DPSK TRANSMISSION EXPERIMENTS OVER DSMF AND NZDSF

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Abstract: This paper reports on trans-oceanic transmission experiments : 125 x 10 Gbps RZ-DPSK over 12380 km of DSMF and 100 x 10 Gbps RZ-DPSK over 9128 km of NZDSF as well as transmission experiments with a mix of RZ-OOK & RZ-DPSK modulation formats over 4300 km of NZDSF. Finally technical solutions allowing to offer cost-optimized design system are discussed.

1 INTRODUCTION

The objective of this paper is to analyze the performances of ultra-long-haul transmission experiments versus the type of modulation format and line fiber. The modulation formats considered in these experiments are Return-to-Zero On-Off-Keying (RZ-OOK) and Return-to-Zero Differential-Phase-Shift Keying (RZ-DPSK). The line fibers are Dispersion-Slope-Matched Fiber (DSMF) and Non-Zero-Dispersion-Shifted Fiber (NZDSF).

RZ-DPSK modulation format associated with balanced receiver is known to provide a theoretical 3 dB Optical Signal to Noise Ratio (OSNR) sensitivity improvement compared to RZ-OOK modulation. However, to fully compare the relative performance of RZ-DPSK and RZ-OOK, the robustness of each format against propagation impairments has been experimentally assessed with both DSMF and NZDSF chromatic dispersion maps over more than 9000 km. Finally, a transmission experiment mixing both types of modulation format over a 4300 km NZDSF link is reported.

2 ULTRA-LONG-HAUL TRANSMISSION OVER DSMF WITH 75 KM EDFA SPACING.

The comparison between RZ-DPSK and RZ-OOK modulation formats with DSMF type is achieved through two transmission experiments : 121 x 10 Gbps RZ-OOK channels over 6500 km and 125 x 10 Gbps RZ-DPSK channels over 12380 km.

For both experiments, the wavelength spacing is 33 GHz and the experimental set-up is fully described in reference [1]. In a back to back configuration and with a 0 dB/nm OSNR, the Q factor value improvement brought by RZ-DPSK is 2.6 dB by comparison with RZ-OOK modulation format.

2.1 121 x 10 Gbps RZ-OOK Modulation Format transmission over 6500 km

In this experiment, the EDFA output power is set to +16 dBm, + 17 dBm and then to + 18 dBm. The Q factor of each of the 121 channels is recorded at +17 dBm and significant channel Q factors are measured for the 2 other settings of EDFA output power, as shown on in Fig.1

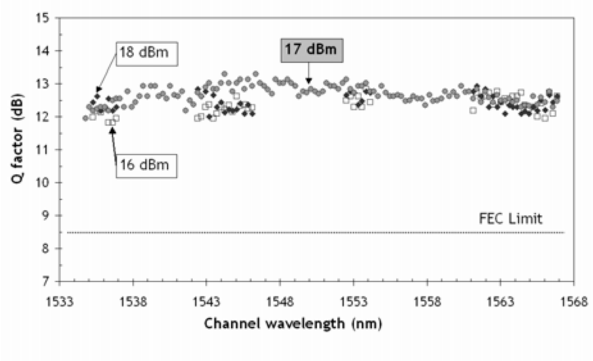

Fig. 1: Q factor measurements of 121 x 10 Gbps RZ-OOK transmission with + 16 dBm, +17 dBm and + 18 dBm EDFA output power.

Q factor performance results are very close versus EDFA output power, demonstrating EDFA output power optimization at + 17 dBm. For that optimized power level, the minimum and average Q factors are respectively 11.9 dB and 12.7 dB.

This also demonstrates that 6500 km is the maximum system length allowing to obtain a Q factor higher than 12 dB, which is the value to be targeted for an industrial system to account for system margins [2], when RZ-OOK modulation format even though a DSMF fiber mapping is used with a 75 km EDFA spacing.

2.2 125 x 10 Gbps RZ-DPSK Modulation Format transmission over 12380 km

In this experiment, the wavelength spacing is kept to 33 GHz. As in the previous section and in order to determine the optimum EDFA output power, Q factor measurements have been performed for different values of EDFA output power level: +16, 17 and + 18,5 dBm.

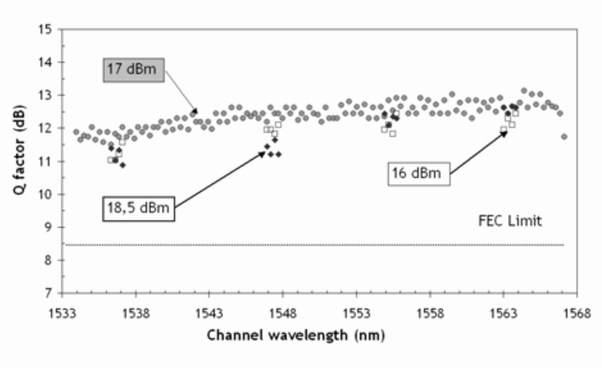

Fig. 2: Q factor of 125 x 10 Gbps RZ-DPSK transmission with + 16 dBm, + 17 dBm and + 18 dBm EDFA output power.

The Q factor of each of the 125 wavelengths is recorded for a +17 dBm EDFA output power and significant channel Q factors are measured for the two other EDFA output power settings and depicted in Fig.2.

Through these transmission experiments, the optimum EDFA output power is 17 dBm. In that configuration, the minimum and average Q factors are respectively 11.5 dB and 12.4 dB.

This also shows that using RZ-DPSK modulation format over DSMF mapping, the transmission length can be almost doubled compared to RZ-OOK modulation format transmission length (6500 km) while keeping the Q factor performance at the same level.

This is in-line with the ~3 dB OSNR sensitivity improvement achieved by RZ-DPSK modulation format over RZ-OOK modulation format and demonstrates that RZ-DPSK is not degraded by non-linear induced pulse distortion when increasing significantly the transmission length.

As a result, RZ-DPSK modulation associated with DSMF mapping is obviously the best candidate for ultra-long-haul system above 7000 km.

3 9128 KM TRANSMISSION OVER NZDSF WITH 61 KM EDFA SPACING.

The line consists in a 4564 km long re-circulation loop and thus only two round trips are performed to achieve the 9128 km transmission length. The zero chromatic dispersion wavelength is close to 1551 nm. Transmission experiments are performed with RZ-OOK and RZ-DPSK to compare the performance of both modulation formats over NZDSF fiber mapping.

3.1 42 x 10 Gbps RZ-OOK Modulation Format transmission over 9128 km

In this transmission experiment, the wavelength spacing is 50 GHz and the EDFA output power is + 12 dBm. The Q factors of the 42 wavelengths are recorded and depicted in Fig.3.

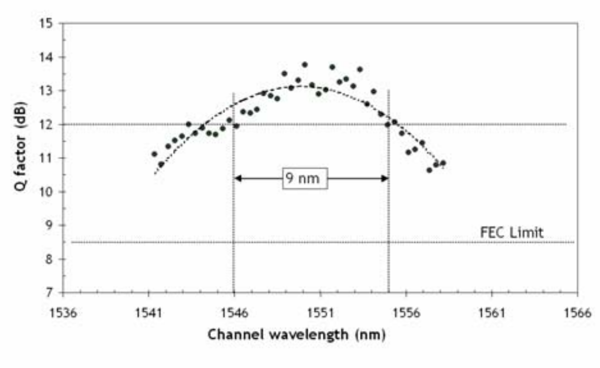

Fig. 3: Q factor measurements of 42 x 10 Gbps RZ-OOK transmission with + 12 dBm EDFA output power.

As expected, the channels located at the extremities of the wavelength multiplex suffer from the high cumulative chromatic dispersion, resulting in a high Q factor degradation.

Slight improvement can be achieved for the outer wavelengths of the multiplex by adding a synchronous phase modulation to provide the well-known Chirp-RZ (CRZ) modulation format. Nevertheless, this technique does not permit dense wavelength multiplexing due to the associated spectral pulse broadening.

In summary, RZ-OOK modulation format can be used over ultra-long-haul NZDSF link only over a narrow spectral range of about 9 nm centered around the zero chromatic dispersion wavelength.

3.2 100 x 10 Gbps RZ-DPSK Modulation Format transmission over 9128 km

In this transmission experiment, the wavelength spacing is 33 GHz and the EDFA output power is adjusted to + 16 dBm. The recorded Q factor of the 100 wavelengths are depicted in Fig.4.

Unlike RZ-OOK modulation, RZ-DPSK modulation format transmission measurement shows Q factor performances degraded in the zero chromatic dispersion region [3], region where Kerr effect induced non-linear interactions are maximum [4] and about 8 nm optical bandwidth around the zero chromatic dispersion wavelength is concerned.

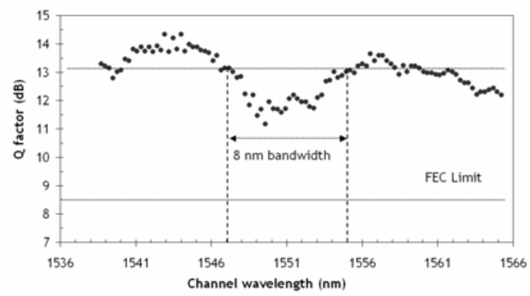

Fig. 4: Q factor measurements of 100 x 10 Gbps RZ-DPSK transmission with + 16 dBm EDFA output power

This phenomenon can be observed for shorter system length as demonstrated in the following section.

It can also be noted that the Q factor recorded for the centre wavelengths modulated with RZ-OOK (Fig.3) is even better than the Q factor obtained with RZ-DPSK at the same wavelength. This therefore raises the interest of using RZ-OOK format in the centre of the multiplex and RZ-DPSK format for the outer wavelengths to optimize the overall transmission performance of NZDSF links which is of particular interest in the case of existing system upgrade.

4 125 X 10 GBPS MIXED RZ-OOK AND RZ-DPSK TRANSMISSION OVER 4300 KM OF NZDSF

In experiments reported hereafter, the wavelength spacing is kept to 33 GHz. The wavelength allocation in the mixed configuration is as follow : 32 RZ-OOK modulated channels located on the multiplex centre, 48 RZ-DPSK modulated channels placed on the left side and 45 RZ-DPSK modulated channels placed on the right side of the optical bandwidth. The Q factor of each of the 125 wavelengths is depicted in Fig. 5.

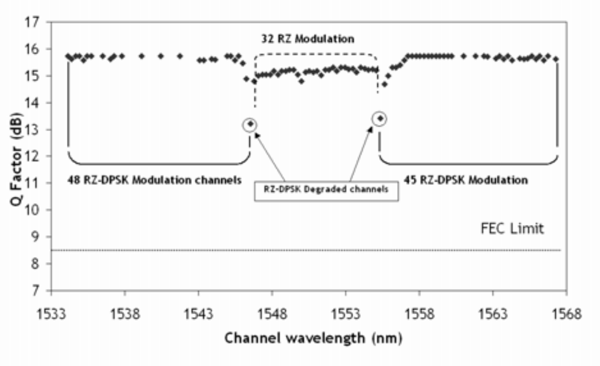

Fig.5 48 + 45 x 10 Gbps RZ-DPSK channels + 32 x 10 Gbps RZ-OOK channels, Q factor measurements - 4300 km NZDSF.

The experimental results show that the RZ-DPSK channels adjacent to the RZ-OOK channels experience a 1.5 dB Q factor degradation due to non-linear interactions with the RZ-OOK modulation [5].

Therefore, a second experiment is carried out with removal of the RZ-DPSK channels # 48 and # 81 to provide a guard band of 66 GHz between the RZ-OOK modulated wavelengths and the RZ-DPSK modulated wavelengths. The transmission results are depicted in Fig. 6.

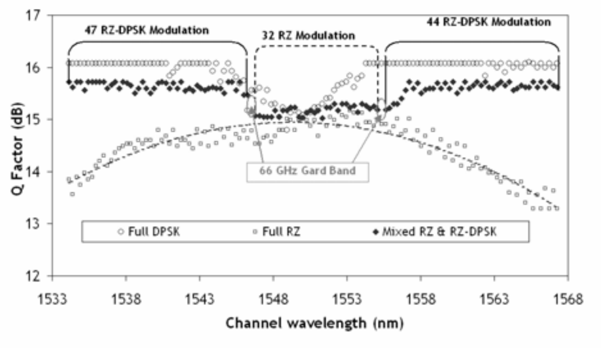

Fig.6 47 + 44 x 10 Gbps RZ-DPSK channels + 32 x 10 Gbps RZ-OOK channels, Q factor - 4300 km NZDSF.

125 x 10 Gbps RZ-DPSK channels and 125 x 10 Gbps RZ-OOK channels, Q factor - 4300 km NZDSF

For comparison with the mixed transmission experiment, the Q factor measurements with RZ-DPSK modulation only and RZ-OOK modulation only are also reported in Fig.6, confirming the Q factor degradation of the center RZ-DPSK modulated wavelengths already reported over 9128 km NZDSF in the above section.

It can be noted that the removal of the two adjacent RZ-DPSK channels permits to achieve better performances for RZ-DPSK channels since these RZ-DPSK channels exhibit an average and a minimum Q factors respectively of 15,6 dB and 15,2 dB. The 66 GHz guard band is enough, and RZ-DPSK channels adjacent to the RZ-OOK channels have no more Q factor degradation.

Concerning the 32 RZ-OOK channels, after a suited channels pre-emphasis, the average and minimum Q factors obtained are respectively 15,2 dB and 15 dB, which is in-line with the performance obtained with full 125 RZ-OOK modulated wavelengths in this part of the multiplex.

Finally, with this mixing of channel modulation formats, the overall transmission performance is optimized.

5 CONCLUSION

RZ-DPSK modulation format is confirmed to perform better than RZ-OOK modulation format for ultra-long-haul system using DSMF mapping. However, for NZDSF links, RZ-OOK modulation format performs as well or even better for the wavelengths located close to the zero chromatic dispersion wavelength. It has been also demonstrated that for such NZDSF links, the mixing of RZ-OOK and RZ-DPSK modulations can provide an optimized solution.

6 REFERENCES

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