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Raman-Assisted Transmission of 16×10 Gbit/s over 240 km using Post-Compensation only

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Abstract: We demonstrate transmission of 16 WDM channels at 10 Gbit/s with 50 GHz channel spacing over 3×80 km NZDSF, with small OSNR penalty, using only a single Raman-pumped dispersion compensating module positioned before the receiver.
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1. Introduction

Dispersion compensation in present-day systems is almost exclusively done using dispersion-compensating fiber (DCF). This is typically used both in the transmitter (pre-), between transmission spans (in-line-) and in the receiver (post-compensation). The distribution of the DCF depends on the dispersion map of the link, which ideally should be optimized to minimize unwanted non-linear degradation of the signal [1]. The optimum map for a given link depends on a number of system parameters, including the optical power into each span, the length and number of spans and the fiber type. By limiting the dispersion compensation to the transmitter and receiver terminals, the dispersion map and transmission link will benefit from reduced complexity, as well as from cheaper and simpler in-line amplifier stages. The reason for the latter is that traditional multi-stage amplifiers can be replaced by simpler amplifiers without mid-access points for DCF. Furthermore, by using Raman amplification in the dispersion compensating module, the so-called DCRA, the minimum signal power in the DCF span is greatly increased, potentially lowering the noise figure of the combined module.

Terminal-only compensation has previously been investigated for standard single-mode fiber (SSMF), where both pre- and post-compensation were used [2]. In this paper, we introduce further simplification by achieving dispersion compensation in a Raman pumped post-compensation module (DCRA) only. Transmission of 16×10 Gbit/s with 50 GHz channel spacing is demonstrated, over 240 km non-zero dispersion shifted fiber (NZDSF) with reduced slope, using this technique.

2. Experimental setup

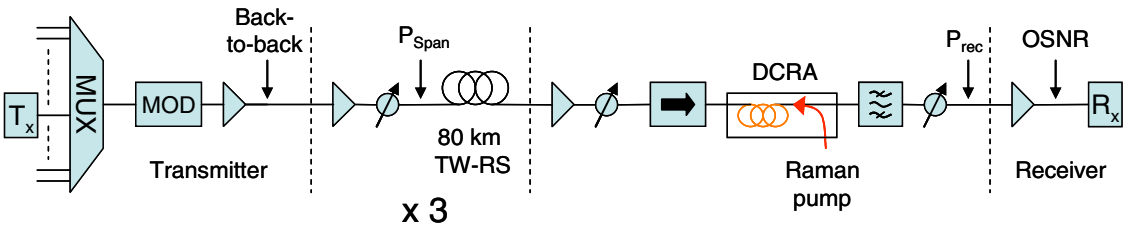

Fig. 1. Schematic of the DCRA post-compensated transmission setup.

The setup is shown in Fig. 1. In the transmitter, 16 co-polarized channels, in the wavelength region from 1547 nm to 1554 nm, are modulated with a 10 Gbit/s NRZ signal, using a Mach-Zender modulator (MOD) and thereafter amplified. The transmission link consists of 3×80 km spans of TrueWave®RS fiber (D = 4.6 ps/nm/km at 1550 nm). The average input power per channel is set to -2 dBm using variable attenuators before each span. The channels are further amplified and sent through a variable attenuator and an isolator before entering the DCRA. The DCRA is backward-pumped using two depolarized pumps, with center wavelengths of 1428 nm and 1456 nm, to obtain a Raman on-off gain of 12 dB and a gain ripple less than 0.3 dB for the combined module in the given wavelength region. The length of the DCF is 7.09 km and for these particular fibers, the residual dispersion of the combined system amounts to 78 ps/nm at 1550 nm.

The channels are selected using a tunable band pass filter and detected in a pre-amplified receiver, where bit error rate (BER) evaluations of all channels are performed. The BER dependence on received

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power (P_{rec}, measured at the input to the pre-amplifier), and the receiver sensitivities (P_{rec} at BER = 10^{-9}) are recorded. The BER dependence on the received optical signal to noise ratio (OSNR) is also recorded. The OSNR is monitored just after the pre-amplifier and varied by changing the received power.

3. Results and discussion

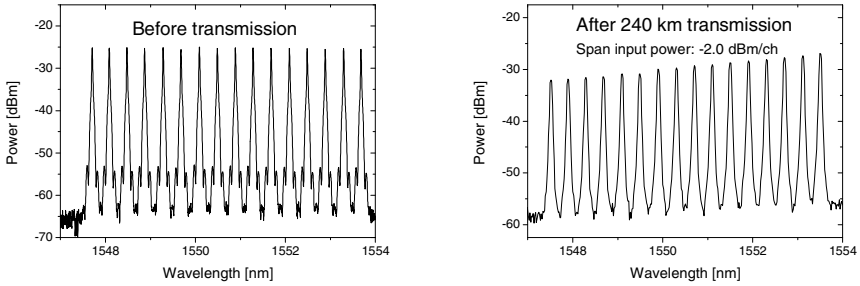

Fig. 2 Channel spectra before (left) and after (right) transmission. The resolution bandwidth is 0.1 nm in both subfigures.

The measured spectra before and after transmission are shown in Fig. 2. The maximum difference in channel power is less than 0.6 dB before transmission, while the values after transmission are seen to increase with wavelength, resulting in a 5 dB power difference between channel 1 and 16. The power tilt results from inter-channel power transfer, due to stimulated Raman scattering (SRS), during transmission [3] and was observed to decrease with decreasing input power into the spans.

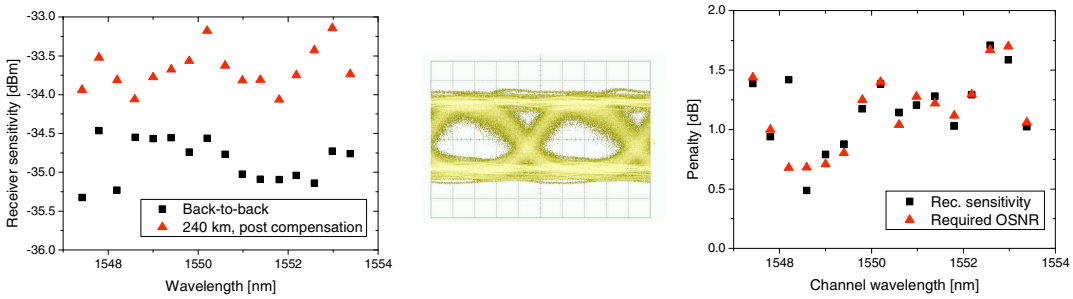

Fig. 3. Left: Back-to-back (square) and after transmission (triangle) rec. sensitivity. Middle: Error-free o/e converted eye diagram of channel 16 after transmission (P_{rec} = -32.9 dBm). Right: Rec. sensitivity (square) and OSNR (triangle) penalty.

All channels are successfully transmitted with error-free performance. The measured receiver sensitivity for each channel is shown in Fig. 3 (left) for the case of back-to-back and after 240 km, post-compensated transmission. Although some variation is seen from channel to channel, there is no clear indication of any wavelength dependent degradation. Fig. 3 (middle) shows an error-free (BER < 10^{-9}) eye diagram of channel 16 after transmission, with a received power of -32.9 dBm. The eye is clearly open. The receiver sensitivity and OSNR penalties for all 16 channels are shown in Fig. 3 (right). The penalties are in both cases close to ~1 dB with a spread of ~1.2 dB. A slight increase in penalty with increasing wavelength can be seen and is attributed to Raman induced cross-talk during transmission, causing power from the lower wavelength channels to be transferred to the higher wavelength channels.

4. Conclusion

In this paper, we have demonstrated and quantitatively evaluated a post-compensated 16x10 Gbit/s WDM system using only a single dispersion compensation/amplifying DCRA module before the receiver. After 240 km of transmission, through commercially available NZDSF, the sensitivity and OSNR penalties are found to be limited to ~1 dB ± 0.6 dB. These results demonstrate that post-compensation based on DCRA is of great practical interest for simplifying optical transmission span designs.

5. References

[1] Y. Frignac and S. Bigo, OFC (2000), TuD3

[2] L. Nelson et al., ECOC (2005), Mo4.2.2.

[3] B.Bakhshi et al., ECOC (2005), Mo4.2.5

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