210 nm E, S, C and L Band Multistage Discrete Raman Amplifier

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Abstract: We demonstrate a multistage Raman amplifier for 210 nm signal amplification with 15 dB gain and 8.1 dB maximum noise figure enabling ESCL-band transmission with 10 Gb/s NRZ signals over 70 km SMF. © 2022 The Author(s)

1. Introduction

The unprecedented growing data demand for the last two decades has led the scientific community to strategize new methodologies for upgrades in current optical networks. One promising technology that has attracted significant attention in recent years for such system upgrade, enabling high data transmission within the existing fibre infrastructure, is multi-band transmission (MBT) [1]. However, a major challenge that lies ahead for future MBT networks is the optimized design and development of optical amplifiers [2]. Experimental demonstration with rare-earth doped fibre amplifiers in the O-E band and hybrid Raman/semiconductor optical amplifiers for S, C, L-band amplification has been previously reported in [3] [4]. In addition, S, C, L-band signal amplification solely with Raman amplifiers has also been reported in [5].

In this study, we demonstrate a ~210 nm bandwidth multistage discrete Raman amplifier (DRA) with signal amplification from 1410-1620 nm. The multi-stage architecture was adopted to minimize pump-to-pump and pump-to-signal overlap over the entire spectral range. Our experimental results show an average gain of 15 dB with a maximum noise figure (NF) of 8.1 dB. Transmission validation was performed with 156x100 GHz spectrally shaped channels combined together with a 10 Gb/s non-return-to-zero (NRZ) modulated test channel over a 70 km long single mode fibre (SMF), showing a maximum power penalty (difference in received power between back to back and 70 km transmission) of 1.7 dB at a BER of 10^{-4}.

2. Multi-stage Raman amplifier setup and characterization

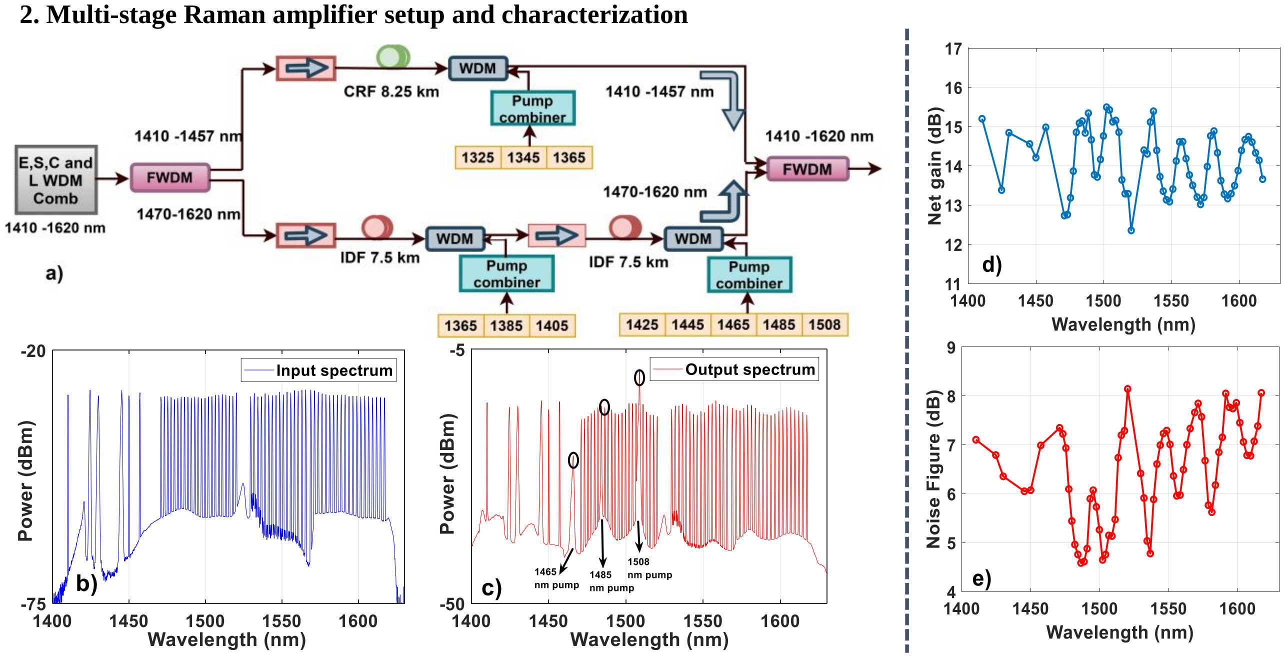

Fig. 1. a) Schematic of multi-stage Raman amplifier, b) input spectrum, c) output spectrum, d) net gain, e) noise figure.

The experimental setup for the multistage amplifier characterization can be seen in Fig. 1a). The setup includes a split-combine approach in which signals from 1410-1620 nm are segregated into two spectral bands using a commercial WDM filter with one band comprising 6 amplified spontaneous emission (ASE) channels from 1410-1457 nm and the other band comprising 60 ASE channels ranging from 1470-1620 nm. The first band was amplified using an 8.25 km length of speciality nonlinear Raman fibre developed by Corning, hereafter known as Corning Raman fibre (CRF) [6][7], with 1325, 1345 and 1365 nm pumps in a backward configured DRA and pump power values of 510, 235 and 245 mW, respectively. The second band was amplified in two stages using so-called inverse dispersion fibres (IDFs) of 7.5 km length in each stage. The pump wavelengths were 1365, 1385, 1405, 1425, 1445, 1465, 1485 and 1508 nm, with pump power values of 540, 317, 249, 375, 258, 166, 63, 210 mW, respectively. The distribution of pumps over the two stages for the S, C, L-band, rather than a single stage, was primarily chosen to minimize pump-to-signal overlap and to improve the S-band NF with an optimal value of 15 dB gain. Guard bands of +/- 2nm were adopted between the signals and 1485 nm and 1508 nm pumps to minimize crosstalk between the Rayleigh back scattered (RBS) pumps and WDM signals, a technique, as described in [8].

Fig. 1b) and 1c) shows the input and output spectrum of the tested 66 ASE channels. The net gain profile with a maximum gain ripple of ~3.2 dB across the entire bandwidth is shown in Fig. 1d) and its corresponding NF can be seen in Fig. 1e). An average gain of 15 dB with a maximum NF of 8.1 dB was observed across the entire bandwidth of 210 nm. The NF for E-band signals comprising of 6 ASE channels from 1410-1457 is observed to be in the range of 6 to 7 dB. However, in a fully loaded E-band grid, we expect a slight increment in the NF due to increased power spectral density. The overall shape of the NF in the S, C, L-band is due to the dual-stage architecture adopted here, resulting in lower values for S band up to 1520 nm because of first stage amplification. Similarly, an increase in the NF is seen from 1530-1620 nm across C and L-bands due to excess loss in first stage and reduced pump to-pump energy transfer in the absence of suitable pumps for the first stage C and L-band amplification [5].

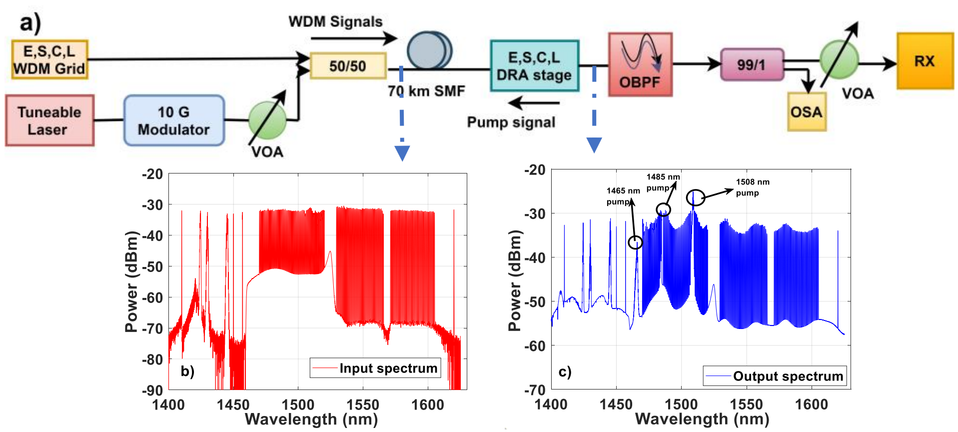

Fig. 2. a) 10 Gbit/s NRZ transmission experimental setup, b) input spectrum, c) output spectrum

3. Transmission setup, results and discussion

The ultra-wideband transmission setup is shown in Fig. 2a). The transmitter section comprises a 10 Gb/s NRZ modulated signal with a PRBS length of 2^{31} -1 combined with WDM spectrally shaped ASE channels using a 3-dB coupler. The WDM spectrum comprises a 100 GHz-spaced 50 GHz spectrally shaped ASE channels in the S, C, L-band and 6 independent channels in the E-band of which 3 channels were generated using diode lasers of ~2 nm linewidth at wavelengths of 1425, 1431 and 1444 nm, and 3 other channels with tunable laser sources fixed at 1410, 1450 and 1457 nm. Altogether, the entire spectrum comprises 156 ASE channels extending from 1410 to 1620 nm. The S- band channels (1470-1520 nm) were generated using a supercontinuum source and a commercial waveshaper (WSS) for channel spacing and flattening followed by a thulium doped fibre amplifier (TDFA). These S-band channels were combined together with a flat channelized C and L-band ASE spectrum extending out to 1608 nm, generated using C and L-band EDFAs and two WSSs for equalization. A tilt in the ASE spectrum in L-band was observed when the channels were fully loaded up to 1620 nm hence, a separate channel using a tunable laser source was added at 1620 nm to validate our transmission bandwidth of 210 nm. The total power to the fibre input section was 16.2 dBm with a power per channel of -5.8 dBm. The transmitted signals were then passed through 70 km of SMF with an average span loss of 14.8 dB compensated using the multistage DRA. The input and output spectrum of the WDM signals can be seen in Fig. 2b) and 2c). The three peaks seen in the S-band output spectrum (circular marker) are the RBS spectrum of the 1465, 1485 and 1508 nm pumps. The receiver section comprises an optical band pass filter (OBPF) for selection of the modulated signals which was then passed through a 99/1 tap whose 1% was used to measure the received OSNR, with the remaining 99% passed to a VOA for received power (Rx) sweep. The output from the VOA was measured using a commercial 10G receiver for bit error rate (BER) estimation.

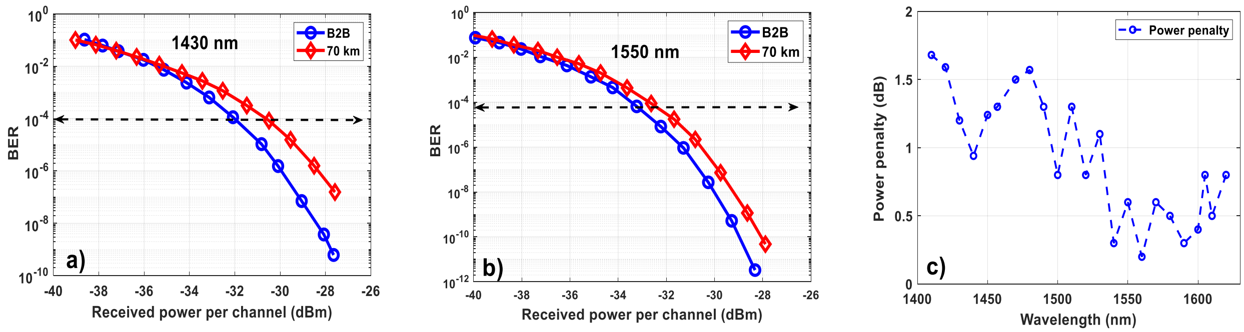

Fig. 3. BER vs received power per channel, a) 1430 nm, b) 1550 nm transmission, c) power penalty vs wavelength.

The 10 Gb/s NRZ transmission performance was measured at intervals of 10 nm extending from 1410-1620 nm. Fig. 3 (a-b) shows the BER vs received power for 1430 nm and 1550 nm signals to compare the performance of E-band signals with conventional C-band signals. A clear degradation in the back-to-back (B2B) performance (blue curve with circular markers) was observed for 1430 nm signals in comparison to 1550 nm signals due to the transceiver, and particularly modulator, limitations in the E-band region. The transmission performance after 70 km SMF + DRA stage was observed to have a larger degradation at 1430 nm in contrast to C-band signals at 1550 nm, showing the receiver limitation, with lower sensitivity towards the lower wavelength region. Fig. 3c) shows the power penalty vs wavelength at a BER level of 10^{-4}. The power penalty is seen to be larger for E-band and S-band signals with a maximum value of 1.7 dB at 1410 nm. This increase in power penalty despite the lower NF towards E and S-bands can be largely attributed to additional nonlinearity and slightly lower transmitted and received OSNR for the lower wavelength signals [5]. These values can be minimized by further optimization of the Raman gain fibre length and by introducing a dual stage architecture with appropriate pumps for the E and S-band stages [9] [10].

4. Conclusion

We experimentally demonstrated 210 nm signal amplification with a multistage discrete Raman amplifier enabling signal transmission from ~1410-1620 nm. Our multistage amplifier shows an average gain of 15 dB and a maximum NF of 8.1 dB within a gain ripple of ~3.2 dB across the target bandwidth. WDM transmission with 156 ASE channels combined with 10 Gb/s NRZ modulated signals shows a maximum power penalty value of 1.7 dB at a BER level of 10^{-4} indicating that such a DRA is a potential candidate for ultra-wideband signal transmission.

5. Acknowledgement

The authors thank Corning Incorporated for provision of the CRF. This work was supported by EU H2020 under Marie Sklodowska Curie grant agreement no. 814276 and EPSRC grant EP/V000969/1.

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