Switchable microwave photonic notch filter based on a half waveplate and a single-drive intensity modulator

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We demonstrate a switchable microwave-photonic notch filter based on a half waveplate, a single-drive intensity modulator and 490 m high-birefringence (Hi-Bi) fiber. The low pass notch filter response can be switched to bandpass response and vice-versa by tuning the half waveplate. Thanks to the orthogonal states of polarization the Hi-Bi fiber, the configuration is free from the problems of optically coherent interference. An expression for the filter transfer function is derived. Measured results match the calculated results and show a notch rejection greater than 40 dB.

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1. Introduction

The large time-bandwidth of photonic processors makes them attractive to process microwave and millimeter-wave signals by overcoming the limitations of existing electronic processors. Most of the conventional incoherent photonic processors cannot realize negative coefficient [1]-[4], thus significantly limits the variety of obtainable transfer functions. Several methods have been proposed to generate negative coefficient, such as cross-intensity modulation of the longitudinal modes in a Fabry-Perot laser [5] and phase modulation based on dispersive medium [6]. But in those methods, excess noise was introduced or no negative taps are actually generated. Recently, a photonic notch filter with negative coefficient based on polarization modulation of phase modulator is proposed [7]. But it lacks the flexibility to switch between bandpass and low pass response.

In this paper, we present a switchable coherence-free microwave photonic filter. It is designed by a half waveplate, a single-drive intensity modulator and 490 m high-birefringence (Hi-Bi) fiber. By adjusting the half waveplate which is placed before the single-drive intensity modulator, the proposed structures can provide conversion between bandpass and low pass notch filter. The configuration is free from the problems of optically coherent interference. An expression for the filter transfer function is derived. Measured results match the calculated results and show a notch rejection greater than 40 dB.

2. System configuration and operation principle

The schematic of the switchable filter is shown in Fig. 1. A continues wave from a DFB laser source is sent to a half waveplate and modulated by single-drive Mach–Zehnder (MZ) intensity modulator which is driven by a radio frequency (RF) signal. The output of the intensity modulator is launched into a polarization controller (PC) and 490 m Hi-Bi fiber, and then connected to a photodetector (PD) which is followed by a network analyzer to display the filter transfer characteristic.

Since the output of the DFB laser is linear polarization, when the half waveplate is 0 degree, the output state of polarization of the half waveplate is align with slow axis of the MZ intensity modulator Hi-Bi pigtail. Under small signal condition ($m << 1$), the output signal of intensity modulator can be approximated as:

$$f(t) = M_1\sqrt{P_i}\exp(j\omega_0 t)\left[1+\frac{m}{2}\cos(\omega_m t)\right] \quad (1)$$

where m is the modulation index, ω_m is the modulation frequency, M_1 is the amplitude factor for the intensity modulation and P_i is the output power of the DFB laser source. After adjusting the polarization controller (PC) and make the input signal equal excited at the two orthogonal axes of the Hi-Bi fiber, the output signal of the slow $f_{\Omega+}(t)$ and fast $f_{\Omega-}(t)$ axes of the Hi-Bi fiber can be expressed as

$$f_{\Omega_+}(t) = M_1\sqrt{P_i}\exp\left[j(\omega_0 t+\pi/2)\right]\left\{1+\frac{m}{2}\cos\left[\omega_m(t+\Delta\tau_d/2)\right]\right\} \quad (2)$$

$$f_{\Omega_-}(t) = M_1\sqrt{P_i}\exp(j\omega_0 t)\left\{1+\frac{m}{2}\cos\left[\omega_m(t-\Delta\tau_d/2)\right]\right\} \quad (3)$$

where $\Delta\tau_d$ is the differential group delay (DGD) introduced by 490 m Hi-Bi fiber. The $\pi/2$ in Eq.(2) exponential term is due to the two orthogonal polarization axes of the 490 Hi-Bi fiber. Then the RF output current can be written as:

$$I(t) \propto M_1^2\left\{\cos\left[\omega_m(t-\Delta\tau_d/2)\right]+\cos\left[\omega_m(t+\Delta\tau_d/2)\right]\right\} = 2M_1^2\cos\left(\frac{\omega_m\Delta\tau_d}{2}\right)\cos(\omega_m t) \quad (4)$$

Equation (4) shows the notch filter response is low pass.

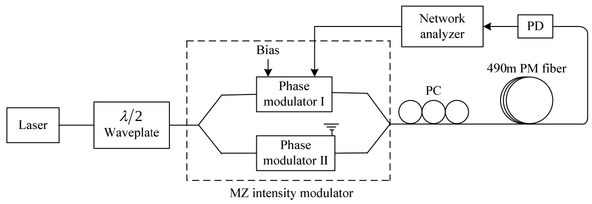

Fig.1. Experimental setup.

However, when the half waveplate is rotated to -22.5 degree, then the RF signal is both modulated by the principle axis of the LiNbO3 phase modulator I [7], which is actually the same principle as polarization modulation. The output signal of the MZ intensity modulator can be approximated as

$$f_{\Omega_+}(t) = M_2\sqrt{P_i}\exp\left[j(\omega_0 t)\right]\left[1+\frac{m}{2}\cos(\omega_m t)\right] \tag{5}$$

$$f_{\Omega-}(t) = M_3\sqrt{P_i}\exp\left[j\left(\omega_0 t+\frac{3\pi}{2}\right)\right]\left[1+\frac{m}{2}\cos(\omega_m t)\right] \tag{6}$$

where M_2 and M_3 are the amplitude factor of the two principle axes of the intensity modulator. By tuning the bias of the intensity modulator, $M_2 = M_3$ can be obtained, which is defined as M . By adjusting the PC to make $f_{\Omega+}(t)$ aligning with the slow axis of the 490 m Hi-Bi fiber and $f_{\Omega-}(t)$ aligning with the fast axes of the 490 m Hi-Bi fiber, then the output signal $f_{\Omega+}(t)$ and $f_{\Omega-}(t)$ can be expressed as

$$f_{\Omega_+}(t) = M\sqrt{P_i}\exp\left[j(\omega_0 t+\pi/2)\right]\left\{1+\frac{m}{2}\cos\left[\omega_m(t+\Delta\tau_d/2)\right]\right\} \tag{7}$$

$$f_{\Omega-}(t) = M\sqrt{P_i}\exp\left[j\left(\omega_0 t+\frac{3\pi}{2}\right)\right]\left[1+\frac{m}{2}\cos(\omega_m t)\right] \tag{8}$$

Then the RF output current can be written as:

$$I(t)\propto M^2\left\{\cos\left[\omega_m(t-\Delta\tau_d/2)\right]-\cos\left[\omega_m(t+\Delta\tau_d/2)\right]\right\} = 2M^2\sin\left(\frac{\omega_m\Delta\tau_d}{2}\right)\sin(\omega_m t) \tag{9}$$

Equation (9) shows the notch filter response is bandpass. Since the amplitude factor M is less than M_1 which is the half waveplate is fixed to 0 degree, the output bandpass response is much less than the low pass response. Further, the FSR is dependent on the DGD of the 490 m Hi-Bi fiber, which can be expressed as

$$f = \frac{1}{\Delta\tau_d} \tag{10}$$

3. Experimental results and discussion

The operation and the characteristics of switchable filter can be verified by the experimental results.The DFB laser source (ANDO AQ8201-13A) has a maximum power of 10 dBm with a linewidth of 5MHz, and the input RF signal power is 0 dBm. By rotating the half waveplate, the notch filter response can be switchable. When it is set to 0 degree, the input linear polarization is aligned with slow axis of the MZ intensity modulator Hi-Bi pigtail. The generated response is low pass, as indicated in Eq.(4). When the half waveplate is set to -22.5 degree, as given by Eq.(9), the notch response is bandpass.

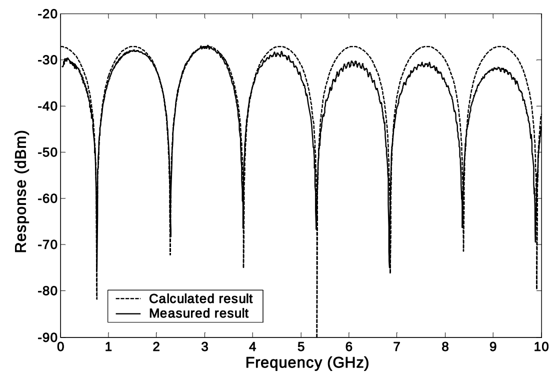

Fig. 2. Measured and calculated low pass notch filter.

In the experiment, the DGD value for the 490 m Hi-Bi fiber is 656 ps. This corresponds to a filter with FSR of 1.524 GHz. When the half waveplate is set to 0 degree or without the half waveplate, it generates low pass response. The measured low pass response is shown in Fig.2, together with the calculated result. The calculated and measured results show good agreement. The low pass filter shows around 40 dB rejection.

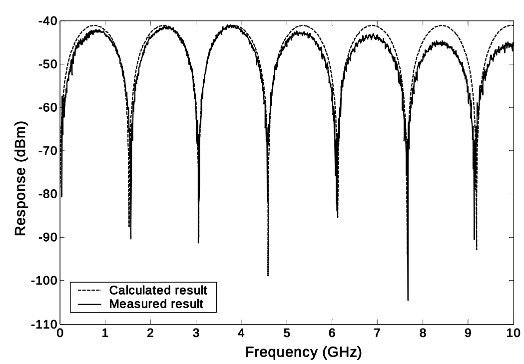

Fig. 3. Measured and calculated bandpass notch filter.

When the half waveplate is set to -22.5 degree, the filter response is bandpass rather than low pass. The measured bandpass response is shown in Fig.3, together with the calculated result. Good agreement can also be seen. However, the peak response compared with the low pass response reduced around 14 dB. This is due to the amplitude factor for polarization modulation for the intensity modulator is less than intensity modulation. Since the output power response for intensity and polarization modulation is proportional to M_1^4 and M^4 respectively, the output maximum response for polarization modulation is much less than intensity modulation. The bandpass notch filter also shows more than 40 dB rejection ratio. The maximum point differences between calculated result and measured result in higher frequency range shown in Fig.2 and Fig.3 are due to the non-uniform response of the PD in the range from 0 to 10 GHz.

4. Conclusions

A novel switchable coherence-free photonic filter has been proposed. It is designed by a half waveplate, a single-drive MZ intensity modulator and 490 m Hi-Bi fiber. This structure can realize a notch filter with capability of switching between bandpass and low pass response by rotating the half waveplate before the single-drive MZ intensity modulator. The low pass and bandpass response corresponds to the intensity and polarization modulation, respectively. Compared with the intensity modulation, the reduced maximum response for polarization modulation also was discussed. The measured results match closely with the theoretical analysis and show that the notch filters achieve about 40 dB rejections.

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