

Impact of Front-FBG Reflectivity in Raman Fiber Laser Based Amplification

G. Rizzelli¹, Md. A. Iqbal², P. Rosa¹, M. Tan², L. Krzaczanowicz², I. D. Phillips², W. Forysiak², J. D. Ania-Castañón¹, and P. Harper²

¹Instituto de Óptica “Daza de Valdés”, CSIC, C/ Serrano 121, 28006 Madrid, Spain ²AIPT, Aston University, Birmingham B4 7ET, UK
giuseppe.rizzelli@csic.es

Abstract: We experimentally analyze the impact of front-FBG reflectivity in ultra-long Raman laser amplifiers performance, showing Q-factor penalties in excess of 1 dB for FBG reflectivities above 10% in a 30 GBaud DP-QPSK transmission system.

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1. Introduction

Using high-order Raman distributed amplification schemes based on ultra-long Raman fiber laser (URFL) architectures [1] allows very low signal power variation (SPV) along the optical fiber link, which gives a remarkable reduction of amplified spontaneous emission (ASE) noise. As a result, record long transmission distances have been reported over the past few years using different configurations of Raman amplifiers in both unrepeated and long-haul transmission systems [2,3]. In Raman amplification systems, increasing the ratio of forward pump power (FPP) to backward pump power (BPP) can limit the growth of ASE and improve OSNR, but it has the side effect of increasing the transfer of relative intensity noise (RIN) from the pump to the intermediate Stokes and co-propagating signal, potentially degrading transmission performance. M. Tan et al. have recently achieved nearly 1000 km extended reach in a 116Gb/s DP-QPSK coherent transmission system by using a random Distributed Feedback Laser (rDFB) amplifier [3] in which they reduced the RIN transfer from the FW pump to the signal by lowering the reflections at the input to close to 0% [4] at the cost of a reduced FW pumping efficiency. Here we present a detailed investigation of the phenomena occurring in the transition from an ultra-long closed cavity laser architecture to an half-open cavity random lasing regime with Rayleigh backscattering feedback. We explore the different lasing regimes that the amplifier goes through by gradually varying the reflectivity at the input end of a 2nd-order ultra-long laser Raman amplifier, and how these regimes affect the transfer of RIN and the build-up of ASE. We quantify the impact of both RIN and ASE in the performance degradation in a single-channel, 2000 km, DP-QPSK coherent transmission system.

2. Experimental setups and results

The schematic diagrams of the 2nd order ultra-long Raman laser amplifiers under investigation are shown in Fig. 1. All of them share a pair of depolarized fiber pump lasers emitting at 1366 nm, 83 km of standard SMF, a high reflectivity (> 95%) FBG at the output end centered at 1454 nm and two WDMs for the efficient coupling of the pumps and the 1550 nm signal into the same transmission fiber. The 1454 nm ports of the WDMs serve as diagnostic output for the monitoring of the first Stokes generated by the pumps at the FBG central wavelength. The left 1454 nm port can also be used to provide a controlled amount of Fresnel back reflection into the cavity.

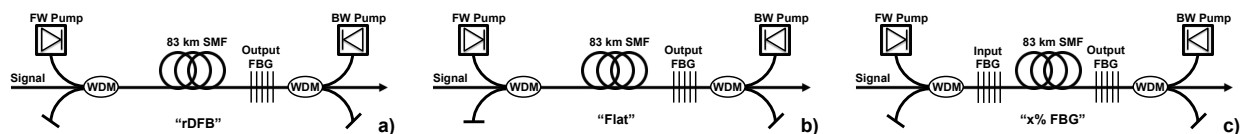


Fig.1. Schematic diagrams of the investigated schemes: a) “rDFB” (<1% Reflectivity), b) “Flat” (6% Reflectivity) and c) “x% FBG”.

Fig. 1a) shows the configuration hereafter referred to as “rDFB”: an angled (APC) connector at the 1455 nm output of the input WDM ensures that the portion of light reflected back towards the transmission fiber is close to 0%, forming a nearly perfect half-open cavity. The scheme sketched in Fig. 1b) includes a flat straight PC connector at the same port (hence the name “Flat”) which reflects back about 6% of the incident light, thus partially closing the cavity. Lastly, Fig. 1c) shows the final stage of the transition towards a closed cavity where the input FBG reflectivity has been varied from 7% to >95%. This last structure is named after the FBG reflectivity adopted.

Signal RIN has been measured by means of a low-noise photodetector and an electrical spectrum analyzer. FPP has been increased at fixed steps so as to obtain forward-to-total pump power ratios between 0% (BW only) and 100% (FW only) adjusting the corresponding BW pump power to achieve zero net gain at the amplifiers output. Fig. 2a) shows the RIN level at 10 MHz as a function of the FPP for different schemes. The inflection point where the amount of RIN transferred from the FW pump to the signal starts to increase substantially gradually shifts towards

lower FPP as the intensity of back reflections increases: the “rDFB” scheme is not affected by RIN at all, showing a reasonably flat trend for FPP up to 1.4 W, whereas the 95% FBG system, representing a closed cavity, can only endure a FPP as low as 320 mW before the RIN builds up.

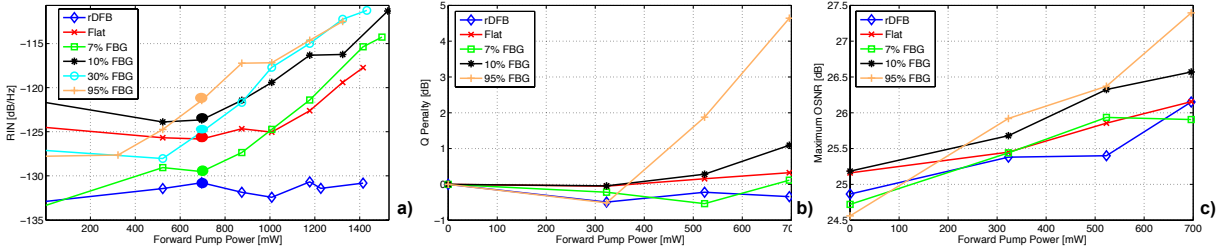


Fig. 2. RIN build-up (a), Q penalty (b) and OSNR (c) for different configurations as functions of the forward pump power.

We evaluated the test-bed performance of each scheme by measuring the Q factor and the OSNR for a single 30 GBaud DP-QPSK channel propagating in a recirculating loop. Fig. 2b) shows the Q penalty calculated as the difference between Q values at the optimal launch power for each FPP after 2007 km. The impact of RIN translates into a penalty greater than 1 dB for reflectivities above 10% and 700 mW FPP. On the other hand low back reflections allow for the use of higher FPP at nearly no cost in terms of performance deterioration. This has the twofold benefit of improving the SPV (and therefore OSNR and transmission performance as a whole) and reducing the total pump power requirement of a rDFB by about 10% when the cavity is partially closed with a PC connector or a 7% FBG. The OSNR variation as a function of the FPP is displayed in Fig. 2c) for a launch power of -1 dBm: it grows as expected with the FPP and the FBG reflectivity thanks to the improved SPV nevertheless at high FPP the RIN contribution has the greatest influence on the system leading to the worsening of the Q penalty in Fig. 2b).

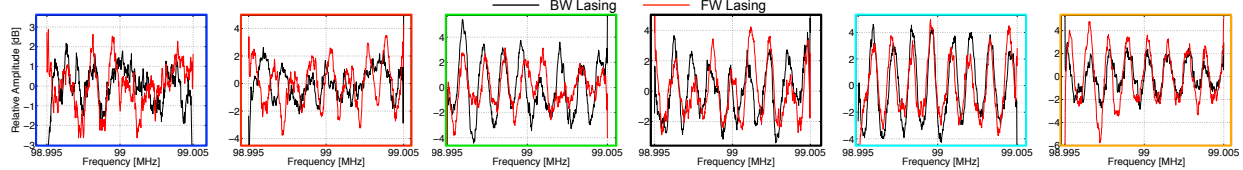


Fig. 3. Longitudinal mode structure of FW (red) and BW (black) propagating 1455 nm lasing component for the configurations shown in Fig. 2a).

The behavior depicted in Fig. 2a) is confirmed by the FW and BW longitudinal mode structure of the 1455 nm Stokes lasing component shown in Fig. 3 for a 700 mW FPP: at this FPP level the lasing at 1455 nm does not have a well defined structure yet in the “rDFB” system, which confirms the dominance of random lasing with Rayleigh backscattering feedback in the forward direction, and the lack of a seeded forward Stokes encompassing the length of the span. The absence of a 1455 nm seed that would mediate in the RIN transfer between the high-order pump and the signal allows for low-RIN operation. The “Flat” configuration begins to show signs of structure in the forward direction, whereas this structure is evident in the cases with FBG. The different RIN growth thresholds for the schemes “7% FBG” and “Flat”, which do display comparable reflectivities, showcases the effect of the reflection bandwidth: the PC connector reflects a signal which is solely filtered by the broadband WDM (60 nm bandwidth), whereas the signal reflected by the FBG is limited by its 0.2 nm bandwidth, resulting in an interesting way to increase tolerance to RIN transfer by broadening the FBG bandwidth.

3. Conclusions

We present an experimental analysis of the effect of grating reflectivity at the input end of a 2nd-order Raman fiber laser based amplifier. RIN transfer to the signal at 1550 nm, longitudinal mode structure of the Stokes component at 1455 nm, Q factor and OSNR of a single channel, 30 GBaud DP-QPSK transmission system employing such an amplification scheme have been measured varying the reflections level from close to 0% to 95%. Results show negligible RIN increment for reflectivities of up to 7% and forward pump powers below 700 mW due to the absence of well-defined lasing modes in these conditions, as well as increased FPP tolerance for lower reflectivities, at the cost of reduced conversion efficiency. For an SMF-based system, 7% is identified as the upper limit to the input side back reflections level in order to keep the Q penalty below 1 dB.

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