Optical Vector Analysis Based on Optical Double-sideband modulation

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***Abstract*— Optical vector analysis (OVA) is of great importance for the fabrication and application of optical devices. In this project, we propose and demonstrate the high-resolution optical vector analysis based on optical double-sideband (ODSB) modulation. Different from the conventional OVA based on optical single-sideband (OSSB) modulation, in which the measurement range is limited by the bandwidth of microwave and optoelectronic components and the measurement accuracy is restricted by the high-order sidebands, the OVA based on ODSB modulation measures the magnitude and phase responses by taking use of both ±1st-order sidebands without spectrum response aliasing. As a result, the measurement range is doubled, and the high-order-sideband induced errors only appear at specific frequencies which are predictable and removable.**

***Index Terms*—optical vector analysis, optical double-sideband, measurement error, measurement range, microwave photonics**

I. Introduction

The rapid development of photonic systems requires high speed and accurate measurement of frequency response of optical devices with large measurement range. Several methods were proposed to measure the frequency response, such as the modulation phase-shift approach [1] and the interferometry method [2], but the two methods rely on wavelength scan of a laser source. Owing to the low wavelength accuracy and poor wavelength stability of typical laser sources, the resolution of the frequency response measurement schemes based on the two methods could not be high (typically several hundreds of MHz). To solve this problem, the method based on microwave photonics was proposed [3], which has much higher resolution (up to 78 kHz in [4]) and better stability. However, the conventional microwave-photonic-based optical vector analysis (OVA) is realized using optical single-sideband (OSSB) modulation, which has many limitations. A number of techniques have been reported to implement the OSSB modulation, but few of them can meet the above requirements. In addition, the OSSB-based OVA can only take use of one sideband to scan one side, which limits the measurement range to the bandwidth of the microwave and optoelectronic components used in the system (typically less than 40 GHz). Furthermore, the OSSB modulation would inevitably stimulate high-order sidebands, especially when the phase modulation index is large, which could introduce considerable measurement errors. In this project, we propose and demonstrate the high-resolution optical vector analysis based on ODSB modulation [5, 6]. As compared with the OSSB modulation, ODSB modulation is wideband, simple, and efficient. However, when a conventional ODSB signal is sent to a photodetector (PD), the ±1st-order sidebands are beat with the optical carrier, generating RF signals with the same frequency, by which the frequency responses carried by the two sidebands cannot be differentiated. To solve this spectrum response aliasing problem, we introduce a frequency-shifted carrier to the measurement system. When the two sidebands after propagating through the optical device-under-test (DUT) and the frequency-shifted optical carrier are combined and beat at a PD, two different frequency components are generated, from which the optical spectral response carried by different sidebands is extracted without aliasing.

II. OVA Based on Based on ODSB modulation

A. Using an Acoustooptic Modulator

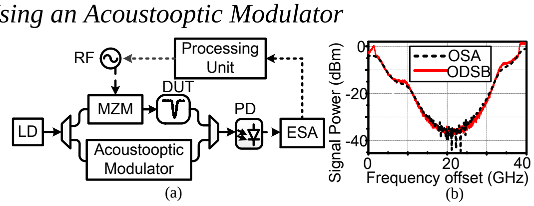

Fig. 1. (a) Schematic diagram, (b) measured magnitude responses. LD: laser diode; MZM: Mach-Zehnder modulator; RF: radio frequency; ESA: electrical spectrum analysis.

The schematic diagram of the ODSB-based OVA using an acoustooptic modulator [5] is shown in Fig. 1(a). An optical carrier from a laser diode (LD) is divided into two branches. One portion is modulated by a sweeping RF signal at a Mach-Zehnder modulator (MZM), which generates a carrier-suppressed ODSB signal. Then, the ODSB signal is injected into a DUT, in which the +1st- and -1st-order sidebands undergo different magnitude responses. The other part of the optical signal passes through an acoustooptic modulator to have its frequency shifted by an angular frequency of $\Delta\omega$. The two signals from the two paths are combined, and then beat at a PD, generating two different frequency components. Then, the magnitude information of different frequency components is extracted by an electrical spectrum analyzer (ESA), as is shown in Fig. 1(b).

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B. *Adopting the Stimulated Brillouin Scattering*

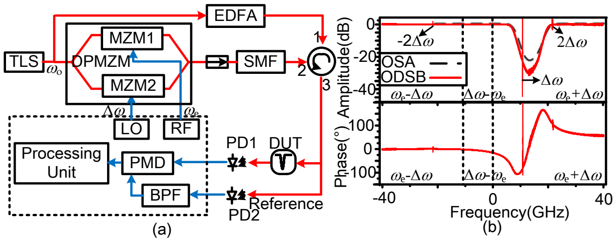

Fig. 2. (a) The schematic diagram and (b) the measured spectrum response. TLS, tunable laser source; EDFA, erbium doped fiber amplifier; SMF, single-mode fiber; BPF, band-pass filter; PMD, phase-magnitude detector.

The schematic diagram of the ODSB-based OVA adopting the stimulated Brillouin scattering (SBS) [6] is shown in Fig. 2(a). A lightwave with an angular frequency of ω_0 is generated by a tunable laser source (TLS) and then divided into two portions by an optical splitter. One portion amplified by an erbium-doped fiber amplifier (EDFA) is served as the stimulated Brillouin scattering (SBS) pump signal. The other part, in the lower path, incorporates a DP-MZM, which consists of two sub-MZMs, i.e. MZM1 and MZM2. In MZM1, the optical carrier is modulated by a frequency-swept RF signal with a frequency of ω_e, producing two sweeping sidebands with frequencies of $\omega_0-\omega_e$ and $\omega_0+\omega_e$. In MZM2, the optical carrier is modulated by a local oscillator (LO) signal with a fixed frequency of $\Delta\omega$, which equals to the Brillouin frequency shift, to produce two wavelength-fixed sidebands with frequencies of $\omega_0-\Delta\omega$ and $\omega_0+\Delta\omega$. SBS is introduced to suppress one wavelength-fixed sideband and enhance the other wavelength-fixed sideband, so the remainder can serve as the frequency-shifted carrier. In the experiment, the magnitude and phase responses of the FBG under test are one-by-one mapped in three segments by respectively detecting the components with frequencies of $\omega_e-\Delta\omega$ ($\omega_e>\Delta\omega$), $\Delta\omega-\omega_e$ ($\omega_e<\Delta\omega$) and $\omega_e+\Delta\omega$. Then, stitching the measured responses together, the spectral responses are achieved, as shown in Fig. 2(b). The transmission response of a fiber Bragg grating (FBG), in a range of 80 GHz, is measured with a resolution of less than 667 kHz by using 40-GHz microwave components.

C. *Using a Dual-Drive Dual-Parallel Mach-Zehnder Modulator*

As can be seen in Fig. 3(a), the frequency-shifted carrier can be generated by a dual-drive dual-parallel Mach-Zehnder modulator (DD-DPMZM) and a 90° hybrid coupler. This method can solve the spikes error problem in [6]. It has a much simpler and more robust configuration as compared with the previously-reported ODSB-based OVA.

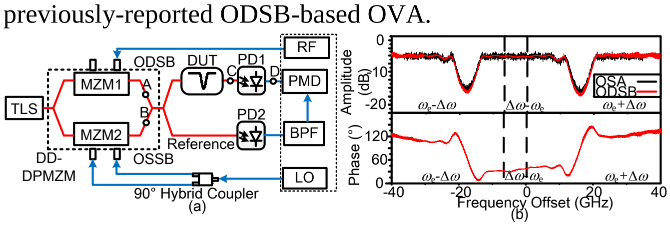

Fig. 3. (a) The schematic diagram and (b) the measured spectrum response.

D. *Adopting the Optical Comb*

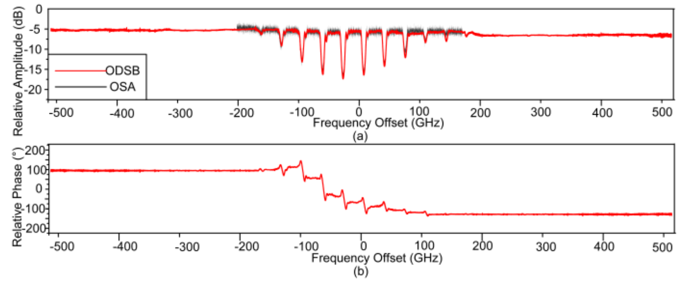

Fig. 4. The measured spectrum response in the frequency range of more than 1 THz.

Replacing the laser source with an optical comb and a tunable optical filter in the proposed optical vector analyzer based on ODSB modulation can measure both magnitude and phase responses in a very broad measurement range. The approach is experimentally demonstrated in the frequency range of more than 1 THz, as can be seen in Fig. 4.

III. Conclusion

In this project, novel approaches to perform high-resolution and high-accuracy optical vector analysis based on optical double-sideband modulation and an acoustooptic modulator, the stimulated Brillouin scattering, a DD-DPMZM and an optical comb are proposed and experimentally demonstrated. The proposed approaches have a doubled measurement range, and better nonlinearity immunity which leads to a higher accuracy and a larger dynamic range.

IV. Acknowledgment & Career Plans

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