Transmission Performance Improvement Using Broadband Incoherent Counter-Pumped Distributed Raman Amplification

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Abstract: We propose a novel dual-order counter-pumped distributed Raman amplification technique using broadband incoherent 1st-order pump to suppress RIN transfer and improve Q-factor and transmission reach by 0.3dB and 833km respectively compared with conventional narrowband pumping.

OCIS codes: (060.4510) Optical communications; (060.2320) Fibre optics amplifiers and oscillators;

1. Introduction

In this paper, we experimentally demonstrate a novel dual-order counter pumped distributed Raman amplification (DRA) technique using a broadband 1st-order pump to mitigate relative intensity noise (RIN) transfer even in counter-pumping and improve transmission performance compared with conventional Raman amplifiers.

DRA shows better optical signal to noise ratio (OSNR) than conventional lumped amplification i.e. erbium doped fibre amplifier (EDFA) [1]. Although bidirectional DRA provides improved OSNR counter-pumping is preferred in long-haul transmission system to avoid the fundamental problem of RIN transfer from co-pump(s) to signal [2]. The signal RIN penalty is very low in counter-pumping DRA due to the averaging over longer span length and lower cut-off frequency of the RIN transfer function [3]. However, this small amount of RIN transfer over 10-100s of kHz from high power and high RIN pump(s), can still limit the transmission performance.

In this paper, we present a dual-order counter-pumping scheme which uses an incoherent broadband 1st-order pump. This pump improves the ASE noise performance by distributing the gain further into the amplifier span and suppress the signal RIN penalty by mitigating the evolution of RIN transfer from higher order 2nd-order pump to signal. Here, the dual-order counter-pumping consists of a 1365nm 2nd-order fibre laser and a broadband 1455nm 1st-order seed, generated using Rayleigh scattering. We show that, the use of inherently depolarized 1st-order broadband pump allows improved transmission performance by reducing the signal RIN penalty compared with conventional 1st-order Raman pumping schemes which use low RIN semiconductor pumps or random fibre laser (RFL) pump with narrow bandwidth profiles. In a 10×120Gb/s DP-QPSK wavelength division multiplexed (WDM) system, our proposed pumping scheme extends the transmission reach up to 7915km with 833km transmission reach improvements compared with conventional Raman pumping schemes. In addition, the use of such broadband pumping can provide a flatter gain spectrum, which reduces the number of pumps required in broadband (i.e. C and L band) transmission.

2. Experimental setup and distributed Raman span characterization

We investigated three dual-order counter-pumped DRA schemes with ~83km standard single mode fibre (SSMF) which include a commercially available depolarized 1365nm Raman pump laser with -113dB/Hz RIN as 2nd-order counter-pump and different 1st-order sources: random fibre laser (RFL) based pump (scheme-1), proposed broadband pump (scheme-2) and commercial semiconductor pump (scheme-3) as shown in Fig. 1(b-d) respectively. In scheme-2, the broadband 1st-order pump seed at 1455nm was generated by counter-pumping a separate 10km SSMF by another 2nd-order 1365nm pump at 3.5W power in an open cavity configuration [4]. This 1st order seed was then amplified with the residual 1365nm pump to launch 20mW of 1455nm broadband pump into the main amplifier span. The length of SSMF in the broadband seed generation section was optimized for efficient generation of stable 1455nm broadband pump power. The 3dB bandwidth and RIN level of the pump were measured as ~12nm and -132dB/Hz respectively. In scheme-3, two 1455nm semiconductor laser diodes with 0.8nm 3dB bandwidth and -135dB/Hz RIN were depolarized through a polarization beam combiner (PBC) and used as 1st-order pump as depicted in Fig. 1(d). The 1st-order pump in scheme-2 and 3 was combined with the 2nd-order 1365nm pump and then to the amplifier span through a 3×1 WDM coupler. An isolator was also used at the 1455nm pump output to restrict the back-propagated pumps. Fixed 20mW and 1W powers of 1st and 2nd order counter-pumps were used respectively in both scheme-2 and 3 to maintain 0dB net loss across the ~83km Raman span.
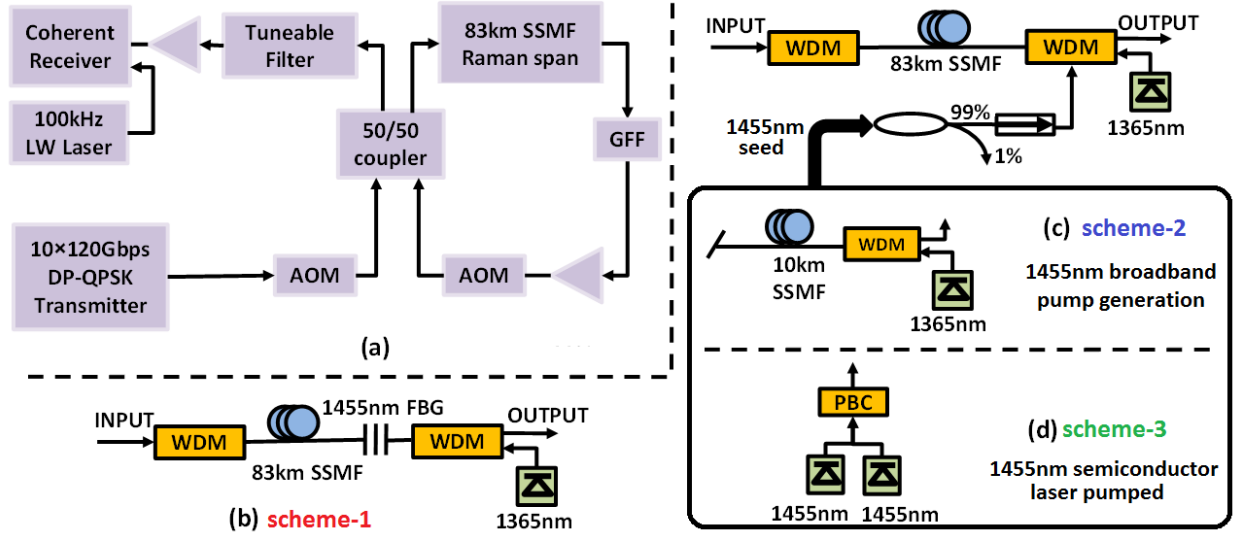
Fig. 1. (a) Coherent transmission experiment setup in a recirculating loop with 83km DRA span; and different dual order counter-pumped only distributed Raman amplification schemes consisting of a 2nd order 1365nm pump and a 1st order 1455nm pump based on: (b) random fibre laser (RFL) using a FBG; (c) proposed broadband pump and (d) semiconductor laser didoes.

Fig. 1(b) shows a RFL based dual order pumping (scheme-1) including a 1365nm pump and a fibre Bragg grating (FBG) centred at 1455nm (95% reflectivity and 0.5nm 3dB bandwidth). The RFL at 1455nm was formed in a distributed cavity created by the Rayleigh scattering and feedback from FBG [5,6] and the measured 3dB bandwidth and RIN level were 0.6nm and -115dB/Hz respectively. A 1365nm pump power of 1.1W was required to overcome the lasing threshold and maintain 16.5dB Raman on-off gain.

Comparisons of the spectral properties and RIN levels of different 1st-order pumps are shown in Fig. 2(a) and (b) respectively. The proposed broadband pump bandwidth is much wider (> 10 times) than the other two schemes as shown in Fig. 2(a). In Fig. 2(b), semiconductor pump shows the lowest pump RIN level (-135dB/Hz). Broadband pump also has similar RIN (-132dB.Hz), whereas RFL pump shows >15dB increased RIN compared with others.

In order to verify the impact of RIN transfer in all the schemes, we maintained similar signal power profiles for all to ensure equal ASE noise performance. The signal power profiles were measured at 194THz (1545.32nm) signal. The pump powers used here provides similar profiles with 5.8~6dB SPVs across all three counter-pumped DRA schemes as shown in Fig. 2(c).

In these dual-order counter pumped DRAs, the main RIN transfer to the signal comes from the high RIN 1365nm fibre laser. So the highest RIN transfer is expected from scheme-1 with both the high RIN 1st and 2nd-order pumps. First order semiconductor pumps based scheme-3 has the lowest 1st order pump RIN (Fig. 2(b)) but narrow bandwidth profile still allows some RIN transfer from 2nd-order 1365nm pump to signal. In scheme-2, the broadband incoherent 1st-order pump also has similar RIN as semiconductor pump, but RIN from higher order pump gets distributed over the wide bandwidth of 1st-order pump and averaged out due to the four-wave mixing effects, which subsequently ensures the lowest overall RIN transfer to the signal.
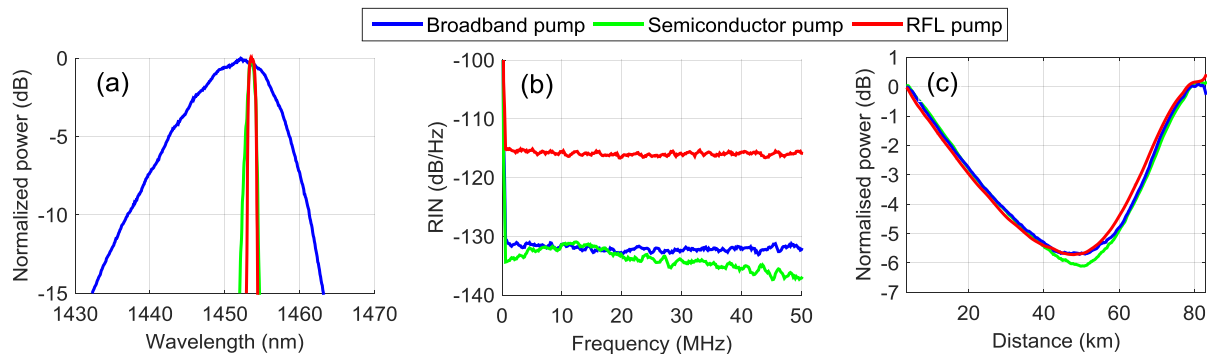

Fig. 2. Comparisons of: (a) 1st-order pump spectra; (b) 1st-order pump RIN; (c) signal power profiles along the amplifier span.

3. Transmission results

A long-haul coherent transmission setup in a recirculating loop with different dual-order counter-pumped DRA schemes is shown in Fig. 1(a). A typical 120Gb/s DP-QPSK transmitter was used with ten 100GHz spaced (193.4~194.3THz) WDM signals, combined with a tuneable 100kHz external cavity laser (ECL) as "channel under test". The total distributed Raman span loss was ~17.6dB including 16.5dB from ~83km SSMF and 1.1dB from the pair of pump/signal combiners at each end. The additional ~12dB passive loop loss from the gain flattening filter (GFF), acousto-optic modulator (AOM) and 50/50 coupler was compensated by a dual-stage EDFA at the end. In the standard polarization diverse coherent receiver, signal was first filtered out with a band pass tuneable filter and amplified by an EDFA before passing into an 80GSa/s, 36GHz bandwidth oscilloscope. Offline digital signal processing (DSP) was used to post-process for the linear impairments and Q factors were calculated from the actual bit-error rate from 2 million bits. A Q-factor of 8.5dB is also considered as a HD-FEC limit for maximum distance.
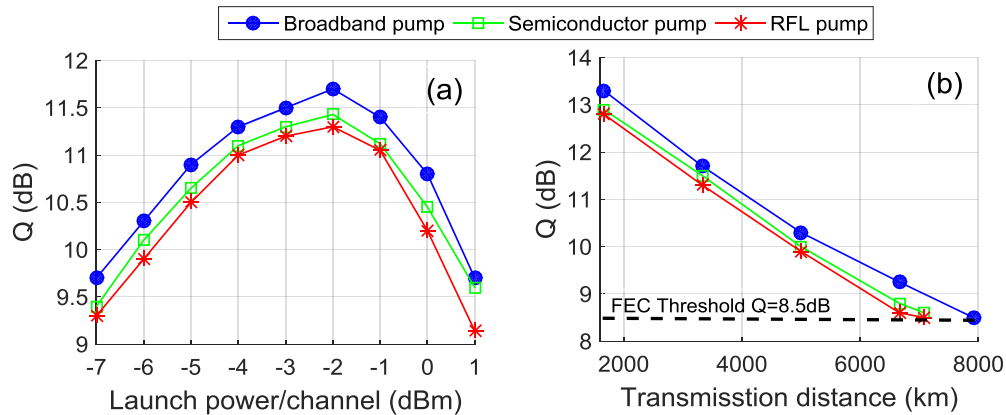

Fig. 3. Transmission performance comparison: (a) Q-factors vs. launch power per channel (dBm) at 3333km and (b) Q-factors vs. transmission distance at optimum launch power for different schemes measured for the centre WDM channel 194THz (1545.32nm).

Fig. 3(a) and (b) shows the Q-factors versus signal launch power per channel and Q-factors versus transmission distance at optimum launch power respectively measured for the middle WDM signal at 194THz (1545.32nm) in three different dual-order counter-pumped schemes. The proposed scheme-2 shows the maximum Q-factor of 11.7dB at optimum launch power per channel (-2dBm) with an improvement of 0.3dB and 0.4dB compared to conventional scheme-1 and 3 respectively. As all the schemes have similar signal power profiles as shown in Fig. 2(c), a similar noise performance is expected for all. However, a similar Q-factor enhancement in both linear and nonlinear regime proves the resulted improvement, due to the mitigation of signal RIN penalty in scheme-2. The RFL based scheme-1 shows the worst Q-factor of 11.3dB at optimum launch power for the highest signal RIN penalty, whereas scheme-3 performs slightly better (0.1dB) than scheme-1. In Fig. 3(b), the proposed scheme-2 provides maximum transmission distance up to 7915km with 833km reach extension compared to similarly performed (~7082km) scheme-1 and 3 considering an HD-FEC threshold of Q = 8.5dB. Q factors and received spectra at maximum transmission distances for all the Raman configurations are available at the conference.

4. Conclusion

We have demonstrated that, using only a 20mW incoherently broadband seed in a dual-order counter-pumped DRA can significantly reduce the RIN transfer from higher order pumps to signal. This allows a minimum of 833km transmission reach extension compared with conventional dual-order Raman counter-pumping schemes based on widely deployed low RIN semiconductor laser and cost-effective FBG assisted random fibre laser. Such broadband pump can provide flatter and wider gain spectrum which is useful and cost-effective for broadband transmission.

References

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