Modulation-Format-Free Bias Control Technique for MZ Modulator Based on Differential Phasor Monitor

H. G. Choi, Y. Takushima, H. Y. Choi, J. H. Chang, and Y. C. Chung
KAIST, Department of Electrical Engineering, 335 Gwahangno, Yuseong-gu, Daejeon 305-701, Korea
(Phone) 82-42-350-3456 (Fax) 82-42-350-3410 (E-mail) ychung@ee.kaist.ac.kr

Abstract: We propose a novel bias control technique based on the differential phasor monitor for the $LiNbO_3$ modulator. For demonstrations, the proposed bias control technique was used for 20-Gb/s QPSK and 43-Gb/s 16-QAM signals.
OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation

1. Introduction

Recently, multi-level modulation formats have attracted many attentions due to its capability of increasing the data rate without increasing the symbol rate [1]-[3]. In order to generate the multi-level modulation formats such as the quadrature phase-shift keying (QPSK), quadrature amplitude modulation (QAM) and orthogonal frequency-division multiplexing (OFDM), it is typically needed to utilize multiple $LiNbO_3$ (LN) modulators in various configurations [2]-[3]. However, the operating conditions of these modulators can easily drift away from their optimal points due to the ambient temperature changes and device aging [4]. Thus, it is indispensable to utilize the automatic bias controller, which can track the optimum bias point of the modulator, for the long-term stability. Previously, it has been reported that such a bias controller can be realized for the QPSK signal by monitoring the bias dithering signals and backward–travelling light [5]-[7]. However, to the best of our knowledge, there has been no report yet on the automatic bias controller for the higher-order modulation formats such as QAM signals.

In this paper, we propose and demonstrate a novel automatic bias control technique based on the differential phasor monitor, which can be implemented cost-effectively by using low-speed analog-to-digital (A/D) converters [8]. In this technique, the feedback signal for the bias control is obtained by calculating the difference between the ideal phasor and the phasor under improper bias conditions. Thus, this technique can be applied to any modulation formats. For demonstrations, we implement the proposed technique for the bias control of 20-Gb/s QPSK and 43-Gb/s 16-QAM signals. The results show that the achieved bit-error rate (BER) by using the proposed technique for the 20-Gb/s QPSK signal is almost identical to the value obtained by manually optimizing the operating condition of the $LiNbO_3$ modulator. No significant difference is observed for the 43-Gb/s 16-QAM signal too.

2. Operating principle of the proposed bias control technique based on the differential phasor monitor

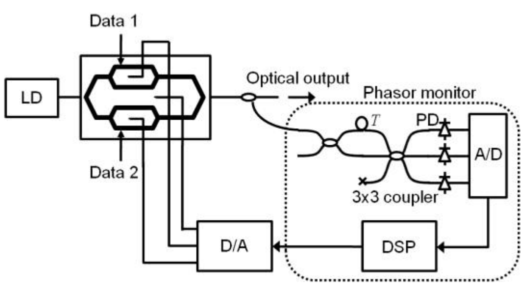

Fig. 1. Schematic diagram of the proposed bias control technique based on the differential phasor monitor.

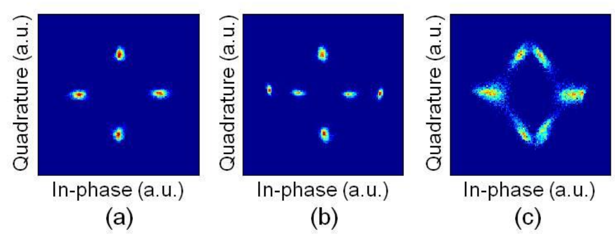

Fig. 2. Differential phasors of QPSK signal with (a) optimum bias, (b) bias error in one of the MZMs, and (c) bias error in MZI.

Fig. 1 shows the schematic diagram of the proposed bias control technique based on the differential phasor monitor. To explain the operating principle of the proposed technique, we assume to control the QPSK modulator made of two parallel Mach-Zehnder modulators (MZMs) nested in a MZ interferometer (MZI). To identify the optimal bias conditions of this modulator, we measure the differential phasor of the QPSK signal by using the differential phasor monitor [8]. We then calculate the bias errors (which are defined as the differences between the ideal differential phasor points obtained by optimal biases and the achieved differential phasor points under non-optimal biases) from the measured differential phasor. For the statistical analysis of these bias errors, we calculate the standard deviations of the amplitude and phase of the measured differential phasor points. Finally, these results are used to generate the feedback signal of the proposed bias control technique. For example, Fig. 2(a) shows the ideal differential phasor of the QPSK signal obtained under the optimal bias conditions (i.e., the bias points of two MZMs and MZI are set to be at their null transmission points and quadrature phase, respectively). However, if these bias points drift away from their optimal conditions, the differential phasor is distorted. When the bias point of the MZI varies, the in-phase (I) component of the differential phasor is broadened, and, as a result, the symbols on the I-axis of the phasor diagram split into four, as shown in Fig. 2(b). This is because the improper phase shift between two binary PSK (BPSK) signals causes two different output power levels with 0˚ or 180˚ phase shift [5]. In addition, when the bias points of two sub MZMs are drifted away from their null transmission points, the symbols on the quadrature-axis (Q-axis) also split into four, as shown in Fig 2(c), since the intensity symmetry in the outputs of these sub MZMs is no longer maintained. Also, the differential phasor points are significantly broadened since the amplitude noise suppression of the driving signal is reduced as the biases drift away from their null transmission points [5]. Thus, we optimized the bias conditions of this QPSK modulator by minimizing the bias errors using a simple hill climbing algorithm. The proposed technique can be applied to any modulation formats since it is based only on the differences in shapes from its ideal differential phasor.

3. Demonstration of the proposed bias control technique for 20-Gb/s QPSK and 43-Gb/s 16-QAM signals

We first demonstrated the effectiveness of the proposed bias control technique using a 20-Gb/s QPSK signal. The bias control loop was implemented by using a differential phasor monitor, as shown in Fig. 1. For the modulation, we applied two 10-Gb/s NRZ signals (pattern lengths = 2^{11}-1) to the QPSK modulator. The amplitudes of the NRZ signals were set to be ~$2V_\pi$. We tapped a small portion of the output signal from the QPSK modulator and directed to the differential phasor monitor. This phasor monitor consisted of three parts; (1) a phase-adjustment-free delay-interferometer (DI) made of a 3x3 coupler, (2) an optical front-end made of three photo detectors, and (3) A/D converters connected to a digital signal processor (DSP). In this monitor, the delay time of the DI was adjusted to be same with the symbol period *T*. The output signals of the DI were sampled by using inexpensive A/D converters operating at 5 MS/s. Then, we obtained the I and Q components of the differential electric field (i.e., differential phasor) of the signal [9]. The measured differential phasor was used to generate the error signals for the proposed bias control technique. For example, as an error signal for the bias control of the MZI in the QPSK modulator, we utilized the amplitude standard deviation of the I component, $\sigma_{A,I}$. This error signal increased as the bias voltage of the MZI drifted away from its optimal point, as shown in Fig. 3(a). On the other hand, the product of the standard deviations of the phase and amplitude of the Q component ($\sigma_{P,Q}$ and $\sigma_{A,Q}$) were used to control the bias voltages of two sub MZMs. Fig. 3(b) shows the product of $\sigma_{P,Q}$ and $\sigma_{A,Q}$ measured as a function of the MZM's bias error. This error signal also increased as the MZM's bias voltage drifted away from their optimal points. Thus, after analyzing the distortions on the measured differential phasor, the feedback signals were sent to the QPSK modulator through digital-to-analog (D/A) converters. We utilized the hill climbing algorithm to search the optimal bias points of the QPSK modulator. The step size of this bias control loop was adaptively adjusted to improve the convergence rate. Fig. 4 shows the error signals of two sub MZMs as well as the MZI in the QPSK modulator measured as a function of the number of feedback iterations (i.e., time) for three different initial bias conditions. The differential phasors measured after 0 and 60 iterations (for square symbol) are also shown at the right side of Fig. 4. This figure clearly shows that the proposed technique can identify the optimal bias points and stabilize them automatically regardless of their initial bias conditions. To verify the effectiveness of the proposed bias control technique, we also measured the BER curve of the QPSK signal while controlling the bias voltages of the modulator automatically. For the demodulation of the QPSK signal, we used a delay interferometer. The demodulated outputs of the delay interferometer were converted to electrical signal via balanced photodetector followed by an error detector. Fig. 5 shows the BER curve obtained by using the proposed bias control technique. For comparison, we also measured the BER curve by manually adjusting the bias voltages of the QPSK modulator to minimize the BER. The result shows that there was no difference in the measured BER curves by using the proposed technique and manually adjusting the bias voltages.

To investigate the feasibility of using the proposed bias control technique for higher-order modulation formats, we evaluated its performance for the 16-QAM signal. For the 16-QAM modulation, two copies of four-level 10.7-Gb/s signals (pattern length = 2^{15}-1) were applied to the dual-parallel MZM shown in Fig. 1 [2]. The peak-to-peak voltage of the four-level signals was ~V_π. The setup used for the bias control of the 16-QAM signal was the same with the one used for the QPSK signal. Fig. 6 shows the differential phasors of the 16-QAM signal measured at the initial random bias conditions (upper left) and after 80 iterations of the feedback loop (upper right). However, it might not be clear how well the proposed technique worked for 16-QAM signal due to the nature (i.e., interference between symbols) of the differential phasor. Thus, we also measured the coherent phasor of the same 16-QAM signal (shown in the lower part of Fig. 6) by using a coherent receiver. This figure shows that the bias voltages are properly adjusted to generate 16-QAM signal. In this experiment, the initial bias errors of two sub MZMs and MZI were 1.5 V_π, 0.7 V_π, and 0.3 V_π, respectively. By using the proposed bias control technique, the bias voltages were converged to their optimum values with errors of only 0.024 V_π, 0.0003 V_π, and 0.047 V_π., respectively. We also measured the BERs of the 43-Gb/s 16-QAM signal obtained by using the proposed bias control technique. Fig. 7 shows the recovered (i.e., after equalization) coherent phasors obtained by using the manual and automatic bias controls. Their corresponding BERs were measured to be 3.6 x 10^{-4} and 6.7 x 10^{-4}, respectively. Thus, there was practically no difference in their performances. From these results, we anticipate that the proposed technique can be used for any advanced modulation formats by monitoring their differential phasors.

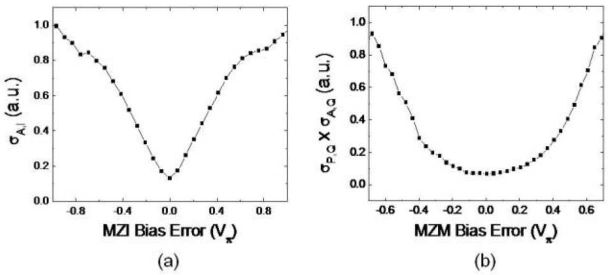

Fig. 3. (a) Bias error of MZI vs. $\sigma_{A,I}$, (b) bias error of MZM vs. product of $\sigma_{P,Q}$ and $\sigma_{A,Q}$.

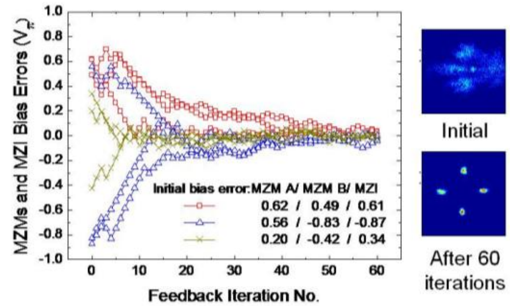

Fig. 4. Bias errors of MZMs and MZI measured as function of the number of feedback iterations. The differential phasor diagrams on the right side are obtained after 0 and 60 iterations.

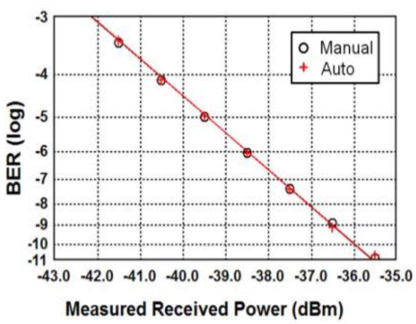

Fig. 5. BER curve of the 20-Gb/s QPSK signal measured by using the proposed bias control technique and manually adjusting the bias voltages.

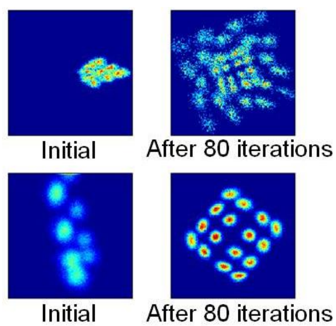

Fig. 6. Differential phasors (upper) and coherent phasors (lower) of 16-QAM signal.

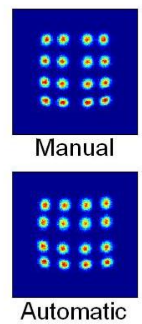

Fig. 7. Recovered coherent phasor of 16-QAM signal by using the proposed bias control technique in comparison with the one obtained by manually adjusting bias voltages.

4. Summary

We have proposed and demonstrated a novel bias control technique based on the differential phasor monitor for the $LiNbO_3$ modulator. Our technique could be used for various advanced modulation formats including the QPSK and QAM signals. The effectiveness of the proposed technique was demonstrated by using 20-Gb/s QPSK and 43-Gb/s 16-QAM signals. The results showed that, in case of 20-Gb/s QPSK signal, the BER curve obtained by using the proposed bias control technique was identical to the one obtained by manually adjusting the bias voltages. We also evaluated the performance of the proposed technique for the higher-order modulation format by using a 43-Gb/s 16-QAM signal. No significant difference was observed in the BERs of the 16-QAM signal obtained by using the proposed technique and the manually adjusting the bias voltages of the dual-parallel MZM.

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