Performance of Backward Pumped Fiber Raman Amplifier with Different Fiber Types

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Abstract

Due to the advantages of the Raman amplifier for the Long-Haul UW-WDM optical communication systems, we would like to look for Raman gain for backward pumping using three different types of fiber. The rate equations and the rate of Raman (FRAs) amplifiers have been numerically resolved. In this way, the gain is simulated for the FRA parameters given that affect the Raman gain for all Raman fiber optic backbone amplifiers, such as fiber type, fiber length, pump strength and gain factor to enhance Raman fiber amplifier gain. Gain is obtained as a function of fiber length and pump strength. According to the results obtained, the gain is strongly dependent on fiber length and pumping power.

Keywords *- Raman Amplifiers, Wavelength Division Multiplexing (WDM), Pump Power and Gain Coefficients*

I. INTRODUCTION

The optical amplifier played a crucial role in the communications revolution that began two decades ago. The multi-band Raman amplifiers (RAs) have attracted more and more attention in recent years [1]. In this type of amplification concept is widely used, for multicast transmission systems long-distance wavelength (and blood) high-capacity. It has already been used in many very long heavy transport and blood transport systems [2]. It supports high bit rate data transmission over long fiber, due to its benefits such as proper gain and optical signal to noise ratio (OSNR) [3]. In addition, it can be used to increase the bandwidth of Erbium doped fiber amplifiers (EDFAs) in hybrid systems [4]. Another important feature of the RAS is its gain bandwidth, determined by the wavelength of the pump. A multi-wavelength pumping scheme is usually used to increase gain flux and bandwidth for high-capacity transmission and blood systems. In the Raman fiber amplifiers inserted into the back, other noise sources, such as relative intensity noise (RIN) transfer [5] are reduced. The Raman amplifier is based on dispersion phenomena Raman scattering is a nonlinear optical process by which the photon, called a photon pump is absorbed by a material while emitting a photon simultaneously from a different energy. The difference in photon energy is compensated by changing the vibrational state of the substance [6].

One of the latest developments and interesting include the constructive use of the so-called Raman effect in optical amplifiers. When the Raman pump wave has slight random power fluctuations in time, it is almost the case, individual bits, differential amplification, which can lead to capacitance fluctuations or jitter. If the rear pump is applied, the average volatility in the capacitance is calculated [7]. Raman fiber amplifiers are now used as days for all Raman or hybrid FRAs/EDFAs at both long distances and very long wavelength lengths divided by multiplex optical communication systems [8]. Raman amplifiers using fiber as a gain method is an encouraging technology for multiplex communication systems to split optical wavelength [9].The paper is organized as follows: Mathematical formulations are presented in Sec. 2. Simulation results and discussion are shown in sec. 3, followed by the conclusion in Sec. 4. According to the obtained results, gain is strongly dependent on the fiber length and pumping power.

II. MATHEMATICAL FORMULATIONS

Optical fiber Raman amplifier employing the bi directionally pumping scheme is able to achieve higher optical signal to noise ratio (OSNR) compared to the one using the backward pumping scheme. The optical power of the first pump source is S P_P and the second source pump is (1-S) P_P respectively, where P_P is the pump power and S is a coefficient showing the power is being pumped in the signal direction. The evolution of the optical signal power (Ps) and the power of the pump source propagating along the fiber cable can described by different equations called propagation equations and Figure 1 shows different pumping direction configurations such as forward, backward and therefore bi-directional pumping direction configurations.

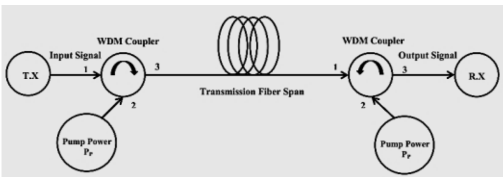

Figure 1. Schematic diagram of distributed fiber Raman amplifier configuration.

The signal and pump power can be expressed as [10-13]:

$$\pm\frac{\partial P_p}{\partial Z} = -\frac{v_p}{v_s} g_R P_p P_s - \alpha_p P_p \qquad (1)$$

$$\frac{\partial P_s}{\partial Z} = g_R P_p P_s - \alpha_s P_s \qquad (2)$$

Where g_R in $W^{-1}m^{-1}$ is the Raman gain coefficient of the fiber cable length, α_S and α_P are the attenuation of the signal and pump power in silica-doped fiber, v_S and v_P are the optical signals and pump frequencies. The signs of"+" or "-" are corresponding to forward and backward pumping. In the general case, when a bi-directional pumping [14] is used (S = 0-1) the laser source work at the same wavelength at different pump power. Therefore to calculate the pump power at point z it can be used:

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

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][16]:

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

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

, Where G_F, G_B are the net gain in the forward and backward pumping respectively. With P_O 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:

$$\alpha_{S,P} = {}^{\alpha}/_{4.343} \qquad (6)$$

, Where α is the attenuation coefficient in dB/km.
The signal intensity at output of amplifier, fiber cable length L is determined by the following expression [17]:

$$P_s(L) = P_s(0)\exp\left(\frac{g_0 P_0 L}{A_{eff}} - \alpha_s L\right) \qquad (7)$$

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:

$$L_{eff} = \frac{1-\exp(-\alpha_p L)}{\alpha_p} \qquad (8)$$

Hence the amplification gain defined as the ratio of the power signal with and without Raman amplification, is given by the following expression [18]:

$$G_A = \frac{P_S}{P_S(0)\exp(-\alpha_s L)} \qquad (9)$$

III. SIMULATION RESULTS AND DISCUSSION

1- Relation of Raman Gain on Pump Power

Figure 1 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; higher gain can be obtained at a longer Raman fiber with sufficient pumping power.

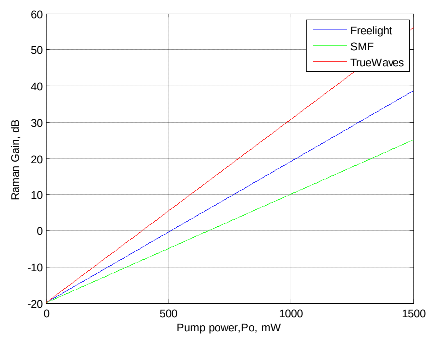

Fig. 1 Raman gain against the pumping power for different fiber types

It's clear that the Raman gain is linearly increased with the power increments, from figure the Raman gain be obtained as follow "SMF=30dB, FreeLight=40dB,TrueWave=50dB" which mean that the Truewave fiber has a higher gain than the two other fiber types.

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 from 200mW up to 800mW are given for a 100 km fiber length. As it is shown below, the gain is attenuated from zero to certain value then the gain increases with increasing the pumping power levels with the fiber length until it reaches a maximum value at 100 km for the three different fiber types (SMF, Freelight and Truewave) having different Raman gain coefficients and constant signal input power.

2.1 Relation between Raman Gain and Fiber Length at different pumping power for SMS Fiber Type

Figure 2; showthe variation of gain with fiber length for different pump powers.

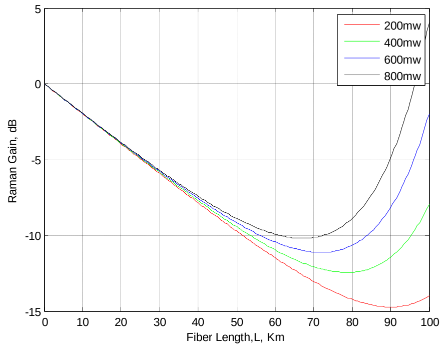

Fig. 2 Raman gain against the fiber length with different pumping power for SMF

From figure 2, we get the attenuation in the gain decreases with increasing the pumping power and also, the gain of the amplifier is increasing. Where in case of pumping power equal to 800mW the gain is attenuated with the fiber length until it reaches a certain level between 60-70 km approximately gain -10.1dB and then increases until it intersects with axis (reaches zero) to reach the maximum value at 100km. But in case of pumping power equal to 200mW the gain is attenuated with the fiber length until it reaches a certain level between 85-90 km approximately gain -14.9 dB and then increases to reach the maximum value at 100km. Then we concluded that we must be increase the pumping power levels to reduced attenuation and increases the gain of the amplifier.

2.2 Relation between Raman gain and Fiber Length at Different Pumping Power for Freelight Fiber Type

Figure3, showthe relation betweenthe gain and fiber length for different pump powers.

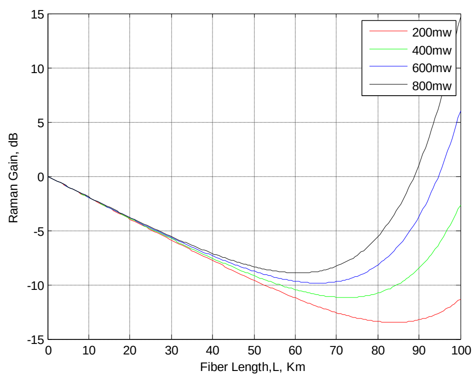

Fig. 3 Raman gain against the fiber length with different pumping power for Freelight

The figure 3; shows the attenuation in the gain decreases with increasing the pumping power and also, the gain of the amplifier is increasing. Where in case of pumping power equal to 800mW the gain is attenuated with the fiber length until it reaches a certain level between 50-60 km approximately gain -9 dB and then increases until it intersects with axis (reaches zero) to reach the maximum value at 100km. But in case of pumping power equal to 200mW the gain is attenuated with the fiber length until it reaches a certain level between 80-85 km approximately gain -13dB and then increases to reach the maximum value at 100km. Then we concluded that we must be increase the pumping power levels to reduced attenuation and increases the gain of the amplifier.

2.3 Relation between Raman gain and Fiber Length at Different Pumping Power for Truewave Fiber Type

Figure4, the obtained gain from an amplifier for four different pump power.

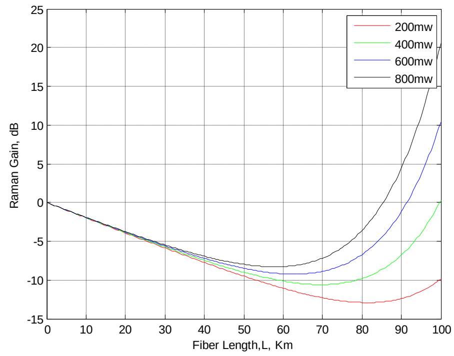

Fig. 4 Raman gain against the fiber length with different pumping power for Truewave

The figure shows the attenuation in the gain decreases with increasing the pumping power and also, the gain of the amplifier is increasing. Where in case of pumping power equal to 800mW the gain is attenuated with the fiber length until it reaches a certain level between 50-60 km approximately gain -7 dB and then increases until it intersects with axis (reaches zero) to reach the maximum value at 100km. But in case of pumping power equal to 200mW the gain is attenuated with the fiber length until it reaches a certain level between 70-80 km approximately gain -12.5dB and then increases to reach the maximum value at 100km. Then we concluded that we must be increase the pumping power levels to reduced attenuation and increases the gain of the amplifier.

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 (SMF, Freelight and Truewave) having different Raman gain coefficients and constant signal input power and different constant pump powers (400mw, 600mw and 800mw)

3.1Relation between Raman Gain and Fiber Length for Different Fiber Types at 400mw Pumping Power

Figure 5; show a comparison between three different fiber types (SMF, Freelight and Truewave) at 400mw pumping power for the fiber types having different Raman gain coefficients and constant signal input power.

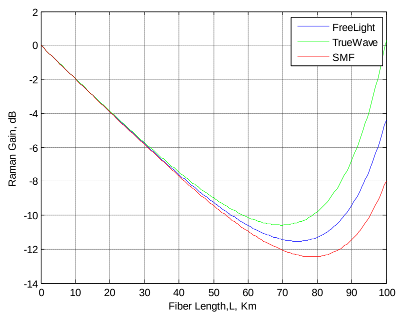

Fig. 5 Raman gain against the fiber length with different fiber types at 400mW pumping power

From figure we get in case of SMS fiber type the gain is attenuated with the fiber length until it reaches a certain level between 70-80 km approximately gain -13 dB and then increases until it to reach the maximum value at 100km. But in case of Ferrlight the gain is attenuated with the fiber length until it reaches a certain level between 70-80 km approximately gain -11.5dB and then increases to reach the maximum value at 100km and in case of Truewave fiber the gain is attenuated with the fiber length until it reaches a certain level between 60-70 km approximately gain -10.4dB and then increases to reach the maximum value at 100km. After simulation the Raman gain for different fiber types along 100Km of fiber span and 300mW pumping power 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.

3.2Relation between Raman Gain and Fiber Length for Different Fiber Types at 600mw Pumping Power

Figure 6; show a comparison between three different fiber types (SMF, Freelight and Truewave) at 600mw pumping power for the fiber types having different Raman gain coefficients and constant signal input power.

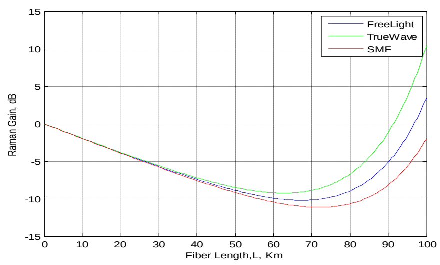

Fig. 6 Raman gain against the fiber length with different fiber types at 600mW pumping power

From figure we get in case of SMS fiber type the gain is attenuated with the fiber length until it reaches a certain level between 60-70 km approximately gain -11dB and then increases until it to reach the maximum value at 100km. But in case of Ferrlight the gain is attenuated with the fiber length until it reaches a certain level between 60-70 km approximately gain -10dB and then increases to reach the maximum value at 100km and in case of Truewave fiber the gain is attenuated with the fiber length until it reaches a certain level between 50-60 km approximately gain -9dB and then increases to reach the maximum value at 100km. After simulation the Raman gain for different fiber types along 100Km of fiber span and 500mW pumping power 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 600mW pumping power is better than in case of 400mW pumping power.

3.3Relation between Raman Gain and Fiber Length for Different Fiber Types at 800mw Pumping Power

Figure 7; show a comparison between three different fiber types (SMF, Freelight and Truewave) at 800mw pumping power for the fiber types having different Raman gain coefficients and constant signal input power.

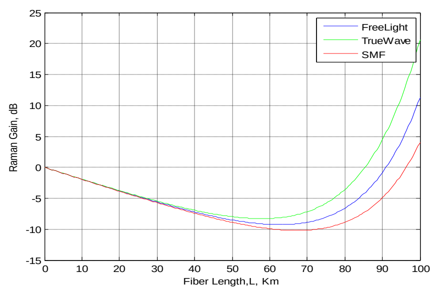

Fig7. Raman gain against the fiber length with different fiber types at 800mW pumping power

From figure we get in case of SMS fiber type the gain is attenuated with the fiber length until it reaches a certain level between 60-70 km approximately gain -10dB and then increases until it to reach the maximum value at 100km. But in case of Ferrlight the gain is attenuated with the fiber length until it reaches a certain level between 50-60 km approximately gain -9dB and then increases to reach the maximum value at 100km and in case of Truewave fiber the gain is attenuated with the fiber length until it reaches a certain level between 50-60 km approximately gain -8dB and then increases to reach the maximum value at 100km. After simulation the Raman gain for different fiber types along 100Km of fiber span and

500mW pumping power 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 800mW pumping power is better than in case of 600mW pumping power and 400mW pumping power, then we get the attenuation in the gain is reduced by increasing the pump power but the gain is increases.

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, –5dBm, applied to the three fiber types.

4.1 Output Signal Power Characteristics for Backward Pumping at 400mW Pump Power

Figure 8; show the output signal power against fiber length at pump power 400mW and constant signal power, –5dBm, applied to the three fiber types.

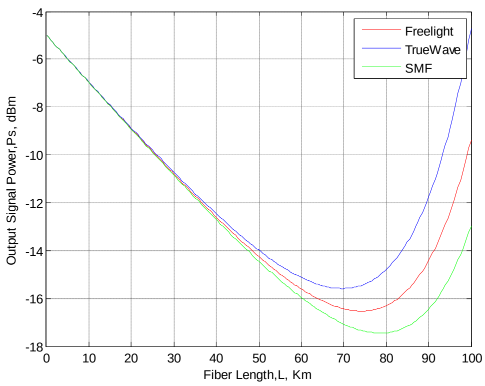

Fig. 8 Output signal power against fiber length at 400mW pumping power and -5dBm input signal power

Figure 8; was simulating the -5dBm of input signal along 100Km of fiber span and 400mW of pumping power in three different fiber types in case of SMS fiber type the output signal power is attenuated with the fiber length until it reaches a certain level between 70-80 km approximately output signal power -17.2 dB and then increases until it to reach the maximum value at 100km. But in case of Ferrlight the output signal power is attenuated with the fiber length until it reaches a certain level between 70-75 km approximately output signal power -16.3dB and then increases to reach the maximum value at 100km and in case of Truewave fiber the output signal power is attenuated with the fiber length until it reaches a certain level between 60-70 km approximately output signal power -15.5dB and then increases to reach the maximum value at 100km. After simulation the output signal power for different fiber types along 100Km of fiber span and 400mW 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.

4.2 Output Signal Power Characteristics for Backward Pumping at 600mW Pump Power

Figure 9; show the output signal power against fiber length at pump power 600mW and constant signal power, –5dBm, applied to the three fiber types.

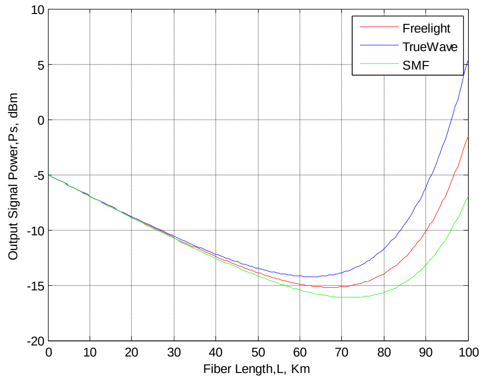

Fig. 9 Output signal power against fiber length at 600mW pumping power and -5dBm input signal power

Figure 9; was simulating the -5dBm of input signal along 100Km of fiber span and 600mW of pumping power in three different fiber types in case of SMS fiber type the output signal power is attenuated with the fiber length until it reaches a certain level between 60-70 km approximately output signal power -16 dB and then increases until it to reach the maximum value at 100km. But in case of Ferrlight the output signal power is attenuated with the fiber length until it reaches a certain level between 60-70 km approximately output signal power -15.1dB and then increases to reach the maximum value at 100km and in case of Truewave fiber the output signal power is attenuated with the fiber length until it reaches a certain level between 50-60 km approximately output signal power -13dB and then increases to reach the maximum value at 100km. After simulation the output signal power for different fiber types along 100Km of fiber span and 600mW 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.

4.3 Output Signal Power Characteristics for Backward Pumping at 800mW Pump Power

Figure 10; show the output signal power against fiber length at pump power 800mW and constant signal power, –5dBm, applied to the three fiber types.

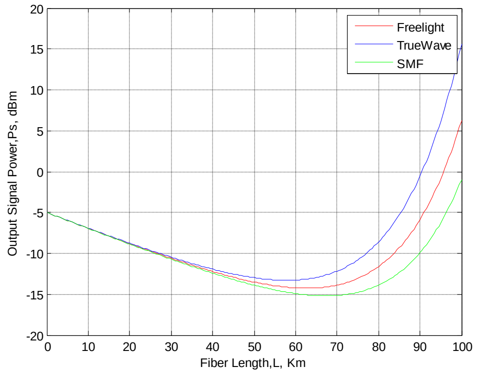

Fig. 10 Output signal power against fiber length at 800mW pumping power and -5dBm input signal power

Figure 10; was simulating the -5dBm of input signal along 100Km of fiber span and 800mW of pumping power in three different fiber types in case of SMS fiber type the output signal power is attenuated with the fiber length until it reaches a certain level between 60-70 km approximately output signal power -15 dB and then increases until it to reach the maximum value at 100km. But in case of Ferrlight the output signal power is attenuated with the fiber length until it reaches a certain level between 55-65 km approximately output signal power -14dB and then increases to reach the maximum value at 100km and in case of Truewave fiber the output signal power is attenuated with the fiber length until it reaches a certain level between 50-60 km approximately output signal power -13dB and then increases to reach the maximum value at 100km. After simulation the output signal power for different fiber types along 100Km of fiber span and 800mW 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.

IV. CONCLUSION

The rate and propagation equations characterizing FRAs are numerically solved 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. In this way, the gain is simulated for the given FRA parameters or the required fiber parameters values could be optimized for a desired FRAs gain. According to the obtained results, gain is strongly dependent on the fiber length and pumping power. The differences between three different fiber types are satisfied.

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