System optimisation of 80Gbit/s single channel transmission over 1000km of standard fibre

V.K. Mezentsev, S.K. Turitsyn and N.J. Doran

The authors have demonstrated by numerical optimisation of a symmetric dispersion map and using nonlinear chirped return to zero modulation format the feasibility of a record 80Gbit/s single channel transmission over 1000km of standard fibre.

Introduction: Over the last decade, an individual channel data rate has continued to grow. Transoceanic transmission distances have already been achieved in single channel experiments for fibre lines based on dispersion shifted fibres at a bit rate of 40Gbit/s. In addition, the problem of increasing a data rate and error free propagation distance in standard monomode fibres (SMF) is becoming very important because of the immediate application to the upgrade of existing terrestrial links. Recently, successful 40Gbit/s transmission over 1000km of SMF has been reported. In this Letter we report the results of the numerical system optimisation of 80Gbit/s transmission over 1000km of SMF.

Transmission simulations: As a sample system for our study we used a symmetric dispersion map (3, 4) (as shown in Fig. 1) similar to the experimental setup. A role of prechirping in such a map is minimised since chirp free points are located exactly at the beginning and at the middle of the map (3, 4). Therefore, input pulse chirp is virtually eliminated from the list of major optimisation parameters. As a matter of fact, precompensation and postcompensation are tuned for largest propagation distance after global system optimisation.

The first half of the dispersion map starts with the SMF transmission fibre followed by the DOF and EDFA amplifier. The second half is a reverse mirror of the first half. Fibre parameters are listed in Table 1. The two EDFA amplifiers are deployed symmetrically to provide a compensation of energy losses. The inline optical bandpass filter with bandwidth 1.4THz follows each amplifier.

Table 1: Fibre parameters

<table>
<thead>
<tr>
<th>Fibre</th>
<th>SMF</th>
<th>DCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispersion [ps/nm/km]</td>
<td>15.8–17.3</td>
<td>-84</td>
</tr>
<tr>
<td>Dispersion slope [ps/nm²/km]</td>
<td>0.064</td>
<td>-0.23</td>
</tr>
<tr>
<td>Effective area [µm²]</td>
<td>80</td>
<td>25</td>
</tr>
<tr>
<td>Loss coefficient [dB/km]</td>
<td>0.22</td>
<td>0.65</td>
</tr>
</tbody>
</table>

A system performance analysis was carried out in terms of the maximum propagation distance corresponding to a bit error rate (BER) less than $10^{-9}$. BER was estimated by means of a Q-factor. The data stream was modelled by periodic bit patterns consisting of a pseudo-random sequence of 128 or 256 Gaussian pulses.

Pattern propagation over transmission and compensation fibres was simulated by a nonlinear Schrödinger equation with the effects of third-order dispersion and Raman gain included. The action of EDFA amplifiers was taken into account by introducing ASE noise to a signal with a typical noise figure of 4.5.

To reach the maximum possible transmission distance, model system and pulse parameters were optimised. It was found that an initial pulsewidth of ~3ps provides the best system performance, and therefore most optimisations were performed for this pulsewidth.

Results: An instant detection at every numerical step was performed to locate the maximum propagation points inside the map period. Fig. 2 shows an evolution of Q-factors along the transmission line for the longest error free transmission achieved. Sharp peaks located near amplifiers marked with vertical gridlines correspond to the best system performance. It turns out that peaks of maximum Q-factor gradually drift away from amplifier locations and eventually take off the amplifier location at $Q = 6$, which is required for error free detection. Such a walk off of the maximum performance points cannot be eliminated by prechirping of the initial pulse or by moving a launch point along the periodic map. An optimum detection offset depends on distance and average dispersion of the map. Detector offset tolerance can be expressed as the width of the peak at $Q = 6$ and it decreases with distance starting at a value of 2km at the first few sections down to zero. Therefore the last couple of peaks are unlikely to be resolved in experiment because of low offset tolerance and BER being barely lower than the required value. The optimal detector locations are shown in Fig. 3. The optimal detector offsets are plotted in terms of accumulated dispersion $D_n = D(z_n) - D_{z_0}$ against number of periods passed $n$, where $D$ is the dispersion of SMF, $z_0$ is the location of the maximum Q-factor and $z_n$ is the amplifier location. These results suggest a simple recipe of postcompensation to match an accumulated dispersion of the post-compensating fibre to the value $D_n$ and to provide the best system performance exactly at the end of the line.

To study the dispersion tolerance, the map average dispersion was varied by means of changing the dispersion of the SMF fibre. The reason for such an approach is to minimise optimisation of the energy balance between fibre losses and amplifier gain. However, in the experiment, a similar purpose is usually achieved by varying the length of the standard fibre or by adjusting the operating wavelength. Note that from the system optimisation standpoint both approaches are equivalent.

Once the fibre configuration and pulsewidth are chosen, the only two essential parameters remain in the problem. One parameter, the average or residual dispersion, characterises the map, while another parameter, peak power, is a signal property.

\[ Q = \frac{1}{\sqrt{1 + \left(\frac{I}{P_0}\right)^2}} \]

Where $I$ is the instantaneous power and $P_0$ is the power at the amplifier location.

\[ D_n = D(z_n) - D_{z_0} \]

Where $D(z_n)$ is the dispersion at the amplifier location $z_n$ and $D_{z_0}$ is the dispersion at the input point $z_0$.
A complete optimisation in the two-dimensional parameter space has been performed. It was found that there exists an island in the power-dispersion plane of stable propagation for slightly anomalous average dispersion. A maximum propagation distance >1300 km (including DCFs) is achieved for a peak power of 4.5 mW for an average dispersion of 0.015 ps/nm/km. A contour plot of the maximum propagation distance against peak power and average dispersion is shown in Fig. 4. Note that the system is tolerant to large peak power variations between 4 and 11 mW. In all such cases the error free propagation distance >1200 km. The system performance is apparently limited by the ASE noise in the low power case and by nonlinear interaction between neighbour bits in the high power case. The maximum propagation distance is achieved in the region of slightly anomalous average dispersion and finite input peak power, which demonstrates that the nonlinear chirp return to zero (NCRZ) modulation format is the best possible candidate to increase system performance in high bit rate transmission over SMF-based fibre links.

**Conclusion:** A system optimisation of the standard fibre transmission line has been performed to increase the total propagation distance. An 80 Gbit/s bit stream is able to propagate over 1000 km of standard fibre. The optimised system and pulse parameters found here can be used to increase the transmission distance in periodic dispersion map experiments and in field trials. The results may also be used for upgrading existing lines based on standard fibres.

© IEE 2000

Electronics Letters Online No: 20001364
DOI: 10.1049/el:20001364

V.K. Mezentsev, S.K. Turitsyn and N.J. Doran (Photonics Research Group, School of Engineering and Applied Science, Aston University, Aston Triangle, Birmingham B4 7ET, United Kingdom)

E-mail: v.mezentsev@aston.ac.uk

**References**