PERFORMANCE ANALYSIS OF WDM AND EDFA IN C-BAND FOR OPTICAL COMMUNICATION SYSTEM

M.M. Ismail, M.A. Othman, H.A. Sulaiman, M.H. Misran & M.A. Meor Said
Centre for Telecommunication Research and Innovation (CeTRi)
FakultiKej. ElektronikdanKej.Komputer
UniversitiTeknikal Malaysia Melaka
Hang Tuah Jaya, Durian Tunggal 76100, Melaka, Malaysia

ABSTRACT
This paper discussed about Wavelength Division Multiplexing (WDM) and Erbium-Doped Fiber Amplifiers (EDFA) and the performance of both WDM and EDFA in C-band frequency range. Optical amplifier is used to compensate for the wakening of information during the transmission because of fiber optic attenuation. There are three general applications of optical amplifiers that are in-line amplifier, power amplifier and also preamplifier. Basically this paper analyzed the performance of an optical system based on the different factors, focusing in C-band frequency. The factors are the different wavelengths, the different length of EDFA, and also the three different types of optical amplifier.

Keywords:*WDM, Optical Amplifiers, Discrete Raman Amplifiers, EDFA, Optimization of EDFA*

1. INTRODUCTION

C-band as known as Conventional Band is the name given in one certain range of electromagnetic spectrum that includes wavelength of microwaves that are used for long distance radio telecommunications. The C-band frequency range for NATO is between 500-1000MHz and for IEEE is between 4-8GHz. For optical fiber communication, the spectrum region for C-band is from 1530nm until 1565nm. Laser pump is a device used to induce stimulated emission. Relay stations in fiber optic communications use laser pumps to boost signals.Laser pumping is the act of energy transfer from an external source into the gain medium of a laser. The pump supplies energy to electrons in an active medium, which raises them to higher energy levels to produce a population inversion.To obtain some of the benefits of forward pumping without using direct coupling is to use higher order pumping. It amplifies the primary pump waves and can reduce the amplifier noise figure. A co propagating higher order pump can be used to pump a counterpropagating pump, thereby amplifying the counterpropagating pump at the signal input end of the fiber.Thus the signal gain is increased at the beginning of the fiber. In general, the copropagating pump is of shorter wavelength than the counter-propagating pump, and the counterpropagating pump is primarily responsible for the gain to the signal wavelengths.

Wavelength Division Multiplexing (WDM) is the basic technology of optical networking [1]. It is a technique for using a fibre (or subsequently optical device) to carry many separate and independent optical channels. The principal is identical to that used when we tune our television receiver to one of many TV channels. Each channel is transmitted at a different radio frequency and we select between them using a “tuner” which is just a resonant circuit within the TV set.For long distance communication to achieve error free reception use of repeaters is essential but repeaters are costly. Therefore we are using the combination of the optical amplifiers namely EDFA with proper gain adjustment. By doing this we can achieve the greater distance at which repeater can be placed and causes substantial advantage in reducing the number of spans. This will lead to saving the whole cost for communication setup. Optical Amplifiers amplifies the optical signals noise and distortion.

Erbium doped fiber amplifier (EDFA) is capable to amplify light in the 1550nm wavelength region (which the attenuation of silica fiber is minimum). The main configuration of EDFA consisting of: 1) The erbium-doped optical fiber 2) The wavelength-selective coupler. 3) The pump laser. WDM is used to couple the pump signal into the doped fiber. The purpose placing the isolator at the output of an amplifier is to prevent back reflection which able damage amplifier performance. Normally, the EDFA configuration can be characterized by pumping schemes into three arrangements: 1) Forward-pumped (co-pumped). 2) Backward-Pumped (counter-pumped) 3) Dual-pumped.

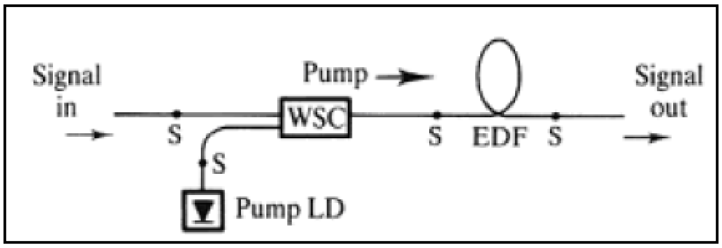

Figure 1: Forward pumped EDFA structure [3]

Efficient EDFA pumping is probable using semiconductor lasers operating near 980- and 1480-nm wavelengths. Most EDFA use 980-nm pump lasers because it can providing more than 100mw of pump power, and used in low-noises required. Pumping at appropriate wavelength provides gain through population inversion the gain spectrum depends on the pumping scheme. The same thing happens with the presence of other dopants, such as alumina and germanium, inside the fiber core. [4]It is important to choose an amplifier with the right characteristic for an application. The most important characteristic of an amplifier are its gain, power output and for WDM its range amplified wavelength. There are three types of EDFAs:

i. Power amplifier

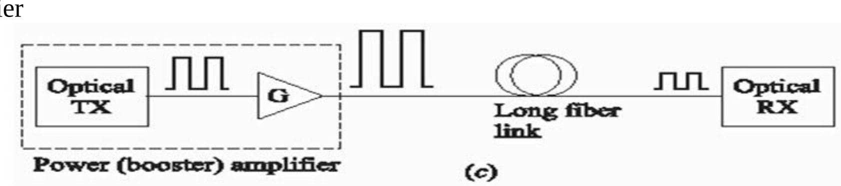

Figure 2: Power amplifier [5]

Power amplifier is placed immediately after the mixing stage at the transmitter end of the system. The input power level will relatively high. The limitation of this amplifier is the total output power. [1]

ii. Line Amplifier

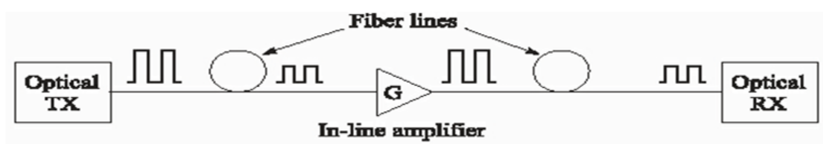

Figure 3: Line Amplifier [5]

This amplifier is placed between the transmitter and optical amplifier. These amplifiers receive a low level signal and then amplify it by as many dB as possible. 30dB is the best level amplifies. This amplifier limitation is the gain, noise and the total output power. [1]

iii. Preamplifier

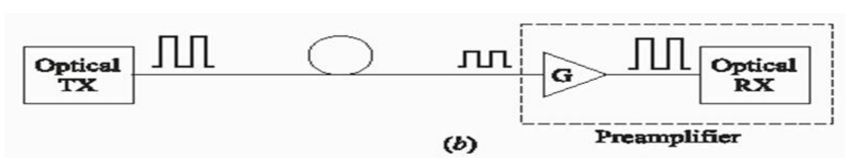

Figure 4: Preamplifier [5]

Optical amplifier is placed before end of the optical receiver to improve the sensitivity. The preamplifier has low level of noise. Only a moderate gain figure is needed because the signal is being fed directly to receiver. [1]

Several optical parameters need to be considered during the simulations setup. The Q-factor is a function of the means and the variances of the currents in the marks and in the spaces that are obtained experimentally in the time domain using an oscilloscope. The Q-factor is a parameter that directly reflects the quality of a digital optical communications signal. The higher the Q-factor, the better the quality of the optical signal.As the Q-factor is related to the analog signal it gives a measure of the propagation impairments caused by optical noise, non-linear effects, polarization effects and chromatic dispersion. In addition BER is defined as the rate at which errors occur in a transmission system or the number of errors that occur in a string of a stated number of bits.BER depends on the signal-to-noise ratio (SNR) and the probability density function (PDF) at the receiver output. The pulse rate expressed by a number, such as 10^{-9}, for examples, which state that, on the average, one error occurs for every billion pulses sent.

The other important parameter is *Eye Height (AU)*. The eye-pattern measurement is made in time domain so that it can allow the effects of waveform distortion to be shown immediately on the display screen of standard BER test.The width of the eye height defines the time internal over which the received signal can be sampled without error due to interference from the adjacent pulses. The best time to sample the received waveform is when the eye height is largest.The more eye closes, the more difficult it is to distinguish between ones and zeros in the signal. Next is the threshold. The signal noise-to-ratio at which this transition occurs is called threshold level.The function of measuring BER threshold are the transmission parameters that guarantee a Bit Error Rate value not higher than a selected threshold and the allocations that maximize the overall system goodput.

Gain also is important in optical communication. Gain is a measure of the ability of the amplifier to increase the power or amplitude of a signal from the input to the output.Basically, it is defined as the mean ratio of the signal output of the system to the signal input of the same system. So, the higher gain of the amplifier system resulting better performance. In order to get a better gain, the optical communication needs a very small Noiase Figure. Noise Figure (NF) is a measure of noise characteristic of an amplifier in a given ratio of input signal due to the output signal. All amplifiers have NF greater than unity which are greater than 0dB and so diminish the signal quality. Even with this degradation, optical amplification improves performance as compare with the system where the receiver amplifier amplifies the signal electrically at the detector process [2]. Noise figure = $\frac{(\frac{S}{R})_{in}}{(\frac{S}{R})_{out}}$ Optical Signal Noise Ratio (OSNR) is the way to assess the quality of the analog communication system. OSNR is a measure of the ratio of the signal power to noise. The higher OSNR, the higher quality signal produced.So, the low noise figure is better.

2. SIMULATION SETUP

a) WDM analysis for different wavelengths

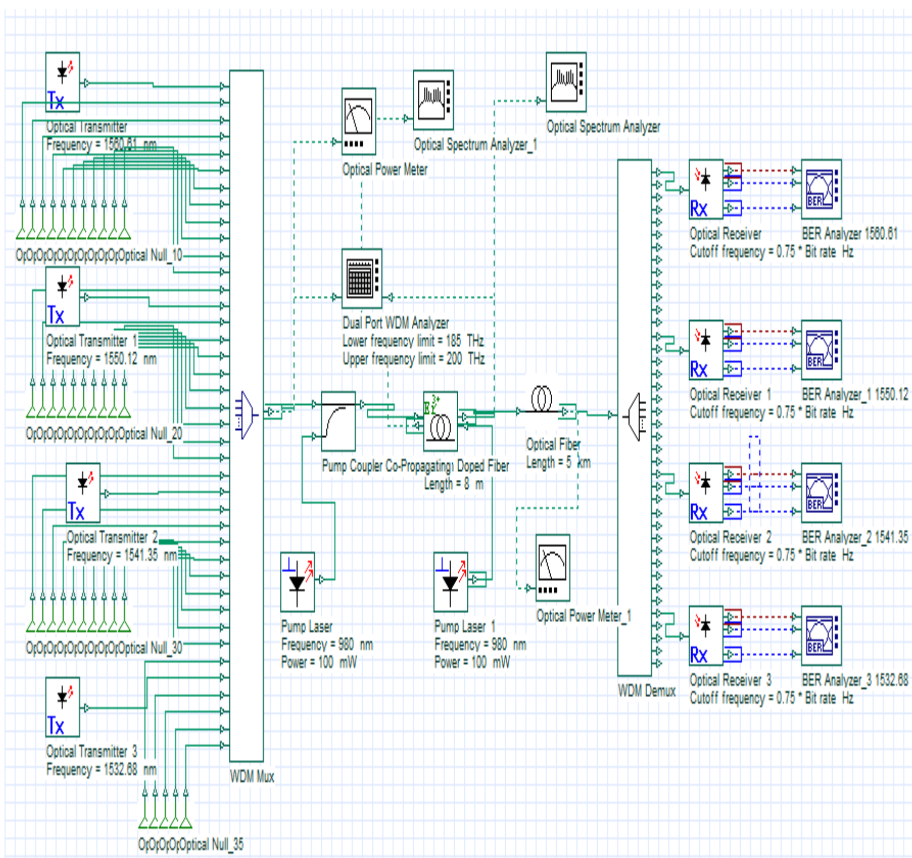

Figure 5: Basic simulation setup

Figure 1 shows the simplified WDM simulation set-up. The four optical transmitters represent four wavelengths across the C band which is 1560.61nm, 1550.12nm, 1541.35nm and 1532.68nm. The optical signals are multiplexed using the AWG multiplexer and an amplified using the EDFA and transmitted over another 5km. Lastly, the AWG demultiplexer will demultiplex the optical signal according to its wavelength. An optical receiver and BER analyzer is applied at each output port to observe the eye diagram. Pump Coupler co-propagating provide gain to the signal directly through the high frequency features on the gain spectrum and pump laser supplies energy to electrons in an active medium, which raises them to higher energy levels to produce a population inversion and experienced a stimulated-emission process. Optical power meter is added to measure the power over a selected wavelength band. Dual port WDM analyzer is used to analyze optical spectra.

b) Circuit setup to investigate the effect of changing length of EDFA to the system.

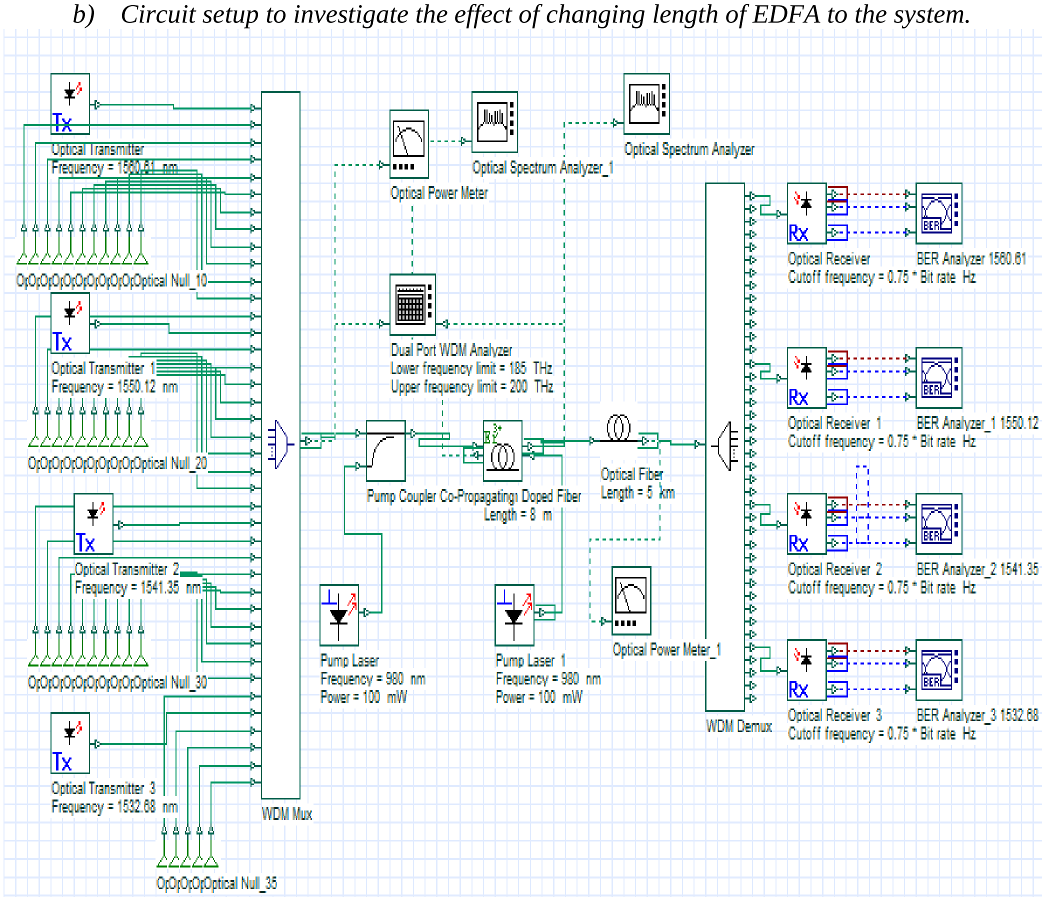

Figure 6: Optical system using different length of fiber

The length of EDFA is change from 6m to 10m (increasing by 1 meter).

c) Three types of amplifier setup

Three different types of amplifier circuit are set up that is in-line amplifier, pre-amplifier, power amplifier.

3. RESULTS AND DISCUSSIONS

a) WDM analysis for different wavelengths

Wavelength (nm)	Max Q factor	Min BER	Eye Height (AU)	Threshold	Gain	Noise Figure (dB)
1560.61	4.8897	4.75094×10^{-7}	0.00377153	0.00551922	37.435838	4.4507
1550.12	4.53815	2.6045×10^{-6}	0.00476262	0.00746336	39.208847	4.36381
1541.35	4.24793	1.00688×10^{-5}	0.00309433	0.00586616	37.075558	4.39612
1532.68	4.61349	1.83479×10^{-6}	0.0131438	0.0203102	43.364277	5.04843

Table 1: WDM analysis for different wavelengths

b) Circuit setup to investigate the effect of changing length of EDFA to the system.

Erbium Doped Fiber Length (m)	Max Q factor	Min BER	Eye Height (AU)	Threshold	Gain	Noise Figure (dB)	Optical power ,dBm (before amplifier)	Optical power ,dBm (after amplifier)
6	4.59208	2.02665×10^{-6}	0.0186351	0.0288849	44.905308	4.94855	-21.865	18.491
7	4.60184	1.93859×10^{-6}	0.0161997	0.0251229	44.293276	5.05267	-21.865	18.320
8	4.61349	1.83479×10^{-6}	0.0131438	0.0203102	43.364277	5.04843	-21.865	18.170
9	4.6053	1.90883×10^{-6}	0.00972601	0.0150516	42.076047	4.97683	-21.865	18.037
10	4.57112	2.24811×10^{-6}	0.00642444	0.010057	40.35427	4.86094	-21.865	17.918

Table 2: Analysis of optical system using different lengths of EDFA

c) Three types of amplifier setup

Type of Optical Amplifier	Erbium Doped Fiber Length (m)	Max Q factor	Min BER	Eye Height (AU)	Threshold	Gain	Noise Figure (dB)	Optical power ,dBm (before amplifier)	Optical power ,dBm (after amplifier)
In Line Amplifier	8	4.62723	1.70391×10^{-6}	0.011052	0.016653	42.58082	6.4037	-21.865	17.613
Preamplifier	8	4.62643	1.717×10^{-6}	0.0116585	0.0178753	41.784202	7.84571	-21.865	18.134
Power amplifier	8	4.64658	1.53633×10^{-6}	0.0105054	0.0152087	43.364277	5.04843	-21.865	17.170

Table 3: Analysis of optical system using different types of amplifier

a) WDM analysis for different wavelengths

In basic simulation setup, a comparison was made among different wavelengths in C-band to determine the result of max Q-factor, min BER, eye height, threshold and gain.1560.61 nm wavelength has the highest Q-factor and the lowest value for minimum BER and threshold while the 1541.35nm wavelength has highest minimum BER and the lowest maximum Q-factor, eye height and gain.The 1532.68 wavelength shows the best performance because they have the highest eye height, threshold, and gain even though it has the highest noise figure.

b) Circuit setup to investigate the effect of changing length of EDFA to the system.

In this category, we differentiate the performance of the system based on the length of EDFA ranged from 6m to 10m. It can be seen that the 6m of EDFA achieve the highest value for eye height, threshold, gain and optical power after amplifier.While7m EDFA only have the average value for all parameter but has the biggest measurement for noise figure. In the other hand, the 8m EDFA shows similar performance with 7m EDFA except for maximum Q-factor because it has the highest value among others. However, 8m EDFA obtained the least value for min BER.As for 9m EDFA, all the parameters were in an average value compared to others and did not show any noticeable performance.10m length of EDFA achieve lowest values in almost all parameters like max Q-factor, eye height, threshold, gain, noise figure and optical power before amplifier. Only the low noise figure shows the advantage of this length of fiber.

c) Three types of amplifier setup

Three types of amplifier setup have been tested and the results obtained are as follows.In-line amplifier has the average value for all optical parameters and did not have any highest or lowest value among them.While pre-amplifier has the highest value for min BER, eye height, threshold and optical power after amplifier. But it has the highest value for noise figure which affect the overall performance of this type of amplifier.For power amplifier, it has the highest value for max Q-factor and gain but lowest value for min BER, eye height, threshold and noise figure.

5. CONCLUSIONS

WDM is one of basic and useful technology of optical networking and communication. A WDM multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths. One of WDM's biggest advantages is that it allows incoming high bandwidth signal carriers that have already been multiplexed to be multiplexed together again and transmitted long distances over one piece of fiber. We have simulated the use of a multi wavelength fiber as light source for a WDM optical network. The different wavelength gives the different data of maximum Q factor, minimum BER, eye height and threshold that we have discussed in the table above. The hybrid C band EDFA that we use in this system with features of wide bandwidth, flattened gain and low NF, may find vast applications in WDM system and light wave transmission.Based on the results obtained and the result analysis, 1532.68 nm is the best wavelength and suitable to be applied in WDM. As for EDFA, it is suitable for long range optical fiber communications.

6. ACKNOWLEDGEMENTS

Authors would like to thank UniversitiTeknikal Malaysia Melaka for supporting this project and also for financing for this journal.

7. REFERENCES

[1] Mr. S. Chaugule, Mr. Ashish More. “WDM and Optical Amplifier (Wavelength Division Multiplexing)”, 2nd International Conference on Mechanical and Electronics Engineering (ICMEE 2010), 2010.

[2] Parekhan M. Jaff, “Characteristic of Discrete Raman Amplifier at Different Pump Configurations”. World Academy of Science, Engineering and Technology 54 2009.

[3] Perekham M. Aljaff, and Banaz O. Rasheed ”Design Optimization for Efficient Erbium-Doped Fiber Amplifiers”, World Academy of Science, Enginnering and Technology46,2008.

[4] R.P.khare "Fiber Optics and Optoelectronics" Republished in India by Oxford University, 2004.

[5] Gerd Keiser “Optical Fiber Communications, Fourth Edition”, Tta McGraw-Hill Educations (Asia),2010.