Novel Design of Very Long, High Capacity Unrepeatered Raman Links

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Abstract *An L-band Raman link concept is analyzed numerically and validated experimentally by transmission of 10×43 Gb/s DPSK channels over 466 km and 82 dB loss, a record capacity for UR links longer than 400 km.*

Introduction

Following the trend in terrestrial optical networks, the 43 Gb/s RZ- and NRZ-DPSK modulation formats are also becoming a preferred WDM signal choice for very long unrepeatered (UR) systems. Ironically, in terms of capacity X distance, the best results to date were achieved with 12.5 Gb/s RZ-DPSK signals[1]. It appears that in ultra-long UR systems, the 10 Gb/s transmission rate is advantageous to 40 Gb/s, even if a large area pure silica core fiber (110μm^2 PSCF) and very strong Raman pumps were used[2]. Hence, it is relevant to research alternative designs with a goal to match or surpass the “12.3 Gb/s results” by transmitting WDM DPSK channels at 43 Gb/s rate.

Design

The proposed approach differs from the traditional UR link designs in a number of methods:

- L-band link implementation with EDF ROPA where the lower efficiency relative to the C-band is offset by more efficient Raman gain and a lower fiber attenuation.
- Raman induced WDM signal tilt is complemented with ROPA L-band gain slope, thus achieving a wider bandwidth[3] than in traditional UR systems.
- Design of Raman pumps with multiple laser diodes to form a low noise, broadband 3W power source suitable for both counter- and co-propagating Raman pumping.
- Very low signal launch power (typically -18 dBm/ch) to prevent early saturation of the forward pumps.
- Placement of a short segment of large area core fiber (A_{eff} =115μm^2) in order to mitigate the Kerr induced impairments on the DPSK signal.

For simplicity, we only present the scenario with large A_{eff} core fiber segment placed at the transmit end region of the highest signal power. It can be shown, that the link would also benefit of an equal segment placed symmetrically, at the receiver end.

Analysis

An extensive numerical simulation was performed for a variety of link architectures. Standard PSCF (A_{eff} =76μm^2) was used for the modeling and the experiment. It’s average attenuation including lumped splice losses was 0.174 dB/km, a value typical for cabled and installed PSCF. For the short segment of large effective core area fiber we used Sumitomo Z+

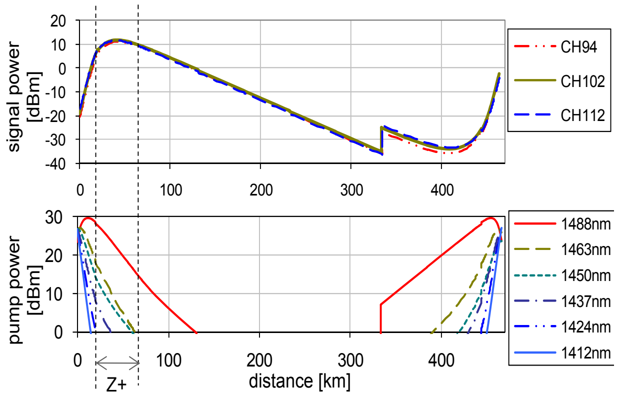

Fig. 1: Signal and Pump power distribution with 43 km of Z+ segment and 2.6 W of total pump power

fiber. The individual pumps were optimized by wavelength and by power for a given link architecture.

Numerically computed pump power and signal power distributions along the line are shown in Fig.1. The results are for the 468-km link example, designed for the purpose of experimental validation within the limits of hardware availability.

For comparison, Fig. 2 shows results for a case where the Z+ segment is 20 km longer than in the previous case, starting at the very beginning of the 468-km line. For the same OSNR as in previous example, the forward pumps need to be 19% stronger than before, and yet the signal peak power in fiber is about 2 dB less than in previous example due to a better distributed gain in forward direction. This allows the total forward pump power to be increased to about 3.2 W without compromising the signal by nonlinear penalties, and thus extending reach and capacity.

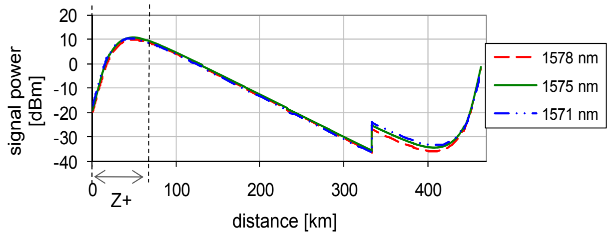

Fig. 2: Signal power distribution for 63 km of Z+ segment and 3.2W of total pump power

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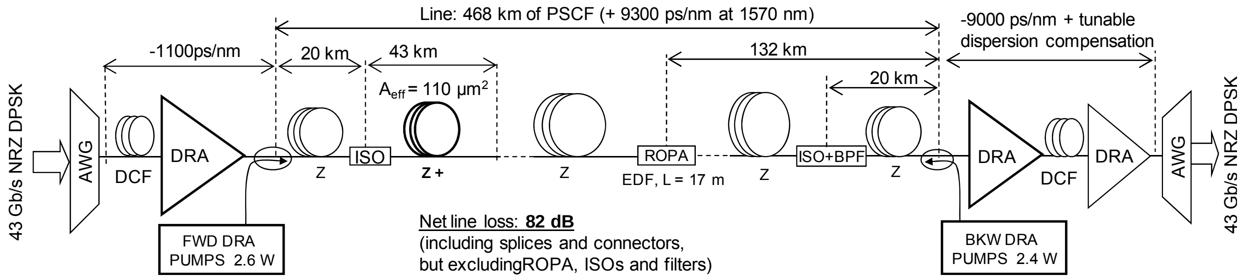

Fig. 3: Experimental System Setup

Experiment

The setup in Fig.3 corresponds to the first design example discussed above (Fig. 1). The line fiber loss, including high-power equipment connectors, was 82 dB @1550nm. The large area core fiber segment (Sumitomo Z+, A_{eff} = 110 µm^2) was placed between 20 km and 63 km from the transmitter to reduce nonlinear penalties. In order to mitigate line instabilities, isolators were placed 20 km from each end, with a pump bypass filter at the receiver side. The ROPA consisted of 17.5 m of Lucent Erbium-doped fiber R37014.

The Raman pump lasers are polarization and wavelength multiplexed into the line [4]. The total forward distributed pump power into the fiber was 2.6 W and the total backward distributed pump power was 2.4 W. The pump laser diodes' RIN was typically -105 dB/Hz. The pump-to-signal RIN transfer penalty in the forward direction was estimated to be less than 0.2 dB and was negligible in the backward direction.

The transmitting and receiving amplifiers were dispersion compensating Raman lumped amplifiers. To compensate for the entire 466 km, external pre- and post-compensation was additionally used.

Ten individual 43 Gb/s transceivers were used for the test signal, using NRZ-DPSK modulation format and 7% overhead to accommodate forward error correction iterative BCH code, as implemented in the Intel "Tenabo" IC. At a BER ≤ 1E-15, the gross coding gain was measured to be 8.8 dB. Hence the "error free" test limit was Q ≥ 9.2 dB.

Test results

The signal spectra in Fig. 4 were recorded with a resolution bandwidth of 0.1 nm. To achieve flat OSNR, a pre-emphasis of about 2.5 dB was applied to the transmit spectrum (Fig. 4). The transmission results are summarized in Fig. 5. For 10 channels the

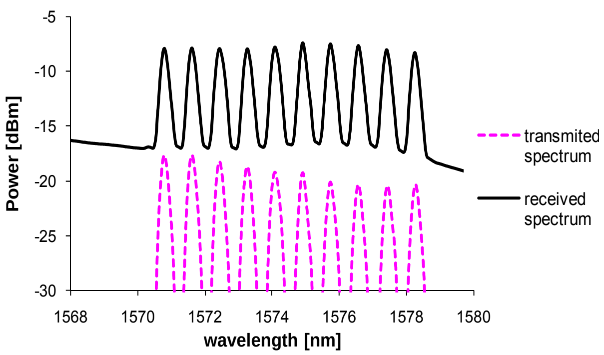

Fig. 4: Transmitted and received spectra recorded with 0.1 nm resolution bandwidth

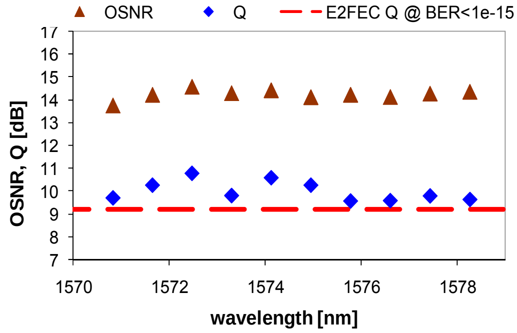

Fig. 5: Measured OSNR (reported at 0.1 nm NBW) and Q values

average OSNR was 14.3 dB and the average Q was 9.8 dB with almost no error-free margin left for the worst channels. However, by reducing the number of channels the margin increased, as shown in Fig. 6. No measurable cross-channel penalty was observed.

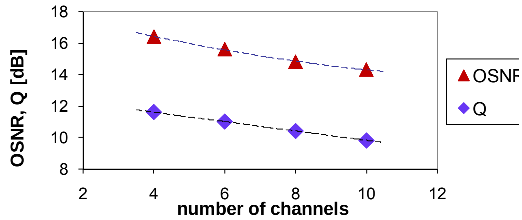

Fig. 6: Average OSNR and Q values as a function of number of channels

Conclusions

A new design approach of ultra-long 43 Gb/s WDM unrepeatered systems has been analyzed and experimentally demonstrated over 468 km of PSCF with an overall loss of 82 dB, comparable to a realistic, installed PSCF cable. The results once again proved the efficiency of Raman UR systems operating in the L-band, indicating that it is possible to design practical ultra-long UR systems, with a capability of 200 Tbkm/s and beyond.

References

1 B. Bakhshi et al, Proc. OFC/NFOEC 2009, OThC4
2 P. Bouselet et al, Proc. ECOC 2008, Mo.4.E.3
3 A. Puc et al, Proc. LEOS 2008, WH5