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Ultrahigh-speed signal transmission / processing technologies

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Abstract We describe signal transmission and processing technologies for 160 Gbit/s OTDM systems, focusing especially on the time-domain optical Fourier transformation technique. Improvements in 160 Gbit/s OOK and DPSK transmission are described in detail.

1. Introduction

Motivated by the increasing demand for high capacity optical networks, many groups have performed 160 Gbit/s OTDM transmission experiments. Intensive efforts have recently been made to extend the transmission distance and increase the system margin by employing polarization multiplexing or advanced modulation formats such as DPSK. In this talk, we first review progress on ultrahigh-speed OTDM transmission. Then, we describe a new technique for distortion-free transmission employing the time-domain optical Fourier transformation (OFT) technique that we recently proposed [1].

2. Key technologies for ultrahigh-speed optical pulse transmission

In parallel with the increase in bit rate, various advanced modulation formats such as CS-RZ, DPSK, and DQPSK have recently been proposed to extend the transmission distance and increase the system margin. Figure 1 shows the way in which ultrahigh-speed optical transmission experiments have shifted from OOK to DPSK and DQPSK in which data are modulated in optical phase changes between bits and demodulated with a delay-line interferometer at the receiver. Since DPSK improves the SN ratio by 3 dB compared with OOK, more stable and long-distance transmission can be realized. In addition, the SN improvement allows transmission at a lower optical power, and thus it is possible to reduce nonlinear optical effects.

At bit rates faster than 40 Gbit/s, the signal pulse width is only a few ps. Therefore, the waveform distortion caused by chromatic dispersion and polarization-mode dispersion imposes a severe limitation on the transmission performance. In addition, even a small variation in dispersion, which is easily caused by environmental changes in the fiber, has a crucial effect on transmission performance. Adaptive dispersion equalization or the optical 3R (Retiming, Reshaping, Regeneration) technique will become the key approach to eliminating such time-varying dispersion.

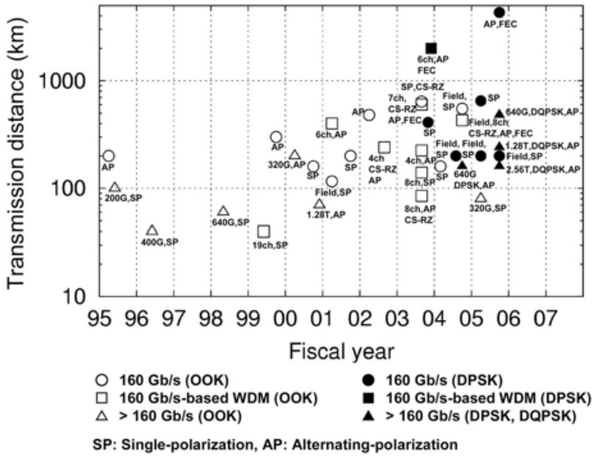


Fig. 1 Evolution of OTDM transmission experiments in various formats (from OOK to DPSK).

3. Distortion-free transmission using time-domain OFT

3.1 Principle of time-domain OFT

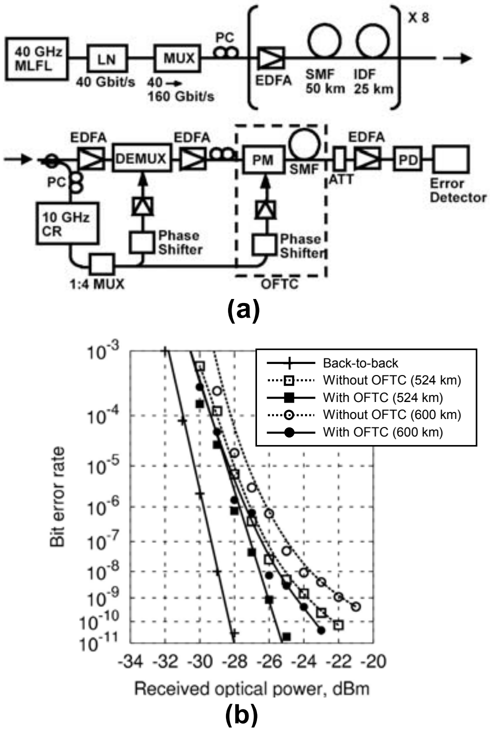
We recently proposed a novel distortion-free transmission scheme that uses transform-limited pulses and time-domain optical Fourier transformation (OFT). With this technique, we take advantage of the fact that the spectral shape is maintained throughout the transmission, even when the fiber has linear perturbations, i.e., $|U(z,\omega)|^2 = |U(0,\omega)|^2$. The unchanged spectral profile is then converted into a time-domain waveform at the receiver by using the OFT technique. Time-domain OFT can be achieved ideally by employing a linear chirp (with a chirp rate K) and a GVD medium (with $D = k''L$). When $D = 1/K$, the output waveform after OFT, $v(t)$, becomes proportional to the spectrum before OFT, $U(z,\omega)$, and hence $U(0,\omega)$:

$$v(t) = \sqrt{\frac{i}{2\pi D}}\exp\left(-i\frac{K}{2}t^2\right)U\left(z, t/D\right)$$
$$= \sqrt{\frac{i}{2\pi D}}\exp\left(-i\frac{K}{2}t^2 + i\beta(t/D)z\right)U\left(0, t/D\right)$$

where ω is converted to t/D. This enables us to reconstruct the original undistorted pulse shape.

3.2 160 Gbit/s-600 km OOK transmission

By applying this technique to 160 Gbit/s OTDM transmission, we successfully demonstrated a single-polarization, OOK transmission over 600 km [2]. The experimental setup is shown in Fig. 2(a). The optical pulse source was a 40 GHz mode-locked fiber laser (MLFL) emitting a 1.7 ps transform-limited Gaussian pulse train at 1550 nm. The 160 Gbit/s OTDM signal was transmitted over 8 spans of 75 km-long dispersion-managed fiber link. After the transmission, the 160 Gbit/s signal was demultiplexed to 40 Gbit/s by using an electro-absorption modulator (EAM) and launched into an optical Fourier transform circuit (OFTC). In the OFTC, the signal was first sinusoidally phase-modulated at an LN phase modulator (PM) with $K = -0.3$ ps^{-2}. The chirped signal then passed through a 36 m SMF. Finally the OFTC output was detected with a photo detector and the bit-error rate (BER) was measured. Figure 2(b) shows the BER curves versus received power after 524 and 600 km transmissions. Without OFTC, the BER curves had an error floor. The error floor at 524 km was suppressed by employing OFT, and the penalty at BER = 10^{-9} with respect to the back-to-back curve was reduced from 4.5 to 2.5 dB. At 600 km, there was a residual error floor even with OFT, but the power penalty was reduced by more than 2 dB.



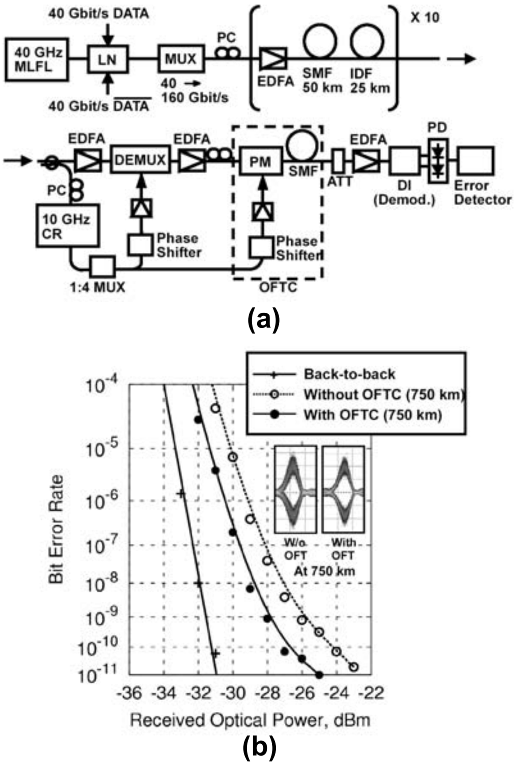
(a)

(b)

Fig. 2 160 Gbit/s-600 km OOK transmission with time-domain OFT. (a) Experimental setup, (b) BER measurement.

3.3 160 Gbit/s-750 km DPSK transmission

In the next step, we applied the OFT technique to DPSK transmission and successfully extended the distance to 750 km. The experimental setup shown in Fig. 3(a) is similar to that in Fig. 2(a) except that a dual-drive push-pull Mach-Zehnder modulator driven by $2V_\pi$ was employed as a DPSK modulator, and a delayed interferometer (DI) and a balanced PD were included in the receiver. The BER performance after a 750 km transmission is shown in Fig. 3(b). The power penalty after a 600 km transmission was 3 dB, which is 3.5 dB lower than that with OOK. At 750 km, error-free transmission was successfully achieved with a penalty of 5.5 dB. By employing OFT, the power penalty was reduced to 3.5 dB. The improvement in the power penalty is attributed to the reduction of the jitter and pulse width, as shown in the inset of Fig. 3(b).



(a)

(b)

Fig. 3 160 Gbit/s-750 km DPSK transmission with time-domain OFT. (a) Experimental setup, (b) BER measurement.

4. Conclusion

Recent progress on ultrahigh-speed OTDM signal transmission and processing technologies was described. A combination of the time-domain OFT technique and the DPSK format is particularly useful for extending the transmission distance and increasing the system margin in a 160 Gbit/s OTDM transmission.

References

[1] M. Nakazawa et al., IEEE PTL, **16**, 1059 (2004).
[2] T. Hirooka et al., IEEE PTL, **18**, 2647 (2006).