Optimisation of Random DFB Raman Laser Amplifier

Paweł Rosa^{1*}, Giuseppe Rizzelli¹, Mingming Tan², and Juan Diego Ania-Castañón¹

¹*Instituto de Óptica, IO-CSIC, CSIC, Madrid, 28006, Spain*

²*Aston Institute of Photonic Technologies, Aston University, Birmingham B4 7ET, UK*

**p.g.rosa@icloud.com*

ABSTRACT

We numerically optimise 2nd-order random DFB Raman laser amplifiers for transmission for the first time. Optical signal to noise ratio, nonlinear phase shift, signal power variation and the impact of the reflectivity of FBG are investigated in the links from 10 – 120 km.

Keywords: Raman amplification, random DFB laser,

1. INTRODUCTION

In both long-haul and unrepeated links, distributed Raman amplification offers a broader bandwidth of operation and improved noise performance compared to lumped amplification. In particular, higher-order pumping can minimise the signal power variation (SPV) and reduce the effective attenuation by pushing the gain farther into the span. Optimised bidirectional Raman pumping can provide the most uniform gain within the transmission span [1] reducing the ASE noise accumulation that results in high received OSNR. However, the unavailability of low RIN high power pumps makes forward pumping in higher order Raman amplifiers problematic due to the RIN transfer from the noisy Raman laser pumps that counterbalance the benefits of distributed bidirectional amplification in transmission links [2].

A novel amplification scheme that uses a single fibre Bragg grating (FBG) at the end of the transmission span forming an open cavity with random distributed feedback (DFB) lasing allows for a form of bi-directional pumping that can significantly extend the coherent data transmission distance [3].

In this paper we investigate the performance of random DFB Raman laser amplifiers with different span lengths, FBG reflectivities and pumps powers.

2. RANDOM DFB LASER AMPLIFIER

The schematic design of the random DFB Raman laser amplifier is shown in Figure 1. To form 2nd-order distributed amplification highly depolarized Raman fibre laser pumps downshifted in wavelength by two Stokes with respect to the frequency of the signal are placed at each end of the fibre. Instead of creating a closed cavity across the span length with a pair of FBGs, a single FBG centered at 1455 nm with a 200 GHz bandwidth was deployed at the end of the transmission line to reflect backscattered Rayleigh Stokes-shifted light from the backward pump at 1366 nm and form a random DFB lasing acting as a 1st order backward pump that amplified the signal at 1555 nm. The lack of an FBG on the side of the forward pump significantly reduces the RIN transfer from the forward pump to the Stokes-shifted light at 1455 nm at the cost of a reduction in the power efficiency conversion in comparison to the 1st and 2nd order Raman amplifiers with closed cavities. This is particularly important, as forward-pumping RIN transfer from inherently noisy high-power pumps can seriously hinder data transmission [2]. In this configuration, the forward pump at 1366 nm amplifies the backward pump propagating random DFB lasing at the frequency specified by the wavelength of the FBG.

Fig. 1. Schematic design of random DFB Raman laser amplifier.

3. SIMULATIONS

To simulate each spectral component in the random DFB laser amplifier we used the well-known numerical model proposed in [1] with appropriate boundary conditions. The choice of the model was justified by the experimental measurement of the signal power distribution measured with a modified optical time-domain reflectometer (OTDR) [4] setup that shows a high degree match. The simulations are performed with the assumption that Raman pumps at 1366 nm are fully depolarized. The bandwidth of the FBG was set to 200 GHz and the noise was measured at 0.1 nm. Standard SMF-28 fibre with an attenuation of 0.19 dB/km at 1555 nm was considered.

The simulated power distribution of each component in 100 km link using random DFB laser amplifier is shown in Fig. 2. The forward and backward pump powers were optimized to give 0 dB net gain at the end of the transmission span. We may notice that the 1455 nm component is dominated by backward propagating lasing (dashed green) that amplifies the signal (solid blue) in C-band region.

Fig. 2. Numerical simulations of 0 dBm signal (solid blue) with initial OSNR of 60 dB, noise (dashed blue), forward pump (solid red), backward pump (solid green), forward lasing (dashed red), backward lasing (dashed green) and backward propagating noise (black) power evolution in the 100 km link. The noise was measured in 0.1 nm bandwidth. Forward and backward pumps were set to 1.5 W to give 0 dB net gain.

Fig. 3 shows simulated (red) results for signal power evolution at 1555 nm in 80 km link confirmed with the experimental data using OTDR (blue). We believe that the residual mismatch in front and the end of the span with the experimental data come from polarization dependent gain from not fully depolarized Raman pumps.

Fig. 3. Simulated (red) and experimentally measured (blue) signal power evolution in 80 km link.

4. RESULTS AND DISCUSSION

The contour plots of the received OSNR, total signal power variation (SPV) and nonlinear phase shift (NPS) in the links from 10 – 120 km are shown in Fig. 4. In the simulations, a single channel at 1555 nm was set to 0 dBm launch power and the forward pump was altered from 0 up to 4 W. The backward pump was adjusted with the respect to the forward pump to fully compensate for the losses in the span (0 dB net gain). The NPS was calculated according to [5]:

$$NPS = \int_0^L \gamma(z) P_s(z) dz$$

where L is the link length, P_s is the optical power along the link and $\gamma = (2\pi n_2)/(\lambda A_{\text{eff}})$. A_{eff} is the fiber effective area and n_2 is the nonlinear refractive index ($\approx 85 \mu\text{m}^2$ and $2.9 \times 10^{-16} \text{ cm}^2/\text{W}$ respectively for standard SMF).

Fig. 4. Contour plots of received OSNR (a), SPV (b) and NPS (c) in links from 10 – 120 km.

The high forward pump power prevents the signal power from dropping at the beginning of the fibre, therefore the received OSNR will increase as expected (Fig. 4a), but still most of the signal gain comes from the backward-amplified 1455 nm component, hence not much RIN is transferred from the forward 1365 nm pump to the signal. A ‘sweet spot’ for the SPV (Fig. 4b) can be found for the forward pump fixed just below 1.5 W. In the simulated fibre length range, further forward pump power increase gives negligible improvement in the SPV, while increasing the NPS (Fig. 4c) significantly. Therefore a reasonable trade-off must be applied.

To evaluate the impact of the reflectivity of the FBG at the end of the transmission span, we compare received OSNR and NPS measured at the lowest SPV that gives a reasonable trade-off between the nonlinear deprivation due to high forward pumping and accumulated ASE. As we can see from Fig. 4b there is a very little improvement in SPV for the forward pump powers above 1.5 W therefore we’ve chosen best SPV below that level for all distances. This will result in a lower total pump power consumption and more acceptable NPS in the actual data transmission system. The results for the FBGs with reflectivity of 50%, 70% and 99% are shown in Fig. 5. The received OSNR (Fig. 5a) remains the same for all FBGs, however, we may notice an improvement in NPS with the higher FBG’s reflectivity (Fig. 5c). Increased reflectivity will also result in better pump power efficiency conversion (reducing the random laser threshold and required pump power).

Fig.5. The impact of the reflectivity of the FBG on received OSNR (a) and NPS (b), measured for the lowest SPV.

5. CONCLUSIONS

A numerical optimisation of a 2nd-order random DFB Raman laser amplifier is investigated for the first time. We present contour plots of received OSNR, SPV and NPS for the distances from 10 – 120 km as a function of the forward pump power. We have found that, for standard SMF, optimal forward pump power is close to 1.5 W for the length range being studied, with backward pumping providing the rest of the required power to ensure full signal power recovery at the end of the span. The impact of different reflectivity of the FBGs on OSNR and NPS is shown to be small, with higher reflectivities being preferable in terms of both accumulated nonlinearities and pump-to-signal conversion efficiency.

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