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Details Study of Gain and Noise Figure of Raman Optical Amplifier in the Wavelength range (1560 – 1610 nm)

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ABSTRACT

We present in this paper, a details study of the gain, noise figure and optical signal to noise ratio (OSNR) of Raman amplifier in the wavelength range (1560 – 1610 nm), which is the L –band. Solving the analytical equation of Raman amplifier for gain, noise figure and optical signal to noise ratio at different input signal powers, different RA lengths and different Raman pump power were considered. From the analysis of the results, We obtained maximum value of gain 13.5 dB and minimum noise figure of 8 dB at 1600nm and -30 dBm input signal power and a flat gain in the signal wavelength (1560 – 1610 nm), which is favorite for wave division multiplexing (WDM). In addition, the results show a strong dependence of gain and noise figure on RA length and Raman pump power. The best values of OSNR were observed at 100 mW pump power of RA. The higher values of OSNR obtained for RA length of 20 km and input signal power 2.6 dBm and the lower values of OSNR obtained for RA length of 45 km and -30 dBm input signal power in the signal wavelength range.

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INTRODUCTION

Light propagating through an optical fiber interacts with the molecules of the fiber. In one process, light is scattered by the molecules, generating a non-propagating vibration of the molecules. This process is known as the Raman Effect (G.P. Agrawal, 2001). The Raman amplifier is very simple. Raman scattering of light is inherent to all silica-based optical fibers. Thus, the Raman amplifier is a very simple way to obtain cancellation of the intrinsic fiber loss. All that is needed to turn the transmission fiber into an amplifier by itself is to launch pump light simultaneously with the signal light (M.E. Lines, 1987). Stimulated Raman scattering (SRS) is the fundamental nonlinear process that turns optical fibers into broadband Raman amplifiers. The capability to improve noise performance by using distributed amplification was demonstrated using distributed Raman amplification into broadband Raman amplifiers (R. H. Stolen and E. P. Ippen, 1973). In the late eighties, Raman amplification was perceived as the way to overcome attenuation in optical fibers and research on long haul transmission was carried out demonstrating transmission over several thousand kilometers using distributed Raman amplification (D. Marcuse, 1980). However, with the development and commercialization of erbium-doped fiber amplifiers through the early nineties, work on distributed Raman amplifiers was abandoned because of its poor pump power efficiency when compared to erbium-doped fiber amplifiers (EDFAs). In the mid-nineties, high-power pump lasers became available and in the years following, several system experiments demonstrated the benefits of distributed Raman amplification including repeater-less undersea experiments (M.E. Lines, 1987), high-capacity terrestrial (R. H. Stolen and E. P. Ippen, 1973, D. Marcuse, 1980)as well as submarine systems transmission experiments (M. N. Islam and Ed, 2003), shorter span single-channel systems including 320 Gbit/s pseudolinear transmission (Desurvire, 1995), and in soliton systems. (E.M. Dianov, 1996) Our work based on details study of the gain, noise figure and optical signal to noise ratio for Raman amplifier in the L –band (1560 – 1610 nm), the analytical expressions of the signals amplified by forward Raman scattering are presented. The cross section of Raman was chosen for GeO_2 fiber glass.

Theory:

When an input signal is introduced to an optical fiber with strong pump, it will be amplified due to

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the Raman interaction between the pump and signal, so the signal and pump power can be described by the following equations (Simranjit Singh and R. S. Kaler, 2015)

$$\frac{dP_s}{dz} = \frac{g_R P_p P_s}{\sigma_p} - \alpha_s P_s \quad (1)$$

$$\frac{dP_p}{dz} = \frac{\omega_p}{\omega_s}\frac{g_R P_p P_s}{\sigma_p} - \alpha_p P_p \quad (2)$$

where P_s is the signal power, g_R is Raman gain coefficient, P_p is the pump power, σ_p is the cross section area of pump, α_s and α_p the fiber losses at signal and pump frequencies (ω_s and ω_p) respectively.

For practical situations, pump power is so large compared with signal power that pump depletion can be neglected by setting $g_R = 0$ in Eq. (2) then we have the pump power for forward pumping as:

$$P_p(z) = P_p(0)e^{\alpha_p z} \quad (3)$$

where $P_p(z)$ is the output pump power at z length of Raman amplifier and $P_p(0)$ is the input pump power.

Solving Eqs. (1) and (3) for signal power we obtain (T. Horiguchi *et al*., 1992).

$$P_s(L) = P_s(0)exp\left\{\frac{g_R P_p(0)}{\sigma_p} L_{eff} - \alpha_s L\right\} \quad (4)$$

with

$$L_{eff} = \frac{1-e^{-\alpha_p L}}{\alpha_p} \quad (5)$$

where $P_s(L)$ output signal power and $P_s(0)$ is the input signal power.

The gain of Raman amplifier is the ratio of output signal to input signal power given as

$$G(dB) = 10log_{10}\left[exp\left\{\frac{g_R P_p(0)}{\sigma_p} L_{eff} - \alpha_s L\right\}\right] \quad (6)$$

The Raman gain coefficient is calculated from the relation (Arwa H. Beshr, Moustafa H. Aly, 2007):

$$g_R = \sigma(\nu)\frac{\lambda_s^3}{c^2 h(n(\nu))^2} \quad (7)$$

γ_s is the Raman cross section of the signal, λ_s is the Stokes wavelength, h Planck's constant and n(ν) is the frequency dependent refractive index.

For noise figure calculation, the number of forward noise photons is given as (Yasuhiro Aoki, 1998)

$$N_{fnoise}(L) = Gexp(-\alpha_s L) \quad (8)$$

The amplified spontaneous emission that the source of noise is given as

$$P_{ASE} = h\nu\Delta\nu N_{fnoise}(L) \quad (9)$$

The noise figure (NF) now calculated as

$$NF = \frac{2P_{ASE}}{h\nu\Delta\nu G} + \frac{1}{G} \quad (10)$$

From Eqs. (8), (9) and (10)

$$NF(dB) = 10log_{10}\left[2\exp(-\alpha_s L) + \frac{1}{G}\right] \quad (11)$$

The optical signal to noise ratio (OSNR) is described by the equation (C. Fludger *et al*., 2000, R. W. Hellwarth, 1963)

$$SNR = \frac{P_s(0)}{h\nu\Delta\nu\left[NF - \frac{1}{G}\right]} \quad (12)$$

The parameters used in our model are listed in Table 1.

Table 1: RA parameters.

Symbol	Definition	Value
g_R	Raman gain coefficient	10×10^{-14}
$\Delta\nu_r$	Reference optical bandwidth	0.1 nm
λ_p	Pump wavelength	1450 nm
α_s	Fiber loss at signal frequency	5.76×10^{-5} dB/m
α_p	Fiber loss at pump frequency	5.76×10^{-5} dB/m
σ_s	Cross sectional area of pump beam	12.6×10^{12} m^2
σ_p	Cross sectional area of signal beam	12.6×10^{12} m^2

RESULTS AND DISCUSSION

Using Eq. (7) and (Arwa H. Beshr, Moustafa H. Aly, 2007), we obtain the Raman gain coefficient for GeO_2 fiber glass at wavelength 1560 – 1610 nm. **Fig.1** shows the gain of RA as a function of signal wavelength, at different values of RA length (20, 25, 35 and 45km). The Raman pump power fixed at 100mW and the input signal power 2.6 dBm. From **Fig.1** for λ< 1580 nm, the gain decreases as RA length increase and for λ > 1580, the gain increases as RA length increase. The RA length 25 km gives the best values of the gain (9 – 10 dB) for L- band range.

Fig.2 shows the noise figure of RA as a function of signal wavelength, at different values of RA length (20, 25, 35 and 45km, Raman pump power fixed at 100mW and the input signal power 2.6 dBm. It is clear that the noise figure increases with the RA length increase and it is nearly saturated for signal wavelength range.

The variations of the gain of RA versus the signal wavelength at different values of input signal power is represented in **Fig.3**, where Raman pump power fixed at 100mW and the RA length is 25 km. As the input signals power increases the gain becomes higher and the maximum value of gain was 13.5 dB at 1600nm and -30 dBm signal power. **Fig.4** shows the noise figure of RA versus the signal wavelength at different values of input signal power, where Raman pump power fixed at 100mW and the RA length is 25 km. As the input signals power increases the noise figure becomes lower and the minimum value of noise figure was 8 dB at 1600nm and -30 dBm signal power.

The gain profile of RA is strongly depends on the Raman pump power, where the gain jump from 4.27 to 29 dB when the pump power changes from 80 to 200 mW at signal wavelength 1600 nm, this can be obtained from **Fig.5**. where **Fig.5** shows the variations of the gain as a function of signal wavelength at different values of Raman pump power, the input signal power fixed at 2.6 dBm and the RA length is 25 km. A flat gain obtained for all cases discussed above in the signal wavelength (1560 – 1610 nm), which is favorite for wave division multiplexing (WDM).

Fig.6 shows the variations of the noise figure as a function of signal wavelength at different values of Raman pump power, the input signal power fixed at 2.6 dBm and the RA length is 25 km. The figure shows lower values of noise occur at 150 and 180 mW Raman pump power, and higher values of noise figure at 80 and 100 mW also intermediate values of noise figure obtained at Raman power of 200 mW. The minimum values of noise figure were 8.1 dB at 1596 nm and 150 mW pump power of RA.

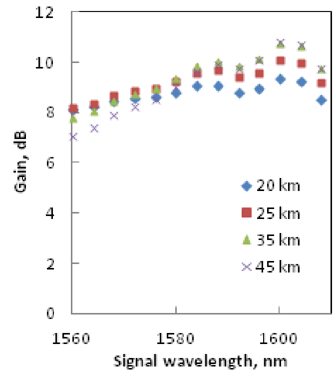

Fig. 1: Gain of RA as a function of signal wavelength at different RA lengths.

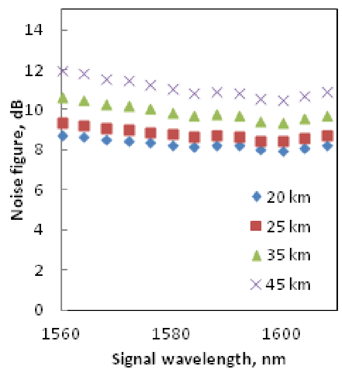

Fig. 2: Noise figure of RA as a function of signal wavelength at different RA lengths.

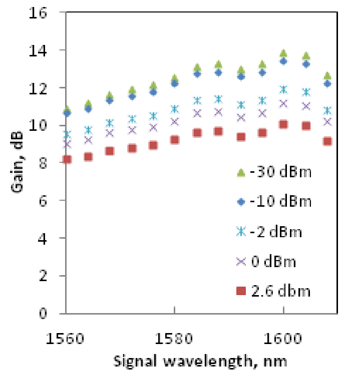

Fig. 3: Gain of RA as a function of signal wavelength at different input signal powers.

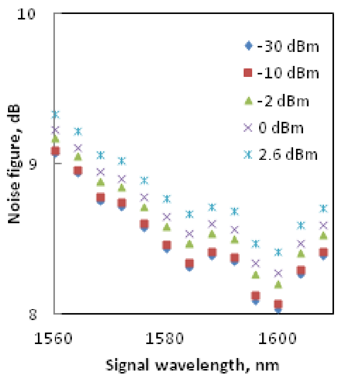

Fig. 4: Noise figure of RA as a function of signal wavelength at different input signal powers.

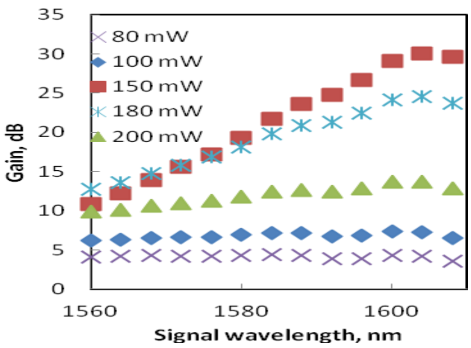

Fig. 5: Gain of RA as a function of signal wavelength at RA pump powers.

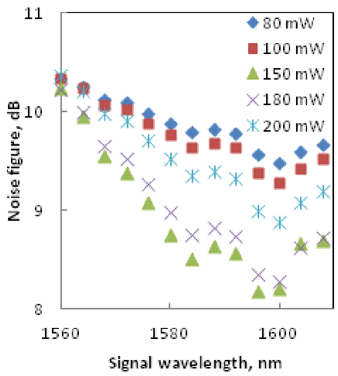

Fig. 6: Noise figure of RA as a function of signal wavelength at RA pump powers.

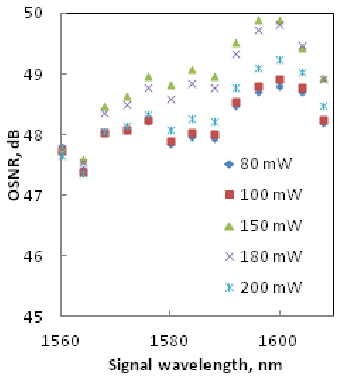

Fig.7: Optical signal to noise ratio (OSNR) of RA as a function of signal wavelength at RA pump powers.

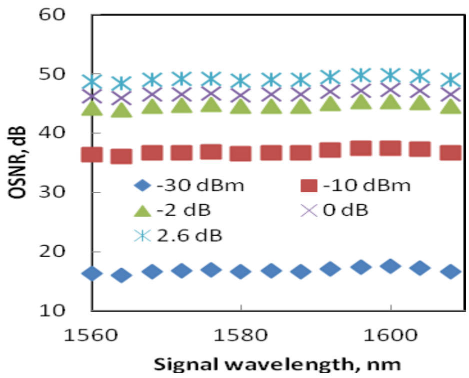

Fig. 8: Optical signal to noise ratio (OSNR) of RA as a function of signal wavelength at input signal powers.

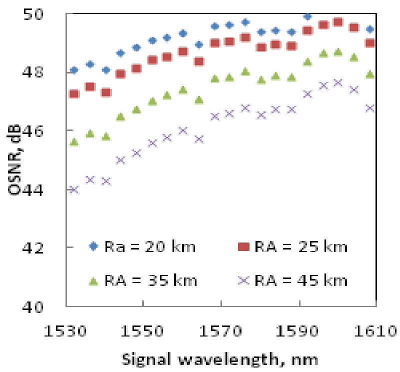

Fig. 9: Optical signal to noise ratio (OSNR) of RA as a function of signal wavelength at RA lengths.

Fig.7 shows OSNR as a function of signal wavelength at different values of Raman pump power, at 25 km RA length and 2.6 dBm input signal power. From **Fig.7** the higher values of OSNR occur at 150 and 180 mW Raman pump power, and lower values of OSNR at 80 and 100 mW also intermediate values of OSNR obtained at Raman power of 200 mW. The best values of OSNR were observed at 100 mW pump power of RA.

Fig.8 shows OSNR as a function of signal wavelength at different values of input signal wavelength, where the Raman pump power 100 mW, and 25 km RA length. From **Fig.8** the higher values of OSNR (48.8 dB) obtained for input signal power of 2.6 dBm and the lower values (16.8 dB) for input signal power of -30 dBm in the signal wavelength range.

Finally, OSNR as a function of signal wavelength at different values of RA length, where the Raman pump power 100 mW, and the input signal power 2.6 dBm is illustrated in **Fig.9**. From **Fig.9** the higher values of OSNR obtained for RA length of 20 km and the lower values of OSNR obtained for RA length of 45 km in the signal wavelength range.

Conclusion:

Our work based on details study of the gain, noise figure and optical signal to noise ratio for Raman amplifier in the L –band (1560 – 1610 nm), the analytical expressions of the signals amplified by forward Raman scattering are presented. The cross section of Raman was chosen for GeO_2 fiber glass. Solving the analytical equation of Raman amplifier for gain, noise figure and optical signal to noise ratio at different input signal powers, different RA lengths and different Raman pump power were done. From the analysis of the results, We obtained maximum value of gain 13.5 dB and minimum noise figure of 8 dB at 1600nm and -30 dBm input signal power and a flat gain e in the signal wavelength (1560 – 1610 nm), which is favorite for wave division multiplexing (WDM). In addition, the results show a strong dependence of gain and noise figure on RA length and Raman pump power. The best values of OSNR were observed at 100 mW pump power of RA. The higher values of OSNR obtained for RA length of 20 km and input signal power 2.6 dBm and the lower values of OSNR obtained for RA length of 45 km and -30 dBm input signal power in the signal wavelength range.

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