Simple and ultrafast automatic bias control for optical IQ modulators enabled by dither vector mapping monitoring

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Abstract: A simple and ultrafast automatic bias control for optical IQ modulators is proposed using dither-vector-mapping monitoring. It is verified in 40/20Gbaud 16/64QAM signal transmissions, and the tracking time (0.3~0.5s) is 30-times faster than commercial products.

OCIS codes: (060.2330) Fiber optics communication; (060.4080) Modulation; (060.4510) Optical communications

1. Introduction

To meet the increasing demands of Internet traffic, much attention has been paid to coherent optical communication systems due to their extremely large transmission capacity [1], and the optical in-phase and quadrature modulator (IQM) is one of the most important components in coherent optical communication systems. However, the stability of IQM could easily drift away from its optimal bias point, because of ambient temperature changes and mechanical vibration [2]. Besides, for dense wavelength division multiplexing applications, the changes of the optical carrier wavelength and power will also cause the bias of modulators to deviate from the optimal bias point, leading to severe second-order distortion [3]. Therefore, it is indispensable to design an automatic bias control (ABC) module to achieve fast and long-term stability. Nowadays, several ABC approaches have been proposed, mainly including optical power detection and dither signal monitoring techniques. Due to the low accuracy of the ABC schemes using power detection [4], most ABCs are based on dither detection technology, such as correlation integral degree (CI) of the dither signals and the optical signal by dither-correlation detection [2] and the power spectrum analysis of 1st and 2nd dither harmonic frequency signals by fast Fourier transform (FFT) [5]. However, for CI and FFT-based ABC schemes, the high computational complexity increases the equipment cost and makes the tracking time longer. At the same time, higher speed and longer transmission distance have higher requirements for bias point control accuracy of the ABC module. Therefore, the ABC scheme with low cost, fast convergence rate, higher sensitivity, and lower complexity is highly desired in the current coherent optical communication system.

In this paper, a simple and ultrafast ABC scheme for optical IQM is proposed, and the optimal bias point of IQM is achieved by using two low-frequency vector signals and the dither vector mapping monitoring (DVMM) technique. The low (-1) and high (1) values of the square wave are used to represent the beginning and end of the vector signal respectively, which saves direct digital synthesis module compared with the reported literature. Besides, DVMM doesn't require complicated calculations like frequency spectral analysis [5] or correlation integral calculation [2]. Therefore, our proposed scheme could be easily realized with lower complexity and faster convergence rate. The proposed ABC module is realized and experimentally verified in both 40Gbaud 16QAM and 20Gbaud 64QAM signal transmission systems. The proposed scheme is proved to have higher sensitivity and long-term stable performance, and the tracking time is only 0.3~0.5s, which is nearly 30 times faster than the current commercial products.

2. Operation Principle

Fig. 1(a) shows the configuration of the proposed ABC method based on DVMM. To monitor dither vector signals, a low bandwidth (<2GHz) photo-detector (PD) is used to detect a small proportion (<10%) of the output optical power. Two different vector signals are applied to dither the bias signal of two child-MZMs (MZM_I and MZM_Q) by a digital-to-analog converter (DAC). And the vector signal can be expressed by $\vec{V}=(-A,A)$, where A (about 0.26% V_π) is the amplitude of vector signal which can be negligible compared with RF signals (RF_I and RF_Q). Meanwhile, these two vector signals are sampled by a low-speed (500kHz) analog-to-digital converter (ADC) for signal processing. The DVMM is then used to calculate the length and direction of the mapped vector ($\overrightarrow{MV}$) signals that are mapped by the IQ modulation curve. The output optical power of this IQM can be written as

$$\overrightarrow{I(t)}=(\alpha E_{in})^2\left[cos\left(\pi\left(V_{BiasI}+\overrightarrow{V_I}\right)/V_\pi\right)+cos\left(\pi\left(V_{BiasQ}+\overrightarrow{V_Q}\right)/V_\pi\right)+4cos\left(\pi\left(V_{BiasI}+\overrightarrow{V_I}\right)/2V_\pi\right)cos\left(\pi\left(V_{BiasQ}+\overrightarrow{V_I}\right)/2V_\pi\right)cos(p)+2\right], \quad (1)$$

where p represents the phase difference between two branches of the parent-MZM. V_{BiasI} and V_{BiasQ} are bias voltages of MZM_I and MZM_Q, respectively. V_π is half-wave voltage. $\overrightarrow{V_I}$ and $\overrightarrow{V_Q}$ are dither vector signal added on these two-child MZMs respectively.

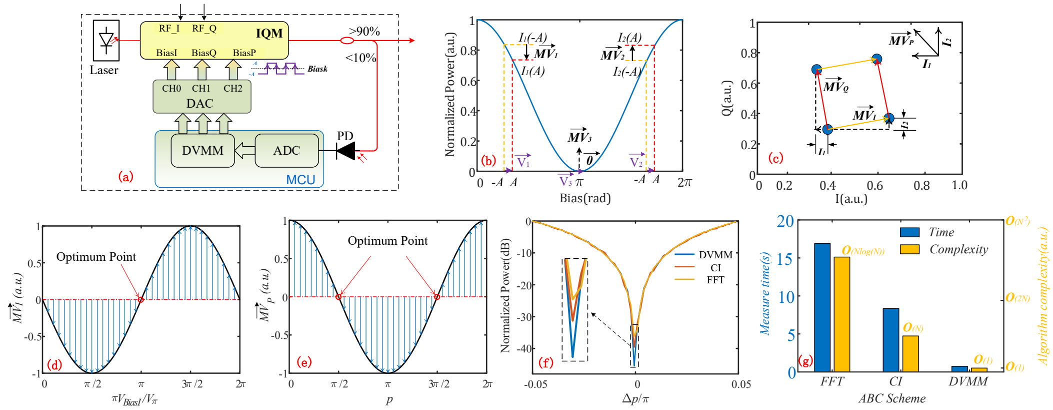

Fig. 1. (a) The proposed ABC based on DVMM, (b) vector signals mapped by modulation curve of MZM_I, (c) constellation diagram of dither mapped vector signals $\overrightarrow{MV_I}$ and $\overrightarrow{MV_Q}$, (d) the simulated $\overrightarrow{MV_I}$ versus bias phase, (e) the simulated $\overrightarrow{MV_P}$ versus bias phase, (f) distinguish ratio of monitored dither signal of different ABC schemes, (g) comparison of complexity and time of different schemes.

For convenience, Fig. 1(b) is used to describe the vector signals mapped by the modulation curve of MZM_I. $\overrightarrow{V_1}$, $\overrightarrow{V_2}$ and $\overrightarrow{V_3}$ can be mapped as $\overrightarrow{MV_1}$, $\overrightarrow{MV_2}$ and $\overrightarrow{MV_3}$, respectively. When the bias phase of MZM_I is around the optimum bias point ($V_{Bias\,I} \approx V_\pi$), $\overrightarrow{MV_3}$ is a zero vector. When the bias phase is away from the optimum bias point ($V_{BiasI} \neq V_\pi$), we can judge whether the current bias phase is on the left or right of π and get the distance of the current bias phase and π by the direction and the modulus of $\overrightarrow{MV_1}$ and $\overrightarrow{MV_2}$, respectively. The relationship between vector $\overrightarrow{MV_I}$ and the bias phase of MZM_I is shown in Fig. 1(d). In fact, MZM_I and MZM_Q are symmetrical in the optical IQ modulator, so the mathematical form of the mapped vector $\overrightarrow{MV_I}$ and $\overrightarrow{MV_Q}$ can be expressed as

$$\begin{cases} \overrightarrow{MV_I}=I_I(A)-I_I(-A)\propto -\sin(A/2)\sin(\pi V_{Bias\,I}/V_\pi)-4\sin(A/2)\cos\left(\pi V_{BiasQ}/2V_\pi\right)\cdot\cos(p)\cdot\sin\left(\pi V_{Bias\,I}/2V_\pi\right) \\ \overrightarrow{MV_Q}=I_Q(A)-I_Q(-A)\propto -\sin(A/2)\sin\left(\pi V_{BiasQ}/V_\pi\right)-4\sin(A/2)\cos\left(\pi V_{Bias\,I}/2V_\pi\right)\cdot\cos(p)\cdot\sin\left(\pi V_{BiasQ}/2V_\pi\right) \end{cases}. \quad (2)$$

For the phase difference of p, we add dither vector signals $\overrightarrow{V_I}$ and $\overrightarrow{V_Q}$ to MZM_I and MZM_Q at the same time. At this time, we can get the constellation diagram as shown in Fig. 1(c). When $p=\pi/2$, the constellation diagrams of $\overrightarrow{MV_I}$ and $\overrightarrow{MV_Q}$ should be orthogonal. But when $p \neq \pi/2$, the constellation diagram will no longer be orthogonal, and the component $\overrightarrow{I_1}$ of $\overrightarrow{MV_I}$ in the Q direction and the component $\overrightarrow{I_2}$ of $\overrightarrow{MV_Q}$ in the I direction will no longer be zero. Therefore, we can add these two components together to get a new vector $\overrightarrow{MV_P}$ whose length is approximately equal to the distance between the current bias point and $\pi/2$, and its direction can indicate whether the current bias point is on the left or right of $\pi/2$. The relationship between vector $\overrightarrow{MV_P}$ and the phase difference p is shown in Fig. 1(e), and the mathematical form of the mapped vector $\overrightarrow{MV_P}$ can be expressed as

$$\overrightarrow{MV_P}=\overrightarrow{I_1}+\overrightarrow{I_2}\propto 8\sin(A/2)\sin\left(\pi V_{BiasI}/2V_\pi\right)\cdot\sin\left(\pi V_{BiasQ}/2V_\pi\right)\cdot\cos(p). \quad (3)$$

To illustrate the advantages of the proposed scheme compared to the current commercial FFT and CI schemes, we have compared the sensitivity, algorithm complexity, and the required time to track the bias point of these several schemes. As shown in Fig. 1(f) and 1(g), DVMM only needs to calculate the vector length through addition and subtraction, and the vector signal has a better ability to resist noise, thus the proposed ABC scheme has higher sensitivity, lower algorithm complexity, and faster tracking time. Note that the tracking time of this proposed scheme is only 0.3~0.5s in our experimental test, which is nearly 30 times faster than the current commercial products.

3. Experimental Setup and Discussions

Fig. 2(a) shows the experimental setup of a single-polarization coherent optical transmission system, and 20Gbaud 64QAM and 40Gbaud 16QAM signal over back-to-back transmission are both evaluated in this test. A continuous-wave (CW) laser with an optical power of 15.5 dBm is used as the optical source. The wavelength and linewidth of this laser are 1550 nm and 100 kHz, respectively. An arbitrary waveform generator (AWG, Keysight M8195A) with

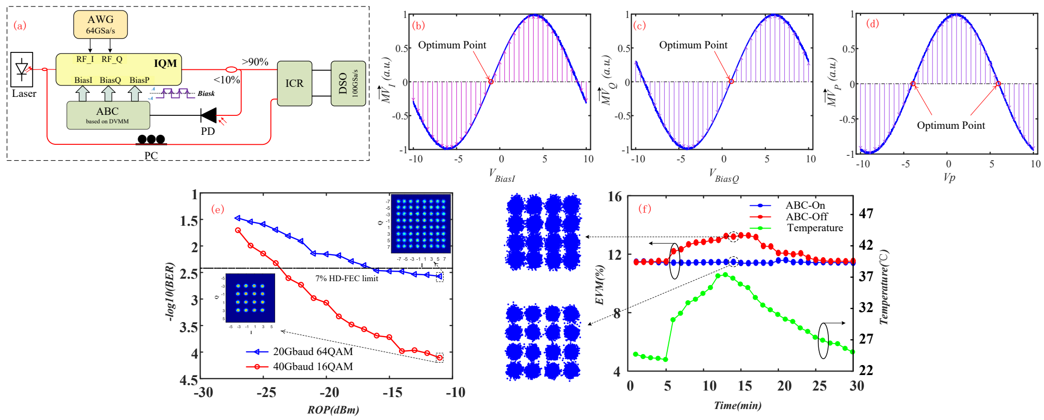

Fig. 2. (a) The experimental setup of 40/20Gbaud 16/64QAM coherent transmission system based on the proposed ABC scheme. The mapped vectors $\overrightarrow{MV_I}$ (b), $\overrightarrow{MV_Q}$ (c), and $\overrightarrow{MV_P}$ (d) versus different bias voltage. The measured BER vs ROP (e) curves with different dither amplitudes. The measured EVM performance (f) under temperature-varying conditions.

a 3 dB bandwidth of 25 GHz is used to generate the electrical signal which is then used to drive an electrical amplifier (EA, Centellax OA3MHQM4) and an optical IQ modulator (Fujitsu FTM7961EX). The optical signal is received by an integrated coherent receiver (ICR) with 23GHz bandwidth. A polarization controller (PC) is adopted to align the polarization states of the optical signal and the LO. The detected electrical signals are captured by a digital sampling oscilloscope (DSO, Tektronix DPO 73304D) operated at 100GSa/s. During the implementation of our proposed ABC method, the modulation depth we use is 0.26% V_π, and the frequency of the dither vector is 10kHz. Figs. 2(b)-(d) show the mapped vectors $\overrightarrow{MV_I}$, $\overrightarrow{MV_Q}$ and $\overrightarrow{MV_P}$ versus different bias voltages in this experiment. In our test, each mapped vector curve is measured when two other bias voltage is set to the optimum point value. It could be clearly observed that the measured curves are in accordance with Eqs. (2) and (3). Fig. 2(e) presents the measured bit error rate (BER) performance of 40Gbaud 16QAM and 20Gbaud 64QAM signal as a function of the received optical power (ROP). It can be observed that the achieved BER value can both be below the 7% overhead hard-decision forward error correction (HD-FEC) threshold of 3.8x10-3 in these two cases.

Furthermore, to evaluate the long-term and stable performance of the proposed scheme, both the error vector magnitude (EVM) performance of the 40Gbaud 16QAM signal and the corresponding environment temperature of IQM are measured and shown in Fig. 2(f). The ROP is kept at -11 dBm in this test, and a hot air blower is used to vary the temperature of IQM indirectly. In the experiment, not only the temperature is varied but also mechanical vibration is induced by the wind, resulting in the fluctuation of the measured EVM performance. Therefore, it could be clearly observed that when the air blower is set to strong wind mode (5th to 20th minutes), EVM performance with ABC-off becomes worse compared with ABC-on, and when the hot air blower is turned off and the temperature cools down completely (25th to 30th minutes), EVM performance of ABC-on and ABC-off are basically the same. Therefore, the proposed scheme can keep the transmission system stable for a long time and the power penalty caused by the proposed ABC could be negligible.

4. Conclusions

In this paper, we propose a novel ABC method for IQM based on dither vector mapping monitoring. Compared with the traditional CI and FFT-based ABC schemes, the essential direct digital synthesis module is not required, and DVMM only needs to calculate the vector length through addition and subtraction, contributing to lower algorithm complexity, higher sensitivity, and faster convergence rate in our scheme. This scheme is verified in both 40Gbaud 16QAM and 20Gbaud 64QAM signal transmission systems, and the tracking time is only 0.3~0.5s. The results show that our scheme is very suitable for high-speed coherent optical communication systems.

5. Acknowledge

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6. References

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