# 320 Gbit/s Single-Polarization DPSK Transmission over 525 km Using Time-domain Optical Fourier Transformation

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***Abstract*** *320 Gbit/s single-polarization DPSK transmission has been successfully demonstrated over 525 km straight transmission line using time-domain optical Fourier transformation, which greatly improved the tolerance to higher-order PMD.*

## Introduction

The increase in bit rate per wavelength channel has been an important subject as regards meeting the increasing demand for ultrahigh-capacity optical networks. Many 160 Gbit/s OTDM transmission experiments, including field demonstrations, have already been reported, and the feasibility of such a high-speed system has been vigorously investigated. Recently, OTDM experiments at 320 Gbit/s and above have been successfully demonstrated [1-4], and intensive efforts have been made to extend the transmission distance and increase the system margin at such high bit rates. In such a high-speed system, the transmission performance becomes very sensitive to both first- and second-order polarization-mode dispersion (PMD) and their temporal fluctuation. For example, because of large signal bandwidth, second-order PMD causes polarization-dependent chromatic dispersion, and its temporal variation would result in serious transmission impairment for 320 Gbit/s long-haul transmission.

Previously we reported a straight-line 160 Gbit/s DPSK transmission over 1,000 km [5], in which we employed a time-domain optical Fourier transformation (OFT) technique [6] to eliminate transmission impairments caused by dispersion, dispersion slope and jitter. Since OFT enables us to eliminate linear distortions that occur during transmission including time-varying perturbation, we can expect this scheme to achieve stable transmission performance when applied to long-distance OTDM transmission at 320 Gbit/s and above.

In this paper, we present the first single-polarization 320 Gbit/s DPSK transmission experiment over 525 km with OFT. By using OFT, the tolerance to second-order time-dependent PMD was greatly improved, and, as a result, we successfully achieved stable error-free performance.

## 320 Gbit/s-525 km DPSK transmission setup

The time-domain OFT technique takes advantage of the fact that the spectral envelope is maintained throughout the transmission, even when the fiber has linear perturbations. This is true even if the perturbations vary with time. The unchanged spectral profile after transmission is converted into a time-domain waveform at the output by OFT, which enables us to obtain a distortion-free pulse waveform and thus simultaneously eliminate linear distortion.

We applied this technique to a 320 Gbit/s OTDM system and undertook a single-polarization DPSK transmission experiment over 525 km. Figure 1 shows the experimental setup. As an optical pulse source, we used a 40 GHz mode-locked fiber laser (MLFL) operated by FM mode locking, which can emit a 0.8 ps pulse at 1550 nm. The pulse train was DPSK-modulated at 40 Gbit/s with a $2^{15}$–1 PRBS using a dual-drive, push-pull operated LN Mach-Zehnder modulator driven at $2V_{\pi}$. The DPSK signal was optically multiplexed to 320 Gbit/s with a single polarization and then launched into a 525 km transmission fiber. The fiber link consisted of seven 75 km spans of dispersion-managed fiber composed of standard single-mode fiber (SMF) and inverse dispersion fiber (IDF), which compensate for the dispersion and dispersion slope simultaneously. The dispersion was precisely compensated to less than 0.1 ps/nm, and the dispersion slope was –0.04

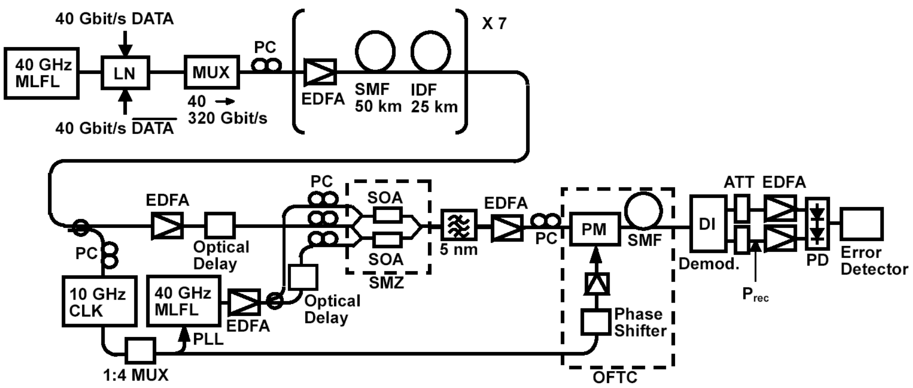


*Fig. 1 Experimental setup for 320 Gbit/s-525 km DPSK transmission with time-domain OFT.*

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ps/nm$^2$ at 1550 nm. The 320 Gbit/s signal was launched into the transmission line through a polarization controller (PC), where the polarization state was adjusted to the principal state of the 525 km fiber link to mitigate the first-order PMD. The average DGD was 1.2 ps. The fiber loss was compensated at each span by using an EDFA. The average input power to each span was +6 dBm.

In the DPSK receiver, the 320 Gbit/s signal was first demultiplexed to 40 Gbit/s by using a symmetric Mach-Zehnder (SMZ) optical switch after extracting a 40 GHz clock signal from the transmitted data train. The SMZ switch is an all-optical interferometric switch, in which semiconductor optical amplifiers (SOA) are installed in each arm of a Mach-Zehnder interferometer [7]. The OTDM signal was amplified to +11 dBm and launched into the SMZ switch. As the optical source for the control pulse, we used another 40 GHz MLFL emitting a 1.8 ps pulse train at 1537 nm, which was PLL operated with the extracted 40 GHz clock. The control pulse was divided by a 3 dB coupler and one part was delayed by 3 ps for the switching. The optical power of the control pulse was set at +10 dBm. At the SMZ output, the demultiplexed signal was separated from the control pulse with a 5 nm optical filter. The switching gate width was 3 ps.

The demultiplexed 40 Gbit/s signal was then launched into an optical Fourier transform circuit (OFTC), from which waveform distortions were eliminated. The OFTC was composed of a 40 GHz LN phase modulator and an SMF. Finally the Fourier-transformed DPSK signal was converted to OOK with a one-bit delay interferometer (DI), and the bit error rate (BER) was measured with a balanced photo-detector (PD).

**Transmission results**

Figure 2(a) and (b) show the waveforms of the demultiplexed 40 Gbit/s signals converted to OOK after 525 km transmissions without and with OFT, respectively, which were measured with an optical sampling oscilloscope. Without OFT, the pulse suffered from timing jitter and peak fluctuation, and the distortions varied with time. Since the residual dispersion and dispersion slope of the fiber were sufficiently small, this fluctuation is likely to be due to the second-order time-dependent PMD. Measurement of the second-order PMD of the 525 km fiber link showed that the polarization-dependent chromatic dispersion varied with time within a ±0.3 ps/nm range. Such a dispersion fluctuation can lead to serious transmission impairment at 320 Gbit/s. Figure 3(a) shows the BER performance against the received power after a 525 km transmission without employing OFT. The BER performance varied over time as shown in this figure. In some cases we could not even obtain a BER below $10^{-9}$.

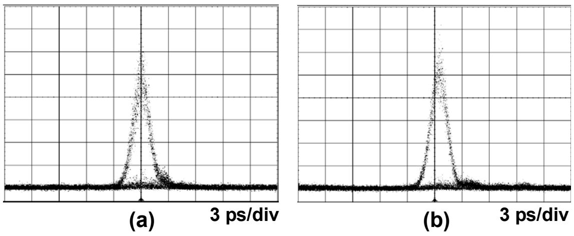


*Fig. 2 Pulse waveform of demultiplexed 40 Gbit/s signal converted to OOK after 525 km transmission. (a) without OFT and (b) with OFT.*

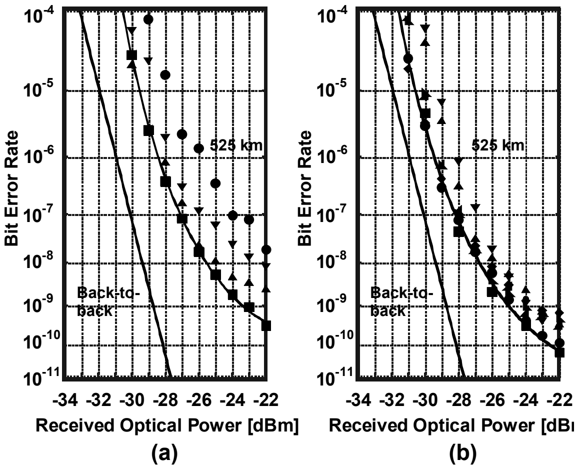


*Fig. 3 BER characteristics for a 320 Gbit/s-525 km transmission.*

On the other hand, by employing OFT, such temporal variations in the transmission performance were largely eliminated. As shown in Fig. 2(b), jitter and amplitude fluctuation were reduced, and the waveform remained almost unchanged over time. The BER characteristics shown in Fig. 3(b) indicate that the system performance is much more stable when OFT is employed. The power penalty at a BER of $10^{-9}$ ranged from 4 to 5.5 dB, but a BER of less than $10^{-9}$ was obtained in all the measurements. This result indicates that OFT works successfully to provide adaptive compensation for higher-order PMD, which results in a large performance improvement for 320 Gbit/s transmission.

**Conclusion**

We have demonstrated error-free 320 Gbit/s DPSK transmission over 525 km by employing OFT. By eliminating the transmission impairments caused by time-varying higher-order PMD using OFT, a stable transmission performance was successfully achieved.

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