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Multi-Tap Photonic Microwave Filter Based on Two-Pump Fiber Optical Parametric Amplifier

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Abstract: A multi-tap photonic microwave filter based on two-pump fiber optical parametric amplifier (OPA) is proposed and an 8-tap filter is experimentally demonstrated. Tunability of the filter is also investigated in the paper, which shows consistency between experimental and theoretical results.
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1. Introduction

Photonic microwave filter attracts more interests recently in the broadband wireless access networks as well as radar and photonic beamsteering of phased-arrayed antennas because of its inherent advantages such as low loss, high bandwidth, immunity to electromagnetic interference (EMI) compared to the ordinary microwave filters [1].

Basically, photonic microwave filters are implemented based on delay-line structure where multiple laser sources are usually used in order to achieve a linear relationship between the input and output radio-frequency (RF) signal and to enhance the Q-factor of the filter. Several approaches have been proposed [2-4]. However, in these approaches the number of laser sources required equals to the number of filter taps, which increases the cost of the system if multi-tap filter is implemented. Recently, a one-pump fiber OPA based photonic microwave filter is demonstrated which can reduce the number of laser sources, but requires a complex delay-line structure [5]. In this paper, we propose a novel method of using two-pump OPA to construct photonic microwave filter which has a much simpler delay-line structure providing flexible tuning ability, and to reduce the laser sources by almost half.

2. Principle

The principle of two-pump OPA based photonic microwave filter is shown in Fig. 1 (a). Two strong continuous-wave (CW) pumps propagate along a spool of nonlinear fiber. The center wavelength of the two pumps is located around the zero-dispersion wavelength v_0 of the nonlinear fiber such that a wide range of signal wavelengths can meet the phase-matching conditions. The wavelengths and powers of the two pumps are carefully chosen to ensure the flatness of the gain spectrum [6]. Then if multiple signal wavelengths are launched into the nonlinear fiber with their wavelengths in the gain region, the pumps will transfer part of their energy to the signals and at the same time to generate another set of wavelengths which are called idlers as shown in Fig. 1 (b). The wavelengths of the signals and idlers are symmetric with respect to the center of the two pumps in terms of frequency. So it is possible to obtain the signals and idlers with equally-spaced wavelengths by careful selection of the signal wavelengths. Then all the signals and idlers are selected using a tunable bandpass filter (TBPF) and launched into a spool of dispersive fiber to introduce an equal amount of time delay between adjacent channels. Time-delayed optical signals are then detected and converted back into electrical signal in the photodetector (PD).

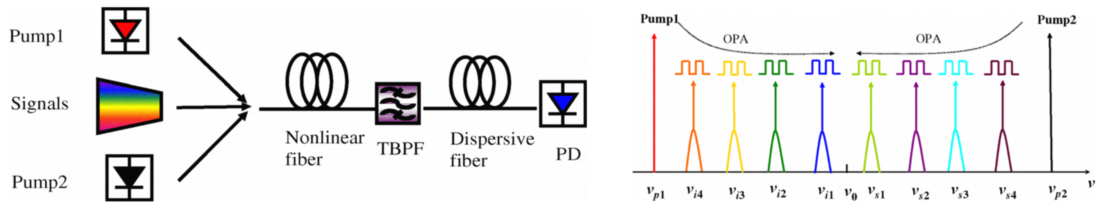

Fig. 1 (a) Two-pump OPA based photonic microwave filter. (b) Principle of two-pump OPA. v_p: pump waves, v_i: idler waves, v_s: signal waves.

3. Experiment

The experimental setup is shown in Fig. 2. Two tunable laser sources (TLSs) TLS1 and TLS2 serve as two pump waves with wavelength of 1535 nm and 1547 nm, respectively. They are then combined together using a 50/50 optical coupler (OC) and launched into a phase modulator (PM). The two pumps are phase modulated by 10-Gb/s 2^7-1 pseudo-random binary sequence (PRBS) to suppress stimulated Brillouin scattering (SBS). After phase dithering the two pumps are splitted into two paths by a wavelength-division multiplexing coupler (WDMC1) and

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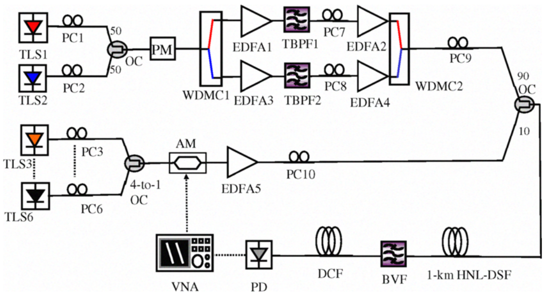

Fig. 2 Experimental setup for two-pump OPA-based photonic microwave filter. Refer to text for details.

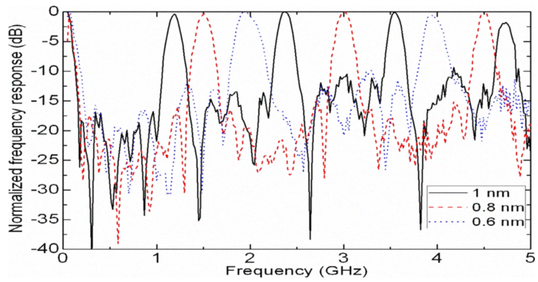

Fig. 3 Frequency response of 8-tap filter. Black solid, red dashed, and blue dotted lines corresponds to wavelength separation of 1 nm, 0.8 nm, and 0.6 nm, respectively.

amplified by two-stage erbium-doped fiber amplifiers (EDFAs) with TBPFs between them to suppress amplified spontaneous emission (ASE) noise. Each pump is amplified to a power of 22 dBm. Polarization controllers (PCs) PC7 and PC8 are used to adjust the state of polarization (SOP) of the two pumps to be orthogonal so that the cross-gain modulation (XGM) and four-wave mixing (FWM) effects can be reduced [7]. They are then combined using another WDMC2. As for the signal branch, TLS1-4 corresponds to the four input signals. They are combined together using a 4-to-1 OC and launched into an amplitude modulator (AM). Optical power of each channel is -12 dBm before the nonlinear fiber. Then signals and pumps are combined together using a 10/90 OC. They are then launched into a spool of highly-nonlinear dispersion-shifted fiber (HNL-DSF) with the zero-dispersion wavelength of 1542 nm and the nonlinear coefficient of 10.4 $W^{-1}km^{-1}$. After parametric amplification, four signals and four idlers are selected by a bandwidth-variable tunable filter (BVF). Then they propagate along a spool of dispersion-compensating fiber (DCF) with dispersion of 850 ps/nm to introduce a relative time delay between eight channels. The frequency response of the filter is monitored by the vector network analyzer (VNA) after photodetection.

Fig. 3 shows the experimental results. Firstly, the wavelengths of the four signals are set to be 1537.5 nm, 1538.5 nm, 1539.5 nm, and 1540.5nm, so the wavelength separation is 1 nm. As a result of dispersion induced time delay, the temporal separation of adjacent channels is 850 ps, corresponding to a free spectral range (FSR) of 1.18 GHz, which matches with the experimental result shown in the black solid line of Fig. 3. Then we change the wavelength separation from 1 nm to 0.8 nm and 0.6 nm, the frequency response curve is observed to shift to a higher frequency as shown in the red dashed line and blue dotted lines of Fig. 3. The FSR also changes from 1.18 GHz to 1.50 GHz and 2 GHz, respectively, which also agrees well with the theoretical value. A mainlobe-to-sidelobe ratio (MSR) of more than 10 dB is obtained in the experiment. The wavelength separation is changed by simply changing the four signals' wavelengths without changing the other parameters of the system. So the proposed photonic microwave filter is tunable and a multi-tap configuration can be implemented using less laser sources.

4. Conclusions

We proposed and demonstrated a novel photonic microwave filter based on two-pump fiber OPA. In this scheme, only half of the laser sources are required to achieve a multi-tap operation. The filter is also tunable by simply tuning the wavelengths of the signals, which shows consistency between experimental and theoretical results.

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