All-Optical Nyquist-OTDM to Nyquist-WDM conversion for Highly Flexible Optical Networks

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Abstract: 50 and 25 Gbaud Nyquist QPSK signals are converted to Nyquist-WDM signals with half baud-rate, by using a phase modulator and an optical Nyquist filter. The EVM were 9% after the conversion employing duo-binary filter.

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1. Introduction

To deal with the drastically increasing network traffic in the internet, both time and frequency division multiplexing techniques, as well as spectral efficient modulation and multiplexing techniques, are developed for the effective use of the limited spectral resources. On the other hand, flexible optical channel control is also an important technology to fully utilize the network resources in dynamically changing network traffic [1-3]. The optical Nyquist pulse coding is one of the most spectral efficient modulation techniques and both optical time division multiplex (Nyquist-OTDM) and wavelength division multiplex (Nyquist-WDM) are investigated for spectral efficient large capacity transmission [4-5]. The Nyquist-OTDM is the better solution for an ultra-high capacity single channel transmission such as over 1 Tbit/s transport system, whereas the Nyquist-WDM is better for the high granular flexible channel control, such as add-drop operation at the network node [3]. For future highly flexible optical network, they are expected to co-exist in the same networks, and seamless conversion between time and frequency domain is needed, to achieve both large capacity transport and high granular channel control.

In this paper, we demonstrate, for the first time, the multiplexing-format conversion from Nyquist-OTDM to Nyquist-WDM by using a simple phase modulator and an optical Nyquist filter. A Nyquist-OTDM signal is phase-modulated by a sinusoidal wave with half frequency of the signal baud-rate. The rising and falling of the phase modulation corresponds to the blue- and red-shift of the carrier frequency. Therefore, the phase-modulated signal becomes a multiplexing of the blue- and red-shifted signals with half baud-rate, and the optical Nyquist filtering achieves the Nyquist-WDM signal. The error-vector-magnitude (EVM) measurement revealed that the multiplexing-format conversion has been successfully achieved for 50 Gbaud to 2 x 25 Gbaud (50G-25G) and 25 Gbaud to 2 x 12.5 Gbaud (25G-12.5G) conversions. The optimum driving condition of the phase modulator is also investigated, and 0.913V is found to be the optimum condition to achieve the highest separation between blue- and red-shifted signals.


Fig. 1. Experimental setup for (a) 25 Gbaud Nyquist signal generation, (b) 50 Gbaud Nyquist-OTDM signal generation, and (c) Nyquist-OTDM to Nyquist-WDM conversion.
2. Operation principle and experimental setup

Figure 1 shows the experimental setup and operation principle of the multiplexing-format conversion. For 25G-12.5G conversion, carrier suppressed return-to-zero (CS-RZ) modulation by single Mach-Zehnder modulator (MZM) is used, and 25 Gbaud signal is directly generated by 25 Gbaud IQ-MZM driven by \(2^{31}-1\) and \(2^{23}-1\) pseudo random binary sequences (PRBSs) for I- and Q-channels, respectively. The following optical Nyquist filter with 25 GHz bandwidth is used for the Nyquist spectral shaping [6]. In 50G-25G conversion, two cascaded MZM for three tones modulation and 2x1 fiber-based OTDM circuit followed by a 50 GHz optical Nyquist filter are used to generate a 50 Gbaud Nyquist signal. The phase modulator used for the multiplexing-format conversion is a simple straight-type LiNbO\(_3\) (LN) modulator driven by a sinusoidal wave with half frequency of the baud-rate. The phase modulation by a sinusoidal wave corresponds to the frequency modulation with a cosine wave; the rising and falling of the phase are the blue- and red-shift of the carrier frequency, respectively, as illustrated in Fig. 1(c). Therefore, each symbol has different carrier frequency with respect to the adjacent symbols, and the signal becomes a WDM of two different carrier frequency channels with half baud-rate. The driving voltage for the phase modulator is determined to achieve the highest separation between blue- and red-shifted components, which is estimated to be slightly lower than \(V_p\) of the modulator. After the phase modulation, the signal spectrum has several extra side-bands and the following optical Nyquist filter removes these side-band components to make a Nyquist-WDM signal. The converted Nyquist-WDM signal is de-multiplexed by another optical Nyquist filter. Then, the signal is received by a coherent receiver to measure the EVM, where duo-binary filter is applied to reduce the cross-talk effect.

3. Experiment and results

Figure 2 shows the experimental spectra at the point (i)-(iv) indicated in Fig. 1(c), and the insets are the received eye-diagrams of before and after multiplexing-format conversion. In both baud-rate cases, the single Nyquist signal is successfully converted to the WDM signal. Even after the de-multiplexing, the eye-diagrams show clear eye-opening, although 12.5 Gbaud signals are suffering from relatively larger cross-talk due to the larger roll-off factor of the optical Nyquist filter. These cross-talk components can be suppressed by duo-binary filter at the receiver.

![Fig. 2. Experimental spectra and eye-diagrams for (a) 25G-12.5G conversion and (b) 50G-25G conversion.](image-url)

Figure 3 shows the measured EVMs for both conversion cases as functions of optical signal-to-noise ratio (OSNR), and the insets are the constellations of the received signals after duo-binary filter, which is the reason of nine-point constellation. In 50G-25G conversion case, EVM of Back-to-Back (B-to-B) is measured for the original 25 Gbaud signal before OTDM, due to the bandwidth limitation of the receiver: an oscilloscope with 13 GHz bandwidth. In both conversions, the EVM of 9% have been achieved.

To verify the operation condition of the multiplexing-format converter, we investigated the relation of driving voltage of the phase modulator and EVM. Figure 4(a) shows the measured EVMs as functions of the driving voltage of phase modulator, for 25G-12.5G conversion with 30 dB OSNR. The spectrum of the phase-modulated continuous wave (CW) laser with the driving voltage at the minimum EVM is indicated in Fig. 4(b). The phase modulation depth can be estimated from the spectrum in Fig. 4(b). The point is that the center three tones show the same...
intensity level, and the optimum driving voltage is estimated to be $0.913 V_{\pi}$ of the modulator, according to the relation between the phase-modulation depth and the spectrum.

Fig. 3. Measured EVMs and received signal constellations for (a) 25G-12.5G and (b) 50G-25G.

Fig. 4. (a) The measured EVMs as functions of the driving voltage for the phase modulator, and (b) spectrum of phase-modulated CW laser with the driving voltage of minimum EVM condition, in 25G-12.5G conversion.

4. Summary

We have experimentally demonstrated, for the first time, a multiplexing-format conversion from Nyquist-OTDM to Nyquist-WDM by using a phase modulator and an optical Nyquist filter. 50 Gbaud and 25 Gbaud single channel Nyquist QPSK signals are successfully converted to 2 x 25 Gbaud and 2 x 12.5 Gbaud Nyquist-WDM signals, respectively. The constellation of the received signals showed clear separation after the duo-binary filter, and the measured EVMs have achieved 9%. The optimum driving voltage for the phase modulator was revealed to be slightly lower than $V_{\pi}$ of the modulator: $0.913 V_{\pi}$.

5. References


