Characteristics of Raman Amplifiers in Fiber Optic Communication Systems

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Abstract. Recently Raman amplifiers have started to attract much attention because the noise figure is smaller and it is less expensive than the EDFA. This paper simulated the characteristics of Raman amplifier by solving the coupled Raman amplifiers equations using the Runge Kutta method. The result of these simulation will be analyzed in terms of gain characteristics. The changing of the input pump power, the input signal power, and the length of Raman fiber amplifier are observed to have high influence to the gain amplifier. This paper also analyzed the noise figure as a result of light scattering in Raman amplifier. The resulting analysis are recommendations for maximum amplifications. In terms of fiber length, maximum gain, effective pump power, and noise figure.

Keywords: Fiber Optic, Fiber Amplifier, Raman Scattering, Pump Power, Signal Power, Raman Gain, Noise Figure.
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INTRODUCTION

Alexander Graham Bell was the originator of the idea of using glass fibers as a carrier signal in optical communication [1]. Fiber optics works by using light as a carrier wave of information sent. In the optical communication system it is necessary to use the repeater component that can amplify the quality of the signal, its function as an amplifier. In optical communications there are two types of amplifiers they are electronic amplifiers and optical amplifiers. One of the amplifiers used in optical communications is the Raman amplifiers. A characteristics that is very important to differentiate between Raman and other optical amplifiers is stimulated Raman scattering (SRS = Stimulated Raman Amplifier), this is the basis for the use of Raman amplifiers [2]. This paper is to analyze the variation of amplifier gain with the pump power, fiber length and the signal power. The variation of noise figure with fiber length is also shown. These simulations is useful to know the characteristics of Raman amplifiers and provide useful information for Raman amplifiers design.

FIBER RAMAN AMPLIFIER

A fiber Raman amplifier uses stimulated Raman scattering (SRS) occurring in silica fibers when an intense pump beam propagates through it.

Raman Gain

When a weak signal is launched by a strong pump, it will be amplified due to SRS by a certain value of sauration. The signal amplification is described by the following equations :

$$\frac{dP_s}{dz} = -\alpha_s P_s + (g_R/A_{eff})P_p P_s \qquad (1)$$

$$\frac{dP_p}{dz} = -\alpha_p P_s - (\omega_p/\omega_s)(g_R/A_{eff})P_s P_p \qquad (2)$$

Where P_p and P_s are the powers f wave at frequencies ω_p and ω_s , α_s and α_p are the fiber loss at frequencies ω_p and ω_s , g_R is the Raman gain coefficient in a fiber, and A_{eff} is the effective core area of the pump.

The numerical simulation which is used in this research in adaptive fourth order Runge Kutta method

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to solve Eq. (1) and (2) over position z of the Raman amplifier from $z = 0$ to $z = L$.

Effective area for Raman gain is determined by mode size and the overlap between pump and Stokes modes, and defined as [3] :

$$A_{eff} = 2\pi \frac{\int \Psi_p^2 rdr \int \Psi_s^2 rdr}{\int \Psi_p^2 \Psi_s^2 rdr}$$

Where Ψ_p , Ψ_s represent the mode fields at the pump and Stokes wavelengths.

Variations of pump and signal powers along the amplifier length can studied by solving the above two coupled equation.

By substituting $P_p(z) = P_p(0)\exp(-\alpha_p z)$ in Equation (1), the signal intensity at the output of an amplifier of Length (L) is given by :

$$P_s(L) = P_s(0)\exp\left(g_R P_0 L_{eff}/A_{eff} - \alpha_s L\right) \quad (3)$$

Where $P_0 = P_s(0)$ is th input pump power and L_{eff} is defined as :

$$L_{eff} = [1 - \exp(-\alpha_p L)/\alpha_p] \quad (4)$$

We define amplifier gain as:

$$G = \frac{output\ power\ with\ Raman\ amplification}{output\ power\ without\ Raman\ amplification} \quad (5)$$

Since $P_s(L) = P_s(0)\exp(-\alpha_s L)$ in the absence of Raman amplification, the amplifier gain is given by :

$$\boldsymbol{G_A = \frac{P_s(L)}{P_s(0)exp(-\alpha_s L)} = exp(g_0 L)} \quad (6)$$

Noise Figure

Another aspect that also influences the signal gain is spontaneous emission. All the excited ions can spontaneously relax from the upper state to the ground state by emitting a photon that is uncorrelated with the signal photons. This spontaneously emitted photons can be amplified as it travels down the fiber and stimulates the emission of more photons from excited ions, photons that belong to the same mode as the electromagnetic field as the original spontaneous photons. It is called an Amplified Spontaneous Emission [4].

The noise figure (NF) relates the amount of ASE noise that is added to the signal relative to amount of gain and can be written as in equation (5).

$$S_{ASE}(v) = (G-1)hv\frac{N_2}{N_2 - N_1} \quad (5)$$

And the noise figure as

$$NF = \frac{1}{G}\left(\frac{2S_{ASE}(v)}{hv} + 1\right) \quad (7)$$

Where S_{ASE} is the ASE power spectral density, h is Plank's constant, v is the signal frequency, G is the observed gain, N_2 is the upper state population and N_1 is the lower state population. For Raman amplifiers the $\frac{N_2}{N_2 - N_1}$ term is always equal to one, whereas in EDFAs it is usually greater than one [5]. Raman amplifiers use long fiber the passive loss of the fiber needs to be added to the noise figure.

SIMULATION AND RESULT

Numerical simulation is solved by Range Kutta method.

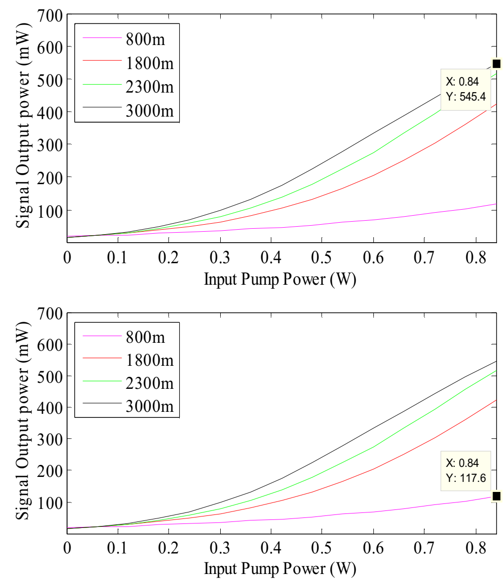

FIGURE 1. The output power signal at the Raman amplifier.

Figure 1. is the solution of the Equation (1) and (2). From the figure we can be see the relationship between pump power with the signal output power. The simulation results is that the greater the pump power, also greater is the signal output power. This is because more photons are absorbed by the molecules to move up from the lower energy level to a virtual energy level, so that the scattering process a boosted signal will be even greater.

At the point of 0.3 W pump power, signal output power began to rise significantly. We can see from the point of pump power 0.3 W at fiber length of 3000 m, the signal output power will increase rapidly until it reaches 545.4 mW. As for the fiber with a length below 3000 m, in this simulation we use one of them is 800 m, then the signal output power is smaller i.e. 117.6 mW. From the results it can be concluded that the Raman amplifier is better used for long distance communication.

Gain is the most important factor in an amplifier. If the signal output power increases, the gain will also increased for relatively same input signal power. The increase will occur exponentially with pump power, until it reaches saturation region.

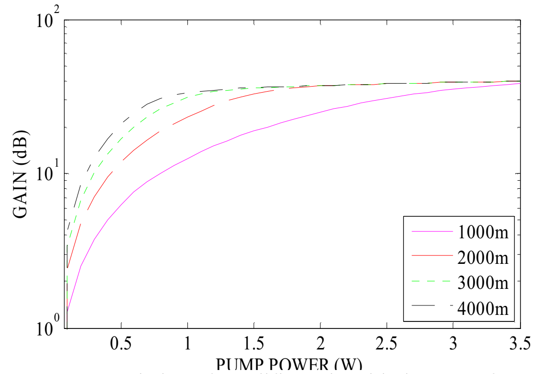

FIGURE 2. Variation of amplifier gain with the pump for several values of the fiber length.

Figure 2. is the solution of the equation (6). From the figure we can see the relationship between pump power with gain. Input signal power used is 0.36mW with pump power of 0.1W until 3.5W. The length of fiber used varies from 1000 m, 2000 m, 3000 m and 4000 m. At the point of pump power 0.1W , the gain will increase. For the fiber with a length of 4000 m, the gain will increase faster than the fiber with a length of 1000m. The figure above shows that for fibers with a length of 2000 m or more and pump power from 0.1 W until 1.5 W the gain will increase rapidly and significantly.

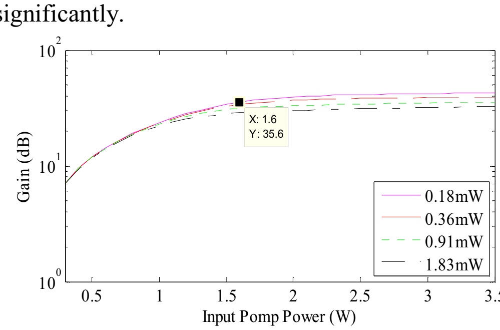

FIGURE 3. Variation of amplifier gain with the signal power for several values of the pump power.

Figure 3. is the solution of the equation (6). From the figure can be seen the relationship between pump power with gain. The length of fiber used is 2000 m. We can see different increase in gain with increasing pump power from 0 W until 3.5 W, by varying the input signal is 0.18 mW, 0.36 mW, 0.91 mW, and 1.83 mW.

The simulation results is that when the pump power is greater, then the gain will increase. If we give the input signal 0.18 mW, the gain will increase more rapidly and at a point of pump power 1.5 W has entered the saturation region. To input signal of 1.83 mW, the gain will increase more slowly and at a point pump power 0.8 W , the gain has entered the saturation region.

From the figure above shows that the maximum gain that can be achieved is about 35.6 dB. And pump power is better used to achieve the maximum gain is approximately from 0.1 W until 1.5 W with a small input signal. Because if the pump power more than 1.5 W, the gain has entered the saturation region.

One aspect that is also very important in the performance of the Raman amplifier is the noise figure which is defined from Amplified Spontaneous Emission (ASE). ASE limits the achievable amplifier gain and increases noise.

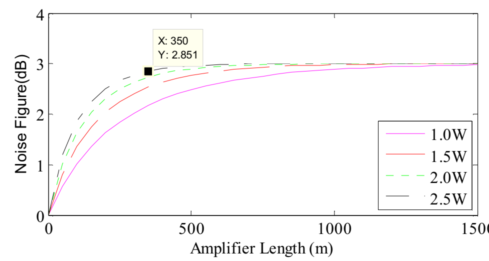

FIGURE 4. Variation of noise figure with the length for several values of pump powers.

Figure 4. is the solution of the equation (6). The longer the amplifier length, then the resulting noise Figure will be even greater until its satirated. In the Figure it appears there was some value of pump power which varies. For the greater value pump power with the noise figure also increase.

In other words, the Noise Figure will increase with increasing input pump power. From the figure can be seen that the Raman amplifier noise produced up to 2.86 dB.

CONCLUSION

Based on the simulations have been carried out with initial parameters, we acquired the characteristics of Raman amplifiers are signal power output increases with increase of pump power insert, with greater increase for longer fiber length. And then gain will increase with increasing pump power, greater fiber length, and if input signal power is smaller, then the resulting gain is even greater. Maximum gain that can be achieved by the Raman amplifier is about 35.6 dB. And then Pump power is effectively to achieve the maximum gain from 0.1 W until 1.5 W and Raman amplifiers are recommended for long distance communications and for fiber with a length more than 2000 m.

Noise figure in Raman amplifier will increase if the amplifier length is greater and input pump power is also greater and Raman amplifier noise produced up to 2.86 dB.

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