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40 Gbit/s soliton transmission experiment in a dense dispersion managed fiber with 100 km repeater spacing

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Abstract
40-Gbit/s single-wavelength soliton transmission experiment was performed in a 100-km long dense-dispersion managed fiber with distributed Raman amplifier in conjunction with EDFA. Bit error rate of < 10^{-9} was obtained over 2,600 km.

1 Introduction

Dispersion management of transmission fiber is a key issue to realize high-speed long-distance optical fiber communication. In a dispersion managed fiber, the optical pulse is periodically stretching and shrinking during transmission. When the bit rate becomes higher for fixed dispersion managed fiber, the overlap between the neighboring pulses causes the intrachannel four-wave mixing and the intrachannel cross-phase modulation, which finally results in amplitude and timing jitters of the transmitted pulses [1]. Therefore, proper dispersion management is important for optimizing system performance. For this purpose, dense dispersion managed fiber (DDMF) has been proposed where the period of the dispersion management is much less than the EDFA repeater spacing [2, 3]. Meanwhile, distributed Raman amplifier (DRA) is very attractive not only to expand transmission bandwidth for WDM systems but also to increase optical signal-to-noise ratio for high-speed systems. By using latter feature of DRA, it is possible to extend the repeater spacing [4]. In this paper, we demonstrate 40-Gbit/s single-wavelength recirculating transmission experiment in 100-km long dense-dispersion managed fiber (DDMF). We use non-zero dispersion-shifted fiber for DDMF where the dispersion slope is not compensated. The use of distributed Raman amplification in conjunction with erbium doped fiber amplifier (EDFA) is effective to increase the transmission distance.

2 Numerical simulation

The DDMF was designed to optimize the map strength of the dispersion management so as to minimize the pulse-to-pulse interaction [5] using commercially available fibers. We use non-zero dispersion-shifted fiber because the optimum map strength for 40 Gbit/s system, where the pulse width is 7 ps, is obtained when the length of each fiber segment is about 10 km, which is relatively a realistic number.

In order to clarify the effectiveness of DRA, we made numerical calculations of 40 Gbit/s optical RZ signal transmission, which simulated the experiment described below. Fig. 1 shows the dispersion map of the DDMF. The average dispersion parameters and dispersion slope of the positive and negative dispersion fibers at 1550 nm wavelength are 3.6 ps/nm/km, 0.066 ps/nm^2/km, -2.7 ps/nm/km and 0.082 ps/nm^2/km, respectively. The fiber loss is 0.21 dB/km. Each splicing loss of 0.1 dB and the device losses required for

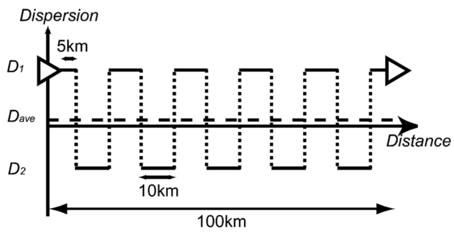
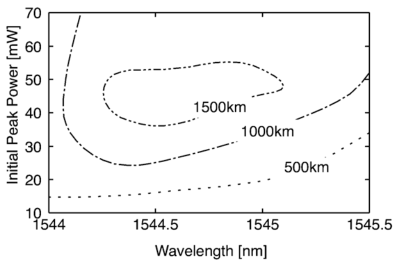
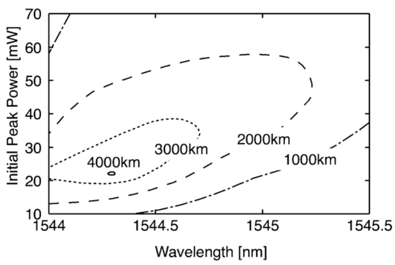


Fig. 1 Dispersion map of the dense dispersion managed fiber.



(a) EDFA only



(b) distributed Raman amplifier and EDFA

Fig. 2 Calculated transmission distance where Q = 6 vs input peak power to the fiber and wavelength.

recirculating transmission loop are taken into account. The noise figure of EDFA repeaters is 4.5 dB. Fig. 2 shows the calculated transmission distance where Q = 6 versus input peak power to the DDMF and wavelength when the signal is amplified with (a) EDFA only and (b) DRA with 10 dB gain in conjunction with EDFA, respectively. The transmission distance can be extended by two times by using DRA. The maximum transmission distance is obtained when the wavelength is 1544.3 nm with DRA, where the average dispersion of the DDMF is zero. In Fig. 2 (b), the wavelength margin is larger for longer wavelength (anomalous average dispersion regime) with higher signal power (e.g. +1 nm at 2,000 km) because dense dispersion managed soliton propagates in that regime. Thus, it is preferable to use slightly longer wavelength than the optimum considering the dispersion variation caused by ambient temperature change.

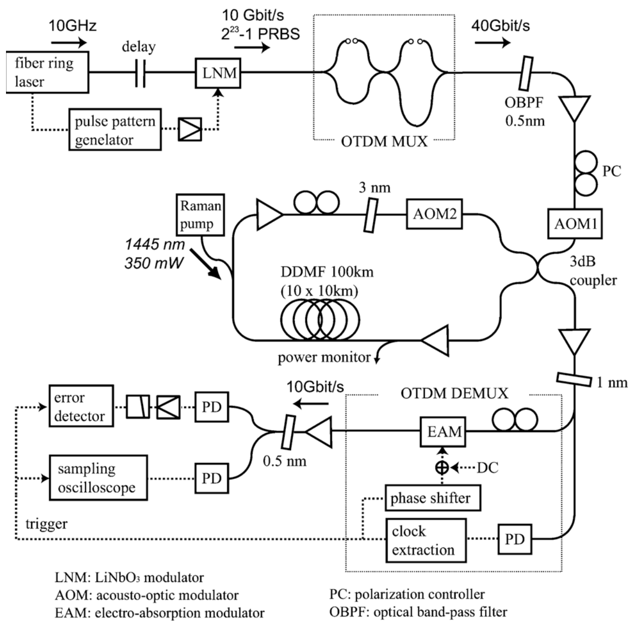


Fig. 3 Experimental setup.

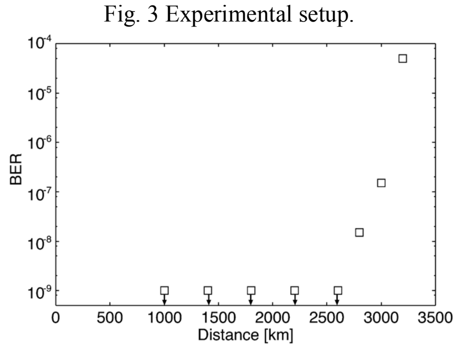


Fig. 4 BER versus transmission distance.

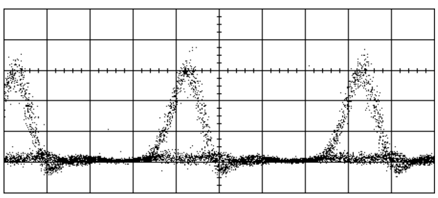


Fig. 5 Observed waveform of a demultiplexed 10 Gbit/s signal at 2,600 km.

3 Experiment

A schematic diagram of the experimental setup is shown in Fig. 3. 40 Gbit/s optical RZ signal was formed by optically time-division multiplexing (OTDM MUX) from 10 Gbit/s, 3 ps optical RZ signal. A 0.5-nm optical bandpass filter was used to broaden the pulse width to 7 ps. The total power of the polarization multiplexed pump lasers for DRA is 350 mW to obtain 10 dB gain. An electro-absorption modulator (EAM) was used for demultiplexing each 10 Gbit/s tributary signal.

We made three transmission experiment where the signal wavelength was changed to 1544.0, 1544.5 and 1545.0 nm. The transmission distances where the bit error rate (BER) = 10^{-9} were 2,600 km at 1544.5 nm and 1,000 km at 1544.0 nm and 1545.0 nm, respectively, which were qualitatively consistent with the simulation. Fig. 4 and Fig. 5 show a measured BER versus transmission distance and observed waveform of a demultiplexed 10 Gbit/s signal at 2,600 km at 1544.5 nm.

4 Conclusion

We have demonstrated 40-Gbit/s single-wavelength soliton transmission experiment in a 100-km long dense-dispersion managed fiber. The use of distributed Raman amplifier in conjunction with EDFA greatly extend the transmission distance. BER of $< 10^{-9}$ was obtained over 2,600 km.

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