Different Pumping Categories of Erbium Doped Fiber Amplifiers Performance Signature With Both Wide Multiplexing and Modulation Techniques

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Abstract— In this paper, dense wavelength division multiplexing (DWDM) for upgrading optical communication systems capacity can be used with different modulation formats that are namely: NRZ (non return to zero), RZ (return to zero) and on-off keying and change the number of channels then show the effect of this on the three different optical pumping techniques. Here optiwave simulation program version 7 can be used with changing the following parameters: EDFA length, pumping power, pumping wavelength, input signal power and also fiber length then we measure the quality factor, BER, input power, output power, Gain, noise figure and bit rate. Based on the simulation results that can be shown later the best pumping technique and the best modulation format for the different number of channels can be shown.

Index Terms— EDFA, DWDM, NRZ, RZ, OFF and on-off keying.

I. INTRODUCTION

In recent years the era of fiber optic communication technology has undergone tremendous growth due to the enormous capacity demand for data transmission systems [1]. In long haul point to point optical fiber communication systems the major problem comes from the various losses that the signal traveling inside the fiber suffers from such as fiber tap losses, attenuation losses, etc [2]. These losses beside the optical power loss that caused by scattering and absorption in the optical fiber are the most important factors limiting the transmission distance in optical fiber communication systems [3]. So, the need for away to compensate and overcome the increased power losses with distance becomes the most urgent and necessary task. Firstly, Electrical repeaters appear as a first solution to allow transmission of signals over long distance [4]. But due to the complexity and the increased installation costs of such repeaters in optical communication systems [5] optical amplifiers appeared and developed and then came partially into the use commercially. Actually the time goes for further improvements [6] and this can appear obviously in optical amplifiers that make the optical signals amplified optically without conversion and also cancel the use of repeaters [7].

The challenging requirement for Wavelength division multiplexing applications is WDM for fiber to the home local access systems [8]. Wavelength division multiplexing (WDM) systems is the core of the universal telecommunication network [9] and also it is the most classic solutions for increasing transmission capacity [5]. WDM is a technology that allows bidirectional communications over one rope of fiber as well as multiplication of capacity and also this bring new essential for optical surveillance and system performance [10]. Depending on the value of the channel spacing WDM systems are divided into coarse or dense. The denser version of WDM is the dense wavelength division multiplexing (DWDM) that result from advances made in the tuning of lasers and wavelength filtering combine different channels to upgrade the capacity of the existing optical networks [11] and also to carry data traffic along with voice traffic[12]. DWDM meet the need for intelligent optical network capability and for increasing the bandwidth without changing the already installed fiber cables [13].

Transmitting the signals over long distance causes degradation of the signals so optical amplifiers comes to boost up these signals [14]. there are different types of optical amplifiers but The key components in wavelength division multiplexing systems in optical communication systems is Erbium doped fiber amplifiers (EDFA)[15, 6]. Erbium is the most interesting element as EDFA can operate in a broad range within 1550 nm window at which the silica attenuation in minimum [16,17]. EDFAs are now used for the combined C and L bands [18]to accommodate bandwidth-hungry internet based applications of the near future and also offer much wider transmission window for the dense WDM systems [19]. EDFA is the most commercially used optical fiber amplifier and also it offers many merits [20,21, 22]and also away to compensate losses. The saturation effects in conjunction with the non uniform gain spectrum of EDFAs lead to decrease in the optical signal to noise ratio and increase in signal power levels to unacceptable values in the systems [23]. For ultra high capacity optical transmission systems the bandwidth of C and L bands is no longer sufficient to meet the current day to day demands of data transmission. So, As a result for this several new optical amplification technologies begin to exist such as S- band EDFA[18]. There are three optical pumping techniques for EDFA namely co-pumping, counter-pumping and bidirectional pumping [24].

II. SIMULATION SETUP

To study the effect of using different number of channels up to 256 channels on the performance of the different pumping techniques that is namely: co-pumping (forward pumping), counter pumping (backward pumping) and bidirectional pumping we use optiwave simulation program version 7 to achieve this goal. We also use three different modulation formats such as NRZ, RZ and OFF. Both RZ and NRZ coding is generated by the engines of the RZ Pulse Generator and NRZ Pulse Generator respectively. By selecting off as modulation type of the transmitter a CW operation is possible. We do this by using the following three circuit diagrams to achieve this goal:

Co pumping (forward pumping):

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In this technique both signals i.e. input and pump propagate in the same direction inside the fiber and they are combined using pump co-coupler or wavelength selective coupler (WSC). Inside the fiber, pump energy is transferred to signal at the input and amplified signal is received at the output of the amplifier.

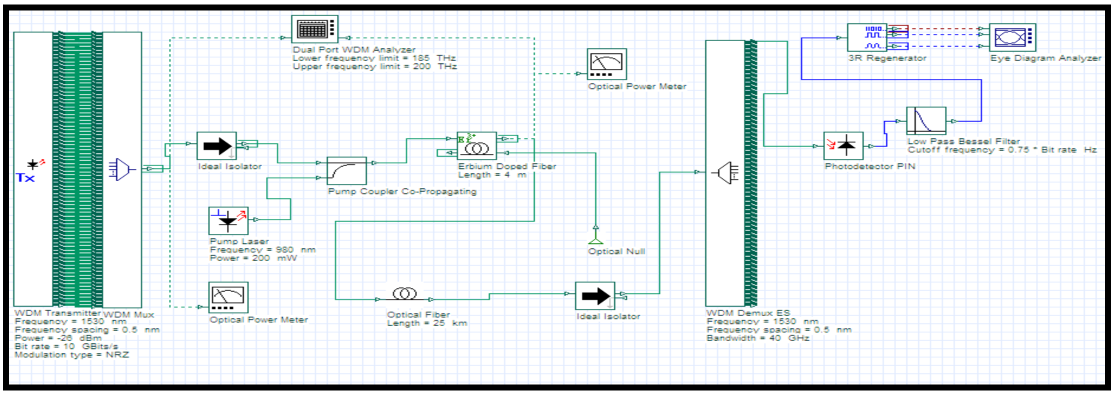

Fig. 1. Model of simulation system in case of forward pumping.

Counter-pumping (backward pumping):

This technique allows the input and pump signals to propagate in opposite direction to each other in the fiber. The direction of both signals is not essential for amplification and they can travel in any direction.

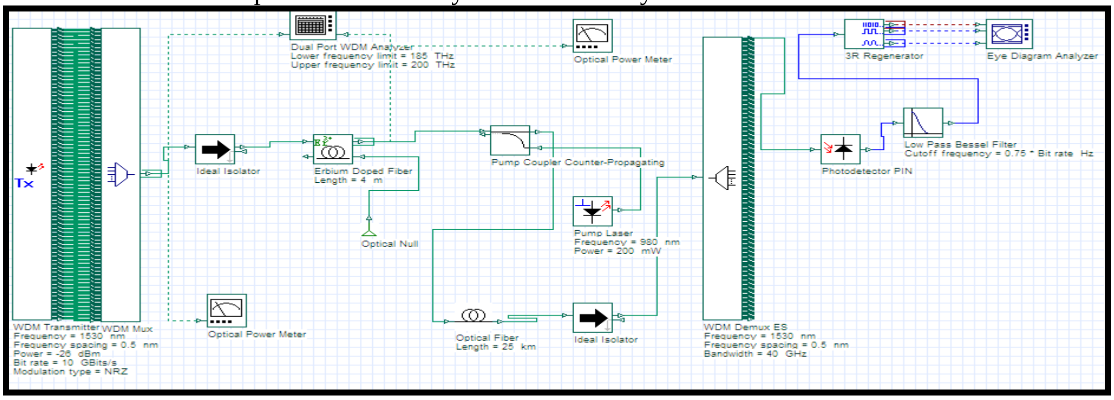

Fig. 2. Model of simulation system in case of backward pumping.

Bidirectional pumping:

Here both signals input and pump travel in one direction but there are two pump signals that travel inside the fiber. One of the two pumps travels in the same direction as the input signal and the other pump signal travels in the opposite direction of the input signal.

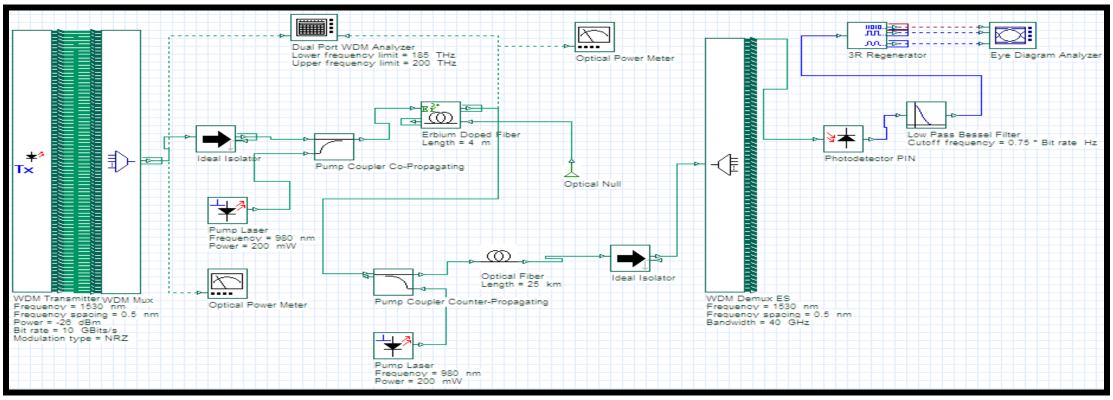

Fig. 3. Model of simulation system in case of bidirectional pumping.

i) WDM transmitter: It is a transmitter array that allows for different modulation types and schemes. It also encapsulates different components and allows users to select different modulation formats and schemes for multiple channels in one single component.

ii) Ideal isolator: it is a device used to ensure that the signal travel in one direction only and there is no feedback for this signal.

iii) Pump laser: it generates an optical signal to be used for optical amplifier pumping.

iv) Pump Coupler Co-Propagating: it can control the attenuation of the signal and pump independently and also the input signals are attenuated and combined.

v) Erbium doped fiber amplifier: it is a bidirectional Erbium doped fiber considering ESA, ion-ion interactions, Raleigh scattering and temperature dependence effects. It also used to perform fast performance analysis of one or more cascaded amplifier in long haul system.

vi) Optical null: it generates an optical signal with zero value.

vii) Pump Coupler Counter-Propagating: it is a subsystem used to control the attenuation of the signal and pump independently.

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viii) Optical fiber: it simulates the propagation of an optical field in a single-mode fiber taken into account the dispersive and nonlinear effects.

ix) Wavelength division multiplexing demultiplexer Equally Spaced (WDM DEMUX ES): it is used to demultiplex a user-defined number of WDM signal channels. The internal filters have a center frequencies that are equally spaced (ES).

x) Photo detector PIN: it is a component that is used to convert an optical signal into an electrical one.

xi) Low pass Bessel filter: this component allows the incoming optical signal and noise pins to be filtered by an ideal filter to reduce the number of samples in the electrical signals.

xii) 3R regenerator: it is used to regenerate an electrical signal and recover the original bit sequence for all the WDM channels.

xiii) Eye Diagram Analyzer: it is avisualizer used to display the electrical signal eye diagram automatically. It is used also to calculate different metrics such as eye diagram, quality factor, eye height, extinction ratio, eye closure, etc.

xiv) Optical power meter: it is used to measure and display the average power of optical signals.

xv) Dual port WDM Analyzer: it is a component that automatically detects and displays the optical power, noise figure, gain, OSNR, SNR, frequency and wavelength for each WDM channel.

xvi) WDM multiplexer: it is a component used to multiplex a user-defined number of input WDM signal channels.

III. Simulation Results and Performance Analysis

The effect of using different number of channels for the different pumping configuration of EDFA that are namely: co-pumping (forward pumping), counter-pumping (backward pumping) and bidirectional pumping can be employed and also this achieved for the different modulation formats such as: NRZ, RZ and on-off keying. The following simulation parameters shown to achieve this goal as shown in the following Table 1:

Table. 1. Simulation parameters used in this model [2, 6, 24, 25]

Operating parameters	value
Signal Input power	-26 dBm
Signal wavelength	1530 nm
Frequency spacing	0.5 nm
Number of output ports	64, 128, 256 output ports
Fiber length	25 km
EDFA length	4, 6, 8, 10 m
Pumping wavelength	980, 1480 nm
Pumping power	200 mW

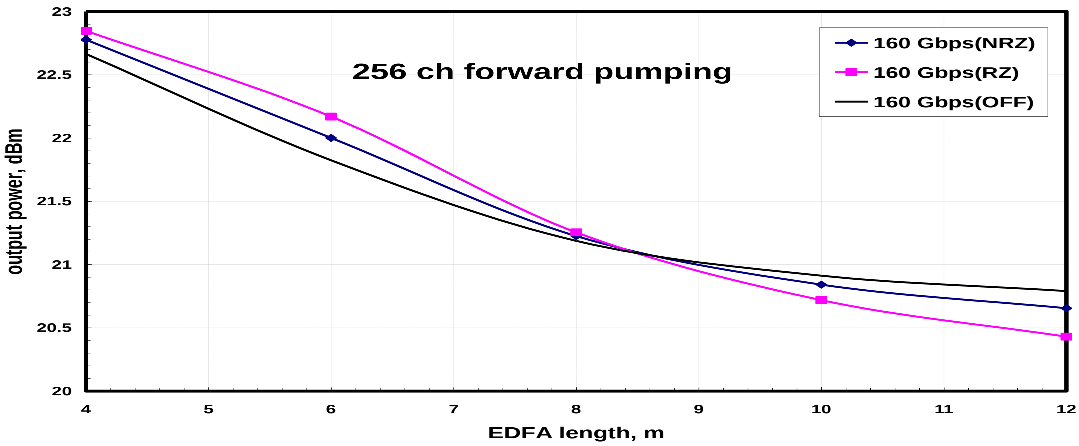

Fig. 4. Output power versus EDFA length for the different modulation formats.

This figure shows that the output power decreases with increasing EDFA length for the different modulation formats. RZ modulation format has the largest value of output power compared to both NRZ and OFF modulation formats and this occur before 8 m EDFA. But after 8 m EDFA the output power of RZ has the lowest value compared to both NRZ and OFF modulation formats at 160 Gbps forward pumping.

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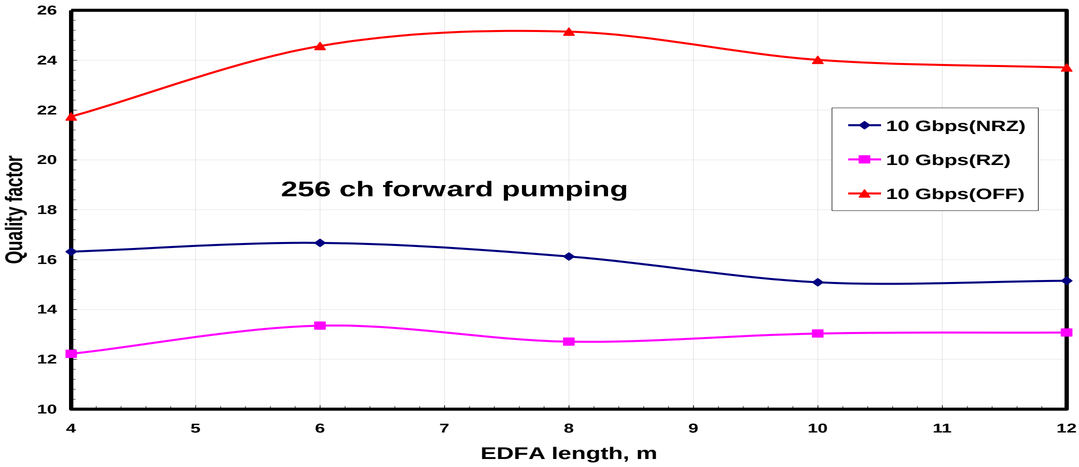

Fig. 5. Quality factor versus EDFA length for the different modulation formats.

This figure shows that the quality factor starts to increase for small values of EDFA length until nearly 8 m and then it decreases with increasing EDFA length further this value. OFF modulation formats has the largest value of quality factor compared to both RZ and NRZ modulation formats and this occur in the case of forward pumping.

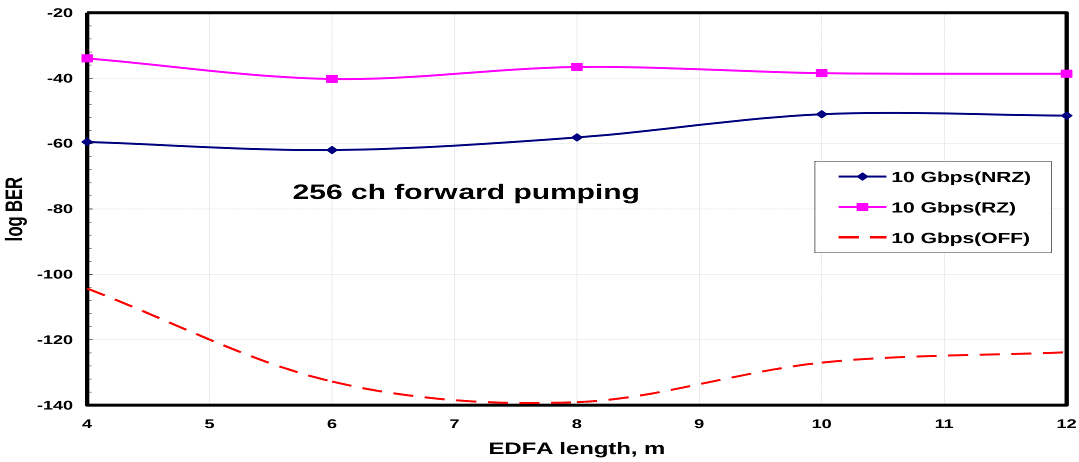

Fig. 6. BER versus EDFA length for the different modulation formats.

It is observed from this figure that the value of bit error rate decreases for the lowest EDFA length and then begin to increase for the greatest EDFA length. RZ modulation type has the largest value of BER and OFF modulation type has the lowest value in the case of forward pumping.

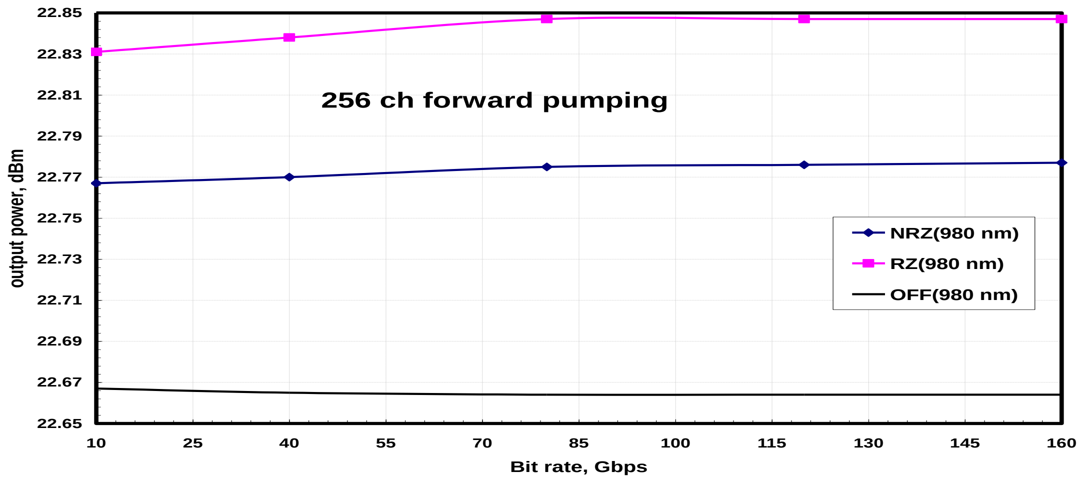

Fig. 7. Output power versus bit rate for the different modulation types.

This figure shows that in the case of forward pumping the value of output power increases with increasing the value of bit rate. Also RZ modulation format has the largest value of output power compared to both NRZ and OFF modulation formats and this occur at 980 nm pumping wavelength.

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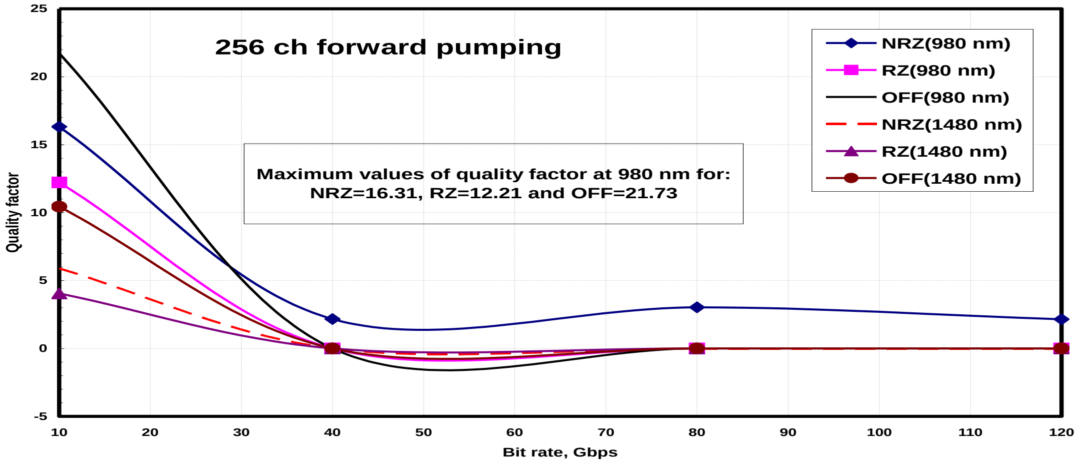

Fig. 8. Quality factor versus bit rate for different pumping wavelengths.

This figure shows that the quality factor at 980 nm pumping wavelength is greater than the quality factor at 1480 nm pumping wavelength. OFF modulation format has the largest value of quality factor and this value decreases with increasing the value of bit rate in case of forward pumping.

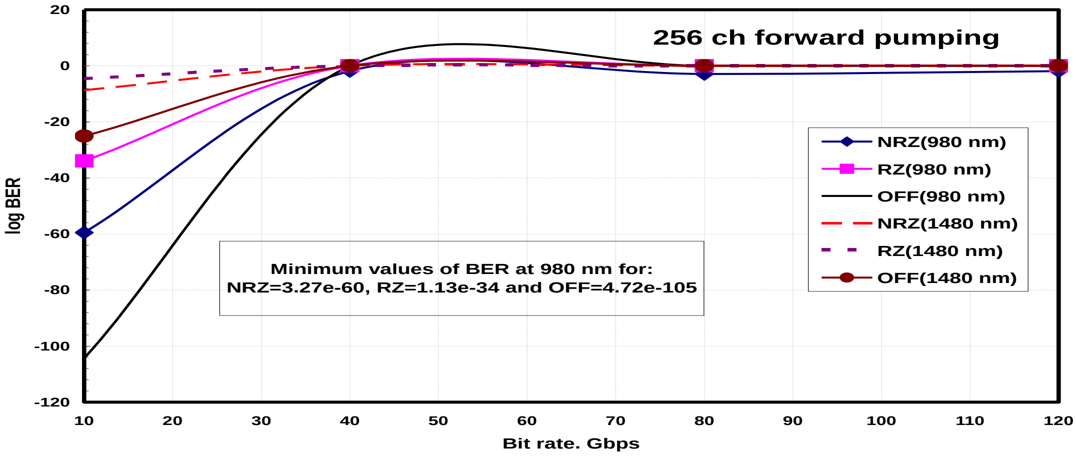

Fig. 9. BER versus bit rate for the different pumping wavelengths.

It is observed from this figure that in case of forward pumping the value of BER increases with increasing the value of bit rate. RZ modulation format at 1480 nm has the largest value of BER compared to other used modulation formats.

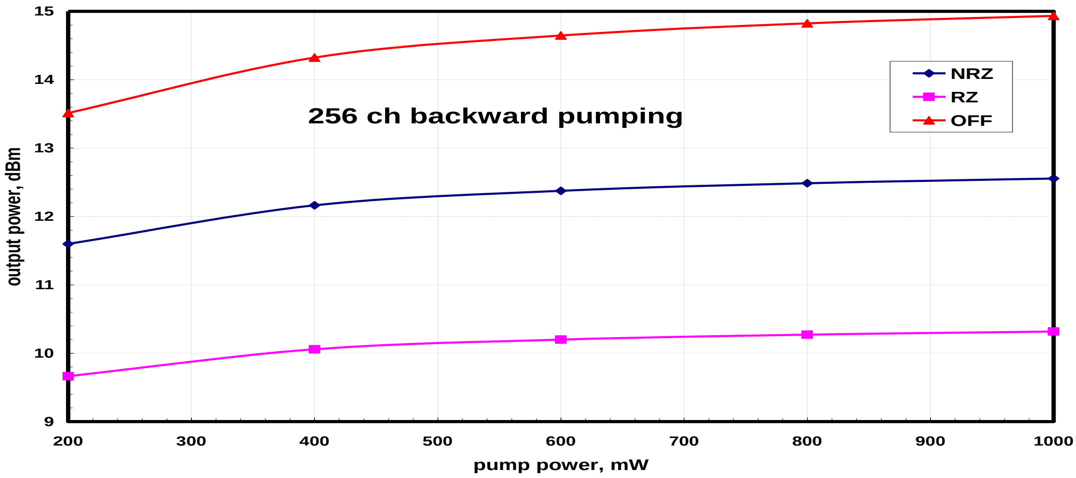

Fig. 10. output power versus pump power for the different modulation formats.

This figure shows that in case of backward pumping OFF modulation format has the largest value of output power compared to both RZ and NRZ modulation formats and this value increases with increasing pump power.

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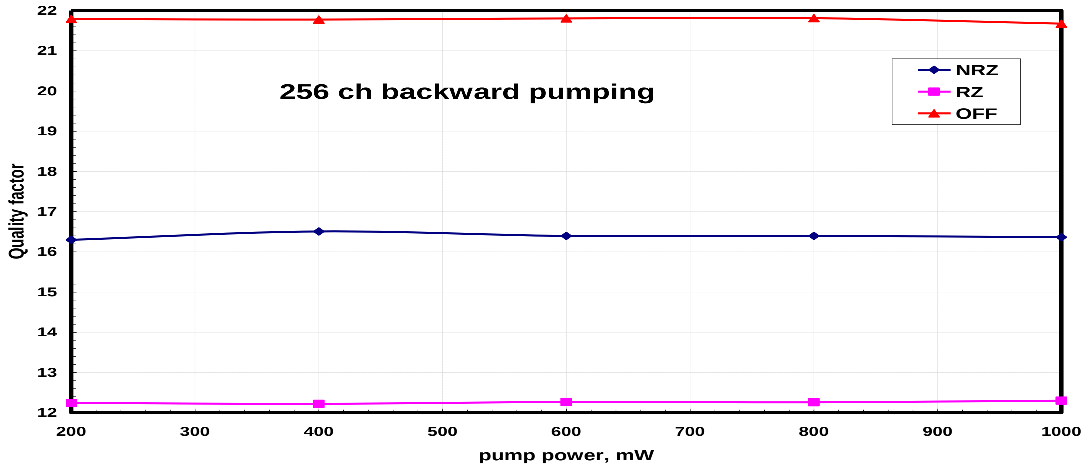

Fig. 11. Quality factor versus pump power for the different modulation formats.

This figure shows that the quality factor slightly increases with increasing the value of pump power. RZ modulation format has the lowest value of quality factor compared to OFF modulation format that has the largest value of quality factor.

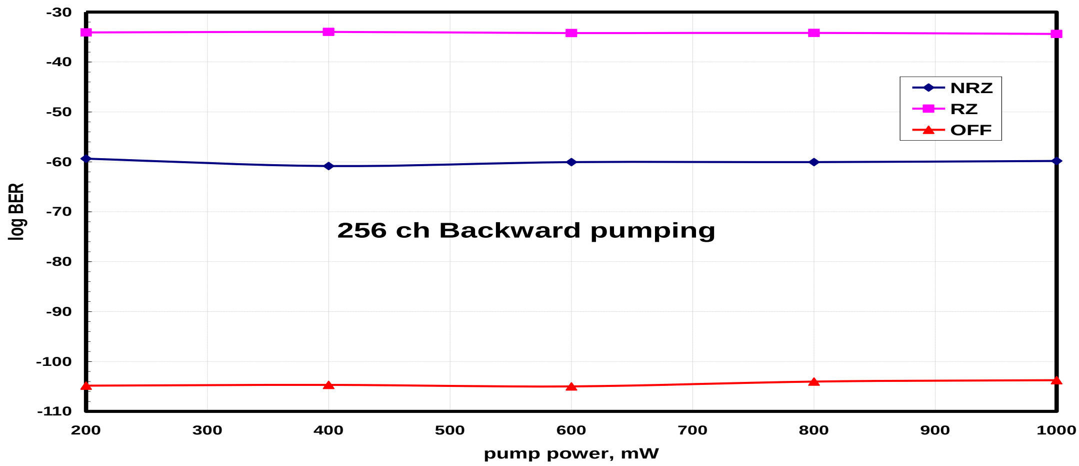

Fig. 12. BER versus pump power for the different modulation formats.

This figure shows that RZ modulation format has the largest value of BER compared to both NRZ and OFF modulation formats. The value of BER slightly decreases with increasing pump power and this occurs in case of backward pumping.

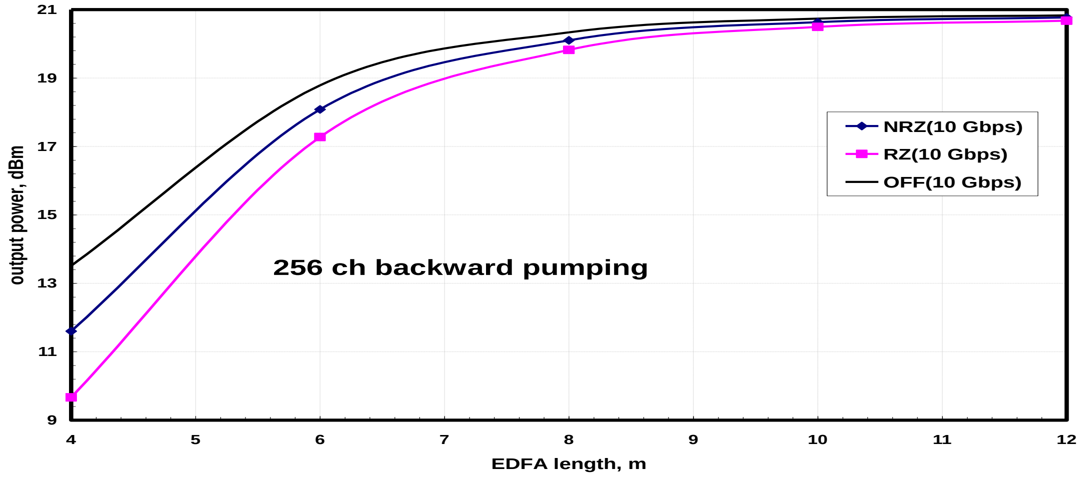

Fig. 13. Output power versus EDFA length for the different modulation formats.

This figure shows that the output power increases with increasing EDFA length for the different modulation formats. OFF modulation format has the largest value of output power compared to both NRZ and RZ modulation formats and this occur in the case of backward pumping.

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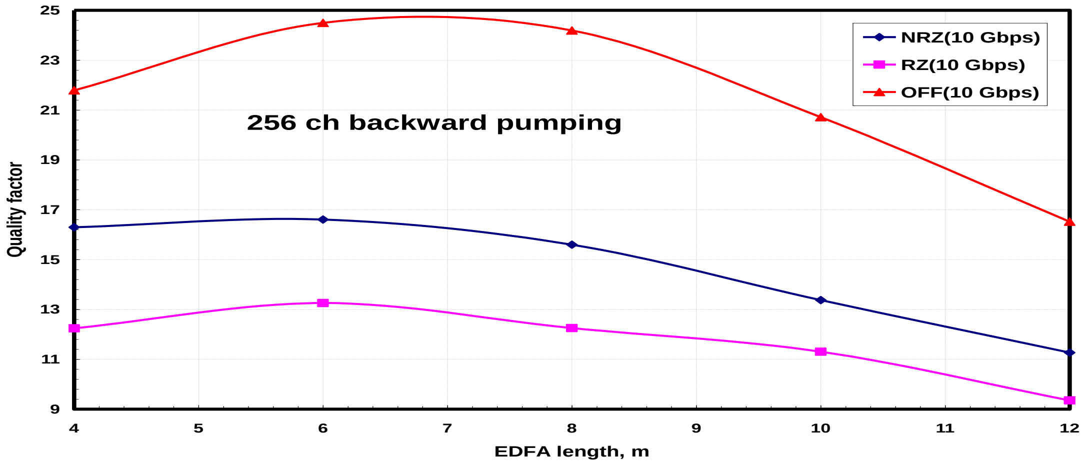

Fig. 14. Quality factor versus EDFA length in backward pumping.

It is observed from this figure that OFF modulation format has the greatest value of quality factor and RZ modulation format has the lowest value. Also the value of quality factor firstly increases until reaching nearly 6 m EDFA and then starts to decrease with increasing EDFA length.

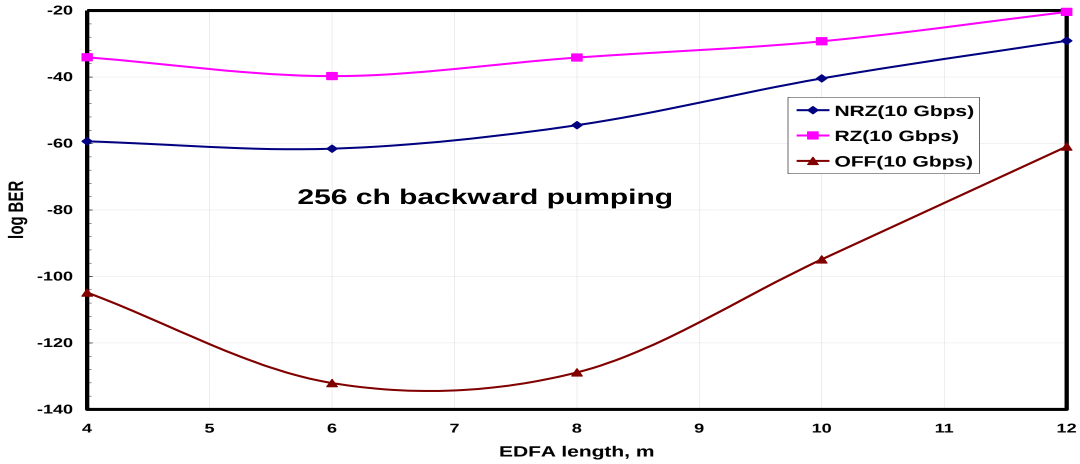

Fig. 15. BER versus EDFA length in backward pumping.

This figure shows that BER decreases with increasing EDFA length until reaching nearly 6 m and then starts to decrease. RZ modulation format has the largest value of BER compared to both OFF and NRZ modulation formats and this occur in the case of backward pumping.

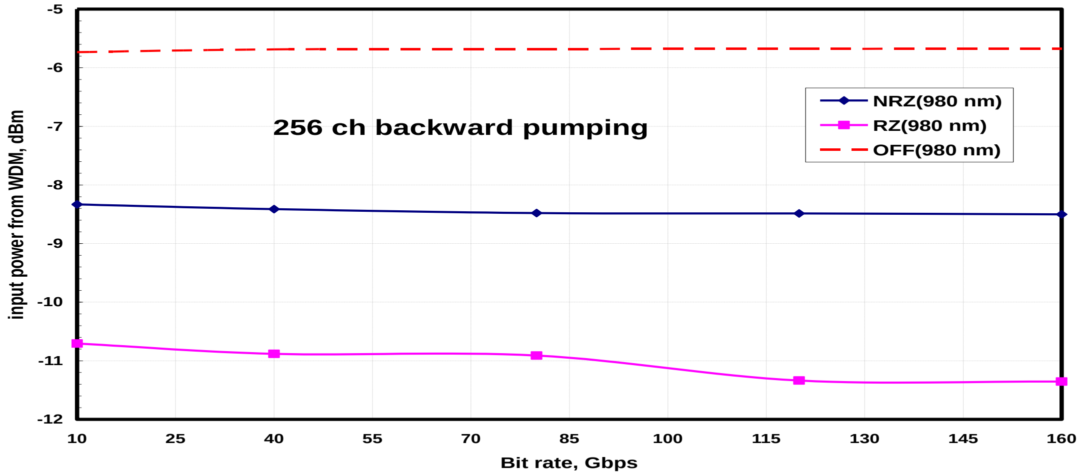

Fig. 16. Input power versus bit rate at different pumping wavelength.

This figure shows that the value of input power slightly decreases with increasing bit rate. OFF modulation format at 980 nm has the lowest value of input power compared to both NRZ and RZ modulation formats and this occur in backward pumping.

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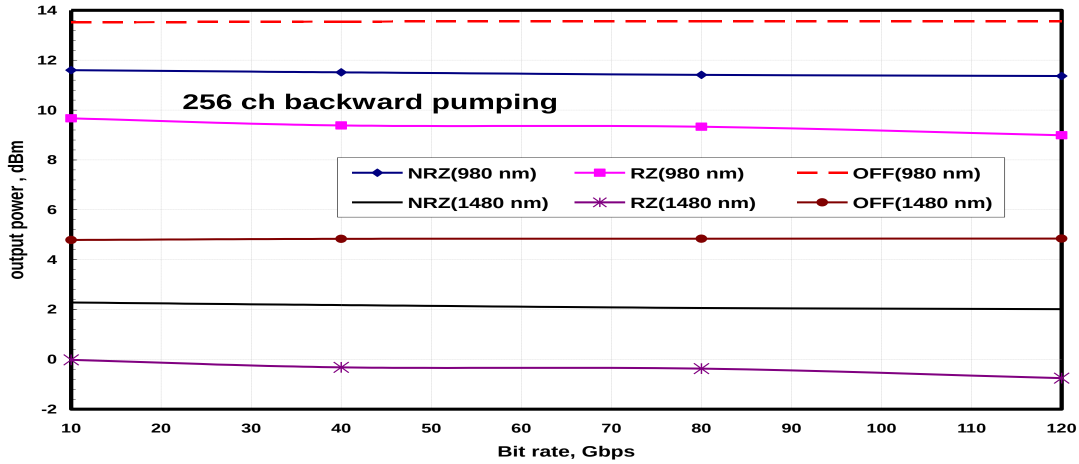

Fig. 17. Output power versus bit rate at different pumping wavelength.

This figure shows that the value of output power slightly decreases with increasing bit rate and also the value of output power at 980 nm is greater than at 1480 nm. OFF modulation format at 980 nm has the largest value of output power compared to both NRZ and RZ modulation formats and this occur in backward pumping.

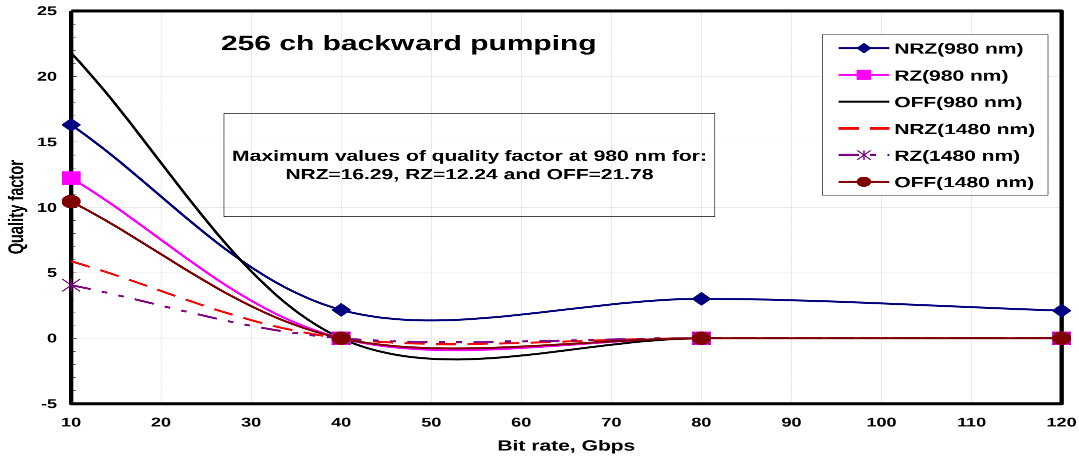

Fig. 18. Quality factor versus bit rate for different pumping wavelengths.

This figure shows that the quality factor decreases with increasing bit rate and also the quality factor at 980 nm is greater than 1480 nm. OFF modulation format has the greatest quality factor at 980 nm compared to other modulation formats and this occur in case of backward pumping.

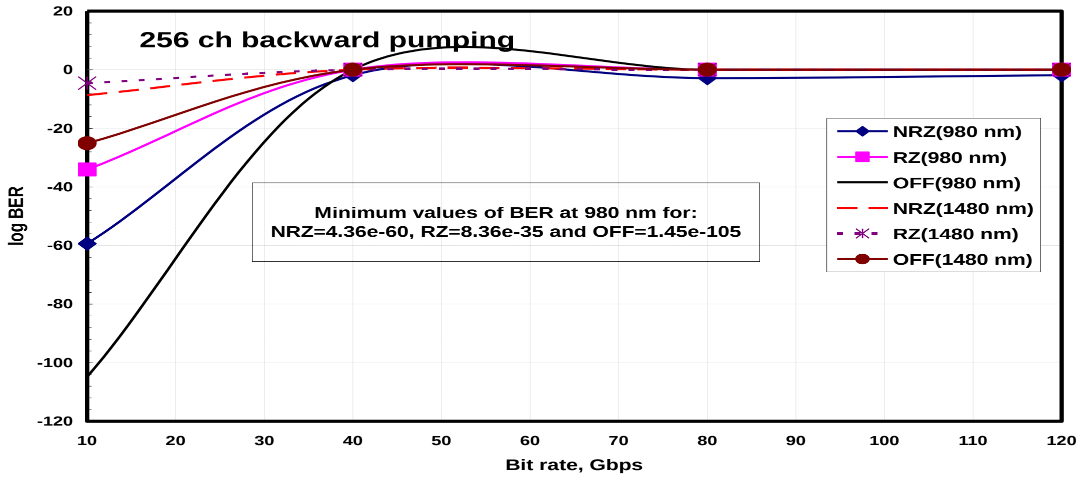

Fig. 19. BER versus bit rate for the different pumping wavelengths.

This figure shows that BER increases with increasing bit rate. RZ modulation format at 1480 nm is greater than at 980 nm and also other modulation formats and this occur in the case of backward pumping.

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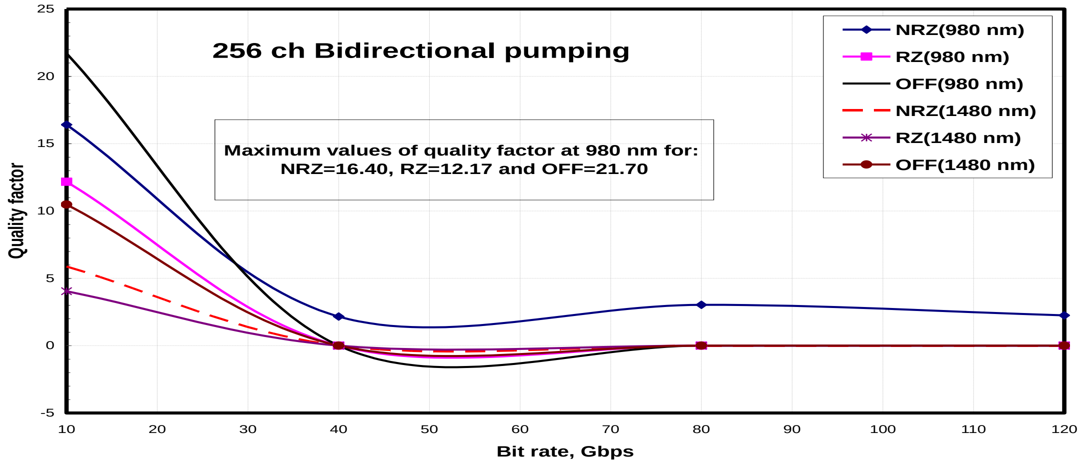

Fig. 20. Quality factor versus bit rate for different pumping wavelengths.

This figure shows that the quality factor decreases with increasing bit rate and also the quality factor at 980 nm is greater than 1480 nm. OFF modulation format has the greatest quality factor at 980 nm compared to other modulation formats and this occur in case of bidirectional pumping.

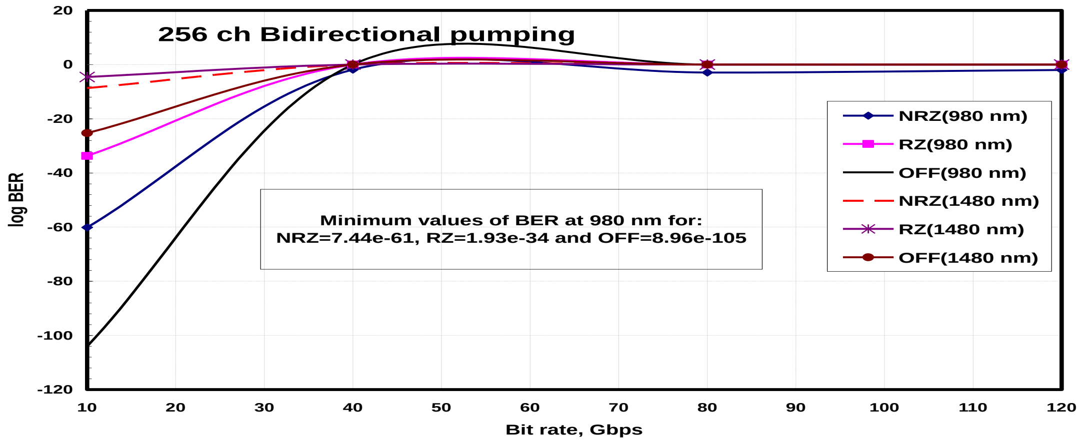

Fig. 21. BER versus bit rate for the different pumping wavelengths.

This figure shows that BER increases with increasing bit rate. RZ modulation format at 1480 nm is greater than at 980 nm and also other modulation formats and this occur in the case of bidirectional pumping.

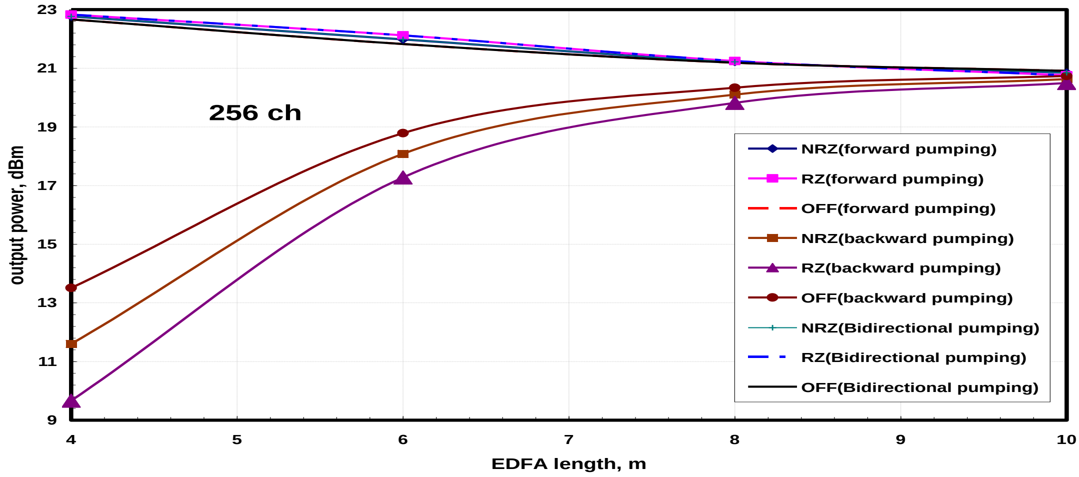

Fig. 22. Output power versus EDFA length for different pumping techniques.

This figure shows that in the case of forward and bidirectional pumping the output power decreases with increasing EDFA length and for RZ modulation format has the largest and the same value of output power compared to both NRZ and OFF modulation formats. In the case of backward pumping the out put power increases with increasing EDFA length and also OFF modulation format has the largest value of output power compared to other modulation formats. The value of output power for both forward and bidirectional pumping is greater than value in backward pumping.

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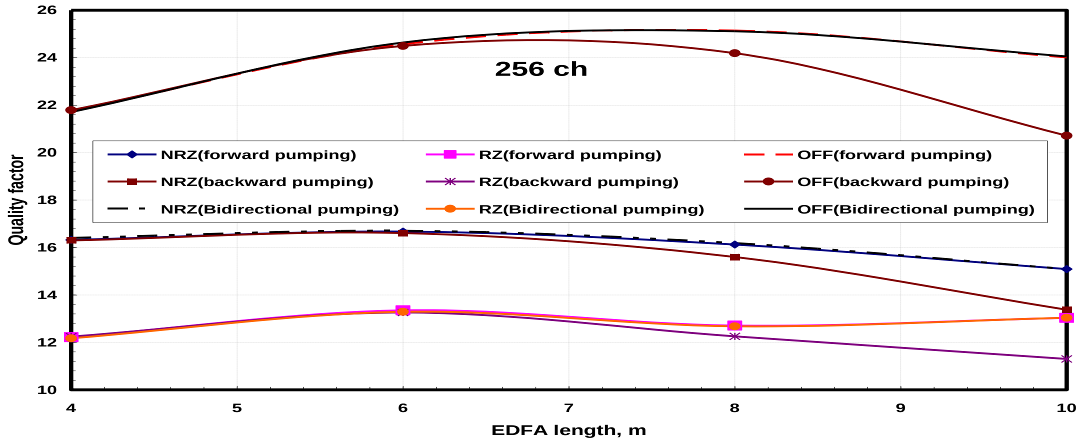

Fig. 23. Quality factor versus EDFA length for the different pumping techniques.

This figure shows that the quality factor for different pumping techniques stars firstly to increase with increasing EDFA length and then it decreases along further length. Both forward and bidirectional pumping techniques have the largest and nearly the same value of quality factor compared to backward pumping technique. OFF modulation format has the greatest quality factor compared to other formats.

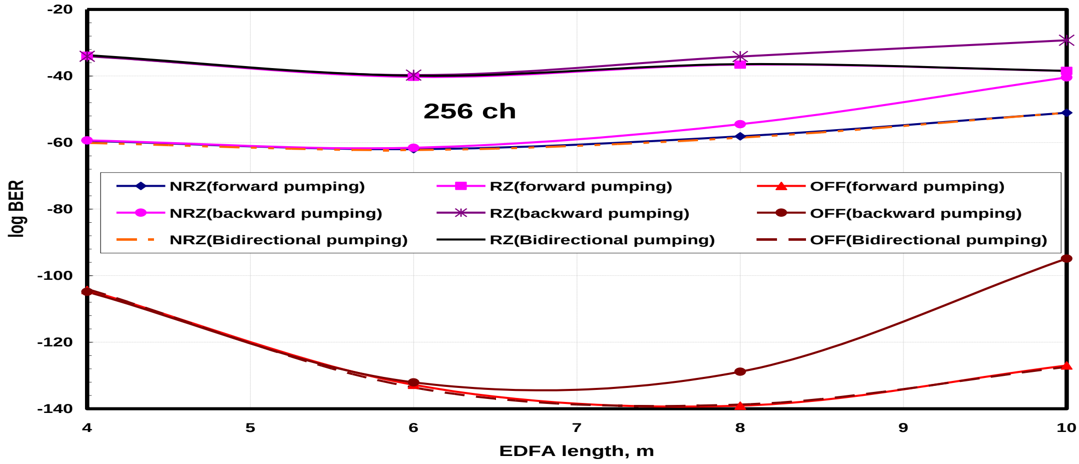

Fig. 24. BER versus EDFA length for the different pumping techniques.

This figure shows that bit error rate for different pumping techniques stars firstly to decrease with increasing EDFA length and then it increases along further length. Both forward and bidirectional pumping techniques have the lowest and nearly the same value of bit error rate compared to backward pumping technique. RZ modulation format has the greatest value of bit error rate compared to other formats

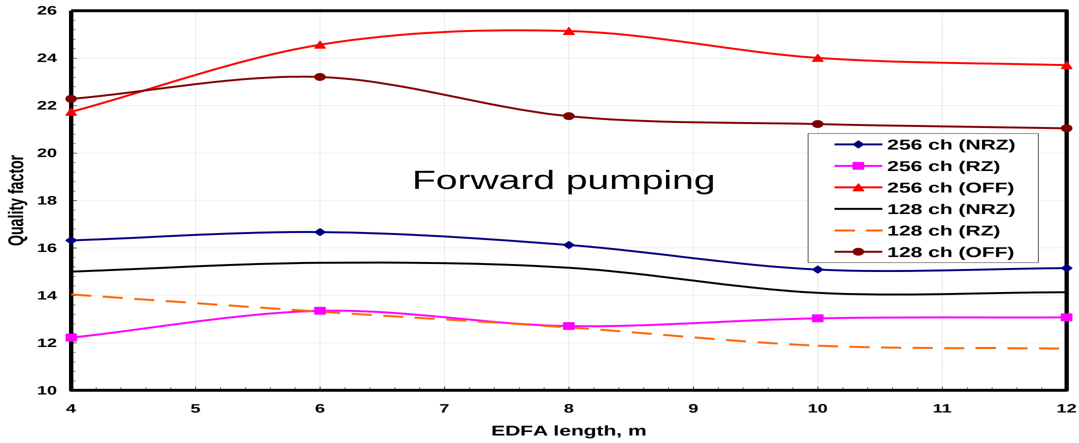

Fig. 25. Quality factor versus EDFA length for different modulation formats.

It is observed from this figure that in case of forward pumping the quality factor for the different modulation formats increases with increasing EDFA length until a certain value and then decreases. OFF modulation format that has 256 channels is greater quality factor than that has 128 channels and also greater than both NRZ and RZ modulation formats. Also the modulation format that has 256 channels is greater quality factor than one that has 128 channels.

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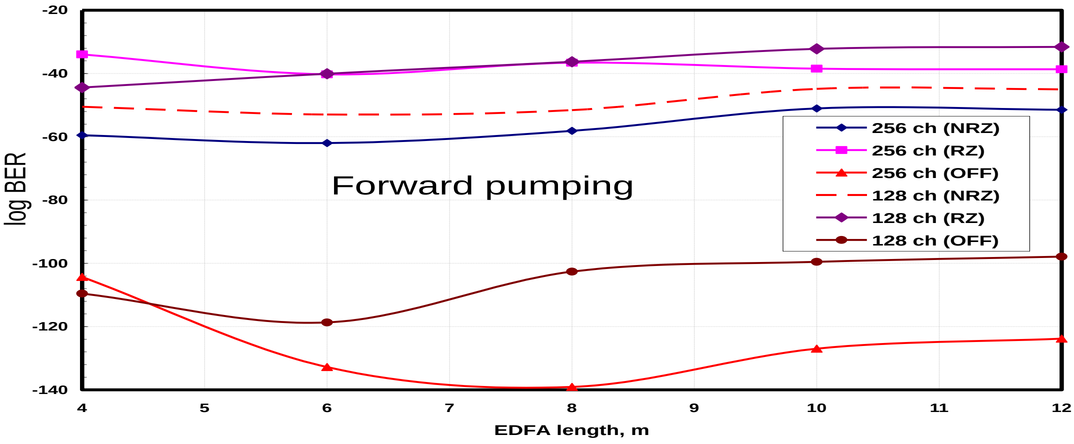

Fig. 26. BER versus EDFA length for different modulation formats.

It is observed from this figure that in case of forward pumping the value of BER for the different modulation formats decreases with increasing EDFA length until a certain value and then increases. OFF modulation format that has 256 channels is lower BER than that has 128 channels and also lower than both NRZ and RZ modulation formats. Also the modulation format that has 128 channels is greater BER than one that has 256 channels.

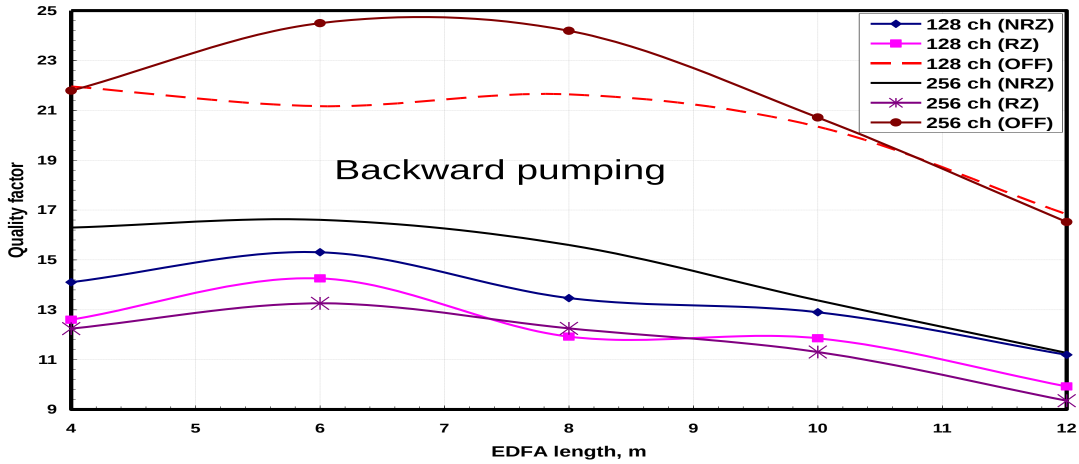

Fig. 27. Quality factor versus EDFA length at different number of channels.

This figure shows that in backward pumping the quality factor decreases with increasing EDFA length for the different modulation formats at different number of channels. Quality factor at 256 channels is greater than at 128 channels. Also, OFF modulation format has the greatest quality factor compared to the other formats.

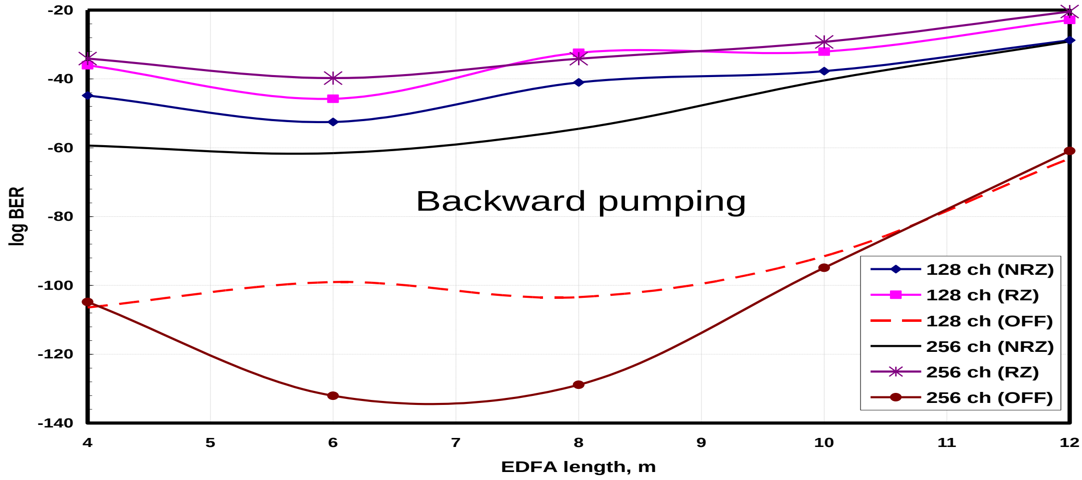

Fig. 28. BER versus EDFA length at different modulation formats.

This figure shows that BER decreases with increasing EDFA length until reaching nearly 6 m and then starts to decrease. RZ modulation format at 256 channels has greater value of BER than 128 channels and also it is greater than both OFF and NRZ modulation formats in case of backward pumping.

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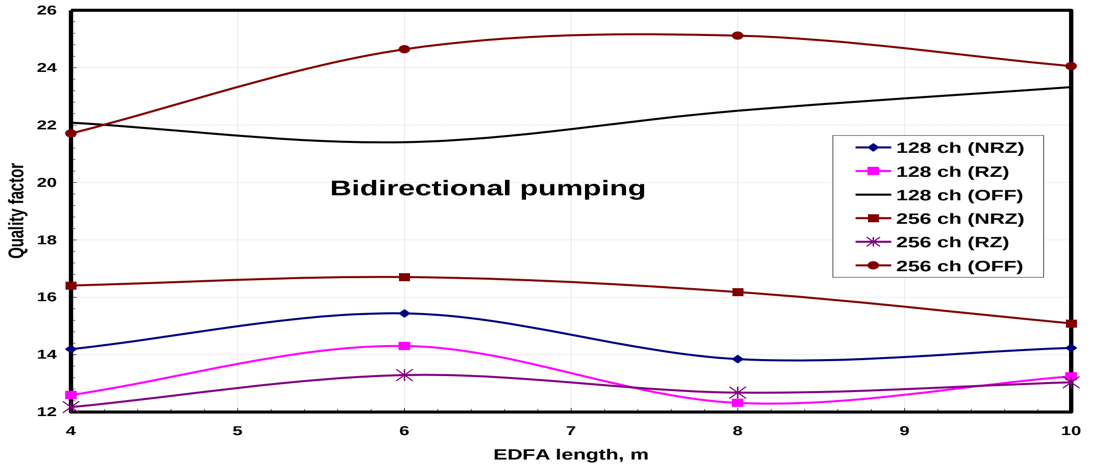

Fig. 29. Quality factor versus EDFA length at different number of channels.

This figure shows that in bidirectional pumping the quality factor firstly starts to increase until reaching nearly 6 m then decreases and this occur with increasing EDFA length for the different modulation formats at different number of channels. Quality factor at 256 channels is greater than at 128 channels. Also, OFF modulation format has the greatest quality factor compared to the other formats.

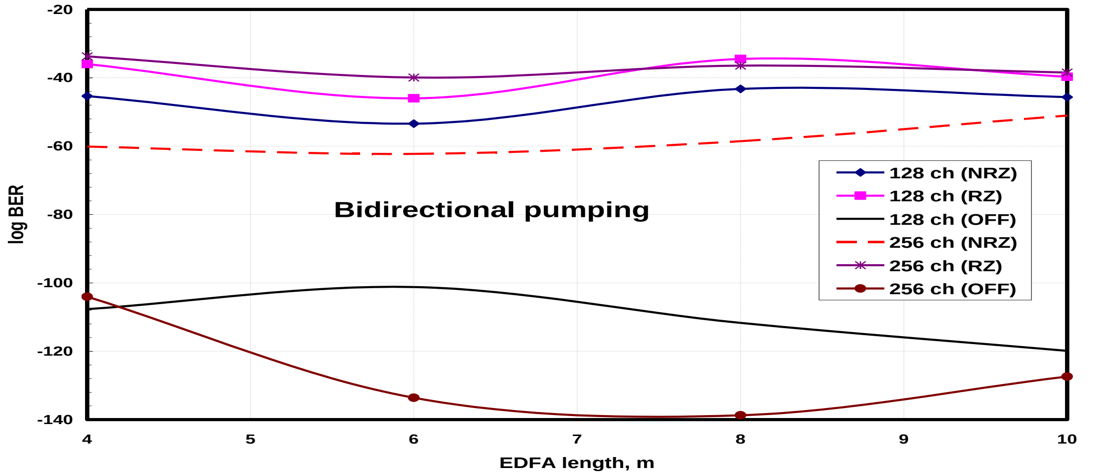

Fig. 30. BER versus EDFA length at different modulation formats.

It is observed from this figure that decreases with increasing EDFA length for the different modulation formats. RZ modulation format for 256 channels has greater value of BER than for 128 channels and also it is larger than both NRZ and OFF modulation formats in case of bidirectional pumping.

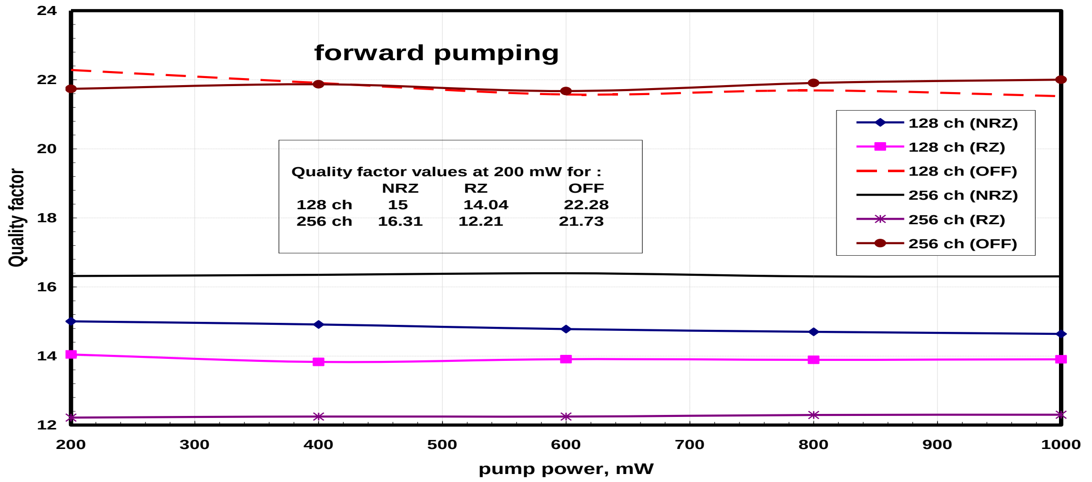

Fig. 31. Quality factor versus pump power at different modulation formats.

This figure shows that the quality factor slightly decreases with increasing pump power for the different modulation formats at different number of channels. OFF modulation formats at 128 channels has quality factor greater than at 256 channels and also greater than both NRZ and RZ modulation formats.

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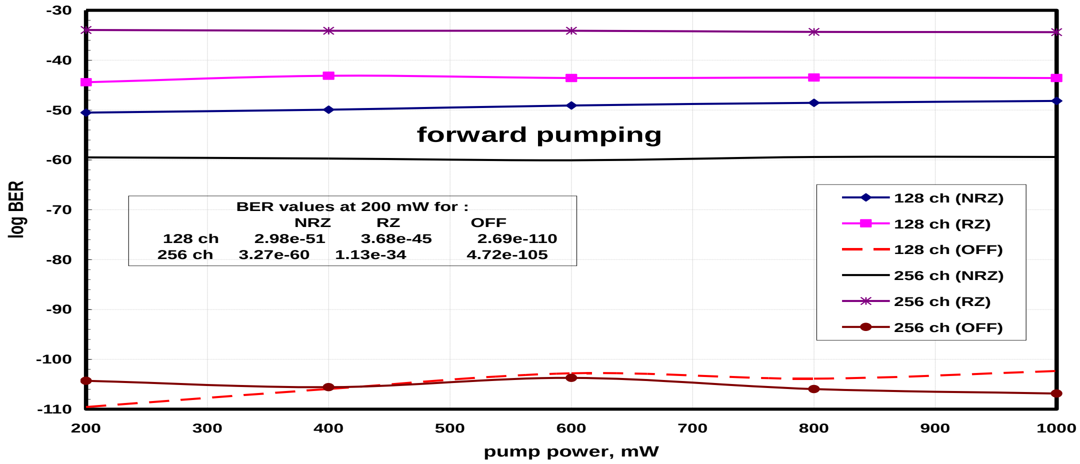

Fig. 32. BER versus pump power at different modulation formats.

This figure shows that the value of BER slightly increases with increasing pump power for the different modulation formats at different number of channels. RZ modulation format at 256 channels has the largest value of BER than both OFF and NRZ modulation formats.

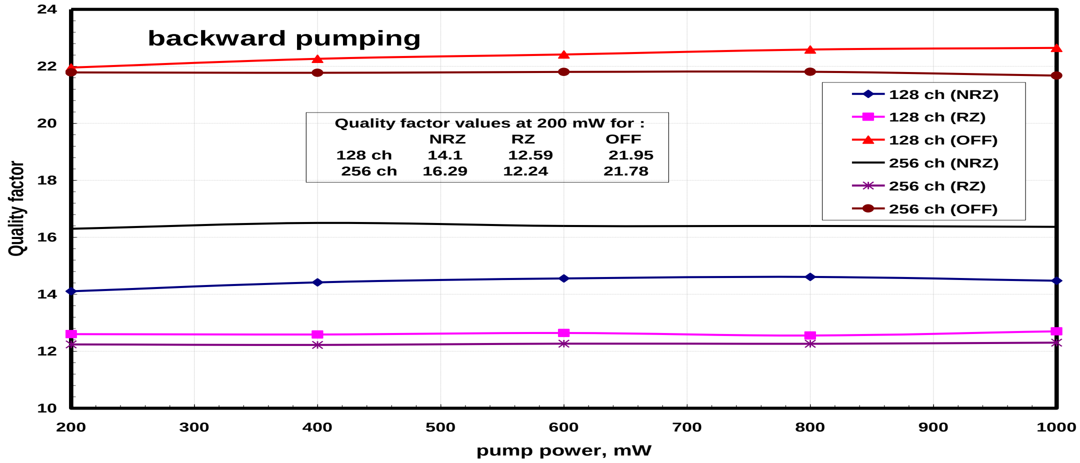

Fig. 33. Quality factor versus pump power at different modulation formats.

This figure shows that in case of backward pumping the quality factor slightly increases with increasing pump power for the different modulation formats at different number of channels. OFF modulation formats at 128 channels has quality factor greater than at 256 channels and also greater than both NRZ and RZ modulation formats.

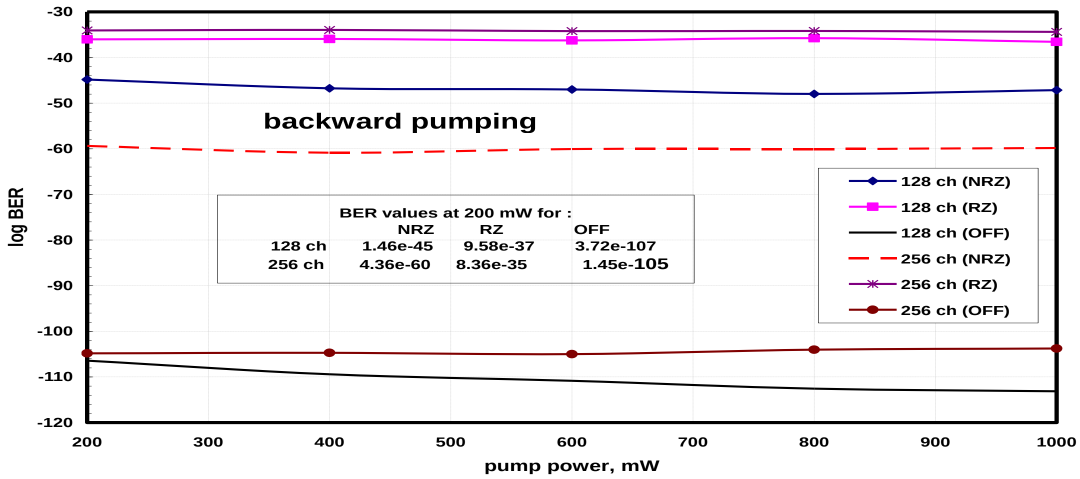

Fig. 34. BER versus pump power for different modulation formats.

This figure shows that the value of BER slightly decreases with increasing pump power for the different modulation formats. Also RZ modulation format for 256 channels has the greatest value of BER compared to other formats in backward pumping.

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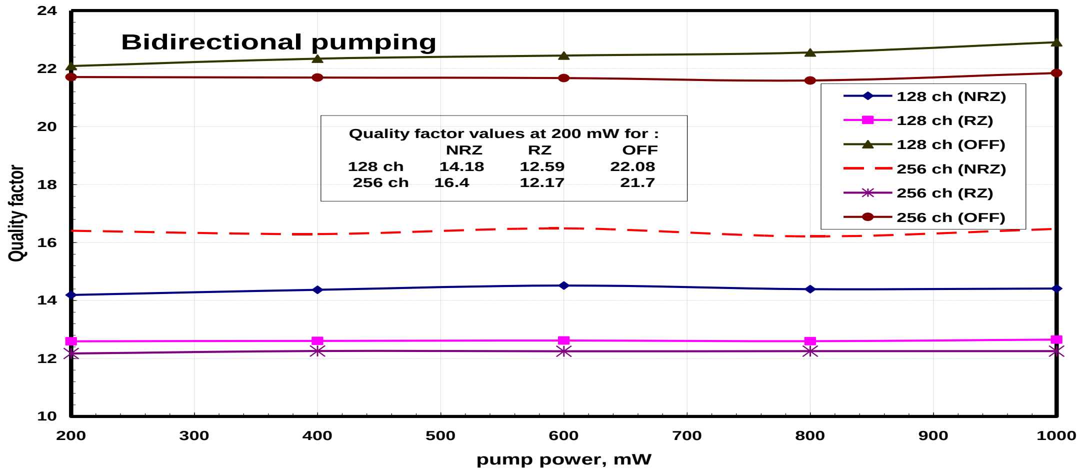

Fig. 35. Quality factor versus pump power at different modulation formats.

This figure shows that the quality factor slightly increases with increasing pump power for the different modulation formats at different number of channels. OFF modulation formats at 128 channels has quality factor greater than at 256 channels and also greater than both NRZ and RZ modulation formats and this occur in case of bidirectional pumping.

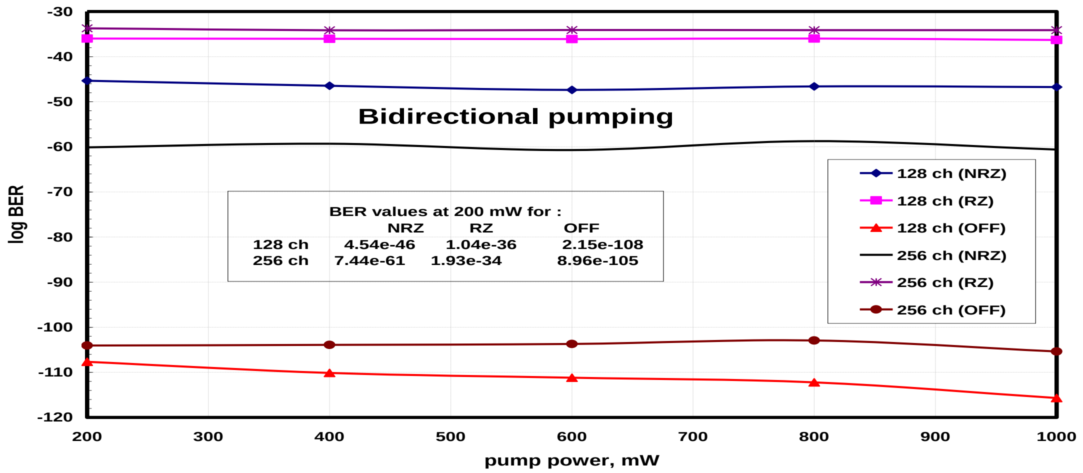

Fig. 36. BER versus pump power for different modulation formats.

This figure shows that the value of BER slightly decreases with increasing pump power for the different modulation formats at the different number of channels. Also RZ modulation format for 256 channels has the greatest value of BER compared to other formats in bidirectional pumping.

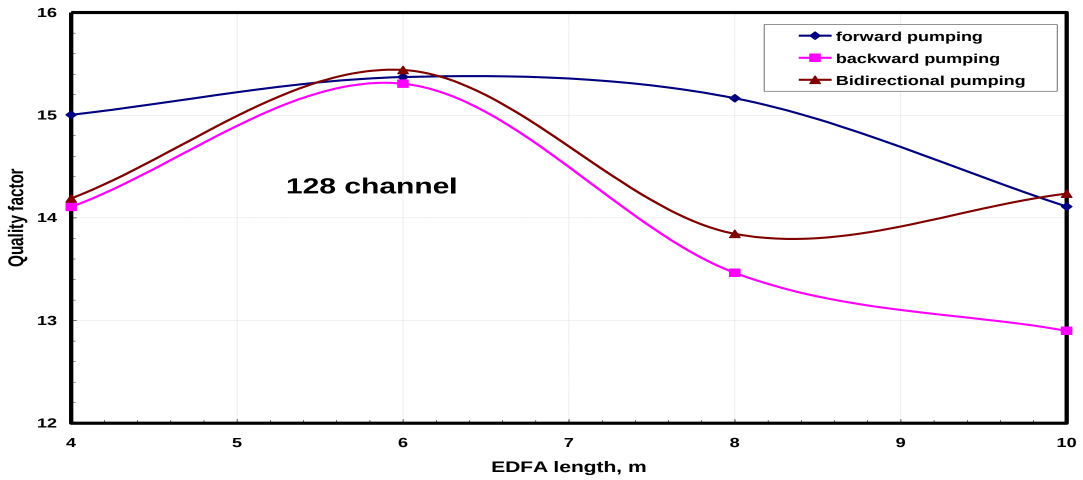

Fig. 37. Quality factor versus EDFA length for the different pumping techniques at 128 channels.

This figure shows that the quality factor for the different pumping configuration firstly increases until reaching almost 6 m and then decreases with increasing EDFA length at 128 channels. Also forward pumping techniques has the largest quality factor compared to other pumping techniques.

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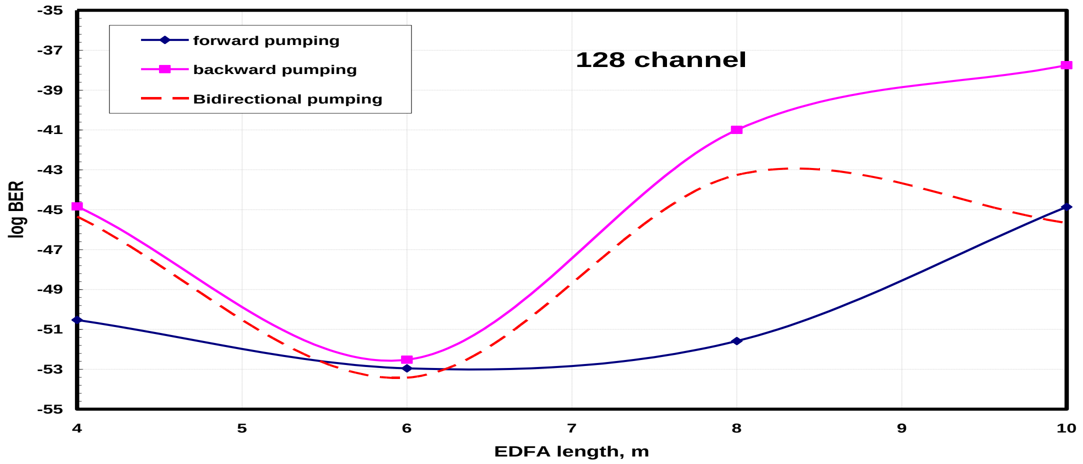

Fig. 38. BER versus EDFA length for the different pumping techniques at 128 channels.

This figure shows that BER for the different pumping configuration firstly decreases until 6 m and then increases with increasing EDFA length at 128 channels. Backward pumping technique has the largest value of BER compared to other pumping techniques.

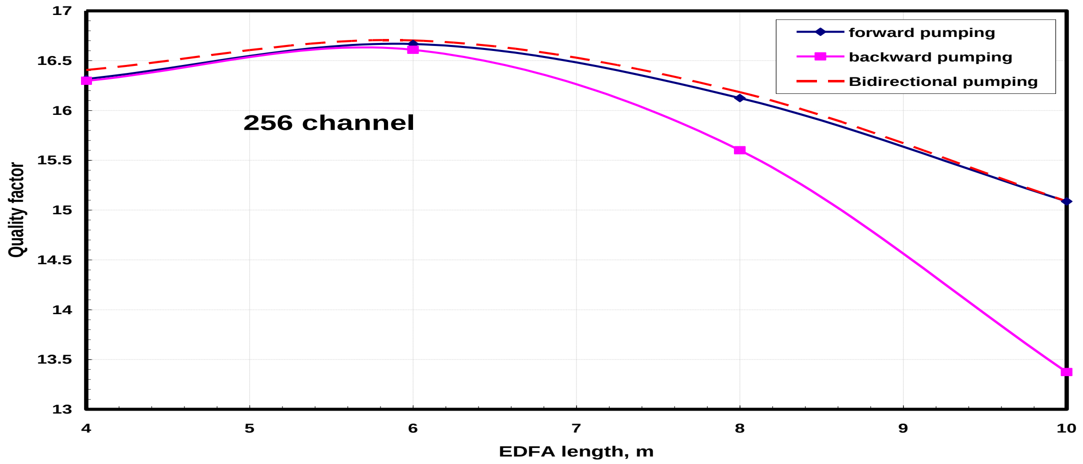

Fig. 39 . Quality factor versus EDFA length for the different pumping techniques for 256 channels.

This figure shows that the quality factor decreases with increasing EDFA length and also the quality factor in the case of bidirectional pumping is greater than both forward and backward pumping techniques.

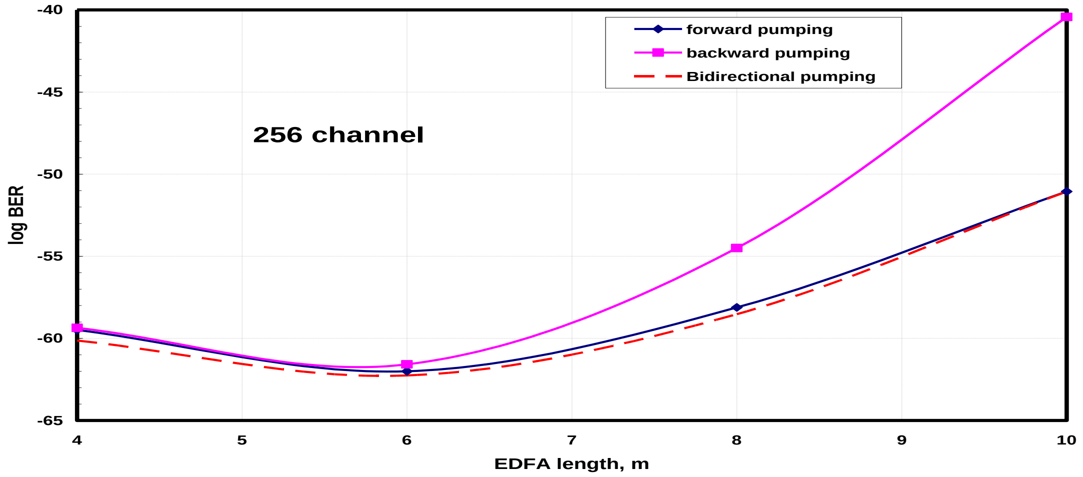

Fig. 40. BER versus EDFA length for the different pumping techniques.

This figure shows that the value of BER increases with increasing EDFA length for the different pumping techniques. Backward pumping technique has the largest value of BER compared to other pumping techniques and this occurs at 256 channels.

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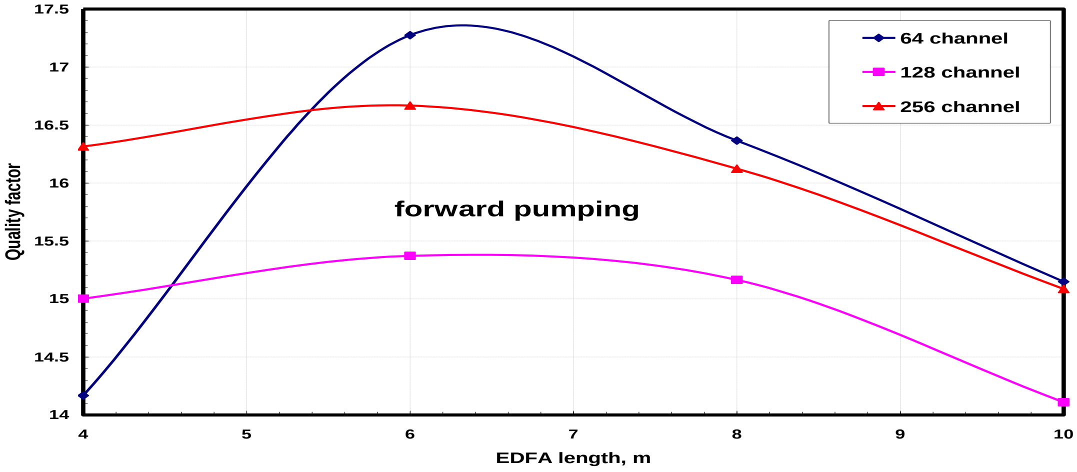

Fig. 41. Quality factor versus EDFA length for the different number of channels.

It is observed from this figure that in the case of forward pumping the quality factor for the different number of channels pass into two steps firstly the quality factor increases with increasing EDFA length and then it is decreases. Also the quality factor for 64 channels has the greatest quality factor than both 128 and 256 channels and this occur under using NRZ modulation format.

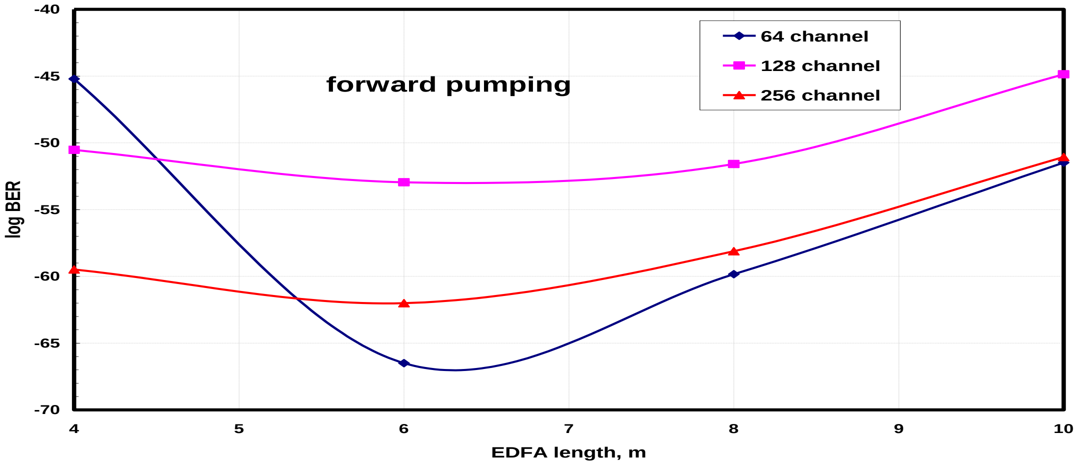

Fig. 42. BER versus EDFA length for the different number of channels.

It is observed from this figure that in the case of forward pumping using NRZ modulation format the value of BER for the different number of channels pass into two steps firstly it is decreases with increasing EDFA length and then it is increases. Also the value of BER for 128 channels has the greatest BER compared to both 64 and 256 channels.

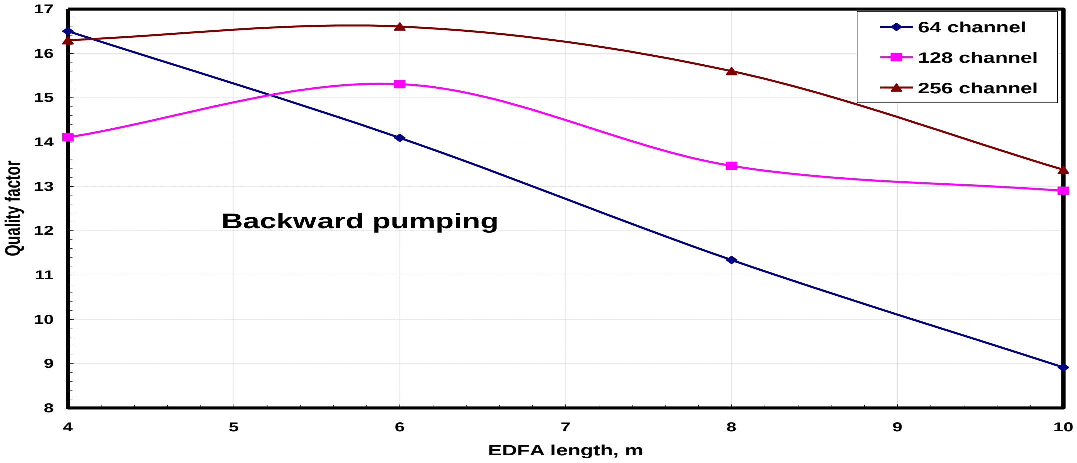

Fig. 43. Quality factor versus EDFA length for the different number of channels.

It is observed from this figure that in the case of backward pumping the quality factor for the different number of channels decreases with increasing EDFA length. Also the quality factor for 256 channels has the greatest quality factor compared to both 128 and 64 channels and this occurs under using NRZ modulation format.

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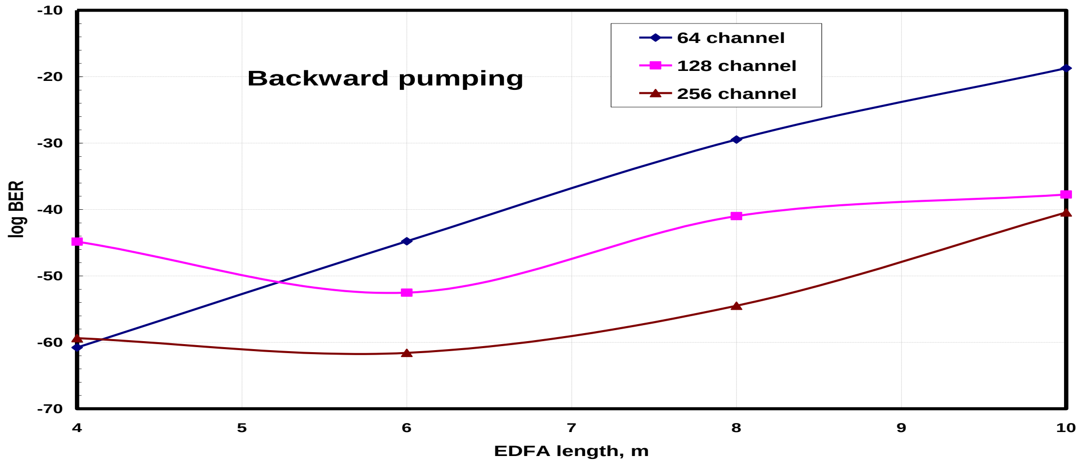

Fig. 44. BER versus EDFA length for the different number of channels.

It is observed from this figure that in the case of backward pumping under using NRZ modulation format the value of BER for the different number of channels increases with increasing EDFA length. Also the value of BER for 64 channels has the greatest value compared to both 128 and 256 channels.

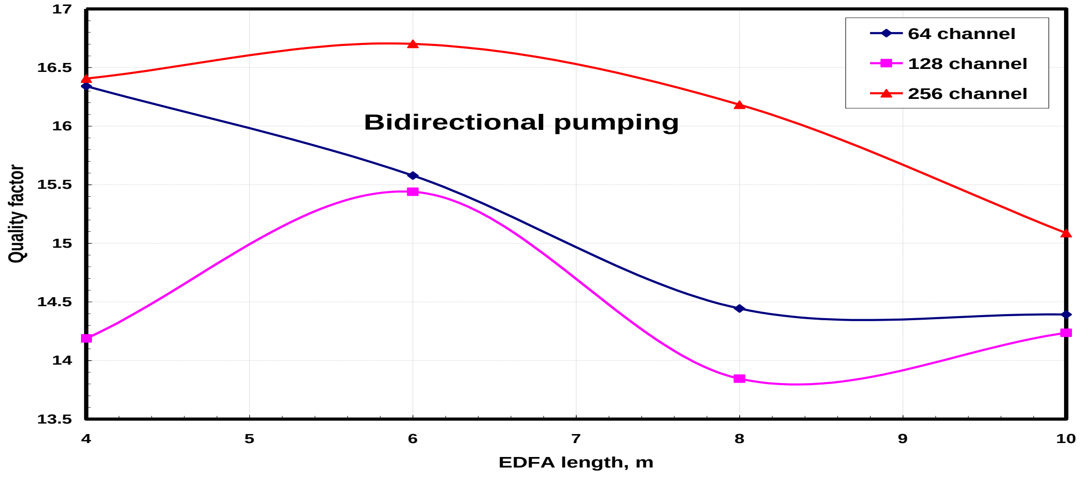

Fig. 45. Quality factor versus EDFA length for the different number of channels.

It is observed from this figure that in the case of bidirectional pumping the quality factor for the different number of channels decreases with increasing EDFA length. Also the quality factor for 256 channels has the greatest quality factor than both 128 and 64 channels and this occur under using NRZ modulation format

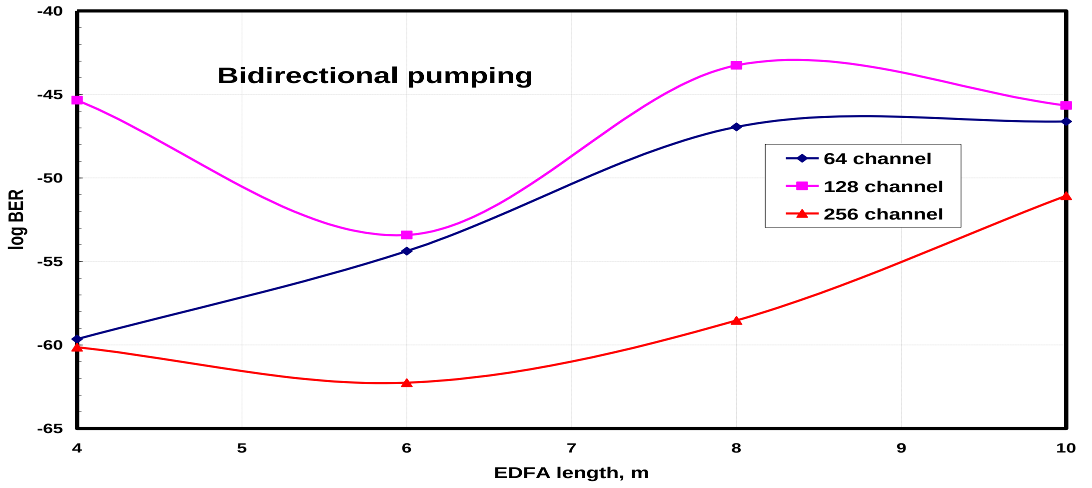

Fig. 46. BER versus EDFA length for the different number of channels.

It is observed from this figure that in the case of bidirectional pumping the quality factor for the different number of channels pass increases with increasing EDFA length. Also the value of BER for 128 channels has the greatest value of BER compared to both 64 and 256 channels and this occur under using NRZ modulation format.

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Table (2): output power for the different pumping techniques at different modulation formats and for different values of input power.

Input power (dBm)	Output power(dBm)								
	Forward pumping			Backward pumping			Bidirectional pumping		
	NRZ	RZ	OFF	NRZ	RZ	OFF	NRZ	RZ	OFF
-40	22.93	22.93	22.92	0.131	-1.36	2.057	22.93	22.94	22.92
-30	22.86	22.89	22.80	8.31	6.23	10.49	22.86	22.89	22.80
-20	22.48	22.62	22.32	15.61	14.17	16.93	22.49	22.62	22.32
-10	21.92	22.02	21.90	19.48	18.80	20.14	21.93	22.02	21.90
0	22.83	22.30	23.76	22.27	21.46	23.42	22.83	22.31	23.76

This Table shows that for the case of forward and bidirectional pumping the value of output power firstly decreases with increasing the value of input power and finally begins to increase. But in the case of backward pumping the value of output power increases with increasing the value of input power. Also at 0 dBm input power, OFF modulation format has the largest value of output power compared to both NRZ and RZ modulation formats and this occur for the different pumping techniques at 256 channels.

Table (3): output power for the different pumping techniques at different modulation formats and for different values of fiber length.

Fiber length (km)	Output power(dBm)								
	Forward pumping			Backward pumping			Bidirectional pumping		
	NRZ	RZ	OFF	NRZ	RZ	OFF	NRZ	RZ	OFF
25	22.76	22.83	22.66	11.59	9.66	13.51	22.76	22.83	22.66
50	22.76	22.83	22.66	11.59	9.66	13.51	22.76	22.83	22.66
75	22.76	22.83	22.66	11.59	9.66	13.51	22.76	22.83	22.66
100	22.76	22.83	22.66	11.59	9.66	13.51	22.76	22.83	22.66

This table shows that the value of output power doesn't change with increasing the value of fiber length and this occur for the different pumping techniques. In case of forward and bidirectional pumping RZ modulation formats have the largest value of output power compared to both NRZ and OFF modulation formats. In the case of backward pumping OFF modulation format has the largest output power compared to both RZ and NRZ modulation formats at 256 channels.

Table (4): Quality factor for the different pumping techniques at different modulation formats for different values of fiber length.

Fiber length (km)	Quality factor								
	Forward pumping			Backward pumping			Bidirectional pumping		
	NRZ	RZ	OFF	NRZ	RZ	OFF	NRZ	RZ	OFF
25	16.31	12.21	21.73	16.29	12.24	21.78	16.40	12.17	21.70
50	11.23	8.725	17.71	11.31	8.708	17.41	11.37	8.677	17.50
75	6.252	2.445	12.21	6.23	2.448	12.26	6.235	2.453	12.33
100	2.17	0	1.60	2.18	0	1.593	2.181	0	1.612

It is observed from this table that the quality factor decreases with increasing fiber length for the different pumping techniques. OFF modulation format has the largest quality factor compared to both NRZ and RZ modulation formats and this occur for 256 channels.

Table (5): Bit error rate for the different pumping techniques at different modulation formats for different values of fiber length.

Fiber length (km)	Bit error rate								
	Forward pumping			Backward pumping			Bidirectional pumping		
	NRZ	RZ	OFF	NRZ	RZ	OFF	NRZ	RZ	OFF
25	3.27×10^{-60}	1.13×10^{-34}	4.72×10^{-105}	4.36×10^{-60}	8.36×10^{-35}	1.45×10^{-105}	7.44×10^{-61}	1.93×10^{-34}	8.96×10^{-105}
50	1.31×10^{-29}	1.31×10^{-18}	1.66×10^{-70}	5.27×10^{-30}	1.52×10^{-18}	2.94×10^{-68}	2.65×10^{-30}	2.00×10^{-18}	6.35×10^{-69}
75	2.00×10^{-10}	0.007	1.32×10^{-34}	2.25×10^{-10}	0.007	6.87×10^{-35}	2.21×10^{-10}	0.006	3.06×10^{-35}
100	1.45×10^{-2}	1	5.05×10^{-3}	1.41×10^{-2}	1	5.12×10^{-3}	1.41×10^{-2}	1	4.99×10^{-3}

It is observed from this table that the value of bit error rate increases with increasing fiber length for the different pumping techniques. OFF modulation format has the lowest value of bit error rate compared to both NRZ and RZ modulation formats and this occur for 256 channels.

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Table (6): Quality factor and Bit error rate for the different different number of channels at different modulation formats for different values of fiber length in the case of forward pumping.

Fiber length (km)	Quality factor (Q) and Bit error rate (BER)											
	128 channels						256 channels					
	NRZ		RZ		OFF		NRZ		RZ		OFF	
	Q	BER	Q	BER	Q	BER	Q	BER	Q	BER	Q	BER
25	15.0	2.98×10^{-51}	14.04	3.68×10^{-45}	22.28	2.69×10^{-110}	16.31	3.27×10^{-60}	12.21	1.13×10^{-34}	21.73	4.72×10^{-105}
50	12.7	2.61×10^{-37}	8.66	2.31×10^{-18}	19.74	4.77×10^{-87}	11.23	1.31×10^{-29}	8.725	1.31×10^{-18}	17.71	1.66×10^{-70}
75	6.21	2.51×10^{-10}	2.49	0.0062	2.951	0.00017	6.252	2.00×10^{-10}	2.44	0.007	12.21	1.32×10^{-34}
100	2.14	1.57×10^{-2}	0	1	0	1	2.172	1.45×10^{-2}	0	1	1.60	5.05×10^{-3}

This Table shows that the value of quality factor decreases and BER increases with increasing fiber length. NRZ modulation format has larger quality factor of about 1.3 and lower BER for 256 channels than 128 channels. OFF and RZ modulation formats have larger quality factor of about 2 and lower BER for 128 channels than 256 channels.

Table (7): Quality factor and Bit error rate for the different number of channels at different modulation formats for different values of fiber length in the case of backward pumping.

Fiber length (km)	Quality factor(Q) and Bit error rate(BER)											
	128 channels						256 channels					
	NRZ		RZ		OFF		NRZ		RZ		OFF	
	Q	BER	Q	BER	Q	BER	Q	BER	Q	BER	Q	BER
25	14.10	1.46×10^{-45}	12.59	9.58×10^{-37}	21.95	3.72×10^{-107}	16.29	4.36×10^{-60}	12.24	8.36×10^{-35}	21.78	1.45×10^{-105}
50	15.05	1.55×10^{-51}	9.241	1.18×10^{-20}	20.08	4.93×10^{-90}	11.31	5.27×10^{-30}	8.708	1.52×10^{-18}	17.41	2.94×10^{-68}
75	6.802	5.14×10^{-12}	2.523	0.0057	3.301	5.76×10^{-5}	6.234	2.25×10^{-10}	2.448	0.007	12.26	6.87×10^{-35}
100	2.179	1.43×10^{-2}	2.072	0.0185	0	1	2.18	1.41×10^{-2}	0	1	1.593	5.12×10^{-3}

This table shows that the value of quality factor decreases and BER increases with increasing fiber length. NRZ modulation format has larger quality factor of about 2 and lower BER for 256 channels than 128 channels. OFF and RZ modulation formats have larger quality factor of about 0.2 and lower BER for 128 channels than 256 channels.

Table (8): Quality factor and Bit error rate for the different number of channels at different modulation formats for different values of fiber length in the case of bidirectional pumping.

Fiber length (km)	Quality factor(Q) and Bit error rate(BER)											
	128 channels						256 channels					
	NRZ		RZ		OFF		NRZ		RZ		OFF	
	Q	BER	Q	BER	Q	BER	Q	BER	Q	BER	Q	BER
25	14.18	4.54×10^{-46}	12.59	1.04×10^{-36}	22.08	2.15×10^{-108}	16.4	7.44×10^{-61}	12.17	1.93×10^{-34}	21.70	8.96×10^{-105}
50	14.88	1.91×10^{-50}	9.23	1.31×10^{-20}	20.20	4.19×10^{-91}	11.37	2.65×10^{-30}	8.677	2.00×10^{-18}	17.50	6.35×10^{-69}
75	6.851	3.65×10^{-12}	2.523	0.0057	3.326	5.19×10^{-5}	6.235	2.21×10^{-10}	2.453	0.006	12.33	3.06×10^{-35}
100	2.179	1.43×10^{-2}	2.072	0.0185	0	1	2.18	1.41×10^{-2}	0	1	1.612	4.99×10^{-3}

It is observed from this table that the value of quality factor decreases and BER increases with increasing fiber length. NRZ modulation format has larger quality factor of about 2 and lower BER for 256 channels than 128 channels. OFF and RZ modulation formats have larger quality factor of about 0.5 and lower BER for 128 channels than 256 channels and this occur in the case of bidirectional pumping.

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Table (9): output power for different number of channels at different pumping configuration for different values of EDFA length.

EDFA length (m)	Output power(dBm)								
	Forward pumping			Backward pumping			Bidirectional pumping		
	64 ch	128 ch	256 ch	64 ch	128 ch	256 ch	64 ch	128 ch	256 ch
4	22.767	22.767	22.772	11.5999	11.595	6.41	22.767	22.767	22.772
6	21.981	21.981	21.989	18.084	18.084	15.097	21.981	21.981	21.989
8	21.222	21.222	21.224	20.102	20.102	19.447	21.222	21.222	21.224
10	20.851	20.851	20.847	20.632	20.632	21.549	20.851	20.851	20.847

This Table shows that for the case of forward and bidirectional pumping the value of output power decreases with increasing EDFA length for both different pumping techniques and different number of channels. In the previous case the output power for 256 channels has largest output power compared to both 64 and 128 channels. But in the case of backward pumping the value of output power increases with increasing EDFA length for the different number of channels.

IV. Conclusion

In summary, Different modulation formats (NRZ, RZ and OFF) can be used to study the behavior of the different pumping configuration (forward pumping, backward pumping and bidirectional pumping). Also the effect of increasing the number of channels up to 256 channels can be analyzed to show the effect of this on the performance of the different pumping configuration of EDFA for the different modulation formats and the simulation results can be shown in the previous Tables. From the previous tables, forward and bidirectional pumping have nearly the same and the largest output power under changing input signal power. In case of forward and bidirectional pumping NRZ modulation format has the largest output power for different values of fiber length but OFF modulation format has the largest value of the output power in the case of backward pumping. OFF modulation format has the largest quality factor and the lowest BER for the different pumping configurations and also for the different values of fiber length. In different pumping techniques OFF modulation format for 128 channels has largest quality factor than 256 channels for the different values of fiber length. in case of forward and bidirectional pumping the output power slightly increases with increasing EDFA length but in case of backward pumping it is decreases with increasing EDFA length.

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