Optik 126 (2015) 2512–2517

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

The study of an ultrawide tunable range single passband microwave photonic notch filter

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ARTICLE INFO

Article history:
Received 28 April 2014
Accepted 5 June 2015

Keywords:
Microwave photonic filter
Stimulated Brillouin scattering (SBS)

ABSTRACT

A single passband tunable microwave photonic notch filter with ultrawide tunable range is presented. It is based on dual-drive Mach-Zehnder modulator and stimulated Brillouin scattering. By introducing two pump signals whose frequency interval equals twice of the Brillouin frequency shift, the available filter tuning range can reach $4f_B$. With the increase of the number of pump light the tuning range of the filter will grow proportionally. The amplitude of the output signal of the notch filter changes with the half-wave voltage and a DC bias voltage of DDMZM.

1. Introduction

Microwave photonic filter is an optical subsystem which can be used to process microwave signals with the advantages of high bandwidth, low loss, reconstruction of the frequency response, and immunity to electromagnetic interference. In the Radio over fiber (ROF) system, the microwave photonic notch filter can be applied to suppressing noise or interference; microwave photonics notch filter has also been used to the moving target identification (MTI) radar system, and in the optical phased array antenna also has a broad application [1–3].

There are quite a number of microwave photonic notch filter structure has been reported [4–9]. Using a single light source, the frequency response is flat, but with a relatively small tuning range [4]. A tunable microwave photonic notch filter based on Silicon ring resonator has been reported, its tuning is performed by heating, and the whole system requires a complex structure to keep the thermal stability [5]. In [9], a notch tuning range of 2–20 GHz is achieved by employing a dual-drive Mach-Zehnder modulator (DDMZM) and a modulated pump light.

Currently, a lot of articles about microwave photonic filter based on stimulated Brillouin scattering effect have been reported. Due to the stimulated Brillouin scattering has the inherent narrow bandwidth, lower threshold, etc., filter response with high-resolution, wide tuning range can be achieved. In this paper, we propose and analyze tunable microwave photonic notch filter based on stimulated Brillouin (SBS) effect and a dual-drive Mach-Zehnder modulator technology. By accurately setting the frequency spacing between two adjacent pumps, the loss spectrum generated by the pump signal of low frequency is offset by the gain spectrum of the pump signal of high frequency. Numerical analysis shows that the frequency tuning range is 4 times as large as stimulated Brillouin frequency shift.

2. Operational principle

The structure of the tunable microwave photonic notch filter based on DDMZM and SBS is shown in Fig. 1. It is composed by the DFB laser, polarization controller (PC), intensity modulator 1,2 (IM), dual-drive Mach-Zehnder modulator (DDMZM), isolator (ISO), coupler, highly nonlinear fiber (HNLF), circulator, vector network analyzer (VNA) and photodetector (PD). The light from the DFB laser is sent into the DDMZM via the PC, and polarization dependent loss can be decreased by adjusting the polarization state of the PC. RF signal output

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http://dx.doi.org/10.1016/j.ijleo.2015.06.014
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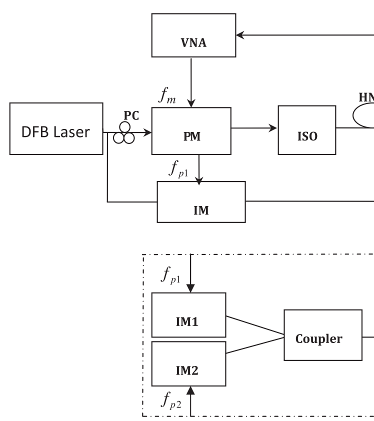

Fig. 1. Operational principle of an ultrawide tunable range microwave photonic notch filter.

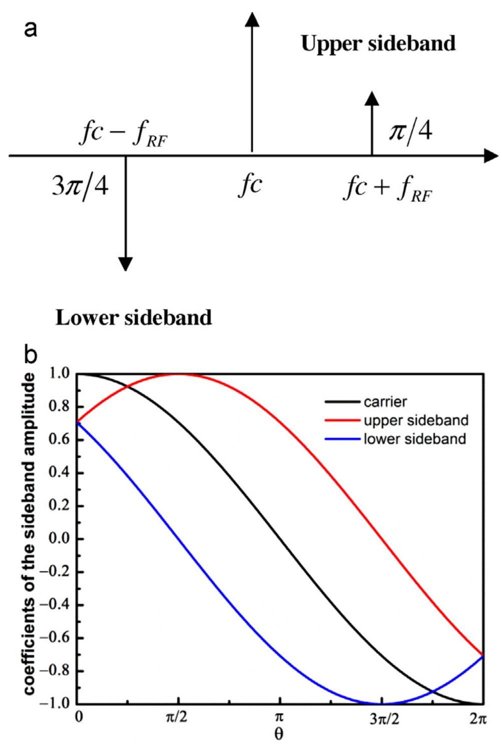

Fig. 2. (a) Coefficients of the sideband amplitude of the carrier, lower sideband, and upper sideband. (b) Dual-drive Mach-Zehnder modulator spectrum.

from the network analyzer is loaded onto the optical carrier via DDMZM and the modulated optical signal is input to the HNLF via the isolator. The optical signal as pump signal generated by intensity modulator (1 and 2) is input to the HNLF through the circulator, and it transports in the opposite direction with the output signal from DDMZM. When meet the conditions of phase matching, stimulated Brillouin scattering effect is generated, thus the modulated signal by the DDMZM is processed. Finally, the signal is input to the detector via the circulator, and it is measured by network analyzer after the photoelectric conversion.

Mathematically, as for small signal modulation the normalized optical field $E(t)$ at the output of the DDMZM can be expressedas [9]:

$$E(t) = \begin{aligned} &[\exp(j\theta) + 1]J_0(m)\exp(j2\pi f_c t) + \\ &[\exp(j\theta) + j]J_1(m)\exp[j2\pi(f_c + f_{RF})t] - \\ &[\exp(j\theta) - j]J_1(m)\exp[j2\pi(f_c - f_{RF})t] \end{aligned} \quad (1)$$

where $J_n(.)$ represents the nth-order Bessel function of the first kind with $n = 0, 1$ and m is the DDMZM modulation index, and f_c is the frequency of the laser and f_m denotes the frequency of injected RF signal. From Eq. (1) we can know that the upper and lower sideband amplitude are different and they are depended on $\theta = \pi V_{DC}/V_\pi$, where θ is the phase induced by the DC bias, V_π represents the half-wave voltage. From Fig. 2(a) we can know that the phase difference between the upper sideband and carrier is always $\pi/4$, while the phase difference between the lower sideband and carrier is always $3\pi/4$. Its spectrum is shown in Fig. 2(a). When $\theta = 0$, the generated upper and lower sidebands has equivalent amplitudes but with π phase difference. When $\theta \in (3\pi/2, 2\pi)$, the amplitude of the lower sideband is greater than the upper sideband. The signal modulated by DDMZM is fed into the HNLF. When a sidebands (upper sideband or lower sideband) are in the gain spectrum (or loss spectrum) range, they will be amplified (or attenuated) due to the stimulated Brillouin scattering