A novel auto-bias control scheme for stabilizing lithium niobate Mach-Zehnder modulator at any operating point*

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In this paper, we propose and experimentally demonstrate an auto-bias control scheme for stabilizing a lithium niobate (LN) Mach-Zehnder modulator (MZM) at any operating point along the power transmission curve. It is based on that the bias drift would change the operating point and result in varying the output optical average power of the Mach-Zehnder modulator and its first and second derivatives. The ratio of the first to the second derivative of the output optical average power is used in the proposed scheme as the key parameter. The experimental results show that the output optical average power of the LN MZM hardly changes at the desired operating point, and the maximum deviation of output optical average power is less than ±4%.

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In fiber-optic telecommunication systems, the integrated lithium niobate (LN) Mach-Zehnder modulator (MZM) is employed to generate the on-off keying (OOK), phase-shift keying (PSK) and other advanced modulation formats[1,2]. Moreover, LN MZMs are extensively used in analog radio frequency (RF)/microwave photonics[3,4], and are also deployed in free-space atmospheric laser communications[5,6]. To gain the best performance, direct current (DC) bias voltage applied to the MZM should be set to meet the optimum operating point. However, the bias point of MZM drifts due to various intrinsic and extrinsic factors[7]. Hence long-term stability of optimum bias point of the MZM is crucial.

Dither-based bias control techniques used a pilot signal for biasing[8-15]. Harmonics of the pilot signal can be detected by a photodetector tapping a small percentage of the optical signal from the MZM's output. Characteristics of the harmonics are analyzed and used to stabilize the bias point. For instance, the odd harmonics will vanish at the quadrature point. Unfortunately, most dither-based bias control techniques are developed for stabilizing the MZM at specific points, such as null/peak and quadrature points. But for arbitrary bias point along the transfer function curve, these techniques do not work again. A dither-based auto-bias control technique was demonstrated for locking an LN MZM at any bias point[16]. However, a calibration step is required in this technique. And the calibration step can be neglected when the RF half-wave voltage of the MZM and the amplitude of the pilot signal are both known precisely, which is a little difficult.

In this paper, we propose a novel dither-free auto-bias control scheme for stabilizing an LN MZM at any operating point. Experimental results demonstrate that the proposed auto-bias control scheme works effectively, and is no longer affected by MZM input power level fluctuation or optical path loss variations. The deviation of output optical average power of MZM is less than ±4% when the proposed auto-bias control technique is deployed.

Considering a single push-pull MZM, the output optical average power over a period of time T can be expressed as

$$\left\langle P_{\mathrm{o}}(t)\right\rangle=\frac{kP_{\mathrm{i}}}{2}\left\{1+\frac{1}{T}\int_0^T\cos\left[\frac{\pi}{V_\pi}\left(V_{\mathrm{s}}(t)+V_{\mathrm{B}}\right)\right]\mathrm{d}t\right\}, \tag{1}$$

where $V_{\mathrm{s}}(t)$ is the non-return-to-zero (NRZ) drive signal with a peak-to-peak voltage of V_{PP}, V_{B} is the direct current (DC) bias voltage applied to the MZM, V_π is the half-wave voltage, P_{i} is the input optical power, and k is related to the insertion loss of the MZM. Then the ratio R of the first derivative to the second derivative of Eq.(1) with respect to V_{B} can be given by

$$R=\frac{\partial\left\langle P_{\mathrm{o}}(t)\right\rangle}{\partial V_{\mathrm{B}}}\div\frac{\partial^2\left\langle P_{\mathrm{o}}(t)\right\rangle}{\partial V_{\mathrm{B}}^2}=$$

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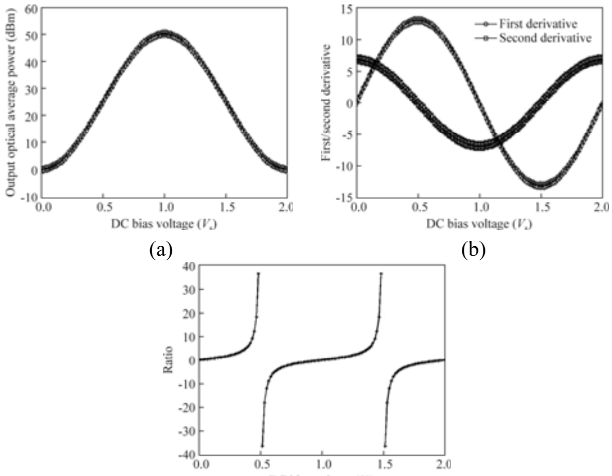
$$-\frac{\pi}{V_\pi}\frac{1}{T}\int_0^T \tan\left[\frac{\pi}{V_\pi}\left(V_s(t)+V_B\right)\right]\mathrm{d}t . \tag{2}$$

The slope of the curve of the output optical average power $\langle P_o(t)\rangle$ is the first derivative $\frac{\partial\langle P_o(t)\rangle}{\partial V_B}$, and the second derivative $\frac{\partial^2\langle P_o(t)\rangle}{\partial V_B^2}$ is the slope of the first derivative. Obviously, the ratio R is independent of the input optical power and the insertion loss of the MZM.

As shown in Fig.1(a) and (b), the output average power and its first and second derivatives change when the bias point of MZM drifts. Moreover, the ratio R increases monotonically with the DC bias voltage in the interval $[0.5V_\pi, 1.5V_\pi]$ as illustrated in Fig.1(c). We take the advantage of this monotonicity to stabilize the LN MZM at any operating point. As long as the ratio is unchanged, the operating point is stabilized. Because the ratio R is independent of input optical power, the proposed scheme cannot be affected by the effect of input power level fluctuation, and is more flexible in applications.

To demonstrate and evaluate the proposed scheme, an experimental setup is designed as illustrated in Fig.2. The input optical power of the MZM is about 3 dBm. An NRZ pulse generator produces an NRZ drive signal which is a 10 MHz bipolar pulse with the peak-to-peak voltage of 8 V. A splitter taps off a small portion of the output modulated light and routes it to a photodetector. Bias control unit processes the data and adjusts the bias voltage.



(a) (b)

(c)

Fig.1(a) Simulated output optical average power and (b) its first derivative and second derivative; (c) The ratio of the first derivative to the second derivative

According to the definition of slope, we set the bias voltage at three adjacent points including the desired point. Using these three points, two first derivatives, which can be used to calculate the second derivative, can be acquired. And then, the ratio is obtained.

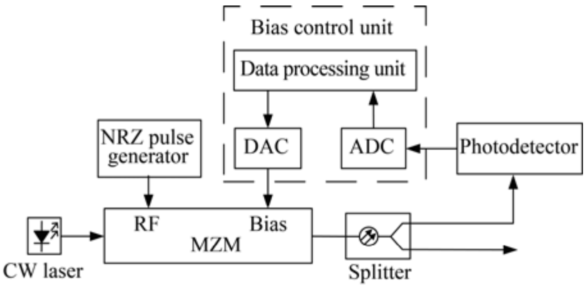
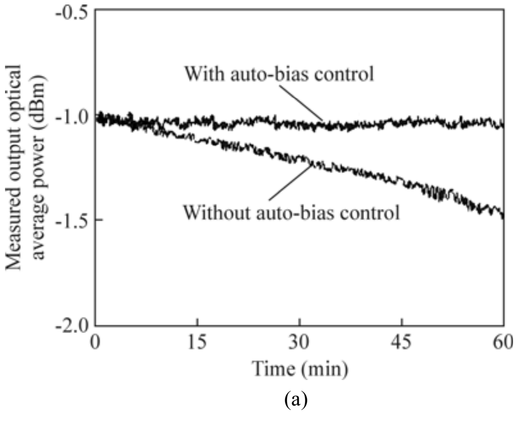


Fig.2 Experimental setup for the proposed bias control scheme of LN MZM

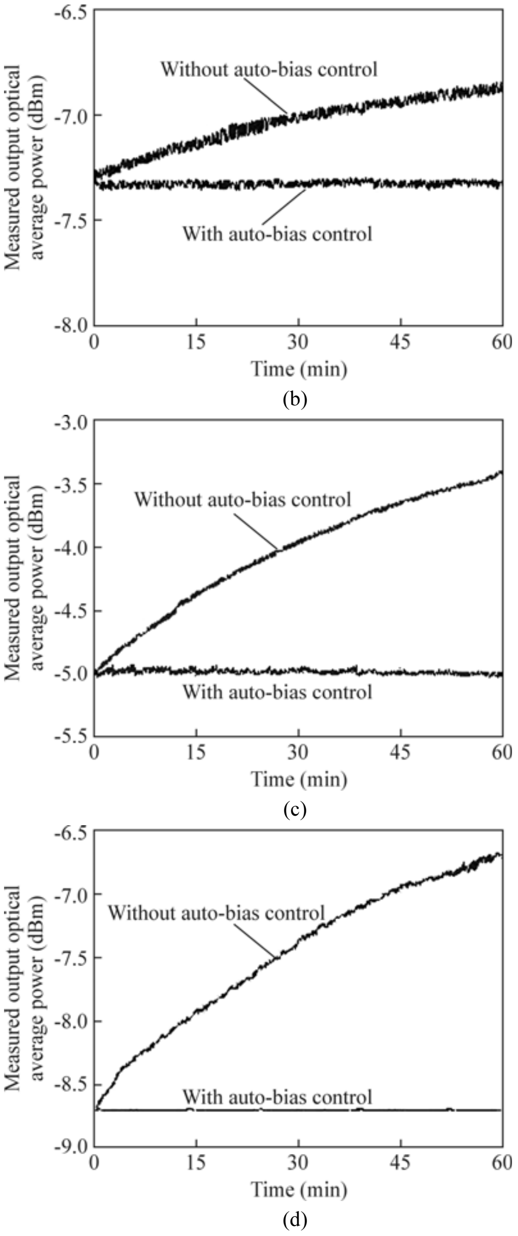
In experiment, firstly, the data processing unit calculates the initial ratio at the desired point. Secondly, the output optical average power is monitored. Once the output optical average power is changed, the data processing unit can refresh the ratio and compare the new one with the initial one to decide whether the fluctuation is caused by the bias point drift. If the ratio changes, the data processing unit will adjust the bias voltage step by step, based on the fact that the ratio is increased as the bias voltage increasing, until the output optical average power almost equals the initial one. Since it is the change of the ratio that determines whether bias drift happens, the effects of input power level fluctuation and optical path loss variations can be eliminated.

To evaluate the performance of the proposed scheme and demonstrate its versatility to any operating point, the operating point is set at four different points respectively, and the measured output optical average power at each operating point in 1 h is shown in Fig.3. The proposed scheme can hold the output optical average power. Taking Fig.3(c) for instance, when experiment starts, the measured output optical average power is about –5 dBm. The measured output optical average power is about –3.5 dBm after 1 h when bias drift happens and auto-bias control scheme is not deployed. By contrast, the output optical average power hardly changes within 1 h when auto-bias control scheme is deployed.

We calculate the mean, minimum and maximum values of the measured output optical average power to evaluate the accuracy and stability of the proposed scheme. The results at four different operating points are listed in Tab.1. The deviations of output optical average power using the proposed scheme can be less than ±4%.



(a)



(b)

(c)

(d)

Fig.3 The variations of the measured output optical average power with and without auto-bias control at four different operating points

Tab.1 Calculated results at four different operating points

$\overline{M}$	Max	Min	$D_+ = \left(Max-\overline{M}\right)\div\overline{M}$	$D_- = \left(Min-\overline{M}\right)\div\overline{M}$
–1.0424	–1.0816	–0.9887	3.76%	–3.88%
–5.0071	–5.0671	–4.9431	1.20%	–1.28%
–7.3315	–7.3601	–7.3034	0.39%	–0.38%
–8.7190	–8.7265	–8.7081	0.09%	–0.13%

A novel dither-free auto-bias control scheme is proposed and demonstrated in this paper. This scheme is able to stabilize an LN MZM at any operating point and eliminate the effects of input power level fluctuation and optical path loss variations. The experimental results obtained at four different operating points show that the output optical average power hardly changes when the proposed scheme is implemented. Furthermore, the maximum deviation of output optical average power of the LN MZM is less than ±4%.

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