Gain Analysis of Fiber Raman Amplifier for Single Signal and Multiple Pump

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Abstract— This paper analyses the Fiber Raman Amplifier for signal gain with the pump power with and without ASE for single signal and multiple pump power in MATLAB. Fiber Raman amplifier 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.

Key words: Fiber Raman Amplifier, Gain Analysis

I. Introduction

In the early 1970s, Stolen and Ippen [1] demonstrated Raman amplification in optical fibers. However, throughout the 1970s and the first half of 1980s, Raman amplifiers remained primarily laboratory curiosities. In the mid-1980s, many research papers elucidated the promise of Raman amplifiers, but much of that work was overtaken by erbium-doped fiber amplifiers (EDFAs) by the late 1980s. However, in the mid to late 1990s, there was a resurgence of interest in Raman amplification. By the early part of the 2000s, almost every long-haul (typically between 300 and 800 km) or ultra-long-haul (typically longer than 800 km) fiber-optic transmission system uses Raman amplification. There are some fundamental and technological reasons for the interest in Raman amplifiers that this project explores. 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.

A fiber Raman amplifier employs the intrinsic properties of silica fiber to obtain the amplification. Thus, the transmission fiber can be used as the amplification medium, where the gain is created along the transmission [2]. The amplification is realized by stimulated Raman scattering (SRS), which occurs when a sufficiently powerful pump is within the same fiber as the signal. Raman amplification is based on the stimulated emission process associated with Raman scattering in fiber for amplification of signal. It is well known that silica-based optical fiber has Kerr nonlinearity. The finite response time of nonlinear polarization due to Kerr effect of medium results in energy loss of incident photon and excitation of molecule vibration or phonon. For silica, the response time is approximately on the order of 10 fs. Even though the response is very fast, the delay of nonlinear polarization with respect to the electric field of incident light wave causes real vibration modes of silica fiber. This process is classically described by imaginary part of nonlinear polarization, which causes absorption of incident wave and gain to Stokes shifted wave [3]. In quantum mechanics, it is described as a process in which an incident photon excites an electron to the virtual state and then the stimulated emission occurs when the electron de-excites down to the upper phonon energy level of glass molecule [4]. In Raman amplifiers, the signal wavelength is longer than the pump wavelength by the equivalent amount of frequency shift. There are two kinds of phonons: one is acoustic phonon and the other is optical phonon. Raman scattering is the scattering between photon and optical phonon while that between photon and acoustic phonon is called Brillouin scattering. Because the optical phonon has almost uniform dispersion relation versus wave number, unlike stimulated Brillouin scattering, the phase matching is easily obtained for arbitrary relative directions between the pump and signal waves. Therefore, Raman amplifiers can take both co- and counter pump schemes [5]. Raman amplifier exploits the optical fiber itself as amplification medium. These fibers usually span tens to hundreds of kilometres 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.

II. Multi signal propagation coupled equation

Fiber Raman Amplifiers (FRA) noise to the signal during the amplification process. The FRA modelling mainly includes ASE noise and dual Rayleigh scattering (DRS) noise. Amplifier Spontaneous Emission amplified spontaneous emission (ASE) noise and double Rayleigh back scattering (DRS) noise. The ASE due to the amplification of Raman spontaneous scattering by pump (signal) overlay the whole Raman gain spectrum. It is the main source of noise in FRA. Therefore the study of ASE noise is very important in order to know the performance of optical system. First we get the power equations of ASE noise from the propagation equations of FRA. Then we analysed a few main factors which influence the Amplifier spontaneous emission (ASE) noise.

III. Mathematical model

Power variation of signals and pumps in the backward pumped fiber Raman amplifier with multiple signal and pump channels can be described by the following system of coupled nonlinear equations. In order to analyse amplification in the designed fiber, we have solved the propagation equation for pump, multiple signal and forward and backward ASE as boundary value problem. In general, for Raman amplifiers, a backward pumping scheme is adopted to suppress the signal power fluctuation caused by pump relative intensity noise [6]. Wave propagation equation for backward pumped FRA with multiple signal and pump channels can be described by the following system of coupled nonlinear equations:

$$\pm \frac{dP_k}{dz} = -\alpha_k P_k + \rho P_k + \sum_{j=1}^{n_p+n_s} \gamma(v_j, v_k) P_k P_j \quad (14)$$

$$\pm \frac{dP_{ASE,k}}{dz} = -\alpha_k P_{ASE,k} + \rho P_{ASE,k} + \sum_{j=1}^{n_p+n_s} \gamma(v_j, v_k) P_j \times [P_{ASE,k} + 2hv_k \Delta v(1 + H_{jk})] \quad (15)$$

Where n_p is the number of pump waves and n_s is the number of signal channels, subscripts j, k denote the jth$(j = 1,2, \dots, n_p + n_s)$ and kth $(k = 1,2, \dots, n_s)$ waves. $P_k, P_{ASE,k}$ represent the kth signal and amplified spontaneous emission (ASE) power, while P_j can be the signal or pump power. $z$is the distance and the $\pm$ sign denotes the propagation directions.

IV. Simulation Result

A. *Simulation results for propagation coupled equation without ASE.*

In this simulation, we have assumed the following parameter [7] is shown in the Table 4.1

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 1 (P_p)	0.1W
7.	Pump power 2 (P_p)	0.5W
8.	Pump power 3 (P_p)	$0.9W$
9.	Pump power 4 (P_p)	1.3W
10.	Pump power 4 (P_p)	1.7W
11.	Pump power (P_p)	1.9W
12.	Signal power (P_s)	$-40\ dBm$
13.	Effective mode area (A_{eff})	$19.625\ \mu m^2$
14.	Raman gain coefficient (g_R)	$5.4 \times 10^{-17}\ km/W$
15.	Fiber type	Conventional SMF

Table 4.1: Simulation results for propagation coupled equation without ASE.

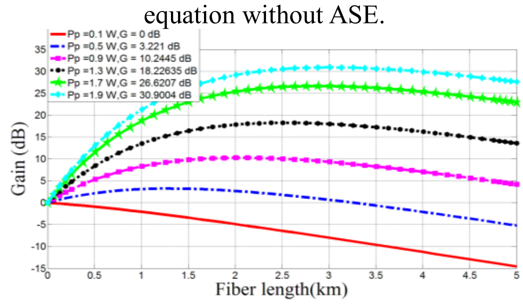

Fig. 4.1.1: Variation of gain with fiber length for different input pump power.

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

In this simulation, we have assumed the following parameter [8] as shown in the Table 4.2

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	Attenuation coefficient of ASE (α_{ASE})	$0.78\ /km$
7	Pump power 1 (P_p)	0.3W
8	Pump power 2 (P_p)	1.1W
9	Pump power 3 (P_p)	1.9W
10	Pump power 4 (P_p)	2.7W
11	Pump power 5 (P_p)	$3.5\ W$
12	Signal power (P_s)	$-40\ dBm$
13	ASE power (P_{ASE})	$-70\ dBm$
14	Effective mode area (A_{eff})	$12.56 \times 10^{-18} km^2$
15	Effective ASE bandwidth (Δv)	$0.125\ THz$
16	Plank's Constant (h)	$6.6280 \times 10^{-10}\ W/THz^2$
17	Boltzmann's constant (k)	$1.3806 \times 10^{-11}\ W/THzK$
18	Fiber type	Conventional SMF

Table 4.2: Simulation result for propagation coupled equation with ASE.

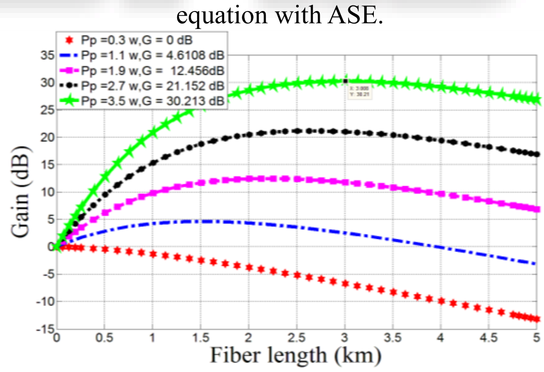

Fig. 4.2.1: Variation of signal gain with the fiber length for different input pump power.

We are using Raman amplifier because the gain is possible at any wavelength as long as pump is available. Broad and flexible gain spectrum can be obtained by using multiple pump.

It has lower noise figure than rare earth doped fiber amplifier and SOA (semiconductor optical amplifier). Raman amplifier uses stimulated Raman scattering where the incoming light with phonon produces photons coherent with incoming light. In SOA electron-hole recombination causes the amplification of incoming signal.

This particular range of frequency is used because of larger penetration, low water absorptivity and Rayleigh scattering increases at short wavelength.

Figure 4.1.1 shows that the gain for single signal and multiple pump without ASE varies as the pump power varies. The gain for pump power of 0.1 , is 0dB. The gain for pump power 0.5W is 3.221dB.The gain for pump power of 0.9 W is 10.2445 dB. The gain for pump power of 1.3W is 18.22635dB. The gain for pump power of 1.7W is 26.6207dB. The gain for pump power of 1.9W is 30.9004dB.

Figure 4.2.1 shows that the gain for single signal and multiple pump with ASE varies as the pump power varies. The gain for pump power of 0.3 , is 0dB. The gain for pump power 1.1W is 4.6108dB. The gain for pump power of 1.9 W is 12.456dB. The gain for pump power of 2.7W is 21.152dB. The gain for pump power of 3.5W is 30.213dB.

V. CONCLUSION

From the above analyses it is seen that Raman gain varies for single signal and multiple pump power for the same fiber length. The maximum gain of 30dB is achieved at the length of 3km both for with and without ASE. 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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