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Tunable fiber comb filter based on simple waveplate combination and polarization-diversified loop

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ABSTRACT

By incorporating a simple waveplate combination (WPC) set composed of two waveplates, we propose a wavelength-tunable fiber comb filter based on a polarization-diversified loop (PDL). The simple WPC set includes three kinds of waveplate groups such as two quarter-wave plates (QWPs), a set of a QWP and a half-wave plate (HWP), and a set of an HWP and a QWP. The PDL is implemented by making a Sagnac birefringence loop comprised of a four-port polarization beam splitter (PBS), two waveplates, and polarization-maintaining fiber (PMF). In the PDL, one end of PMF is connected to one port of the PBS with its slow axis $\pi/4$ (45°) oriented with respect to the horizontal axis of the PBS, and the other end of PMF is concatenated with the waveplates. First, we investigated light polarization conditions required to continuously tune the absolute wavelength location of the proposed filter in terms of input and output states of polarization (SOPs) of a birefringence element, or PMF. Then, three analytic transmittances of the filter were derived for the three WPC sets with arbitrary orientation angles of waveplates through Jones matrix formulation. And eight specific orientation angle sets of two waveplates, which caused phase shifts increasing linearly from 0° to 315° by a step of 45° in a sinusoidal transmittance function, were found for each WPC set. In particular, it has been theoretically proved that an orientation angle set of two waveplates, which can induce an arbitrary phase shift in the sinusoidal transmittance function, always exists for each WPC set. This implies that the comb spectrum of the proposed filter can be continuously tuned within one channel bandwidth by the proper control of the waveplate orientation angles. Finally, the input SOPs of PMF and the wavelength-dependent evolution of its output SOP were examined on the Poincare sphere at the eight specific waveplate angle sets. The relationship between the wavelength tuning and the SOP evolution was also discussed.

1. Introduction

Optical fiber comb filters with the merits of simple design, ease of use, low insertion loss, and good compatibility with fiber communication systems have been considered as efficient wavelength-selective components, which can be employed to process optical signals and isolate neighboring channel signals to decrease crosstalks in dense wavelength-division-multiplexed (DWDM) optical systems. Besides the use of signal processing apparatuses, fiber comb filters can also be utilized for various optical applications such as optical pulse train generation [1], multiwavelength lasing [2–4], and microwave signal processing [5]. In order for a comb filter to meet the requirement of spectral tunability in some optical components such as DWDM filters and multiwavelength lasers, it is important to finely tune the absolute wavelength of the filter to the desired spectral location. Considerable efforts have been made to realize the tunability of a comb filter by using a polarization-diversified loop (PDL) [6–8], a Lyot configuration [9,10], Sagnac birefringence loop [3,11], and fiber gratings [12,13]. In particular, fiber comb filters based on a PDL [14,15], which are constructed by using a polarization beam splitter (PBS), have strong advantages in multiwavelength switching and tuning capabilities [6,16], compared with Sagnac birefringence comb filters (SBCF) based on a fiber coupler [17]. PDL-based comb filters are also input-polarization-independent, whereas comb filters based on a Lyot configuration [18–20] are not. In the case of the fiber gratings, instead of using electronic or optical schemes to change light polarization [3,6–11], one should control tension/pressure or temperature applied to the grating for spectral tuning, which can affect its durability and cause the degradation of spectral characteristics such as visibility and insertion loss.

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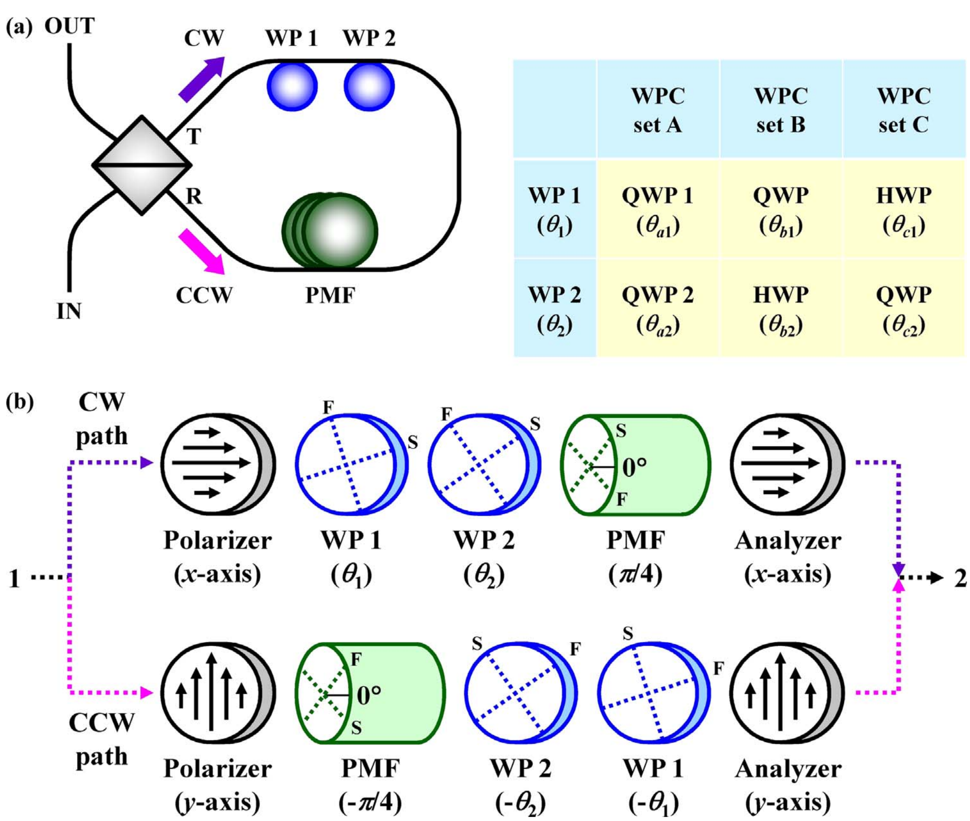
In the PDL-based comb filters, the wavelength tuning of a periodic comb spectrum was done by adjusting the effective birefringence of the PDL with an ordered waveplate combination (WPC) of a half-wave plate (HWP) and a quarter-wave plate (QWP) before polarization-maintaining fiber (PMF) [6]. This WPC can induce a phase shift ranging from 0° to 360° in the filter transmittance. Other WPC sets such as two QWPs, two HWPs, and a set of a QWP and an HWP could be considered as candidates for the wavelength tuning. Since the above WPC set in [6] was suggested, however, there has been no report on other suitable WPC to realize the tunability of the PDL-based comb filter yet. Furthermore, in the previous filter [6], an additional HWP, used to set the effective orientation angle of the slow axis of PMF as $\pm\pi/4$ ($\pm 45°$) with respect to the horizontal axis of the PBS, was employed and located behind PMF for obtaining good visibility, or comb spectra with high extinction ratios. But, the structural and operational simplicity of the comb filter can be overshadowed by the use of this HWP. As for some practical applications of this comb filter, the added HWP can increase the insertion loss and also the spectral distortion induced by its dispersive birefringence, or wavelength-dependent phase difference. As an intuitive but costly approach, the continuous tuning of the absolute wavelength can also be electrically implemented by replacing PMF with a differential group delay modulator, or a birefringence modulator [18,19].

Here, we propose a PDL-based tunable fiber comb filter using a simple WPC set composed of two waveplates. The simple WPC set includes three kinds of waveplate groups such as two QWPs, a set of a QWP and an HWP, and a set of an HWP and a QWP. The PDL is composed of a four-port PBS, a WPC set, and PMF, forming a Sagnac birefringence loop. In the PDL, one end of PMF is concatenated to one port of the PBS with its slow axis $\pi/4$ (45°) oriented with respect to the horizontal axis of the PBS, which obviates the need for a supplementary HWP, and the other end of PMF is coupled to the waveplates. To the best of our knowledge, this is the first PDL-based comb filter whose wavelength tunability is implemented by using only two waveplates. In Section 2, light polarization conditions required to continuously tune the absolute wavelength location of the proposed filter will be described for input and output states of polarization (SOPs) of a birefringence element, or PMF. Then, in Section 3, analytic filter transmittances will be derived for the three WPC sets with arbitrary orientation angles of the two waveplates through the Jones matrix formulation. On the basis of these transmittances, eight specific orientation angle sets of the two waveplates, allowing phase shifts that linearly increase from 0° to 315° by a step of 45° in a sinusoidal transmittance function, will be elicited and explained for each WPC set. In particular, it is theoretically proved that an orientation angle set of two waveplates, which can induce an arbitrary phase shift in the transmittance function, always exists for each WPC set. Moreover, in Section 4, the input SOPs (SOP_{in}'s) of PMF and the wavelength-dependent evolution of its output SOP (SOP_{out}) will be investigated on the Poincare sphere at the eight specific waveplate angle sets, and the relationship between the wavelength tuning and the SOP evolution will be also discussed. Finally, a brief summary will be given in Section 5.

2. Principles of operation

Fig. 1(a) shows the schematic diagram of the proposed filter that consists of a four-port PBS, a WPC set composed of two waveplates indicated as the WP 1 and WP 2, and PMF that is connected to the port R of the PBS with its slow axis $\pi/4$ oriented with respect to the horizontal axis of the PBS. The WPC set selected for the wavelength tuning can be one of three waveplate groups such as two QWPs, a set of a QWP and an HWP, and a set of an HWP and a QWP, designated as WPC sets A, B, and C, respectively. Input light entering the PBS is decomposed into two orthogonally polarized components such as linear horizontal and vertical polarization ones. Linear horizontal polarization (LHP) and linear vertical polarization (LVP) components make a transit through the Sagnac loop of the filter, i.e., the PDL, in clockwise (CW) and counterclockwise (CCW) directions, respectively. Basically,



	WPC set A	WPC set B	WPC set C
WP 1 (θ_1)	QWP 1 (θ_{a1})	QWP (θ_{b1})	HWP (θ_{c1})
WP 2 (θ_2)	QWP 2 (θ_{a2})	HWP (θ_{b2})	QWP (θ_{c2})

Fig. 1. (a) Schematic diagram of proposed filter and (b) light propagation path.