Review of Bias Point Stabilization Methods for IQ Modulator

Mingzhu Zhang[1,2], Yupeng Li[1,2(✉)], Xiaoming Ding[1,2], and Xiaocheng Wang[1,2]

[1] Tianjin Key Laboratory of Wireless Mobile Communications and Power Transmission, Tianjin Normal University, Tianjin 300387, China
fx_lyp@163.com
[2] College of Electronic and Communication Engineering, Tianjin Normal University, Tianjin 300387, China

Abstract. The main sub-device of In-phase and Quadrature (IQ) modulator is Mach-Zehnder Modulator (MZM) based on LiNbO$_3$ crystals, and the susceptibility of LiNbO$_3$ material to external environment such as temperature and device aging will lead to changes in the intrinsic properties of MZM, which will degrade the quality of optical signal originally biased at a specific voltage. In order to ensure the effective transmission of signals in optical communication systems, this paper summarized the bias point stabilization control method for IQ modulators in optical communication systems.

Keywords: IQ modulator · Bias point · Control of stability

1 Introduction

Generally speaking, the modulator used to generate higher-order modulated signals is IQ modulator, which consists of two MZMs and one Mach-Zehnder Interferometer (MZI) that is known as phase modulator. The branches of the two MZMs are the In-phase (I) branch and the Quadrature (Q) branch respectively, and both of them work in the push-pull mode. The phase modulator mainly produces a certain phase shift for the optical signal of I/Q channels, which is generally 90° [1, 2].

Using IQ Modulation at the transmitter side, the real and imaginary parts of the amplified RF signal are generally loaded into the I- and Q-way Radio Frequency (RF) ports of the IQ modulator. The basic structure of the IQ modulator is shown in Fig. 1. The signal light enters the IQ modulator input port and is divided into two paths by the coupler into the I/Q two branches, and the two paths will be coupled into one signal at the output for output. And the three modulators are controlled by three bias voltages respectively [3, 4].

The main advantage of IQ modulation is the ability to very easily combine independent signal components into a composite signal, which is later decomposed into independent signal components.IQ modulators can actually be seen as a combination of a phase modulator and an intensity modulator and are widely used in higher order modulation formats such as QAM. Meanwhile, IQ modulator is an important device

choice in ultra-high-speed coherent systems, and stabilizing its bias point is of great significance for communication system stability.
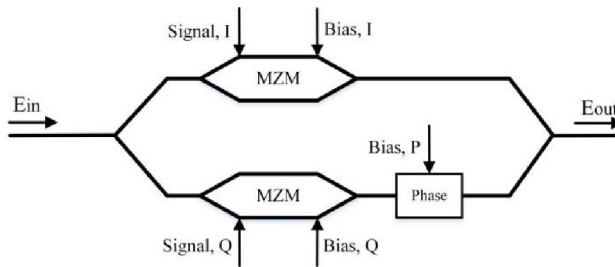

**Fig. 1.** Basic structure of the IQ modulator

2 IQ Modulator Bias Point Stabilization Control Method

IQ modulator bias point stabilization control methods can be classified into three main categories according to the essential principles: power monitoring, dither signal and phase monitoring based bias point stabilization control technique.

Figure 2 shows the schematic diagram of the power monitoring based bias point stabilization control technique. The principle of this bias point stabilization control technique is based on finding a special value of the average optical power and RF power spectrum signal. The Coupler separates a small portion of the signal from the IQ light modulation signal into the photodetector, which converts the light signal into an electrical signal. Followed by the electrical signal into the RF detector, then into the analog-to-digital converter, and finally into the control unit. Control unit analyzes the received signal in order to control the three output signals of the digital-to-analog converter, i.e., the three bias voltages of the IQ optical modulator.

The schematic diagram of the dither signal based bias point stabilization control technique is similar to that the schematic diagram of the power-based bias point stabilization control technique, therefore it is no longer drawn. But the difference is that the key to this method is to add the pilot signal to the bias control signal in both I/Q paths, while the phase shift bias voltage contains only the Direct Current (DC) signal. The comparison signal obtained from the clock signal in the oscillator is sent to the bias control unit, where the data is analyzed and the bias point is stabilized [5, 6].

The schematic diagram of the phase monitoring based bias point stabilization control technique is similar to that the schematic diagram of the power-based bias point stabilization control technique, therefore it is no longer drawn. But the difference is that the method incorporates a differential phase detector in the system. The stability of the bias voltage is controlled by monitoring the phase information of the modulating signal. The control unit determines whether the bias voltage drifts according to the difference between the real-time phase information and the ideal phase information, and controls the bias point stability by algorithm controlling the three bias voltages.
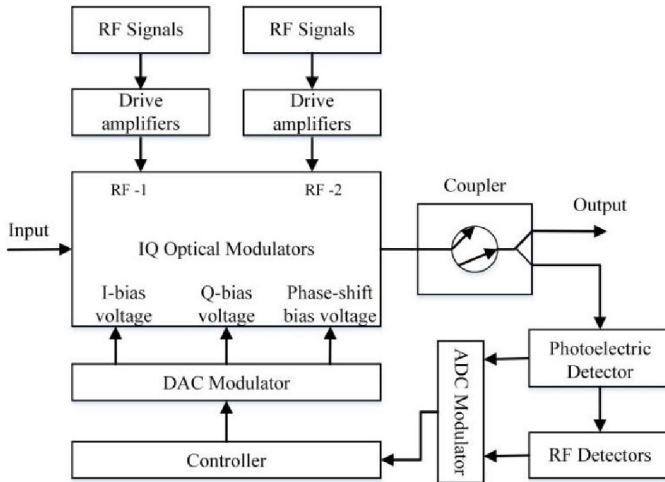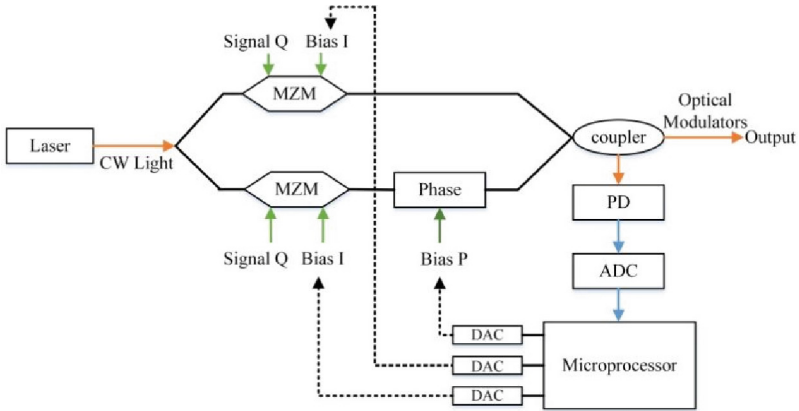
Fig. 2. The schematic diagram of the power monitoring based bias point stabilization control technique

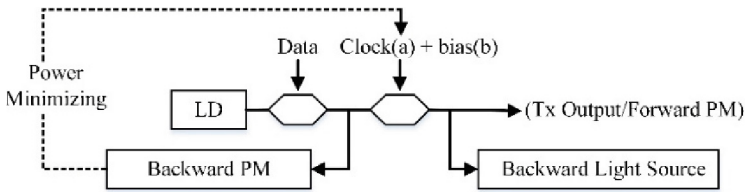### 2.1   Power Monitoring Based Bias Point Stabilization Control Technique

Method 1: The ratio of the first- and second-order bias of the mean power of the output signal is used for direct regulation similar to a look-up table, and the regulation of the bias voltage is subsequently achieved by the corresponding iterative algorithm.

The scheme diagram of ratio of the first- and second-order bias of the mean power of the output signal is shown in Fig. 3. Firstly, for monitoring and regulating the two sub-MZMs, the mean power can be used as a rough monitoring indicator, and then the ratio of the first- and second-order bias of the mean power to the bias can be used as a specific regulation indicator. When the bias point is changed, the corresponding bias ratio can be calculated and then looked up in the table, which saves the corresponding iteration time. After the two MZMs are adjusted, the variance and normalized variance are calculated based on the sampled data, and the phase modulator is iteratively adjusted according to the normalized variance, and the position with the smallest normalized variance is the best bias [7, 8].

Method 2: The bias point stabilization control technique using reverse waves. A wavelength adjustable light source is added at the output of the IQ modulator, and an optical signal is input to the modulator, which propagates in the opposite direction to the modulated optical signal. A power monitoring instrument is placed at the input of the target modulator to minimize the power of the reverse wave by monitoring it, in order to stabilize the bias point at the optimal working position. This scheme increases the power consumption and cost of the modulation system [9, 10]. Figure 4 shows a schematic of the configuration of the monitoring and control scheme.

Fig. 3. The scheme diagram of ratio of the first- and second-order bias of the mean power of the output signal

Fig. 4. Configuration schematic of the monitoring and control scheme

2.2 Dither Signal Based Bias Point Stabilization Control Technique

Method 1: As shown in Fig. 5, the structure of the integrated DP-QPSK modulator is shown, and the lead signals are added to the bias control signals of the I-way, Q-way and the phase shift between the two ways, respectively, setting the frequencies f_I, f_Q and f_P, so that three beat frequency signals can be obtained with frequencies $f_I - f_Q$, $f_I - f_p$ and $f_Q - f_p$, respectively, and by eliminating these three beat frequency signals, the Mach-Zehnder modulator of the I-way and Q-way can be stabilized [11, 12].

Firstly, Control the outer MZM at Quad by nulling the detected beat signal at frequency of $(f_I - f_Q)$. Secondly Control the inner MZM at Min by nulling the detected beat signal at frequency of $(f_Q - f_p)$. And finally Control the inner MZM at Min by nulling the detected beat signal at frequency of $(f_I - f_p)$.

Mathematically speaking, the magnitudes of the beat terms at the difference frequencies are proportional to the 2nd order partial derivatives of the detected photocurrent with respect to the corresponding bias voltages. Therefore, the three bias conditions derived from the above control technique should satisfy the following system of three equations:

$$\frac{\partial^2 I_{\text{out}}}{\partial v_{I,\text{dc}} \cdot \partial v_{Q,\text{dc}}} = 0 \tag{1}$$

$$\frac{\partial^2 I_{\text{out}}}{\partial v_{I,\text{dc}} \cdot \partial v_P} = 0 \tag{2}$$

$$\frac{\partial^2 I_{\text{out}}}{\partial v_{Q,\text{dc}} \cdot \partial v_P} = 0 \qquad (3)$$

In the above equations, I_{out} denotes the current at the output. $V_{I,\text{dc}}$, $V_{Q,\text{dc}}$ and V_P denote the DC voltages at the I-way MZ modulator, Q-way MZ modulator and phase modulator terminals, respectively.
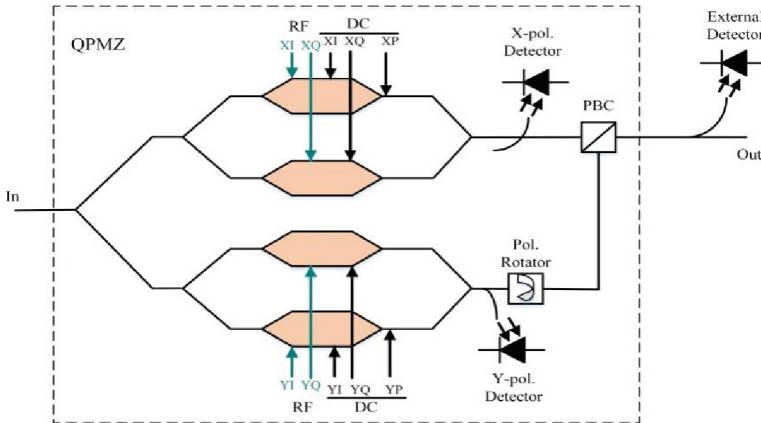

Fig. 5. Integrated DP-QPSK modulator structure diagram

Method 2: Figure 6 shows the automatic bias control method based on two different dither signals. The bias signals of the two sub-MZMs (Bias I and Bias Q) are dithered with two sine waves. A microprocessor unit (MPU) is then used to monitor the average optical signal power, the transmitted dither signal, and the correlation integral of the detected dither signal for automatic bias control. The scheme does not require FFT-based spectral analysis and is easy to implement directional bias adjustment. The algorithm has lower complexity and faster convergence [13, 14].
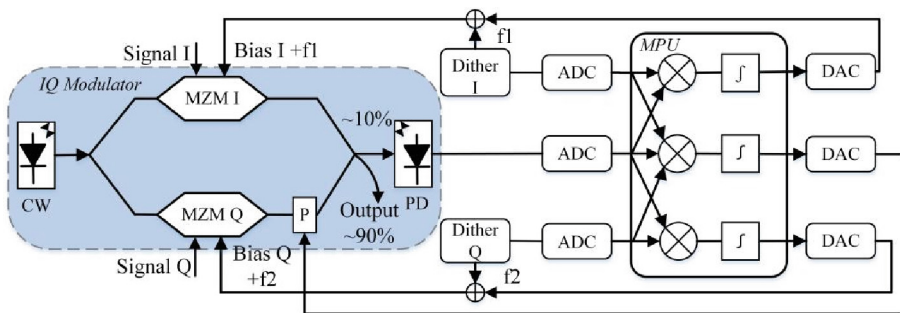

Fig. 6. Automatic bias control method based on two different dither signals

Method 3: Stabilization control technique using the ratio of peak to average optical power of modulated optical signal. In I/Q bias control signal to add the guide frequency signal, combined with the modulation coefficient for bias point stability control. The system structure is simple, but the flexibility is not good [15, 16]. Figure 7 shows the configuration of the modulator bias control block. The bias voltages applied to the ports each include a DC bias voltage and a dither signal.
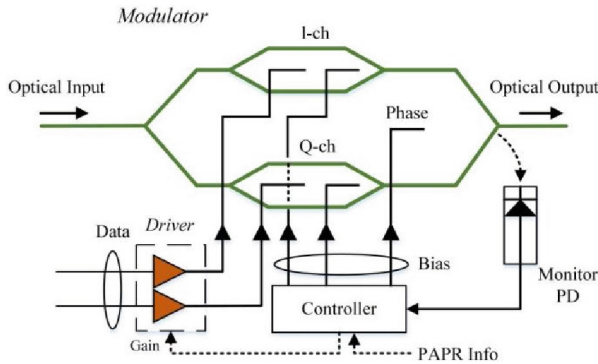

Fig. 7. Configuration diagram of the modulator bias control block

2.3 Phase Monitoring Based Bias Point Stabilization Control Technique

Figure 8 shows the method of bias point stabilization control based on phase monitoring. The method is not limited by the modulation format and has good flexibility. It is based on the principle that the bias voltage changes after the bias point drift, resulting in the phase of the output optical signal also changes. First, we set all three bias voltages to work at the optimal point to obtain the phase in the ideal situation, and then judge the
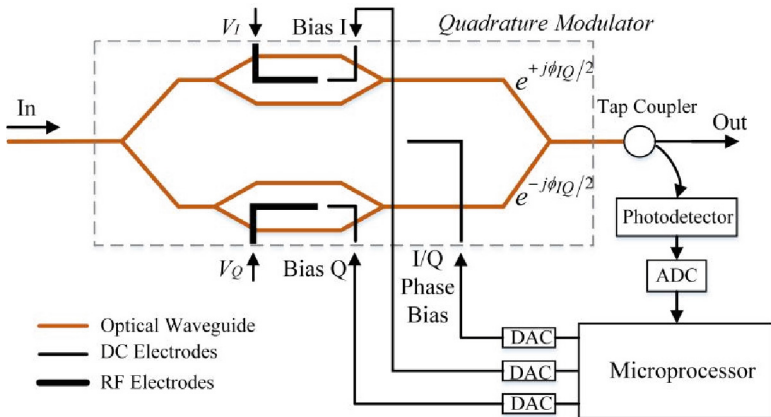

Fig. 8. The method of bias point stabilization control based on phase monitoring

drift of the bias point by comparing the real-time phase with the ideal phase, and use the feedback control system to adjust the three bias points [17, 18].

3   Conclusion

This paper summarizes the automatic bias point stabilization control techniques for IQ optical modulators. Each of these bias point stabilization control techniques has its own advantages and disadvantages, but their ultimate goal is the same, i.e., to quickly and stably control the bias voltage from the IQ optical modulator at the best possible position. Finally, by summarizing and comparing the advantages and disadvantages of different bias point stability control methods, a theoretical basis for subsequent research is provided.

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