Microwave Photonic Signal Processing Based on Polarization Modulator

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***Abstract*—A polarization modulator (PolM) is a special phase modulator with complementary phase modulation indices for TE and TM modes of an input lightwave. A PolM incorporated with a polarizer can perform intensity modulation, phase modulation, and the combination of the aforementioned two modulations, providing unprecedented flexibilities for microwave photonic signal processing systems. In this project report, an optical single sideband polarization modulation scheme, a microwave photonic filter and an optically controlled beamforming network are proposed and demonstrated based on PolMs with high performance, simple configurations, and flexible operations.**

***Index Terms*—polarization modulation, single sideband modulation, microwave photonic filter, optical beamforming**

I. Introduction

MICROWAVE photonic signal processing has been drawing a lot of attentions due to the intrinsic characteristics of photonic technologies, i.e., large bandwidth, low loss, wide frequency tunability and immunity to electromagnetic interference (EMI) [1]. Up to now, the extensively studied microwave photonic signal processing functions include, but are not limited to, microwave frequency up/down conversion, frequency filtering, phase shifting, and beamforming. Traditionally, the electro-optic conversion is performed by an intensity modulator (IM) or a phase modulator (PM), which is not really effective in some way since only one dimension of the lightwave, i.e., the intensity or the phase, is used. With the growing demand of the spectral resources, new modulation schemes with high spectral efficiency are highly desirable, which leads to the development of the polarization modulation realized by a polarization modulator (PolM). The PolM can act as a dual-parallel-PM with complementary modulation indices on the TE mode and TM mode of an input optical signal. With the complementary phase modulations, optical single sideband polarization modulation (OSSB-PolM), microwave photonic filtering and optically controlled beamforming network (OBFN) can be implemented.

II. Polarization Modulator

Mathematically, when an optical light E_{in} is modulated by a cosine signal $\phi(t)$ at a PolM, the output field of the PolM can be expressed as,

$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = \frac{\sqrt{2}}{2} E_{in} \begin{bmatrix} \exp\left(j\left(\beta\phi(t) + \frac{\phi_0}{2} \right) \right) \\ \exp\left(-j\left(\beta\phi(t) + \frac{\phi_0}{2} \right) \right) \end{bmatrix} \quad (1)$$

where β is the phase modulation index of the PolM and ϕ_0 is the phase difference between the TE and TM modes.

If a polarizer with its polarization direction aligned with one of the axes is followed to select one axis of the generated signal, phase modulation can be obtained. If the polarization direction of the polarizer is set to be 45º, intensity modulation can be realized. If other polarization directions are selected, the combination of phase and intensity modulations can be achieved. Therefore, polarization modulation has high flexibilities with the ability to implement all the phase modulation and/or intensity modulation based functions.

III. Optical Single Sideband Polarization Modulation

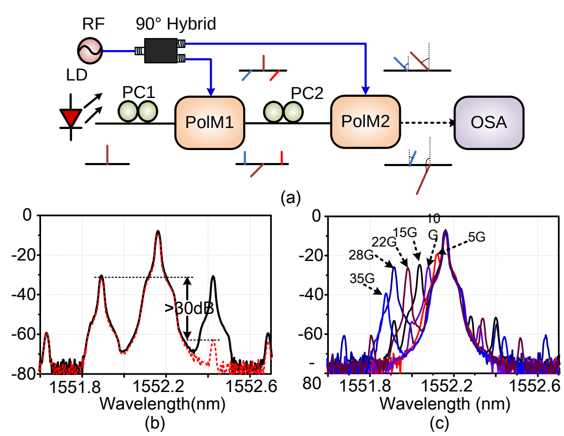

Fig. 1. The schematic diagram of the OSSB-PolM system (a), and the spectra of the generated (b) and frequency tunable (c) OSSB signals .

OSSB-PolMis a combination of two orthogonally polarized single sideband signals with the phase differences between the optical carrier and the remained sideband complementary. Different microwave photonic signal processing functions can be implemented based on OSSB-PolM [2]. However, most of the previously reported systems implemented the OSSB-PolM modulation using a PolM and an optical filter, which is wavelength dependent and bandwidth limited. To solve these problems, OSSB-PolM based on cascaded PolMs is proposed in this project [2]. Fig.1 (a) is the schematic diagram of the two cascaded PolMs based OSSB-PolM system. By applying two orthogonal RF signals to the two PolMs, and controlling the polarization states between the two PolMs, an OSSB-PolM

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modulated signal can be generated. The optical spectrum and the frequency tunable optical spectra are shown in Fig. 1 (b) and (c). The operation bandwidth of the experimental system is from 2 GHz to 36 GHz which is mainly determined by the working bandwidth of the 90 degree hybrid. The generated OSSB-PolM can be employed to implement OSSB modulation with tunable optical carrier to sideband suppression (OCSR) [2], microwave photonic phase shifter, microwave photonic filter and so on.

IV. Microwave Photonic Filter

Microwave photonic filter is one of the most typical signal processing functions, and has been extensively studied in the past decades. Previously, three main kinds of finite impulse response (FIR) filters are proposed, named as positive-coefficient filter, negative-coefficient filter and complex-coefficient filter, among which, the last one is highly desirable in practical applications thanks to its high central frequency tunabilities. However, to tune the central frequency of a complex-coefficient filter, one has to control each tap independently, requiring complex driving circuits and sophisticated control algorithms. To solve this problem, a microwave photonic filter [3] realized by a two-PolM based microwave photonic phase shifter [4] is proposed. By applying an amplitude controllable sawtooth wave signal to the second PolM and fixing the time delay difference between adjacent taps, the central frequency of the microwave photonic filter can be controlled. Fig. 2 shows the schematic diagram and the experimental results of the microwave photonic filter. The proposed single parameter tunable microwave photonic filter has a fast tuning speed and can be easily expanded to multi-tap systems.

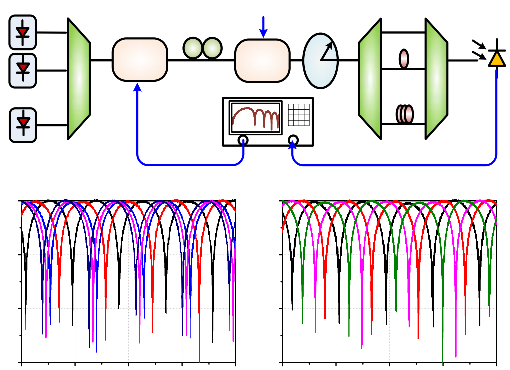

Fig. 2. The schematic diagram of the microwave photonic filter (a) and the frequency responses of the filter around 13 GHz (b) and 40 GHz (c).

V. Optically Controlled Beamforming Network

A beamforming network plays a significant role in multifunction radars and high-throughput wireless communication systems. In this project, an OBFN [5] is also proposed and demonstrated using polarization modulation based microwave photonic phase shifters [6]. A 4-element 14-GHz phased array antenna is built based on the OBFN. By adjusting the phase shift of each tap, the radiation patterns of the phased array antenna can be tuned. Fig. 3(a) shows the experimental set up and Fig. 3 (b) and (c) are the photos and results of the OBFN. From Fig. 3 (c) we can see that, the beam direction can be tuned from -30º to 30º with different phase shift settings.

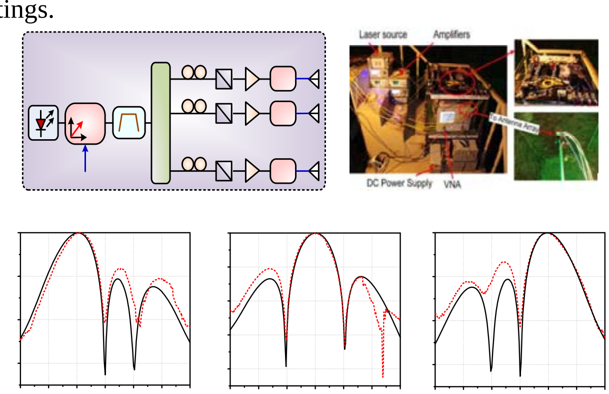

Fig. 3. The experimental set up of the OBFN (a) and the photos (b) and the results (c) of the system.

VI. Conclusion

In this project, a novel OSSB-PolM scheme, a microwave photonic filter and an OBFN are proposed and implemented based on one or two PolMs. The proposed systems have compact configurations with good reconfigurability, and also have flexible operation with a high tuning speed. They will find wide applications in microwave photonic signal processing systems, radars and communication systems.

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