Comparison of 40 GHz optical demultiplexers using SMZ switch and EA modulator in 160 Gbit/s-500 km OTDM transmission

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Abstract: We compare two types of optical demultiplexers, one with a symmetric Mach-Zehnder (SMZ) switch and the other with an electro-absorption modulator (EAM), when used for 160 Gbit/s (4×40 Gbit/s) OTDM transmission over 500 km. By combining the SMZ switch with a time-domain optical Fourier transformation technique, we succeeded in obtaining slightly better bit-error rate performance than with the EAM.

Keywords: ultrahigh-speed optical transmission, optical time division multiplexing, optical demultiplexing, symmetric Mach-Zehnder switch, electro-absorption modulator, time-domain optical Fourier transformation

Classification: Photonics devices, circuits, and systems

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1 Introduction

Optical time division multiplexing (OTDM) enables us to achieve ultrahigh speed transmission at a single wavelength with a bit rate beyond the limit of electrical signal processing. One of the key technologies for OTDM is an optical demultiplexer, which selects a low bit-rate signal from a high-speed OTDM data sequence on the receiver side. Several schemes have already been demonstrated for ultrahigh-speed optical demultiplexing, including the use of an electro-optical switch with an electro-absorption modulator (EAM) [1] and an all-optical switch based on nonlinear optical effects in semiconductor optical amplifiers (SOA) or optical fibers [2, 3]. When demultiplexing a 160 Gbit/s OTDM signal to 40 Gbit/s, EAM and SOA type optical demultiplexers are typically employed. With EAM, 160 → 40 Gbit/s demultiplexing can be easily realized in a simple configuration [4, 5], which is very advantageous in terms of system cost. An SOA has also recently been used for ultrahigh-speed demultiplexing. Slow gain recovery can be overcome by inserting an optical filter at the SOA output to compensate for the slow gain dynamics [6], or by introducing a symmetric Mach-Zehnder (SMZ) configuration to cancel out the slow relaxation of the phase shift [7].

In this paper, we compare two types of demultiplexers, one with an SMZ switch and the other with an EAM, when used for 160 Gbit/s (4×40 Gbit/s) OTDM transmission over 500 km. Since the transmitted pulse has distortions caused by fiber dispersion, polarization-mode dispersion (PMD), ASE noise and fiber nonlinearities accumulated in the transmission line, it is very important to minimize additional distortion at the demultiplexer by optimizing the gate width and shape. By combining the SMZ switch with an optical

Fourier transformation (OFT) technique [8], we have succeeded in obtaining slightly better bit-error rate (BER) performance than with the EAM.

2 Principle of SMZ and EAM demultiplexers

An SMZ switch is an all-optical interferometric switch, in which semiconductor optical amplifiers (SOA) are installed in each arm of a Mach-Zehnder interferometer [9]. Each SOA introduces a π phase shift into a data pulse through cross phase modulation (XPM) with a control optical pulse. By introducing a phase shift in the second arm just after the phase shift has been generated in the first arm, the slow relaxation of the phase shift (approximately 100 ps) can be cancelled out, enabling us to achieve ultrafast optical switching. By choosing an appropriate optical power for the control pulses and their relative delay, we can realize a rectangular-like ultra narrow switching window. Such rectangular gating is advantageous in terms of avoiding the conversion of timing jitter to intensity fluctuation during the demultiplexing [3].

In contrast, an EAM is an electro-optical switch based on the Franz-Keldysh effect. Because of its nonlinear absorption characteristics, a switching window as narrow as 4–5 ps can be easily obtained simply by applying a 40 GHz sinusoidal voltage. An EAM is much easier to handle than an SMZ switch because of its simple configuration. However, since the switching characteristics of an EAM are closer to being sech or Gaussian than rectangular, demultiplexing may cause additional waveform distortion to the signal.

3 160 Gbit/s-500 km OTDM transmission experiment

We employed an EAM or an SMZ switch as the demultiplexer in a 160 Gbit/s-524 km OTDM transmission and compared their performance. The experimental setup for the 160 Gbit/s OTDM transmission is shown in Fig. 1 (a). The optical pulse source was a 40 GHz mode-locked fiber laser (MLFL) emitting a 1.7 ps pulse train at 1550 nm. The pulse train was modulated at 40 Gbit/s with a $2^{15} - 1$ PRBS, and optically multiplexed to 160 Gbit/s in a fiber delay-line multiplexer. The OTDM signal was transmitted over a 524 km dispersion-managed fiber link. The average dispersion and dispersion slope were -4×10^{-4} ps/nm/km and 3×10^{-3} ps/nm²/km, respectively. The input power to each span was set at +8 dBm.

After the transmission, the 160 Gbit/s signal was demultiplexed to 40 Gbit/s by using an EAM or an SMZ switch after extracting a 40 GHz clock signal from a transmitted pulse train. Part of the transmitted signal was coupled to a 10 GHz clock recovery circuit [10] and its output was 1:4 multiplied to obtain a 40 GHz clock. The OTDM signal was amplified to +3 dBm and launched into a demultiplexer. When the EAM was employed as the demultiplexer [Fig. 1 (b)], it was driven by the 40 GHz clock signal amplified to 6 V_{pp} with a DC bias of -3.3 V. This provided a 4.6 ps switching window whose shape was close to Gaussian. When the SMZ switch was employed [Fig. 1 (c)], we used another 40 GHz MLFL emitting a 1.8 ps pulse

Fig. 1. (a) 160 Gbit/s OTDM transmission setup. (b) and (c) show the configurations of EAM and SMZ based demultiplexers, respectively.

train at 1537 nm as an optical source for a control pulse. The MLFL was PLL operated driven by the 40 GHz clock, to enable a control pulse train synchronized to the transmitted signal to be generated. The control pulse was divided by a 3 dB coupler and one part was delayed by 5.5 ps for the switching. The optical power of the control pulse was set at +13 dBm. At the SMZ output, the signal was separated from the control pulse with a 2 nm optical filter. The switching gate width was 4.3 ps and closer to a rectangular shape. It should be noted that the gate width of the SMZ switch can be set at less than 3 ps by reducing the time interval between the two control pulses.

The demultiplexed 40 Gbit/s signal was launched into an optical Fourier transform circuit (OFTC), from which waveform distortions had been eliminated. OFT is a technique that makes distortion-free transmission possible by using the spectral envelope profile of the transmitted signal, which is unchanged during transmission even in the presence of linear perturbations [8]. By converting the transmitted spectrum into the time-domain using OFTC, the input pulse waveform can be completely reconstructed at the output terminal. The OFTC was composed of a 40 GHz LN phase modulator and a 36 m long SMF. Finally we detected the OFTC output with a photo detector and measured the BER.

Fig. 2. Pulse waveform of demultiplexed 40 Gbit/s signal after 524 km transmission. (a) and (b) are the results when demultiplexed with the EAM and SMZ, respectively.

4 Experimental results

We measured the demultiplexed pulse waveform from a 160 Gbit/s OTDM signal after propagation over 524 km. Figure 2 (a) shows the result when the signal was demultiplexed to 40 Gbit/s with the EAM. After a 524 km transmission, the pulse width had broadened to 2.8 ps, and ripples appeared in the tail due to the dispersion slope in the transmission fiber. The pulse also suffered from jitter. After demultiplexing, the residual neighboring pulse of the original 160 Gbit/s signal was suppressed to less than -15 dB. With OFT [Fig. 2 (a) right], it is clearly seen that the distortions were eliminated successfully. The pulse width was reduced to 1.9 ps and the pulse width almost recovered to its pre-transmission value. The ripples and jitter were also suppressed.

Figure 2 (b) shows the result when employing the SMZ switch as a demultiplexer. After demultiplexing [Fig. 2 (b) left], the pulse width was broadened to 3.5 ps. This is caused by the 2 nm optical filter inserted at the output of the SMZ switch to remove the control pulses at 1537 nm. As a result of such strong filtering, the residual control pulse components were suppressed to less than -50 dB, however part of the signal spectrum component was also eliminated at the same time, resulting in signal pulse broadening. It should

Fig. 3. BER measurements. (a) Without OFT, (b) with OFT.

also be noted that the distortions that appear in the demultiplexed waveform with SMZ are smaller than those with EAM [Fig. 2(a) left]. This is attributed to the narrower and more rectangular-like switching gate of the SMZ switch, which enables us to suppress the ripples in the tail and avoid conversion from timing jitter to intensity fluctuation. However, the suppression ratio of the neighboring channel in the original 160 Gbit/s pulse train was limited to -12 dB, which was worse than with the EAM. By employing OFT [Fig. 2(b) right], the pulse width was reduced to 2.5 ps and the suppression ratio was also improved. The pulse width did not completely recover to its original value even with OFT, since the spectral width is narrowed by strong filtering as mentioned above.

Figure 3(a) shows the BER measurement that we obtained without employing an OFT. The BER characteristics with the SMZ switch are better than those obtained with the EAM. This is because the demultiplexed waveform suffers less from waveform distortion because of the narrower and more rectangular-like switching gate of the SMZ switch, as shown in Fig. 2. When the same 2 nm filter as used in the SMZ switch is inserted after the EAM, the BER can be improved but remains slightly worse than that of the SMZ switch. A BER measurement obtained with OFT is shown in Fig. 3(b). The power penalty at $\text{BER} = 10^{-9}$ is improved by ~ 2 dB in all cases with the OFT. Again the SMZ switch performs slightly better than the EAM even when combined with a 2 nm filter. This is because, in contrast to the EAM whose absorption characteristics have little wavelength dependence, the spectrum modification during demultiplexing with the SMZ switch is smaller. This property is beneficial for OFT operation, in which the frequency spectrum is converted to a temporal waveform.

5 Conclusion

We have compared the use of an SMZ switch and an EAM for demultiplexing a 160 Gbit/s OTDM signal to 40 Gbit/s after a 500 km transmission. The narrow and rectangular-like switching characteristics of the SMZ switch lead to its slightly better performance when combined with OFT.

Acknowledgments

This work was supported by a Specially Promoted Research Grant (16002008) from the Ministry of Education and Science of Japan.