BALANCE OF X AND Y POLARISATIONS IN COHERENT TRANSMISSION

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Abstract: The signal distortion of a polarisation-multiplexed coherent signal due to the unbalanced performance of the two cross-polarised signal components caused by the transponder itself and by PDL in the fibre link was studied experimentally using a 40 Gbps PM-QPSK transponder. OSNR variation of the individual polarisations degraded the overall Q performance, whereas the digital signal processing in the transponder did not cause additional degradation even after imperfect transmission.

1. INTRODUCTION

Expanding existing submarine cable systems beyond their original capacities by upgrading the line terminal equipment is highly desirable for economic reasons. One way to increase the capacity in an existing system is to replace the original 10 Gbps transponders with 40 or 100 Gbps transponders. However, many transoceanic systems operating with merely adequate margins require advanced modulation and strong forward error correction (FEC) when seeking to increase the capacity by adding wavelengths.

One candidate for upgrading existing 10 Gbps systems to 40 or 100 Gbps is a coherent technology such as polarisation-multiplexed phase-shift keying [1, 2]. However, it is well known that coherent signals having two orthogonally polarised components are very sensitive to fibre nonlinear effects in long-haul transmission [3-5]. A polarisation-multiplexed coherent signal is also distorted by any imbalance in the performance of the two cross-polarised components caused by the transponder or by polarisation dependent loss (PDL) in the fibre link. Extensive transmission performance investigations have been made into the interplay between PDL and fibre nonlinear effects [6-9]. PDL may degrade a polarisation-multiplexed coherent signal by unbalancing the performance of the cross-polarised components and causing a bit by bit variation in the state of polarisation (SOP), referred to as “loss of orthogonality” in previous work [8, 9]. It is important when designing a system to investigate not only the average performance, but also the performance of each individual polarisation. It should be noted that unbalanced performance of the polarisations could also be caused by imperfections in the transponder.

In this paper, we report an experimental study of the unbalanced performance of orthogonally polarised signal components caused either by the transponder or by differential transmission performance, focusing on the individual polarisations. These experiments revealed the possibility of degradation by unbalanced performance of the polarisations due to either the transponder or PDL in the fibre link.

2. INVESTIGATION OF DEGRADATION DUE TO UNBALANCED PERFORMANCE OF POLARISATIONS

Both the Q and the Q time variation of a coherent signal comprising a pair of cross-polarised components are subject to degradation by imbalance in the performance of the polarisations due to either imperfections in the transponder or polarisation-dependent effects such as PDL and polarisation dependent gain (PDG).

The total power in a polarisation-multiplexed coherent signal is unaffected by any of the polarisation dependent effects because it comprises two orthogonally polarised components. The Q of such a coherent signal is the sum of the Qs of the X- and Y-polarisations, and its degradation by polarisation dependent effects is caused by degradation of the OSNR in one polarisation, and by variation of the SOP, which latter leads to imperfect demultiplexing of the two cross-polarised components during digital signal processing. Imbalance in the performance of the two polarisations can also be caused by imperfections in the transponder itself. We studied the Q degradation due to unbalanced performance experimentally.

Effects of SOP and Power Variation

Figure 1 shows the test set-up. Amplified spontaneous emission (ASE) noise was coupled onto a 40 Gbps polarisation-multiplexed quadrature phase-shift keying (PM-QPSK) signal, and polarisation scrambling at 170 Hz was applied via the polarisation scrambler (PSCR). The PDL simulator is variable from 0 to 2.5 dB. The pre-FEC bit error ratio (BER) was measured after the arrayed wavelength grating (AWG) demultiplexer. It was found that the OSNR of each polarisation was unchanged even after inserting PDL. Therefore, this experiment can evaluate the Q degradation due to changes in the SOP and the received optical power separately for each polarisation.

The Q factor was 7.0 dB without PDL and no Q degradation occurred even when 2.5 dB of PDL was inserted. This shows that varying the SOP and the power of each polarisation do not degrade the digital signal processing by the transponder.

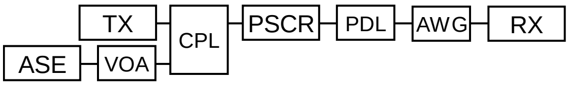

Figure 1: Test Setup for Variation of SOP

Effect of OSNR Degradation

The PDL was then inserted before the ASE noise, as shown in Figure 2. This simulated performance imbalance due to PDL in the fibre link or transponder imperfections. The relative optical powers of the polarisations varied in time with the PSCR, such that with PDL the relative OSNRs of the polarisations also varied due to the ASE noise. The received optical power of the 40 Gbps PM-QPSK signal remained constant, even when the degree of PDL was altered.

The test results and the calculated Q factors based on the OSNR degradation of each polarisation are shown in Figure 3. The measured Q factor was degraded by 0.4 dB with 2.5 dB PDL, which is 0.1 dB better than the calculated overall Q factor. The Q factors calculated with 2.5 dB of PDL were 7.2 dB overall, and 8.8 dB and 6.0 dB respectively for the two polarisations.

This result shows that OSNR variation of an individual polarisation will on its own degrade the overall Q factor.

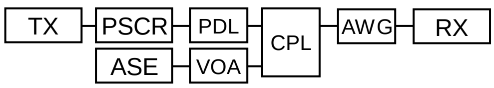

Figure 2: Test Setup for Differential Q

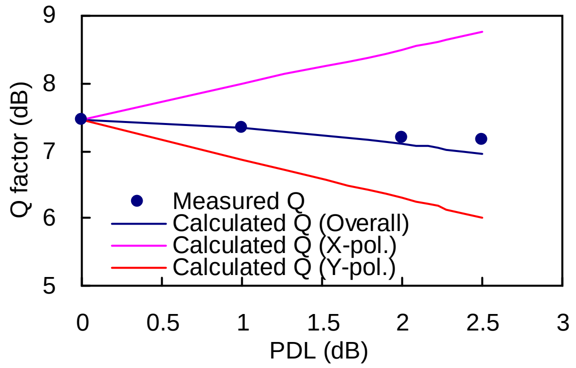

Figure 3: Q Factor as a Function of PDL

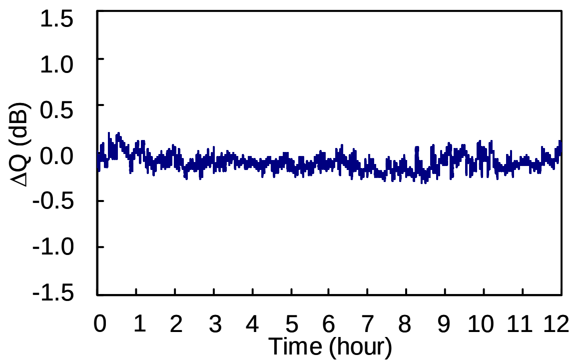

Figure 4: Q Time Variation after Transmission

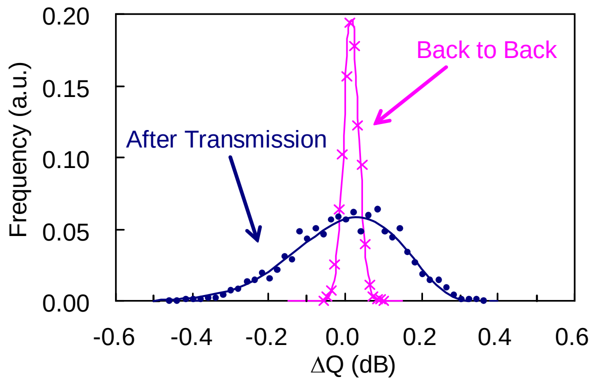

Figure 5: Histogram of Q Factors after Transmission

3. STABILITY OF REAL-LIFE 40 GBPS PM-QPSK TRANSMISSION

The post-transmission Q performance was evaluated using a 40 Gbps transponder with a 0.02 dB standard deviation of back to back Q factor. The Q difference between the polarisations was less than 0.1 dB. A 40 Gbps PM-QPSK signal at 1541.15 nm was transmitted over legacy long-haul non-dispersion slope matched fibre along with 8 continuous-wave (CW) lights spaced at 200 GHz. ASE noise was added at the transmit side to evaluate the performance with reduced OSNR. The optical powers of the 40 Gbps PM-QPSK signal and the CW lights were respectively 0 and 5.9 dBm/ch. The Q factor of the 40 Gbps PM-QPSK signal was measured for 12 hours at one second intervals, and is plotted in Figure 4. The average Q factor and its standard deviation were 8.6 dB and 0.10 dB.

Figure 5 is a histogram of the measured post-transmission Q factors, the horizontal axis being the difference from the average Q factor. The back to back Q distribution is also shown in this figure. The post-transmission Q is slightly down on the back to back value, and closely fits a Maxwellian distribution. It is considered that the Q variation is due to PDL in the transmission fibre, which also has a Maxwellian distribution, and that the digital signal processing in the transponder did not cause any additional Q variation.

4. CONCLUSIONS

The Q degradation due to performance imbalance between two orthogonal polarisations caused by the transponder and by PDL in the fibre link was studied experimentally using a real 40 Gbps PM-QPSK transponder. The OSNR variation of each polarisation due to the PDL and transponder imperfections degraded the Q performance. The digital signal processing in the transponder did not cause any additional degradation even after imperfect transmission.

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