Microwave photonic filters based on multi-longitudinal-mode fiber lasers

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Abstract: In this paper, we present our recent results in microwave photonic filters based on multi-longitudinal-mode fiber lasers. Theoretical analysis and experiments were carried out, and the experimental results show excellent agreement with the numerical simulations.
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1. Introduction

Microwave photonic filter (MPF) is a powerful technique for implementing signal processing functions of microwave signals. It offers the advantages of low loss, wide bandwidth, tunability, and reconfigurability. Current implementations of the MPF mainly use a single incoherent light source with coherent time smaller than the minimum delay time of the filter to ensure stable filter operation [1]. However, its performance is limited by phase induced intensity noise. In addition, delay tuning can be difficult which limits the reconfigurability of the filter. Multisource MPF offers much promise. However, finding a suitable light source has been a challenge. Previous demonstrated schemes in this direction include using independent lasers operating at different wavelengths [2], spectrum slicing the output of a broadband source [3], or using the multimode output spectrum of a Fabry–Pérot (F-P) laser [4]. The main problem associated to the first approach is the high cost when a large Q-value is desirable. Spectrum slicing will introduce large amplitude noises. Variation of mode power distribution in the F-P laser has limited the performance in filter implementation.

Recently, we proposed and successfully demonstrated an MPF using multiwavelength fiber laser as light source [5]. Afterwards, several MPF schemes using multiwavelength fiber lasers have been reported [6-8], and multi-wavelength fiber lasers are proven to be good optical sources for MPFs. Since the fiber laser is under multi-longitudinal-modes operation, which is different from the previous laser sources, it is necessary to investigate how the mode structure affects the response of the MPF.

In this paper, we present our recent results in microwave photonic filters based on multiwavelength fiber lasers which are under multi-longitudinal-modes operation. Theoretical analysis and experiments were both carried out, and the experimental results show excellent agreement with the numerical simulations.

2. Theory of microwave photonic filter based on multi-longitudinal-mode fiber laser

The configuration of the proposed microwave photonic filter based on multiwavelength fiber laser is shown in Fig. 1. The detailed information of the MPF and the multiwavelength fiber laser can be found in references [5, 9].

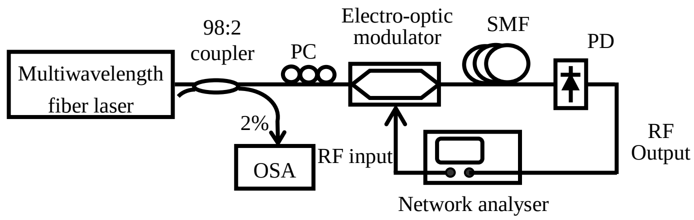

Fig.1. Diagrams of the proposed filter.

The frequency response of the proposed transverse MPF based on multiwavelength multi-longitudinal-mode fiber laser can be deduced from the theory of conventional transverse MPF by adding the multi-longitudinal-mode term [10]. The frequency response can be expressed as a product of three functions:

$$H(\Omega) = \left| \cos\left(\frac{\beta_2 L \Omega^2}{2}\right) \sum_{k=1}^{N} A_k^2 e^{-i\Omega(k-1)\Delta\tau_w} \sum_{p=1}^{M} B_p^2 e^{-i\Omega(p-1)\Delta\tau_m} \right| \qquad (1)$$

Where β_2 is the dispersion coefficient of the delay fiber, L is the length of the delay fiber, A_k^2 is the optical power of the *k-th* wavelength, B_p^2 represents the optical power distribution of the longitudinal-modes in a single wavelength, $\Delta\tau_w$ and $\Delta\tau_m$ are respectively the time delay between adjacent wavelengths and adjacent longitudinal-modes：

$$\Delta\tau_W = \Delta f_W \cdot 2\pi L \cdot \beta_2 \qquad \Delta\tau_M = \Delta f_M \cdot 2\pi L \cdot \beta_2 \tag{2}$$

Where Δf_W is the wavelength spacing, which is determined by the F-P comb filter in the multiwavelength fiber laser cavity, Δf_M is the longitudinal-mode spacing, which is determined by the multiwavelength fiber laser cavity length.

In equation (1), the first term represents the dispersion-induced frequency response. The second term is the frequency response of a typical transversal FIR filter with wavelength taps. While the third term represents the frequency response of an MPF with longitudinal-mode taps. Using equation (1), the profile of the three terms and the final frequency response of the MPF can be simulated and analyzed, and as can be seen that the frequency response of the proposed MPF can be considered as a conventional transverse filter with response reshaped by another conventional transverse filter with longitudinal-mode taps. Since the longitudinal-mode spacing is much narrower than the wavelength spacing, the shaping effect can be ignored at relative low frequency region. That is, multiwavelength fiber laser with multi-longitudinal-mode operation can be used as an optical source for microwave photonic filters.

3. Implementation of MPFs using multi-longitudinal-mode fiber lasers

We first performed the experiment with the MPF configuration shown in Fig. 1. Fig. 2 shows one typical transfer function of the filter and the corresponding output spectrum of the multiwavelength fiber laser. As shown in Fig. 2(a), good agreement is observed between experimental results (solid line) and calculated results from conventional theory proposed in [10] by considering the taps as single-longitudinal-mode lasing, except that there is a minor difference at the third peak, which should result from the reshaping effect of the multi-longitudinal-mode taps. Obviously, the results confirmed the conclusion above.

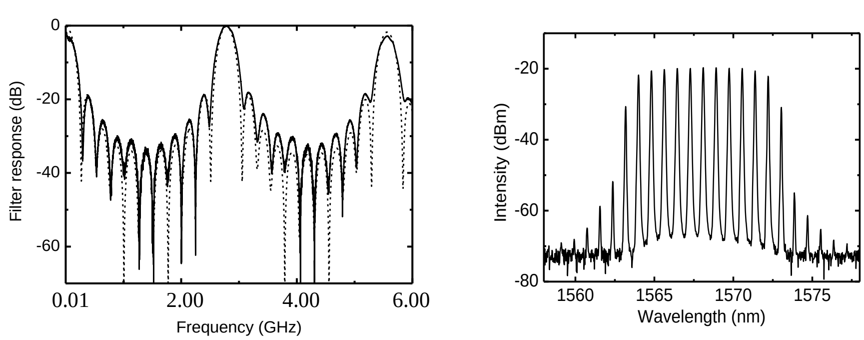

Fig.2. (a) Experimental (solid line) and simulated (dashed line) filter response and (b) Corresponding output spectrum of the fiber laser.

Another experiment of an incoherent complex coefficient MPF based on multiwavelength phase modulation and a high birefringence fiber loop mirror (Hi-Bi FLM) was also demonstrated [11]. The experimental setup is shown in Fig. 3. Multiple taps of the filter are generated by a multiwavelength fiber under multi-longitudinal-mode operation. The Hi-Bi FLM performs PM-to-AM conversion, also provides different phases of the RF modulated signals for taps at different positions of the Hi-Bi FLM transmission spectrum during the conversion. As a result, microwave photonic filter with positive, negative, or complex coefficients has been achieved by control of the multi-wavelength input at different positions of the Hi-Bi FLM transmission spectrum with positive and negative slopes. Figure 4 (a) shows one typical transfer function of the filter with negative coefficient. The corresponding output spectrum from the multiwavelength fiber laser is shown in Fig. 4 (b). The transfer function of the Hi-Bi FLM is also shown in the same spectra to illustrate the taps position.

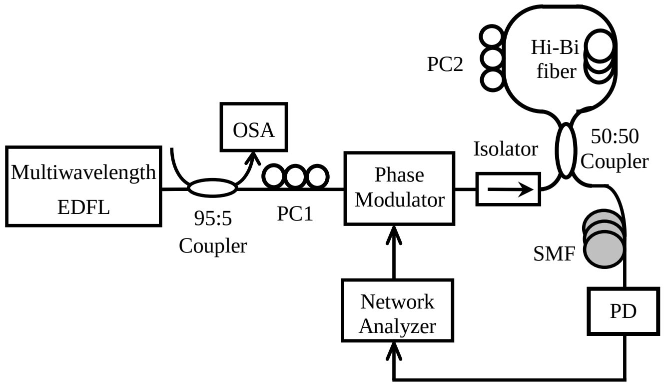

Fig. 3. Schematic diagram of the proposed incoherent complex coefficient MPF.

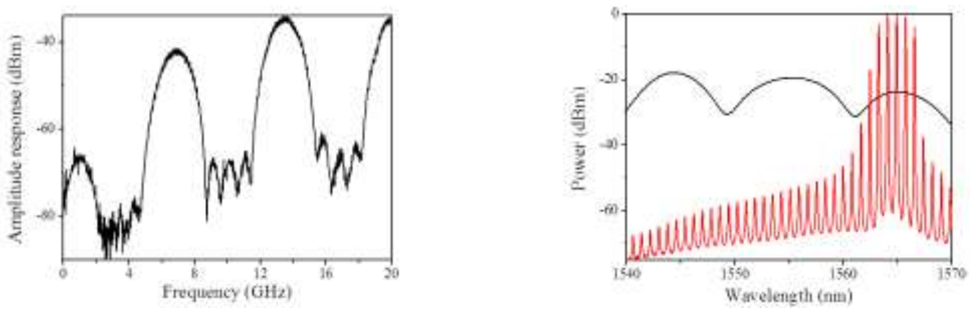

Fig.3. (a) The measured responses of the MPF and (b) the corresponding output spectrum from the fiber laser with illustration of the taps positions at the Hi-Bi FLM.

4. Summary and Conclusion

In conclusion, we have investigated of the characteristics of microwave photonic filter using multiwavelength fiber lasers which are under multi-longitudinal-mode operation. Recent experimental results were also presented, which showed good agreement with the numerical simulations.

5. References

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