Noise Figure Analysis Of Distributed Fibre Raman Amplifier

G. M. Isoe, K. M. Muguro, D. W. Waswa

Abstract: Fibre Raman amplifiers are being deployed in many new long-haul and ultra long-haul fibre-optic transmission systems, making them the first and most widely commercialized nonlinear optical devices in telecommunications. One of the main reasons for this is their improved noise figure and reduced nonlinear penalty of fibre systems hence allowing for longer amplifier spans. In this paper, we have critically analyzed by simulation the noise figure of Distributed fibre Raman amplifiers for different pumping schemes. The main sources of optical noise and their effects on the noise figure and optical signal to noise ratio are also discussed. Our results show that the optical signal to noise ratio (OSNR) is higher for forward pumping than in backward pumping, while the noise figure (NF) was higher for backward pumping than in forward pumping. Both the NF and OSNR remains almost the same for shorter fibre length (< 10 Km), but change differently at longer fibre lengths and pump powers, depending on the pump configuration used. It was also found that OSNR increased as pump power increase beyond 100mW as the NF reduced for the two pump configuration. Results from our study are important in the design optimization of fibre Raman amplifiers in long haul signal transmissions.

Index Terms: Fibre Raman amplifier (FRA), Noise figure (NF) and Optical signal to noise ratio (OSNR)

◆

1 INTRODUCTION

Distributed fibre Raman amplification entails creating a gain medium within the transmission fibre which amplifies the signal channel before they reach the optical receiver. This has been proved over time to improve greatly the signal-spontaneous beat noise performance allowing longer transmission distances [1]. Raman amplification using the transmission fibre as the gain medium is a promising technology for the optical long haul DWDM communication system. Noise figure (NF) is the main factor which dictates the performance of any Raman amplifier. It is a measure of how much the amplifier degrades the signal [2]. If a signal is allowed to propagate along the fibre with no loss and with no amplification, then its signal to noise ratio (SNR) at the receiver end would be equal to that of the input value and its NF will be equal to one. But In practical situations, this is not possible. In fact the worst case is if the signal experiences loss during transmission and then is amplified. In such a case, a high gain is needed to amplify the signal and to attain this; the gain required from the amplifier at the end has to be increased. In order to achieve this, more pump power is required meaning more amplified spontaneous emission (ASE) noise and other noises generated in the amplifier and also the input signal power to the amplifier is decreased [3]. Lower signal power implies that the ASE noise is competing with the signal for achieving gain. These two factors combine to degrade the output SNR and increase the NF by a great factor.

2 NOISE FIGURE FORMULAE

Basically, the NF is the ratio of the SNR at the input of an amplifier to the SNR at the output of an amplifier.

$$NF = \frac{SNR_{input}}{SNR_{output}}. \qquad (1)$$

Where, SNR is defined as the ratio of signal power to noise power.

$$SNR = \frac{signals\_power}{Noise\_power}. \qquad (2)$$

In situations where two amplifiers are cascading to each other and the gain of the first amplifier is lower than that of the second one, then the NF of the system is given as:

$$NF = NF_1 + \frac{NF_2 - 1}{G_1}. \qquad (3)$$

Where, G_1 is the gain of the first amplifier, NF_1 and NF_2 is the noise figure of the first and second amplifier respectively. NF can also be defined in terms of ASE noise. In such a case, NF can be approximated by taking measurements of the noise power added by the amplifier (P_{ASE})

$$NF = \frac{1}{G}\left(1 + \frac{P_{ASE}}{E_{pH} B_0}\right). \qquad (4)$$

Where, G is the on-off gain, E_{pH} is the photon energy of the signal, B_0 is the optical band width and P_{ASE} is the noise power [4].

3 FACTORS AFFECTING NOISE FIGURE

Noise sources such as Double Rayleigh Scattering (DRS), Amplified spontaneous emission (ASE), and Relative intensity noise (RIN) are the main factors which affect the NF of a fibre Raman amplifier (FRA). These noise sources can affect both the NF and its spectrum. To begin with, ASE noise is generated as a result of spontaneous Raman scattering (SRS) during the process

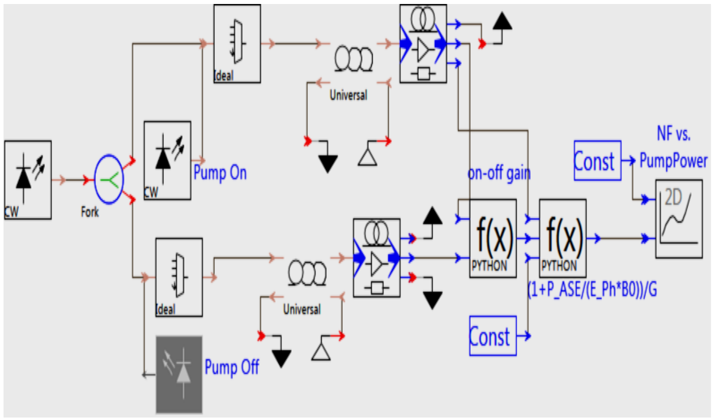
---

- G. M. Isoe, K. M. Muguro, D. W. Waswa, D.K. Boiyo
- Optical Fibre and Laser Research Group, University of Eldoret, P.O Box 1125, Eldoret-30100 Kenya
- Tel: +254-53-2063101; Fax: +254-053-43047
- E-mail: georgeisoe35@gmail.com

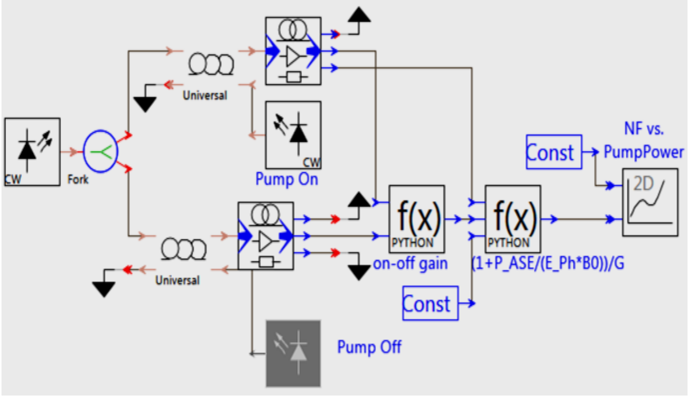
of optical amplification. This noise degrades the OSNR by adding a wider band of background noise around the signal wavelength hence affecting the general performance of any optical communication system [5]. On the other hand, Double Rayleigh scattering (DRS) is basically as a result of elastic reflections of light, due to homogeneities in the Raman fibre's refractive index that froze into glass in the process of solidification. DRS noise is proportional to both fibre length and gain. In FRA, Rayleigh backscattering of the signal can be reflected in the forward direction and experience some gain. It can also be backscattered again and again before reaching the receiver. Unlike the ASE noise, the DRS noise is distributed exactly over the same wavelength band as the transmitted signal. This makes a big challenge to filter it out hence limiting the maximum amount of Raman gain an amplifier can give as well as degrading the SNR [6], [7]. NF of a FRA can also degrade as a result of pump depletion. Pump depletion is the reduction in the transmitted pump power in a laser. In distributed Raman amplifier, the pump to signal energy transfer can lead to high effective pump attenuation. This in turn leads to a shorter pump penetration into the fibre hence degrading the NF [8]. Polarization mode dispersion (PMD) also affects the NF. PMD in optical fibres is an impairment brought about by polarization dependent delays in propagation of a signal pulse leading to pulse spreading. PMD can not only lead to inter-symbol interference, but also temporal fluctuations of the pump state of polarization (SOP). These two effects combine to limit the transmission capacity of a Raman fibre [9].

4 NOISE FIGURE BEHAVIOR FOR DIFFERENT PUMPING SCHEMES

NF changes differently with respect to fibre length and pump power for different pumping schemes i.e. forward and backward pumping schemes. When the pump power is set to propagate in the same direction with the signal, it is called forward or co-pumping. When the pump power travels in the opposite direction with that of the signal, then it is referred to as backward or counter pumping schemes.



(a)



(b)

Figure 1: *(a) and (b) diagram of a distributed Raman fibre amplifier for forward and backward pumping schemes respectively.*

Fig.1: (a) and (b) shows the simulation set up of a distributed RFA for forward and backward pumping schemes respectively using Virtual Photonics, Inc. (VPI), version 9.0. A -10dBm source signal transmitting at a wavelength of 1550nm was used while the pump wavelength was set at 1450nm. This ensured maximum amplification of the signal which in RFA occurs when the pump-signal detuning is 100 nm. The signal source and the pump were coupled using the wavelength division multiplexer (WDM) as the input coupler. Both were then propagated in a 100 km single mode fibre after which the pump wavelength was removed. The fibre was set to simulate wideband nonlinear signal transmission parameters. The signal power at the output was measured using the power meter module and the results were analyzed. The noise power at the output was also analyzed separately.

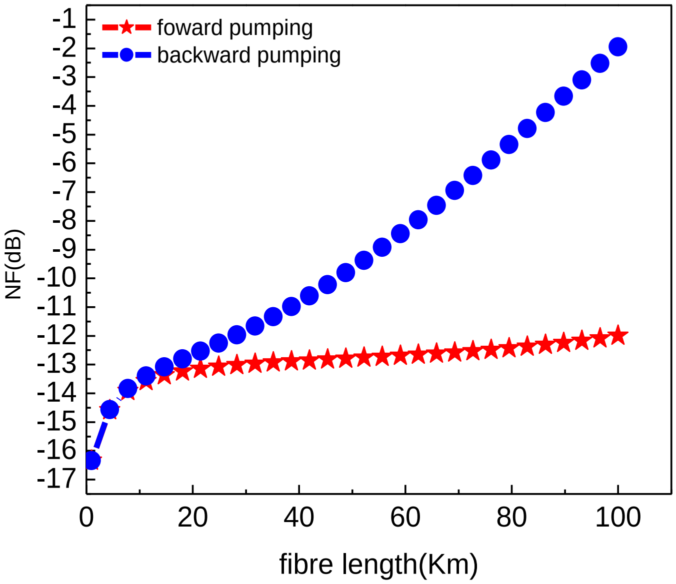


Figure 2: *Noise figure (dB) verses fibre length (Km) at different pumping schemes.*

Fig 2: shows the noise figure as a function of fibre length for forward pumping and backward pumping. It is found that at short fibre lengths < 10 Km, a low NF is obtained with no significant difference between forward and backward pumping. When the fibre length increases beyond 11 Km, there is a gradual increase in NF both for forward pumping and backward pumping with no remarkable difference between the two. Backward pumping records the highest NF at longer fibre lengths. This shows that the main contributor to noise is the back pump which transfers its pump noise to the signal. In forward pumping scheme signal power is high because input signal and pump signal are propagates in same direction. So, from definition of SNR, high signal power leads to high SNR at output and then from noise figure definition, if SNR at output is high, then Noise figure is small.

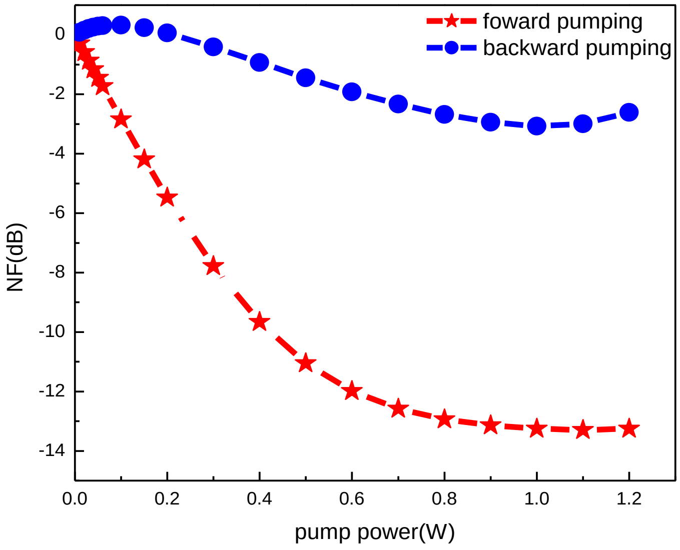


Figure 3: *Effective NF as a function of pump power at different pumping schemes.*

The above results gives the effective NF , at the receiver input terminal at a 0.2 nm bandwidth, as a function of pump power, for different pumping schemes respectively. From the above results, the NF decreases gradually in the two pumping schemes for pump powers < 0.7 W. Forward pumping provides the least NF because the Raman gain is still concentrated at the input end of the fibre where the power levels are still high, while counter pumping recorded the highest noise figure. However, at pump powers > 0.8 W, the effect of double Rayleigh scattering is seen to increase the NF as it is evident in the case of backward pumping schemes, with forward pumping suffering less from this effect. This shows that the effects of DRS noise are more evident at higher pump powers especially in the presence of a back pump and they are the main contributor of noise in Raman amplifiers.

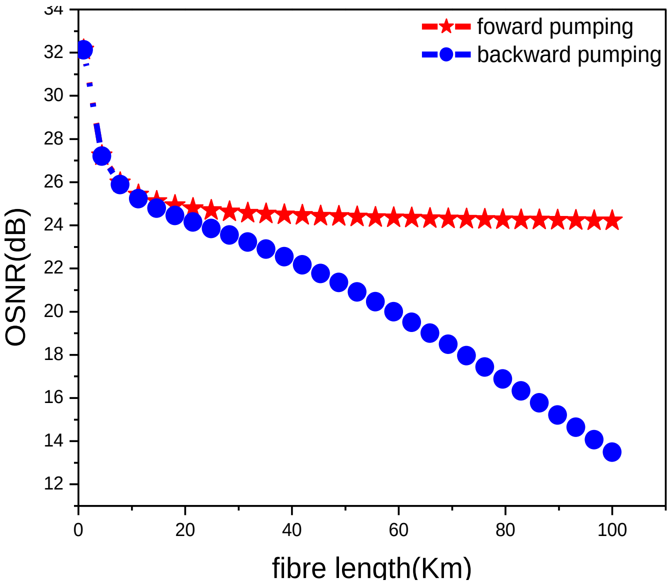


Figure 4: *OSNR (dB) verses fibre length (Km) at different pumping schemes.*

The above result shows the OSNR variations as a function of fibre length at different pump configuration. From the above figure, the OSNR reduces exponentially for small fibre lengths < 10 Km with no much difference between backward and forward pumping. This is because the signal power remains at relatively low levels throughout this link length. However, for fibre lengths longer than 11 Km, the OSNR for counter pumping reduces greatly because the back pump transfers its noise to the signal which was travelling at low amplification powers. This in turn degrades the OSNR at the fibre output to levels where further pumping will not improve it to a remarkable level. This shows that in order to maintain the OSNR at relatively higher levels throughout the transmission fibre, then it is wise to pump the signal from the fibre in put so as to limit noise accumulation as the signal travels along the fibre.

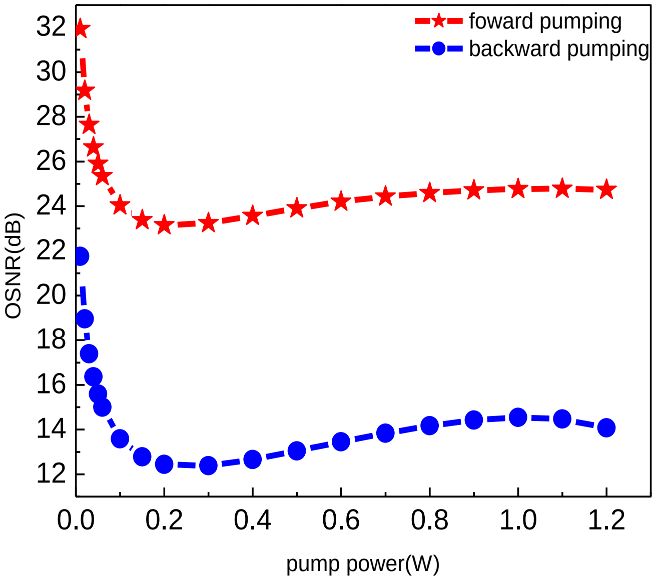


Figure 5: *Effective NF as a function of pump power at different pumping schemes.*

Above figure shows the results obtained for OSNR, for the two pumping schemes for a 0.2 nm bandwidth as measured at the output of the optical Raman amplifier. From the above results, the OSNR reduces exponentially in the three pumping schemes for pump powers < 0.1 W. This is because the pump power over this range is weak and not capable to compensate for attenuations in the signal, as it propagates through the fibre. Thus the signal power continues to decrease when the pump power is very low which resulted in decreasing OSNR.As pump power increase above 0.2 W the OSNR gradually increased in both the forward and the backward pumping scheme. The results show that forward pumping provides the highest OSNR. However at pump power beyond 1.0 W double Rayleigh scattering is seen to degrade greatly the maximum obtainable OSNR as is evident in the case of backward pumping scheme. This suggests that DRS increases when high pump powers are used in the amplification.

5 CONCLUSION

In this paper, various aspects of the Noise Figure have been investigated and explained with reference to various situations. Noise Figure for different pumping schemes has been analyzed and inferred that forward pumping scheme offers better noise performance as opposed to backward pumping scheme. Our study has also found out that Signal degradation in optical fibre during Raman amplification depends on the fibre length, pump power and the pumping scheme used. The OSNR decreases with an increase in fibre length. This decrease is significant in backward pumping than in forward pumping at longer fibre lengths. On the other hand, the NF increases rapidly for backward pumping with increase in fibre length while it showed no remarkable change when forward pumping was considered. Higher pump powers also leads to RBS noise which in turn degrade the OSNR. Backward pumping experiences the highest NF while forward pumping has the highest OSNR. From our results, RBS noise was very minimal in forward pumping hence making it superior in noise performance compared with backward pumping. We strongly recommend this pumping configuration in any long haul signal transmission systems aimed at attaining low noise levels. We would also like to recommend for an extensive research on the methods of improving the Noise Figure to be carried out especially on modern fibre which are currently used as the amplifying medium.

References

[1] I. Haxell, N. Robinson, A. Akhtar, M. Ding, & R. Haigh, “2410km all-optical network field trial with 10Gb/s DWDM transmission,” In proc.OFC 2000, mar 2000, post-deadline paper pD41-1.

[2] C. H. Kim, J. Bromage, and R. M. Jopson. "Reflection-induced penalty in Raman amplified systems." Photonics Technology Letters, IEEE 14.4 (2002): 573-575

[3] H.A. Haus, “The Noise Figure of Optical Amplifiers”, IEEE Photonics Technology letters, vol. 10, no. 11, November 1998.

[4] D. Dimitropoulos, R. D. Solli, R. Claps, O. Boyraz, Member, IEEE, and B. Jalali, Fellow, OSA, “Noise Figure of Silicon Raman Amplifiers, Journal of Lightwave technology, vol. 26, no. 7, April 1, 2008.

[5] G. P. Agrawal, Fibre Optical Communications Systems, 3rd Edition, John Willey& Sons, inc. (2002).

[6] B. Bristiel, S. Jiang, P. Gallion, and E .Pincemin, “New Model of Noise Figure and RIN Transfer in Fibre Raman Amplifiers”, ieee photonics technology letters, vol. 18, no. 8, april 15, 2006.

[7] R. G. Smith, “Optical power handling capacity of low loss optical fibre as determined by stimulated Raman and brillouin scattering,” Appl. Opt., vol. 11, no. 11, pp. 2489–2494, 1972.

[8] A. Kobyakov, M. Sauer, and D. Chowdhury (2010). Stimulated Brillouin scattering in optical fibres. Advances in optics and photonics, 2(1), 1-59

[9] C. H. Govind P. Agrawal “Raman Amplification in fibre optical communication systems”, 1st ed. Elsevier Academic Press, 2005.