Tunable Microwave Photonic Notch Filter Based on a high-birefringence linearly chirped fiber Bragg grating

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Abstract. In this paper, a continuously tunable microwave photonic notch filter is proposed and experimentally demonstrated. This filter is based on the differential group delay generated by a high-birefringence linearly chirped fiber Bragg grating. This microwave photonic filter belongs to the orthogonal polarization approach, polarization maintaining structure ensures the filter free from the random optical interference problem. Its response is induced by the differential group delay (DGD) of the Hi-Bi LCFBG and it can be varied by tuning the grating through adding gradient strength to the grating. Free spectral range tuning by 9.27 GHz with more than 35 dB notch rejection is achieved.

1. Introduction
Optical processing of microwave and millimetre-wave signals using microwave photonic filters (MPFs) has attracted significant interest because of the advantages of high time-bandwidth product, low loss, immunity to electromagnetic interference (EMI), and tunable and adaptive functions [1, 2]. In order to achieve stable operation, the incoherent MPF is more attractive in practice. There are mainly two approaches to satisfy the requirement of incoherent operation: keeping the laser coherence time smaller than the optical delay time, and making the state of polarization (SOP) of the optical signals to be orthogonal [4]. For the first approach, fulfilling the coherence time condition restricts the free spectral range (FSR) of the MPF [3]. If laser array [4], sliced wideband source [5], or multi-wavelength lasers [6] are used, the system complexity and cost will be high. For the applications which require low cost and compact MPFs, the second approach is a good choice. The MPF based on orthogonal polarization has been proposed in [7], but it has only step tuning ability. Continuously tunability has been achieved using a high-birefringence linearly chirped grating (Hi-Bi LCFBG), a polarization beam splitter (PBS) and a Hi-Bi coupler [8]. However, the free spectral range (FSR) tuning is relative small because of the uniform strength applied to the grating. The notch rejection may also be affected with a LCFBG inside a fibre loop because the limited reflectivity of the grating causes signal crosstalk.

In this paper, a continuously tunable MPF is proposed which is based on a Hi-Bi LCFBG and a polarization maintaining (PM) circulator. This MPF belongs to the orthogonal polarization approach, polarization maintaining structure ensures the MPF free from the random optical interference problem. The MPF response is induced by the differential group delay (DGD) of the Hi-Bi LCFBG and it can
be varied by tuning the grating through adding gradient strength to the grating. FSR tunability of 1.11 GHz and 40 dB notch rejection are achieved.

2. Configuration and operation principle

The configuration of the proposed MPF is shown in Figure 1. Continuous wave (CW) light from a laser diode (LD) is modulated by a Mach-Zehnder modulator (MZM) which is driven by an RF signal from a vector network analyzer (VNA). The output of the MZM is fed to a Hi-Bi LCFBG through a half waveplate and a PM circulator. The half waveplate is used to excite two orthogonal and equal power linearly polarized optical components. Since the whole structure is polarization maintaining, the two orthogonal components propagate along the slow and fast axes, get reflected by the Hi-Bi LCFBG, detected by a photodetector (PD) and the frequency response is measured by a network analyzer.

![Figure 1. Experimental setup. (LD: laser diode, VNA: vector network analyzer, PD: photodetector)](image)

The key component of our system is the Hi-Bi LCFBG. For a fiber Bragg grating, the strongest mode coupling occurs at the wavelength $\lambda_B$ that can be back reflected from the grating. The Bragg wavelength is a function of grating pitch $\Lambda(z)$ [9]

$$\lambda_B = 2n_{eff} \Lambda(z)$$  \hspace{1cm} (1)

where $n_{eff}$ is the effective refractive index of the fibre. A linearly chirped FBG has a variable pitch which is a linear function of distance along the grating so that the Bragg wavelength and reflection location along the grating forms a linear relation. As a result, when the optical signals with different wavelengths input into a FBG, they are reflected differently at different locations along the grating so that the time delay of the LCFBG is also a linear function of the wavelength. When fabricating LCFBG into a Hi-Bi fiber, because of the refractive index difference between the x and y axes, the grating spectra for the two orthogonal polarization axes have a shift in wavelength domain. So, when the two intensity modulated orthogonal components reflect by the Hi-Bi LCFBG, they are delayed differently and a certain amount of differential group delay (DGD) occurs between the fast and slow axes. Since there are two orthogonal components, the MPF is a two-tap transversal filter and its normalized transfer function is

$$|H(f)| = |\cos(\pi f \Delta T)|$$  \hspace{1cm} (2)
where \( f \) is the RF frequency and \( \Delta T \) is the DGD of the system. The FSR of the filter is described by

\[
FSR = \frac{1}{\Delta T}
\]

(3)

The DGD in Equation (2) and (3) actually contains two parts: Hi-Bi LCFBG DGD \( (\tau_g) \), and fixed DGD \( (\tau_0) \) which comes from the polarization maintaining fiber (PMF) pigtailed of the modulator, circulator and Hi-Bi LCFBG. The Hi-Bi LCFBG DGD can be tuned by applying gradient strength to the grating to cause a change of the pitch. Figure 2 (a) shows the cantilever beam structure used for this purpose [10]. By tuning the FBG using this structure, the reflection spectrum broadens or narrows with the DGD reduced or increased a certain amount \( (\Delta \tau_g) \) as indicated in Figure 2 (b). However, the centre wavelength remains fixed. By using this property, the FSR tuning is achieved though varying the DGD at a fixed wavelength. Then Equation (3) can be rewritten as

\[
FSR = \frac{1}{\tau_0 + \tau_g + \Delta \tau_g}
\]

(4)

![Figure 2](image)

**Figure 2** (a) Cantilever beam for tuning the Hi-Bi LCFBG and (b) schematic reflectivity and group delay
3. Results and discussion

The Hi-Bi LCFBG used in the experiments is fabricated by exposing a hydrogen-loaded PM fibre to a 244 nm UV laser beam through a linearly chirped phase mask. Figure 3 (a) shows the measured reflection spectra for the fast and slow axes. It is clearly seen that the spectra width can be varied up to 0.3 nm. According to Eq. (4), in order to achieve bigger FSR tuning range, $\tau_0$ needs to be small. To
get a smaller $\tau_0$, the short wavelength port of the Hi-Bi LCFBG was connected to the PM circulator in our experiment and the working wavelength was the shortest wavelength which can be reflected by both slow and fast axes, e.g. 1554.3 nm. The measured filter responses are shown in Figure 3 (b), the FSRs when the FBG spectrum compressed, at normal position, or broadened are 2.21 GHz, 6.75 GHz and 11.48 GHz, respectively. An FSR tuning range of 9.27 GHz was achieved. Actually, the FSR tuning range can be further increased through compensating the fixed DGD by adding another section of PMF which has similar length as the PMF pigtails with its slow axis align with the fast axis of the PMF pigtails (90° rotation).

4. Conclusion
We have demonstrated a simple continuously tunable microwave photonic notch filter which is based on a Hi-Bi linearly chirped fibre Bragg grating as tuning element. The polarization maintaining structure is free from the problem of random optical interference. FSR tunability of 9.27 GHz with more than 35 dB notch rejection has been achieved.

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