Gain Analysis of Fiber Raman Amplifier at 870nm band

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Abstract— This paper analyses amplification characteristics over 870 nm band in a nonlinear fiber and obtained the variation of signal gain with the pump power with and without amplified spontaneous emission (ASE) for single pump and signal wavelengths in MATLAB environment. Stimulated Raman amplification can occur in any fiber because the the pump photon is excited to a virtual level, Raman gain can occur at any signal wavelength by proper choice of the pump wavelength and the Raman gain process is very fast.

Key words: Gain Analysis, Fiber Raman Amplifier

I. INTRODUCTION

Raman amplification in optical fibers has found wide application in optical fiber communication (OFC) system. Fiber Raman amplifiers have been attracting a great attention in these days, because of their capability to increase the transmission capacity and repeat less span length. There are mainly three reason for the renewed interest in Raman amplification. One is the capability of to provide distributed amplification, another is the possibility to provide gain at any wavelength by selecting appropriate pump wavelengths, and the third is the fact that the amplification bandwidth may be broadened simply by adding more pump wavelengths. Raman amplifier exploits the optical fiber itself as amplification medium. These fibers usually span tens to hundreds of kilometers in length. By setting up extra pump lasers that propagate through the span of the amplifier, energy is transferred from the pumps to the signals (known as the Stimulated Raman Scattering effect) and results in signal boost. In order to provide the desired gain for signals in different channels, it is sometimes necessary to set up several pumps at different wavelengths.

In this work fiber Raman amplifier gain for single pump and single signal without ASE noise in MATLAB environment is simulated. Fiber Raman amplifier (FRA) has been recognized as an enabling technology for optical fiber communication system with its low noise and broad gain bandwidth characteristics. The FRA has experienced increase attention for their flexible control of bandwidth and spectral position of optical gain. Raman amplifier exploits the optical fiber itself as amplification medium. Raman amplification is based on stimulated Raman scattering process. Raman gain is obtainable in any conventional transmission fiber if suitable pump lasers are available. The pump wavelength determines the gain spectrum of a Raman amplifier. The 870 nm band (700– 900 nm) is important for biomedical applications because of the availability of the popular Ti: Sapphire lasers and also because it permits much larger penetration depths in tissue. The low absorptivity and scattering of light in tissue in this band enable in vivo imaging and subcellular sensing applications.

II. WORKING PRINCIPLE

The Raman scattering effect is the inelastic scattering [1]. When a monochromatic light beam propagates in an optical fiber, spontaneous Raman scattering occurs as shown in figure 2.2 (a). It transfers some of the photons to new frequencies. The scattered photons may lose energy (Stokes shift) or gain energy (anti-Stokes shift). If the pump beam is linearly polarized, the polarization of scattered photon may be the same (parallel scattering) or orthogonal (perpendicular scattering). If photons at other frequencies are already present then the probability of scattering to those frequencies is enhanced. This process is known as stimulated Raman scattering as shown in figure 2.2(b). In stimulated Raman scattering, a coincident photon at the downshifted frequency will receive a gain. This feature of Raman scattering is exploited in Raman amplifiers for signal amplification.

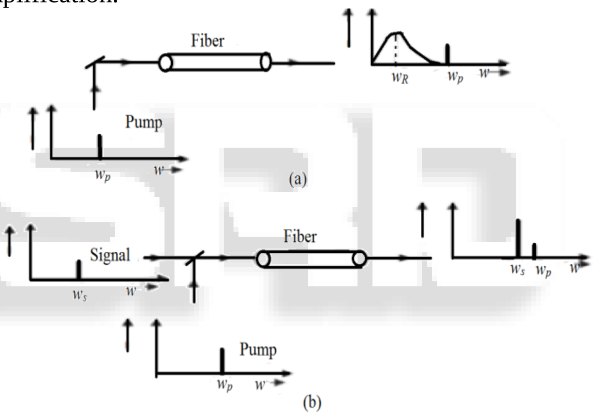

Fig. 2.2(a): Spontaneous Raman scattering phenomenon (b) Stimulated Raman scattering phenomenon [2] .

A schematic of an optical telecommunication system employing Raman amplification is shown in Figure 2.3.1. The signal propagates from the transmitter (Tx) to the receiver (Rx). The pump travelling in the same direction as the signal is called the co- or forward pump, and the pump travelling in the opposite direction of the signal is called the counter- or backward pump.

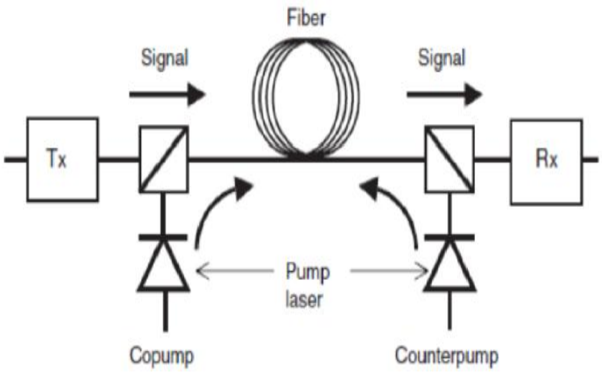

Fig. 2.3.1: Schematic of an optical communication system employing Raman amplification [3]

When a weak signal is launched with a stronger pump, it will be amplified due to SRS. The signal amplification is described by the following equations.

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

$$\xi \frac{dP_P}{dz} = -\,\alpha_p P_P - \frac{\omega_p}{\omega_s}\left(\frac{g_R}{A_{eff}}\right) P_p P_s \qquad (2)$$

where $g_R \ \frac{m}{W}$ is the Raman gain coefficient of the fiber, A_{eff} is the effective mode area of the fiber, α_s and α_p are the attenuation coefficients at the pump and signal wavelength, P_p and P_s are the pump and signal power, ω_p and ω_s are angular frequencies of pump and signal. The $\xi = \pm$ represents the forward and backward pump respectively. The evolution of the pump, P_p, and signal, P_s, power along the longitudinal axis of the fiber Z in the Raman amplified system can be expressed by equation (1) and (2) .Hence we can evaluate the pump and signal power by integrating equation (1). The first term of the equation (1) and (2) represents the intrinsic signal (pump) loss and second term represents the signal gain (pump depletion) due to SRS. The power variations of pump and signal power along the amplifier length can be studied by solving the above two coupled equations.

III. Simulation Result

A. Simulation results for propagation coupled equation without ASE.

In this simulation, we have assumed the following parameter [4] is shown in the Table 3.1

S.No	PARAMETERS	VALUES
1	Fiber length (L)	5 km
2	Signal wavelength (λ_s)	908 nm
3	Pump wavelength (λ_p)	870 nm
4	Attenuation coefficient of Pump (α_p)	0.78 $/km$
5	Attenuation coefficient of Signal (α_s)	0.78 $/km$
6	Pump power (P_p)	1.9 W
7	Signal power (P_s)	$-40\ dBm$
8	Effective mode area (A_{eff})	19.625 μm^2
9	Raman gain coefficient (g_R)	5.4 $\times 10^{-17}\ km/W$
10	Fiber type	Conventional SMF

Table 3.2: Simulation result for propagation coupled equation without ASE.

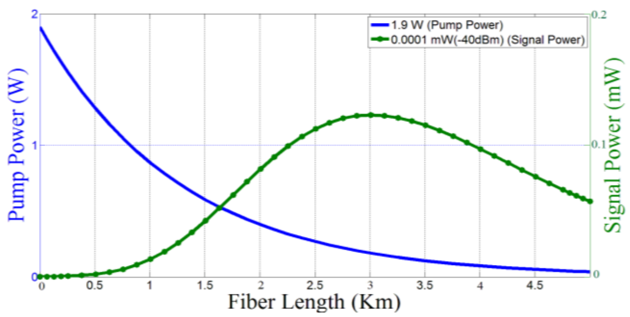

Fig. 3.1.1: Variation of optical power with the fiber length for a fiber Raman amplifier.

Figure 3.1.1 shows the amplification of input signal with the fiber length when the pump power becomes less than 0.2 W, it does not amplify the signal due to attenuation of pump power. To amplify the signals, a sufficient amount of power is required. The signal is amplifying upto certain level after that it is decreasing because of insufficient pump power.

Figure 3.1.2 shows that as we increase the pump power the signal gain will also increase but for the pump power below than 0.2 W it does not amplify the signal, hence the gain will be zero. For achieving the signal gain pump power should be greater than 0.2 W.

Figure 3.1.3 shows that variation of signal gain with fiber length. As we can see from the figure for a given pump power the signal gain increases up to certain length of fiber and then begins to decrease after a maximum point. As we can see that at fiber length of 3 km we are achieving maximum gain=30.9 dB. The physical consideration for the decrease in signal gain is insufficient stimulated Raman scattering due to excessive pump depletion and getting higher losses.

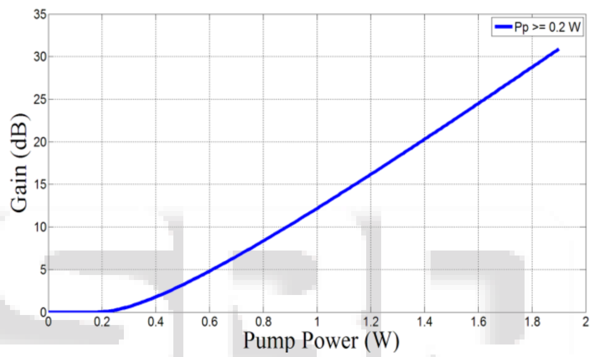

Fig. 3.1.2: Variation of signal gain with the input pump power for a fiber Raman amplifier.

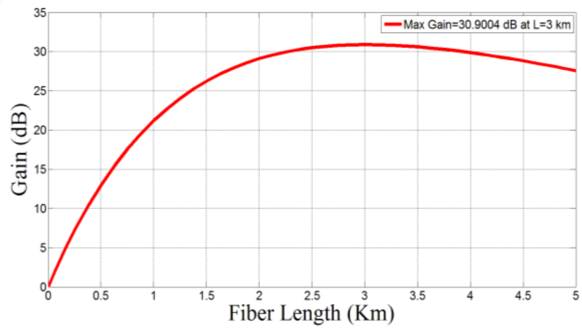

Fig. 3.1.3: Variation of signal gain with the fiber length.

B. Simulation results for propagation coupled equation with ASE power.

In this simulation, we have assumed the following parameter [5] as shown in the Table 3.2

S No.	PARAMETERS	VALUE
1	Fiber length (L)	5 km
2	Signal wavelength (λ_s)	908 nm
3	Pump wavelength (λ_p)	870 nm
4	Attenuation coefficient of Pump (α_p)	0.78 $/km$
5	Attenuation coefficient of Signal (α_s)	0.78 $/km$
6	Attenuation coefficient of	0.78 $/km$

	ASE (α_{ASE})	
7	Pump power (P_p)	$3.5\,W$
8	Signal power (P_s)	$-40\,dBm$
9	ASE power (P_{ASE})	$-70\,dBm$
10	Effective mode area (A_{eff})	$12.56 \times 10^{-18} km^2$
11	Effective ASE bandwidth (Δv)	$0.125\,THz$
12	Plank's Constant (h)	$6.6280 \times 10^{-10}\,W/THz^2$
13	Boltzmann's constant (k)	$1.3806 \times 10^{-11}\,W/THzK$
14	Fiber type	Conventional SMF

Table 3.2: Simulation result for propagation coupled equation with ASE.

Figure 3.2.1 shows the amplification of input signal with the fiber length. When the pump power becomes less than $0.4\,W$, it will not amplify the input signal, to amplify the signal power sufficient amount of power is required. In this simulation $0.4\,W$ of pump power and $1e-4\,mW$ of signal power are given to the fiber input and hence at the output amplified signal power of $0.123mW$ is achieved.

Figure 3.2.2 shows that variation of signal gain with the input pump power. As the pump power increases the gain will also increases but for the pump power below than $0.4\,W$, it does not amplify the signal hence the gain will be zero. To achieve the gain the pump power should be greater than $0.4\,W$. In this simulation, it required greater pump power because pump power is also transfer its energy to ASE power, and also amplify the amplified stimulated emission (ASE) power.

Figure 4.2.3 shows that as we increase the pump power the signal gain also increases, and we achieved almost same gain (Gain = 30.213 dB) but it required much power due to ASE

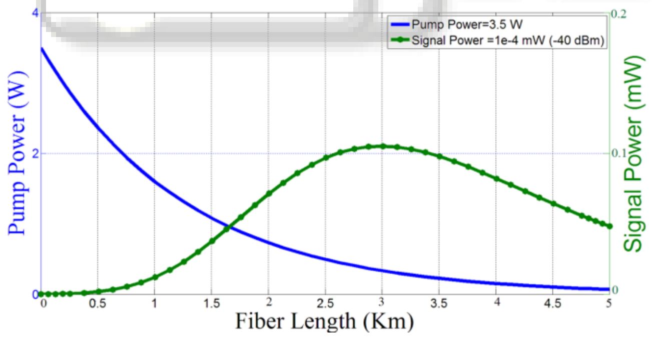

Fig. 3.2.1: Variation of optical power with the fiber length with ASE.

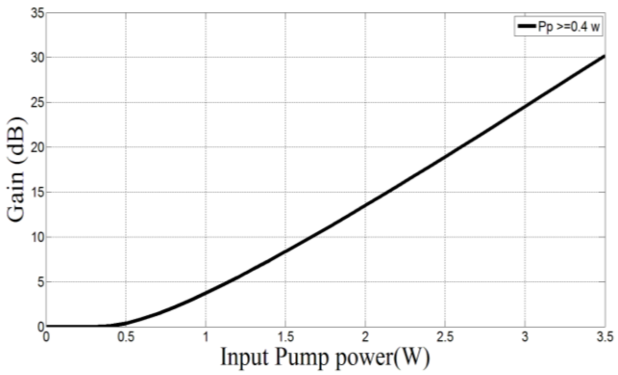

Fig. 3.2.2: Variation of signal gain with the input pump power for a fiber Raman amplifier.

By solving the propagation coupled equation in MATLAB environment for single pump and single signal it is found that the threshold power for the single pump and single signal without ASE amplifier system is 0.2 W. By simulating we achieved a maximum gain of 30.90 dB with pump power of 1.9 W at fiber length of 3 km. Similarly for the single pump and single signal with ASE amplifier system threshold power is 0.4 W and the maximum gain of 30.213 dB with pump power of 3.5 W at fiber length of 3 km is achieved.

IV. Conclusion

Modelling for Raman fiber amplifier characteristics has been carried out including the effect of forward and backward ASE, pump depletion, Rayleigh scattering, etc. The Fiber Raman amplifier simulation model has been generated by using boundary value problem (BVP4C) and by using ordinary differential equation (ODE45) function in MATLAB environment. We conclude that the boundary value condition (BVP4C) gives better accuracy as compare to ordinary differential equation model (ODE45).

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