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Dual and triple output bandpass microwave photonic filter using a 3×3 collinear coupler

G. NING*, P. SHUM, J. Q. ZHOU
Network Technology Research Centre, Nanyang Technological University, Research TechnoPlaza XFrontier Block 4th Storey 50 Nanyang Drive, Singapore 637553

New structures that can realize dual and triple output coherent-free bandpass microwave photonic filter are presented. They are based on a Sagnac loop interferometer containing a phase modulator, a 3×3 collinear coupler and without non-reciprocal bias unit. Measured results demonstrate robust notch filter responses for DFB laser source or broadband source.

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1. Introduction

Microwave and millimeter-wave signals distributed over optical fibers are of great interest for many applications such as broad-band wireless access networks, wireless sensor networks, and satellite communication systems. There are many advantages of all-optical microwave filters. These include large time-bandwidth products, insensitivity to electromagnetic interference, low loss, lightweight and the ability to directly process microwave and millimeter-wave signals in the optical domain [1]-[2]. A very useful component in radio frequency (RF) systems is a high-resolution notch filter. However, most of the conventional incoherent photonic processors can not realize negative coefficient [1-2], which significantly limits the variety of obtainable transfer functions. Several methods have been proposed to generate negative coefficient, including cross-intensity modulation of the longitudinal modes in a Fabry-Perot laser [3] and phase modulation based on dispersive medium [4]. Recently, a Sagnac loop based on equivalent negative taps photonic notch filter also been proposed [5]. However, it need the $\pi/2$ nonreciprocal bias unit and can not provide the dual and triple output response, which is useful for suppressing the dominant phase-induced intensity noise in photonic signal processors, and for beam forming applications.

In this paper, we demonstrate new structures that can realize dual and triple output coherence-free bandpass microwave photonic filters for DFB laser source and broadband source, respectively. They are based on a Sagnac loop interferometer containing a phase modulator and a 3×3 collinear coupler, and non-reciprocal bias unit is not required. Notch responses are obtained by modulating the clockwise and counterclockwise propagating waves inside the Sagnac loop at different time. Experimental results demonstrate robust notch filter responses.

2. Experimental setup

The schematic of the proposed dual output filter is shown in Fig. 1(a). Light from a DFB laser source for dual output is launched into the port 1 of a circulator. The output of the circulator is coupled into a Sagnac loop which consists of a 3×3 collinear coupler, a polarization controller and a phase modulator. The phase modulator is located away from the loop centre. The phase modulator is driven by an input RF signal. The light from the laser source is launched into the port 2 of the 3×3 collinear coupler and is split into two equal parts; so half of the light travels in the clockwise (CW) direction, passing through the polarization controller (PC) and the phase modulator. The other half travels in the counter-clockwise (CCW) direction. Since the collinear coupler has single mode fiber pigtails, the PC makes the CW state of polarization (SOP) same as the CCW signal in the two ports of the phase modulator, which is not needed if the collinear coupler has Hi-Bi pigtails. The output modulated signals (coupler port 1, 3) are detected by a photodetector (PD) respectively, which is followed by a network analyzer to display the filter transfer characteristics. Fig. 1 (b) shows the schematic of triple output filter. A broadband source (a semiconductor optical amplifier (SOA)) is used in pace of DFB laser source and the polarization controller is not needed in the Sagnac loop.

For both configurations, after the CW and CCW light recombination at the 3×3 collinear coupler, they will arrive at the PD at exactly the same time. Consequently, there is no coherence problem in the system.

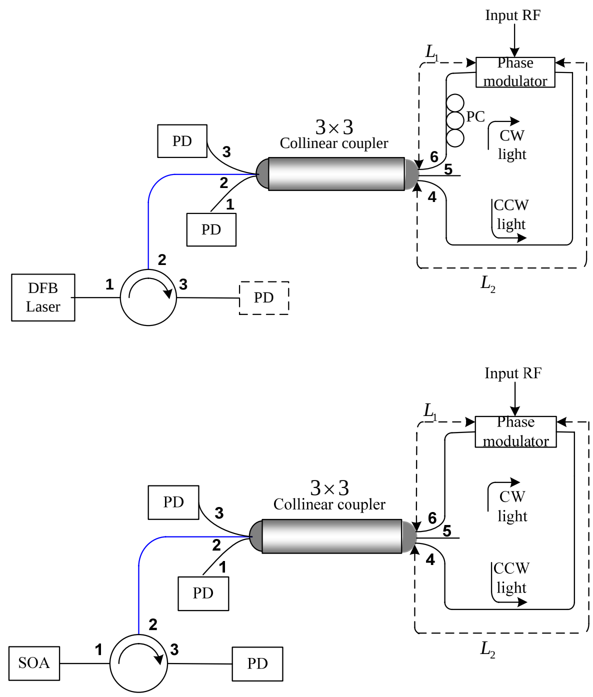


Fig. 1. Experimental setup (a) dual output using DFB laser source; (b) triple output using broadband source.

For both laser sources, the free spectral range (FSR) is dependent on the time difference between the CW and CCW light:

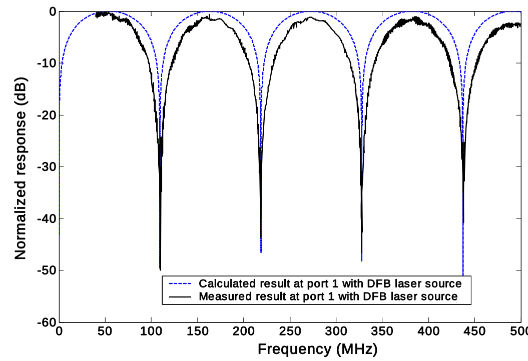
$$\Delta T = T_2 - T_1 = n\left(L_2 - L_1\right)/c \qquad (1)$$

where $L_2 - L_1$ is the path difference for the phase modulator location in the Sagnac loop, n is the fiber refractive index, and c is the speed of light.

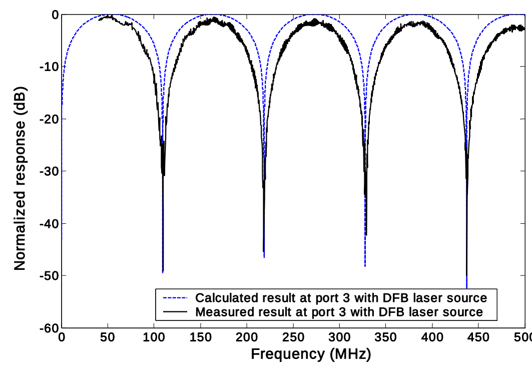
3. Experimental results

The operations of the dual and triple output filters have been verified by experiments. For dual output filter, the DFB laser source has a maximum power of 14.28 dBm and a linewidth of 100 kHz, and the input RF signal power is 0 dBm. The triple output filter uses the SOA (Kamelian OPA-20-N-C-FU) broadband source which has 250 mA maximum current and 0.5 dB polarization dependent gain (PDG). In the experiment, the path difference $L_2 - L_1$ for the phase modulator location in the Sagnac loop is 1.83 m. This corresponds to a filter with an FSR of 109.29 MHz.

When the input source is DFB laser source, the measured dual output bandpass responses for port 1 and port 3 are shown in Fig. 2 (a) and Fig. 2(b) respectively, together with the calculated results. Excellent agreement can be seen. The lowest measurement frequency of the calculated result is limited by the network analyzer (40 MHz). However, since the response is periodic, extrapolating the results shows that the filter response is bandpass. We also measured the output of circulator port 3 and found no filter response appeared. The little phase noise observed maybe because SOP difference between CW and CCW light has small fluctuations after recombination at the coupler.



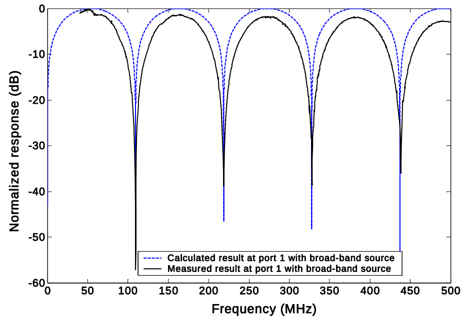
(a)



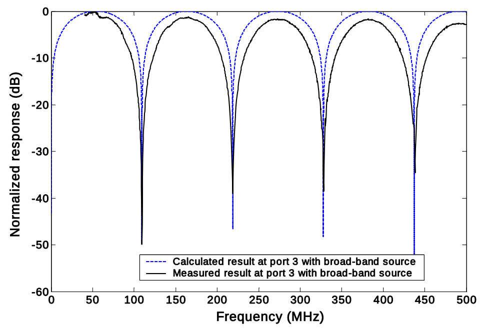
(b)

Fig. 2. Measured and calculated response at coupler (a) port 1 using DFB laser source and (b) port 3 using DFB laser source.

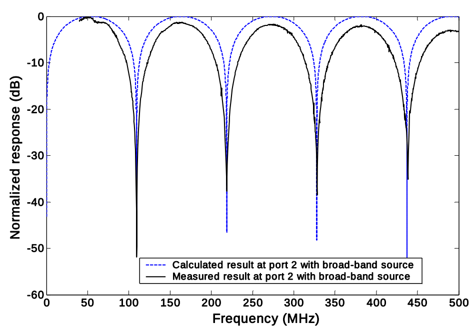
When the input laser source is broadband source from the SOA whose drive current is 244.6 mA, the filter has triple output response at coupler port 1, 3 and circulator port 3. Since the degree of polarization (DOP) of the broadband source is very small (DOP□ 0.25), the SOPs of CW and CCW light can be consider the same, and the polarization in the Sagnac loop can be disconnected. The measured triple output bandpass responses are shown in Fig. 3 (a), (b) and (c) for coupler port 1, 3 and circulator port 3, respectively. The agreement between the measured and calculated results is again very good. No phase noise was observed at the output of the filter. Further, the filter response for the triple output is almost the same. The continuous tunability of the bandpass filter can be realized by inserting the time delay line in the Sagnac loop.



a



b



c

Fig. 3. Measured and calculated response at (a) coupler port 1, (b) coupler port 3 and (c) circulator port 3 using broadband source.

4. Conclusion

New structures that can realize dual and triple output coherent-free bandpass microwave photonic filter has been presented. They are based on a Sagnac loop interferometer containing a phase modulator, a 3×3 collinear coupler and without non-reciprocal bias unit. Measured results demonstrate robust notch filter responses for DFB laser source or broadband source.

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*Corresponding author: gxning@ ntu.edu.sg