Evaluation of Performance Penalty from Pump-Signal Overlap in S+C+L band Discrete Raman Amplifiers

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Abstract: We experimentally investigate the transmission penalty on 30GBaud PM-QPSK signals due to adjacent Raman pumps in a 15dB gain, 150nm S+C+L-band discrete Raman amplifier. We report 4nm guard-band around the Raman pump ensures negligible Q^2-penalty. © 2019 The Author(s)

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1. Introduction

Recently, there has been a clear trend in increasing the system throughput by pushing the transmission bandwidth towards S and L bands alongside the conventional C band. The proper design and optimisation of ultra-wideband (UWB) optical amplifiers is essential for enabling ultra-high capacity transmission utilising the available bandwidth of currently deployed standard single mode fibre (SSMF) based optical networks [1]. Multi-band and seamless S+C+L band transmission have been demonstrated recently using rare-earth doped fibre amplifiers in different bands and semiconductor optical amplifiers (SOAs) respectively [2, 3]. Discrete Raman amplifiers (DRAs) also offer seamless, flat and UWB amplification using stimulated Raman scattering due to a set of multiplexed pumps [4]. However, Raman pumps overlap with the signal spectral band in Raman amplifiers with >13THz bandwidth and the fundamental Rayleigh backscattered (RBS) light creates crosstalk and even transmission penalties due to Kerr nonlinearities [5]. In DRAs, the use of smaller core area gain fibre with higher nonlinear co-efficient than SSMF could make the pump broadening and nonlinear penalties even worse [5]. These unwanted crosstalk and nonlinear effects could degrade the optical signal to noise ratio (OSNR) of the neighbouring signals requiring broader guard bands, which in turn reduces the effective transmission capacity [6].

Here, for the first time in an S+C+L band (1475-1625nm) DRA with ~15dB average net gain, we experimentally demonstrate that the transmission penalties from overlapping commercial semiconductor pump lasers (1485nm and 1508nm) depend on the RBS level and spectral linewidth of the Raman pumps. We also report that Q^2-penalty on the neighbouring 30GBaud PM-QPSK signals can be restricted to negligible level by keeping a guard-band of ~4nm around the pumps. Additionally, >4dB Q^2-penalty is measured on signals within 1.5nm of the 1508nm pump having RBS level up to the amplified signals.

2. Experimental setup

The experimental setup of the S+C+L band signal transmission through 70km of SSMF compensated by a DRA is shown in Fig. 1 (a). The input WDM signal consisted of (i) three CW lasers and a tuneable 30GBaud PM-QPSK signal in S-band, (ii) 300GHz spaced channelised ASE in C+L bands, and (iii) another CW laser at the longest 1625nm wavelength. The total input WDM signal power was 15dBm, with a very flat spectrum except the three S-band CW lasers (Fig. 1 (b)), which were limited by their maximum output power.

The transmission loss (14.3dB) from the 70km SSMF span was compensated by the dual-stage DRA. The DRA consisted of two consecutive stages of 7.5km inverse dispersion fibre (IDF), with nonlinear coefficient more than three times higher than the SSMF [7]. The eight backward Raman pumps (1365, 1385, 1405, 1425, 1445, 1465, 1485 and 1508nm) were distributed over the first and second stages in order to improve the noise figure (NF) tilt and achieve overall flat Raman gain of 15dB by reducing the strong pump-to-pump Raman energy transfer compared with conventional backward pumped single-stage DRA designs [4]. However, the 1485nm and 1508nm pumps, which are required to provide gain for the L-band signals, fall directly in the S-band part of the signal band. In Fig. 1(b), the RBS components of these pumps can be seen within the forward propagating amplification bandwidth where RBS from the 1508nm pump is as high as the amplified signal levels because of the relatively higher pump power level, and additional Raman amplification from the other shorter wavelength pumps. The pump powers used in the experiment are 305, 490, 180, 370, 330, 188, 87, and 186mW (increasing order of pump wavelengths). At the receiver end, the PM-QPSK signal was filtered out using a tuneable bandpass filter and amplified using a commercial thulium doped fibre amplifier (TDFA) before passing on to the coherent receiver where the signal was received with an 80GSa/s, 36GHz bandwidth oscilloscope and processed using offline digital signal processing.

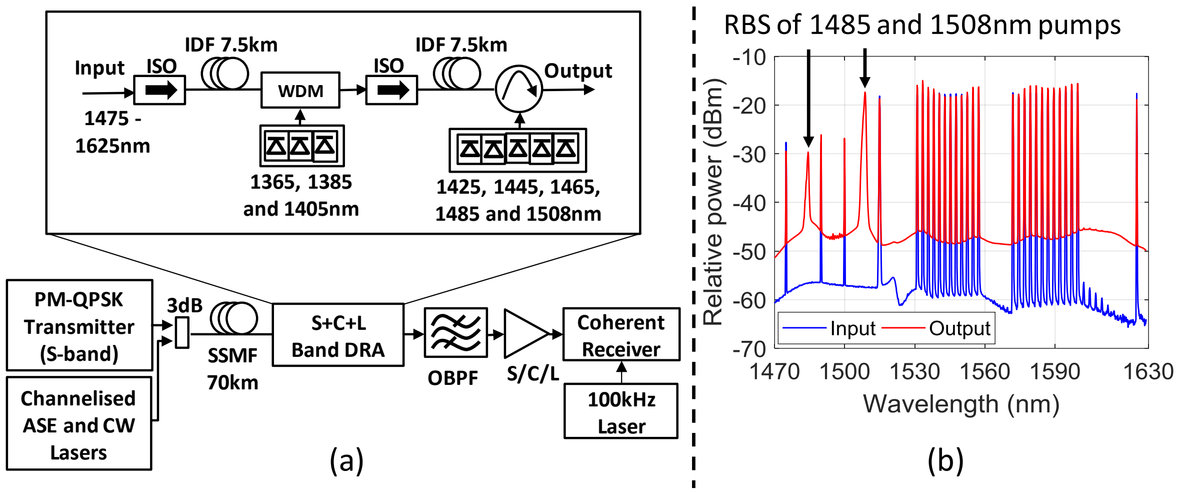

Fig. 1. (a) Transmission experiment setup using S+C+L band DRA and (b) Input to the span and output spectra from the DRA.

3. Results and discussion

The penalties on the spectrally adjacent and relatively low power WDM signals in the S-band, due to crosstalk and Kerr induced nonlinear products arising from the relatively high power counter-propagating 1485nm and 1508nm Raman pumps depend mainly on the launched power of these Raman pumps and their spectral properties. The spectra of the two overlapping pumps are shown in Fig. 2.

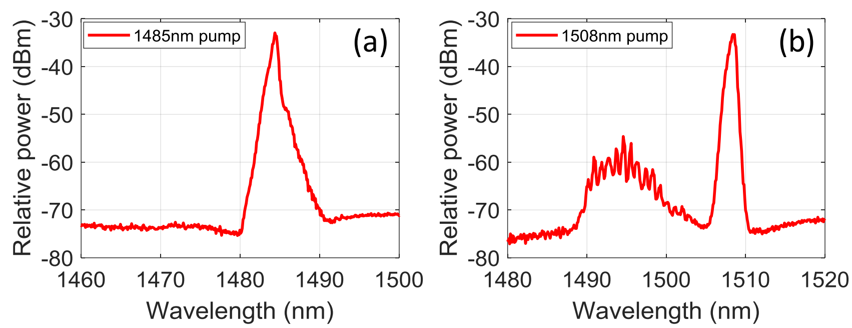

Fig. 2. Pump spectra of overlapping (a) 1485nm and (b) 1508nm semiconductor laser diode pumps.

Although the commercial semiconductor pump lasers have a typical 3dB linewidth of 1~1.5nm, the tail can be spread out by a few nanometers as shown in Fig. 2(a). Moreover, there may be significant side-lobes at different operating conditions (i.e. drive current, temperature) spectrally removed from the central wavelength, as shown in Fig. 2 (b). However, the side-lobe of this particular 1508nm pump has very low power compared with the main peak, so the RBS components from this side-lobe give rise to negligible penalty on the WDM signals, compared with the high power density main lobe.

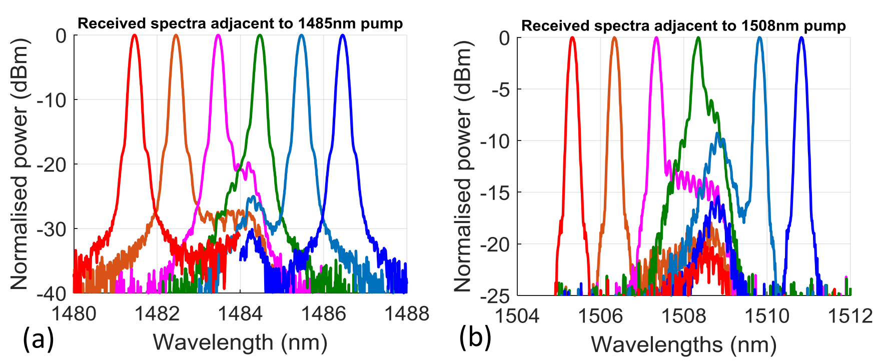

Fig. 3. Filtered received PM-QPSK signal spectra at different wavelengths with respect to (a) 1485nm and (b) 1508nm pump wavelength.

Spectra of the received and filtered PM-QPSK signals adjacent to the two overlapping pumps at 1485nm and 1508nm, are shown in Fig. 3(a) and (b), respectively. It can be clearly seen that the received signal OSNR degrades as the signal moves closer to the pump, and that the signals adjacent to the 1508nm pump suffer greater interference than those adjacent to the 1485nm pump, which we attribute to the relatively higher 1508nm launch pump power leading to >13dB RBS level in comparison (Fig. 1(b)).

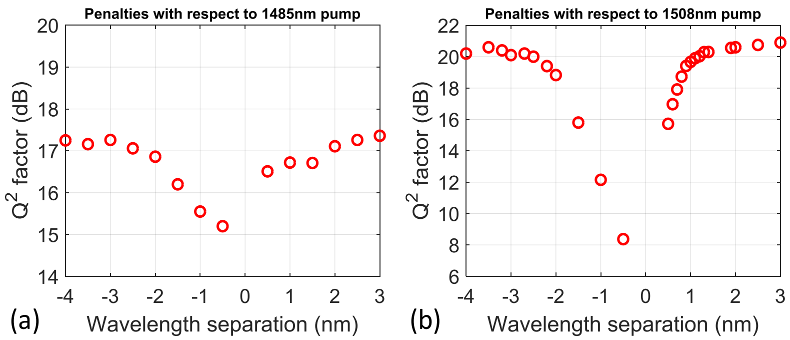

Fig. 4. Q^2 factors after 70km span vs wavelengths separation from the overlapping pumps: (a) 1485nm and (b) 1508nm.

The Q^2 factors were measured for a range of S-band signals adjacent to the 1485nm and 1508nm pumps until there was no significant penalty from the pump induced crosstalk, as shown in Fig. 4(a) and (b) respectively. The average back-to-back (B2B) Q^2 factors for the PM-QPSK signals in 1482-1488nm and 1504-1511nm wavelength regions were 19.3dB and 21.3dB respectively. The additional penalties from the B2B performance around the 1485nm pump compared to the 1508nm were due to the lower OSNR of the transmitted signal and additional nonlinear penalties through the first stage of the DRA [7]. It is clear from Fig. 4 that the Q^2 penalties on signals adjacent to the 1508nm pump are more significant than those in the vicinity of the 1485nm pump, which is consistent with the lower OSNR penalties and lower level of RBS shown in Fig. 1(b) and Fig. 3. A significant >4dB Q^2 penalty is observed within 1.5nm of the 1508nm pump, whereas the Q^2 degradation is limited to only 1dB within the same vicinity for 1485nm pump mainly due to the 13dB lower level of RBS. It is also clear that almost no penalty can be observed on the signals which are >±2nm apart from both the pumps. Consequently, for the specific semiconductor laser diode pumps used in this experiment (Fig. 2), a minimum of 4nm guard band should be retained around the pump and modulated signals in order to obtain negligible penalty from crosstalk and Kerr nonlinearities in the 150nm S+C+L band DRA under study.

4. Conclusion

We have experimentally investigated the penalty from overlapping Raman pumps within the signal band in a practical DRA with >13THz bandwidth. We have shown that crosstalk penalty from the overlapping pumps depends mainly on the spectral linewidth and the power level of the Rayleigh backscattered light of the pumps. In an S+C+L band DRA with 15dB gain, >4dB Q^2 penalty was observed from adjacent conventional semiconductor laser diode pumps within 1.5nm, with RBS level as large as the amplified 30GBaud PM-QPSK signals. Moreover, a 4nm guard band around the pump wavelength ensures negligible Q^2 penalties. Therefore, guard bands between the overlapping pumps and modulated signals must be designed in UWB DRAs using conventional semiconductor pumps, carefully considering the trade-off between overall effective bandwidth and minimum crosstalk penalty.

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