A Novel Frequency-Modulation (FM) Demodulator for Microwave Photonic Links based on Polarization-Maintaining Fiber Bragg Grating

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Abstract: A novel scheme for demodulating frequency-modulated optical signals is proposed. It uses polarization-maintaining fiber Bragg grating (PM-FBG) as a frequency discriminator. The basic principle and preliminary results of linearity and demodulation are presented.

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1. Introduction

Frequency modulated (FM) microwave photonic links (MPLs), where the optical frequency of the laser is varied with the input signal, are considered as promising alternatives to optical intensity modulated (IM) MPLs due to their advantages such as reduced effect of fiber nonlinearity, facilitation of multichannel operation, higher signal-to-noise ratio and higher modulation efficiency [1-3]. Recovery of input signal, often called demodulation, with high fidelity is a key consideration of any MPL [1,2]. Two approaches are possible for demodulating an input signal for FM-MPL. First, a coherent detection system can be used at the cost of undesired complexity at the receiver [3]. To overcome the complexity of first approach, an optical filter (which acts as an FM discriminator) can be used which converts FM to IM before detection of input signal. In an FM-MPL where an FM discriminator is employed is called FM direct-detection (FM-DD) links. FM demodulator for an FM-DD link is the focus of this paper.

Many FM discriminators have been demonstrated [1-7]. Among them, fiber Bragg grating (FBG) based FM discriminators have been shown to provide a simple solution with low dc-bias and high linearity [5-7]. FM discriminators using single FBG can provide good linearity, but they still suffer from dc-bias (or carrier leakage) due to finite reflectivity at carrier frequency [5]. To remove the dc-bias, a new scheme has been attempted in which two FBGs with exactly same reflectivity profiles are arranged in such a way that there is no overlap between their reflection profiles and their tails meet each other. Although the method demonstrates improvement in removing dc-bias for large FM indices, it also shows carrier leakage (dc-bias) and nonlinear distortion for small modulation indices [6, 7]. Moreover, it requires two custom fabricated FBGs with exactly same reflectivity profiles. So, there is a need for a scheme whereby the carrier leakage and nonlinear distortion for low FM indices can be easily removed while retaining the same performance for large FM indices.

Here, we present a new and simple approach for FM demodulation with zero dc bias and good linearity. Our approach uses an FBG fabricated in a polarization maintaining (PM) fiber, called as PM-FBG, as a frequency discriminator. Because of the birefringence property of PM fiber, a PM-FBG has two identical reflection profiles with slightly shifted peak wavelengths corresponding to two orthogonal polarizations. This ability of PM-FBG to give two wavelength-detuned reflection peaks saves the burden of fabricating two independent FBGs. Moreover, due to the shift in the two reflection profiles along two orthogonal directions, it provides a natural quadrature point by which linear operation with zero dc bias can be obtained.

2. Principle of operation

The reflection spectrum from a PM-FBG features two resonance peaks. Their wavelengths are given by

$$\lambda_s = 2\Lambda n_{eff}^s \text{ and } \lambda_f = 2\Lambda n_{eff}^f, \tag{1}$$

where Λ is the grating period, λ_s (λ_f) and n_{eff}^s (n_{eff}^f) are the Bragg wavelength and the effective refractive index for the polarization component along the slow (fast) axis, respectively [8]. Note that n_{eff}^s and n_{eff}^f are nearly equal and so the two reflection peaks are not very far apart.

With this basic understanding about PM-FBG, here is how the proposed demodulator works: A proper PM-FBG is chosen so that its two resonances share an overlapping region in the middle of them as shown in Fig. 1(a). An unmodulated optical carrier is first tuned to the crossover wavelength between the two Bragg reflection peaks, as illustrated by the left panel of Fig. 1(a). The polarization of the injected optical carrier is adjusted so that equal amount of optical power is reflected by the PM-FBG along its fast and slow axes. The two orthogonally polarized reflection signals are separately detected, and the detector outputs are subtracted from each other to create a *null* (i.e., balanced photodetection), as shown in the right panel of Fig. 1(a). Now, when the carrier is dislocated from the crossover wavelength, the reflected powers along the fast and the slow axes change toward opposite directions due to the opposite signs of their corresponding reflectivity slopes. This allows the balanced photodetector (BPD) to generate a large, bias-free response, as shown in the right panel of Fig. 1(b). This is the basic idea for FM demodulation. For example, when carrier sweeps sinusoidally near the crossover wavelength, as depicted by Fig. 1(c), the reflected powers along the fast and the slow axes also change sinusoidally but with a 180-degree phase difference which in turn generates a large, bias-free response at the output of BPD.

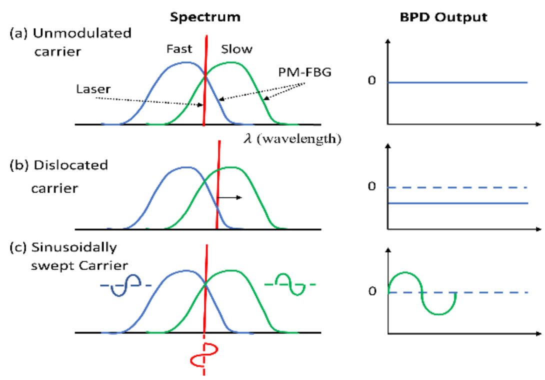

Fig 1: Operating principle of the proposed scheme: The reflection spectrum of PM-FBG relative to laser (left) and the corresponding output of BPD (right) for (a) unmodulated carrier, (b) dislocated carrier, and (c) sinusoidally swept carrier cases.

3. Experiment

A layout of the experimental setup is shown in Fig. 2(a). The FBG fabricated on a PANDA-type PM fiber is used. It has two Bragg reflection peaks about 0.6 nm apart, with each peak having a 0.4-nm full width at half maximum (FWHM) (see Fig. 3(a)). A single-frequency, tunable, external-cavity diode laser operating near 1550 nm serves as the light source and its wavelength is tuned to the crossover wavelength of the two Bragg peaks, as shown in Fig. 3(a). The fiber-coupled laser output passes through an isolator before entering an electro-optic modulator (EOM), which is used to apply modulation to injected optical frequency. The output of EOM is given to the input of polarization controller (PC), which is used to set the polarization state of the light. A polarization-maintaining 50:50 coupler takes the output of PC to feed it into the PM-FBG and sends the reflected power toward the output. A fiber-coupled polarization beamsplitter splits the two orthogonal polarization modes in the output, feeding them into the two photodiodes of a balanced amplified photoreceiver (Thorlabs PDB 440C). The receiver provides a transimpedance gain of 5.1×10^4 V/A. All the fibers and fiber connectors after the polarization controller are PM type so that the polarization state is preserved.

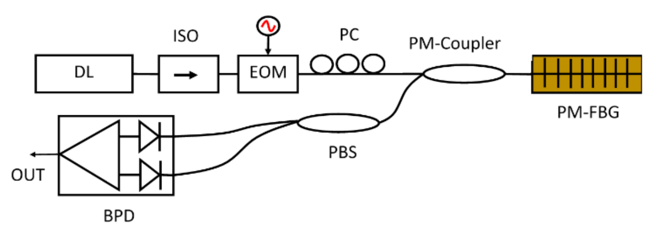

Fig 2: Schematic of the experimental setup for FM demodulation. DL: diode laser, ISO: fiber-coupled isolator, EOM: electro-optic modulator, PBS: polarization beam splitter, PC: polarization controller, PM-Coupler: polarization-maintaining coupler.

4. Results

Linearity is an important consideration for FM to IM conversion. In order to test the linearity of the proposed demodulator, we first tune the unmodulated optical carrier at the crossover wavelength between two Bragg reflection peaks as shown on Fig. 3(a) and adjust the polarization such that a null is achieved at the output of BPD. After that tone modulation at 1 MHz is applied to the optical carrier through EOM. Fig. 3(b) shows the peak-to-peak voltage at the output of BPD as the FM modulation index at the input is increased. It can be seen from Fig. 3(b) that highly linear operation even for low FM modulation index is achieved. It is important to mention that the maximum value of FM modulation index for linear operation is only limited by the FWHM of FBG.

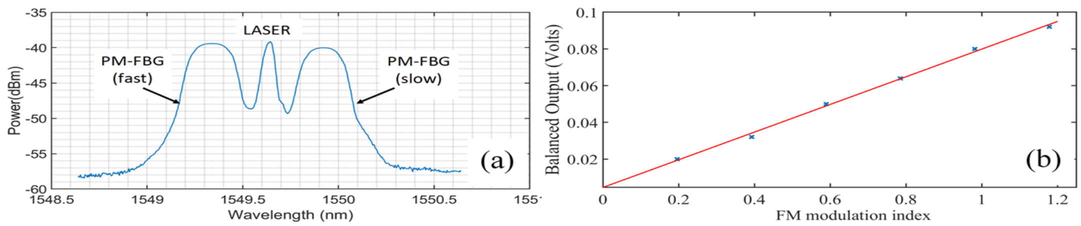

Fig 3: (a) Laser wavelength is tuned to the crossover point between the two PM-FBG Bragg peaks. The spectrum is measured by simultaneously coupling outputs from a mode-locked laser and the DL into the PM-FBG. (b) Measurements of peak-to-peak voltage at output of BPD as FM modulation index is increased (blue cross marks). Red line represents linear fitting.

Faithful recovery of an FM signal is another important aspect of an FM demodulator. Fig. 4 shows the result of the proposed scheme in demodulating an analog FM signal when optical carrier is tuned at crossover wavelength. Fig. 4(a) shows the trace of applied modulation to the optical carrier through EOM. The recovered signal at the output of BPD is shown in fig. 4(b). The recovered signal preserves the shape of input signal and contains all the features of input with very slight deviation. Note that the average voltage recovered signal is almost zero dictating zero dc-bias.

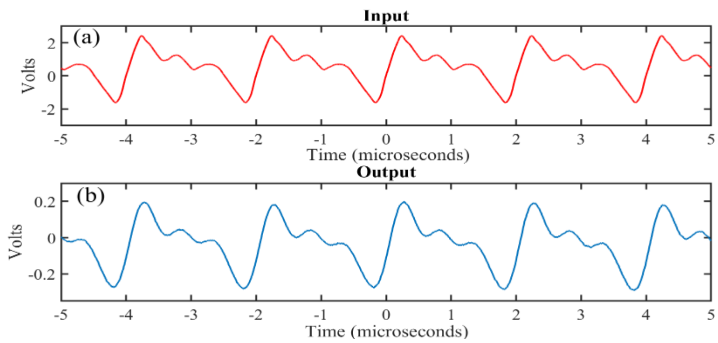

Fig 4. (a) Input to the EOM for modulating an optical carrier tuned at the crossover wavelength of PM-FBG. (b) Output of the BPD.

5. Conclusion

A new scheme for optical FM demodulation based on polarization-maintaining fiber Bragg grating is devised. Preliminary results of linear demodulation of optical FM is demonstrated. Faithful recovery of an arbitrary modulating signal is also shown. We hope to present more results at the conference.

6. References

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