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Modelling Of an Erbium Doped Fiber Amplifier and Simulation of Its Gain Flattening Methods

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***Abstract*— The gain flatness of EDFA (Erbium Doped Fiber Amplifier) plays an important role for WDM optical application and all optical self-routed wavelength addressable networks. EDFA have biggest disadvantage in having different gain for different wavelength. The main purpose of this work is to obtain the gain non-uniformity for each channel in order to equalize the amplitude gain in a WDM (Wavelength Division Multiplexing) system. The system is simulated to achieve gain flatness of EDFA through different fiber parameters. The design parameters for an EDFA simulation perspective are investigated. Complex effects of EDFA are researched and simulated with an optical environment design software tool named OptiSystem.**

***Index Terms*— ASE, BER, EDFA, WDM.**

I. Introduction

The new light wave generation, with vastly improved capacity and cost, is based on the recent development of EDFA's. Undersea systems were the early beneficiaries, as EDFA repeaters replaced expensive and unreliable electronic regenerators. The use of Erbium doped fiber amplifiers is desirable in such systems to reduce the number of repeaters. An equally attractive feature of the EDFA is its wide gain bandwidth. Along with providing a gain at 1550nm, in the low-loss window of silicon fiber, it can provide a gain over a band that is more than 4000 GHz wide. With available WDM (Wavelength Division Multiplexing) technics and devices, commercial systems transport more than 16 channels on a single fiber; and the number is expected to reach 100. Thus, more than 250 optical channels with a channel spacing of 15 GHz (0.1 nm) can be multiplexed into a fiber communication link and amplified by optical amplifiers placed periodically. But the EDFA gain varies with wavelength of signals. There comes the need of flattened EDFA gain and an optimized noise figure.

In this study, we initially investigates the design parameters for an EDFA (Erbium Doped Fiber Amplifier) simulation perspective. A set of rate equations with boundary conditions are solved for the pump power inside the resonator cavity and the signal flow build up inside the cavity. Secondly, complex effects which occur during the gain and noise figure improvement operations of EDFA are researched and simulated with an optical environment design software tool named OptiSystem.

II. Modelling

For modelling an EDFA, we use the rate equations and propagation equations of a three level laser system which is the basic of a 980nm pumped EDFA. Consider the following three level system.

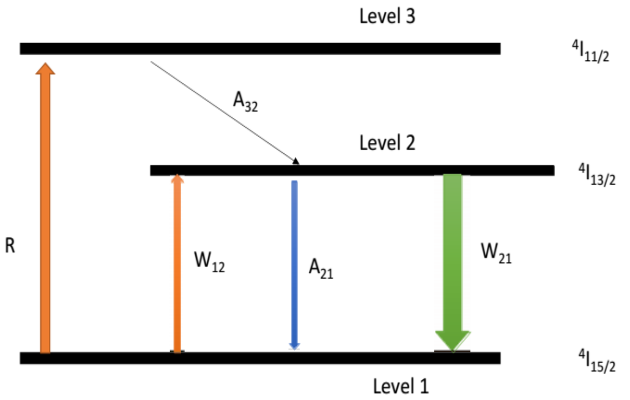

Figure 1. *Three level system of laser*

Figure shows all the important transition between the levels. R- Absorption rate (pumping rate) from level 1 to level 3, corresponding to 980nm pumping. W_{12} and W_{21} - Absorption rate and Stimulated emission rate between level 1 &2, A_{21} - Spontaneous decay rate from level 2 to level 1, A_{32} – Non-radiative decay rate from level 3 to level 2. By definition, level 1 is the ground level, level 2 is the metastable state having a life time $\tau = 1/A_{21}$ and level 3 is the pump level. Then the atomic laser rate equations of these three levels can be written as,

$$\frac{dN_1}{dt} = -RN_1 - W_{12}N_1 + W_{21}N_2 + A_{21}N_2 \tag{1}$$

$$\frac{dN_2}{dt} = W_{12}N_1 - W_{21}N_2 - A_{21}N_2 + A_{32}N_3 \tag{2}$$

$$\frac{dN_3}{dt} = RN_1 - A_{32}N_3 \tag{3}$$

N_1, N_2 and N_3 are the electron densities in levels 1,2 &3. By considering the fact that A_{32} >>R populations of the three level systems are,

$$N_1 = \rho\,\frac{1 + W_{21}\tau}{1 + (R + W_{12} + W_{21})\tau} \tag{4}$$

$$N_2 = \rho\,\frac{(R + W_{12})\tau}{1 + (R + W_{12} + W_{21})\tau} \tag{5}$$

$$N_3 = \frac{R}{A_{32}} n_1 \approx 0 \tag{6}$$

Where, $\rho = N_1 + N_2 + N_3$ the erbium ion concentration. As shown in equation N_3 is zero, this is due to the fast decay from level 3 to 2. Therefore 980nm pumped EDFA can be

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analyzed by considering only levels 1&2. For a single mode fiber, R,W_{12} and W_{21}, as a function of fiber coordinate z and radial axis r, can be written as,

$$R = \frac{P_p(z)}{\tau P_p^{\,sat}} \psi_p(r) \tag{7}$$

$$W_{12} = \frac{\sigma_{sa}}{\tau(\sigma_{sa}+\sigma_{se})} \frac{P_s(z)}{P_s^{\,sat}} \psi_s(r) \tag{8}$$

$$W_{21} = \frac{\sigma_{se}}{\tau(\sigma_{sa}+\sigma_{se})} \frac{P_s(z)}{P_s^{\,sat}} \psi_s(r) \tag{9}$$

ψ -denotes radial mode envelop distribution and subscripts s and p stands for pump and signal. σ_a, σ_e are the absorption and emission cross sections. Substituting eqns 7-9 in 5, we get the population density of level 2,

$$N_2(r,z) = \rho(r)\frac{\frac{P_p(z)}{P_p^{\,sat}}\psi_p(r) + \frac{\sigma_{sa}}{(\sigma_{sa}+\sigma_{se})}\frac{P_s(z)}{P_s^{\,sat}}\psi_s(r)}{1+\frac{P_p(z)}{P_p^{\,sat}}\psi_p(r)+\frac{P_s(z)}{P_s^{\,sat}}\psi_s(r)} \tag{10}$$

$\rho(r)$ is the erbium density distribution.

A. Propagation equation for signal

When a signal of wavelength λ with intensity I_s (power per area) passes through an active medium of length dz, Then intensity change dI_s,

$$dI_s = (\sigma_e(\lambda)N_2 - \sigma_a(\lambda)N_1)\, I_s dz \tag{11}$$

For a single mode propagation, and signal power of $P_s(\lambda)$, the light intensity distribution $I_s(\lambda,r,\theta)$

$$I_s(\lambda,r,\theta) = P_s(\lambda)\frac{\psi_s(\lambda,r,\theta)}{\int \psi_s(\lambda,r,\theta) r dr d\theta} \tag{12}$$

Where θ is the azimuthal coordinate and S denote the integral should be over the entire transverse plane. From the above two equations, signal propagated is written as,

$$\frac{dP_s(z)}{dz} = P_s(\lambda)\{\sigma_s(\lambda)N_2(\lambda,r,\theta) - \sigma_a(\lambda)N_1(\lambda,r,\theta)\}\psi_s(\lambda,r,\theta) r dr d\theta \tag{13}$$

ψ_s is the normalized mode power.

$$\psi_s(\lambda,r,\theta) = \frac{\psi_s(\lambda,r,\theta)}{\int \psi_s(\lambda,r,\theta) r dr d\theta} = \frac{\psi_s(\lambda,r,\theta)}{\pi\,\omega_s^{\,2}(\lambda)} \tag{14}$$

ω - mode power size.

Above mentioned differential equations are solved by using fourth order Runge-Kuttae method to obtain signal and pump power flow in EDF.

III. SIMULATION

The optical conversion efficiency is quite high (slope efficiency of 0.61) whereas the ratio of the output power to the absorbed pump power is 0.69.

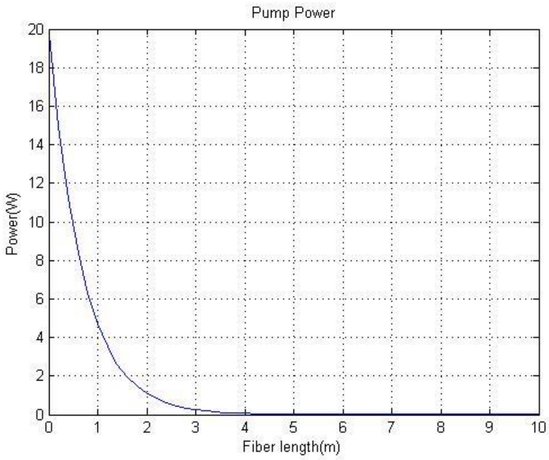

Figure 2. *Pump power v/s fiber length*

As fiber length increases, power gets reduced.

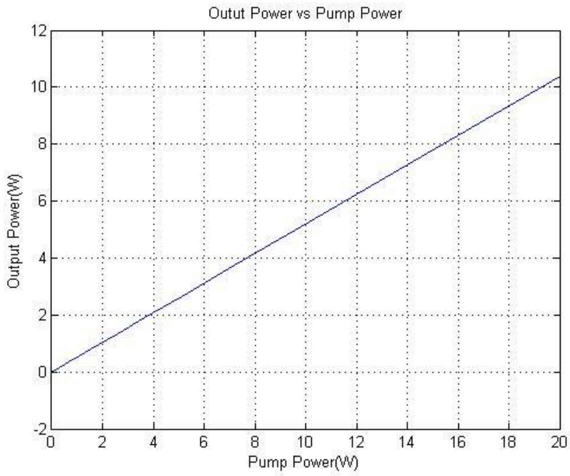

Figure 3. *Output power v/s pump power*

Graph shows pump and signal powers as a function of position along the fiber. Pump is injected at z=0 where the mirror reflectivity is high.

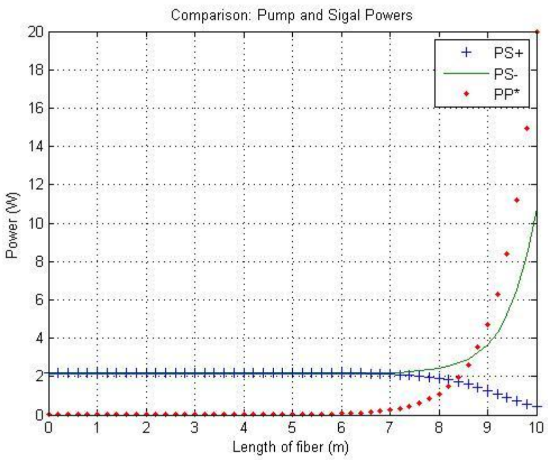

Figure 4. *Backward signal inbuilt*

Pump and signal power as a function of position along the fiber, except that the pump is injected at z=L where the mirror reflectivity for the signal is much lower.

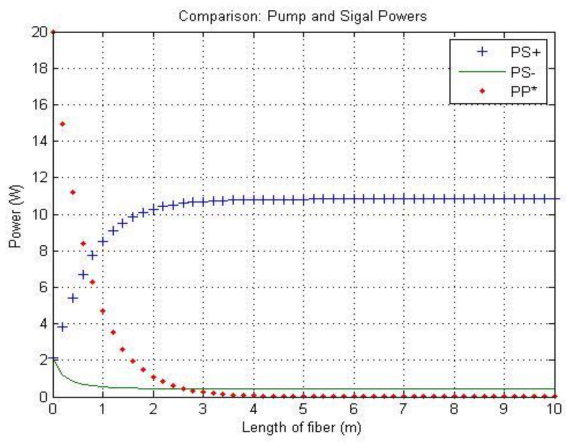

Figure 5. *Forward signal inbuilt*

Although increasing the fiber length will absorb more power, at some point the signal output power will start to decrease due to the losses that become significant when the pump power is low.

IV. Gain Flatening Methods Using Matlab

In DWDM transmission systems and their related optical networks, one of the key technological issues is the achievement of broad and flat gain bandwidth for EDFA. Gain differences occur between optical channels having large wavelength spacing. In long amplifier chains, even small spectral gain variations can result in large difference in the received signal power, causing inacceptably large BER descrepancies between received signals. For some optical channels, complete power extinction can occur at the system output due to inefficient gain compensation along the amplifier chain. Additionally, the ASE generated in the region of highest gain in equalized EDFAs causes homogeneous gain saturation, which affects WDM channels at longer wavelength.

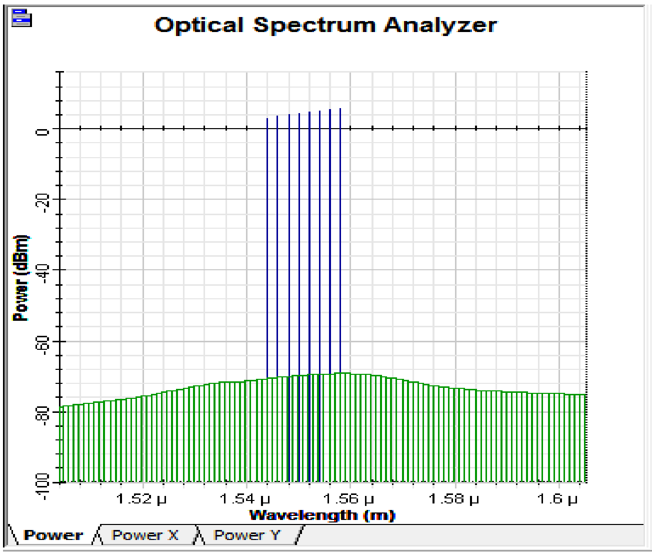

Figure 5. *Spectrum before flattening*

A. Use of Gain Flattening Filter.

For a fixed length of EDFA, pump power is varied to achieve a predetermined gain. Output is optimized for different average insertion losses of Gain flattening filter.

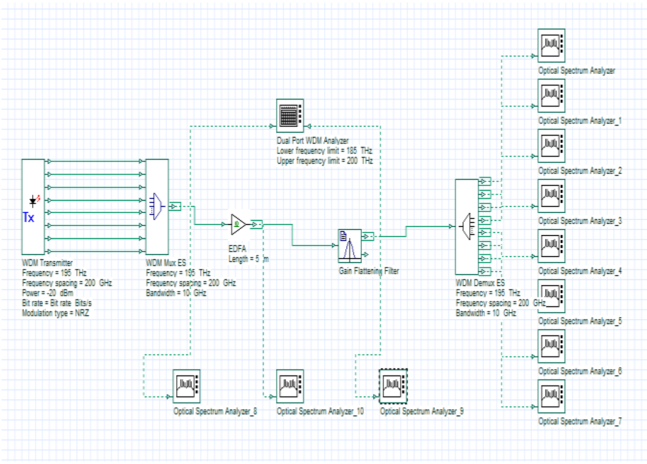

Figure 6. *Use of gain flattening filter*

B. Changing Pump Power and EDF Length.

Both pump power and EDF length is varied. Pump power is varied from 0 to 180mW. And EDF length is varied from 1 to 6m. An optimized pump power and EDF length is found for the flattened gain EDFA.

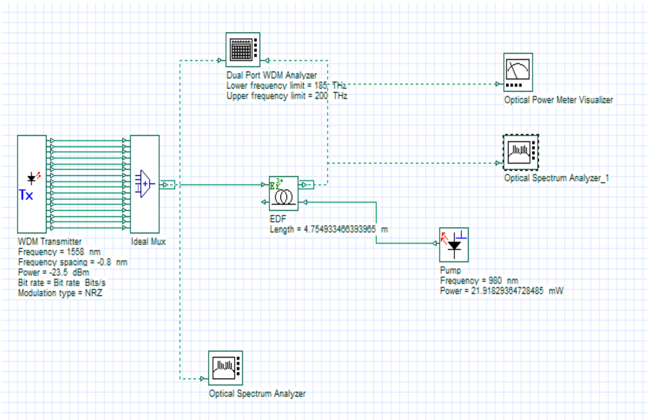

Figure 7. Changing pump power and EDF length

C. *Adaptive method using matlab component*

Here we use a Matlab component as the gain flattening device. Code calculates the power obtained for each signal (wavelength). And selects the wavelength with minimum power.(or the wavelength got minimum gain).Then Matlab component attenuates other signal powers to the selected minimum power to equalize the gain.

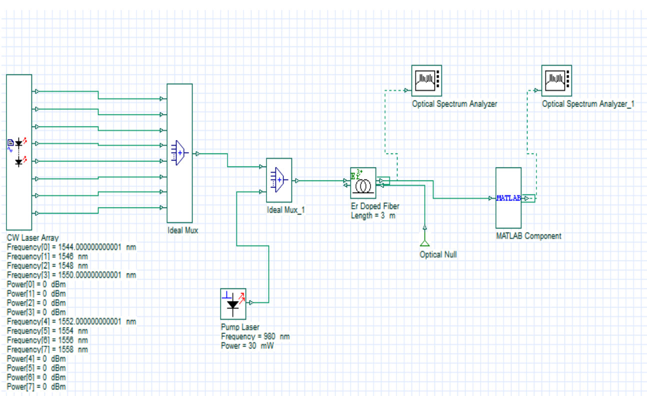

Figure 8. *Gain flattening method*

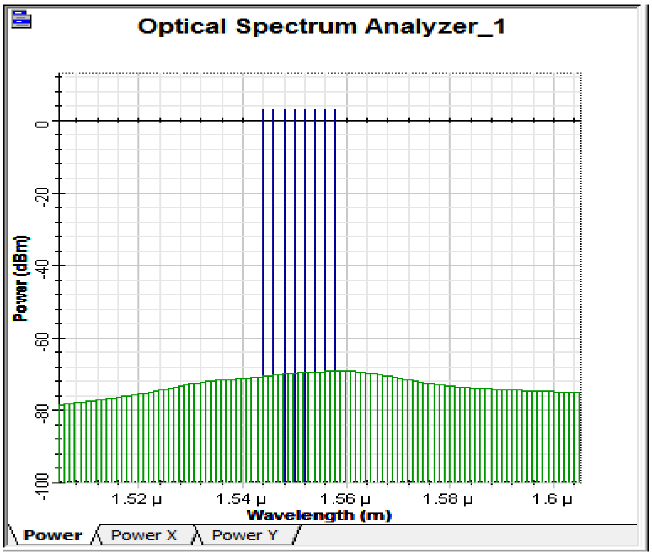

Figure 6. *Flattened spectrum*

V. Conclusion

In the design of EDFAs, many factors such as pumping wavelength, fiber length, fiber core radius, input signal power, fiber numerical aperture, and Erbium concentration have great influences. To find optimum values of these factors, we need a reliable and effective method. Although genetic algorithm can be quite helpful, sometimes it is hard to work with this method because of lengthy computational time and complexity. The population inversion can be controlled by optimizing fiber length and injected pump power to EDFA. With the proper selection of fiber length and injected pump power to EDFA, the population inversion can be controlled which in turn helps in maintaining the uniformity of gain in a WDM system.

References

[1] Saleh, A. A. M., R. M. Jopson, J. D. Evankow, and J. Aspell, Modeling of gain in erbium-doped fiber amplifiers, IEEE Photon. Technol. Lett., Vol. 2, No. 10, 714 - 717, 1990.

[2] Giles, C. R. and E. Desurvire, Modeling erbium-doped fiber amplifiers, J. Lightwave Technol., Vol. 9, No. 2, 271 - 283, 1991.

[3] Lu, Y. B. and P. L. Chu, Gain flattening by using dual-core fiber in erbium-doped fiber amplifier, IEEE Photon. Technol. Lett., Vol. 12, No. 12, 1616 - 1617, 2000.

[4] Martin, J. C., Erbium transversal distribution influence on the effectiveness of a doped fiber: Optimization of its performance, Opt. Commun., Vol. 194, 331 - 339, 2001.

[5] Choi, B. H., H. H. Park, and M. J. Chu, New pumped wavelength of 1540-nm band for long-wavelength-band erbium-doped fiber amplifier (L-band EDFA), J. Quantum Electron., Vol. 39, No. 10, 1272 - 1280, 2003.

[6] Yeh, C. H., C. C. Lee, and S. Chi, S- plus C-band erbium-doped fiber amplifier in parallel structure, Opt. Commun., Vol. 241, 443 - 447, 2004.

[7] Singh, R., Sunanda, and E. K. Sharma, Gain flattening by long period gratings in erbium doped fibers, Opt. Commun., Vol. 240, 123 - 132, 2004.

[8] Cheng, C. and M. Xiao, Optimization of an erbium-doped fiber amplifier with radial effects, Opt. Commun., Vol. 254, 215 - 222, 2005.

[9] Cheng, C. and M. Xiao, Optimization of a dual pumped L-band erbium-doped fiber amplifier by genetic algorithm, J. Lightwave Technol., Vol. 24, No. 10, 3824 - 3829, 2006.

[10] Chang, C. L., L. Wang, and Y. J. Chiang, A dual pumped double- pass L-band EDFA with high gain and low noise, Opt. Commun., Vol. 267, 108 - 112, 2006.

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