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EDFA Gain Optimization for WDM System

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Abstract: The gain flatness of erbium-doped fiber amplifier (EDFA) is a key device for wavelength division multiplexing (WDM) application in modern optical network systems. The purpose of this paper is to correct the gain non-uniformity for each channel in order to equalize the amplitude gain in a wavelength division multiplexing (WDM) system. The system is simulated using Optisystem software to achieve gain flatness of EDFA through optimized fiber length and pump power. The gains are flattened within 24±0.299dB from 1546nm to 1558nm band of wavelength with noise figure (NF) <6dB and bit error rate (BER) $<10^{-9}$ for 16-channels simultaneous amplification in a single stage EDFA. A WDM system which includes an EDFA is modeled and obtained maximum uniformed gains.

Keywords: EDFA, gain flatness, fiber length, pump power, WDM

1. INTRODUCTION

EDFA is an optical amplifier that uses a doped optical fiber as a gain medium to amplify an optical signal. The signal which is to be amplified and a pump laser are multiplexed into the doped fiber, and the signal is amplified through interaction with the doping ions. EDFA is the best known and most frequently used optical amplifier suited to low loss optical window of silica based fiber.

A particular attraction of EDFAs is their large gain bandwidth, which is typically tens of nanometers and thus actually it is more than enough to amplify data channels with the highest data rates without introducing any effects of gain narrowing. A single EDFA may be used for simultaneously amplifying many data channels at different wavelengths within the gain region. Before such fiber amplifiers were available, there was no practical method for amplifying all channels between long fiber spans of a fiber-optic link. One had to split all data channels, detect and amplify them electronically, optically resubmit and again combine them. The introduction of fiber amplifiers thus brought an enormous reduction in the complexity, along with a corresponding increase in reliability.

In WDM systems by multiplexing, a stream of wavelength channels particularly in C and L-band regimes can simultaneously amplify to a desired power level where the amplification of any particular channel is dependent on the signal wavelength, the number of signals present in the system, the input signal powers and its absorption and emission cross-sections [1].

The gain-flattened erbium-doped fiber amplifier (EDFA) is a key component in long haul multichannel lightwave transmission systems such as the Wavelength Division Multiplexing (WDM) [2]. One difficulty in implementing a WDM system including EDFA's is that the EDFA gain spectrum is wavelength dependent. In a WDM system, the EDFA does not necessary amplify the wavelength of the channels equally. EDFA in a WDM system are often required to have equalized gain spectra in order to achieve uniform output powers and similar signal-noise ratios (SNR) [3]. There are several methods in designing a flat spectral gain EDFA such as by controlling the doped fiber length and the pump power [2,4], proper choosing of optical notch filter's characteristic [5], by using an acousto-optic tunable filter [6] and by employing an inhomogeneously broadened gain medium [7]. This paper achieves gain flatness of EDFA by controlling the doped fiber length and the pump power for a given input power of -26dBm and a desired output power of more than 8dBm.

2. METHOD

The software Optisystem is used to design the EDFA in the WDM system. The system consists of 16 input signals (channels), an ideal multiplexer, two isolators, a pump laser, erbium doped fiber, demultiplexer, photodetector PIN, low pass Bessel filter and 3R regenerator as shown in Figure 1.

The input of the system is 16 equalized wavelength multiplexed signals in the wavelength region of 12nm (1546nm-1558nm) with 0.8nm channels spacing. The power of each channel is -26dBm. The pumping at 980nm is used to excite the doped atoms to a higher energy level. An input optical isolator prevents Amplified Spontaneous Emission (ASE) and signals from propagating in backward direction. Otherwise, reflected ASE would reduce the population inversion, hence reducing the gain and increasing the noise figure. The output isolator prevents light from output reflections re-entering in the EDFA. The desired gain is 23dB and output power of more than 8dBm with a gain flatness of less than 0.5dB. The fiber length and pump power are selected as parameters to be optimized to achieve the desired gain under output power and gain flatness constraints.

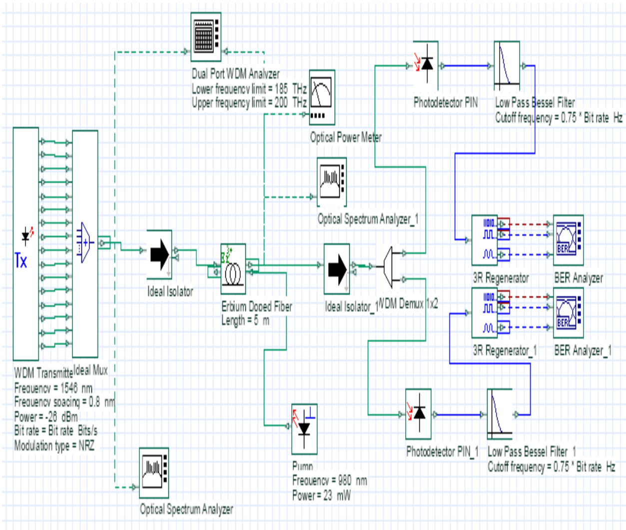

Figure 1. Schematic design of EDFA in WDM system

3. RESULTS AND DISCUSSION

The pump power is bound between 0 and 50mW while the fiber length is bound between 1 and 20m. The output power is measured by varying pump power for different fiber length at a constant input power of -26dBm as shown in Figure 2. The output power increases as the pump power increases. For a given pump power, the output power increases in initial stage and tends to decrease after the fiber length was optimized and remain almost constant. It is observed that the optimum value of fiber length is between 4m to 6m due to the minimum losses.

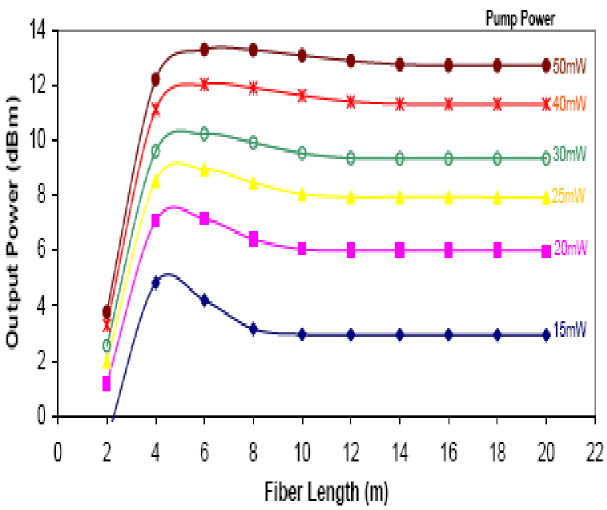

Figure 2. Variation of output power along the fiber length for different pump powers at a constant input power

The optical gain and noise figure (NF) for multi-channels amplification were measured for different pump powers. The fiber length was set at 4m as the reference since the optimum fiber length is between 4 to 6m. The gain flatness is a maximum difference among individual channels gains when the input power signals are equal. Figure 3 shows the gain and NF variation of -26dBm/ch amplification for different pump powers. As the pump power increases, the gain increases while the NF decreases however, the gain flatness increases along with the increased of the pump power.

The pump power of 10mW has very low gain and high noise figure while the pump power of 40mW has high gain and less noise but yield the highest gain flatness of 1.72dB. This shows that the pump power of 10mW and 40mW does not offer good performance for the system since the objective of this paper is to achieve the most equalized gain for every channels. Meanwhile the pump power of 20mW and 30mW has an acceptable noise figure of 5dB however the pump power of 30mW yield higher gain flatness of 1.41dB as compared to 20mW. Therefore, the best gain and NF was found to be at the optimum pump power of 20mW with a low gain flatness of 0.89dB at C-band.

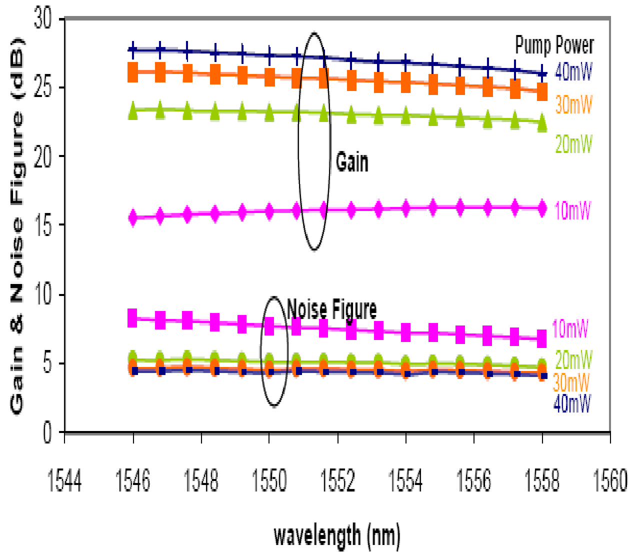

Figure 3. Gain and NF variation of -26dBm/ch amplification for different pump powers.

Figure 4 shows the results viewed from a visualizer in the OptiSystem software. It displayed a clear view of the gain flatness for different pump powers (10, 20, 30 and 40mW) when the power (dBm) versus the wavelength (m). The best case for the maximum gain flatness is at 20mW while the power of 40mW represent the worst case as it yield the most unequalized gain. The fiber length is varied for different values of pump powers in the range of 20mW to 25mW as shown in Figure 5.

For each pump power, the output power increases and decreases after reaching a maximum value. As the fiber length increases, Er3+ ions available to excite increases and output power increases. After a certain length, when all pump power is exhausted, the unexcited Er3+ ions results in the decreased of output power. It is observed that the optimum fiber length is found to be 5m with an output power of 8.408dBm. Figure 6 shows the gain variation of -26dBm/ch amplification for different pump powers at the optimum fiber length of 5m. As the pump power increases, the gain flatness became worst which lead to more noise and bit-error-rate (BER). The maximum gain flatness of 0.299dB was found to be at the optimum pump power of 23mW with an average gain of 24.27dB.

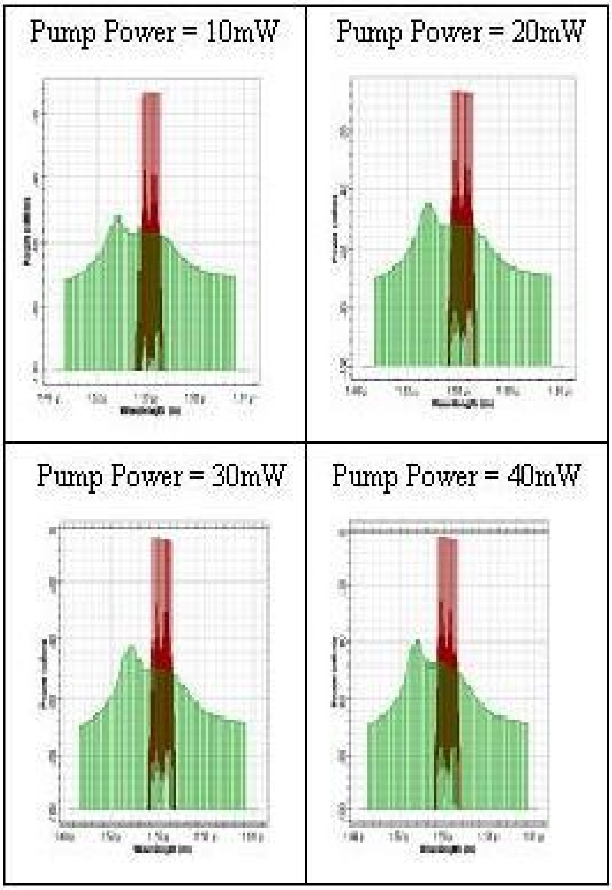

Figure 4. Output power (red) and noise spectrum (green).

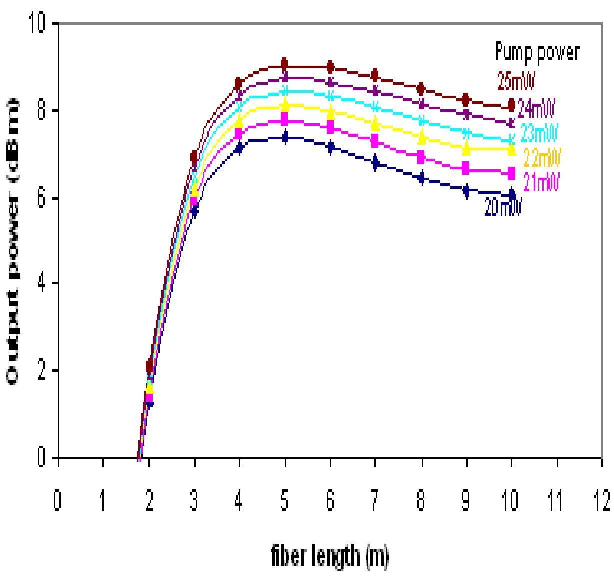

Figure 5. Variation of output power along the fiber length for different pump powers (20-25mW)

The average gain of 24.27dB and NF of 6dB for optimum pump power (23mW) and fiber length (5m) is shown in Figure 7. The performance of the system was analyzed using BER analyzer as shown in Figure 8. The eye pattern for Channel 1 gives a big opening which means that the intersymbol interference (ISI) is low. The width of the opening indicates the time over which sampling for detection is performed. The optimum sampling time corresponding to the maximum eye opening, yielding the greatest protection against noise. The bit error rate (BER) was measured to be at an average of 10^{-14} for channel 1. In Figure 9, the bit error rate (BER) was measured to be at an average of 10^{-16} for channel 16.

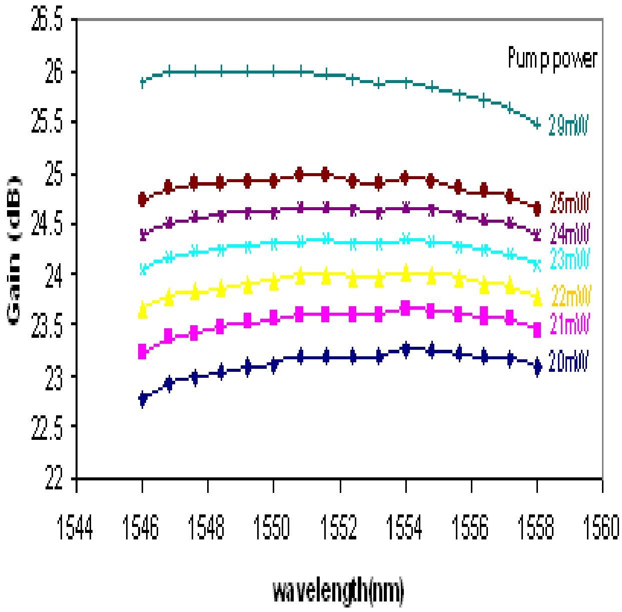

Figure 6. Gain variation for different pump power (20-29mW)

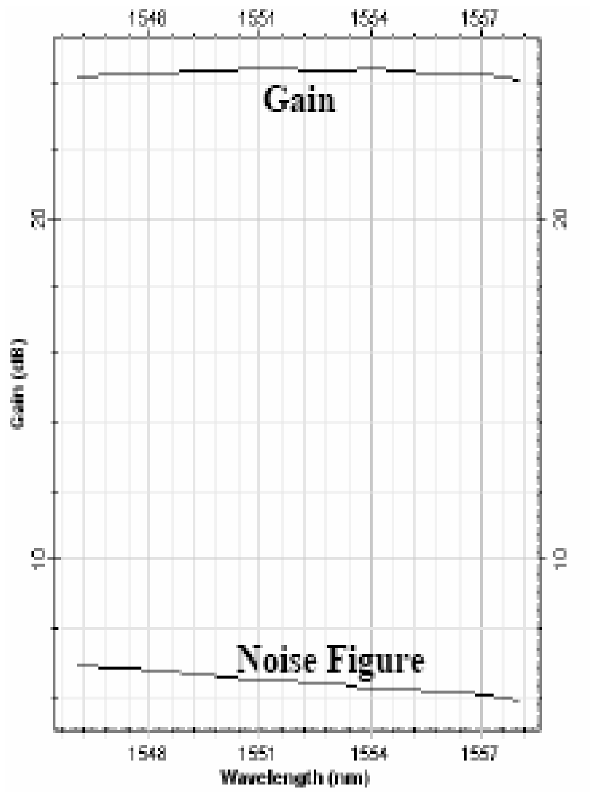

Figure 7. Gain and NF for optimum pump power and fiber length.

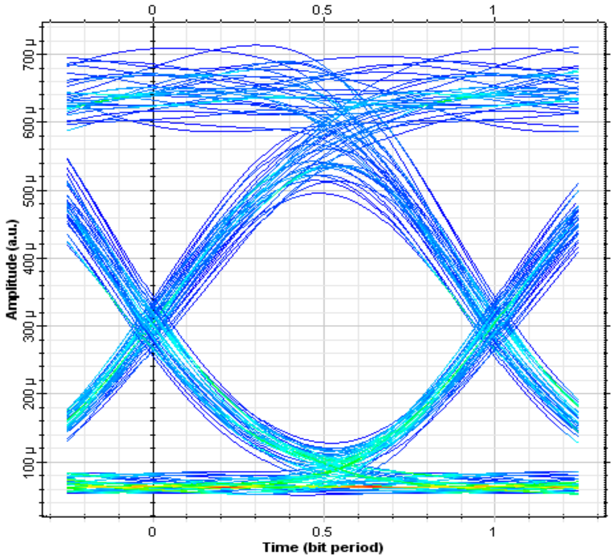

Figure 8. Eye pattern (Channel 1)

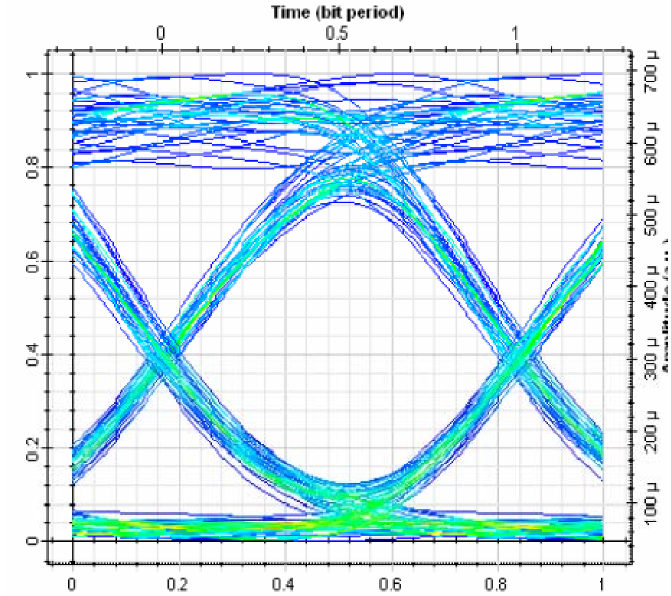

Figure 9. Eye pattern (Channel 16)

4. CONCLUSION

The population inversion can be controlled by proper choosing of fiber length and injected pump power to EDFA. The optimum fiber length is 5m whereas the optimum pump power is 23mW. The system for 16-channel amplification was designed with 24±0.299dB intrinsically gain flatness from 1546nm to 1558nm bandwidth. The output power of 8.408dBm and an average noise figure of 6dB were obtained from the simulation. This WDM system has a good performance of BER which is in the range of 10^{-14} to 10^{-16}.

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REFERENCES

[1] S. Yoshida, S. Kuwano, and K. Iwashita, Electron, Lett, 1995.

[2] S.Y.Park, et al., "Doped fiber length and pump power of gain- flattened EDFAs", *Elect. Lett*. 32, 2161, 1996.

[3] Y. Sun, A. K. Srivastava, J. Zhou, and J. W. Sulhoff, "Optical fiber amplifiers for WDM optical networks", *Bell Labs. Tech. J.*, vol. 4, pp.187-206, 1999.

[4] Surinder Singh a, R. S. Kaler, "Gain flattening approach to physical EDFA for 16 × 40 Gb/s NRZ-DPSK WDM optical communication systems", *Fiber and Integrated Optics*, vol. 25, Issue 5, pp. 363-374, 2006

[5] M. Tachibana, et al., "Erbium-doped Fiber Amplifier with flattened gain spectrum", *IEEE Photon. Tech. Lett.* 3, 118, 1991.

[6] S. F. Su, et al., "Flattening of Erbium-doped fiber amplifier gain spectrum using an acousto-optic tunable filter", *Electro. Lett*, 29, 477, 1993.

[7] E. L. Goldstein, et al., "Inhomogeneously broadened fiber amplifier cascade for transparent multi-wavelength lightwave networks", *J. Light. Tech*. 13, 782, 1995.