

# Performance evaluation of 20 Gbps single-channel dispersion-managed soliton transmission

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The performance of 20 Gb/s single-channel dispersion-managed soliton (DMS) transmission over 10,000 km using two different types of dispersion maps is evaluated. The combination of standard single-mode fiber (SSMF) and dispersion compensating fiber (DCF) and standard single-mode fiber (SSMF) and reverse dispersion fiber (RDF) are used to make the dispersion maps. The performance of the system is analyzed by the Q-factor and eye-patterns.

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## 1. Introduction

Rapid developments have taken place within the last few years in the research and development of long-haul (trans-oceanic) optical fiber communication systems [1]. Optically amplified systems are now a commercial reality, creating path lengths of several thousands kilometers. Aggregate system capacity has been dramatically increased by using wavelength-division multiplexing (WDM) transmission technologies; data rate has exceeded 100 Gb/s even for transoceanic applications [2-5]. Soliton communication is a leading candidate for long-haul lightwave transmission links because it offers the possibility of dynamic balance between group-velocity dispersion (GVD) and self-phase modulation (SPM), the two effects that severely limit the performance of non soliton systems [6]. In such systems, soliton WDM transmission is quite attractive; because soliton based systems have potential to carry higher channel bit rate signals than non return-to-zero (NRZ) systems. They need a smaller number of channels for the same system capacity. The key technological issues in soliton WDM transmission are the reduction of collision-induced timing jitter and four wave mixing. To mitigate these effects, several techniques, such as dispersion tapering fiber spans [7-9], sliding frequency guiding filters and inline synchronous modulation have been proposed.

Network-service providers have to evaluate the performance of different fibers to meet future traffic requirements, while installing new transmission lines. Mostly, two types of optical fibers are available at present for high bit rate, long-haul transmission systems. One is standard single mode fiber (SSMF) and other is non-zero

dispersion fibers (NZ-DSFs). Recent capacity of commercial terrestrial systems increased up to several terabits per second [10-13] over thousands of kilometer distance.

Dispersion-managed solitons (DMS) are likely to become a key enabling technology for the long-distance, high speed optical fiber communication systems when the single channel bit rate is increased to 160 Gb/s [14]. To support dispersion-managed solitons at high bit rates, it is necessary to use a dispersion map, where one amplifier span consists of many dispersion-managed periods [15-16].

In this paper a 20 Gb/s single-channel RZ dispersion-managed soliton transmission over 10,000 km using two different dispersion map is simulated and performance is analyzed for different transmission lengths in terms of Q-factor and eye-diagram. The goal of this study to compare the performance of two different types of dispersion maps for long-haul soliton transmission.

## 2. Experimental setup

The schematic diagram is shown in Fig. 1. A single channel (at 1550 nm) 20 Gb/s RZ soliton transmission over 10000 km long fiber span using EDFA as in-line amplifier is considered. In transmitter, a 20 Gb/s optical soliton data stream was produced by time-division-multiplexing 10 Gb/s RZ data pulses which were generated with a DFB-LD, a sinusoidally-driven electroabsorption (EA) modulator and two LiNbO<sub>3</sub> intensity modulators operated at 10 Gb/s by a 2<sup>15</sup>-1 pseudorandom bit sequence. The pulse width obtained was

10–15 ps. In addition, each 20 Gb/s OTDM signal was modulated at 20 GHz by a LiNbO<sub>3</sub> phase modulator in order to improve transmission characteristics. To reduce the soliton interaction, an in-line optical filter with a bandwidth of 1800 GHz is also inserted at every amplifier location.

RZ-format is used because it has a few advantages over the NRZ-format, mainly because it can better withstand the impact of fiber nonlinearity and polarization mode dispersion (PMD). But, in this paper the impact of PMD is not taken into account because it affects more the performance of high bit-rate systems. The schematic diagram of first dispersion map is shown in Fig. 2.

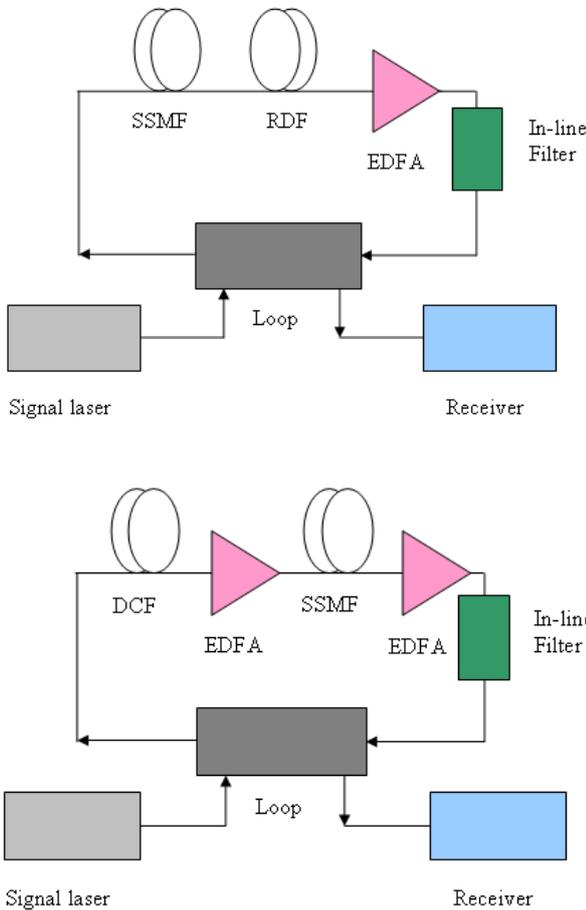


Fig. 1. System configurations (each with 250 spans).

It is composed of the combination of standard single-mode fiber (SSMF) and reverse dispersion fiber (RDF). In this dispersion map  $D_1$  and  $D_2$  are the dispersion of fiber of both the sections respectively. The lengths of these two sections are  $L_1$  and  $L_2$  respectively and  $L_1 + L_2 = L_{map}$ , where  $L_{map}$  is known as the period of the map. It is numerically investigated that soliton interaction between

neighboring pulses can be minimized by arranging the GVD profile such that it satisfies the condition; map strength ( $S$ ) = 1.65 in a lossless case. Map strength can be defined as

$$S = \frac{\lambda^2}{2\pi c} \frac{(D_1 L_1 - D_2 L_2)}{T_{FWHM}^2}$$

and the average dispersion of the DMS can be defined as

$$D_{avg} = \frac{(D_1 L_1 - D_2 L_2)}{L_1 + L_2}$$

The average dispersion  $D_{avg}$  for the first dispersion map is 0.25 ps/nm/km and the length of the two fiber segments used is 20 km each. Amplifier distance for both the dispersion maps is taken equal to the map period. For the second dispersion map, SSMF + DCF is used as shown in the Fig. 3. The average dispersion  $D_{avg}$  for this combination is 0.10 ps/nm/km and the dispersion map' period is 40 km. which is composed of the 34 km of SSMF and 6 km of DCF. Table.1 lists relevant parameters of the existing types of fiber, which are considered in this study. The acronyms in the left-most column stand for the standard single-mode fiber (SSMF), dispersion-compensating fiber (DCF), and reverse dispersion fiber (RDF). The EDFA is used to compensate in-line losses. EDFA is optimized for almost flat gain (gain ripple 0.4 dB and noise Fig. 5 dB) to meet out span losses.

At the receiver end the signal is passed through a photodetector then after it is optically filtered with a low pass Bessel filter with band width four times the bit rate. Finally the signal is fed to a BER analyzer.

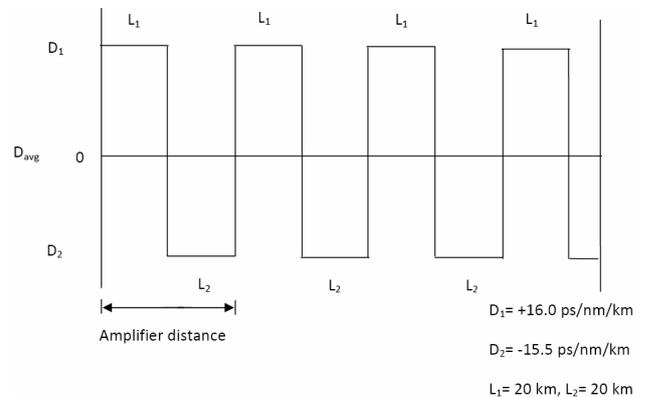


Fig. 2. Dispersion map for SSMF + RDF configuration.

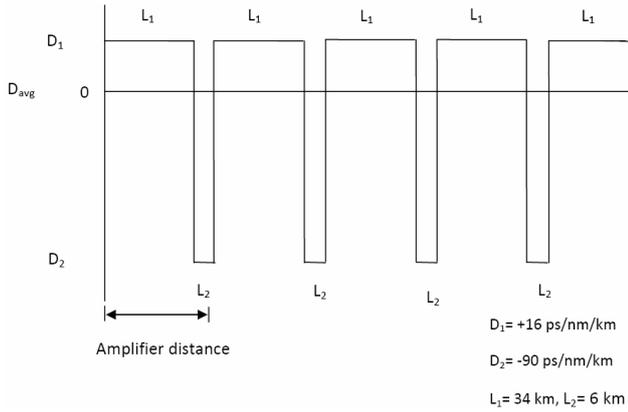


Fig. 3. Dispersion map for SSMF + DCF configuration.

Table 1. Fiber parameters at 1550 nm.

Fiber Type	Group Velocity Dispersion (ps/nm/km)	Dispersion Slope (ps/nm <sup>2</sup> /km)	Loss (dB/km)	Effective area( $\mu\text{m}^2$ )
SMF	16	0.07	0.21	78
DCF	-90	-0.35	0.50	20
RDF	-15.5	-0.45	0.23	30

### 3. Results and discussion

The propagation of the pulses is described by the nonlinear Schrödinger equation and is solved by the split-step Fourier method. During the simulation the length of DCF or RDF is varied in order to tune the dispersion. The in-line EDFAs are optimized to compensate span losses. Amplifiers are pumped by dual pumping scheme with pump wavelengths at 980 nm and 1480 nm. These optical amplifiers are placed uniformly along the transmission line to yield the best combination of overall gain and SNR. A low pass Bessel filter is introduced at the receiver for low inter symbol interference (ISI).

The simulation is carried out for various parameters. By using all optimized values, the resulting Q-factor for various transmission distances is obtained. The performance of a transmission system is acceptable if its Q-factor is 6 ( $\text{BER} \approx 10^{-9}$ ) or above. For shorter transmission distances performance of both the configuration of dispersion maps is found acceptable. By observing eye-patterns it is found that for moderate distances the performance of SSMF + RDF is better than the dispersion map consists of SSMF + DCF. For the transmission distances up to 6000 km both the

configurations shows good eye-patterns as shown in Figs. 4 and 5. Then after, the performance of both the systems decreases abruptly but the SMF + RDF degrades much faster. In spite of all these, the transmission system consists of dispersion map of SMF + RDF works better up to 10,000 km beyond that both the system becomes unacceptable. The SMF + RDF perform better than SSMF + DCF because for SSMF + DCF the corresponding map strength is too high all realistic values of the amplifier spacing and the dispersion managed solitons (DMS) are possible only for low map strengths and weak anomalous dispersion. When the map strength is increased from 1.65, the dispersion tolerance gradually decreases until it reached to quasi-linear regime.

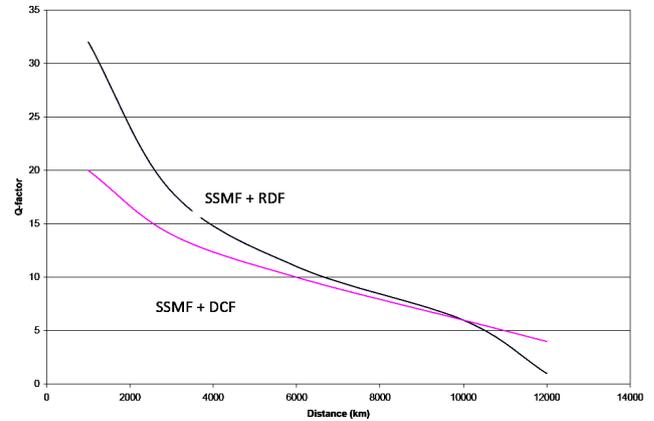


Fig. 4. Q-factor for different input powers.

The optimum average dispersion of SSMF + RDF is higher than the other one and it approaches to zero as the distance is increased. The reason is that the timing jitter induced by pulse-to-pulse interactions and amplifier noise increases with distance, imposing a lower limit of the tolerable dispersion for long-haul systems.

### 4. Conclusions

The performance of 20 Gb/s single-channel dispersion managed-soliton (DMS) transmission over transoceanic distances (10,000 km) using two different types of dispersion maps consists of SSMF + DCF and SSMF + RDF is evaluated for different transmission distances using Q-factor and optical eye-diagram. The performance of dispersion map consists of SSMF+RDF is found better for long-haul soliton based communication systems.

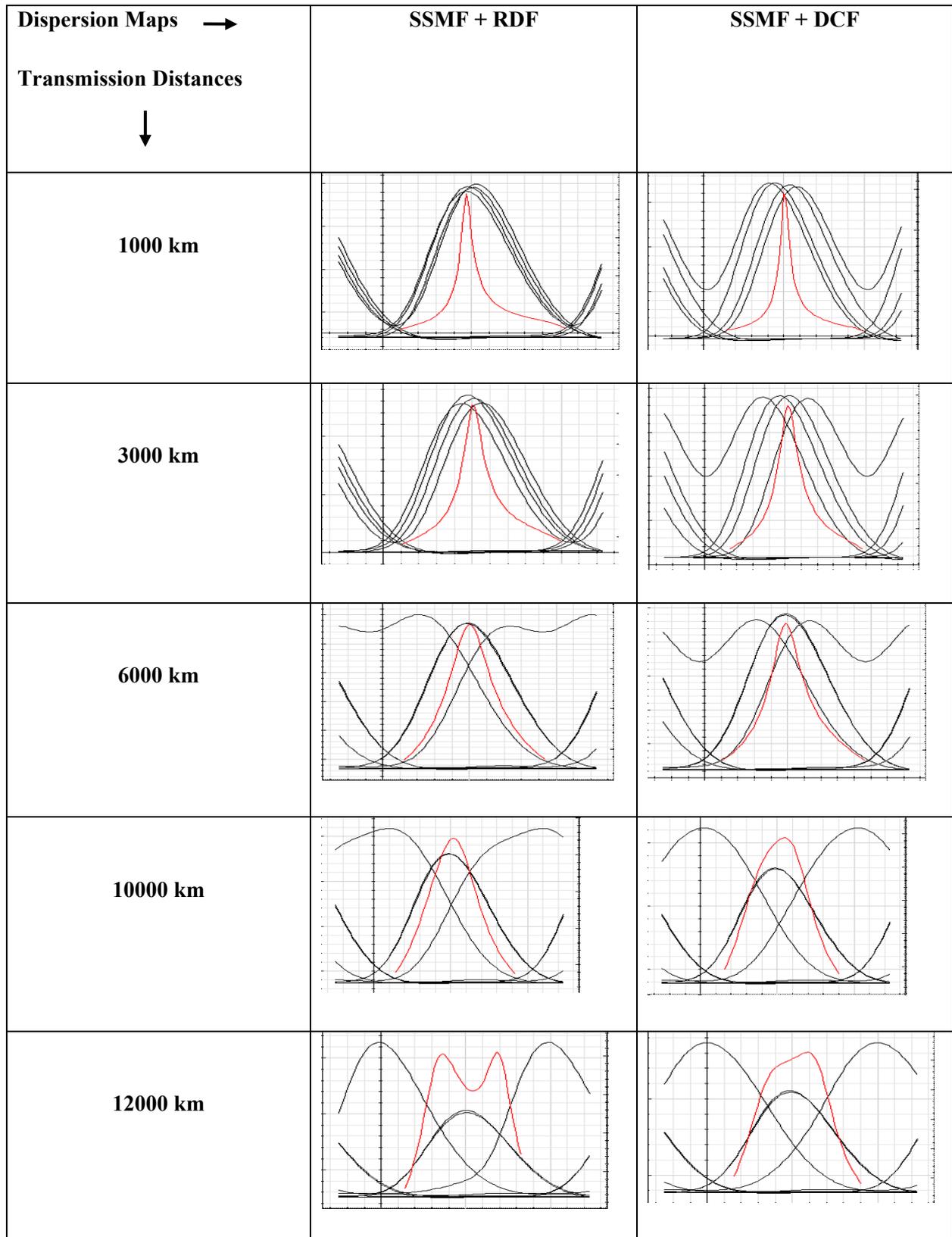


Fig. 5. Optical Eye-patterns of SSMF+RDF (Left) and SSMF+DCF (Right) for different transmission distances.

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### References

- [1] H. Taga, N. Edagawa, S. Yamamoto, S. Akiba, J. Lightwave Technol. **13**(5), 829 (1995).
- [2] N. Bergano, C. Davidson, M. Ma, A. Pilipetskii, S. Evangelides, H. Kidorf, J. Darcie, E. Golovchenko, K. Rottwitt, P. Corbett, R. Menges, M. Mills, B. Pederson, D. Peckham, A. Abramov, A. Vengsarkar, Proc. OFC'98, San Jose, CA, post-deadline paper, PD-12, 1998.
- [3] H. Taga, N. Edagawa, M. Suzuki, N. Takeda, K. Imai, S. Yamamoto, and S. Akiba, "213 Gbit/s (20 \_ 10.66 Gbit/s), over 9000 km transmission experiment using dispersion slope compensator," in *Proc. OFC'98*, San Jose, CA, post-deadline paper, PD-13, 1998.
- [4] M. Suzuki, N. Edagawa, H. Taga, N. Takeda, K. Imai, I. Morita, S. Yamamoto, H. Kidorf, M. Ma, F. Kerfoot, R. Maybach, H. Adelman, V. Arya, C. Chen, S. Evangelides, D. Gray, B. Pederson, A. Puc, E. Shibano, T. Miyakawa, E. Nazuka, Proc. OFC'98, San Jose, CA, post-deadline paper, PD-17, 1998.
- [5] M. Nakazawa, K. Suzuki, H. Kubota, A. Sahara, E. Yamada, Electron. Lett. **34**, 103 (1998).
- [6] G. P. Agrawal, Fiber Optic Communication Systems, 3<sup>rd</sup> Ed., John Wiley & sons, NY, 2002.
- [7] M. Nakazawa, K. Suzuki, H. Kubota, A. Sahara, E. Yamada, Electron. Lett. **34**, 103 (1998).
- [8] P. Mamyshev, L. Mollenauer, Opt. Lett. **21**, 396 (1996).
- [9] L. Mollenauer, P. Mamyshev, M. Neubelt, Proc. OFC'96, San Jose, post-deadline paper, PD. 22, 1996.
- [10] M. Koch, in Proc. of OFC (OSA), 2007.
- [11] J. Yu, K. Kojima, N. Chand, M. C.Fischer, R. Espindola, T. G. B. Mason, Proc. of ECOC, paper PD10, 2001.
- [12] G. P. Agrawal, Nonlinear Fiber optics, 3<sup>rd</sup> Ed., Academic Press, SanDiego, C A, 2001.
- [13] K. Ennger, K. Petermann, IEEE Photonics Technology Letters **8** (3), 1996.
- [14] J. Martensson, A. Berntson, IEEE Photon. Technol. Lett. **13**(7), 2001.
- [15] A. H. Liang, H. Toda, A. Hasegawa, Opt. Lett. **24**, 799 (1999).
- [16] S. K. Turitsyn, M. P. Fedoruk, A. Gornakova, Opt. Lett. **24**, 869 (1999).

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