Raman Amplifier Characteristics with Variation of Signal Power and Pump Power With and Without Amplified Spontaneous Emission

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ABSTRACT
Raman amplifier characteristics shows the coupling of signal power and pump power using propagation coupled equation in forward direction using MATLAB environment. The calculation of propagation coupled equation with and without amplified spontaneous emission in a single-mode fiber at wavelength of 850nm.

General Terms
Fiber Raman Amplifier (FRA), Signal Amplification

Keywords
Signal power and pump power, amplified spontaneous emission, propagation coupled equation.

1. INTRODUCTION
Raman amplification has found wide application in optical fiber communication (OFC) system. These days Fiber Raman amplifiers have been attracting a great attention, because it has great capability to increase the transmission capacity and repeat less span length. There are mainly three reasons for the renewed interest in Raman amplification. First is the capability to provide distributed amplification, second 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. Fiber Raman amplifier (FRA) has low noise and broad gain bandwidth characteristics due to which it has been recognized as an enabling technology for optical fiber communication system. The FRA is well known for their flexible control of bandwidth and spectral position of optical gain. Raman amplifier exploits the optical fiber itself as amplification medium. Raman amplification works on the principle of stimulated Raman scattering process. Raman gain can be achieved in any conventional transmission fiber if suitable amount of pump lasers are available. The pump wavelength determines the gain spectrum of a Raman amplifier. Raman fiber amplifiers (FRAs) hold much promise for telecommunication systems. Since they can operate within transparency window of optical fiber with a practically arbitrary wavelength. In this paper, coupling of signal power with pump power using propagation coupled equation with noise and without noise have been measured and also observed the power requirement in transmitting message from source to destination with and without amplified spontaneous emission. The 800 nm band (700-900 nm) is important for biomedical applications because of the availability of the lasers and also because it permits much larger penetration depth in tissue. The latter is due to a compromise between Rayleigh scattering which increases at shorter wavelengths and water absorption which increases at longer wavelengths in this wavelength band.

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 [1]. The amplification is realized by stimulated Raman scattering (SRS), which occurs when a sufficiently powerful pump is within the same fiber as the signal.

2. METHOD OF MEASUREMENT
The fiber Raman amplifier is used to amplify the signal by the Raman interaction with a strong optical wave at higher frequency which is called a “pump” power. The signal can be pumped in two directions either in forward direction or backward direction. This signal can be tuned with respect to the pump frequency and the Rama gain coefficient can be found maximum at a frequency separation of 13 THz between pump and signal. The Fiber Raman amplifier will suffer nonlinear absorption rather than amplification, if the signal frequency is higher than the pump frequency.
The inelastic scattering occurs in the Raman scattering effect [2]. When a light ray propagates in an optical fiber, spontaneous Raman scattering occurs as shown in figure 1 (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 1(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.

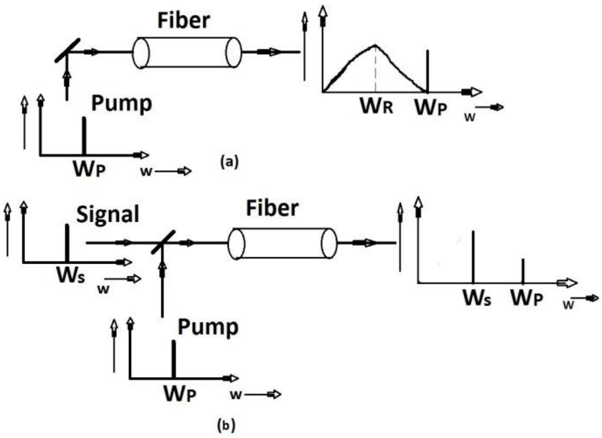

Fig 1: (a) Spontaneous Raman scattering phenomenon (b) Stimulated Raman scattering phenomenon [3]

According to electromagnetic concepts, the growth of stimulated Raman scattered signal intensity [2] is proportional to the product of the pump (I_P) and signal (I_S) intensities such that

$$\frac{dI_S}{dz} = g_R I_P I_S \qquad (1)$$

Here g_R is known as Raman-gain coefficient.

3. RAMAN PROPAGATION COUPLED EQUATION AND SIMULATION RESULT

3.1 Raman Equation

When a weak signal is launched with a stronger pump, it will be amplified due to stimulated Raman scattering. When a pump photon strikes on the system, an electron in the ground energy state can absorb the photon energy and be excited to virtual energy level which is called absorption [4]. Since this is an unstable state, the electron will shortly return to the vibration level by emitting a signal photon. This emission of signal photon is in phase with incident photon i.e. called spontaneous emission. When the electron is still in its virtual energy level and a pump photon strikes on the system, the electron is immediately stimulated to drop to the ground energy level by emitting a signal photon which is called stimulated emission. The difference in the energy between the pump photon and signal photon is called vibration level or molecular vibration, which determines the frequency shift $\Omega = v_p - v_s$ and shape of the Raman gain curve.

Raman amplification is an optical process based on the phenomenon of SRS in which an input light (Called the Stokes field) induced the inelastic scattering of a blue-shifted pump light in an optical medium (typically, as optical fiber) in the nonlinear regime [5].

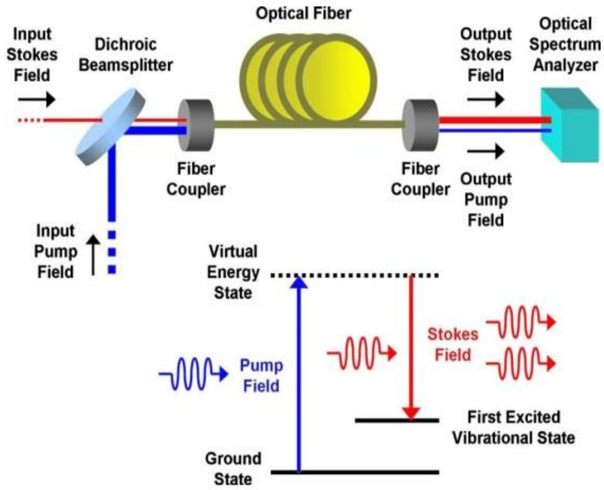

Fig 2: Schematic of an optical communication system employing Raman amplification [1]

SRS is described by the following propagation coupled equations:

$$\frac{dP_s}{dz} = -\alpha_s P_s + \left(\frac{g_R}{A_{eff}}\right) P_p P_s \qquad (2)$$

$$\xi \frac{dP_P}{dz} = -\,\alpha_p P_P - \frac{\omega_p}{\omega_s}\left(\frac{g_R}{A_{eff}}\right) P_p P_s \qquad (3)$$

Where g_R is the Raman gain coefficient of the fiber, $Aeff$ 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 $\xi = \pm$ represent 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 (2) and (3) .Hence we can evaluate the pump and signal power by integrating equation (2).

The first term of the equation (2) and (3) 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. Assuming the case of forward pump propagation, the second term of equation (2) can be neglected making an assumption of pump of pump depletion (small signal amplification), Eq. (2) and (3) can be solved for the signal intensity as a function of z

$$P_s = P_s(0) exp\left[\frac{g_R}{A_{eff}}\frac{P_p(0)}{\propto_p}(1 - e^{-\propto_p z}) - \propto_s z\right] \quad (4)$$

Raman property of optical fiber considerably depends on the radiation wavelength.

3.2 Simulation Result

In this simulation, the following parameters are used to simulate the propagation coupled equation with and without amplified spontaneous emission. The length of the conventional optical fiber of $5\,km$ in which the signal wavelength and pump wavelength is $850\,nm$ and $788\,nm$ respectively. For independent measurement, the loss coefficient are found to be $0.78\,/km$ and signal power in both case is $-40\,dBm$ while the pump power is taken as 1.9 W without using ASE similarly the pump power required is 3.5 W while using ASE. The effective mode area is $12.56 \times 10^{-18} km^2$, ASE power is $-70\ dBm$ and effective ASE bandwidth is 0.125 THz and Raman gain coefficient is $5.4 \times 10^{-17} km/W$.

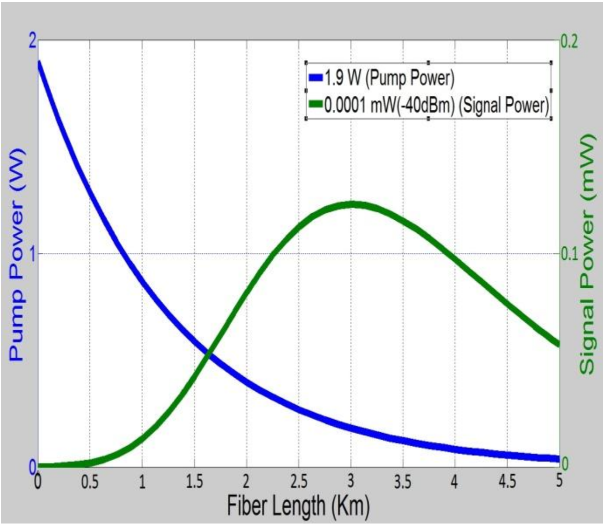

Fig3: Variation of optical power with the fiber length for a fiber Raman amplifier

Figure 3 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 up to certain level after that it is decreasing because of insufficient pump power.

Figure 4 shows that as the pump power increases 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 5 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 $0.123\ mW$ is achieved.

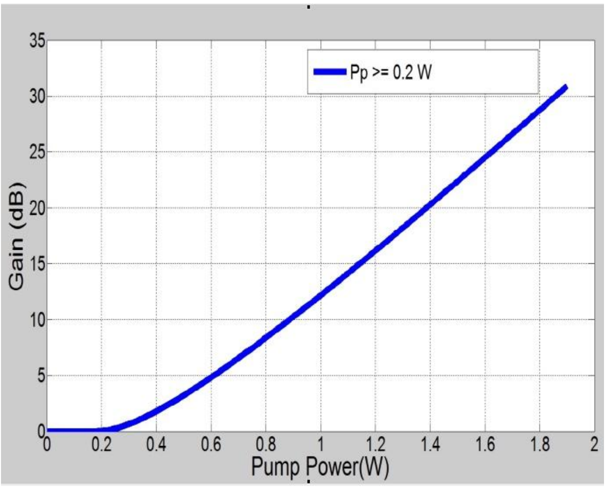

Fig 4: Variation of signal gain with the input pump power for a fiber Raman amplifier

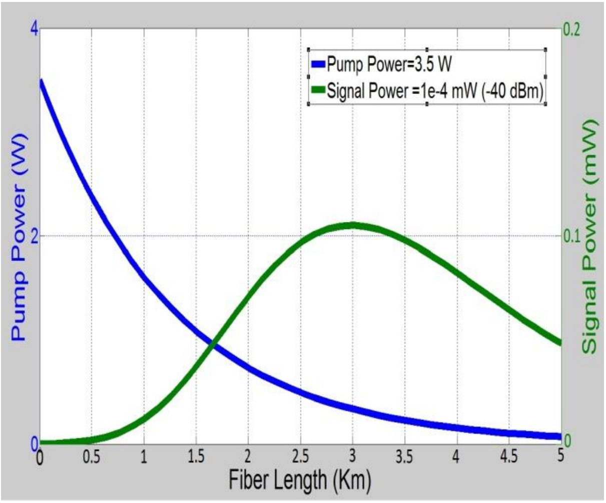

Fig 5: Variation of optical power with the fiber length with ASE

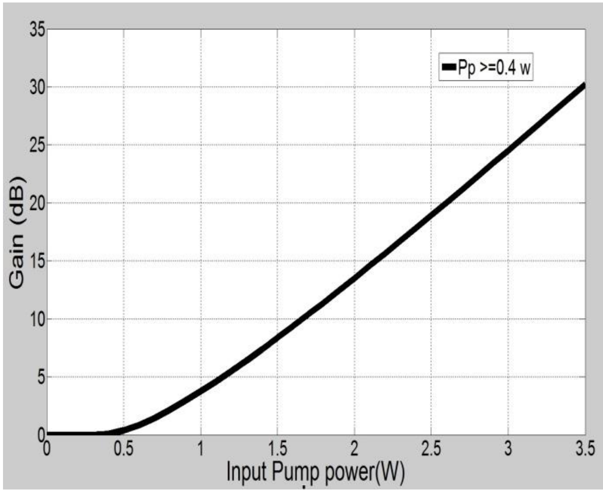

Fig 6: Variation of signal gain with the input pump power for a fiber Raman amplifier

Figure 6 shows that variation of signal gain with the input pump power. As the pump power increases the gain will also increase 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.

4. CONCLUSION

This paper reported the amplification of signal power in two different situations in optical fiber at wavelength near 850 nm. By solving the propagation coupled equation in MATLAB environment for single pump and single signal. In this simulation the pump power required is just double to achieve minimum gain while simulating in ASE environment. At particular length of fiber of 3 km, the maximum amplification of signal is achieved in both the case and similarly getting maximum gain at 3 km. For further amplification that required another pump power to amplify the signal after 3km of fiber length so that the strength of signal power will continue to transmit.

5. REFERENCES

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