Forward Raman Amplification Characterization in Optical Networks

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Abstract**—** Optical networks that apply the technology of dense wavelength-division multiplexing (DWDM) have recently resulted in a considerable increase in existing telecommunications infrastructures. They are expected to play a significant role in the next generation networks and the future Internet. This is because these networks can support a large variety of services having very different requirements in terms of bandwidth, latency, reliability and other features. The purpose of this paper is to analyze a forward Raman amplification WDM Optical Network in terms of output noise power, signal power and pump power. Results show that an increase in pump power leads to an increase in the output noise power, while a continuous increase in fibre lengths leads to an exponential drop in the output pump power which leads to an increase in the output signal power.

Keywords**—** Fibre, Raman, WDM.

I. Introduction

Optical amplifiers are major elements to any fiber-optic communication system. Even though modern optical fibers have very minimal losses, (< 0.2 dB/km) continuous amplification of the transmitted signal to its original power becomes necessary especially at longer fibre lengths [1]. The amplification process is essentially independent of the details of the spectral channel layout, modulation format or data rate of the transmission span [2], thus permitting the system operator to later re-configure these parameters without having to upgrade the amplifiers [3]. Multi-wavelength pumped Raman amplifiers (RAs) have attracted more and more attention in recent years [4]. In this type of amplification a widely used concept, for high capacity long distance wavelength division multiplexing (WDM) transmission systems was used. They have already been used in many ultra long-haul dense WDM (DWDM) transmission systems. They support high bit rate data transmission over long fiber spans, due to its benefits such as proper gain and optical signal to noise ratio (OSNR). In addition, it can be used for increasing the bandwidth of Erbium doped fiber amplifiers (EDFAs) in hybrid systems. Another important feature of RAs is its gain bandwidth, which is determined by pump wavelength. Multi-wavelength pumping scheme is usually used to increase the gain flattening and bandwidth for high capacity WDM transmission systems. In forward pumped fiber Raman amplifiers, other noise sources, such as the relative intensity noise (RIN) transfer are minimized, because this scheme can suppress the related signal power fluctuation. OSNR of this excitation is tilted, and channels with longer wavelength have longer OSNR respect to the shorter wavelength channels [5, 6].

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II. Theory

In the process of Raman amplification, the signal and pump power evolution over a given fibre length is governed by the following coupled equations;

$$\frac{dp_s}{dz} = g_R p_p p_s - \alpha_s p_s, \tag{1}$$

And

$$\mp \frac{dp_p}{dz} = -\frac{\omega_p}{\omega_s} g_R p_p p_s - \alpha_p p_p. \tag{2}$$

Where $g_R\left(\mathrm{w}^{-1}\mathrm{m}^{-1}\right)$ is the Raman gain coefficient, α_s and α_p are the signal and pump attenuations respectively, while ω_s and ω_p is the signal and pump angular frequencies respectively. The $\mp$ sign represents the backward and forward propagation of the pump wavelength respectively.

Equations 1 and 2 shows that the signal is amplified by the pump at a certain proportion, with the constant of proportionality being determined by the Raman gain efficiency, and losses as a result of attenuations in the optical fibre. Assuming that there is no pump depletion i.e. in equation 2, g_R =0, then the pump power $p_p(z)$ as a function of distance (z) in a fibre of length (L) in the forward pumping scheme p_f is given as;

$$p_f = p_p(z) = p_0 e^{-\alpha p(l-z)} \tag{3}$$

Equation 3 shows that the pump power reduces as a result of energy transfer to the signal and attenuations along the transmission fibre. In order to overcome the problem of pump depletion, the pump must be set to operate at relatively higher powers compared with the signal power.

III. RESEARCH DESIGN

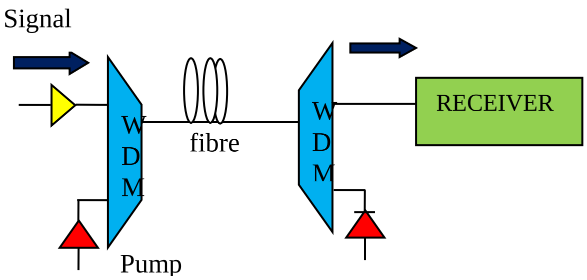

Figure 1: Distributed Raman fibre amplifier for forward pumping scheme.

Fig.1 shows the schematic representation of the simulation set up. The RFA on a forward pumping scheme was simulated using Virtual Photonics, Inc. (VPI), version 9.0. A -10 dBm source signal transmitting at a wavelength of 1550 nm was used while the pump wavelength was set at 1450 nm. 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.

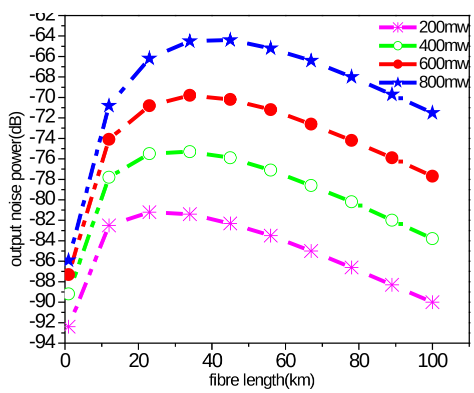

Figure 2 Output noise power (dB) as a function of fibre length.

Figure 2 shows the effect of increasing the pump power to the output noise power as a function of fibre length at different pumping schemes. For shorter fibre lengths, (< 15 Km) an increase in pump power leads to a sharp increase in the output noise power. This is because when the pump power is increased over this short transmission span, there will be more power used to transmit the signal hence more noise generated. However at longer fibre lengths,(> 20 Km) for each of the pump power, the output noise power increases up to a maximum value then continually drops as evident in the figure above. Since the pump is set to at 1450 nm, when the fibre length is increased, the silica ions will be excited to the higher energy level where their lifetime is very short (1μs). This will therefore cause an increase in the output power hence an increase in the output noise. However, after a certain fibre length the pump gets exhausted and the unexcited silica ions will result in a continuous decrease of the output power hence a continuous decrease in the output noise.

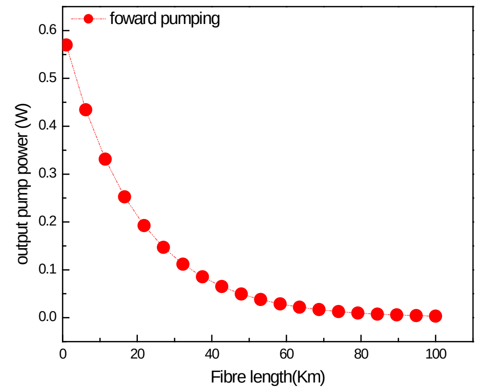

Figure 3 Variations of the pumping power against the fiber link length.

The output pump power variation against the fibre length for a forward pumping scheme is shown in Fig 3. From the figure, the output pump power reduces exponentially with increase in fibre length. This is because as the fibre length increases, there is a more contact time between the pump and the signal thus the pump transfers more of its power to the signal.

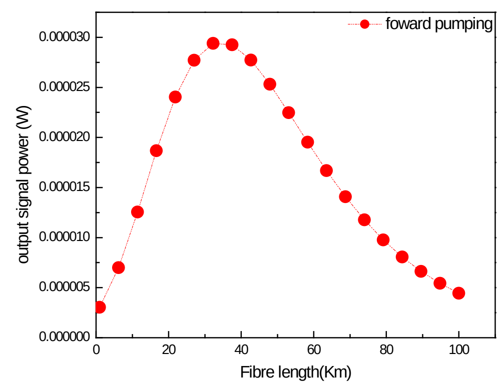

Figure 4 Variations of the signal power against the fiber link length.

From fig.4, an increase in fibre length leads to an increase in the output signal power because the signal is continuously amplified by the pump but after attaining maximum amplification, further increase in fibre length leads to a continuous drop in signal power. This is due to pump depletion. Pump depletion is the reduction in the transmitted pump power along the fibre.

IV. CONCLUSION

In a summary, a forward Raman amplification for DWDM photonic networks was characterized over a wide range of affecting parameters. It was observed that an increased fiber link length leads to the increase of both signal power and noise power, while an increase in fibre length causes a decrease in output pumping power. Also, a continuous increase in both pump power and fibre length was found to increase the noise power gradual.

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