Impact of the polarization mode dispersion on a field demonstration of 40 Gbit/s soliton transmission over 500 km

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Today, one of the targets for research in optical communication is to increase the TDM bit rate up to 40 Gbit/s by keeping a large span loss. In this work, the transmission at 40 Gbit/s has been successfully demonstrated in field on an installed cable 500 km long by using soliton signals with alternate polarizations without any in-line control. This experiment was compatible with a record 24.5 dB span loss. The method of the alternate polarizations consists in the transmission of adjacent pulses with orthogonal state of polarization and it permits to reduce the soliton interaction allowing us to use pulses with longer time duration limiting the instability effects due to the periodical amplification [1-2].

In fig. 1 we report the experimental set-up. The DFB output is launched in the 20 Gbit/s transmitter which uses a tandem-EAM for 10 ps pulse generation and coding. The transmitter is fed with 20 GHz clock signal and 20 Gbit/s data provided by the 10 towards 20 Gbit/s multiplexer. The 20 Gbit/s signal is optically time and polarization multiplexed to obtain a 40 Gbit/s signal with alternate polarizations.

At the transmission output, the signal is time demultiplexed from 40 to 10 Gbit/s by a tandem-EAM. The 10 Gbit/s receiver output is finally sent to a 10 Gbit/s BER and Q factor performance analyzer.

The transmission line is an assembly of 102 km DSF spans (with 24.5 dB loss) and EDFA amplifiers. The average chromatic dispersion was equal to 0.14 ps/nm/km at 1549 nm (0.2 ps/nm/km at 1550 nm), while the average Polarization Mode Dispersion [3] was 0.25 $\mathrm{ps}/\sqrt{\mathrm{km}}$. The PMD of the EDFAs was not measured but was assumed to have a non negligible contribution to the total PMD of the link.

In fig 2. We report the Q factor versus the link length considering 3 different wavelengths with an input power of 8.7 dBm that it was the power that permitted to reach the highest performance. The system permits to achieve good performance up to the distance of 500 km. The main degrations of this link is due to the PMD. In fact the same experimental set-up, operating on an equivalent link installed in a laboratory with a PMD lower than 0.1 ps/$\sqrt{km}$, permitted to reach the distance of 700 km with a Q factor higher than 6. It has to be pointed out that the Q factor showed strong fluctuation in the time for distances longer than 400 km due to the variation of the PMD caused by the variations of the environmental conditions. Conversely the variations of the Q factor around the distance of 200 km at the wavelength of 1549.5 nm are due to the pulse collisions as predicted in ref. [2].

The time fluctuations of the Q factor are shown in figs. 3 and 4 where the Q factor, measured at different times, is reported for the distance of 500 km at the wavelength of 1549 nm (fig. 3) and 1550 nm (fig. 4) with an input power of 8.7 dBm. The figures show two kind of fluctuations: a slow and a fast one. The long term drift can be attributed to the PMD evolution of the buried cable, conversely fast fluctuations are mainly due to the birefringence evolution of the fiber pieces connecting the buried fibers. By considering measurements made during a week we have seen that, even though at both the wavelengths the Q factor can oscillate between 5 and 18, the time in which Q remained under the six value is limited to some minute. Furthermore at 1550 nm the Q factor can assume higher values than at 1549 nm, even if at 1550 nm stronger fast fluctuations are present.

We explain this behaviour in terms of the Self Trapping Effect (STE) [4] that permits the PMD compensation when some conditions due to the Group Velocity Dispersion (GVD), to the Kerr effect, to the PMD and to the pulse duration are satisfied. Numerical simulations of the field experiments, with the method reported in ref. [5], have shown how the nonlinear process of the PMD compensation strongly depends on the realization process of the random mode coupling.

In fig. 5 we report the Q factor obtained by simulations for different realizations (cases) of the random mode coupling assuming two different operating wavelengths (1549 nm and 1550 nm), while the other parameters are the same as in figs. 3 and 4. As shown by the figure, at 1550 nm it is confirmed that at 1550 nm the Q value can assume higher values even though stronger fluctuations are present.

By looking at the pulse shape at the link output, in the presence of the PMD two effects can be present when a pulse is launched into the fiber: a pulse broadening and a group delay depending on the input state of polarization [3]. The latter behaviour can be very detrimental in the case of a soliton system with alternate polarization since it can induce a Differential Group Delay (DGD) between the orthogonal pulses. The STE can only compensate the pulse broadening, as a consequence if the particular realization of the random mode coupling induces a large DGD the system shows a low Q value both at 1549 nm and 1550 nm. Conversely if the DGD is lower than 15% of the bit time a good Q factor can be observed in both the wavelengths but at 1550 nm the conditions are better since the STE is more efficient [5].

In conclusion, a field demonstration of 40 Gbit/s soliton transmission with 102 km - 24.5 dB spans has been carried out over 500 km for the first time. Our results show the detrimental impact of a PMD of 0.25 ps/$\sqrt{km}$ on long term performance of the system.

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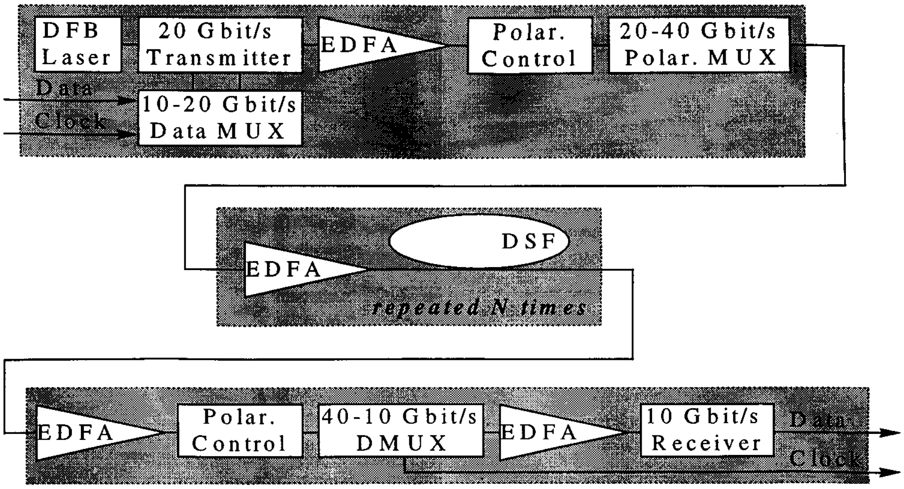

Fig. 1: experimental set-up for the field experiment.

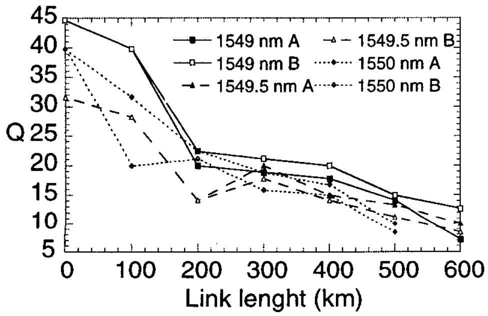

Fig.2 : Q-measurements vs distance for both the 2 orthogonal polarization streams (A and B) for three values of the wavelength and for the input power of 8.7 dBm.

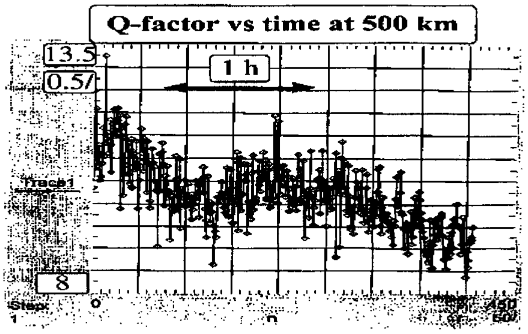

Fig.3 : Q-measurements obtained at different times for the distance of 500 km, for the input power of 8.7 dBm at 1549 nm.

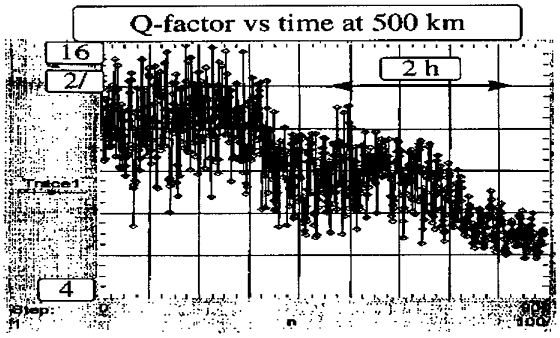

Fig.4 : Q-measurements obtained at different times for the distance of 500 km, for the input power of 8.7 dBm at 1550 nm.

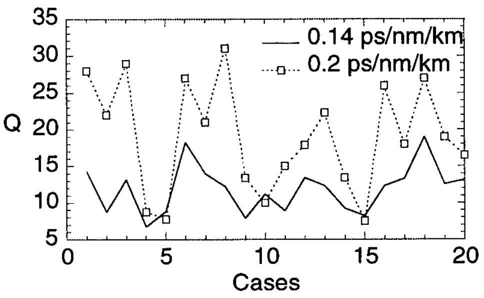

Fig. 5: Q factor vs different realizations of the random mode coupling process for the same link of figs. 3 and 4.