TRANSMISSION OF 16 X 10Gb/s THROUGH SINGLE SPANS UP TO 370 km WITHOUT REMOTELY PUMPED AMPLIFIERS

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Abstract *We present measurement results for unrepeatered transmission up to 370km using next-generation terrestrial system technologies and optimised fibres.*

Introduction

Long spans often form key parts of fibre-optic networks. Examples occur in coastal areas and islands, in festoons and through remote applications where service access is problematic. While these links have no need for "wet" active components, they are often built with a submarine mindset and budget. Pushed by the imperatives of low-cost and high-performance, next-generation networks inexpensively exploit technologies familiar to submarine system designers. In this paper we describe how the combination of next-generation system technology with hybrid optical fibre solutions extends the single-span reach to 370 km for 16 channels of 10 Gb/s.

Previous researchers[1] have shown ultra-high capacity at 310 km; or, with the use of remote optically pumped amplifiers (ROPAs)[2,3], reaches from 350 to 442 km. ROPAs are avoided in the current study because they require undesirable cabling complexity and present obstacles to future capacity upgrades.

The key equipment technologies exploited for extended single-span reach are:

- Low-distortion transmitter waveform
- High-gain forward error correction (FEC)
- High-gain distributed Raman amplification

The optimised hybrid optical fibre span takes full advantage of the above system technologies by enabling:

- Reduced non-linear distortion
- Highly efficient Raman gain
- Lower loss
- Reduced dispersion compensation

Measurement System

The single-span reach was measured using commercially available system equipment and fibre. A diagram of the system is shown in Figure 1.

The system consists of a single 370 km span, made up of two fibre types. The first 269 km are Corning® Vascade™ L1000 fibre with an effective area of 101 μm^2 and dispersion of 18.5 ps/nm·km, as specified at 1550 nm. The next 101 km are Corning® Vascade™ LS+ fibre, with an effective area of 50 μm^2 and dispersion of -3 ps/nm·km. The total loss of the fibre, including connectors, is 71 dB.

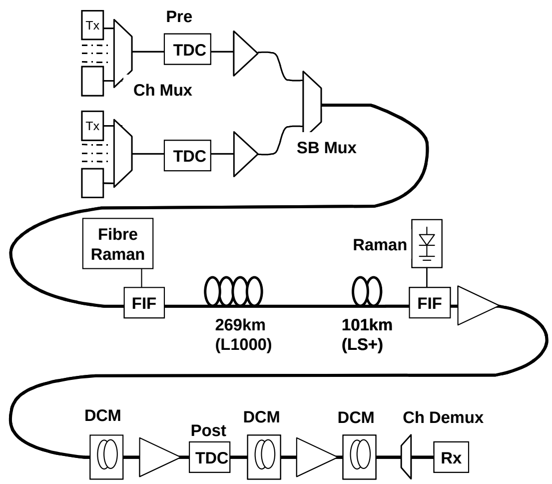

Figure 1. Schematic diagram of measurement configuration.

The signal is modulated with a return-to-zero (RZ) format. A tuneable dispersion compensator (TDC) provides approximately –400 ps/nm of "pre" compensation while simultaneously enabling dispersion contour measurements. The 16 channels are amplified with two parallel erbium-doped fibre amplifiers (EDFAs) each carrying an 8-channel sub-band. The sub-bands are combined using a low-loss filter (SB Mux), and fed into the fibre with the co-propagating Raman amplifier at the first fibre-interface filter (FIF). The launch-power into the large-core fibre is controlled to +13 dBm/channel, and an optical spectrum analyser (OSA) provides feedback for per-channel equalisation. Co-propagating Raman amplification provides 7.2 dB gain using a fibre-laser pump source. The fibre dispersion is sufficient to limit transfer of amplitude noise onto the signal from the co-propagating Raman source.

The Vascade L1000 fibre with large effective area and loss of 0.187 dB/km enables propagation of the first 269 km. The Vascade LS+ fibre provides some dispersion-compensation and, more importantly, enables counter-propagating Raman gain of 33 dB with sufficiently low backscatter to mitigate multi-path interference. This high Raman gain permits completion of the final 101 km in the 370 km single-span link. The signals pass through the second FIF to reach the first receive-side EDFA at -6 dBm/channel, followed by the necessary dispersion-compensation and amplification.

The signal is encapsulated into a G.709 digital wrapper but obtains greater performance by using a proprietary concatenated Reed-Solomon FEC encoding algorithm. This provides 8.4 dB net equivalent coding gain.

Results

Optical eye diagrams measured at the receiver are shown in Figure 2. The upper figure shows the eye for single-channel propagation, with +11 dBm/channel launch power and 10.4 dB co-propagating Raman gain. The lower figure shows the eye diagram for one channel of the 16-channel spectrum with +13 dBm/channel launch power and 7.2 dB co-propagating Raman gain. The reduction in gain compared to the single-channel case is due to power saturation. The net Raman gain from co- and counter-propagation is approximately 40 dB in the multi-channel case.

The eye diagrams indicate that there is little measurable multi-channel penalty and that the system is optical-signal-to-noise ratio (OSNR) limited. At lower channel counts, the signal launch power is limited by stimulated Brillouin scattering (SBS), for which the separately measured threshold is 16.5 dBm/channel with RZ modulation. Even with the reduced eye-opening shown in the bottom of Figure 2, the raw bit-error-rate (BER) after 370 km is sufficiently low to ensure that the BER is less than 10^{-16}, with 1.1 dBQ minimum margin.

A measurement of the optical spectrum after propagation is shown in Figure 3, along with the measured Q and the corresponding FEC Q limit for error-free operation.

Conclusion

Ultra-long single spans up to 370 km and 71 dB loss may be traversed with 16 x 10Gb/s data capacity using optimised fibre and next-generation system technology, including high-gain FEC and Raman amplification. The single-channel effects of self-phase modulation and SBS dominate the non-linearities, and careful attention must be paid to power control.

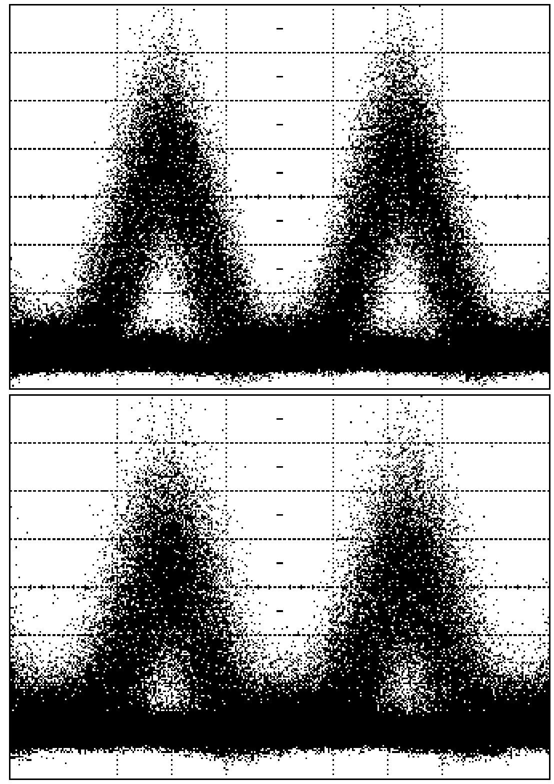

Figure 2. Optical eye diagrams after single-span transmission through 370 km. Details are in the text.

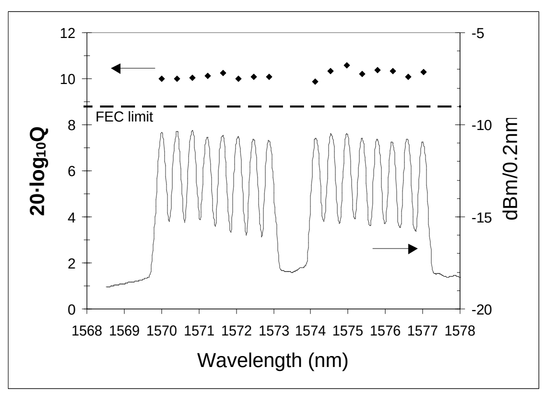

Figure 3. Optical spectrum after transmission through 370 km. Q is shown compared with the FEC limit.

References

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