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Distributed Backward Pumped Raman AmplifiersGain without Attenuation: A New Approach

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Abstract: Optical amplifiers have made a great achievement and a huge revolution in the world of optical communications, backward pump Raman amplifier suffers from decrease in gain. The main objective of this paper is to solve the problem of decrease that occurs in gain of backward pumped Raman amplifier.To solve this problem, models of two of backward pumped Raman amplifiers are used in a cascaded form to overcome the attenuation in gain. We present the results in the case of using one backward pumped Raman amplifier compared to the model that we designed to show the difference between the using one backward pumped Raman amplifier and two backward pumped Raman amplifiers. Three types of fibers with different gain parameters are used. We have obtained maximum gain 27.8989 dB for Truewave fiber type.

Keywords:Backward Pump Raman Amplifier, Pump Power, Attenuation, Gain Coefficient,gain parameters.

1.Introduction

The optical amplifier has played a critical role in the telecommunication revolution that has begun two decades ago. Multi-wavelength pumped Raman amplifiers (RAs) have attracted more and more attention in recent years [1]. This type of amplification is widely used for high capacity long distance wavelength division multiplexing (WDM) transmission systems. was used. RAs are used it in many ultra-long haul dense WDM (DWDM) transmission systems [2]. RA supports high bit rate data transmission over long fiber spans, due to its advantages such as proper gain and optical signal to noise ratio (OSNR) [3]. In addition, it can be used for increasing the bandwidth of erbium doped fiber amplifiers (EDFAs) in hybrid systems [4].

Another important feature of RAs is its gain bandwidth, which is determined by pump wavelength. Usually, multi-wavelength pumping scheme is used to increase gain flattening and bandwidth for WDM transmission systems with high capacity. Other noise sources, such as the relative intensity noise (RIN) transmission, are minimized in backward pumped fiber RAs [5]. Raman amplification is based on stimulated Raman scattering (SRS),the non-linear effect in fiber optical transmission that results in signal amplification if optical pump waves with the correct wavelength and power are launched into the fiber [6]. One of the most recent and interesting developments is the constructive usage of the so-called optical amplifier Raman effect[4]. To achieve signal amplification, RA uses the intrinsic properties of silica fibers. This means that the fiber of transmission can be used as an amplifier, and therefore the internal attenuation of data signals transmitted over the fibers within the fibers can be combated. The amplifier operating on this principle is known as the Distributed Raman Amplifier (DRA). The physical property behind DRAs is SRS. This occurs when a sufficiently large pump is co-launched at a lower wavelength than the signal to be amplified. Raman gain depends strongly on the pump power and the frequency offset between pump and signal. Amplification occurs when the pump photon gives up its energy to create a new photon at the signal wavelength plus some residual energy, which is absorbed by the phonons (vibrational energy). When building DRAs designers face the question of using forward or backward pumping (or even both) with respect to signal propagation. The backward pumping scheme is most commonly used as it offers several advantages. Pump noise greatly affects WDM signals that should be amplified by applying forward pumping as the Raman cycle is almost instantaneous [7, 8].When the Raman pump wave has slight fluctuations in random power at the right time, which is always the case, individual bits may be differentially amplified, resulting in volatility or amplitude fluctuations. If it is backward pumped,the amplitude fluctuations will be averaged out [9].

The paper is organized as follows: Basic model and analysis in Sec. 2. Proposed model in Sec. 3. Results and discussion are shown in sec. 4,

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followed by the conclusion in Sec. 5.The main objective of this paper is to solve the problem of attenuation that occurs in gain of backward pump RA. The design model of backward pump RA improves the attenuation gain, where two of pump RAs are used in a cascaded form to compensate and reach high gain.And we succeeded to get a gain with minimum attenuation; the parameters that affect the Raman gain of RA are investigated for three different types of fiber.

1. Basic Model and Analysis

A backward fiber RA system scheme is shown in Fig.1. When the pump energy propagates in the direction of the signal, it is called the co-pumping or front pumping scheme, and when the pump moves in the opposite direction, it is called counter-pumping or backward pumping. The pump power marked as $P_S$is placed at the end of the transfer period and is switched in the center of silica fibers using optical couplers [10-12].

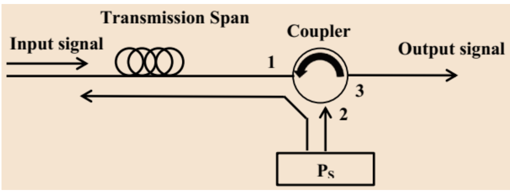

Fig. 1BackwardpumpRaman amplifier system scheme[11].

The fiber signal propagates in the fiber using the power signal according to a differential equation. This equation not only describes the attenuation of the signals due to propagation, but, also the power transmission from the power signal as follows [13-16]

$$\pm\frac{\partial P_r}{\partial Z} = -\frac{\omega_r}{\omega_i} G_R P_r P_i - \alpha_r P_r \quad (1)$$

$$\frac{\partial P_i}{\partial Z} = G_R P_r P_i - \alpha_i P_i \quad (2)$$

Where G_R is the Raman gain coefficient associated with the fiber type ($W^{-1}.m^{-1}$), α_i and α_r are the attenuation coefficients associated with the optical signal and the pumping power, respectively, $\omega_i$and$\omega_r$are the angular frequencies of the optical signal and the pumping power,respectively [5].

The pump power at point z,P_r, is defined by

$$P_r(Z) = SP_r(0).e^{-\alpha_r Z(1-s)} = P_r(0).e^{-\alpha_r(L-Z)} \quad (3)$$

If Pr values are substituted in Eq. (2), and are combined from 0 to L for the signal power at the forward and back pump, this yields [17-19]:

$$P_i(Z) = P_i(0).e^{\left(G_R P_0\left(\frac{(1-\exp(-\alpha_r Z))}{\alpha_r}\right)-\alpha_i Z\right)} = G_F.P_i(0) \quad (4)$$

$$P_i(Z) = P_i(0).e^{\left(G_R P_0\left(\frac{\exp(-\alpha_r L)(1-\exp(-\alpha_r Z))}{\alpha_r}\right)-\alpha_i Z\right)} = G_B.P_{i_s}(0) \quad (5)$$

Where G_F, $G_B$are the gain for forward and backward pumping, respectively, P_O is the pump power at the end of the input, α_i and α_r are the linear signal and pump energy attenuation coefficients in the optical fibers expressed as [20, 21]:

$$\alpha_{i,r} = {}^{\alpha}/_{4.343} \quad (6)$$

where α is the attenuation coefficient in dB/km.

2. Proposed Model

A typical DRA scheme using twoRAs with backward pumpingin a cascaded form to boost the Raman is shown on Fig. 2.

The marked pump sources P_{S1} and $P_{S2}$are placed at both ends of the transfer period and their strength is changed in the center of silica fibers using optical couplers.

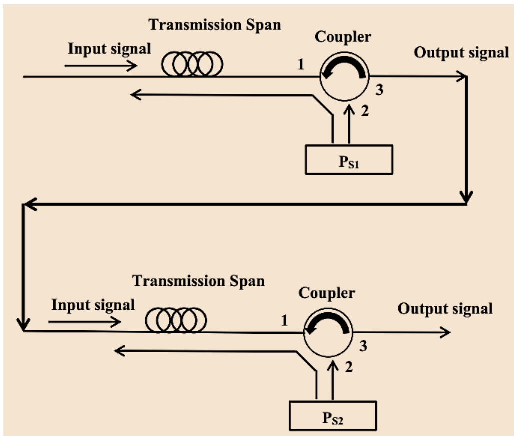

Fig. 2 Design model of two amplifiers are cascaded.

The overall gain of the RA can be obtained from Eqs.(4) and (5) by using two Raman pump amplifiers in a cascaded form to enhance the Raman gain which can be expressed as:

$$G_T = \frac{G_B}{i(G_B)} \quad (7)$$

where $G_T$is the total gain of backward pump RA and i, indicates the number of units from backwardpumpedRA then,

$$G_T = exp\left[g_R P_0 \times \frac{\exp(-\alpha_P L_1)(\exp(\alpha_P z) - 1)}{\alpha_P} - \alpha_S Z\right] / exp\left[g_R P_0 \times \frac{1 - \exp(-\alpha_P L_2)}{\alpha_P} - \alpha_S Z\right] \quad (8)$$

$$G_T = exp\left[g_R P_0 \times \frac{\exp(-\alpha_P L_1)(\exp(\alpha_P z) - 1)}{\alpha_P} - i(g_R P_0 \times \frac{\exp(-\alpha_P L_2)(\exp(\alpha_P z) - 1)}{\alpha_P})\right] \quad (9)$$

$$G_T = exp[g_R P_0 \times (W - i(g_R P_0 \times H)] \quad (10)$$

where;

$$W = \frac{\exp(-\alpha_P L_1)(\exp(\alpha_P z) - 1)}{\alpha_P} \quad (11)$$

and

$$H = \frac{\exp(-\alpha_P L_2)(\exp(\alpha_P z) - 1)}{\alpha_P} \quad (12)$$

The signal power at the output of the amplifier is determined by [22]:

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

The effective length, L_{eff}, is the length at which nonlinear effect or SRS still occurs in fibers and is defined as

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

The amplifier gain defined as the power signal ratio with or without Raman amplification is therefore obtained by [4]

$$G_A = \frac{P_i}{P_i(0)\exp(-\alpha_i L)} \quad (13)$$

3. Results and Discussion

The resultsare simulated in two cases:
Case one: using one backward pumpedRA.
Case two: using two backward pumpedRAs in a cascaded form.
The gain and the affecting parameters, in the two cases are studied for comparison.

3.1 Relation of Raman Gain on Pump Power

Figure 2, (a,b)shows the variation of the gain with the pump powerfor different types of fibers at a constant input power. In this simulation, a distance of 80 km is used for three different types of fiber and the supplied pump power increases from 0 to 2 W. It is clear that, gain of FRA linearly increases with pump power. As a result, the gain coefficient increases for high pump powers. In addition, a higher gain can be obtained at a longer fiber with sufficient pumping.

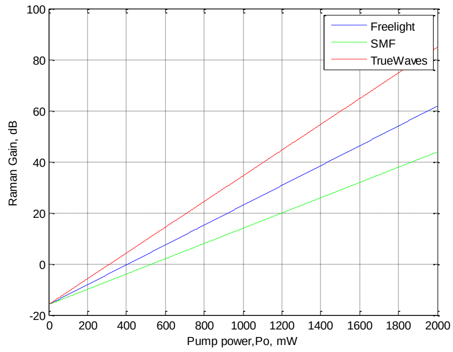

Fig. 2a Raman gain against the pumping power for different fiber types according to basic model.

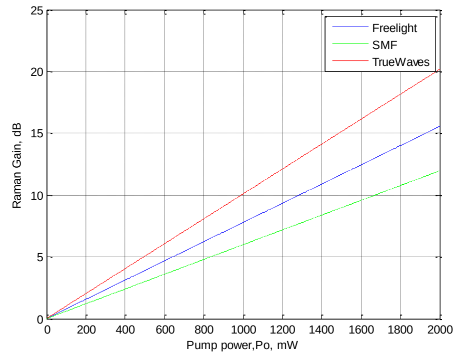

Fig. 2b Raman gain against the pump power for different fiber types according to proposed system.

Again Raman gain is linearly increased with the pump power using both basic model and proposed system.

3.2 Raman Gain Fiber Length with Specific pumping Capacity

In this section, we show the gain variationwith the fiber length at different pumpingschemes for the three different fiber types (SMF, Freelight and Truewave) at a fixed signal input power.

4.2.1 Relation between Raman Gain and Fiber Length for SMF Fiber Type with different pumping power

Figure 3, (a, b) show the obtained gain for three different pump power levels: 400, 600, 800mWfor an 80 km fiber length. The results are simulated by using one backward pumpedRAand using two backward pumpedRA in a cascaded form according to the proposed system.

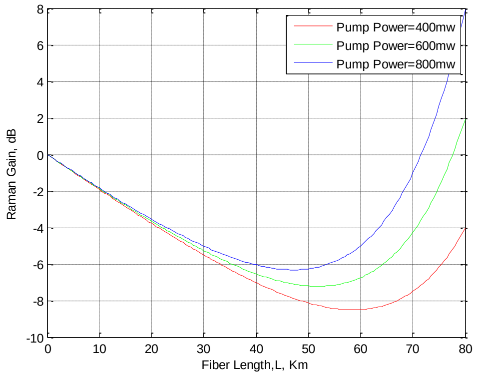

Fig. 3 a Raman gain against the fiber length at different pump powers for SMF according to basic model.

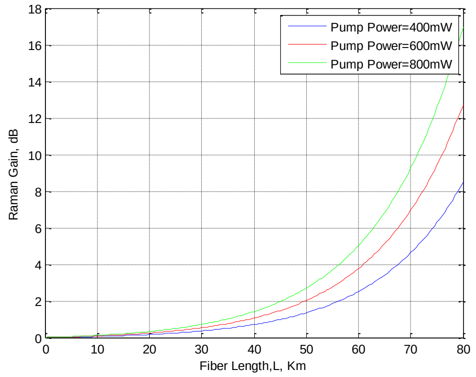

Fig. 3 b Raman gain against the fiber length at different pump powers for SMF according to proposed system.

From obtained result we get gain with minimum attenuation from feedback pump Raman amplifier.

4.2.2 Relationship between Raman gain and Fiber Length for Freelight Fiber Type at different pumping power

Figure (4, b) display the obtained gain at the three different pump powers 400, 600 and 800mWfor a 80 km fiber length, for the two mentioned cases.

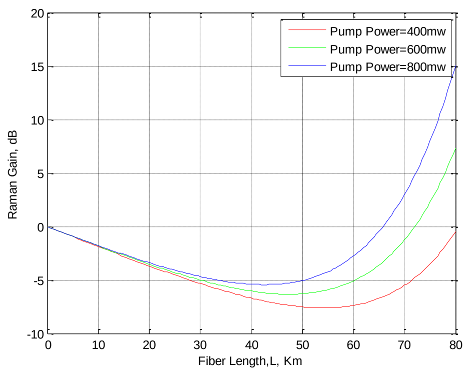

Fig. 4 a Raman gain against the fiber length at different pump powers for Freelight according to basic model.

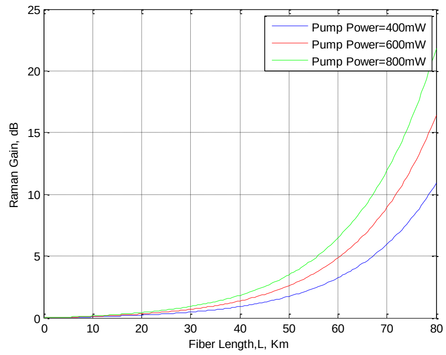

Fig. 4 b Raman gain against the fiber length at different pump powers for Freelight according to proposed system

The result simulated by using of two cases:

<u>Case one:</u> using one feedback pump Raman fiber amplifier according to basic model and analysis as show in figure 4, a in this case attenuation in gain is appeared.

<u>Case two:</u> using of two feedback pump Raman fiber amplifiers in cascaded form according to the proposed system in this case gain without attenuation as show in figure 4, b.

4.2.3 Raman gain Against Fiber Length at different pumping power for Truewave Fiber Type

Figure (5, b) the obtained gain from an amplifier for three different pump powers400, 600 and 800mW are given for a 80 km fiber length.

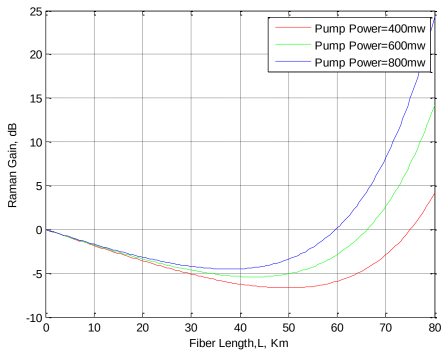

Fig. 5 a Raman gain against the fiber length at different pump powers for Truewave according to basic model.

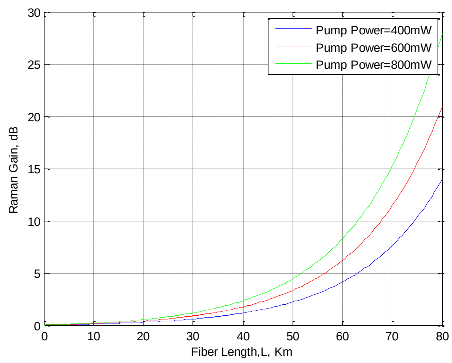

Fig. 5, b Raman gain against the fiber length at different pump powers for Freelight according to proposed system.

By compare the obtained results in figure 5, a, and figure 5, b we get attenuation in occurs in case of basic model but in case of proposed system the gain without attenuation.

4.3 Relationship between Raman Gain and Fiber Length

The variation of the gain with the fiber length of the three different fiber types (SMF, Freelight and Truewave) is investigated as follows.

4.3.1Relationship between Raman Gain and Fiber Length at 800mW Pumping Power for Different Fiber Types

Figure 6(a, b) shows a comparison between three different fiber types (SMF, Freelightand Truewave) at different Raman gain coefficients, fixed signal input power and 800mW stationary pump power.

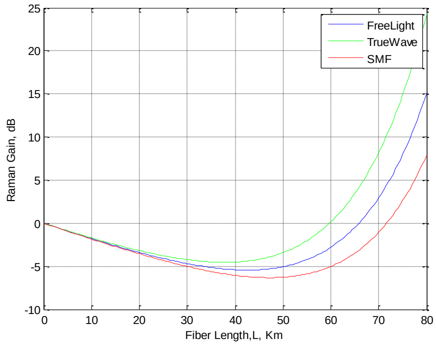

Fig. 6 a Raman gain against the fiber lengthfor different fiber types at 800mW pump power according to basic model.

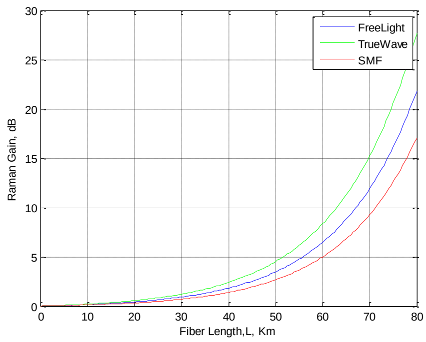

Fig. 6 b Raman gain against the fiber length for different fiber types at 800mW pump power according to proposed system.

It clear from comparison between figure 6, a, and figure 6, b the attenuation in gain appears in case of basic model but doesn't appearsin proposed system design.

4.4 Output Power Signal Characteristics for Backward Pumping

This section describes how the output signal power varies with the fiber length of the different pump and the fiber span of 80 km at a fixed signal power, –5 dBm, applied to the three fiber types.

4.4.1 Output Signal Power Characteristics for 800mWBackward Pump Power

Figure 7(a, b) show output signal power versus fiber length at pump power of 800 mW and a fixed signal power, -5 dB, for the three fiber types.

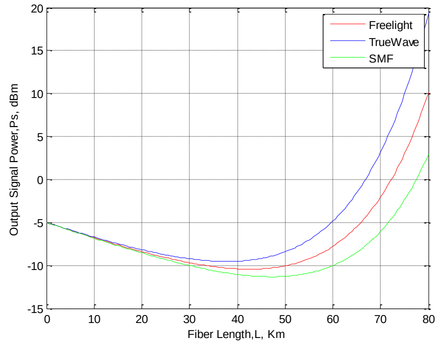

Fig. 7aOutput signal power against fiber length at 800mW pumping power and -5dBm input signal power according to basic model.

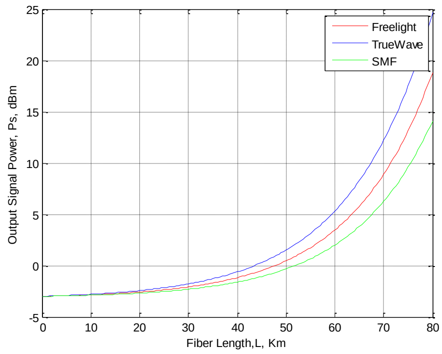

Fig. 7 b Output signal power against fiber length at 800mW pumping power and -5dBm input signal power according to proposed system.

From Fig. 7the proposed system is better performance than the basic model in terms of attenuation.

4.5 Relation between the Effective Length and Fiber Length for Different Fiber Types

In this section, we study the variation of effective length with fiber length for the three different fiber types (SMF, Freelightand Truewave) having different Raman gain coefficients as shown in Fig. 8.

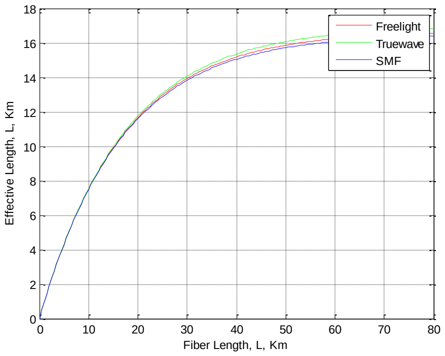

Figure 8 Relation between the Effective Length and Fiber Length for Different Fiber Types

From Fig.8, the effective length increases with fiber length linearly for three different fiber types, and then it tends to saturation at around 50Km.

5 Conclusion

We design a model of two of backward pumped Raman amplifiers are used in a cascaded form to overcome the attenuation in gain. The result of proposed system design gives gainwithout attenuation of distributed backward pumpedRA and solves the problem of attenuation that occurs in gain of backward pumped RA. From study we obtained the main numerical values as in table 1.

Table 1, Comparison between different fibers and maximum gain

Type of Fiber	Maximum gain (g_{max}) for one backward pumped Raman amplifier	Maximum gain (g_{max}) for two backward pumped Raman amplifier
SMS	g_{max}= 7.9084 dB at L= 80 km and Pp= 800 mW	g_{max}= 16.9819 dB at L= 80 km and Pp= 800 mW
Freelight	g_{max}= 15.0785 dB at L= 80 km and Pp= 800 mW	g_{max}= 21.8339 dB at L= 80 km and Pp= 800 mW
Truewave	g_{max}= 24.3060 dB at L= 80 km and Pp= 800 mW	g_{max}= 27.8989 dB at L= 80 km and Pp= 800 mW

We also simulate and analyze the parameters that affect the Raman gain of fiber Raman amplifier for three different types of fiber. The gain depends heavily on the length of the fiber and the pumping power, according.

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