A little bit of Raman makes the Repeater go a long way

Xtera's Stuart Barnes, Wayne Pelouch and Nigel Taylor share a rare insight into a Regional System. From the analysis of comprehensive system data, the long-term economic benefits of low NF Raman techniques become abundantly clear.

1. Introduction

The deployment Raman Amplification has been used in a variety of terrestrial applications and particularly where there are economic benefits. One major example is fiber over long power line systems. Over the years Xtera has successfully installed several of these, including the World's largest powerline networks: CFE in Mexico and TIM Brazil[1]. In this case, the Raman is superimposed over the EDFA gain to lower the Noise Figure (NF) of the amplifiers and enable greater reach[2,3].

In long-span undersea links (> 300 km), distributed Raman has become a required technology to increase OSNR and avoid subsea amplifiers[4]. With Remotely Pumped Optical Amplifiers (ROPAs), over 600 km spans have been demonstrated with a 100G channel.[5]

In the above cases, local electrical power is readily available and power consumption is not a primary concern. In contrast, subsea systems are powered by distant high voltage (constant DC current) equipment at landing stations and electrical power is limited[6]. Due to space charge build up in the polyethylene insulation of the cable[7], which eventually leads to break down, power utilization is at a premium. However, for regional subsea links there is ample power to employ distributed Raman in addition to a C-band EDFA over many fiber pairs (FPs).

Xtera has developed two configurations of commercial subsea hybrid Raman-EDFA amplifiers. In the first configuration, the Raman gain is in the C-band and is used to significantly reduce the noise figure (NF) and/or increase the amplifier separation (up to 140 km). In the second configuration, Raman amplification extends the bandwidth as a simpler alternative to parallel, multiplexed C- and L-band EDFA configurations. As the EDFA gain decreases in the L-band, the Raman gain increases, avoiding the need for a separate L-band EDFA or band multiplexers. In this case, the Raman gain in the L-band is the limiting factor in span loss and this design favors short (< 80 km) spans and high OSNR / high-capacity applications.

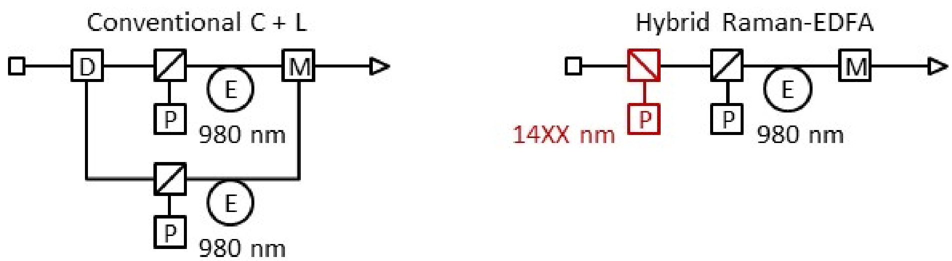


Figure 1 Conventional C+L compared to Hybrid Raman-EDFA

D = C/L Demux; P = Pump; E = doped fibre; M = C/L mux

It is interesting that only the Raman wavelength needs to be changed to support these two configurations so that a common hardware platform is used for both cases.

2. Deployments

Using Raman all our deployed subsea systems have primarily been of the C-band type with an average NF of about 2.5 dB. Although each Raman amplifier requires additional power, Xtera can use the low NF to extend the repeater separation and reduce the number of repeaters required to support a desired OSNR. Furthermore, there are a couple of notable side benefits that maximize the system operation. The additional Raman gain extends the bandwidth, relative to EDFA-only designs, by a few nm to 40 nm in the C-band (1528 ~ 1568 nm).

The Raman gain can be adjusted in each amplifier (from the shore end using active supervisory[8]) to tune the per-span tilt, correcting for slight variations in span loss and larger changes to span loss from cable repairs. Thus, the performance of the system can be optimized through-out its operational lifetime. This is a significant operational advantage and yields an ability to reduce risk of an unknown number of future required repairs.

Active supervisory communication is an attractive feature of our Raman repeater design and we have been privileged to receive regular information from a couple of systems that are in service. We show these here for an 11-span link with span lengths of slightly less than 130 km and a NF of around 2.5 dB on average. Since the system was built just over four years ago, we have amassed weekly data on the health of the system (power consumption of all the key components (980 pumps, 14XX pumps, relays, capacitors, Zener diodes…), temperatures of key components, gain, pressure, and humidity. In the next white paper we will share the value of these sensors from a Repeater build and operational perspective

3. Raman Pumps

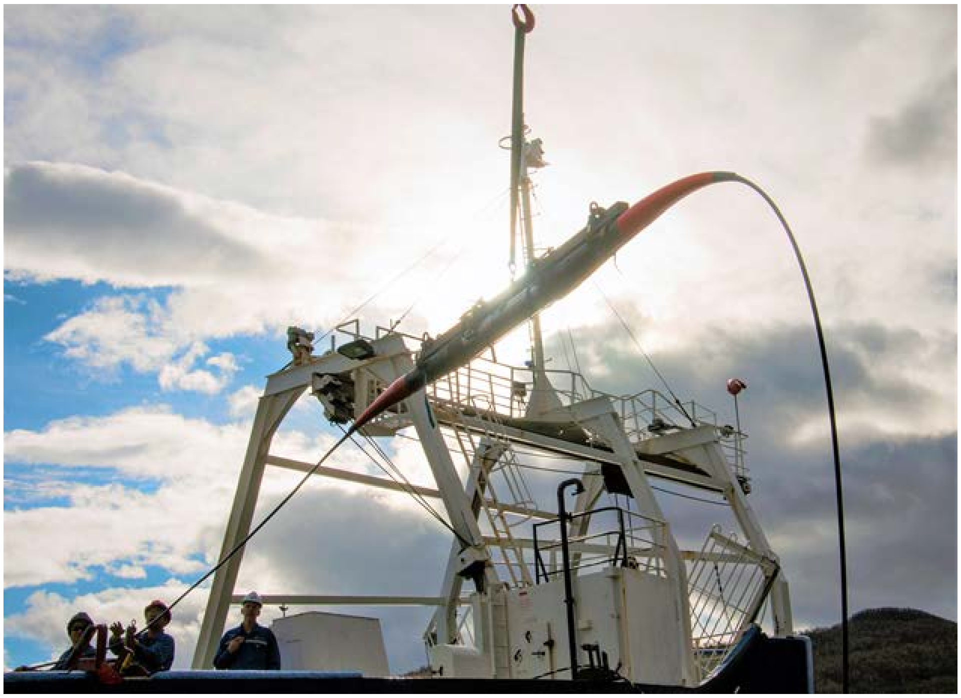
We have looked at all components in detail but have focused this short paper only on the Raman pumps. Over the lifetime of the system studied, and one that has been in service significantly longer, we have seen no measurable degradation of pump performance, either in terms of amplifier gain or power consumption. The average power consumption per 14XX pump currently is less than 1% different from that measured at the outset. This conclusion is supported by measurements on a slightly older system, where the pumps are similarly showing no significant changes in power consumption.

Date	14XX pumps (relative power)
Nov-18	1145.6 +/- 12.3
Feb-21	1144.4 +/- 12.7

Table 1 14XX pump ageing, 24 pump sample

14XXnm pumps have been deployed in significant volumes over the last two decades and have an enviable track record and the ageing data supports this conclusion. Xtera's earlier all-Raman 100-nm amplifiers used up to 20 14XX laser diodes each and have been in continuous service since 2004. We will be considering this and the ageing data from all the constituent components in a follow-up paper as we probably have the most comprehensive data on components in the field due to our supervisory techniques. The reliability analysis of the 14XX laser manufacturer and our own field data clearly show the failure-in-time (FIT) rate to be exceptionally low for 14XX laser diodes, significantly lower than the 980-nm lasers. The FIT Rate of is ~1 FIT for the 1480nm pumps and slightly higher for the 980nm pumps.

The inclusion of 14XX pumps in the repeater increases the power consumption of the system. However, the reduction in NF by about 2 dB allows longer span lengths to be achieved and a fewer number of repeaters to be deployed. For a hypothetical 1800 km system, a repeater with < 200 mW of Raman pump into the line fiber can reduce the number of repeaters by 3.



There are two types of soft failures that submarine systems are vulnerable to. These do not cause the link to fail but cause a decrease in the design bandwidth. System repairs to the fiber cable can cause the gain profile to tilt and we can tune the tilt of each amplifier from the shore end using active supervisory to maximize performance[8]. Secondly, ageing of the system can lead to similar effects and we have shown that in conjunction with AI the operator has the tools to re-optimise the system throughout the lifetime[9].

This results in a significant cost savings and an indirect benefit on net reliability. A Raman repeater also benefits from the use of standard effective-area fiber. Thus, the cabled fiber costs are lower as well leading to cost savings for the entire subsea plant.

4. Concluding Remarks

The utilization of Raman in a subsea repeater has a significant benefit in both the link design and operation. Although it is true that we will not see Raman being used in trans-Pacific links, due to their extremely tight power requirements, it can be advantageous from both a performance and economic perspective for regional links with lower power requirements. We have also demonstrated that the Raman laser diodes are extremely reliable and stable over the system lifetime. In addition, the value of an intelligent repeater with the ability to collect operational data and adjust to varying conditions is clear.

We will discuss the reliability of all components in our repeater in a follow up White Paper later this year.

A little bit of Raman goes a long way!

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