Raman Amplification in CWDM Systems with Low Power Pumps

Meire C. Fugihara, Armando Nolasco Pinto

Abstract— **We apply Raman amplification to Coarse Wavelength Division Multiplexing (CWDM) systems without access to the middle of the link. We show the feasibility of achieving Raman amplification with low power lasers. These low powers can be made available through the use of semiconductor lasers. Theoretical results with a four-channel CWDM system is shown for three basic configurations – forward, backward, and bidirectional.**

Index Terms— **Optical fiber amplifiers, Raman scattering.**

I. INTRODUCTION

COARSE Wavelength Division Multiplexing (CWDM) is a cost-effective solution for low (≤10Gbps) speed point-to-point optical transmission systems. As the channels are far apart (20nm) the spectrum used tend to be of the order of hundreds of nanometers. This precludes the use of erbium fiber based optical amplifiers. Therefore some other form of optical amplification must be used in order to increase the reach of the systems. A solution proposed in this paper is Raman amplification. The Raman amplification bandwidth can be enlarged by the use of multiple pumps. This is a good characteristic of this amplifier that makes it very interesting to be used in CWDM systems. Besides this, the fiber link can be used as the active medium.

In the first part of this paper it is described the model of the simulated system. In a second part it is shown results of flat gain for a four-channel CWDM system considering the different configurations of the amplification system.

II. MODELING

Our developed system works with four channel CWDM system, it means an amplification spectrum larger than 80nm, remembering that CWDM channels are spaced by 20nm. Another restriction that we have in our system is the access only to the ends of the transmission link. This makes the system simple and more cost-effective. The basic system to be amplified is shown in fig. 1. The system to be developed has a transmitter, with four CWDM channels, a transmission line, in our case a link of optical fiber, and a receiver in the end of the optical fiber.

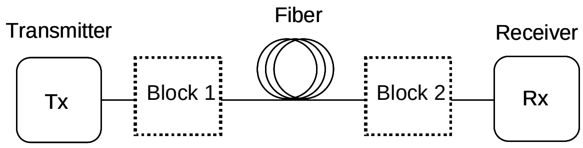

Fig. 1. System to be considered in simulations.

The main idea is to use only the ends of the transmission line. In other words, we want to amplify without insert any component in the middle of the optical fiber. As in fig. 1, we will use, basically, two blocks placed in the ends of the optical fiber. These blocks represent the components added to the system to amplify the channels. In our case, these blocks are composed by laser pumps, couplers, isolators, and circulators depending on the configuration of the amplifier.

Our purpose is to use Raman amplification in this system using the fiber as the active medium. This amplification system is called distributed amplifier. Raman amplification can be obtained basically using three configurations: (a) co-propagating, when the pump is sent forward with the signal (in fig. 1, one laser pump with a coupler substitutes block 1), (b) counter-propagating, when the pump is sent backward with the signal (in fig. 1, one laser pump with a circulator substitutes block 2), and (c) bidirectional, when there are two pumps, one forward and another backward with the signal (in fig. 1, one laser pump with a coupler substitutes block 1 and one laser pump with a circulator substitutes block 2).

The mathematical model used in this work is based on the resolution of the propagation equations of pumps and signals along an optical fiber. This propagation is well described through a system of differential equations such [1]

$$\frac{dP^{\pm}(z,\nu_k)}{dz} = \mp\alpha(\nu_k)P^{\pm}(z,\nu_k) \pm \pm\sum_{j\neq k}\left\{g(\nu_j,\nu_k)\cdot\left[P^{\pm}(z,\nu_j)+P^{\mp}(z,\nu_j)\right]\cdot P^{\pm}(z,\nu_k)\right\} \quad (1)$$

where $P^{+}(z, \nu)$ and $P^{-}(z, \nu)$ are optical powers of forward and backward propagating waves respectively, α is the attenuation coefficient, $g(\nu_j, \nu_k)$ is Raman gain coefficient at frequency ν_k due to frequency ν_j. The $g(\nu_j, \nu_k)$ value depends on the frequencies as it can be seen in equation 2 [1],

This work was partially supported by the Portuguese Scientific Foundation, FCT, through the Ph.D. fellowship SFRH/BD/16734/2004 and by the PT Innovation through the IT project P289, “Raman Amplification for CWDM systems”.

Meire C. Fugihara is with the Institute of Telecommunications and Dept. of Electronic, Telecommunications, and Informatics,University of Aveiro, 3810-193, Aveiro Portugal (e-mail: meire@av.it.pt).

Armando Nolasco Pinto is with the Institute of Telecommunications and Dept. of Electronic, Telecommunications, and Informatics,University of Aveiro, 3810-193, Aveiro Portugal (e-mail: anp@det.ua.pt).

$$g(n_j,n_k)=\begin{cases}\dfrac{g_r(n_j-n_k)}{K_{eff}A_{eff}} & n_j>n_k\\ -\dfrac{n_k}{n_j}\cdot\dfrac{g_r(n_k-n_j)}{K_{eff}A_{eff}} & n_j<n_k\\ 0 & n_j=n_k\end{cases} \quad (2)$$

where K_{eff} depends on the state of polarization between the two waves, A_{eff} is the fiber effective area.

The simulations developed in this work are based on the resolution of the coupled ordinary differential equations based on equation (1). There are some numerical methods to solve this problem. The way we choose is the resolutions through Runge-Kutta method. The choice of this method is due its stability and accuracy.

III. Results

It was simulated a CWDM system composed by a four-channel signal laser with 1510, 1530, 1550, and 1570nm with power of 1mW each one. The link is a fiber with 80km, with 0.23dB/km of pump and a signal loss, the considered effective area is 80μm^2. And it was optimized the wavelength and the power of the two pumps that is used in the amplification system.

It is simulated the three basic configurations of the Raman amplifier with two pumps with low power, maximum of 250mW each one. The optimized wavelengths are 1420 and 1463nm. To the forward and the backward system it was used 200mW to each pump, and to the bidirectional configuration it was used 200mW to the 1420nm pump (forward) and 250mW to the 1463nm pump (backward).

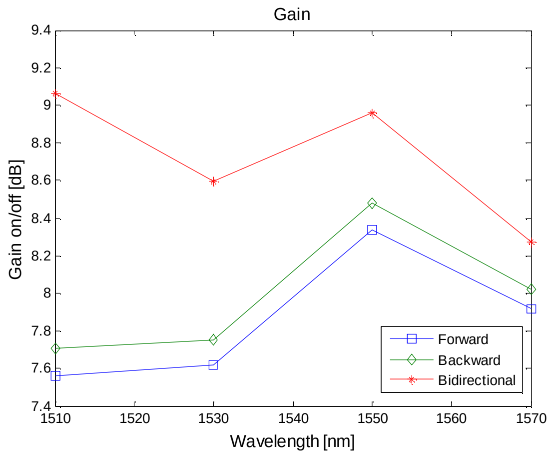

Fig. 2. On/off gain to a bidirectional four-channel CWDM system with two pumps, 1420nm with 200mW and 1463nm with 250mW.

Fig. 2 shows the on/off gain to the three systems. The definition of on/off gain is the ratio of the power of the signals at the end of the fiber with pumps on and the power of the signals at the end of the fiber with pumps off. The forward system has a maximum ripple of 0.78dB. This small ripple means that the signals reached the end of the fiber with powers nearest the same. That means a good approximation to an ideal uniform gain. The backward system has a maximum gain ripple of 0.76dB. To the bidirectional system, it is used the 1420nm pump with 200mW and the 1463nm pump with 250mW. The reason of changing the pump power of 1463nm pump is because 200mW do not produce a uniform gain, changing to 250mW it produces a ripple around the same of the two systems above. It happens due the interactions between the powers of the pumps. This system has a maximum ripple of 0.79dB. Table 1 shows the values of ripple to the different pumping configurations. It can be seen that even changing the configuration of the amplification system, the maximum ripple is still less than 1dB to pump powers less than 250mW.

TABLE I
Comparison of Maximum Ripple to Different Pumping Configurations

Pumping Configuration	Pump wavelength and power	Ripple [dB][a]
Forward	1420nm/200mW and 1463nm/200mW	0.78
Backward	1420nm/200mW and 1463nm/200mW	0.76
Bidirectional	1420nm/200mW and 1463nm/250mW	0.79

Fig. 3 shows the propagation of the signals and the pumps l along the fiber. It can be seen that the signals reached the end of the fiber with around the same powers.

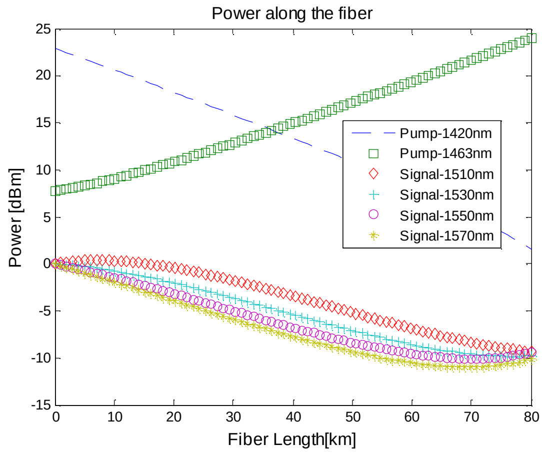

Fig. 3. Propagation of the pumps and the signals to the bidirectional system with pump 1420nm with 200mW and pump 1463nm with 250mW.

Each signal has a different contribution of each pump along the fiber. It happens to all configurations. Optimizing the pumps wavelengths and powers, the signals reach the end of the fiber with around the same values of powers.

IV. Conclusion

A CWDM system, with four channels, with flat gain, ripple smaller than 1dB, was achieved, by using two low power pumps, with less than 250mW.

References

[1] C. Sheng, M. Xiaoming, L. Jinsong, "Effect of Pumping directions on the Performance of Fiber Raman Amplifiers Bi-directionally Pumped at Multiple Wavelengths," Journal of Microwaves and Optoelectronics, vol. 3, pp. 20-26, 2003.