10 Gbit/s ALTERNATE POLARIZATION SOLITON TRANSMISSION OVER 300 km STEP-INDEX FIBRE LINK WITH NO IN-LINE CONTROL

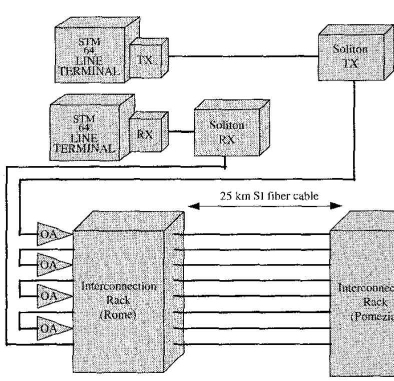
Franco (1), A. Schiffini (1), R. Corsini (1), M. Romagnoli (2), M. Tamburrini (2), S. Cascelli (3)

(1) Pirelli Cavi &Sistemi, viale Sarca, 222, 20126 Milano, Italy. (pierluigi.franco@pirelli.com)
(2) Fondazione Ugo Bordoni, via B. Castiglione, 59, 00142 Roma, Italy. (tambur@fub.it)
(3) Istituto Superiore delle Comunicazioni e Tecnologie dell'Informazione, viale Europa, 190, 00144 Roma, Italy

Abstract. Error-free transmission over a 300 km step-index fibre link between Roma and Pomezia using a 10 Gbit/s stream of alternate-polarization solitons was performed. Standard 10 Gbit/s SDH line terminals were used at the transmitter and receiver sides.

The growing demand for large capacity communication links is facing the problem of the already installed fibre infrastructure around the world that is mostly constituted by step-index (SI) fibres with zero dispersion at 1.3μm. So far dispersion management and/or wavelength division multiplexing have been demonstrated to be suitable solutions for upgrading the existing fibre infrastructure. Those solutions require system adjustment as for instance the introduction of dispersion compensating fibres or, in the case of WDM, an upgrade in terms of number of channels instead of simply increasing the capacity of the single channel that would save in overall transmission bandwidth.

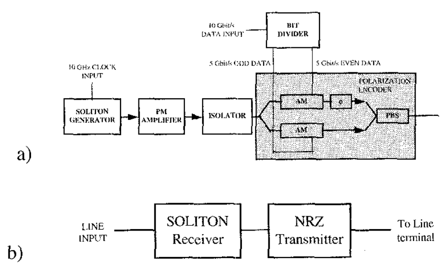
Fig. 1: Line configuration



In this work, conversely, we report an optimized transmission scheme that permits to improve the maximum distance achievable on SI fibre with just a single channel, without resorting to the insertion of in-line components (as for instance chirped gratings, dispersion-compensating fibres, mid-span phase-conjugators, or even synchronous amplitude or phase modulators). The method simply exploits the reduced interaction efficiency experienced by orthogonal solitons to increase the duty cycle in the data stream [1], and it is implemented with a polarization encoder that alternates orthogonal states of polarization in the data stream. The effectiveness of alternate polarization encoding has been theoretically predicted [2] and experimentally verified at 40 Gbit/s over 800 km in a dispersion-shifted fiber setup [3]. The maximum transmission distance achieved with our SI fibre system, based on alternate polarization encoding, was 300 km thus extending the limit of 253 km found with the dispersion supported transmission (DST) technique [4] that is another method of transmission with no in-line control.

The experimental setup is reported in Fig.(2.a). The 5 GHz soliton pulses emitted by the soliton generator have duration adjustable between 45 ps and 65 ps and about -3 dBm of average power. The pulses are amplified by means of a polarization maintaining optical amplifier up to 11 dBm and sent to the polarization encoder.

Fig. 2: a) Polarization encoding source scheme, b) RZ to NRZ converter

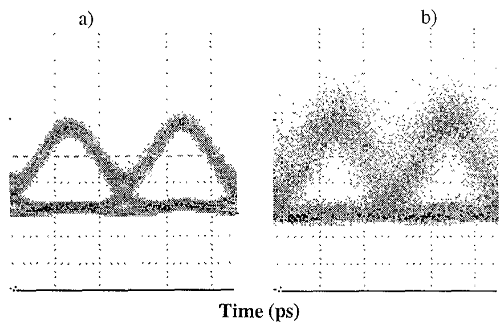


The 10 Gbit/s electrical data are provided by the STM-64 line terminal whose clock also drives the entire setup. The electrical signal is divided into 2x5 Gbit/s electrical bit streams by means of the bit divider. The two 5 Gbit/s electrical bit streams are used to modulate the 5 GHz optical pulse streams by means of Mach-Zehnder modulators. Finally, the two 5 Gbit/s optical pulse streams are time interleaved by introducing a 100 ps differential delay, and combined by means of the polarization encoder. The output of the whole source is a 10 Gbit/s pulse train with adjacent time slots having orthogonal polarization (alternate polarization encoding). A typical eye diagram is reported in Fig.(3.a).

The link is made with a 25 km cable containing also 20 SI fibres (ITU -T G652), looped back in pairs at a transit station in Pomezia (25 km south of Rome) in order to obtain 10 spans of 50 km each. All the terminations of the spans are located in Rome (see Figure 2). The mean attenuation, chromatic dispersion and polarization mode dispersion of these fibres are respectively 0.24 dB/km, D = 16.2

ps/nm/km and PMD = 0.04 ps/km$^{1/2}$. At each span end we introduced a commercially available optical amplifier with a saturated output power of +14 dBm. The maximum polarization dependent gain of the amplifiers was PDG = 0.3 dB, whereas the maximum differential group delay was DGD = 1 ps.

Fig. 3: Eye diagram of the 10 Gbit/s orthogonal polarization coded signal at the output of the transmitter (a) and after 300 km; (b).Horizontal scale 20 ps/div



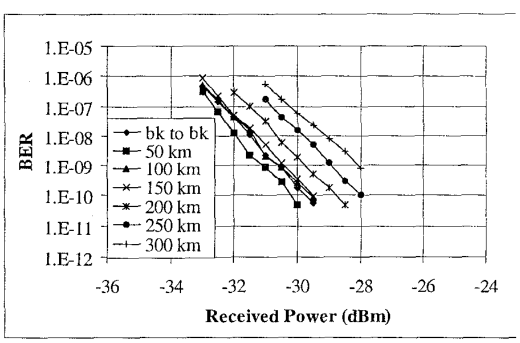
The configuration with all the terminations in the same lab permitted to check the quality of the transmission after each span of 50 km by monitoring the signal just before each amplifier. The soliton pulses at the end of the line were detected by means of a RZ to NRZ converter placed just before the STM-64 line terminal receiver (Fig. 2.b).

The eye diagram obtained after 300 km is reported in Fig.(3.b). As it can be seen, with 50 ps pulses (that is the optimal FWHM pulse duration obtained from numerical simulation of performance evaluation) the eye pattern is quite clean up to 300 km, while for longer propagation distances a good transmission result can not be obtained.

Several parameters were adjusted to get the best result: line input power, amplifiers gain, pulse duration.

The bit error rate (BER) measured by the receiver terminal is reported in Fig.(4) versus the power level at the preamplifier input.

Fig. 4: BER measurement results for the source back to back and after each 50 km.



As shown by BER results, after 200 km the power penalty of the system was 1.5 dB and less then 3 dB at the end of 300 km. In this configuration, after 300 km, a BER below 10^{-9} was achieved with a received optical power of -28 dBm. For comparison we also evaluated the system performance with a 10 Gbit/s bit-error rate test set. We noticed that at 300 km of propagation distance it is possible to reach excellent values of BER measurement down to 10^{-12} with a 2^7-1 word length. With the same word length the transmission up to 500 km is also feasible. These results obtained with the short word suggest that the real limitation of the system arises from some pattern effect that is increasingly efficient the longer the pattern. In fact by resorting to deterministic data stream we found that short patterns are more stable than longer ones.

Conclusion

. We report the longest propagation distance of 300 km obtained at 10 Gbit/s using conventional step-index fibre link without any dispersion compensating technique or in-line signal control but only with optical amplification every 50 km.

Acknowledgments.

M.R. and M. T. have performed this work in the framework of the agreement between Fondazione Ugo Bordoni and the Italian Post and Telecommunication Administration. This work has been partially carried out under the ESTHER project of European Union ACTS programme.

References

/1/ C. De Angelis, S. Wabnitz, M. Haelterman, 'Bandwidths limits due to polarization multiplexed soliton interactions', *Electr. Lett.*, 29, pp.1568-1570 (1993).

/2/ F. Matera, M. Romagnoli, B. Daino, B., 'Alternate polarization soliton transmission in standard dispersion fibre links with no in-line controls', *Electr. Lett.*, 31, pp.1172-1174 (1995).

/3/ F. Favre F., D. Le Guen, M. Moulinard, M. L. Henry, P. L. Francois, F. Devaux, T. Georges,'Single-wavelength 40 Gbit/s, 8x100 km span soliton transmission without any in-line control', *Electr. Lett.*, 33, pp.407-408 (1997).

/4/ B. Wedding, B. Franz, B. Junginger, '10-Gb/s optical transmission up to 253 km via standard single mode fiber using the method of dispersion supported transmission', *J. of Lightwave Tech.*, 12, pp.1720-1727 (1994).