ISSN: 1226-7244 (Print)
ISSN: 2288-243X (Online)
논문번호 15-01-04

j.inst.Korean.electr.electron.eng.Vol.19,No.1,027~032,March 2015
http://dx.doi.org/10.7471/ikeee.2015.19.1.027

A Flexible and Tunable Microwave Photonic Filter Based on Adjustable Optical Frequency Comb Source

Thanh Tuan Tran*, Dongsun Seo*★

Abstract

A flexible and tunable microwave photonic filter based on adjustable optical frequency comb source is demonstrated. We use a combination of a dual parallel Mach Zehnder modulator and an intensity modulator to generate fifteen comb lines with proper weights to implement a desired filter. The optical comb weights, corresponding to the tap coefficients of the filter, are flexibly changed by adjusting the operation parameters of the modulators. The achieved bandwidth and stopband attenuation of the tunable filter are 0.7 GHz and 20 dB, respectively. In addition, we overcome the undesired low frequency suppression appeared in a conventional scheme by applying a dual parallel Mach Zehnder modulator for single sideband suppressed carrier modulation.

Key words: Microwave photonic filter, tunable filter, optical comb source, optical modulator, microwave photonics

I. Introduction

Radio frequency (RF) technology has been developed and achieved incredible results in recent years. However the RF technology showed some bottlenecks due to the bandwidth limit of electronic components [1]. Microwave photonic technology emerges as a most interesting field to break out many bottlenecks that are inherent in traditional RF signal processing. Instead of processing in the electrical domain, the RF signal is converted into the optical domain to exploit many advantages of optical processing. A microwave photonic filter (MPF) is one of the most important applications with great advantages, such as reconfigurable and tunable capabilities in broad frequency range and immunity to electromagnetic field [2].

In an MPF, a finite impulse response (FIR) filter is implemented based on optical delay taps. An array laser source was employed to give tap weight functions. Generally the tap weights were given by optical intensity modulators and/or liquid crystal modulators [1,2]. Since an intensity modulator could give only positive coefficients, a low pass filter was implemented. To implement a band-pass or high-pass filter, negative coefficients should be applied. Various solutions have been proposed such as a couple of Mach-Zehnder (MZ) modulators [3,4] or a 2x1 MZ modulator [5]. Recently, a new method

* Dept. of Electronics, Myongji University, Yongin, Kyonggido 449-728, Korea

★ Corresponding author: phone : 031-330-6369, email: sdsphoto@mju.ac.kr

※ This work was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (#2012-0008390) and by the IITP funded by the Ministry of Science, ICT, and Future Planning (#14-823-04-006).

Manuscript received Jan. 22, 2015; revised Feb. 06, 2015; accepted Feb. 11, 2015 .

to assign complex coefficients to the delay taps has been proposed [6]. In the reference [6], the optical carriers and sideband signals were manipulated separately by single sideband (SSB) suppressed carrier (SC) modulation and using pulse shaper. Tunability of a filter was achieved by assigning complex tap weights or by applying the delay between the carrier and sideband signals.

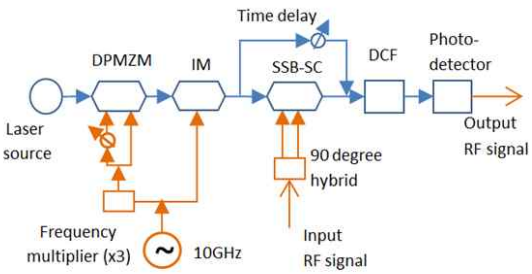
In this paper, we consider applications of a dual parallel MZ modulator that plays two of key roles in an MFP implementation: adjustable optical comb generation and RF signal modulation. Instead of several cascaded phase and/or intensity modulators [7], we use a dual parallel MZ modulator to generate optical frequency comb (OFC). The intensity of comb lines are adjusted by changing the bias, phase and amplitude of sinusoidal modulation signal.

Previously, a combination of a single side band modulator and a delay line interferometer (DLI) was used for a delay line interferometer to do the SSB-SC modulation [6.8]. However, the DLI for carrier suppression induces undesired attenuation of the useful sideband signal. Here we suggest the use of an SSB-SC modulator to reduce the low frequency impairment.

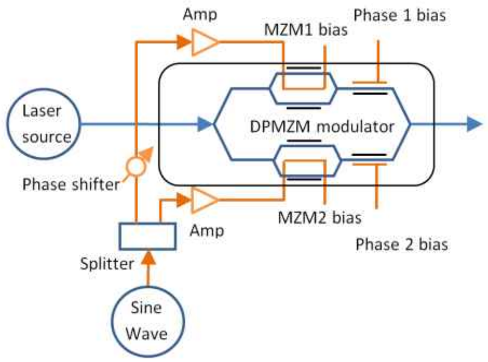
II. Principle

A schematic to generate optical frequency comb using a dual parallel MZ modulator is shown in figure 1(a). Individual MZ modulator is separately driven by a sinusoidal modulation signal with different amplitude. Optical comb lines with various weights are realized by controlling the operating parameters: the phase bias 1 & 2, the bias voltages and amplitudes of the sinusoidal signals of individual modulators, and the RF phase shifter. This compact scheme could generate up to nine comb lines with high flatness [10]. Here we generate five comb lines with controllable weights.

Figure 1(b) shows a block diagram of a suggested microwave photonic filter. An adjustable optical comb source is generated as discussed above. The optical comb signal is divided into two arms: one for delay of carrier signal and the other for input RF signal modulation. The delay for the carrier signal allows the filter to have tunability [8]. At the other arm, the RF signal is converted to an optical SSB-SC signal by the SSB-SC modulator.



(a)



(b)

Fig. 1. Schematic of a microwave photonic filter based on adjustable optical frequency comb source; (a) adjustable optical comb source based on dual parallel MZ modulator, and (b) block diagram fof the suggested microwave photonic filter.

The transfer function of the filter is written as [5],

$$H(w_{RF}) \propto \sum_{n=0}^{N-1} p_n e^{-jn\Delta w(\psi_2 w_{RF}+\tau)} \quad (1)$$

where p_n is the power of the n-*th* comb, Δw the frequency spacing of the OFC source, τ the relative time delay between the two arms, w_{RF} the input

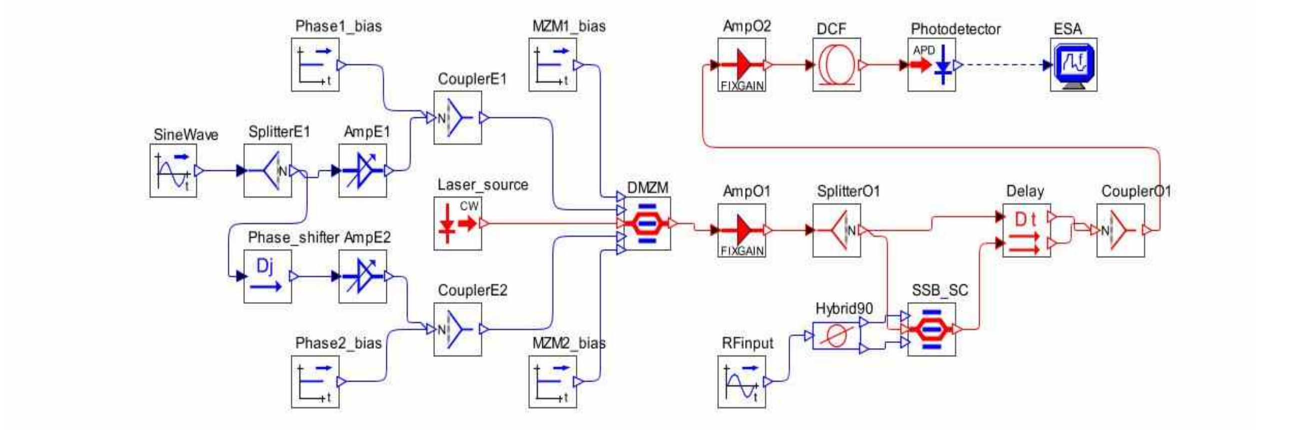


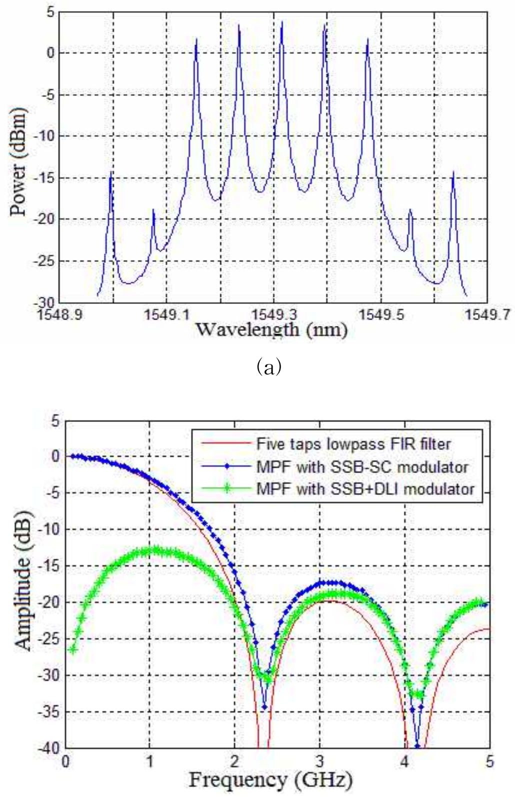
Fig. 2. Schematic of microwave photonic filter used for Optisim platform simulation.

signal frequency, N the number of comb lines, and ψ_2 the fiber dispersion parameter. Equation (1) shows that the shape of an MPF is determined by the spectral comb intensity and its pass-band is tuned by varying the time delay between the carriers and sideband signals (*i.e*, the two arms).

III. Simulation

The microwave photonic filter is simulated based on the Optsim platform as shown in figure 2. A continuous wave (CW) laser is applied to a dual parallel MZ modulator to generate an adjustable optical frequency comb with 10 GHz spacing frequency. The comb source is equally divided and amplified by Erbrium doped fiber amplifiers (EDFAs). In the lower arm, the comb signal is injected into a SSB-SC modulator and modulated by the RF input signal. In the upper arm, the signal experiences variable time delay for pass-band tuning.

The optical signals from two arms are combined and pass through a dispersion compensating fiber with the dispersion of -1250 ps/nm at 1550 nm. The optical signal is converted to electrical signal by a 12 GHz, photo-detector with the responsivity of 0.80 A/W. The transfer function of the MPF is measured by monitoring the



(a)

(b)

Fig. 3. A microwave photonic filter with five taps; (a) combination of SSB modulator and delay line interferometer (DLI) (green).

photodetector output as sweep the input RF frequency.

An ideal finite impulse response (FIR) filter with five positive taps is designed by the window method used in [6]. We obtain a filter with 1 GHz of bandwidth and 18 dB of side lobe suppression (red line in figure 3). The tap weights are assigned into the individual OFC lines by deliberately adjusting the bias of the dual parallel MZ modulator and amplitude of driving sinusoidal signal. Figure 3(a) shows the optical spectrum of the OFC source with corresponding tap coefficients of the filter. The blue line in figure 3(b) shows the amplitude response of the designed microwave photonic filter. It shows very similar characteristics to the ideal filter.

Previously, a combination of an SSB modulator and a delay line interferometer (DLI), known as a differential phase shift keying demodulator (DPSK), for SSB-SC was proposed [6]. Figure 4 shows transmission characteristics of a DLI, showing the low frequency component suppression near its notch optical spectrum of the adjustable OFC, and (b) amplitude responses of an ideal five tap FIR filter (red), an MPF with SSB-SC modulator (blue), and an MPF with a frequency. Due to this suppression, the implemented filter shows large attention in low frequency as shown by the green line in figure 3(a). Here we suggest using the SSB-SC modulator to reduce the

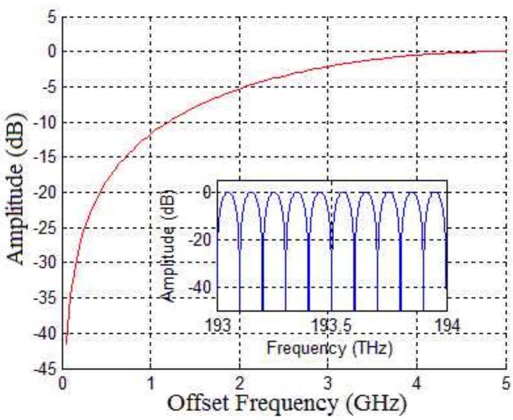


Fig. 4. The transfer function of a delay line interferometer filter.

undesired low frequency suppression.

To implement a sharp and narrow band-pass filter we need a larger number of taps (*i.e.*, spectral comb lines). Therefore, we add an intensity modulator after the dual parallel MZ modulator and achieve fifteen taps. Figure 5(a) shows an example of the optical spectrum of the modified comb source. With this source, we implement a low pass filter with 0.5 GHz bandwidth as shown by the blue line

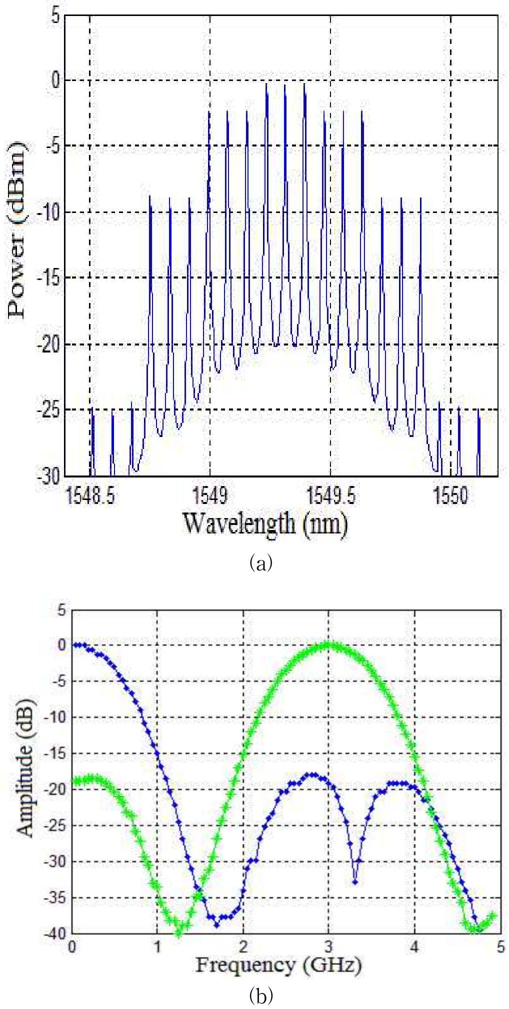
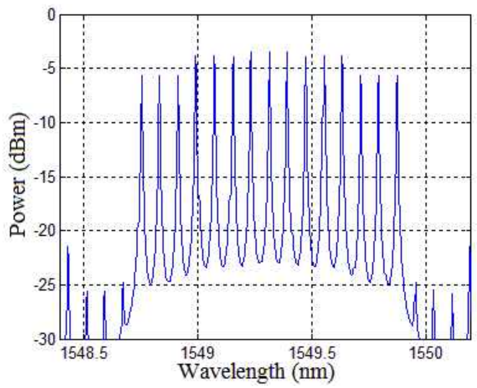
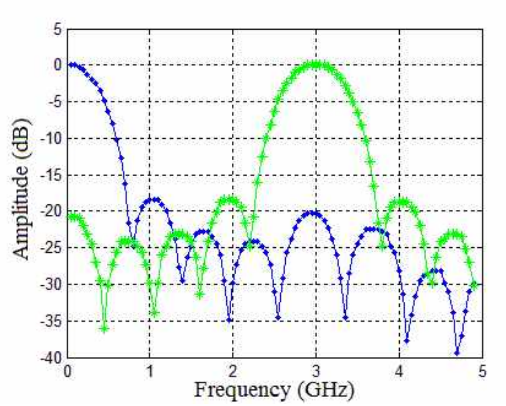


Fig. 5. Microwave photonic filter with fifteen taps; (a) optical spectrum and (b) amplitude responses for low pass filter (blue line) and band-pass filter (green line).

in figure 5(b). By adjusting the delay of the upper arm in figure 1(b), we achieve a band pass filter with center frequency at 3GHz and 1GHz bandwidth, as shown by the green line in figure 5(b). We can adjust again the comb source to have the filter with narrower bandwidth. In this case, corresponding optical spectrum is shown in figure 6(a). The low-pass filter with 0.36 GHz bandwidth and its shifted band-pass filter with 0.72 GHz bandwidth at 3 GHz center frequency are shown figure 6(b). In this way, we implement a flexible and tunable filter using modulators based, adjustable comb source.



(a)



(b)

Fig. 6. Same type of filter of figure 5 but different tap weights; (a) optical spectrum and (b) amplitude responses for low pass filter (blue line) and band pass filter with 0.73 GHz bandwidth (green line).

IV. Conclusion

A reconfigurable and tunable microwave photonic filter based on adjustable comb source was demonstrated. The comb source was implemented by simple combination of modulators. To assign desired tap weights to the comb lines, we deliberately adjust the operating parameters of the used modulators. For examples, we showed tunable filters with 1 GHz bandwidths with 18 dB stopband attenuation. We showed that a conventional filter using a SSB modulator and DLI could remove the spectral carriers, but unintentionally suppress the sideband signal at low frequencies. To overcome this undesired effect, we suggested a scheme using a dual parallel MZ modulator for SSB-SC modulation by deliberately controlling the phase condition between individual modulators. Finally, by cascading an intensity modulator to the dual parallel MZ modulator, we obtained 15 comb lines. Based on the comb lines, we again achieved a flexible and tunable filter, but with narrower bandwidth and higher stopband attenuation. The achieved bandwidth and attenuation were 0.7 GHz and 20 dB, respectively. Other types of filters are able to implement by deliberately adjusting the system parameters.

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BIOGRAPHY

Tran, Thanh Tuan (Student Member)

2010: B.S degree in Electronic and Telecommunication Engineering, Danang University of Technology
2013-Present: Student, Dept. Electronics, Myongji University

Seo, Dongsun (Life Member)

1980: B.S. degree in Electronics, Yonsei University
1985: M.S. degree in Electronics, Yonsei University
1989: Ph.D. degree in Electrical Engineering, Univ. of New Mexico, USA
1990 ~ Present: Professor, Dept. of Electronics, MyongJi University
<Research interests> Optical pulses, Optical CDMA, Microwave photonics, Coherent optical communications