ALL-RAMAN AMPLIFICATION EXTENDS THE LIFE OF PREVIOUS GENERATION UNREPEATERED SYSTEMS

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Abstract: The recent upturn in demand for bandwidth-intensive service has operators of unrepeatered submarine networks reviewing their options for cost-effectively increasing the capacity on existing unrepeatered submarine networks. They are finding that the application of all-Raman amplification enables a simple and cost-effective upgrade for systems, including those with older generation remote optically pumped amplifiers.

1 INTRODUCTION

Unrepeatered submarine systems are a cost-effective solution to transmit high capacity communication channels over moderate distances of a couple of hundred kilometers. The added expense of a repeatered system is often avoided by splicing a remote optically pumped amplifier (ROPA) into the line fiber to maximize the unrepeatered transmission distance [1]. These passive "in-line" devices have been installed over the past 5 or 7 years to links ranging from 300 to 350 km. The links were designed for a maximum capacity of around 40 Gb/s (16 x 2.5 Gb/s or 4 x 10 Gb/s). However, a recent surge in demand for bandwidth-intensive applications has forced operators to investigate options for quickly meeting the rising capacity demands.

New deployments would provide the additional capacity and support for higher bit rates [2], but from a provider perspective is not the optimum solution due to the capital investment it represents and the time-to-market penalty. Similarly, upgrade scenarios which would require the removal of ROPAs, are complex and expensive.

The wide-spectrum enabled by Raman amplification [3] offers an attractive and cost effective solution to upgrade ROPA-assisted unrepeatered links without having to remove the ROPAs. By transmitting in a spectral window shifted with respect to the C-band, where ROPAs usually operate, a significant capacity increase can be achieved. As shown in Figure 1, the residual Raman pump power "bleaches" the ROPA and does not adversely affect the signal transmission.

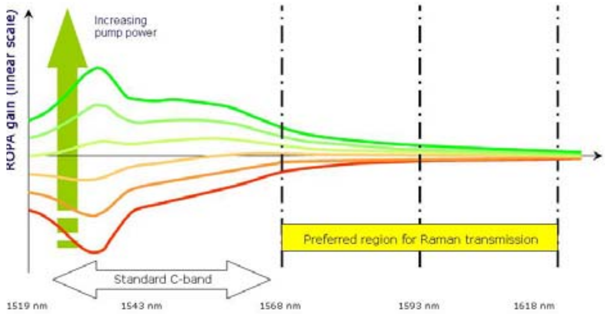

Figure 1: ROPA & RAMAN Transmission Windows

This paper demonstrates the feasibility of the upgrade of a ROPA enhanced unrepeatered link using the concept described above.

2 EXPERIMENTAL VALIDATION

A link, with characteristics mimicking currently deployed links, was emulated by inter-connecting (via connectors) four sections of G.654 fiber for a total fiber length of 304 km, as shown in Figure 2. The total span loss was 53.3dB (at 1550nm), including connectors and splice losses. The dispersion of the span was slightly over 5,700ps/nm, measured at 1570nm.

A ROPA, inserted in the span at about 87km from the Receive Terminal, consisted of an isolator connected to a 10m long piece of commercial Erbium-doped fiber.

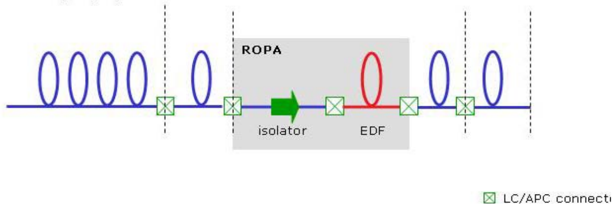

Figure 2: ROPA Placement

Commercially available all-Raman DWDM equipment was connected at both ends of the span. The transmit terminal, Figure 3, was equipped with two shelves with twenty 10G transponders on the ITU-grid. The odd channels were combined via a 100GHz multiplexer

(Mux). Each input port of the multiplexer is equipped with a variable optical attenuator (VOA). An even multiplex, constructed using a similar multiplexing scheme, was then combined with the odd multiplex to form a channel comb, with channels spaced 50GHz apart. In addition, two groups of 5 fixed-wavelength DFB lasers (odd channels) and 8 External Cavity lasers (even channels), were combined with the transponder channels. The resulting 33 channel plan covers a wavelength window of about 25nm in the L-band, between 1567.54 and 1592.10nm.

Data (a 2^{31}-1 pseudo-random bit sequence) are encoded on the DFB laser and on the ECL wavelengths by separate Ti:$LiNbO_3$ Mach-Zehnder modulators. Stimulated Brillouin Scattering is suppressed by applying on each laser source a sine-wave modulation (modulation depth =3%, frequency between 7 and 15kHz) to broaden the spectrum. The channel comb was fed into an all-Raman, wideband, Ingress amplifier which combines a discrete stage and a distributed stage pumping the line fiber in the forward direction. The launched pump power is about 1.5W, distributed over several pump wavelengths.

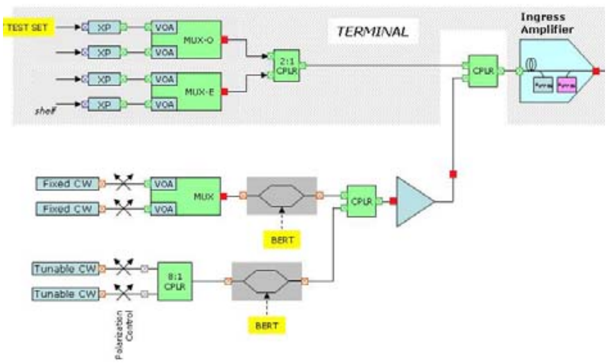

Figure 3: Raman transmit terminal arrangement

The receive terminal, Figure 4, employed a 100-nm wide, all-Raman, Egress amplifier consisting of a distributed stage and two discrete stages. The pump power launched into the line (in the backward direction) was about 0.7W, distributed over several pump wavelengths.

The Egress amplifier was followed by a narrow-band (25nm) all-Raman dual-stage amplifier, used as a pre-amplifier. The received 50GHz spaced channels were de-interleaved into two 100GHz spaced channel groups, and further de-multiplexed by two separate array-waveguide gratings. The transponder channels were detected by their corresponding transponders whereas stand-alone receivers were used for detection of the DFB and the ECL channels.

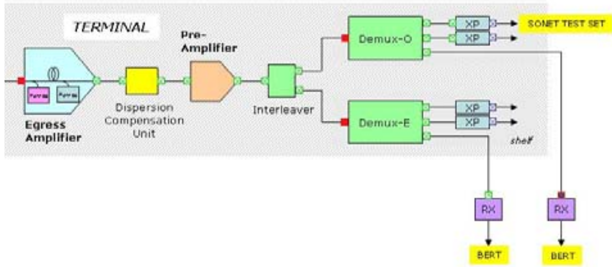

Figure 4: Raman receive terminal arrangement

The combined Raman amplifiers were compensating for about 65% of the total link chromatic dispersion induced by the line fiber. The residual chromatic dispersion was compensated by means of a low-loss dispersion compensation unit placed between the Egress amplifier and the pre-amplifier.

An in-house system design tool was used to model this link. Figure 5 depicts the signal power profile along the line fiber for all 33 channels. The maximum signal power in the line is about +10dBm/ch approximately 25km away from the transmit terminal. The ROPA provides approximately 3dB of gain with about 8mW of residual pump power.

Figure 5: Simulated signal power profile along the link

Figure 6, Figure 7, and Figure 8 depict the normalized signal spectra recorded at the output of the ingress amplifier (launch spectrum), the input of the egress amplifier, and the output of the pre- amplifier respectively. The launched channels were slightly pre-emphasized (using the VOA of the multiplexer) in order to equalize their OSNR performance at the receive side. The pre-emphasis spectral dependency corresponds to the overall link noise figure (determined mainly by the ROPA and the distributed gain in the segment between the ROPA and the receiver), The peak-to-peak ripple at the output of the pre-amplifier was no greater than 3.5 dB which was well within the dynamic range of the transponder receivers (10 dB), and resulted mainly from the overall link gain.

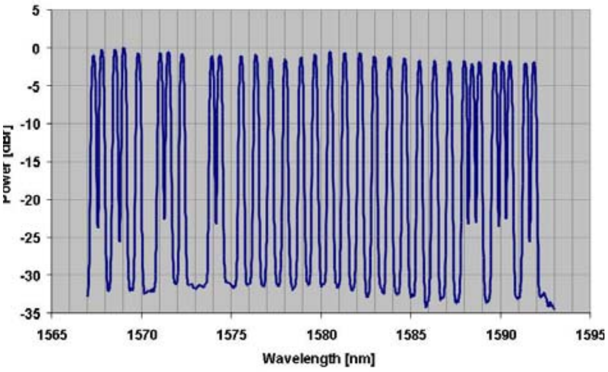

Figure 6: Ingress amplifier normalized signal spectrum

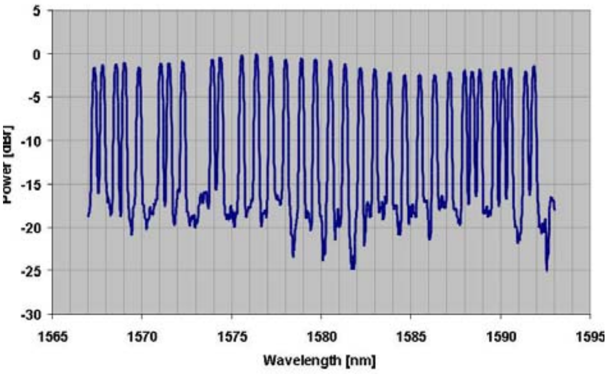

Figure 7: Egress amplifier normalized signal spectrum

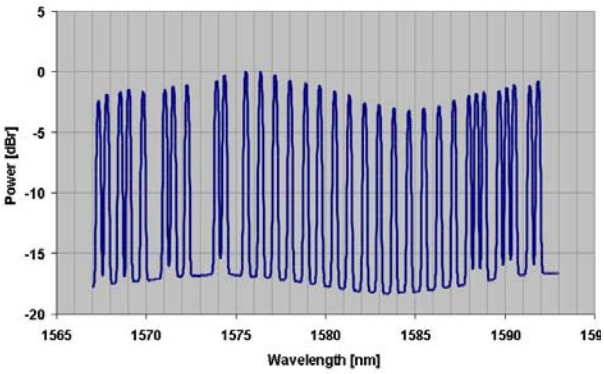

Figure 8: Pre-amplifier normalized signal spectrum

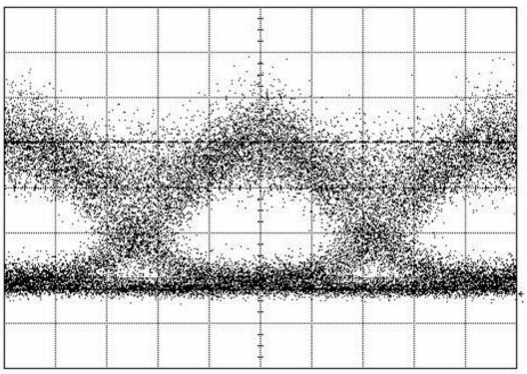

Figure 9: Received eye pattern @ 1592.10nm

A typical received eye pattern is shown in Figure 9 (channel at 1592.10nm). The eye was wide open; the corresponding Q was 16 dB, well above the FEC (RS255/239) "error-free" (BER better than 10^{-15}) Q-limit of 11.8 dB.

The overall transmission performance of the link is summarized in the chart of Figure 10. Qualitatively, the Q variation across the transmitted spectrum closely follows the OSNR spectral variation. This indicates that the nonlinearities in the link were low and that the residual dispersion slope was pretty flat within the transmitted band, a result of good dispersion slope compensation.

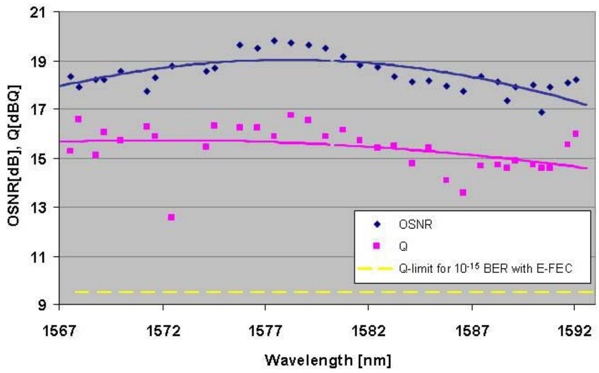

Figure 10: Link transmission performance

In order to demonstrate the robustness of the link, the launched power of the "worst" channel (1588.73nm) was gradually reduced Figure 11 to the point where un-corrected errors started to appear after FEC. The rest of the channels were maintained at their nominal launch level. The results are shown in Figure 12. The channel had to be attenuated by 4 dB before observing errors for a BER of 10^{-12}.

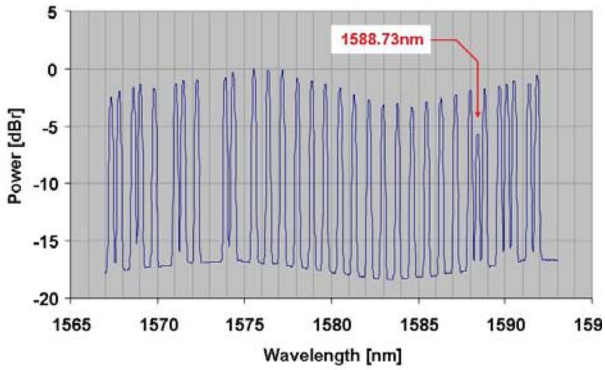

Figure 11: Pre-amplifier output signal spectrum

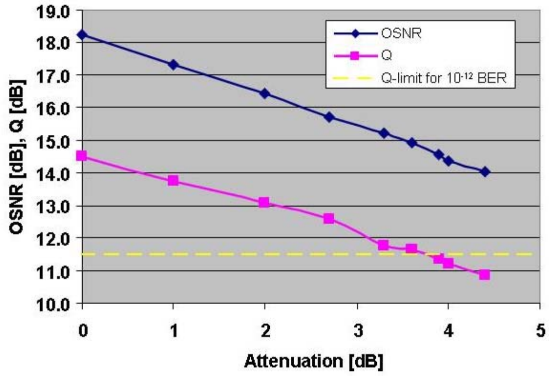

Figure 12: 1588.73 Performance as a function of attenuation

3 CONCLUSION

The upgrade of a typical ROPA enabled unrepeatered submarine segment was successfully demonstrated. While the maximum capacity of older generation ROPA systems are limited to approximately 40 Gb/s, the demonstration shows that commercially available all-Raman amplification can be used to significantly increase the capacity of these systems. Thirty-three channels at 10 Gb/s (a 10 fold increase in capacity) were transmitted over a span of 304 km without removing the ROPA. Raman technology allows operators to maximize the use of existing assets by enabling upgrades that result in a capacity that would have been obtained with the deployment of a new system, at a fraction of the cost.

4 REFERENCES:

[1] P.B. Hansen and L. Eskilden (1997). Remote Amplification in Repeaterless Transmission Systems. *Optical Fiber Technology*, 3, 221-237

[2] A. Kaminski et al (2005). All-Raman Unrepeatered Tranmission over 440km of Standard PSCF, ECOC 2005 Proceedings, vol. 1, Paper Mo4.2.7, 77-78

[3] M.W. Chbat and H. Février (2004). Reaping the benefits using an all-Raman terrestrial amplified transmission technology in unrepeatered applications. *Submarine Telecoms Forum*, 14, 21-24