Performance Analysis of 32 × 10 Gb/s DWDM Optical System using YDFA for Different Channels Spacing

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Abstract- In this paper, 32 × 10Gb/s dense wavelength division multiplexing (DWDM) optical system using ytterbium doped fiber amplifier (YDFA) having 100GHz, 75GHz, 50GHz and 25GHz channel spacing with starting frequency 193.414THz has been investigated. The performance of the end channel (first) has been considered being the worst case scenario to analyze the system. The DWDM system is evaluated by varying the length for the optical fiber from 40-160km. It has been found that as the channel spacing decreases the performance drastically degrades owing to four wave mixing (FWM) effect. The best results have been reported for the system at the 100GHz channel spacing where the maximum Q factor (23.35dB) and output power (-1.156dBm) is achieved at 40km fiber length. Further, it is found that the maximum repeater-less transmission distance of the system with 100GHz and 25GHz channel spacing is 160km and 60km corresponding to BER < 10^{-9}.

Keywords: DWDM, YDFA, Q-factor, BER, EDFA, CW Laser, PRBS.

I. INTRODUCTION

Now-a-days there is demand for higher system capacity to carry large volumes of data across long distances. The signal power level degrades as travel along the fiber due to the fiber non-linearties. In early days of fiber optic communication the electronic regenerators were used to overcome the losses of the fiber. These regenerators firstly convert the optical signal in to electrical and then again in to electrical and it is very difficult to use these devices for long-haul communication. Also, these regenerators when used with wavelength division multiplexing the system became complex and expensive. The above mentioned disadvantages of electronic regenerators led to the invention of the optical amplifiers [1]. There is no need of optical to electrical conversion in optical amplifiers, as they amplify the signal directly, the data rate and repeater-less transmission distance also increases.

Wavelength division multiplexing (WDM) is a technology in which two or more than two signals are combined on to single fiber by using different wavelength. These signals are combined at the transmitter side and are separated at the receiver by using multiplexer and demultiplexer. In dense wavelength division multiplexed system the channel spacing becomes denser but more wavelengths can be accommodated in same C Band(1530-1565nm) [1-4]. In case of 100GHz system would use 20 channels but as the channel spacing reduces to 50GHz system should use 40 channels. Optical amplifiers when used with WDM system the overall performance of the system is increased. Since 1980's, for long haul communication Erbium doped fiber amplifier (EDFA) is used with WDM systems. EDFA is capable of amplifying multiple signals on different wavelength and is mainly used in 1500nm-1600nm band. To transmit optical signal over hundreds or thousands of kilometers, EDFA has been used as inline or booster amplifier. It should have low noise figure and good gain bandwidth [2]. Raman fiber amplifiers give broad bandwidth and substantially reduce the fiber nonlinearities. The value of OSNR is enhanced and repeater-less transmission distance is increased by using Raman amplifiers [3]. Kim et al. [7] transmit optical signals over 80km through SMF (single mode fiber) at a speed of 10Gb/s to analyze the parameters like extinction ratio, maximum output power, rising/falling time and chirp parameters to maximize dynamic range o input signals by using SOA's as a booster amplifier.

By cascading amplifiers, the performance of the system can be enhanced. EDFA when combined with Raman to form hybrid amplifier it have advantages over individual amplifiers [5].Carena et al. [6] designed hybrid Raman/EDFA for yielding closed form analysis by considering the fiber non-linearities. He observed that by combining the Raman/EDFA, maximum repeater-less transmission distance increases compared to individual amplifiers.

Masuda et al. [8] designed hybrid Raman/EDFA and achieve seamless 3.0-, 1.3-, and 1.0-dB bandwidth of 80, 76 and 69nm. Masum-Thomas et al.[9] used discrete Raman amplifier with Thulium doped fluoride fiber to form hybrid amplifier. He demonstrated that when bandwidth is 75nm, then gain > 20dB was attained and for 50 nm bandwidth the gain > 30dB and noise figure between 7 and 8dB was attained. Pizzinat et al. [10] analyze the effect of EDFA/distributed Raman amplification WDM system by considering the noise properties of Raman amplification at high data rate. He observed that pure Raman amplification let the BER constant whereas input power decreases to about 6dB.

Paschotta et al. [11] explained that YDFA is likely to find wider use because of its broad bandwidth and efficient performance. He also investigated that YDFA offers number of interesting applications in near future because of its broad amplification bandwidth. Moghaddam et al. [12] analyzed the performance of erbium–ytterbium doped fiber amplifier (EYDFA) and observed that in wavelength range from 1541 to 1565nm using a multimode pumping at 927nm EYDFA achieve output power higher than 23dB and flat gain.

Kaler et al. [13] analyze 16, 32 and 64 channel WDM systems at 10Gb/s with EDFA, Raman and SOA amplifier by considering the transmission distance and dispersion. He observed that when dispersion is 2ps/nm/km and channels are less SOA provide best results and performance drastically degrades as the as the channels increases. Performance of EDFA is better than SOA. Raman amplifiers reduce the effect of non linearities and provide better performance in L-band.

In this paper, we extend the previous work by considering 32 channels for ytterbium amplifier as a in-line-amplifier having 100GHz, 75GHz, 50GHz and 25GHz channel spacing. The performance is evaluated in terms of Q-factor, BER, output power, optical spectrum and eye diagrams by varying the length of the optical fiber. This paper is organized in to four sections. In section 2, the DWDM system is explained. In section 3, evaluated results have been discussed and finally, in section 4 conclusions are made.

II. SYSTEM DESCRIPTION

The system for 32 channels DWDM system at various channel spacing that are amplified by YDFA is shown in Figure 1.

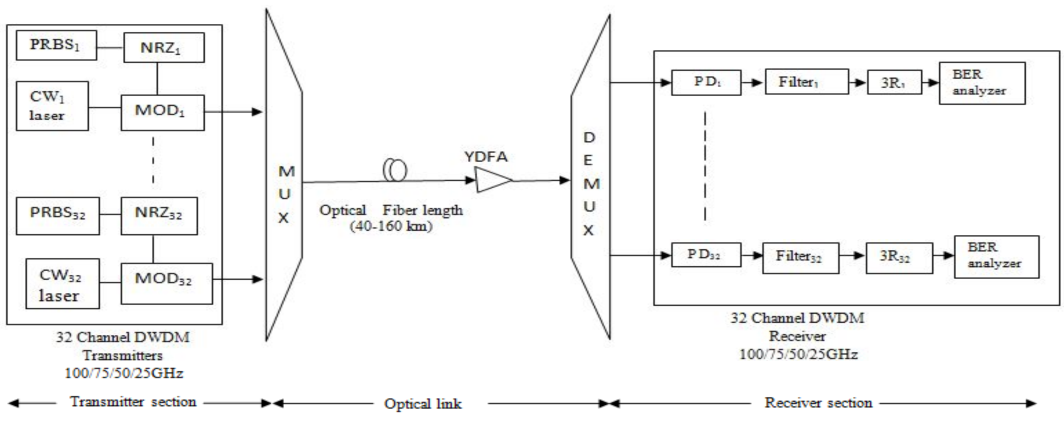


Figure. 1 Schematic diagram of DWDM system

In this system, 32 channels are transmitted by using WDM transmitter at 10Gb/s data rate having 100GHz, 75GHz, 50GHz and 25GHz channel spacing and reference frequency is 193.4THz. 32 channel WDM transmitter is made up by using 32 transmitters, in which each transmitter contain data source, driver, Continuous Wave (CW) laser source and external modulator (Mach-Zehander). Signal is generated at 10Gb/s by data source using pseudo random bit sequence (PRBS) generator. The order of the PRBS generator is 7. Logical input signals are converted in to electrical signal with the help of the drivers. CW laser source generates 32 laser beams with the starting frequency of 193.4THz and frequency range 193.4-196.5THz, 193.4-195.725THz, 193.4-194.95THz and 193.4-194.175THz for channel spacing 100GHz, 75GHz, 50GHz and 25GHz respectively. Parameters of laser source are: line-width = 10MHz and power = 10dBm. Mach-Zehander modulator with extinction ratio = 15dB is used as the external modulator to modulate data source signals using laser.

Transmitted signals are multiplexed and launched in to optical fiber, where YDFA is used to amplify the signals. Results are evaluated by varying the length of optical fiber from 40-160km. Parameters of optical fiber are: attenuation = 0.2dB/km, dispersion slope = 0.07ps/nm^2/km and dispersion = 6ps/nm/km. Parameters of YDFA are: length = 5m, ytterbium ion density = 1×10^{25}m^{-3}, ytterbium doping radius = 3.4µm and numerical aperture = 0.2.

These signals are then demultiplexed by using demultiplexer. These modulated signals are converted in to original signals with the help of optical receivers. Optical receivers comprise of PIN photodiode, low pass bessel filter and 3R regenerator. BER analyzer and spectrum analyzers are used as visualizers to obtain the value of BER, Q-factor, eye diagrams and signal spectrums. The performance of the system is considered in terms of maximum Q-factor, BER, output power, eye diagram and optical spectrum.

III. RESULTS AND DISCUSSIONS

The performance of 32×10Gb/s DWDM system using YDFA is analyzed for different channel spacing i.e., 100GHz, 75GHz, 50GHz and 25GHz and performance is compared in terms of Q-factor, BER and output power. Q-factor and the BER are inversely proportional to each other as the q-factor increases the BER value should decrease.

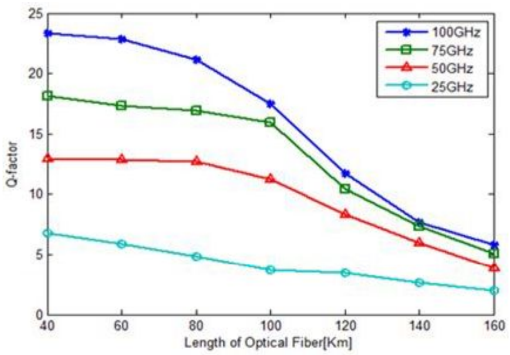


Figure 2 Q-factor vs. transmission distance

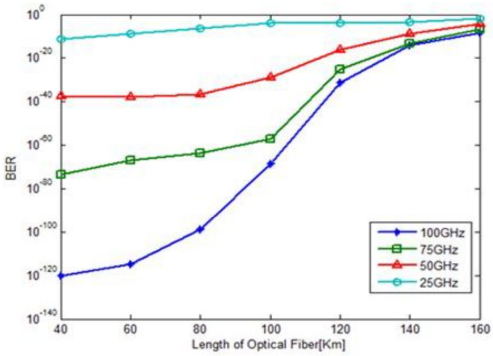


Figure. 3 BER vs. transmission distance

Figure. 2 shows the plot of Q-factor as a function of distance at 6ps/nm/km dispersion at different channel spacing (100GHz, 75GHz, 50GHz and 25GHz). From the graph it is observed that as the channel spacing reduces the performance degrades due to the effect of four wave mixing and SPM. The best Q-factor value obtained is 23.35dB at channel spacing = 100GHz. The variation in Q- factor at 100GHz channel spacing is from 23.35dB to 5.82dB, 18.15dB to 5.08dB for 75GHz, 12.94dB to 3.86dB for 50GHz and from 6.76dB to 2.007dB for 25GHz channel spacing.

Graph of BER vs. transmission distance is shown in Figure. 3. It is observed from the graph that as channel spacing reduces the BER value increases, due to the effect of four wave mixing and SPM. The variation in the value of BER for 100GHz is from 10^{-121} to 10^{-9}, from 10^{-74} to 10^{-7} for 75GHz, from 10^{-38} to 10^{-5} for 50GHz and from 10^{-12} to 10^{-2} for 25GHz channel spacing. The minimum value of BER which is 10^{-32} and 10^{-28} is achieved at 120km transmission distance for 100GHz and for 75GHz channel spacing where as in case of 50GHz and 25GHz channel spacing minimum value of BER is 10^{-38} and 10^{-12} achieved at 40km of transmission distance. From the Figure. 2 and 3 we also observed the maximum repeater-less transmission distance for 100GHz, 75GHz, 50GHz and 25GHz channel spacing.

Table- 1. Maximum repeater-less transmission distance at various channel spacing

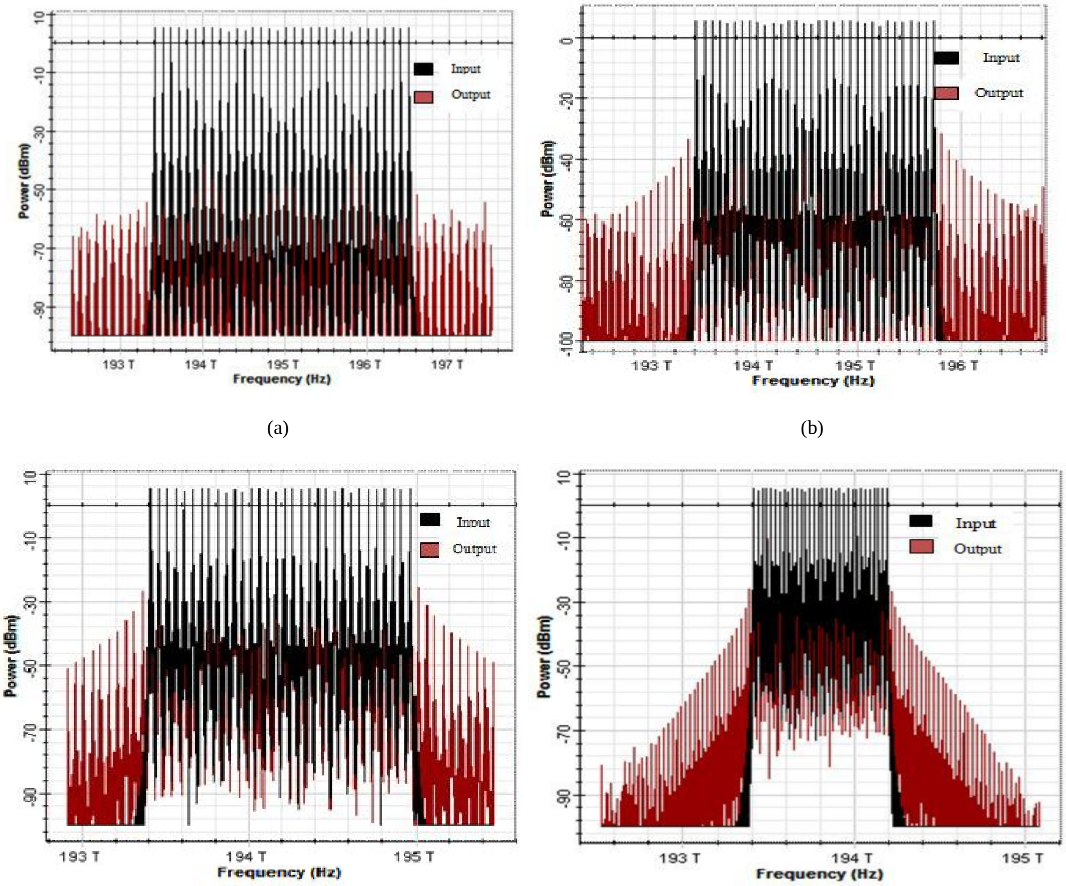
Channel Spacing	**Maximum Repeater-less Transmission Distance BER ≤ 10^{-9}**
100GHz	**160km**
75GHz	**150km**
50GHz	**140km**
25GHz	**60km**

The performance of the system is also analyzed by considering the output power. The maximum output power is obtained at 100GHz channel spacing and as the spacing reduces there is decrease in output power because of non linear effects (FWM and SPM). The variation in output power as a function of length for different channel spacing is shown in table 2.

Table -2 Output power at various channel spacing

Distance(km)	**Output power (dBm) for various channel spacing**			
	100GHz	**75GHz**	**50GHz**	**25GHz**
40	**-1.156**	**-1.259**	**-1.517**	**-2.760**
60	**-5.167**	**-5.253**	**-5.530**	**-6.774**
80	**-9.163**	**-9.249**	**-9.525**	**-10.773**
100	**-13.171**	**-13.249**	**-13.525**	**-14.772**
120	**-17.171**	**-17.244**	**-17.527**	**-18.774**
140	**-21.174**	**-21.244**	**-21.519**	**-22.775**
160	**-25.174**	**-25.244**	**-25.519**	**-26.775**

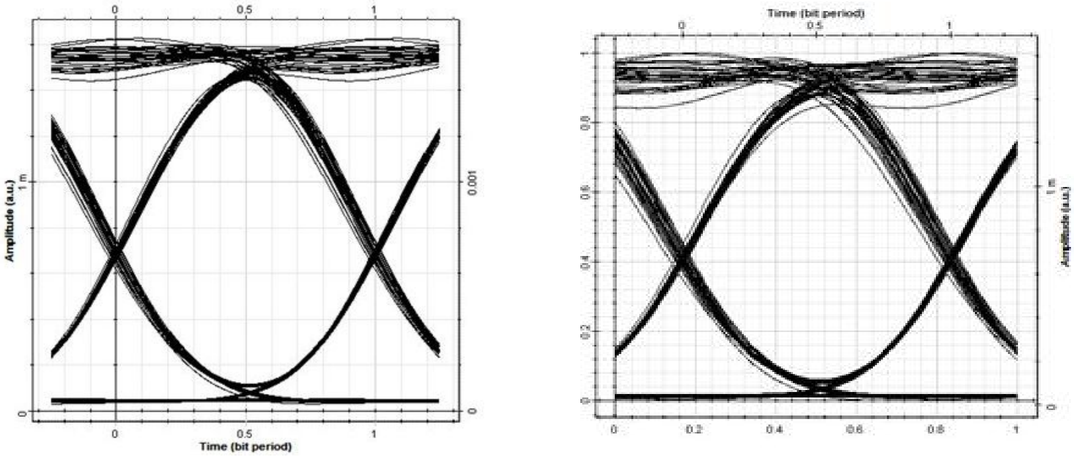
In this system, optical spectrums are used to analyze the effect of four wave mixing by reducing the channel spacing. The input and output optical spectrums of 32 channel DWDM system at 100GHz, 75GHz, 50GHz and 25GHz channel spacing at 50km fiber length is shown in figure 5. From these figures it is observed that as the channel spacing reduces the effect of four wave mixing drastically increases.



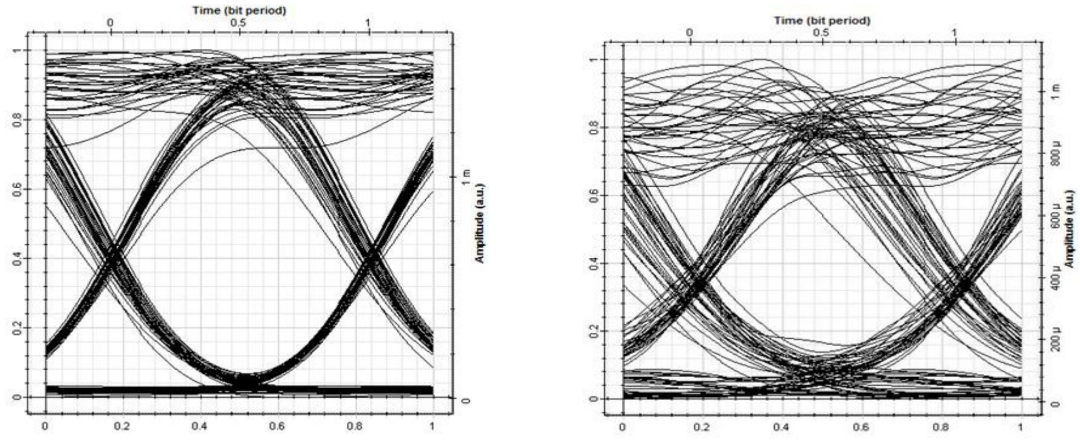
(a) (b)

(c) (d)

Figure 5. Input and output spectrums at various channel spacing at 50km fiber length: (a) input and output signals for 100GHz channel spacing, (b) input and output signals for 75GHz channel spacing, (c) input and output signals for 50GHz channel spacing, (d) input and output signals for 25GHz channel spacing.



(a) **(b)**



(c) (d)

Figure 6. Showing eye diagrams for different channel spacing at 50km of fiber length: (a) 100GHz channel spacing, (b) 75GHz channel spacing, (c) 50GHz channel spacing, (d) 25GHz channel spacing.

The results are also supported by the eye diagrams for different channel spacing obtained from BER analyzer at first channel at a transmission distance of 50km and dispersion = 6ps/nm/km as shown in Figs 6(a)- 6(d). The worst eye opening is shown in case of 25GHz channel spacing.

IV. CONCLUSION

The 32 × 10 DWDM system has been analyzed using YDFA having 100GHz, 75GHz, 50GHz and 25GHz channel spacing and performance has been analyzed on the basis of transmission distance. From the results it is observed that best results have been reported for the system at 100GHz channel spacing (23.35dB). Maximum repeater-less transmission distance for 100GHz, 75GHz, 50GHz and 25GHz channel spacing achieved at 160km, 150km, 140km and 60km respectively. At last, from the optical spectrums it has been observed that as the channel spacing reduces the effect of four wave mixing drastically increases.

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