PERFORMANCE STUDY OF FORWARD AND BACKWARD HYBRID OPTICAL RAMAN AMPLIFIERS

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ABSTRACT

In this paper to enhancement the Raman gain, two Raman Amplifiers (RAs) are used one is forward pump Raman amplifier and the second is feedback pump Raman amplifier in cascaded form. The performance of the system is analyzed in terms of fiber type, fiber length, pump power and gain coefficient for enhancement the gain of fiber Raman amplifier. We present the performances and characteristics of RAs by utilizing a set of coupled differential equations and numerical simulations. Three types of fibers with different gain characteristics are used in our numerical simulations. So, the optimum initial values of the pump powers for a system with three pumps are recalculated and optimized again.

Keywords: Raman Amplifiers, Forward Pump Raman Amplifier, Pump Power and Gain Coefficient

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1. INTRODUCTION

More than 20 years have passed since the use of fiber optic communications for commercial use and new technological developments. [1] The Raman amplifier process is the transfer of power of the pump to signal because of the interaction of Raman between the optical and vibrational conditions of the medium molecules [2]. Recently many investigations involving nonlinear processes are important in connection with microwave phototherapy systems such

as microwaves, microwaves, ultrasonic fiber systems, etc. However, the use of nonlinear techniques for fiber deserves attention from studies on SBS as well as SRS [3-4]. Raman amplifiers with multiple wavelengths (RAs) have attracted more and more attention in recent years [5]. In this type of amplification concept is widely used, to use high-frequency long-wave division (WDM) multithreaded systems. Optical amplifiers are the main components of any optical fiber communication system. Although modern optical fiber has losses of less than 0.2 dB / km, amplification of the signal sent to its original intensity is necessary at sufficiently long distances [6]. Optical amplifiers in optical communication systems enhance channel capacity and transmission lengths. Raman amplifiers play an important role [7-8]. The important feature in RA is the gain bandwidth, which is determined by the wavelength of the pump. A multi-wavelength pumping system is typically used to increase the gain and bandwidth amplitude of high-capacity WDM transmission systems. In the Raman amplifiers of the rear pumping fiber, other noise sources, such as RIN are reduced [9]. This paper show the performance of hybrid of optical Raman amplifiers to enhancement the gain of the amplifier, also the parameters affecting on Raman gain of fiber Raman amplifier for three different fiber types can be studied.

2. MODELING AND ANALYSIS

The scheme of a typical DRA which uses two Raman fiber amplifiers the first forward pump Raman amplifier and the second is feedback pump Raman amplifier in cascaded form to enhancement the Raman gain of feedback Raman amplifier is shown on Fig. 1. When the pump power propagates in the direction of the signal, it is called co- or forward pumping scheme, and when the pump travels in the opposite direction, it is called counter or backward pumping. The pump sources marked as P_{S1} and P_{S2} are placed at both ends of the transmission span and their power are switched in the medium of the silica fiber using optical couplers [10].

Figure 1 Design model of hybrid Raman amplifier system scheme

The fiber signal propagates in fiber media with the power signal according a couple of differential equation, this equation describe not only the signals attenuation due to propagation but also the power transfer from the power signal as follow [11-13]:

$$\pm \frac{\partial P_p}{\partial Z} = -\frac{\omega_p}{\omega_s} G_R P_p P_s - \alpha_p P_p \quad (1)$$

$$\frac{\partial P_s}{\partial Z} = G_R P_p P_s - \alpha_s P_s \quad (2)$$

Where G_R is the Raman gain coefficient related to the fiber type ($W^{-1}.m^{-1}$), α_s and α_p are the attenuation coefficient related to the optical signal and the pumping power in same order, ω_s and ω_p are the angular frequency related to the optical signal and the pumping power in same order [14].

Therefore to calculate the pump power at point z it can be used:

$$P_p(Z) = SP_p(0).e^{-\alpha_p Z(1-s)} = P_p(0).e^{-\alpha_p(L-Z)} \quad (3)$$

If the values of P_p are substituted in differential equation (2), and it is integrated from 0 to L for the signal power in the forward and the backward pumping, it can be written as [15-17]:

$$P_s(Z) = P_s(0).e^{(G_R P_0 \left(\frac{(1-\exp(-\alpha_p Z))}{\alpha_p} \right) - \alpha_s Z)} = G_F. P_s(0) \quad (4)$$

$$P_s(Z) = P_s(0).e^{(G_R P_0 \left(\frac{\exp(-\alpha_p L)(1-\exp(-\alpha_p Z))}{\alpha_p} \right) - \alpha_s Z)} = G_B. P_s(0) \quad (5)$$

Where G_F , G_B are the net gain in the forward and backward pumping respectively. With P_0 being the pump power at the input end, α_s and α_p are the linear attenuation coefficient of the signal and pump power in the optical fiber respectively, can be expressed as [18][19]:

$$\alpha_{s,p} = \alpha / 4.343 \quad (6)$$

Where α is the attenuation coefficient in dB/km.

From equation 4, 5 we can get the total gain of fiber Raman amplifier due to using forward pump Raman amplifier and feedback pump Raman amplifier in cascaded form to enhancement the Raman gain of feedback Raman amplifier can be expressed as:

$$G_T = G_F \times G_B \quad (7)$$

Where, G_t the total gain of forward pump Raman amplifier and feedback pump Raman amplifier then,

$$G_T = \exp \left[g_R P_0 x \frac{\exp(-\alpha_p L)(\exp(\alpha_p Z) - 1)}{\alpha_p} - \alpha_s Z \right] \times \exp \left[g_R P_0 x \frac{1 - \exp(-\alpha_p Z)}{\alpha_p} - \alpha_s Z \right] \quad (8)$$

$$G_T = \exp \left[g_R P_0 x \frac{\exp(-\alpha_p L)(\exp(\alpha_p Z) - 1)}{\alpha_p} + g_R P_0 x \frac{1 - \exp(-\alpha_p Z)}{\alpha_p} - 2\alpha_s Z \right] \quad (9)$$

$$G_T = \exp \left[g_R P_0 x \frac{x + y + w}{\alpha_p} - 2\alpha_s Z \right] \quad (10)$$

Where;

$$x = \exp(-\alpha_p L) \cdot \exp(\alpha_p z), \quad y = \exp(-\alpha_p L) \\ \text{and } w = \exp(-\alpha_p Z)$$

The signal intensity at output of amplifier, fiber cable length L is determined by the following expression [20]:

$$P_s(L) = P_s(0) \exp\left(\frac{g_0 P_0 L}{A_{eff}} - \alpha_s L\right) \quad (11)$$

The effective length, L_{eff} is the length over which the nonlinearities still holds or stimulated Raman Scattering (SRS) occurs in the fiber and is defined as:

$$L_{eff} = \frac{1 - \exp(-\alpha_p L)}{\alpha_p} \quad (12)$$

Hence the amplification gain defined as the ratio of the power signal with and without Raman amplification, is given by the following expression [21]:

$$G_A = \frac{P_s}{P_s(0) \exp(-\alpha_s L)} \quad (13)$$

3. RESULTS AND ANALYSIS

In this section the result simulated by using of two Raman fiber amplifiers the first forward pump Raman amplifier and the second is feedback pump Raman amplifier in cascaded form to enhancement the Raman gain of feedback Raman amplifier, where for backward Raman amplifier only the gain is attenuated from input signal power to intersect the zero axis or reach to zero and continues to negative part then reflect to increase to reach maximum value at fiber length span, but in this case gain is start to increasing from zero to indicated value of Raman gain due to using forward pump Raman amplifier then the gain is attenuated slowly but doesn't reach to zero gain then occurs reflection to the gain to reach maximum value at final span fiber length.

3.1. Relation of Raman Gain on Pump Power

Figure 2 shows the variation of gain with pump power for different fiber Types at a constant signal input power. In this simulation, a span of 100 km for three different fiber types is used and the pump power supplied was increased from 0 to 1.5W. It is clear that, the gain of the FRA linearly increases with pump power As a result; the gain coefficient in dB/W increases for high pump powers. In addition, a higher gain can be obtained at a longer Raman fiber with sufficient pumping.

It's clear that the Raman gain is linearly increased with the power increments, from figure the maximum Raman gain be obtained as follow " FreeLight=79dB/W, DSF=90dB/W, TrueWave=115dB/W" which mean that the Truwave fiber has a higher gain than the two other fiber types.

Figure 2 Raman gain against the pumping power for different fiber types

3.2. Relation between Raman Gain and Fiber Length at different pumping power

In this section we show, the variation of gain with fiber length for different pump powers for the three different fiber types (Freelight, DSF and Truewave) having different Raman gain coefficients and constant signal input power.

3.2.1. Relation between Raman Gain and Fiber Length at different pumping power for DSF Fiber Type

Figure 3, the obtained gain from an amplifier for three different pump power levels 900, 1000, 1100mW are given for a 100 km fiber length. As it is shown,

Figure 3 Raman gain against the fiber length with different pumping power for DSF

Also, this result simulated by using of two Raman fiber amplifiers the first forward pump Raman amplifier and the second is feedback pump Raman amplifier in cascaded form to enhancement the Raman gain of feedback Raman amplifier, as shows figure 3, gain is start to increasing from zero to indicated value of Raman gain due to using forward pump Raman amplifier then the gain is attenuated slowly but doesn't reach to zero gain then occurs reflection to the gain to reach maximum value at final spam fiber length. This achieved by using high pumping power as shown in figure 3. Then we concluded that we must be increase the pumping power levels to reduced attenuation and increases the gain of the amplifier and in this case the gain doesn't reach to zero gain also this results give the DSF fiber type is the most powerful Raman amplification media than Freelight fiber type this is because of large Raman gain coefficient and low power signal attenuation. Also, in case of 1000mW pumping power is better than in case of 900mW pumping power.

3.2.2. Relation between Raman gain and Fiber Length at different pumping power for Freelight Fiber Type

In the figure 4, the obtained gain from an amplifier for three different pump power 900, 1000 and 1100mW are given for a 100 km fiber length. As it is shown,

Figure 4 Raman gain against the fiber length with different pumping power for Freelight

This result simulated by using of two Raman fiber amplifiers the first forward pump Raman amplifier and the second is feedback pump Raman amplifier in cascaded form to enhancement the Raman gain of feedback Raman amplifier, where for backward Raman amplifier only the gain is attenuated from input signal power to intersect the zero axis or reach to zero and continues to negative part then reflect to increase to reach maximum value at fiber length spam as shown in previous results , but in this case gain is start to increasing from zero to indicated value of Raman gain as shown in figure 4 due to using forward pump Raman amplifier then the gain is attenuated slowly but doesn't reach to zero gain then occurs reflection to the gain to reach maximum value at final spam fiber length. This achieved by using high pumping power up to 900mW as shown in figure 4.

3.2.3. Relation between Raman gain and Fiber Length at different pumping power for Truwave Fiber Type

Figure 5, the obtained gain from an amplifier for three different pump powers 900, 1000 and 1100mW are given for a 100 km fiber length. As it is shown,

Figure 5 Raman gain against the fiber length with different pumping power for Truwave

The result in figure 5, simulated by using of two amplifiers the first forward pump Raman amplifier and the second is feedback pump Raman amplifier in cascaded form to enhancement

the Raman gain of feedback Raman amplifier, as shows figure 5, gain is start to increasing from zero to indicated value of Raman gain due to using forward pump Raman amplifier then the gain is saturated from 30km to 70km then gain is start to increasing to reach maximum value at final spam fiber length. This results give the true wave fiber type is the most powerful Raman amplification media than the other two types this is because of large Raman gain coefficient and low power signal attenuation. Also, in case of 1100mW pumping power is better than in case of 900 and 1000mW pumping power.

3.3. Relation between Raman Gain and Fiber Length for Different Fiber Types

In this section we show, the variation of gain with fiber length for the three different fiber types (Freelight, DSF and Truewave) having different Raman gain coefficients , constant signal input power and constant pump powers 900mw.

3.3.1 Relation between Raman Gain and Fiber Length for Different Fiber Types at 900mw Pumping Power

Figure 6; show a comparison between three different fiber types (Freelight, DSF and Truewave) at 900mw pumping power for the fiber types having different Raman gain coefficients and constant signal input power.

Figure 6 Raman gain against the fiber length with different fiber types at 900mW pumping power

This result simulated by using of two amplifiers the first forward pump Raman amplifier and the second is feedback pump Raman amplifier in cascaded form to enhancement the Raman gain of feedback Raman amplifier, where for backward Raman amplifier only the gain is attenuated from input signal to intersect the zero axis or reach to zero and continues to negative part the reflect to increase to reach maximum value at fiber length spam as shown in previous results , but in this case gain is start to increasing from zero to indicated value of Raman gain as shown in figure 6 due to using forward pump Raman amplifier then the gain is attenuated slowly but doesn't reach to zero gain then occurs reflection to the gain to reach maximum value at final spam fiber length. This achieved by using high pumping power up to 900mW as shown in figure 6. This results give the true wave fiber type is the most powerful Raman amplification media than the other two types this is because of large Raman gain coefficient and low power signal attenuation.

3.4. Output Signal Power Characteristics for Backward Pumping

This section show how the output signal power varies with the fiber length for different pump powers and fiber span of 100 km at a constant signal power, -4dBm , applied to the three fiber types.

3.4.1. Output Signal Power Characteristics for Backward Pumping at 900mW Pump Power

Figure 7; show the output signal power against fiber length at pump power 900mW and constant signal power, -4dBm , applied to the three fiber types.

Figure 7 Output signal power against fiber length at 900mW pumping power and -4dBm input signal power

Figure 7; was simulating the -4dBm of input signal along 100Km of fiber span and 900mW of pumping power in three different fiber types in case of Freelight fiber type the output signal power is start to increasing from zero to indicated value of output signal power as shown in figure 7, due to using forward pump Raman amplifier then the output signal power is attenuated slowly to reach zero then occurs reflection to the output signal power at 70km fiber length to reach maximum value at final spam fiber length. But in case of DSF the output signal power is start to increasing from zero to indicated value of output signal power as shown in figure 7, due to using forward pump Raman amplifier then the output signal power is attenuated slowly but doesn't reach to zero then occurs reflection to the output signal power to reach maximum value at final spam fiber length. and in case of Truewave fiber the output signal power is start to increasing from zero to indicated value of output signal power as shown in figure 7, due to using forward pump Raman amplifier then the output signal power is attenuated slowly then occurs reflection to the output signal power to reach maximum value at final spam fiber length. After simulation the output signal power for different fiber types along 100Km of fiber span and 900mW pumping power this results give the Truewave fiber type is the most powerful output signal power media than the other two types this is because of large Raman gain coefficient and low power signal attenuation.

3.5. Relation between the Effective Length and Fiber Length for Different Fiber Types

In this section we show, the variation of effective length with fiber length for the three different fiber types (Freelight, DSF and Truewave) having different Raman gain coefficients.

Figure 8 Relation between the Effective Length and Fiber Length for Different Fiber Types

From figure 8, we get the effective length is increased with fiber length linearly for three different fiber types, and then it was go to saturation at around 60Km.

4. CONCLUSION

The obtained results gives enhancement the gain of the amplifier, also we simulate and analyze the parameters affecting on Raman gain of fiber Raman amplifier for three different fiber types. The Raman gain of an optical signal is observed to depend on the selection of pump power. The FRA gain is obtained as a function of fiber length and pump power. The differences between three different fiber types are satisfied.

According to the obtained results, gain is strongly dependent on the fiber length and pumping power.

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