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Proposal for Coordinate Transformed Electronic Pre-compensator and Investigation of its Robustness to Bias Error

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Abstract: We propose a novel electronic pre-compensation transmitter, the coordinates of whose I/Q channels are transformed in order to reduce excess loss. Robustness to bias error in its modulator is investigated numerically.

1. Introduction

Electronic pre-compensation for equalizing chromatic dispersion in optical fiber transmission systems has been rigorously investigated [1-5]. Compared to prior optical dispersion compensation methods, electronic pre-compensation is expected to reduce power consumption and equipment size, to enable adaptive equalization, and to increase the range of compensatable dispersion values. In the pre-compensator, an optical I/Q modulator based on a dual parallel Mach-Zehnder modulator (MZM) [6] is usually used to generate an arbitrary complex electric field. However, this conventional structure has a problem with unwanted excess loss. Meanwhile, the modulator bias of a dual parallel MZM is quite important for the establishment of good pre-compensation performance. However, tolerance to bias offsets has not been studied to date.

In this paper, we propose a novel pre-compensator architecture whose I/Q coordinates are transformed. This enables the excess insertion loss to be mitigated as compared to a conventional pre-compensator. We also present the tolerance to bias offset in a dual parallel MZM.

2. Coordinate Transformed Pre-compensator

Fig. 1 shows the schematic diagram of a conventional electronic pre-compensator. The input data sequence is converted to two orthogonal pre-distorted signals, i.e. a real (I-ch) and an imaginary (Q-ch) part. The signal processing is executed by inverse-convolution between the input data stream and the impulse response of the transfer function of the optical fiber link. When the pre-compensator generates a signal for 0 ps/nm dispersion, 3 dB excess loss occurs. This is because the imaginary part (Q-ch) does not exist for 0 ps/nm. To avoid the excess loss, we propose the coordinate transformation of the I/Q channels in the dual parallel MZM shown in Fig.2. Here, after the real and the imaginary parts are combined and the coordinates are rotated through angle θ, a transformed I/Q signal is produced as shown in the equations below.

$$D_r(t)' = \cos\theta \cdot D_r(t) + \sin\theta \cdot D_i(t)\,, \qquad (1)$$

$$D_i(t)' = -\sin\theta \cdot D_r(t) + \cos\theta \cdot D_i(t)\,, \qquad (2)$$

where $D_r(t)$ and $D_i(t)$ are the original real and imaginary parts for pre-compensation.

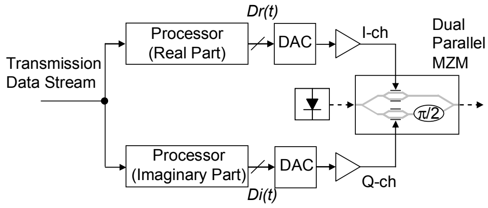

Fig.1. Conventional pre-compensator.

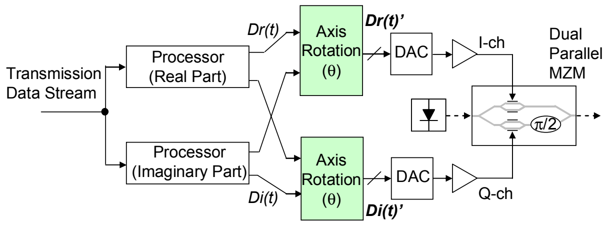

Fig.2. Proposed coordinate transformed pre-compensator.

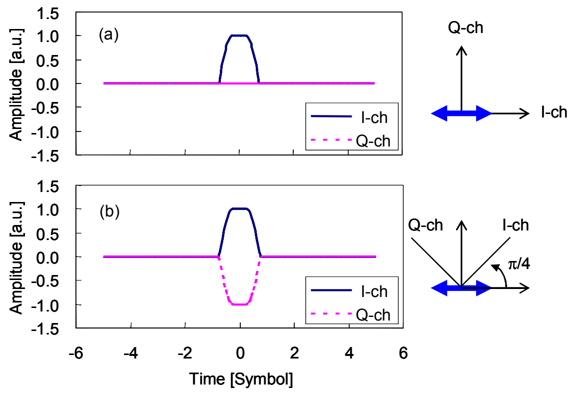

Fig.3. Example of complex electric field:
(a) Conventional pre-compensator (b) Proposed coordinate-transformed pre-compensator.

Fig. 3 shows the complex electric fields of a single pulse transmitted from the conventional (a) and proposed (b) pre-compensator for a pre-compensation value of 0 ps/nm. In the conventional case, there is no Q-ch component. The light traveling along the Q-ch arm is lost when constructing the dual parallel MZM output. This causes an unwanted 3dB excess loss as mentioned above.

In contrast, the coordinates are rotated by π/4 in the case of the proposed configuration as shown in Fig.3(b). Since the I-ch and Q-ch amplitudes become equal, no excess loss occurs.

Fig. 4 shows the calculated I-ch/Q-ch power ratio for the coordinate transformed pre-compensator. In this calculation, we assumed an NRZ, PRBS 9, 40 Gb/s data sequence. The DAC was assumed to work at 80 Gsample/s – 6 bits quantization, which corresponds to double over-sampling of the symbol rate. We treated the processor of the pre-compensator as an FIR (Finite Impulse Response) filter. The number of taps of the FIR filter was 65 symbols. The total dispersion being pre-compensated was varied from 0 to 2000 ps/nm. As shown in Fig. 4, $\theta=\pi/4$ results in the same output power in the I-ch and Q-ch regardless of the pre-compensation value. This result shows that the coordinate transformation scheme is effective for dispersion pre-compensation.

We calculated the excess loss against the rotation angle for a range of dispersions being pre-compensated, as shown in Fig. 5. The maximum improvement of 3dB was obtained when a rotation angle of π/4 was chosen for 0 ps/nm. The excess loss changed cyclically with the rotation angle.

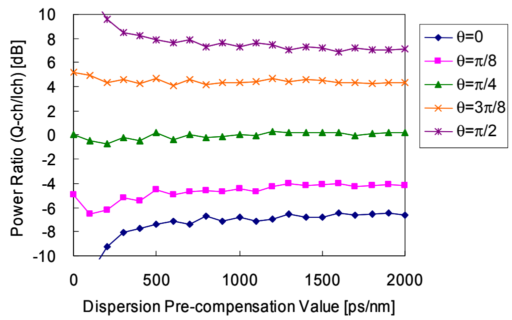

Fig.4. Q-ch/I-ch power ratio with coordinate transformation for various dispersions.

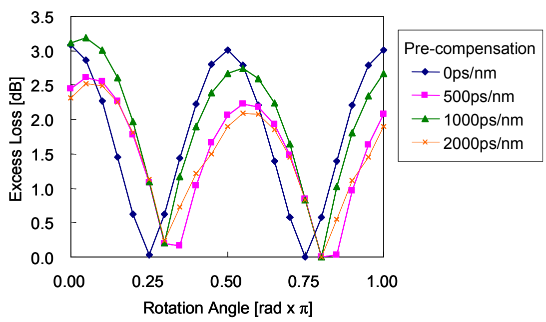

Fig.5. Excess loss vs. rotation angle for various dispersions.

3. Tolerance to Bias Control Error

Three independent bias control units are necessary for I-ch MZM, Q-ch MZM and the relative phase between the I-ch and Q-ch. Because the different I-ch/Q-ch power ratio due to the coordinate transformation could change the tolerance to bias offsets, we investigated the tolerance to bias error with and without the coordinate transformation. Fig. 6 shows the eye opening penalty vs. bias errors in the I-ch and Q-ch, and the phase difference between the I-ch and Q-ch. The penalties are normalized to the minimum penalty for each θ. In these calculations, the total amount of dispersion to be pre-compensated is 2000 ps/nm, and the DAC has 6 quantization bits. The rotation angles are 0 and π/4. The allowable bias error window for $\theta=\pi/4$ is 0.1 π for an eye opening penalty of 0.5dB. This is comparable to the requirement of a conventional pre-compensator ($\theta=0$).

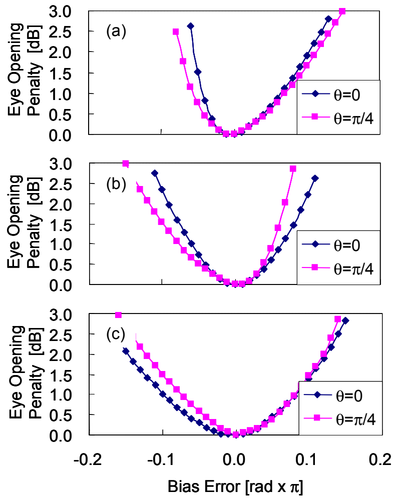

Fig.6. Eye opening penalty vs. bias error:
(a) I-ch MZM (b) Q-ch MZM (c) Phase difference between I-ch and Q-ch.

4. Conclusion

We have proposed a novel electronic pre-compensator with coordinate transformation. The excess loss of the dual parallel MZM was improved by up to 3dB thanks to the π/4 axis rotation. We also show the tolerance to bias error of the dual parallel MZM. The results show that the axis rotation is effective in diminishing the insertion loss of the modulator, while retaining the same robustness as a conventional pre-compensator.

Acknowledgments

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References

[1] M. M. El Said, *et al.*, *J. Lightwave Technol.*, vol. 23, no.1, 388, 2005.
[2] D. McGhan, *et al.*, *OFC/NFOEC2005,* paper PDP27, 2005.
[3] R. I. Killey, *et al.*, *OFC/NFOEC2006*, paper OWB3, 2006.
[4] P. J. Winzer, *et al.*, *ECOC2005*, paper Tu.4.2.2, 2005.
[5] H. Yang, *et al.*, *ECOC2006*, paper We.1.5.2, 2006.
[6] K. Higma, *et al.*, *IEE Electron. Lett.*, vol. 37, no.8, 515, 2001.