



Wide Tunability Microwave Photonic Filter Based on Brillouin-Raman Fiber Laser: A Modeling Study

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Abstract. A simulation model of microwave photonic filters (MPF) based on Brillouin Raman fiber laser (BRFL) is demonstrated. A wide tunability filter in terms of its bandwidth and free spectra range is achievable by controlling BRFL optical channel numbers and wavelength spacing thanks to the high optical channels count offered by the BRFL. Characteristics of MPF based on the BRFL parameters were investigated and reported. This model serves as the reference for practical MPF design using multiwavelength BRFL. A high selectivity filter could be achievable with 38.1 MHz 3 dB bandwidth.

Keywords: Microwave photonic filter · Brillouin Raman fiber laser · Dispersive medium

1 Introduction

Microwave photonics which is a multidisciplinary field of utilizing properties of photonic technologies has been widely explored to improve on the microwave/wireless systems [1, 2]. Microwave Photonic Filter (MPF) is a photonic system that perform tasks equivalent to microwave filters in a radio frequency (RF) system. The interest in MPF is due to the advantages inherent to photonics such as low loss, high bandwidth, insusceptible to electromagnetic interference, tunability and reconfigurability [3–6].

As shown in Fig. 1, RF to optical conversion is realized by directly or externally modulating a single continuous wave (CW) source or an array of CW source. The input RF signal carried by the optical carrier is sent to a photonic circuit that samples the signal in the time domain, weights the samples and combines them in a subsystem of optical delay lines or other photonic components. Finally, at the output of the subsystem, the resulting signal is optically RF converted by single or array of optical receivers producing the output RF signal [6].

The use of multiwavelength fiber laser in microwave photonic filter has been reported in [4, 5]. There are several approaches of obtaining multi wavelength fiber laser operation

which are Brillouin-Raman fiber laser (BRFL) [11, 13–15], Brillouin-erbium fiber laser (BEFL) [8, 10], erbium-doped fiber laser (EDFL) [7], and Brillouin fiber laser (BFL) [9]. However, due to the low erbium gain and the spectral shape of the erbium gain, low number of optical channels and non-flat channels amplitude are generated in EDFL and BEFL [7–10]. A BRFL is achieved through the Raman amplification in fiber laser cavity to continuously generating optical channels. [16]. It has several desirable traits such as stable operation at room temperature, flat and large gain bandwidth, compatibility with fiber properties, and design simplicity [8, 10–15]. BRFL generates multiple-channel output with wavelength spacing ~ 0.08 nm, ~ 0.16 nm, or ~ 0.24 nm, due to the single, double and triple Brillouin frequency spacing, respectively. Reported works have shown that BRFL have been able to generate from 215 up to 443 optical channels [10, 12]. From previous works, it has been found that a higher number of channels can improve the Q-factor of the filter response [5]. Meanwhile, a flat gain from the multiwavelength fiber lasers can improve the resolution of the filter response.

In this work, BRFL in MPF is studied through computational means. Parameters such as evenness of optical channels, number of optical channels, and wavelength spacing were varied using realistic parameters in reported literatures. The large number of higher order Brillouin Stokes channels generated by BRFL shows the potential for high selectivity MPF. The FSR of can also be manipulated using the wavelength spacing and the dispersion of the dispersive medium. The study shows that BRFL is a promising multiwavelength fibre laser that can be incorporated in MPF for high selectivity, tunability and flexibility.

2 Modelling of MPF Based on BRFL

The configuration of the MPF of a multi-wavelength BRFL is depicted in Fig. 1. A BRFL based MPF was simulated with Matlab program, based on the transfer function given by [16]

$$|H(f)| = R \cos\left(\frac{\lambda_0^2 D f^2}{4\pi c}\right) \left| \sum_{n=1}^N P_n e^{-j.2\pi f.(n-1).D.\Delta\lambda} \right|$$

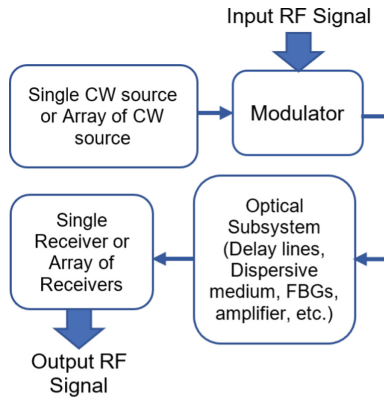


Fig. 1. A basic architecture of MPF.

where R is the photodetector responsivity, λ_0 is the central wavelength of multiwavelength light source, D corresponds to total dispersion of the dispersive medium, N is the total number of optical carriers, P_n is the relative optical power of tap n and $\Delta\lambda$ is the wavelength spacing between adjacent optical channels. The central frequency, λ is set at constant 1550 nm, while the photodetector's sensitivity is set at 0.6. The other parameters such as wavelength spacing, number of optical taps (fiber laser channels) and total dispersion were varied to study the output spectrum of the setup.

3 Results and Discussion

The relationship of the evenness of the BRFL channels amplitude and the normalized frequency response of the MPF is shown in Fig. 2. The wavelength spacing is set at 0.08 nm, number of optical taps at 50, and total dispersion of 450 ps/nm in a 25 km singlemode fiber (SMF) as the dispersive medium. A perfectly flat top or even optical channels is simulated by setting all relative optical power coefficients at 1, while the uneven optical taps were generated as random coefficients between 0.8–1.0, which is a reasonable amplitude variation in BRFL channels [8, 11, 13–15]. By looking at Fig. 2(b), it is observed that noiselike ripples exist at the side lobes of the frequency response generated by uneven taps, as compared to smooth sidelobes generated by flat top optical taps. However, when comparing the center passband around 27.78 GHz, no significant difference is observed. Therefore, an MPF constructed using BRFL optical channels that are slightly uneven will still be serviceable for practical situations.

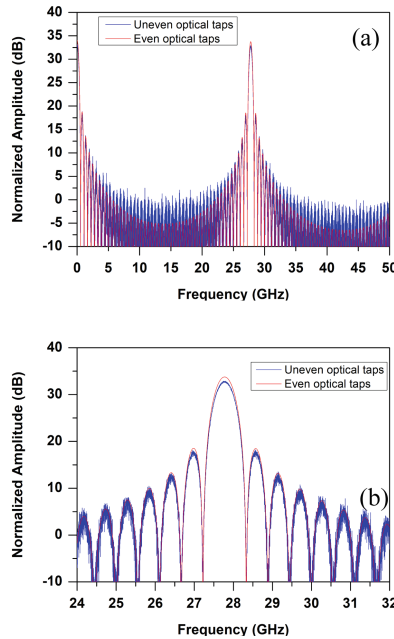


Fig. 2. (a) Filter response and (b) magnified view with even optical taps and uneven optical taps at $\Delta\lambda = 0.08$ nm and $n = 50$.

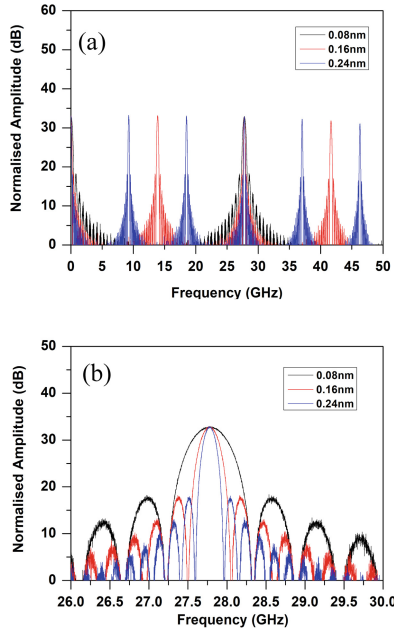


Fig. 3. (a) MPF filter response and (b) magnified view with 0.08, 0.16 and 0.24 nm wavelength spacing at $n = 50$.

Frequency responses of MPF with different wavelength spacing are depicted in Fig. 3 (a) and (b). The choices of wavelength spacing are based on commonly reported frequency spacing from multiwavelength fiber lasers of single wavelength spacing (10 GHz) [13], double spacing (20 GHz) [8, 11, 14, 15] and triple spacing (30 GHz) [10, 12], respectively. Tunability can be achieved by varying the wavelength, as evident in Fig. 4(a). The increase in wavelength spacing to 0.16 nm shifts the center passband from 27.8 GHz to 13.9 GHz, and a further increase to 0.24 nm shifts the passband to 9.25 GHz. The 3-dB bandwidth or the Q factor of the frequency response can also be tuned using different wavelength spacing. In Fig. 4(b), the 3-dB bandwidth of the frequency response narrowing from 276 MHz to 86.8 MHz as it increases from 0.08 nm to 0.24 nm.

Figure 4(a) and (b) illustrate the frequency response spectrum and its magnified view at 50, 100 and 200 number of optical channels. BRFL have been shown to be able to go up to 200 optical taps [10, 12]. The results are generated using the 0.8–1.0 uneven optical channels and 450 ps/nm SMF. The tunability of the bandwidth in this design can be achieved by increasing the number of taps. The 3-dB bandwidth of the frequency response decreases from 276 MHz to 89.6 MHz. Note that the peak amplitude of the first passband also increases when the number of optical taps increase.

Frequency response of the MPF can be adjusted by using different length of fiber as the dispersive medium as depicted in Fig. 5. Frequency response at total dispersion of 360 ps/nm, 450 ps/nm, -390 ps/nm and -585 ps/nm were simulated. These parameters were based on 20 km SMF, 25 km SMF, 10 km dispersion compensated fiber (DCF) and 15 km DCF, respectively, while other parameters were set at $n = 200$ and $\Delta\lambda = 0.028$ nm.

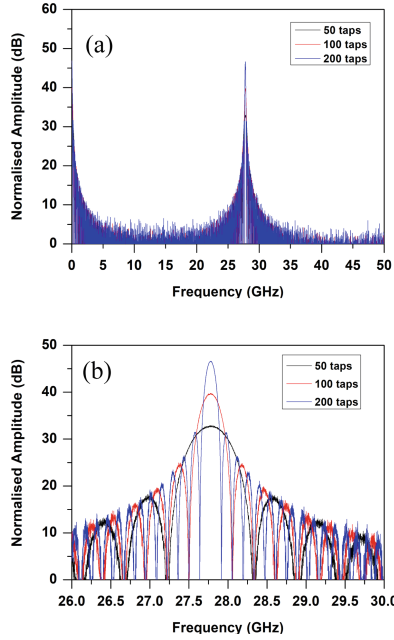


Fig. 4. (a) MPF filter response and (b) magnified view of 50,100 and 200 optical taps at $\Delta\lambda = 0.08$ nm.

As shown in Fig. 5(a), the higher the dispersion, the smaller the FSR. When the length of the SMF increases, so does the attenuation, therefore alternate delay lines can be used such as a linearly chirped fiber Bragg grating(LCFBG) which can reach very high dispersion without the attenuation. This also gives the device another option of tuning its FSR such as manipulating LCFBGs with applied strain, temperature, electrical and magnetic effects [17–19].

Table 1 shows all the computed FSR and 3 dB bandwidth by varying the number of optical taps and wavelength spacing. The lowest achievable FSR and 3 dB bandwidth was found to be 9.25 GHz and 29.6 MHz, respectively, when $n = 200$ and $\Delta\lambda = 0.024$ nm. Compared to previous MPF based on BEFL, which yielded a FSR of ~ 1.99 GHz and bandwidth of about 220 MHz [5], a higher selectivity in a BRFL based MPF is shown due to the high number of optical channel generated. The tunability of the MPF by using a BRFL is significantly improved as compared to a BEFL, as the higher number of optical channels translates to a wider range of tunability. Please note that in the previous BEFL work, a tuning bandwidth of ~ 24 MHz per optical channel was achieved [5]. The MPF in this setup is able to achieve tunability in terms of bandwidth as the number of optical channels can easily be changed by changing the pump power [8, 11, 13–15]. Figure 6 shows the relationship of the 3 dB bandwidth and number of taps, which shows that the bandwidth decreases exponentially against the number of channels. This means that at high number of taps, fine tuning of the frequency response bandwidth can be achieved. At 10 optical taps and 0.08 nm wavelength spacing, a large 3 dB bandwidth

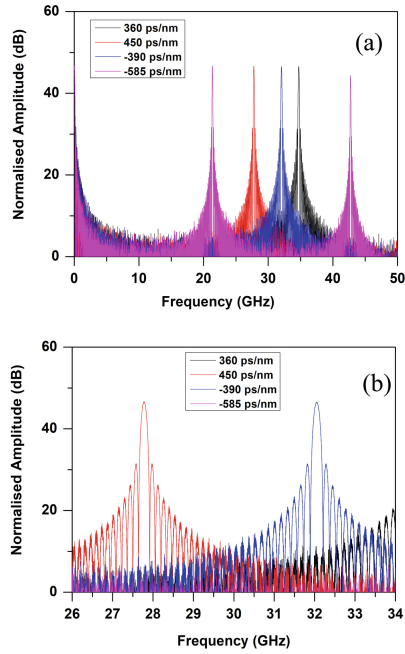


Fig. 5. (a) MPF filter response and (b) magnified view of 360 ps/nm, 450 ps/nm, -390 ps/nm and -585 ps/nm at $n = 200$, $\Delta\lambda = 0.08$ nm

Table 1. FSR and 3dB bandwidth using different BRFL wavelength spacing and channels.

Wavelength spacing ($\Delta\lambda$)	No. of channels	FSR (GHz)	3 dB bandwidth (MHz)
0.08 nm	50	27.80	437.9
	100	27.80	225.0
	200	27.80	113.4
0.16 nm	50	13.90	224.1
	100	13.90	111.9
	200	13.90	57.5
0.24 nm	50	9.25	149.0
	100	9.25	76.6
	200	9.25	38.1

of 1920.8 MHz is achieved while 38.1 MHz is achieved at 0.24 nm and 200 optical taps, which corresponds to a tuning range of ~ 1.88 GHz.

With its high selectivity and tunability, a potential novel spectral zoom function can be realised. Whereby any RF region of interest can be selected and centered on with the appropriate bandwidth [20].

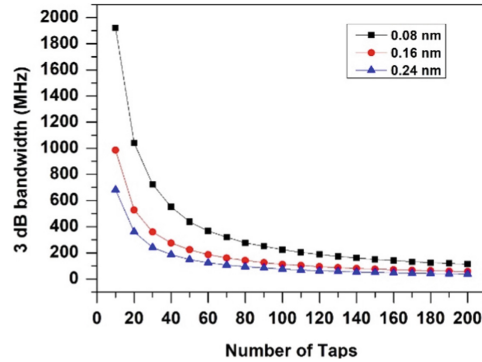


Fig. 6. MPF 3-dB bandwidth at different number of taps and wavelength spacing.

4 Conclusion

This study proposed and modelled an improved MPF based on multiwavelength BRFL. Fine tuning of filter bandwidth can be achieved by tuning the number of optical channels, offered by a multiwavelength BRFL translates to a wider range of tunability of ~ 1.88 GHz in the MPF. Using realistic parameters based on reported works, a narrow bandwidth of 38.1 MHz was demonstrated, showing the potential for a high selectivity filter. The study shows that there is potential for multiwavelength BRFL to achieve a highly tunable MPF that is controlled using a combination of different optical channel, wavelength and dispersion.

Acknowledgments. This work is supported by Universiti Tunku Abdul Rahman Research Fund (UTARRF) IPSR/RMC/UTARRF/2020-C2/S04.

Authors' Contributions. The research idea is contributed by all the authors. Zhi-Yong Yau is the master's degree research student who is supervised by Yu-Gang Shee, Eng-Hock Lim, and Mohd Adzir Mahdi.

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