Technical Paper

L-Band unrepeatered WDM experiment over 451 km using all-Raman amplification and ROPA

A. Puc, D.I. Chang, G. Grosso, J. Ellison, R. Oberland, S. Burtsev, P.A. Perrier, W. Pelouch, S. Webb

Abstract

Unrepeatered distributed Raman link with ROPA combining 22×10.7Gb/s and 3×43Gb/s NRZ DPSK signals in L-band is demonstrated. The net span loss was 80 dB over 451 km of "legacy" G.654 fiber.

1. Introduction

The use of distributed Raman amplification (DRA) and discrete Raman amplifiers (RA) is a powerful method to span ultra-long unrepeatered distances [1]. In addition, such "Raman links" can be enhanced by remotely pumped erbium doped fiber (EDF or ROPA). This way, high capacity and ultra-long unrepeatered distances were achieved [2], [3], [4], and most impressively [5]. All these results were obtained in C-band wavelength region where remotely pumped EDF (or ROPA) is most efficient. Also, large and ultra large effective core area (>100μm^2) fibers were generally used in order to minimize nonlinearities and to maximize ROPA distance from the fiber end.

In this paper, unlike the above mentioned systems in C-band, we propose an effective unrepeatered Raman system with ROPA operating in the lower L-band (typically from 1565nm to 1590nm), using a legacy pure silica core fiber (PSCF, G.654) with a core area of about 80μm^2. Here, the ROPA efficiency is sacrificed in order to benefit more from distributed Raman amplification and lower span loss in the L-band. With proper selection of Raman and ROPA pumps, the negative gain slope of EDF can be effectively compensated by the positive distributed Raman gain slope. The resulting overall system gain and noise figure become reasonably flat over a 25-nm wide wavelength region, so that there is no need for a gain flattening filter (GFF).

The experimental results presented here demonstrate that the "L-band Raman/ROPA" yields similar or better results than conventional C-band ROPA systems demonstrated to date.

2. Design of ROPA enhanced Raman system in L-Band and experimental setup

The system functional block diagram is shown in Figure 1. All the transmitting and receiving amplifiers are dispersion compensating Raman amplifiers. In addition, dispersion compensating fiber is used for both pre-compensation and post-compensation in order to overcome the accumulated positive dispersion over 451 km of PSCF (Sumitomo Z-fiber in this experiment).

Source: Lasers & Electro-Optics Society annual Conference 2008
Key topics: Large capacity and long distance unrepeatered systems, 40G

The DRA in the forward and backward pump assemblies differ only in launch power. They consist of spectrally multimode high power laser diodes at six different wavelengths. The total forward pump power in the fiber was about 2.3 W and the total backward pump power in the fiber was 2.6 W.

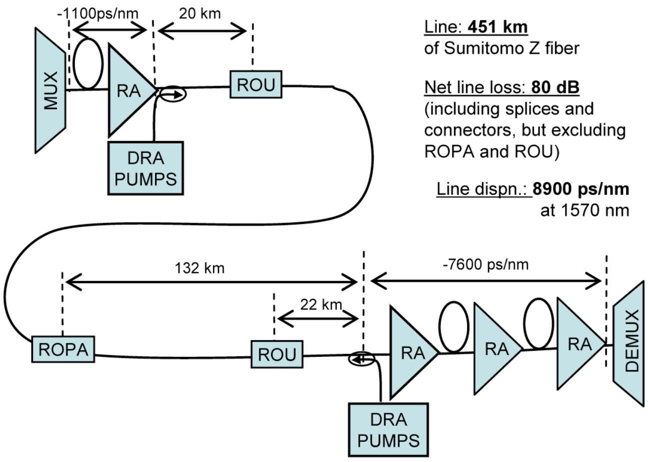

Figure 1: Functional Block Diagram and Experimental Setup

The signal launch power has been chosen such that the distribution of the forward gain is spread as much as possible along the line for a given pump power. The signal power profile along the line plays an important role in a compromise between system noise figure and nonlinear transmission impairments, out of which the self-phase modulation (SPM) appeared to be dominant. The signal power profile is shown in Figure 2.

The ROPA consists of 17.5 m long EDF of type OFS R37014 type. Its position was optimized with respect to the available pump power and OSNR. The ROPA consists of 17.5-m long EDF (OFS R37014). Its position was optimized with respect to the available pump power and OSNR (132 km from the receiving end). In order to alleviate MPI penalties and amplified line instabilities, passive remote optical units (ROU) were placed in the regions of highest Raman gain.

In the “forward pumped” Raman amplification region, a standard intensity modulated NRZ signal suffers from strong stimulated Brillouin back-scattering (SBS), unless a rather strong SBS suppression modulation is applied to the signal which can introduce a non-negligible transmission penalty. In contrast, DPSK modulated signals are largely immune to SBS and thus very appropriate to forward pumped Raman systems.

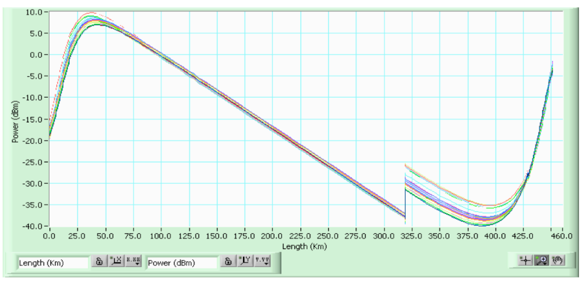

Figure 2: 25 Channels Signal Power distribution along the line

The counter-propagating pump relative intensity noise (RIN) transfer is negligible, and the co-propagating pump RIN transfer Q penalty is estimated to be less than 0.1 dB. The measured PDG value of the LRA amplifiers is < 0.5 dB, of which the majority, 0.3 dB, comes from PDL of the in-line components, and the remainder is due to residual polarization of the pumps. Polarization-mode dispersion of the discrete stage of the LRA amplifiers is < 0.6 ps, with most of the contribution coming from the LRA gain fiber.

The enhanced forward error correction (E-FEC) circuit used in the system is commercially available and is based on an iterative BCH codec, operating at 0.93 code rate. For both types of signals, 10.7Gb/s and 43Gb/s, the measured gross E-FEC coding gain at BER$\leq 10^{-15}$ was greater than 8.5 dB. Hence, the "error free" test limit was Q $\geq$ 9.5 dB.

3. Experimental results

Launched and received spectra are depicted in Figure 3. The 10.7Gb/s channels OSNR was 10.7 dB average, and the 43 Gb/s OSNR was 13.9 dB average. The OSNR and Q test results are summarized in Figure 4. The transmission of 22×10.7Gb/s NRZ DPSK and 3×43 Gb/s NRZ DPSK signals was error free after E-FEC (BER <1E-15).

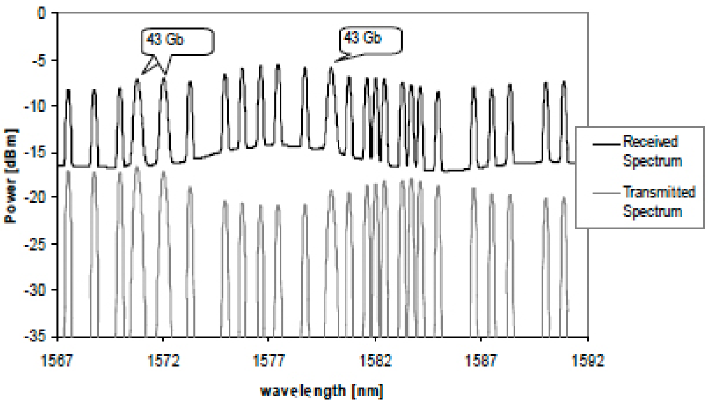

Figure 3: Received and transmitted spectra over 451 km and 80 dB span loss

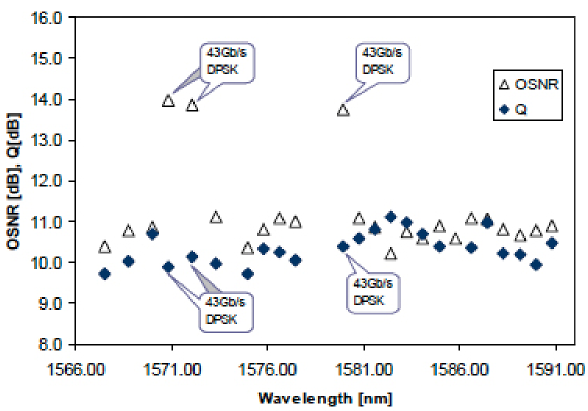

Figure 4: Q and OSNR, measured at the receiver end

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The demonstrated "capacity $\times$ distance" was 153 Tb/s km (78 Tb/s km in [5]), and the demonstrated "capacity *x* span loss" was 27 Tb/s dB (13 Tb/s dB in [5]).

4. Conclusion

We have proposed and experimentally confirmed an efficient and cost effective design of an ultra-long unrepeatered Raman L-band system, enhanced by EDF-based ROPA. The experimental validation of the system demonstrates a robust "error free" transmission of 22 *x* 10 Gb/s and 3 *x* 43 Gb/s NRZ DPSK modulated signals over 451km and span loss of 80 dB.

The demonstrated method is of practical importance because it employs cost effective legacy PSCF and readily available EDF for ROPA that is not optimized for use in L-band. However, if a large effective core area low loss fiber together with an optimized EDF would be used instead, transmission distances over 500km with comparable transmission capacity could be achieved.

References

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Contact: **Corporate Headquarters**
Xtera Communications - USA
500 W. Bethany Drive, Suite 100
Allen, TX 75013
USA

T + 1 972 649 5000
F + 1 972 747 0344

E info@xtera.com
www.xtera.com

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