Field Experiment of 112 Gb/s Dual-Carrier DQPSK Signal Transmission with Automatic Bias Control of Optical IQ Modulator

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Abstract: We demonstrate a simple and cost-effective automatic bias control scheme of quadrature modulator for advanced modulation formats, and confirm its performances in field transmission of 112 Gb/s dual-carrier DQPSK signal over 797-km of installed fiber.

OCIS codes: OCIS codes: (060.5060) Phase modulation, (060.4080) Modulation

1. Introduction
Increasing data traffics require a continuous expansion of network capacity, and advanced modulation formats play a critical role in moving to high-capacity transmission [1]-[7]. Up to recent days, to generate multi-level optical signal such as quadrature phase-shift keying (QPSK), quadrature amplitude modulation (QAM) and optical orthogonal frequency division multiplexing (OFDM), most of the advanced modulation formats typically used an integrated LiNbO$_3$ (LN) inphase/quadrature (IQ) modulator structure with two-parallel Mach-Zehnder modulators (MZM) nested in MZ interferometer (MZI). Optimum operating conditions of the optical IQ modulators should be null transmission points in two MZMs for the generation of inphase/quadrature data, and the quadrature phase ($\pi$/2) difference between inphase and quadrature data. When IQ modulators are used in actual transmitters for advanced modulation formats, it is critically important to prevent bias drift from their optimal points due to temperature change, stress, and device aging. Thus, a simple and cost-effective automatic bias controller which can search proper bias points and track their optimum points is essential for the long-term operation. Several schemes have been reported to control the bias condition of IQ modulator using backward light, differential phasor monitor, asymmetric sinusoidal dithering wave, and RF power of signal along with optical power [4]-[7]. These schemes would require additional light, complex constellation monitor, or precise lock-in amplifier module [4]-[6]. Their performances evaluations in real environments were also not reported yet.

In this paper, we demonstrate a simple and cost-effective bias control technique for optical IQ modulator. The optimal bias conditions of two MZMs and MZI are obtained by applying low frequency square-wave (~10 kHz) and detecting RF signal power, respectively. Neither additional light nor complex control circuit is required in the scheme. It is easy to distinguish and to estimate independently the bias drift of two MZMs and MZI. For demonstration, we implement the automatic bias control scheme in 112 Gb/s dual-carrier-differential QPSK (DC-DQPSK) transmitter, and investigate its long-term stability performances in a field experiment of 112 Gb/s DC-DQPSK signal transmission over 797-km over installed fiber and ROADMs.

2. Bias Control Scheme and Experiment of Bias Control Loop

![Optical IQ modulator and automatic bias control scheme based on square wave and RF power detection](image)

Fig. 1. Optical IQ modulator and automatic bias control scheme based on square wave and RF power detection (a) schematic diagram (b) RF power spectrum when IQ data are driven by 28 Gb/s. RF power of square-wave within 10 kHz is used for the control of MZM (bias 1&2) and that of signal power less than 700 MHz is used for the control of MZI (bias3).
Fig. 1 shows the schematic diagram of automatic bias control technique. The IQ modulator is composed of an integrated two-parallel MZMs nested in MZI, and the bias points of two MZMs and MZI should set to be at their null transmission points and quadrature phase, respectively. To search proper bias points and track their optimum conditions, the low frequency square-wave and detecting its RF power was used to control two MZMs (bias 1 and 2), whereas the RF power of QPSK signal was used to control MZI (bias 3). Since the frequency of square-wave (i.e 10 kHz) is less than typical low-frequency cut-off of high-speed receiver, we could avoid penalty induced by square-wave dithering. Each square-wave for MZM1 and MZM2 is applied at different time to estimate independently the bias points of two MZMs. There is no dithering tone for MZI (bias 3). At the output of IQ modulator, small portion of output signal was tapped, and then it was applied to the bias controller. The bias controller detects the RF power of square wave less than 10 kHz and RF power of signal less than 700 MHz, and these results are used to generate feedback signal of control circuit.

![Graph](attachment:image1.png)

Fig. 2. Simulated results for (a) RF power of 10 kHz square-wave versus bias of MZM and (b) RF power of 56 Gb/s QPSK signal with various RF filter bandwidth versus bias of MZI.

![Graph](attachment:image2.png)

Fig. 3. Measured performances of the automatic bias control scheme (a) Monitoring signal for MZMs and MZI with automatic bias control (b) BER curve of 56 Gb/s DQPSK signal measured by automatic bias control and manually optimizing bias voltages.

Fig. 2 shows simulated RF power of 10 kHz square-wave and 56 Gb/s DQPSK signal with different bias conditions. Since the RF power of square wave follows the transmission characteristics of MZM, the detected RF power becomes minimum value at their null transmission point, as shown in Fig 2(a). The RF power of signal also becomes minimum value when inphase and quadrature data has \( \pi/2 \) phase difference, as shown in Fig. 2(b). Since this characteristic is independent of RF filter bandwidth, we could control bias of MZI with low-frequency electric components. Thus, we optimize the bias conditions of IQ modulator by minimizing the measured RF power of square-wave and that of QPSK signal.

Fig. 3(a) shows the measured monitoring signal of two MZMs and MZI in the 56 Gb/s DQPSK signal as a function of the number of feedback iterations. For the modulation, we applied two 28-Gb/s NRZ signals (pattern lengths = \( 2^{31}-1 \)) to the QPSK modulator. The amplitudes of the NRZ signals were set to be \( \sim 2V_p \). The results show that the control loop searches the optimum bias conditions of each MZM and MZI one-by-one, and stabilizes all bias voltages within 45 iterations. We also confirmed the convergences to optimal operating points for many random initial biases and phases. Fig. 3(b) shows the measured BER curve obtained by using automatic bias control and manually adjusting the bias voltages to minimize the BER. As expected, there was no difference in the measured BER curves and no penalty induced by low-frequency square-wave.
3. Performance Evaluation in Field Transmission Experiment

We implemented the automatic bias control scheme in 112 Gb/s DC-DQPSK transceiver [1], and evaluated its long-term performances in field transmission of 112 Gb/s DC-DQPSK signal over 797-km over installed fiber. The DC-DQPSK is composed of two optical carriers, and each carrier is modulated by DQPSK format with 28 Gbaud symbol rate. The transmission experiment was carried out by combining a prototype of 100-Gb/s transponder, ROADM systems, field deployed fibers, and 100GE tester, as shown in Fig. 4(a). A 100GE test set was used to generate 100GE traffic and to analyze the transmission performance. The output of 100GE test set was connected to the 112 Gb/s transponder. The 100GE traffic was wrapped into an OTU4 frame, and connected to DC-DQPSK transceiver. The transmission line was composed of 797 km of SSMF and NZDSF with 9-ps/nm/km dispersion. Span lengths varied from 40 km to 106 km while span loss was fixed at 25 dB. After transmission, the carrier OSNR was measured to be 21.5 dB. The de-multiplexed 112 Gb/s signal was connected to delay interferometer, and the demodulated outputs were converted to electrical signal via balanced photo-detector (BPD). Automatic control of delay interferometer was also implemented by minimizing the output of peak-detector embedded in BPD. For BER measurement, FEC decoding at the framer was turned off, while bit-rate was still 112 Gb/s. Fig. 4(b) shows measured BER of 100GbE traffic. The average BER was measured to be 3.5x10^-3, and the BER was quite stable over 19.2 hours. The range of BER variation was quite small from 2.4x10^-3 to 5.2x10^-3, and the control stability of modulator and delay interferometer as well as transmission link affected these BER variation. One can see that the control loop is quite robust even in the presence of significant amount of amplitude and phase noise. From these results, we confirmed that the proposed automatic bias control technique could be used to actual transmitters of advanced modulation formats for long-term operation.

4. Summary

We have demonstrated a simple and cost-effective bias control technique for optical IQ modulator based on low frequency square-wave (~10 kHz) along with RF power of signal. Neither additional light nor complex control circuit was required in the scheme. The effectiveness of the automatic bias control scheme was demonstrated in 112 Gb/s DC-DQPSK transmitter, and its long-term stability performances was investigated in a field experiment of 112 Gb/s DC-DQPSK signal transmission over 797-km over installed fiber and ROADMs. The control loop showed that there was no OSNR sensitivity penalty compared with manual optimization of bias conditions. The results of field experiment also indicated that the control technique could be used to actual transmitters of advanced modulation formats for long-term operation.

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References