Novel Tunable Multi-passband Microwave Photonic Filters Based on Fiber Mach-Zehnder Interferometer and Fiber Delay Lines

Hao Chen, Zuowei Xu, Hongyan Fu*, and Dan Zhang
Department of Electronic Engineering
School of Information Science and Engineering, Xiamen University, Xiamen 361005, China

Abstract— In this article, we propose and demonstrate two new approaches to implement microwave photonic filters with multi-passband based on the sliced broadband optical source with fiber Mach-Zehnder interferometer and fiber delay lines. The proposed MPFs are simple in construction, easy to implement, and the experimental results show good tunability and reconfigurability.

1. INTRODUCTION

Microwave photonic filters (MPFs) have been under constant research in the last two decades. Compared with the traditional electronic filters, MPFs enjoy the advantages of broad bandwidth, low loss, good tunability, and the immunity to electromagnetic interference, etc. [1–3]. Many techniques have been reported to realize functional MPFs, among which MPFs based on continuous sampling of a broadband optical source and dispersive medium have drawn much attention, since its free spectrum range is infinite in the theory, and thus resulting in a single passband frequency response [4, 5]. Although the single-passband MPF has shown good application potential, in many practical applications, multi-passband MPFs with freely tunable central frequencies are more desirable. Most techniques reported in literature to realize MPFs are not applicable for this kind of multi-passband MPFs, since most of them have periodic frequency responses and their passbands move simultaneously when tuning the MPFs, while their free spectrum ranges keep the same. In this article, we propose and demonstrate two new approaches to implement MPFs with multi passbands based on the sliced broadband optical source (BOS) with fiber Mach-Zehnder interferometer (FMZI) and fiber delay lines. Dual-passband MPFs with good tunability and frequency response characteristics have been achieved in the experiment. The proposed multi-passband MPFs are easy to implement, simple in construction, and show good application potentials in fiber wireless systems and sensing systems.

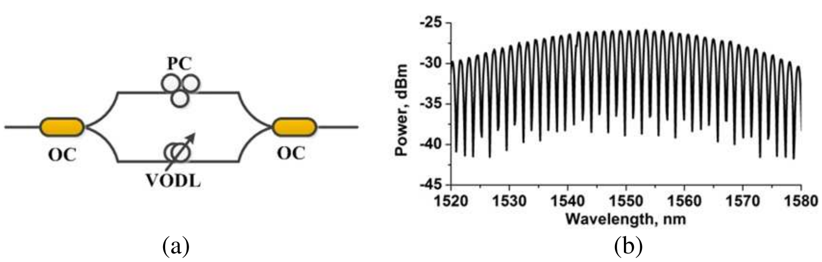

Figure 1: (a) The structure of an FMZI and (b) the sliced spectrum of the BOS after the FMZI.

2. EXPERIMENTAL SETUP AND RESULTS

The proposed multi-passband MPFs are based on the FMZI to act as a spectrum slicer for the BOS to achieve continuous optical sampling, whose structure is shown as Fig. 1(a). The FMZI is made by connecting two 3 dB optical couplers (OC) together, with a polarization controller (PC) in one arm of the FMZI in order to achieve the best extinction ratio of the sliced comb spectrum, and a variable optical delay line (VODL) in the other arm of the FMZI to tune the wavelength spacing of the FMZI. The transfer function of the FMZI can be expressed as:

$$T(\omega) = \frac{1}{2}\left[1 + V\cos\left(2\pi\frac{\omega}{\Delta\omega}\right)\right] \tag{1}$$

*Corresponding author: Hongyan Fu (fuhongyan@xmu.edu.cn).

where V is the visibility of the FMZI, and can be changed by adjusting the polarization controller in one arm of the FMZI; $\Delta\omega$ is free spectrum range of the FMZI, which is determined by the optical path difference of the two arms of FMZI, ΔL. The FMZI is an optical comb filter, and the sliced spectrum of the BOS after the FMZI is shown in Fig. 1(b).

2.1. Dual-pass MPF Based on FMZI and Dual-path Fiber Delay Line

The experimental setup of the dual-passband MPF based on an FMZI as a slicing filter and a dual-path fiber delay line is shown as Fig. 2. The light from a BOS is transmitted through the FMZI to obtain the continuous optical samples, after which the light is modulated by the electro-optic modulator (EOM) by microwave signals to be processed, and then launched into the dual-path fiber delay line which is composed of two 3 dB optical couplers and has different fiber lengths in each path. After that, the light is recombined and detected by the photodiode, and measured by the vector network analyzer (VNA).

In the experiment, after the EOM, the sliced optical source is firstly delayed by a coil of 25 km single mode fiber (SMF) which acts as the dispersive medium, and then sent to the dual-path fiber delay line composed by two 50:50 optical couplers and another coil of 25 km SMF. The modulated light is split into two branches, one of which transmits through 25 km SMF and the other one goes directly through the branch, and recombined together and detected by the PD and measured by the vector network analyzer (VNA) after the dual-path fiber delay line. The frequency responses with separate fiber delay lines and dual-path fiber delay lines are shown as Figs. 3(a) and (b), respectively. One can see that, with the dual-path fiber delay line dual-passband MPF can be realized with each passband identical to the single-passband MPF when separate dispersive fiber is used.

By adjusting the length of the VODL in one arm of the FMZI, the wavelength spacing of the FMZI can be tuned, and thus the central frequencies of both passbands, shown as the measured frequency response in Fig. 4(a). Fig. 4(b) shows the relationship between central frequencies of

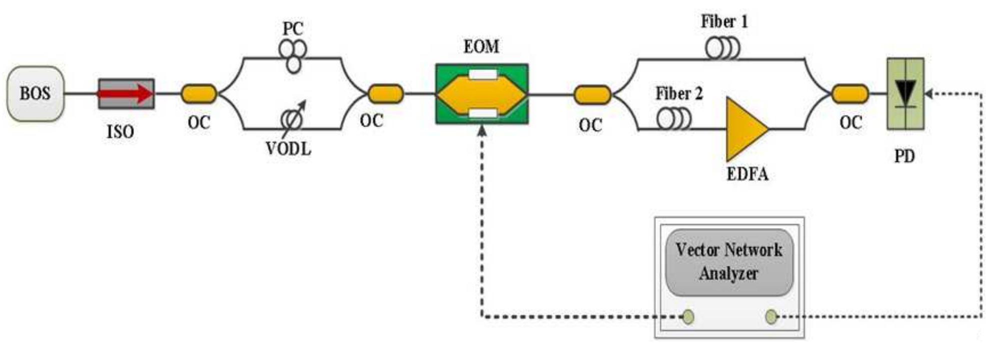

Figure 2: Experimental setup of the dual-passband MPF which utilizes an FMZI and a dual-path fiber delay line (BOS: broadband optical source, ISO: optical isolator, OC: optical coupler, PC: polarization controller, VODL: variable optical delay line, EOM: electro-optic modulator, EDFA: erbium doped fiber amplifier, PD: photodiode.)

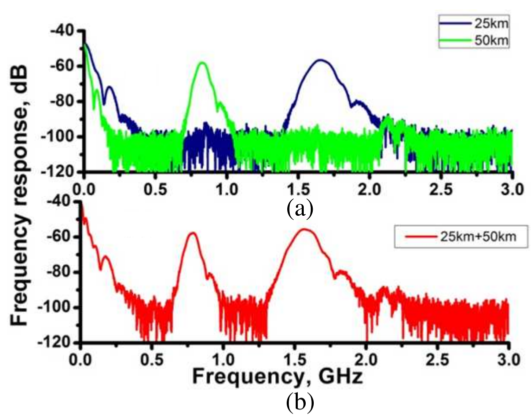

Figure 3: The frequency response with (a) single passband (with single fiber delay line) and (b) dual-passband (with dual-path fiber delay line).

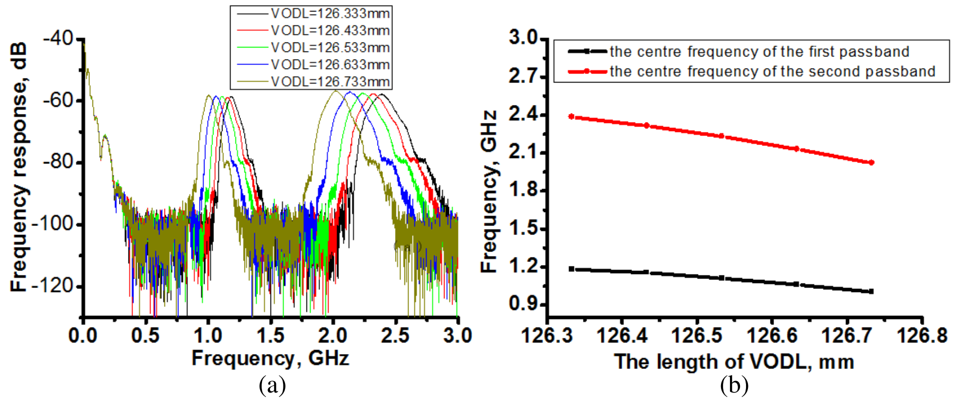

Figure 4: (a) The measured frequency responses with different length of VODL and (b) the relationship between the central frequencies of each passband and the length of VODL.

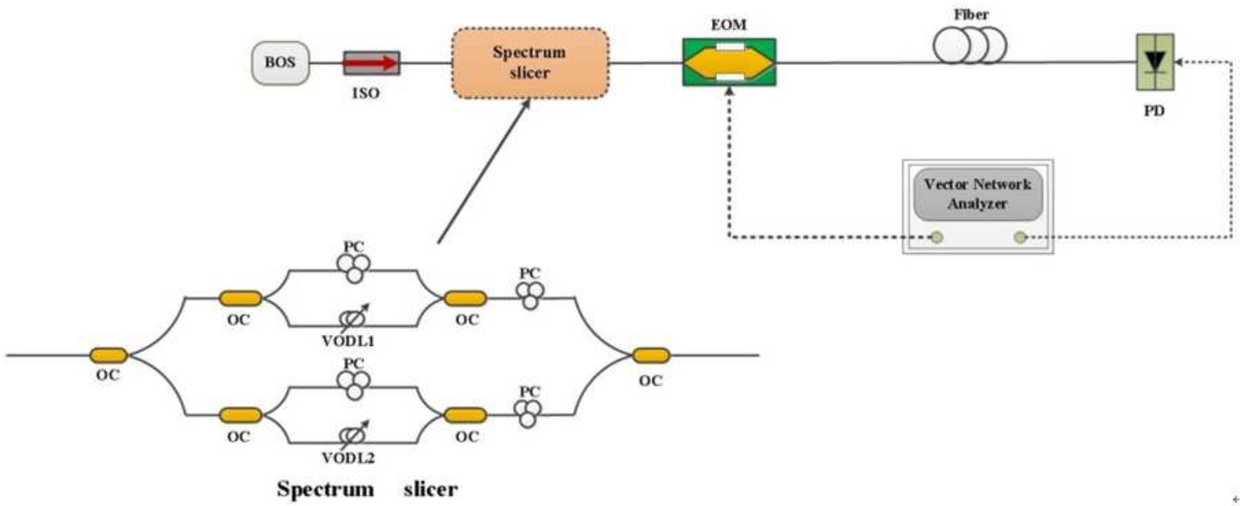

Figure 5: Experimental setup of the dual-passband MPF based on paralleled FMZIs and a dispersive medium.

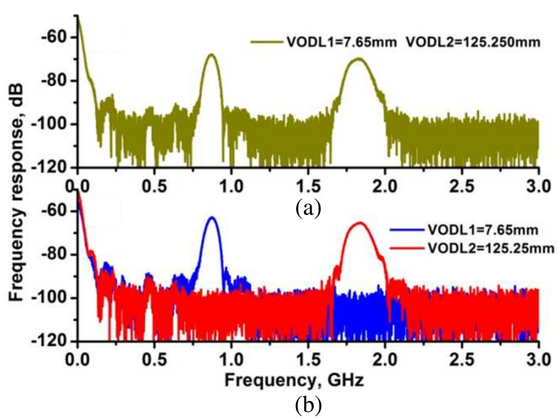

Figure 6: The frequency response of the proposed (a) dual-passband MPF (with two paralleled FMZIs) and (b) with single passband (with one FMZI).

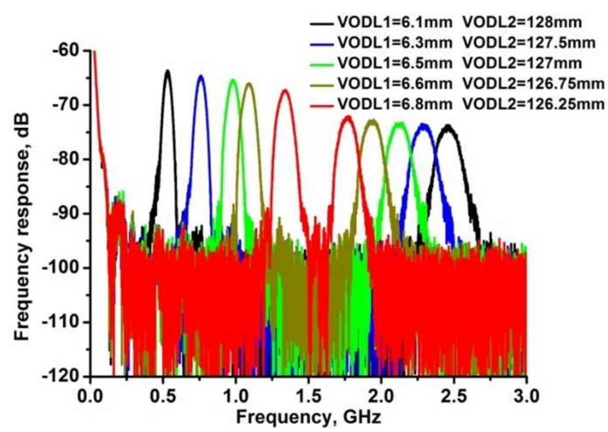

Figure 7: The frequency responses when the lengths of VODL1 and VODL2 are tuned simultaneously.

each passband and the length of VODL. The experimental results show that the central frequency of each pasaband has a good linear relationship with the length of VODL.

2.2. Dual-passband MPF Based on Paralleled FMZIs and a Dispersive Medium

The experimental setup of the dual-passband MPF which was realized by using paralleled FMZIs and a dispersive fiber is shown as Fig. 5. In the experiment, two paralleled FMZIs are used as the spectrum slicing filter to obtain the optical samples, after which the light is modulated by microwave signals to be processed through an EOM. Then, the modulated light is launched into a dispersive medium which in our experiment is coil of single mode fiber, and then recovered by the high speed PD. The frequency response of the proposed dual-pasaband MPF was measured by the VNA.

In the experiment, when we use paralleled FMZIs (VODL1 = 7.65 mm VODL2 = 125.25 mm), dual-passband frequency response can be realized, as shown in Fig. 6(a). As a comparison, the frequency responses by using single FMZI have also been measured with the same length of VODL, as shown in Fig. 6(b). One can observe that, the passbands of the dual-passband MPF are identical to that of the separated single-passband MPF. Both passbands of the proposed MPF can be tuned by adjusting the length of the VODLs, and Fig. 7 shows the frequency responses of the proposed MPF when the length of VODL1 and VODL2 are tuned simultaneously. One can see from the experimental results that the proposed MPF shows good tunability, and both passbands can be tuned freely by adjusting the optical path difference of the corresponding FMZI.

3. CONCLUSIONS

In this article, we proposed two new approaches to implement MPFs with multi-passband based on the sliced broadband optical source with fiber Mach-Zehnder interferometer and fiber delay lines. The first approach is based on an FMZI as a slicing and a multi-path fiber delay line. In our experiment, the frequency response with dual passbands has been achieved by using a dual-path fiber delay line, and the central frequencies of both passbands can be tuned by adjusting the length of the VODL. By employing fiber delay lines with more paths, multi-passband MPF can be realized with this method. The second approach is to employ paralleled FMZIs and a dispersive medium to realize the multi-passband MPF, and in this way the central frequencies the passbands can be tuned freewill by adjusting the optical path difference of each FMZI. In our experiment, dual-passband MPF has been obtained by using two paralleled FMZIs, and the central frequencies of both passbands can be tuned freely. Multi-passband MPF with desirable number of passbands can be realized by introducing more FMZIs in this technique. In conclusion, our proposed approaches to realize multi-passband MPFs are easy to implement, exhibit good tunability, flexibility, and thus show good application potential in the wireless communication and measurement systems.

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