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Modelling of an Optical Fibre Raman Amplifier

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Abstract The transmission of signals in long-haul optical fibre systems requires signal amplification. Raman amplification is based on SRS and it requires a frequency shift of 13.2 THz provided by signal and pump wavelengths of 1450 nm and 1550 nm respectively. This paper shows that Raman gain increases with the fibre length and with the gain saturating differently for different pumping configuration at different fibre lengths. A Raman gain of 30 dB was obtained using a - 20 dBm signal and a 24 dBm pump. This study is of great significance in improving the transmission capacity of long-haul systems and transmission of data with higher bit rates.

Keywords: Transmission, optical fibre communications, SRS, OFRAs.

I. Introduction

Optical Fibre Raman Amplifiers (OFRAs), based on the nonlinear effect of stimulated Raman scattering (SRS) have found application in light wave systems for compensating signal power losses in fibre. The increasing bandwidth demand in dense-wavelength-division multiplexing (DWDM) systems has also enhanced the use of OFRAs in broadband amplification [1], [2]. OFRAs have unique characteristics which include; a wide amplification bandwidth, low noise and high optical saturation power. The gain is tunable to any wavelength and signal amplification occurs during transmission in the fibre thus allowing distributed Raman amplification. Initial measurements have focused on a co-pumped scheme and simulations [3], [4]. This paper considers three pumping schemes (co-, counter and bi- directional pumping) to realize high signal gain and long-haul transmission. This paper will analyze the above areas of concern in OFRAs and give its recommendations in ensuring that high data rates and long distance transmissions are realized. This study is of great significance in improving the transmission capacity of a long-haul system and transmission of data with higher bit rates. This will contribute immensely to the ICT sector e.g. digital villages and e-learning, unlocking the economy and realization and attainment of Kenya's vision 2030 and Millennium development goals (MDGs).

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II. RAMAN AMPLIFICATION

During Raman amplification, the signal and pump power evolution over fibre length is guided by the following coupled equations [5]:

$$\frac{dP_s}{dz} = \frac{g_R}{A_{eff}} P_P P_S - \alpha_S P_S \quad \ldots\ldots\ldots\ldots\ldots (1)$$

$$\xi \frac{dP_p}{dz} = -\frac{\omega_P}{\omega_S} \cdot \frac{g_R}{A_{eff}} P_P P_S - \alpha_P P_P \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Where $P_{s,\,p}$ represents the signal and pump power, g_R is the Raman gain coefficient, $\alpha_{s,p}$ represents signal and pump loses/ attenuation and $\omega_{s,p}$ are signal and pump frequencies respectively. ξ indicate the pumping schemes of the pump; ξ=+1 for co-pumping and ξ= -1 for counter-pumping, A_{eff} is the effective core area and z is the propagation distance.

Equations (1) and (2) illustrates that the pump power provides the energy for amplification and depletes as signal power increases. As pump power approaches the signal power, the optical gain is reduced and gain saturation occurs.

The amplification gain defined as the ratio of the power of the signal with and without Raman amplification, is given by,

$$G_A = \frac{P_S(L)}{P_S(0)\exp(-\alpha_S L)} = \exp\left(\frac{g_R P_0 L_{eff}}{K A_{eff}} - \alpha_S L\right) \ldots. (3)$$

Where L_{eff} is the effective length in which non linear effects accumulate and K is the polarization factor.

III. METHODOLOGY

Fig 1 shows setup that was used.

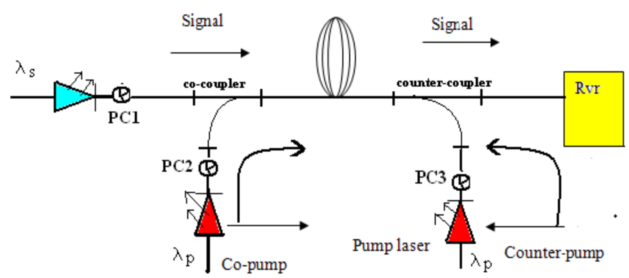

Fig 1 shows the design of a Raman amplifier

Two laser sources were used as pump signals (λ_P) with frequencies of 1450 nm while the probe signal (λ_S) was at a frequency of 1550 nm. The pump and signal were coupled together into the fibre using co-propagating or counter-propagating couplers. The states of polarization (SOPs) of the signal and the pump were controlled using a polarization controller (PC). A fork was used to separate the signal and the pump and then noise filtered using a Bessel optical filter. The gain was measured using a dual port Wavelength division multiplexing (WDM) analyzer.

IV. RESULTS AND DISCUSSION

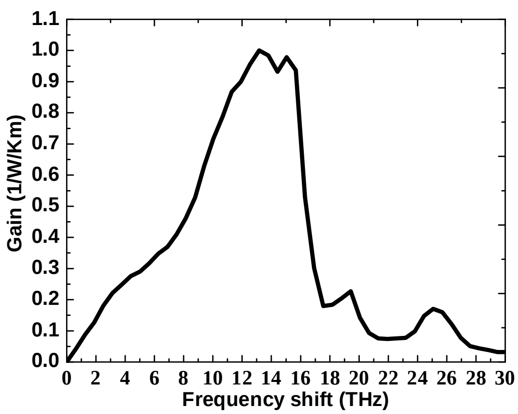

Fig 2 shows the normalized Raman gain profile

Fig 2 shows the spectrum for gain with the peak Raman gain maximum at 13.2THz which is an equivalent of frequency shift (ω_p-ω_s) of 100nm between the signal and pump frequency. This frequency shift is attributed to the non-crystalline nature of Silica glass (has inconsistent physical and chemical structure) which allows molecular vibrational frequencies produced as a result of SRS to spread out into overlapping bands and creates a continuum.

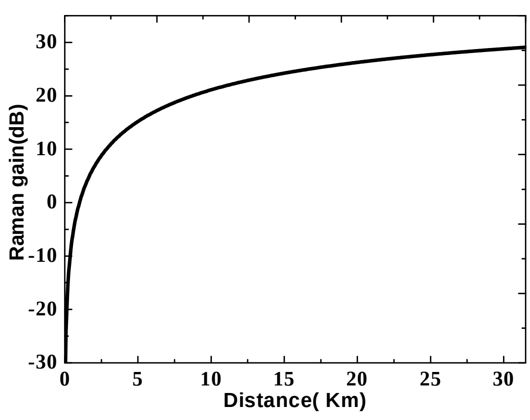

Fig 3 Attainment of a 30dB Raman gain over the total fibre length

As shown in Fig 3, Raman amplification is distributed over the fibre length with different gains at each point of the fibre. It shows that the gain contribution by Raman amplification equalizes the total power loss at the end of a passive fibre. For a 31.5km fibre, with a loss of 0.19dB/km, a total power loss of (31.5 × 0.19= 6dB) requires a Raman gain of more than 6dB to compensate for these losses. This is achieved by our model (gain of 30dB). The longer the fibre, the more coupling or interaction between the pump and the signal resulting in more pump power being transferred to the signal and therefore more signal gain. The flattening gain observed after 15km is attributed to the Raman gain being dominant over losses for shorter fibre lengths. The net gain starts to increase exponentially with fibre length, but not for longer lengths. This is due losses which accumulate in longer lengths and the net gain decreases. In between the two occurrences (after 15km), the net gain reaches a maximum and the gain curve starts to flatten.

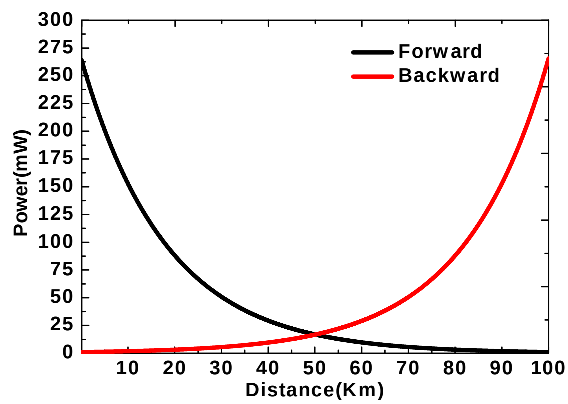

Fig 4 illustrates how pump power evolves over length for different pumping schemes (co- and counter- propagation)

Fig 4 shows the pump evolution for forward and backward pumping over a 100 km fibre. In both pumping schemes, the pump power reduces over the length. This is because of the power transfer from the pump to the weak signal to provide gain for the signal power (pump depletion). The curves for the two pumping configurations intersect at 50 km which is the middle of the total fibre span with a pump power of 12dBm. This is the case for a bidirectional pumping where the signal is pumped from both ends. Bidirectional pumping shows a balanced result in terms of noise, gain and nonlinearities which accumulate over the length of the fibre. This is because forward pumping achieves a low noise while backward pumping provides a high signal gain [6].

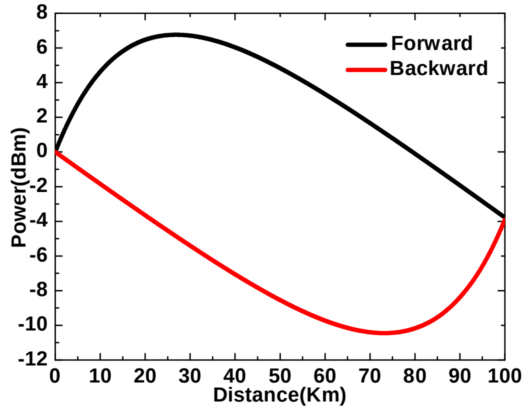

Fig 5 shows signal power evolution over fibre length

Fig 5 shows the evolution of the signal power (in dBm) with respect to the total fibre length for different pumping configurations. The curve shows a changing attenuation scheme due to the presence of Raman amplification in the fibre. Fig 5 shows that in both pumping configurations, there is a large gain due to effects of nonlinearities in the fibre, because of the power dependence of the refractive indices of the core and cladding. In the backward pumping, the minimum signal power was reached at a distance of approximately 75 km. In forward pumping, the maximum signal power was attained after approximately 25 km implying that the fibre serves a loss medium upto the point of minimum power, that the signal-to-noise ratio (SNR) becomes worse in proportion to the loss.

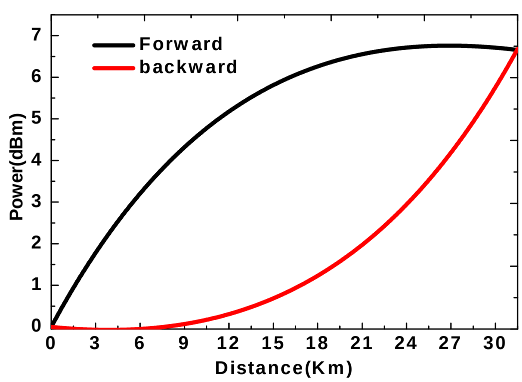

Fig 6 illustrates the Raman gain evolution over the total fibre length for forward and backward pumping configurations.

Fig 6 shows the gain evolution which was taken as the decibel difference in power of the Raman pumped fibre and the passive fibre without amplification. It shows that in forward pumping, an optimum length (approximately 26 km) exist at which the gain maximizes. The coupling results in the power being transferred from the pump to the signal leading to signal gain. It is also evident that for a specified fibre length, input pump power, and loss, the same gain is achieved over the total length for both forward and backward pumping configurations with no pump depletion.

V. CONCLUSION

In this study, we described the characteristics of a Raman amplifier as a function of fibre length for different pumping configurations: forward pumping (co-pumping), backward pumping (counter-pumping) and bidirectional pumping using two simulation tools; Optisystem and Matlab. Backward pumping provides a high Raman gain while forward gain has a lower noise. Thus a bi-directional pumping is recommended to optimize both magnitudes of gain and noise. A high signal gain has been attained for long distance transmissions.

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