DESIGN METHODOLOGIES FOR 25 GHz SPACED RZ-DPSK SYSTEMS OVER CONVENTIONAL NZ-DSF SUBMARINE CABLE

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Abstract: In order to increase the capacity of existing submarine cable systems cost-effectively, upgrade methodologies are discussed considering various fibre types, modulation formats, bit-rates, and FEC. As an example of an upgrade scenario, 25 GHz spaced 10 Gbps RZ-DPSK over legacy fibre was closely investigated. The experimental results showed excellent Q performance over the whole waveband after 8,329km transmission. However the Q performance around a system's zero-dispersion region is degraded as the periodic dispersion compensation length reduces. In addition, 40 Gbps RZ-DQPSK transmission around a system's zero-dispersion region is examined. These results suggest that nonlinear phase matching between the signals and ASE probably plays the primary role in the zero-dispersion region, resulting in a strong dependency on the dispersion map. The possibility of electrical dispersion compensation at the transmitter and receiver is also discussed.

1. INTRODUCTION

Expanding existing submarine cable systems beyond their original capacities by upgrading the line terminal equipment is essential for economic reasons. Also replacing the existing transponders with newly developed transponders has the further user benefit of reducing the operating costs due to power consumption, equipment footprint etc.

40 Gbps RZ-DPSK (Return to Zero Differential Phase-Shift Keying) and RZ-DQPSK (RZ Differential Quadrature Phase-Shift Keying) technologies [1-3] are one way to increase the capacity in an existing system which has a large performance margin. Furthermore, the digital coherent technologies such as DP-BPSK (Dual Polarization Binary Phase-Shift Keying), SP-QPSK (Single Polarization QPSK), and DP-QPSK make feasible the transmission of 40 Gbps signals over trans-oceanic distances [4]. Strong FEC based on LDPC (Low Density Parity Check) technology [5] will be a key enabler to realize 40 Gbps submarine cable systems.

On the other hand, it is also known that 40 Gbps signals are very sensitive to fibre nonlinear effects in long-haul systems regardless of the modulation format. Also, commercially available FEC for 40 Gbps is weaker than that for 10 Gbps. Therefore, especially for long-haul legacy-fibre systems, 10 Gbps RZ-DPSK modulation with strong FEC [6] can be the best solution from the points of view of total capacity, implementation cost and stability. RZ-DPSK modulation promises to improve the OSNR margin by 3 dB, which makes it possible to double the capacity of 10 Gbps RZ-OOK (RZ On-Off Keying) systems. Since the channel spacing of existing systems is typically 50 GHz, the target channel spacing for RZ-DPSK should be 25 GHz.

The dispersion map of the wet plant cannot be changed for existing systems, but the dispersion compensation value and its implementation at the dry plant can be re-designed to optimise for new modulation formats using the latest dispersion compensation techniques.

For these reasons, it is important to investigate intensively the transmission performance of RZ-DPSK at reduced channel spacing on typical legacy non-dispersion-slope-matched fibre installed around 2000, including the use of electrical dispersion compensation. It has been reported that RZ-DPSK carriers are sensitive to nonlinear effects near the system's zero-dispersion region [7, 8], even though RZ-DPSK exhibits superior tolerance to accumulated dispersion [9-11]. This paper reports an experimental study into the dependency of 10 Gbps RZ-DPSK transmission performance on a range of dispersion maps for 25 GHz spaced DWDM systems over legacy long-haul non-dispersion-slope-matched fibres. The technical potential of electrical dispersion compensation techniques and 40 Gbps transmission are also discussed.

2. EXPERIMENTAL SETUP

The experimental setup is shown in Figure 1. The 48 CW laser-diodes were arrayed between 1549.32 and 1558.78 nm with a channel spacing of 25 GHz. The RZ-DPSK signals were generated in two Mach-Zehnder LN modulators: one for the RZ pulse carver and the other for the DPSK modulation. The even and odd channels were separately modulated with 10 Gbps PRBS 31 signals, and also separately low-speed polarization scrambled at around 1 MHz, before being combined in an interleaver.

The 643 km fibre loop consisted of 16 EDFA repeaters, 12 NZ-DSF (Non-Zero Dispersion Shifted Fibre) spans of fibre and two SMF (standard Single Mode Fibre) spans. The average span length, span loss, effective area, dispersion at 1550 nm, and dispersion slope of the NZ-DSF spans were respectively 45 km, 10.5 dB, 70 μm^2, -0.25 ps/nm/km and 0.108 $ps/nm^2/km$. The residual dispersion was compensated by two spans of SMF. The line system's zero-dispersion wavelength was 1552.52 nm, which corresponds to Ch. 17. The gain, output power and noise figure of each EDFA repeater were 10.5 dB, -7.3 dBm/ch and 4.5 dB, respectively.

A polarization scrambler was inserted into the loop to emulate every state of polarization in the loop, and was driven by a low speed loop-asynchronous signal. At the receiver, the required signal was extracted using an interleaver and an optical filter.

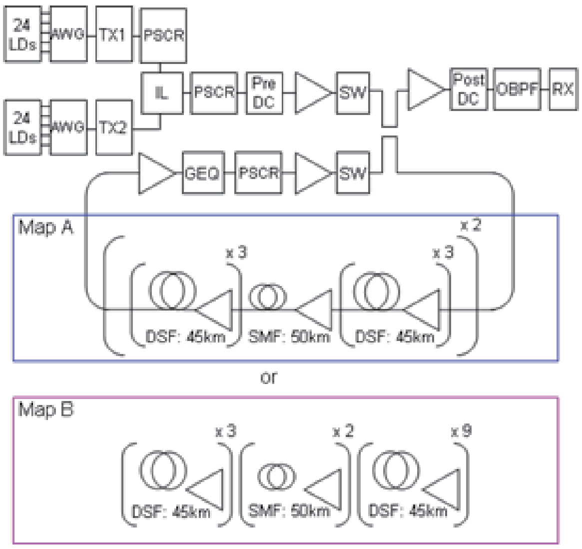

Figure 1: Experimental Setup

In order to investigate the impact of the dispersion map, we compared the two dispersion maps shown in Figure 2. Maps A and B have different periodic dispersion compensation lengths of 321 km and 643 km. The post- and pre- dispersion compensation values were also altered to shift the cumulative dispersion in the transmission fibre.

Figure 3 shows a view of the 10 Gbps DPSK transponder card.

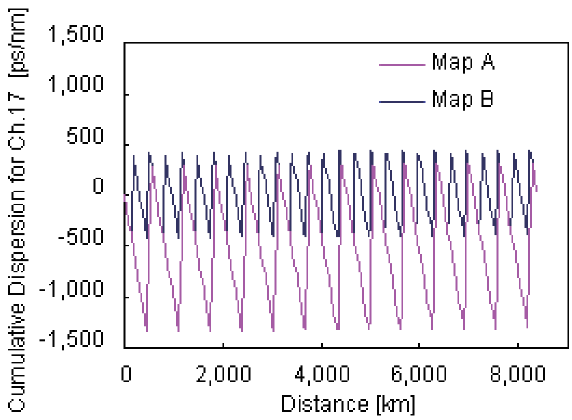

Figure 2: Two Dispersion Map Arrangements

Figure 3: DPSK Transponder Card

3. RESULTS

Figure 4 shows for Map B the received spectrum at 8,359 km. The average OSNR was 11.8 dB, which agreed well with the value calculated from the repeater parameters.

Figure 5 shows the measured Q for Ch. 17, the worst-Q channel, after 8,359 km transmission, as a function of the pre-dispersion compensation value for Map A. The cumulative dispersion in the transmission fibre is always negative and does not cross zero-dispersion provided the negative pre-dispersion value is greater than -320 ps/nm. The Q factor was maximum with pre-dispersion compensation of -500 ps/nm and post-dispersion compensation of +500 ps/nm. The maximized Q was about 0.5 dB better than that with pre- and post- dispersion compensations of 0 ps/nm. Although the effect is not large, such optimization can be useful in an already existing transmission fibre.

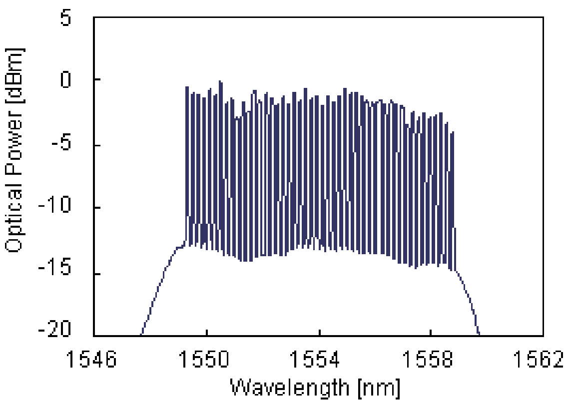

Figure 4: Received Optical Spectrum

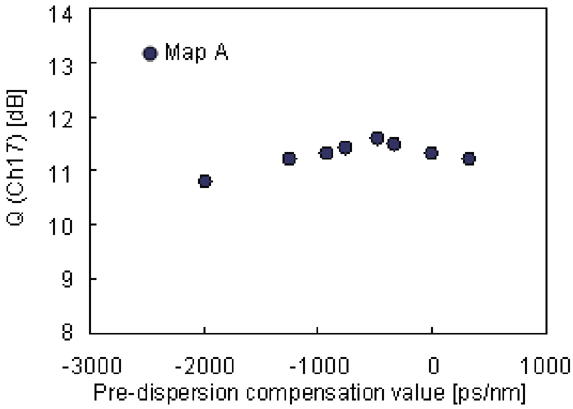

Figure 5: Q Factor vs. Pre-Dispersion Value

The measured Q factors of all channels for Maps A and B are shown in Figure 6. The transmitted spectral shape for Map A was pre-emphasized to maximize the transmission Q of each channel. Figure 6 clearly shows that the transmission performance was degraded around the system's zero-dispersion region with Map A, while excellent performance was obtained from Map B. The period of the dispersion compensation appears to be more important than the pre- and post-dispersion arrangement.

The average and worst Qs after 8,359 km transmission with Map B were 13.7 dB and 13.2dB, which is approximately 5 dB better than the limit of typical FECs.

Figure 7 shows the measured Qs of Chs. 2, 17, and 35 for Map B as a function of the transmission distance. The Q factor of Ch. 17 was degraded compared to the other channels as transmission distance increased and the Q difference was 1.2 dB after 9,600 km transmission.

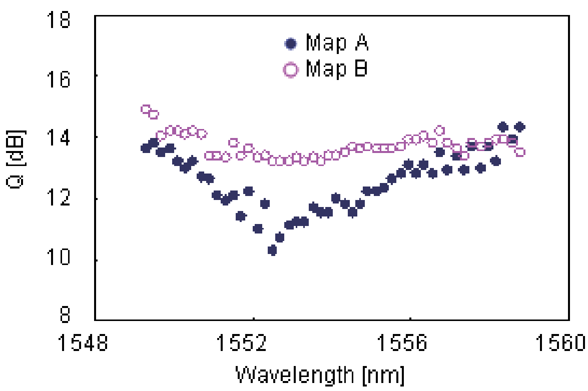

Figure 6: Q Factors of Maps A and B

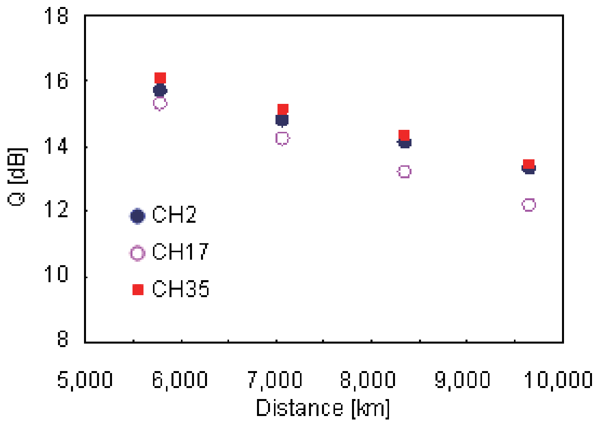

Figure 7: Q Factors vs. Transmission Distance

4. DISCUSSION

Degradation of the transmission performance near the system's zero-dispersion region was confirmed when 25 GHz spaced RZ-DPSK wavelengths were transmitted over non-dispersion matched fibre with a repeater output power of -7.3 dBm/ch and a dispersion compensation period of 321 km. The experiment also verified that the transmission performance can be improved by using a longer dispersion compensation period of 643 km, which supports the theoretical work [7]. These experimental results suggest that the interplay among chromatic dispersion, Kerr nonlinearity, and ASE noise has a significant impact on system performance and plays the primary role in the zero-dispersion region, resulting in the strong dependency on the dispersion map [12-15]. Even for the worse dispersion map with a 321 km period, having unbalanced pre- and post- dispersion compensation was confirmed to be helpful in reducing the penalty. From this point of view, the electrical dispersion compensation at the transmitter is useful to optimize the pre-dispersion compensation value.

Figure 8 shows the Q factors of 50 GHz spaced 48 x 40 Gbps RZ-DQPSK 3,215 km transmission for the dispersion compensation period of 321 km. No significant Q degradation around the zero-dispersion region was observed probably because the shorter dispersion length of 40 Gbps signals compared to the 10 Gbps signals mitigate the accumulation of the nonlinear phase noise [15].

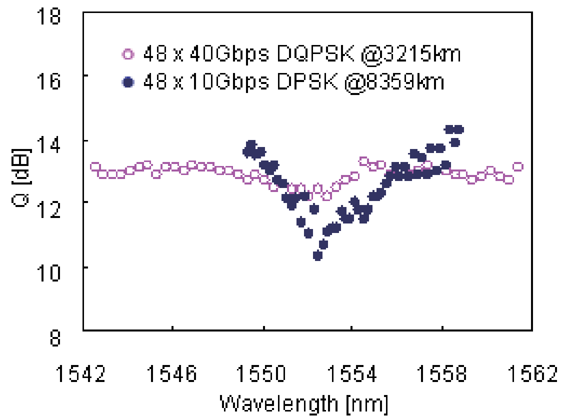

Figure 8: Q Factors of 48 x 40 Gbps Transmission

5. CONCLUSION

We report an experimental study on the dependency on the dispersion map of RZ-DPSK transmission performance in a 25 GHz spaced DWDM system, which agrees well with a theoretical study.

Careful investigation, including that of the migration scenario, is required when upgrading to the ultimate capacity using RZ-DPSK, because system parameters such as the OSNR, the bandwidth of the repeaters, and the dispersion map of the fibre are different in each system.

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