Transmission of 80 Gbit/s over 840 km in standard fibre without polarisation control

G.E. Tudury, R. Salem, G.M. Carter and T.E. Murphy

Error-free pseudolinear transmission of 80 Gbit/s single-channel data over 840 km of standard fibre without optical regeneration, forward-error correction or polarisation control is described. Gated autocorrelation and spectral measurements reveal that the performance is limited primarily by the optical signal-to-noise ratio, rather than dispersion or nonlinearity.

Introduction: At speeds of up to 40 Gbit/s, there has been a significant effort to conduct laboratory transmission experiments that accurately simulate the polarisation effects that occur in deployed fibre systems. In contrast, many of the ground-breaking high-speed optical-time-division multiplexed (OTDM) transmission experiments have implicitly required manual polarisation control either after the transmitter or before the receiver [1–5]. One reason for this discrepancy is that many of the optical clock recovery and demultiplexing schemes used at speeds of beyond 40 Gbit/s are polarisation-dependent and therefore require an established input polarisation state at the receiver. Also, because of the stringent requirement on fibre dispersion, OTDM experiments often use polarisation-interleaved multiplexing [4] and sometimes polarisation based demultiplexing to mitigate intersymbol interference that would otherwise result from uncompensated dispersion. Finally, to overcome the effects of PMD and PDL, many high-speed systems require that the signal be launched along a principal polarisation state of the fibre [5]. In this Letter, we describe an 80 Gbit/s transmission experiment that achieves error-free operation after 840 km without requiring any manual polarisation control in the transmitter or receiver.

System description: Fig. 1 shows the experimental setup of the 80 Gbit/s recirculating loop. Data pulses with duration of 2.6 ps were generated using a 10 GHz modelocked fibre laser, which was passively multiplexed to 40 GHz and on–off modulated with a 2^{23}–1 pseudorandom binary data sequence. One additional multiplexing stage was employed to produce an 80 Gbit/s data sequence. All multiplexing stages used polarisation-maintaining fibres to ensure that the interleaved pulses all have the same polarisation state. The resulting signal was launched into a 210 km recirculating loop consisting of six dispersion maps. Each dispersion map begins with 10 km of conventional SMF-28 fibre ($D = 17$ ps/nm km, $D' = 0.058$ ps/nm^2 km at 1550 nm), dispersion compensation fibre (DCF), followed by an additional 25 km of SMF-28 fibre. The DCF was selected to compensate for both the dispersion and dispersion slope of the 35 km SMF-28 span. The 7 km length of the DCF in each module is not counted in the total propagation distances claimed here. The average optical power was 0 dBm at the beginning of each dispersion map, and a combination of Raman amplification and erbium-doped fibre amplification was used to compensate for propagation losses.

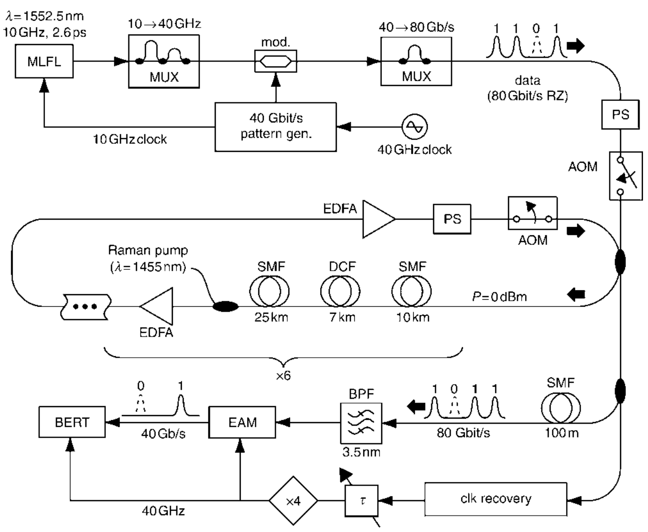

Fig. 1 *80 Gbit/s transmission setup*

Polarisation scrambling was employed both prior to and inside the loop in order to simulate more realistically straight-line performance and prevent spurious performance improvements associated with preferred launch conditions or loop periodicity [6, 7]. The signal emerging from the loop was studied using time-gated optical spectrum, autocorrelation, and bit-error-rate measurements. The OTDM receiver uses a polarisation-independent clock recovery system based on two-photon absorption in a silicon avalanche photodiode [8], followed by polarisation-independent demultiplexing from 80 to 40 Gbit/s in an electroabsorption modulator.

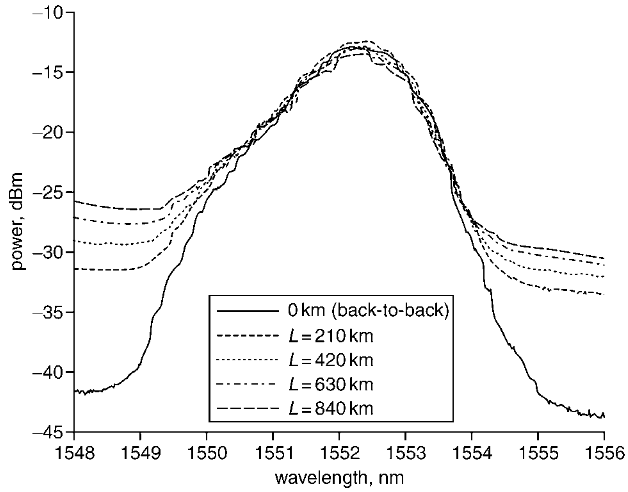

Fig. 2 *Time-gated optical spectra of received signal after 0, 1, 2, 3 and 4 round trips in circulating loop*

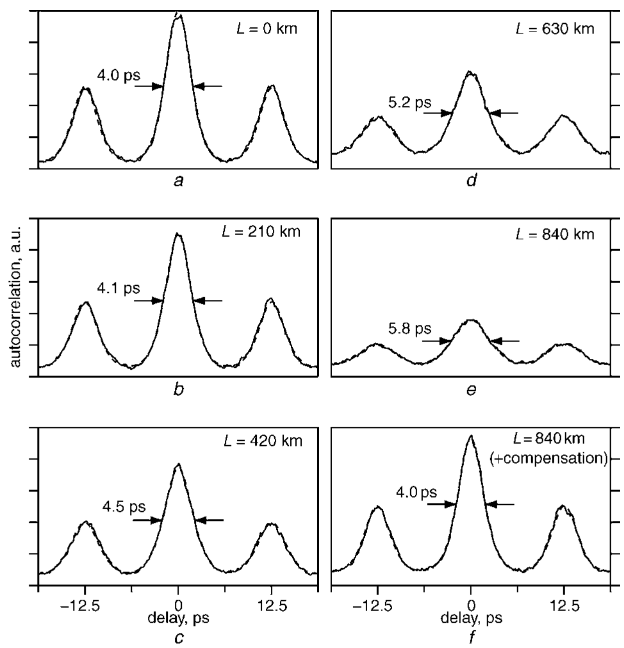

Fig. 3 *Time-gated autocorrelation measurements of 80 Gbit/s data after 0, 1, 2, 3 and 4 round trips*

Final trace shown in *f* depicts autocorrelation after residual dispersion is compensated for by adding 100 m of additional fibre

Results: Fig. 2 shows the optical spectra of the data after 0, 1, 2, 3 and 4 round trips in the loop, measured on a spectrum analyser with a 2 nm resolution bandwidth. While the spectral shape and bandwidth show very little change after propagation, the background noise level accumulates steadily as a result of amplified spontaneous emission. After four round trips (840 km), the ratio of the optical signal power to the noise in a 0.1 nm bandwidth was measured to be 27.7 dB. Based on back-to-back measurements of Q against OSNR with noise injection, we predicted that an OSNR level of 27.7 dB should be sufficient for error-free operation, provided that there are no additional penalties from dispersion or nonlinearities.

Figs. 3*a–e* show the measured autocorrelation traces after 0, 1, 2, 3 and 4 round trips. Although the fibre span was nominally dispersion-compensated, the autocorrelation peak broadens from 4 to 5.6 ps over 840 km, as a result of uncompensated dispersion. By adding 100 m of additional SMF-28 fibre outside the loop to compensate for this residual dispersion, we obtained the autocorrelation shown in Fig. 3*f*, which closely matches the input autocorrelation.

Fig. 4*a* shows the *Q*-value against distance, as determined by measuring the bit-error-rate as a function of the decision threshold. The squares denote the measured *Q*-value obtained without the additional 100 m of post-compensation fibre. The open circles show the performance after 840 round trips with the additional post-compensation fibre. To help separate the roles of dispersion and noise in the system, we compared the *Q*-values observed after propagation to the *Q*-value obtained in back-to-back measurements with the same OSNR levels. The triangles in Fig. 4*a* shows the back-to-back performance obtained with four-different OSNR levels selected to match the OSNR levels that were experimentally observed after 1, 2, 3 and 4 roundtrips. When performing the back-to-back measurements, the OSNR was varied by artificially injecting amplified spontaneous emission noise prior to the receiver. The measurements shown in Fig. 4*a* show that, when the dispersion of the system is fully compensated for, the performance of the system approaches that obtained in back-to-back measurements with the same OSNR, which suggests that in this system the attainable bit-error-rate is limited primarily by accumulated noise. Fig. 4*b* shows the bit-error-rate against threshold voltage after 840 km, confirming error-free operation.

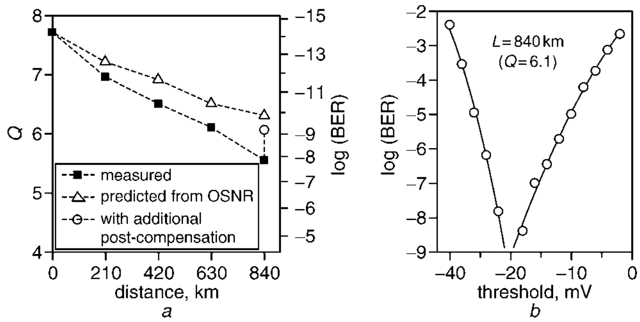

Fig. 4 *Measured Q against distance, and bit-error-rate against decision threshold*

a Measured *Q* against distance
b Bit-error-rate against decision threshold after 840 km transmission, with post-compensation of residual dispersion

Conclusions: We have demonstrated the successful transmission of 80 Gbit/s single-channel data over 840 km of conventional fibre without using any manual polarisation control or tracking in the transmitter or receiver. When the dispersion is fully compensated for, the performance is observed to be primarily limited by the attainable optical signal-to-noise ratio at the receiver.

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