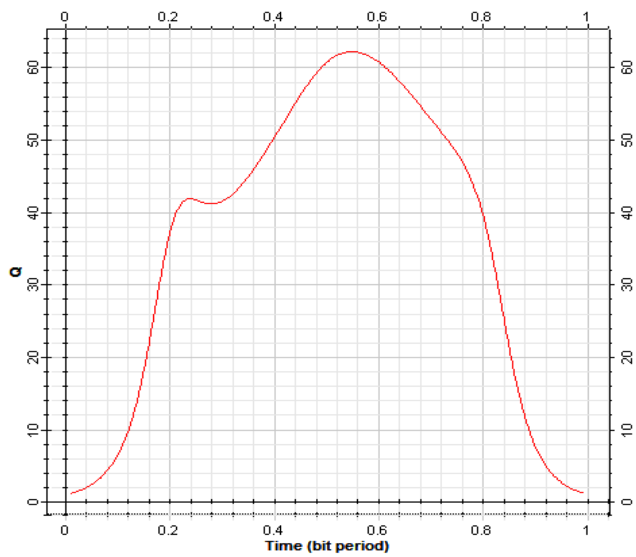

Fig. 15: Q factor at worst effected channel 5(193.5 THz) for RAMAN

III). HYBRID. As HOA is a multistage amplifier in which two or more amplifiers are cascaded. In this paper EDFA and Raman amplifiers are cascaded to make an HOA. The specifications of various components used in this configuration are such as a Single Mode Fiber of length 35km, RAMAN of length 60 km, Dispersion Compensating Fiber of 5 km and 1m is considered. The dispersion of SMF is 16.75 and dispersion slope is .075 whereas for Dispersion Compensating Fiber dispersion is-117.25 and dispersion slope is -.525 as calculated by the formula mentioned in system description.

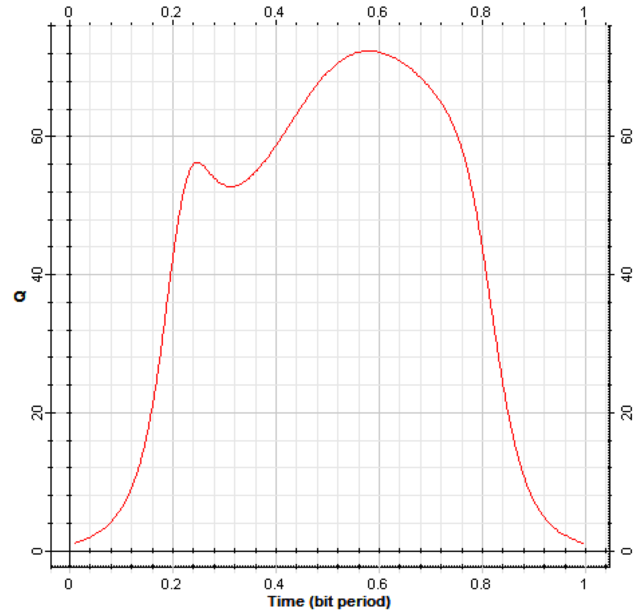

Fig. 16: Q factor at worst effected channel 6 (193.6 THz) for EDFA+RAMAN

A pump is required for RAMAN amplification. An array of four frequencies that are 1405 nm, 1415 nm, 1435 nm, 1460 nm and powers 20 mw, 20 mw, 90 mw, 100 mw respectively were taken in account. Then power at the demultiplexer is 1.796 dBm. After this fig. 16 shows the results of Bit Error Rate analyzer at the output for the worst effected channel and it is found that the 6th channel had the worst output resulting in a Q factor of 72.4138 and BER 0.

Table 5: Comparison of different configurations of optical amplifiers for Duobinary modulated WDM system

Configuration	Modulation Format	Quality factor of Worst effected Channel	Power at Receiver (dBm)
EDFA	Duobinary	28.1084	1.502
RAMAN	Duobinary	62.2196	1.097
EDFA and RAMAN	Duobinary	72.4138	1.796

From the above table no.5 and graphs it is analysed that the Hybrid combination of EDFA and RAMAN amplifier gives better results on the basis of Q factor and BER as compared to RAMAN amplifier and EDFA amplifier. It is also observed that RAMAN amplifier gives better result than EDFA amplifier.

4. CONCLUSION

At the end among all the configurations of optical amplifiers Hybrid Optical Amplifier gives the best results for intensity modulated WDM system(HOA > RAMAN > EDFA) in all modulation formats: NRZ, RZ, CSRZ and Duobinary when compared amongst the worst effected channels of different configurations. Among the modulation formats CSRZ modulated WDM system gives better results as compared to Duobinary, NRZ and RZ modulated WDM system.(CSRZ > Duobinary > NRZ > RZ). To make the comparison more effective and relevant it is performed by taking constant span distance and similar power at the receiver's end. Although the signal power remained approximately same for all the configurations, it is observed that the Q factor in case of Hybrid (NRZ - 52.8288, RZ - 54.5309, CSRZ-73.0937, Duobinary-72.4138) was maximum, as the noise was minimum in this case. Hence it is evident that the Hybrid amplifier works best for gain compensation. It is also observed that RAMAN gives better results than EDFA.

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