Performance Optimization of Backward Pumped Fiber Raman Amplifiers

Eman Salah[1], Fathy M. Mustafa[2] and Adel Zaghloul[3]

[1] Electrical Engineering Department, Faculty of Engineering, Zagazig University, Zagazig, Egypt.
[2]Electrical Engineering Department, Faculty of Engineering, Beni-Suef University, Beni-Suef, Egypt.
[3]Electrical Engineering Department, Faculty of Engineering, Zagazig University, Zagazig, Egypt.

***Abstract*—this paper investigates Raman gain for backward pumping using three different fiber types. The rate and propagation equations characterizing fiber Raman amplifiers (FRAs) are numerically solved. In this paper, the gain is simulated for the given FRA parameters affecting on Raman gain for all optical backward pumped fiber Raman amplifier such as fiber type, fiber length, pump power and gain coefficient for enhancement the gain of fiber Raman amplifier. From obtained results, gain is strongly dependent on the fiber length and pumping power. Also, gain is obtained as a function of fiber length and pump power.**

***Index Terms*—Raman Amplifiers, Pump Power and Gain Coefficients**

I. Introduction

Research began to amplify Raman in fiber optics in the early 1970s. The benefits of Raman amplification in transmission fibers have already been investigated in the mid-1980s. Optical amplifiers can be divided into two main categories: optical fiber amplifiers (OFAs) and semi-conductive optical amplifiers (SOAs) [1]. DWDM is a technique that places data from different sources together on an optical fiber, with each signal carrying at the same time along its own separate wavelength. [2] Raman Amplifiers (RAs) are a set of amplifiers that have different applications in optical communication. In general, optical amplifiers can be used to enhance the performance of optical communication systems. Raman fiber amplifiers are all used by Raman or hybrid FRAs / EDFAs for both long-distance and very long wavelengths divided by multiple optical communication systems [3]. The Raman amplifier is based on dispersion. Raman Sitters is a linear optical process through which the photon, called the photon pump, is absorbed by an object while a photon is emitted simultaneously from a different energy. The difference in photon energy is compensated by changing the vibration state of the content [4]. The Raman scattering phenomena (SRS) inducer is a nonlinear effect in optical fibers and as a result is amplified optical signal [5]. The Raman amplifier is better because it provides amplified amplitude within the fiber. The amplification amplifier uses transmission fibers as a gain medium by doubling the pump wavelength and signal wave length. Increases the length of the spans between the amplifiers and the renewal locations provides inflation to larger and different regions. [6] There are three fiber amplifiers; the first forward pumped Raman amplifier, the second backward pumped Raman amplifier and the Raman two-way booster pump. The Raman amplifier with the front pump was found to perform better when compared with the rear pump amplifier because the pump wave is applied before transmission loss and the rear pump helps to achieve higher gains. In 2001, Emori.et al. empirically demonstrated a bidirectional scheme that realized both flat gain and noise figure [7]. The Raman Flattened Fractional Distributed Multiplexer (FRA) amplifier can reduce noise and nonlinear noise to a large extent compared to background disturbances, especially when high Raman gain is needed [8]. The pump power required to achieve specific Raman gain depends on components such as Raman gain factor, polarization, fiber length, fiber losses due to pump depletion, and wavelength [9]. The paper is organized as follows: Mathematical formulations are presented in Sec. II. Simulation results are shown in sec. III, followed by the conclusion in Sec. IV. According to the obtained results, gain is strongly dependent on the fiber length and pumping power.

II. Mathematical Model

Figure 1 shows schematic diagram of backward pumping direction configurations. The optical power of the first pump is S P_P and 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 (P_S) and the power of the pump source propagating along the fiber cable can described by different equations called propagation equations.

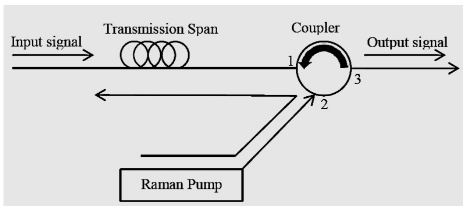

Figure 1. Schematic diagram of backward fiber Raman amplifier configuration.

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

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

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

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:

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

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 backward pumping, it can be written as [15][16]:

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

, Where G_B are the net gain in the backward pumping. 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:

$$\alpha_{S,P} = {}^{\alpha}/_{4.343} \quad (5)$$

, 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]:

$$P_s(L) = P_s(0)\exp\left(\frac{g_0 P_0 L}{A_{eff}} - \alpha_s L\right) \quad (6)$$

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:

$$L_{eff} = \frac{1-\exp(-\alpha_p L)}{\alpha_p} \quad (7)$$

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

$$G_A = \frac{P_S}{P_S(0)\exp(-\alpha_s L)} \quad (8)$$

III.Simulation Results

1. 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.

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

Figure 2, the obtained gain from an amplifier for four different pump power levels 300, 500, 700, 900 mw are given for a 100 km fiber length. As it is shown, 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.

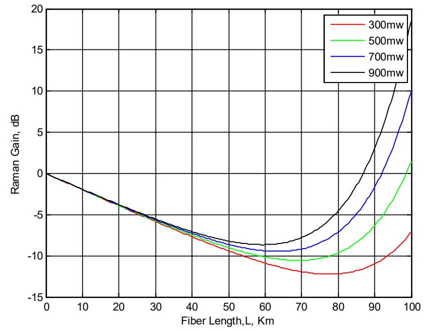

Fig. 2 Raman gain against the fiber length with different pumping power for DSF

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 900mW the gain is attenuated with the fiber length until it reaches a certain level between 55-65 km approximately gain -8.8 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 300mW the gain is attenuated with the fiber length until it reaches a certain level between 70-80 km approximately gain -12.8dB 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.

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

Figure3, show the relation between the gain and fiber length for different pump powers.

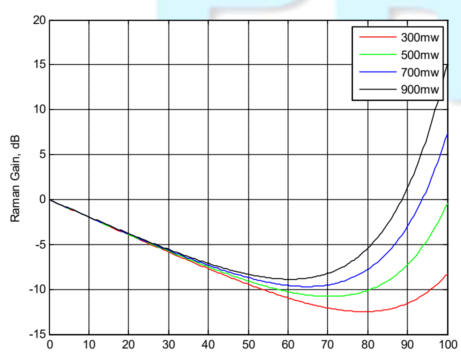

Fig. 3 Raman gain against the fiber length with different pumping power for Freelight

From figure 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 900mW the gain is attenuated with the fiber length until it reaches a certain level between 55-65 km approximately gain -8.1dB 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 300mW the gain is attenuated with the fiber length until it reaches a certain level between 70-80 km approximately gain -12 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.

1.3 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.

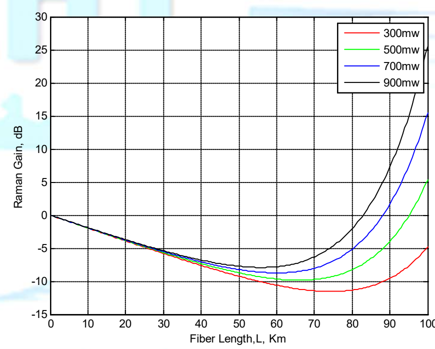

Fig. 4 Raman gain against the fiber length with different pumping power for Truewave

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 900mW the gain is attenuated with the fiber length until it reaches a certain level between 50-60 km approximately gain -7.5 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 300mW the gain is attenuated with the fiber length until it reaches a certain level between 70-80 km approximately gain -11.2dB 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. 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 pump powers 700mw.

2.1 Relation between Raman Gain and Fiber Length for Different Fiber Types at 700mw Pumping Power

Figure 5; show a comparison between three different fiber types (Freelight, DSF and Truewave) at 700mw pumping power for the fiber types having different Raman gain coefficients and constant signal input power.

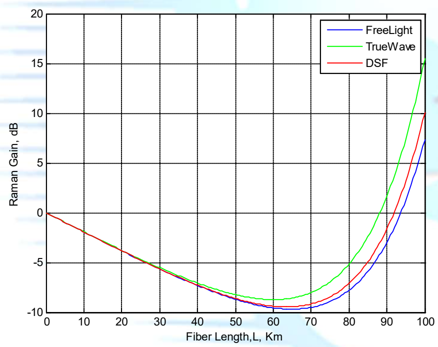

Fig. 5 Raman gain against the fiber length with different fiber types at 700mW pumping power

From figure we get in case of Freelight fiber type the gain is attenuated with the fiber length until it reaches a certain level between 60-70 km approximately gain -9.8dB and then increases until it to reach the maximum value at 100km. But in case of DSF the gain is attenuated with the fiber length until it reaches a certain level between 60-70 km approximately gain -9.6dB 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 55-62 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 700mW 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. 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 powers, –4dBm applied to the three fiber types.

3.1 Output Signal Power Characteristics for Backward Pumping at 700mW Pump Power

Figure 6; show the output signal power against fiber length at pump power 700mW and constant signal power, –4dBm, applied to the three fiber types.

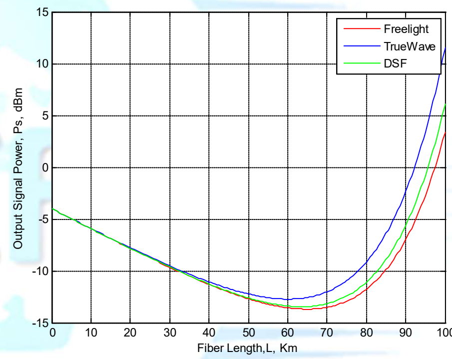

Fig. 6 Output signal power against fiber length at 700mW pumping power and -4dBm input signal power

Figure 6; was simulating the -4dBm of input signal along 100Km of fiber span and 700mW of pumping power in three different fiber types in case of Freelight 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 -13.8 dB and then increases until it to reach the maximum value at 100km. But in case of DSF the output signal power is attenuated with the fiber length until it reaches a certain level between 60-70 km approximately output signal power -13.7dB 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 55-65 km approximately output signal power -12dB 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 700mW 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. Relation between the Effective Length and the Attenuation of Pump Power

Figure 7; show the relation between pump power attenuation and effective length.

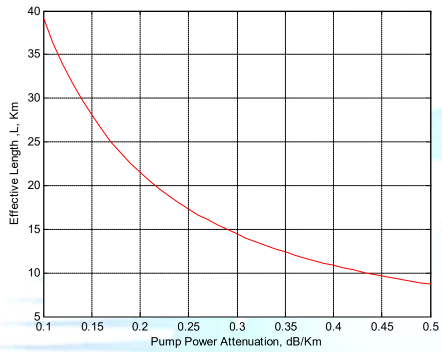

Figure 7; relation between pump power attenuation and effective length.

From figure 7, we get if pump power attenuation increases the effective length is decreases and vice versa is true. The effective length was term to clarify how much the pumping power effect on the fiber media.

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.

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.

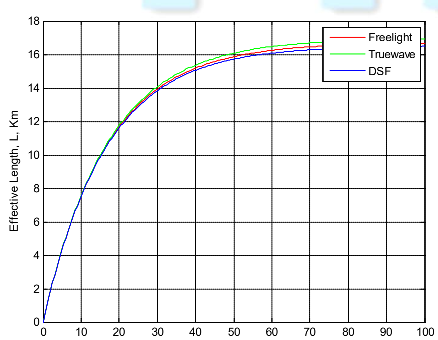

Figure 8; Relation between the Effective Length and Fiber Length for Different Fiber Types

IV. Conclusion

From simulation results we get 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 paper, the gain is simulated for the given FRA parameters values could be optimized for a desired FRAs gain. According to the obtained results also, the gain is strongly dependent on the fiber length. The differences between three different fiber types can be studied.

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