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Analysis of EDFA Parameters Amenable for Ultra High Bitrate Based DWDM System

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Abstract: ***Exponential growth in data centric services often leads to overhaul of backbone and access networks. Design of high transmission capacity of up to 640Gbps DWDM system with EDFA was analyzed to meet less distortion in an optical backhaul system. Further the length of EDFA and pump power of EDFA are varied and evaluated for 16, 32 and 64 channels data transmission efficiently, such that it caters to the requirements of access networks. Parameters such as pump power and length of optical Amplifier in DWDM system are studied and its output characteristics are analyzed from co-channel and counter-channel propagations. The dependences parameters such as maximal BER, minimal SNR values among all the channels with signal power detection for each pump power results are obtained and compared to the same. Evaluations of Quality factor and BER for each pump power with all three configurations were done for different lengths of EDFA. The DWDM system with suggested optimum EDFA parameters gives good results in terms of Q-factor, eye opening and BER.***

Key words: BER, DWDM, Eye Height, EDFA.

I. INTRODUCTION

In the last years, the large capacity and demand for data transmission has led to an incredible growth within the field of optical fiber communication. According to the newest Cisco Visual Networking Index (VNI) forecast, global IP traffic will increase nearly threefold over the subsequent 5 years, and can have increased nearly 100 fold from 2015 to 2020. It has reached 1.1 zettabytes (ZB) each year or 88.7 exabytes (EB) per month by the tip of 2016. By 2020, global IP traffic will reach 2.3 ZB each year, or 194 EB per month [1]. In order to meet the growing demands of increasing bandwidth in networking services, DWDM is the most important method which is used to improve capacity enhancements and high-speed network connections where, several stream of data are multiplexed in a single fiber optic cable that in turn increases the bandwidth per fiber [2]. In WDM systems, channels must have proper channel spacing to avoid inter channel interference.

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A key feature of WDM is that it forms an orthogonal set of carriers, which is distributed and switched without interspersing with one another. This will keep optical power intensity significantly very less to avoid non-linear effects without affecting the system performance [3]. Optical fiber handles most of the digital data traffic with unlimited capacity. However, due to the nonlinearities in the fiber, the capacity increases in wavelength division multiplexing (WDM). [4]. WDM system is capable of providing a multi-channel amplification without any interference by employing single stage EDFA, which is one of the best known and widely used optical amplifier [5]. WDM technology along with gain-flattened EDFA allows the transmission of data in multiple channels over the same fiber, thus making it possible to transmit data over large a distance which plays a key role in long distance communication [6].The main use of EDFA is to encounter the problems like Rayleigh scattering, attenuation and distortions that improves the signal quality [7]. A typical EDFA having a length of 10-30m, a pumping laser, and devices (like WDM) for combining the signal and pump wavelengths so that they can be multiplexed and sent through the EDF [8]. The performance of EDFA configurations was analyse by varying input signal, fiber length and pump power, however the pursuance in transverse dimensions of EDFA is not considered, more over EDFA was assumed optimal with no up conversion effects [9]. Various reflective configurations of EDFA are fixed with Static filter and applicable set of parameters are used after curve fitting the ASE profile for each configuration.

The study proposes to analyze the optimum design parameters for EDFA system by designing a DWDM based optical network system with single stage EDFA for 16 channels, 32 channels and 64 channels with 10Gbps/channel to investigate its efficiency over nonlinearities. Performance of high bit rate DWDM system confines by varying different parameters such as pump power, fiber length and reaches high quality of service that includes analysis of Q factor, BER, gain, signal power, and noise figure as well as signal to noise ratio.

Section 2 envisages about DWDM system modeling and design parameters used for analysis and followed by evaluation of the proposed system in Section 3.

II. DWDM SYSTEM MODELING

The simulation model of a WDM system with an in-line EDFA is displayed in Fig. 1. It is an N channel WDM transmission system with NRZ scheme with OOK modulation format.

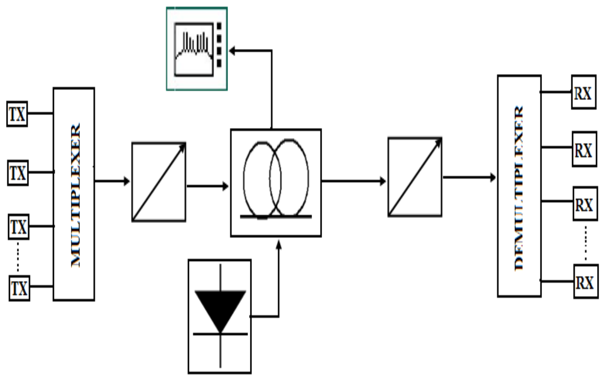

Fig1 WDM System

The channel spacing's used in this system is 0.8nm. The center frequency used for the 16,32,64 channel transmitters were in the following lower and upper cut of frequency ranges from 185 THZ to 200THZ with the Resolution bandwidth of 0.1nm. Each WDM transmitters consists of a data source, continuous wave (CW) laser, NRZ coder, and external Mach-Zehnder modulator (MZM). Power of -25dBm is chosen in the WDM transmitter as which will be the operating power. A NRZ encoder processes this sequence. Pump laser is chosen with the pump frequency of 980nm and pumping power, which varies from the range of 150mw to 500mw. Pump frequency of 980nm is chosen because EDFA has obtained higher amplification efficiency at 980nm.

Specification of the in line EDF is discussed as below, Length of EDF varies from 2m to 10m and Er^{3+} ions metastable lifetime is chosen as 10ms. Core radius of Er^{3+} ions are 2.2um and Er^{3+} ions doping radius is considered as 2.2um. Er^{3+} ion density is expressed as $1e^{+025}m^{-3}$ and Numerical aperture of EDF is considered as 0.24. These values are predefined and chosen as per the requirements for the simulation setup. The output power of the WDM Transmitter was -25dBm, and it operates at a frequency based on the channel spacing of the WDM system. The MZM modulates the intensity of continuous wave radiation has extinction ratio of 30dB and insertion loss of 3dB.

The parameters of pumping radiation of which were chosen, so as to get the insignificant pumping power that could guarantee the required quality of the signal in all channels of the WDM framework under consideration. In the wake of handling through EDF, the transmitted optical stream was part among N-channel optical receivers utilizing a ideal isolator. The receiver consists of a electrical low pass Bessel filter and PIN photodiode with f_c 7.5 GHZ. The optical signal when processed through ideal isolator is detected using a PIN photodiode. The PIN photodiode filters out high frequency noise from the signal.

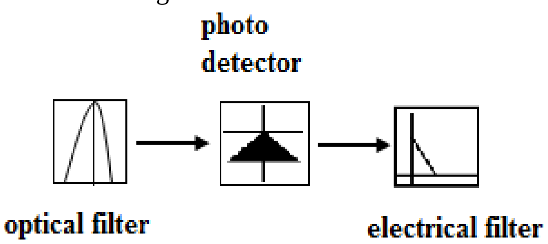

Fig 2 Receiver Section

To estimate effect of changes of pump power with shifting the length of EDF using channel dispersing, the conditions of the maximal BER values among all the channels on the intensity of the detected signals were obtained for each pump power and variable length of Erbium Doped fiber. To examine the proposed system, OptiSystem simulation was choosen. This simulation tool can handle simulations of complex optical multichannel correspondence frameworks without the requirement for powerful hardware and is being used by engineers in both scholarly and modern associations around the world, due to giving high precision results, which are near the real time examination results.

III. RESULTS AND DISCUSSION: -

The parameters of the EDFA in WDM systems, for example, decision of pump power and EDF length were picked such a way, that the principal target was to locate the minimal pumping powers that could guarantee the low BER values in all the channels below the $1*10^{-9}$ limit for channel spacing 0.8nm, and dependence of in-line EDFA execution on the channel spacing of the WDM system was examined.

Amplification was not required on account of 0.8nm channel spacing; as such spacing is sufficiently high to avoid the previously depicted inter channel crosstalk. Moreover, bigger optical channel data transmission at the receiver permits abstaining from filtering a part of e relating signal energy without letting through a part of energy of the nearby channels. It was concluded that the pump should co-spread with the signal along the EDF, as it is preferred for getting low noise figure contrasted and bidirectional and counter-propagating pump setups [11].

To choose the suitable pump wavelength, maximal BER values were seen at power of the 980 nm in the system with 0.8nm channel spacing. The maximal amplification efficiency in EDFAs is accomplished at, 980 nm. This is clarified by the way that, in general, 980 nm pumps is fit for accomplishing more significant level of population inversion at moderately high pump powers than the 1480 nm pump at this particular length of EDF. In long stretch optically enhanced connections, signals propagate together with ASE noise, and PG makes optical power be transferred from signals to spectral noise, thus fundamentally changing the ASE noise spectral shape at the receiver and possibly reducing the system performance [10]. The ASE development can be unfavorable since, being spectrally near the carriers; the receiver cannot filter the signal. However, the signal force is decreased because of the transfer of optical power to noise. The signal power is sufficiently high, fiber nonlinearity emerges during transmission. This includes four wave mixing (FWM) and self phase modulation (SPM) nonlinear impacts. When the wavelength difference between interacting spectral component decreases the efficiency of FWM increases. Therefore, if the signal power is sufficiently high, the channel spacing is less, the higher is the efficiency of FWM that happens between the channels, and the higher measure of inter channel crosstalk is created.

More over the presence of SPM results in inter channel crosstalk at generally little estimations of channel spacing, as it causes widening of the channel spectrum and results in overlap of neighbor channel spectrum.The significant part of the power is identified with ASE noise that is delivered by the EDFA, however the reason for the distinction in power penalty is identified with the part of inter channel crosstalk caused due to fiber nonlinearity [12]. When the signal power sign is sufficiently high, the channel dispersing is smaller, the efficiency of FWM is high that happens between the channels, and the higher measure of inter channel crosstalk is created. Moreover, at moderately little estimations of channel spacing the SPM causes widening of channel spectrum and, in this manner, brings about overlap of neighbor channel spectrum.

3.1 Eye height characteristics

The eye diagram characteristics for all the three different WDM system channel configurations are shown for co-channel propagation in the figure 3.(a), 3.(b) and 3.(c) respectively. A low pass raised cosine filter having roll off factor of 0.5 is used. The eye diagram characteristics gave wide eye opening, depicts that inter symbol interference (ISI) is less. It is observed that height of the eye opening is around 7.5 to 8 m of EDF lengths for all the three WDM channel configurations for various pump power varying in the order 150mW- 500mW.The wide eye-opening yields the more protection towards noise.

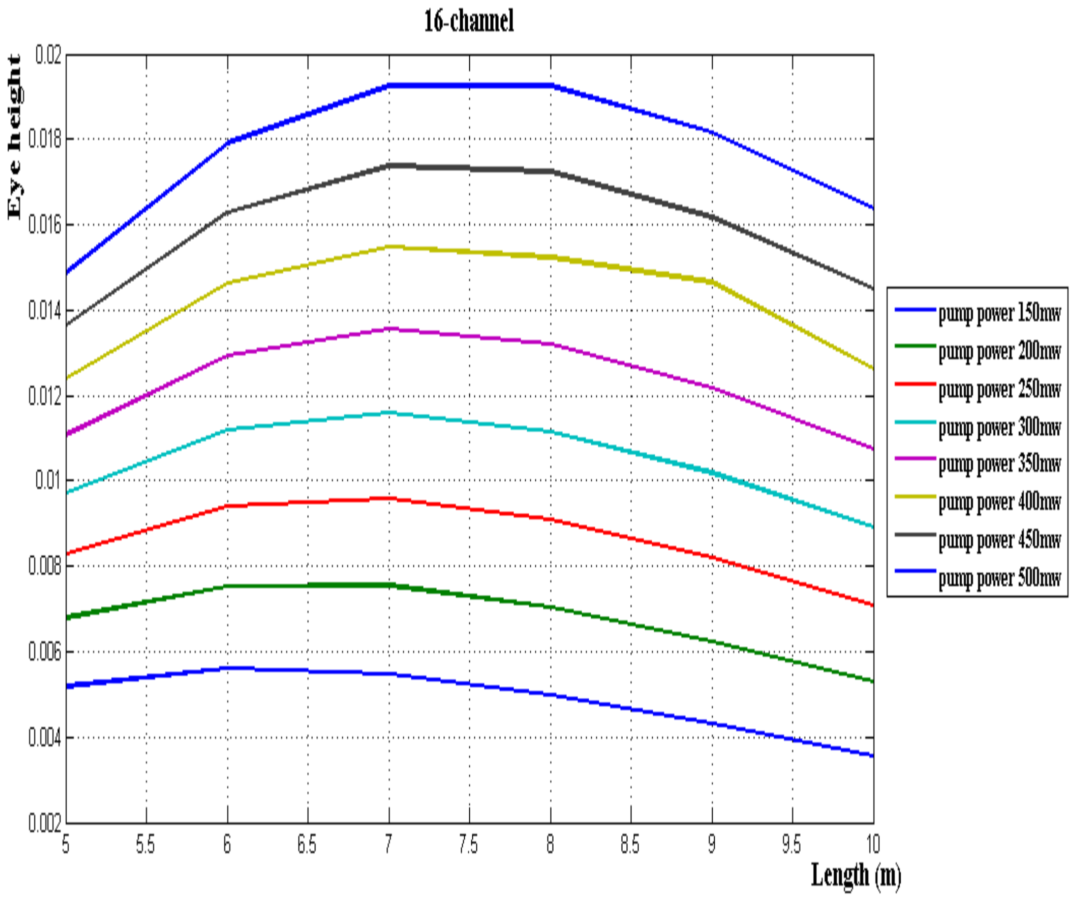

Fig 3.(a). Plot between Length and Eye height for 16-Channels

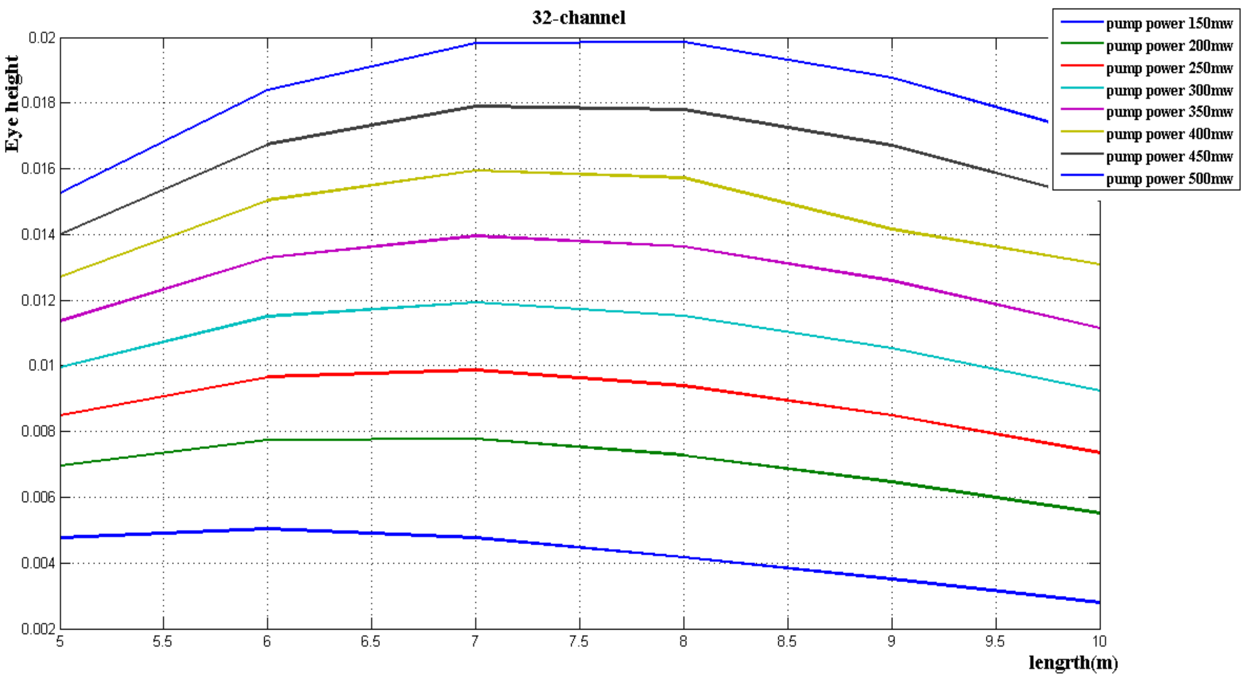

Fig 3.(b). Plot between Length and Eye height for 32-Channels

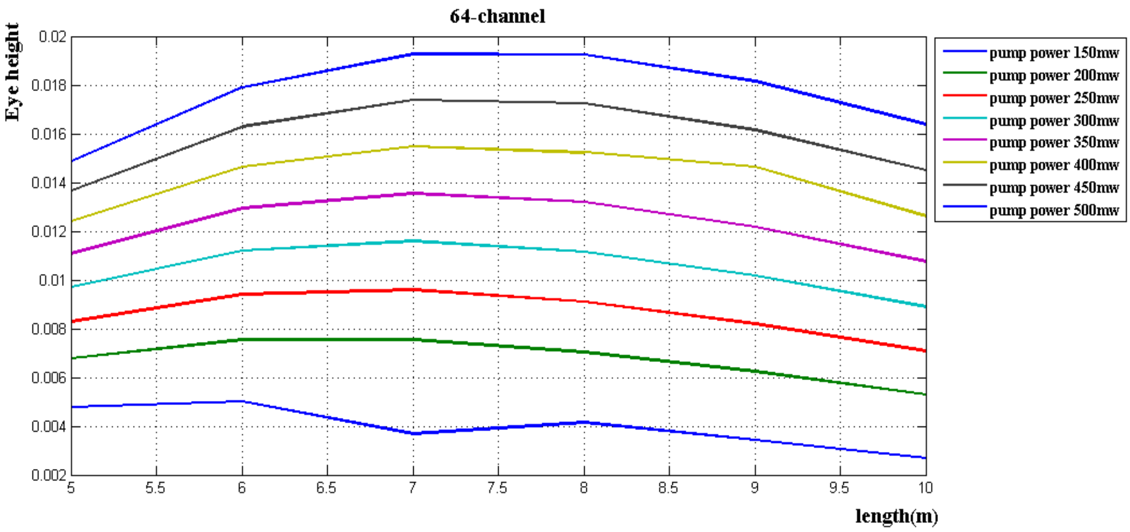

Fig.3.(c).Plot between Length and Eye height for 64 Channels

3.2 Q- factor Characteristics

Q-factor and BER is one of the most significant components that restricting the transmission distance in optical communication. So as to transmit signals over long distances, it is important to have a low BER and high Q-factor inside the fiber. Q factor measures the quality of analog signal with respect to signal to noise ratio (SNR). In that capacity, it considers physical weaknesses to the signal, for instance, noise, chromatic scattering and any polarization or nonlinear impacts – which can corrupt the signal and cause bit errors. However, if the Q factor value is high, SNR is better and therefore the probability of bit errors is less.

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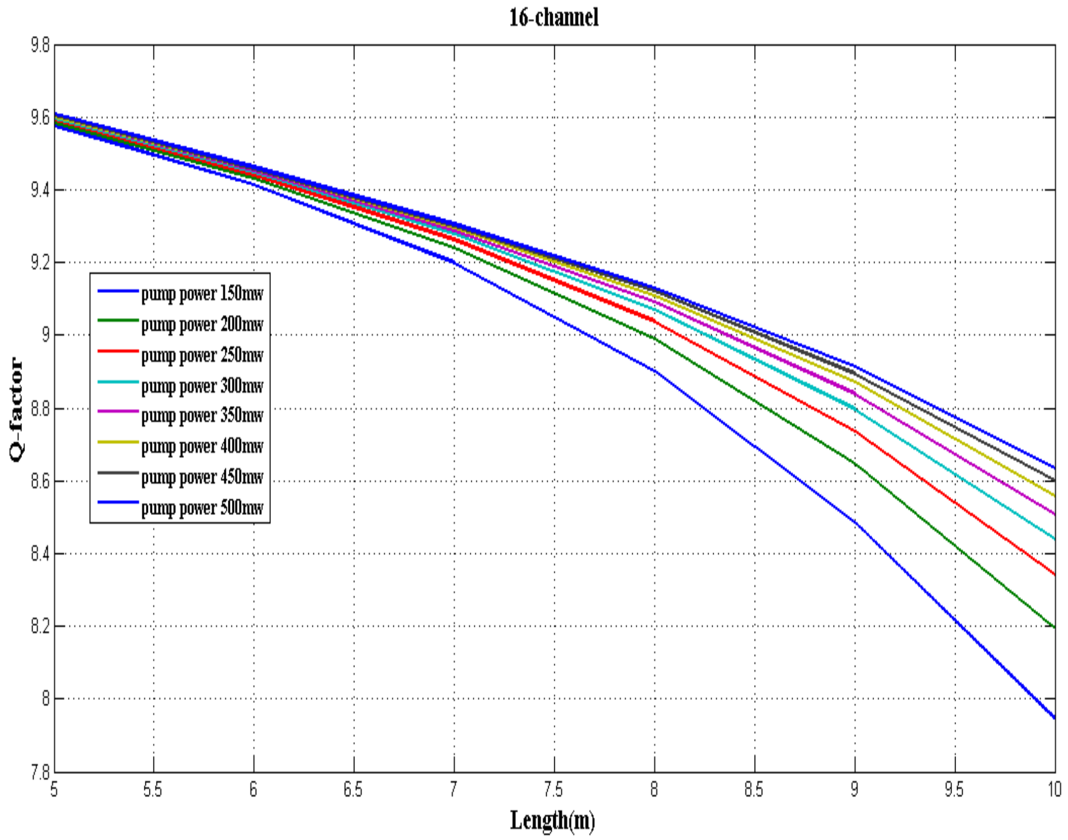

Fig 4 (a). Plot between Length and Q-factor for 16-Channels

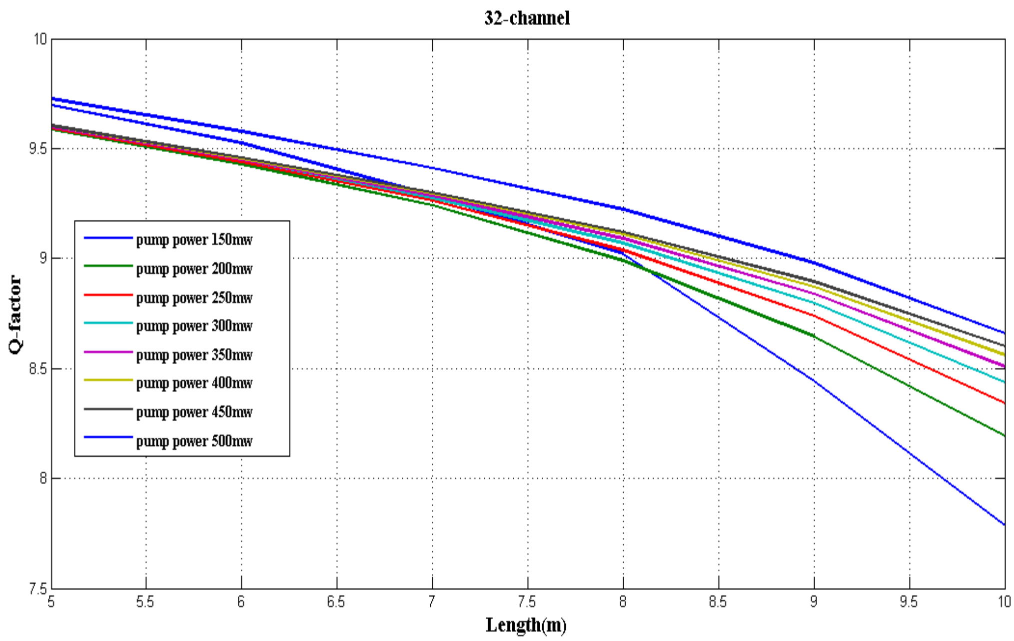

Fig. 4. (b). Plot between Length Vs Q-factor for 32-Channels

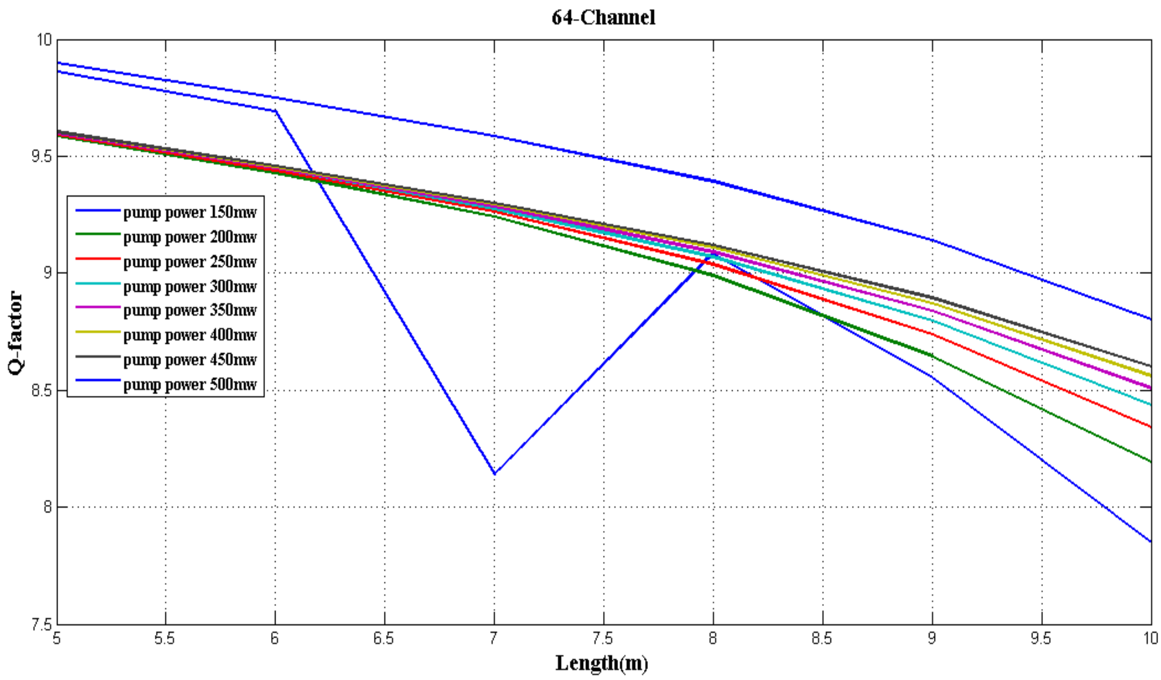

Fig .4. (c). Plot between Length Vs Q-factor for 64-Channels

Figure 4.(a), 4.(b) and 4.(c) depicts characteristic of Q-Factor with respect to various EDF length for different pump powers ranging from 150mW-500mW.The quality factor dips in to the minimum level at length 7m for the pump power range of 500mw and gradually it raises and reaches the saturation level of the different powers. This variation is mainly due to inter channel cross talk of the fiber optic devices which induces non linearities.

3.3 BER Characteristics

To assess the BER in optical systems, ASE noise is the restricting component. The bit Error rate (BER) is the number of bits that have errors comparative with the total number of bits received during transmission. The BER means that how regularly information must be retransmitted as a result of an error. Too high a BER may demonstrate that a slower information rate would really improve overall transmission time for a given amount of transmitted information, since the BER may reduce, bringing down the number of packets that must be available. The BER might be improved by picking a strong signal quality (except if this causes cross-talk and more bit errors), by choosing a moderate modulation or line coding, and by applying channel coding scheme, for example, repetitive forward error correction codes [1].

Fig. 5.(a), 5.(b), 5.(c) shows the variation of Length and BER for all the set of simulations, at pump power 400mw, there will be a rise in Bit error rate and reaches to high level, because of the deviations in the characteristics of the fiber optical devices due to its channel cross talks.

For 64 channels, the deviation in the BER at 500mw will occur to the same deviations as obtained in quality factor for the same pump power analysis, since the BER and Q-factor are closely related to each other. These kinds of variations are mainly due to the impact of large number of channels designed in their limited range of bandwidth leading to inter channel cross talk that raises the fiber non linearities.

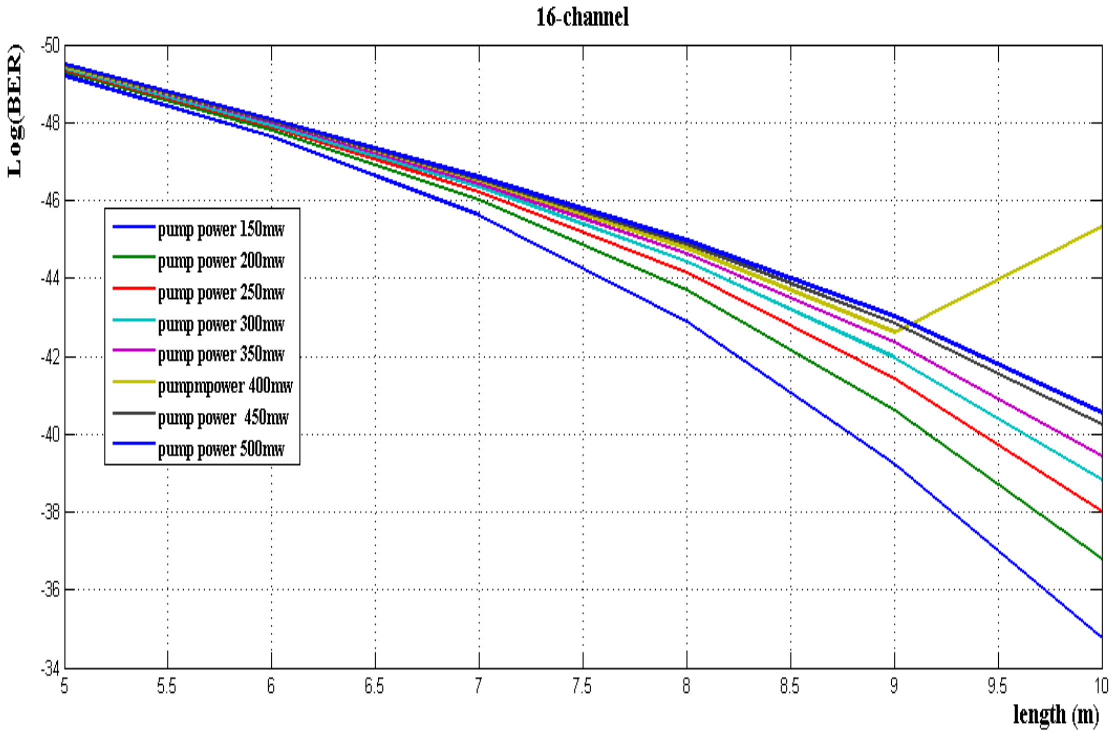

Fig .5. (a). Length Vs Log (BER) for 16 Channels

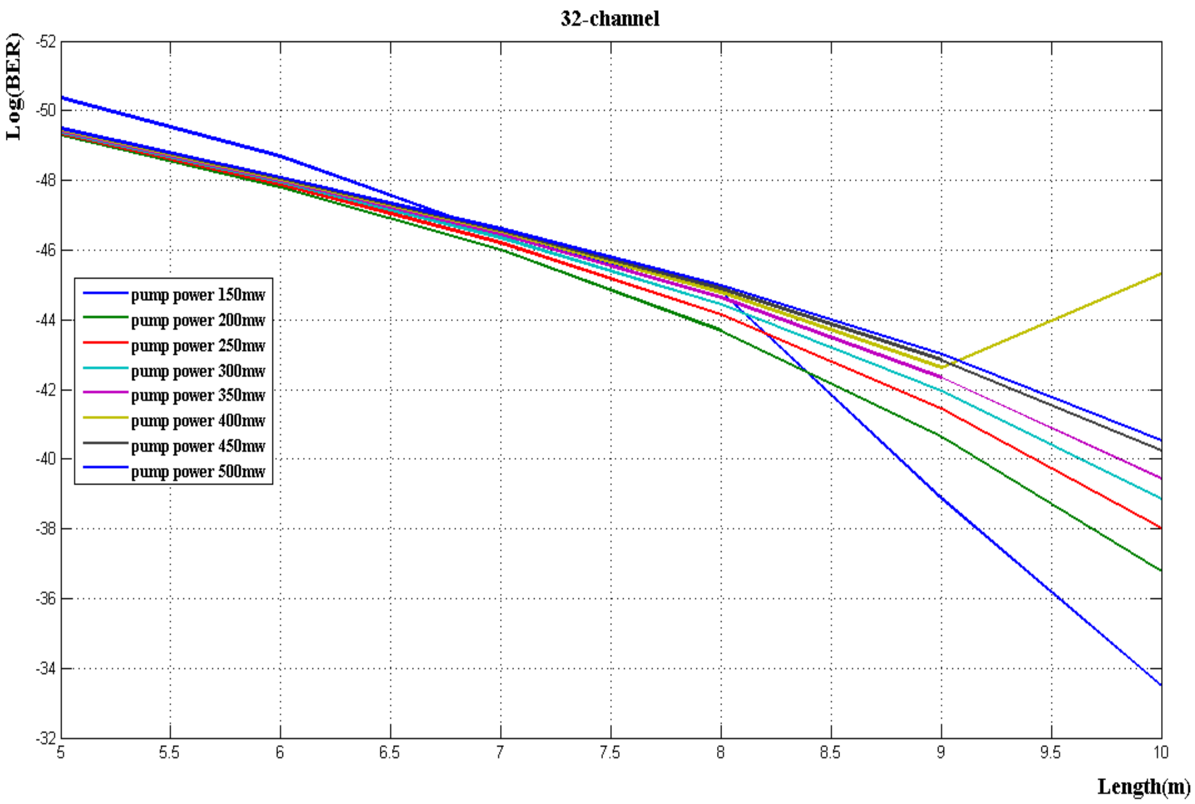

Fig .5. (b). Length Vs Log (BER) for 32 Channels

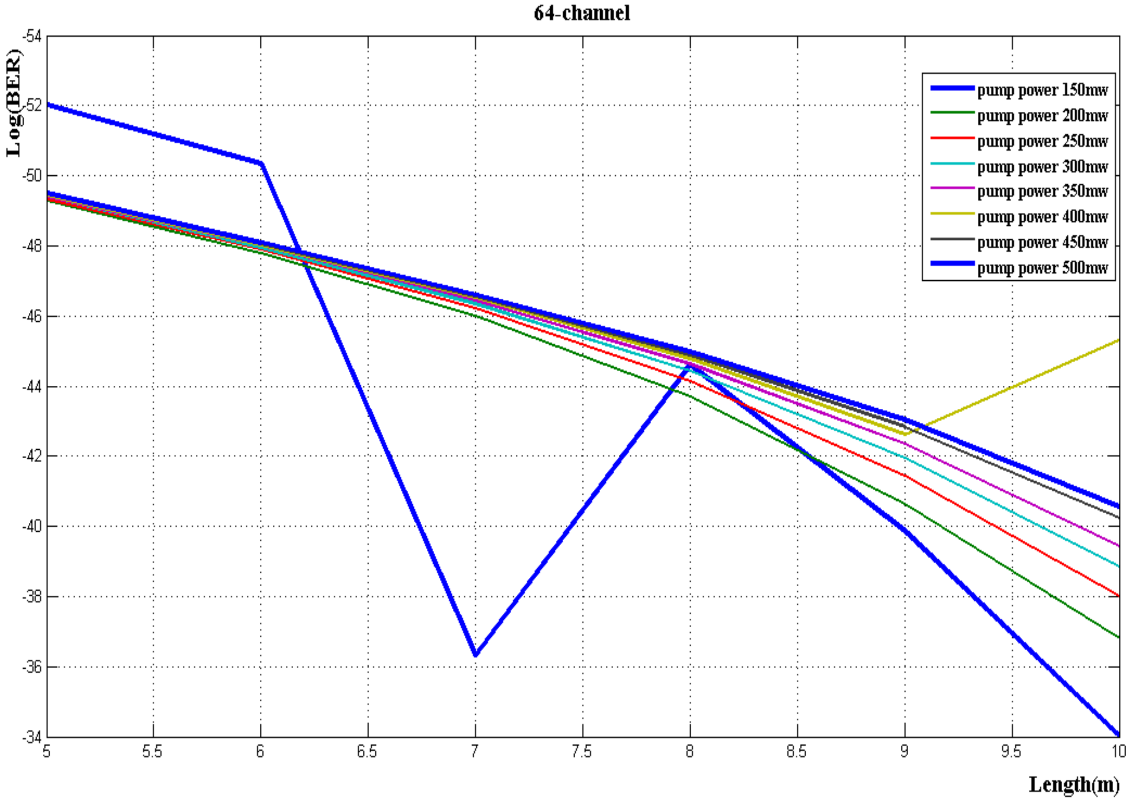

Fig .5. (c). Length Vs Log (BER) for 64 Channels

3.4 Analysis based on Fixed EDF Length

From the analysis of Q factor, BER, Eye height, it is found that EDF optimum length of 8m for short distance communications provides better efficiency. Hence to analyze, an ultra-high bit rate DWDM system with fixed EDF length of 8m chosen. Performance of DWDM system was evaluated based on analysis of the output gain spectrum for 16 channels (WDM-1), 32 channels (WDM-2) and 64 channels (WDM-3) for different pump powers ranging from 150mW- 500mW. The WDM-1 configuration have exhibited slightly increased flattened gain from 1550 nm to 1565nm band of wavelength for the pump power in the range of 500mW. Quality factor was found to be deviating from 0.8 for that channels that uses the operating band with a wavelength of 1550 nm to 1565nm. Meanwhile the WDM-2 configuration has an increased slope with a flattened gain level that deviates in the range of 0.7 over the operating wavelength from 1550nm to 1582 nm for the pump power in the range of 500mW. The WDM-3 configuration have a slope increasing flattened curve over the operating band wave length 1550 nm to 1610nm for the same pump power as WDM-2 configuration. At a pump power of 400mW, for both WDM-1 and WDM-2 configurations exhibits same Q-factor.

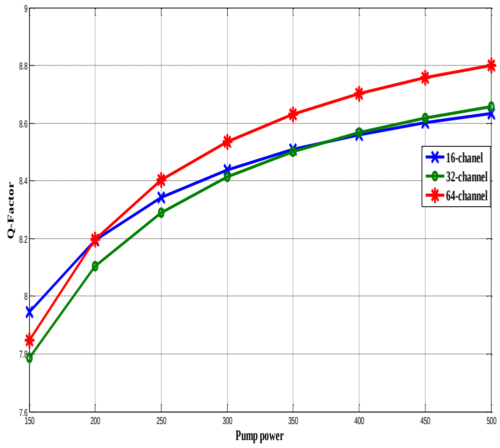

Fig 6. Pump power vs Q factor for Co-channel propagation

Fig 6 shows that the analysis of Q factor for three WDM channel configurations. In co-channel propagation, it is observed that the Q factor for 64 channels (WDM-3) is higher compared to 32 and 16 channels (WDM -2 and WDM-1). The value of Q factor for WDM-3 configuration is 8.80105 for the pump power of 500mW. The Q-factor of WDM-3 configuration varies from 7.84854 to 8.80105 for different pump powers up to a maximum value of 500mW.

The Q factor for the WDM-1 configuration is lower when compared to the other two configurations with its maximum value being 8.63468 For the pump power of 500mw

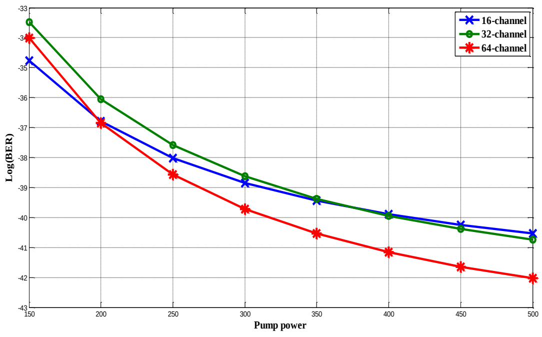

Fig 7. Pump power vs Min BER for Co-Channel propagation

Fig 7 illustrates the BER of co-channel channel propagation for the three WDM configurations. Generally, WDM system with more number of channels will be higher compared to less number of channels due to its transmission capacity. The BER of WDM-1 configuration varies in the range of 10^{-16} to 10^{-20}, for WDM-2 configuration range of BER found to be between 10^{-17} to 10^{-18}, whereas for WDM-3 configuration have the BER in the range of 10^{-16} to 10^{-19} were observed by varying pump power from 150mW to 500mW. For high capacity DWDM system, no of channels transferred through the single fiber has to increase manifold. When the signal power is high, with less channel spacing, effects of FWM was higher between channel results in huge amount of inter channel crosstalk as envisaged in BER analysis. This study depicts for WDM-3 configuration, optimum EDFA fiber length of 8m and pump power of 200mW beyond nonlinear effects dominates as envisaged in the analysis of Q-factor.

IV. CONCLUSION

This review gives a précise on choice to gauge the effect of changing pump power and length of an in-line EDF. As in a WDM system while picking the configuration of the amplifier, it was found that, when 980 nm pump wavelength is utilized, less pumping power is required to guarantee a specific degree of amplification. To evaluate execution of the EDFA, the reliance of BER estimations of the channels with the worst signal quality on the power of the detected signal was observed for every one of the three observed values of various WDM designs, and these outcomes were contrasted and the distinctive pump powers and length acquired in WDM systems. While comparing the performance of the EDFA at various values of pump power and length of EDFA, the significant part of the power penalty is related with ASE noise delivered by the EDFA, however the reason for the difference in it is related with their Q factor and BER are the part of inter channel crosstalk brought about by fiber nonlinearity. Further, ideal EDFA fiber length and pump power of 8m and 200mW was recommended for efficient ultra-high bit rate (640Gbps) data transmission.

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