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Citation	Wang, R., Tang, M., Zhang, H., Feng, Z., Lin, R., Fu, S., . . . Shum, P. P. (2014). Programmable Bandwidth-Variable Optical Temporal Differentiator Based on Linearly Chirped Fiber Bragg Grating and Digital Thermal Controller. Asia Communications and Photonics Conference 2014, ATh2C.3-. doi:10.1364/ACPC.2014.ATh2C.3
Date	2014
URL	http://hdl.handle.net/10220/46828
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Programmable Bandwidth-Variable Optical Temporal Differentiator Based on Linearly Chirped Fiber Bragg Grating and Digital Thermal Controller

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Abstract: We experimentally demonstrate an all-fiber structured bandwidth variable second-order optical temporal differentiator based on linearly chirped fiber Bragg grating and digital thermal controller. The bandwidth can be reconfigured from 0.55 nm to 0.8 nm.

OCIS codes: (230.2285) Fiber devices and optical amplifiers; (250.4745) Optical processing devices

1. Introduction

Optical signal processing could overcome the electronic bottleneck, the optical temporal differentiator (OTD) is one of the basic elements to provide real-time derivation in the all-optical domain [1]. The OTD is attracting lots of interests due to its potential wide applications in the future all-optical processing system.

In comparison with the first-order OTD, high order OTD could offer more complex temporal waveforms. Currently, OTDs can be mainly achieved by nonlinear effects of semiconductor optical amplifiers (SOAs) [2], silicon micro-ring resonators [3], fiber gratings [4, 5], etc. Among those methods, the fiber grating based OTDs have advantages of low insertion losses, and full compatibility with fiber optic systems. However, all previous fiber grating-based OTDs have fixed operation bandwidth, which is unfavorable for future optical communication.

Recently, we have proposed and experimentally demonstrated a wavelength-tunable second-order optical temporal differentiator [6]. The central frequency of the differentiation can be reconfigured from 192.141 to 192.616 THz. Nevertheless, the optical pulses signal are generated from a relatively low repetition rate mode-locked fiber laser and the bandwidth of the pulse is fixed. For real applications, an OTD with reconfigurability to meet various input pulse bandwidth will be desirable. In this paper, we experimentally demonstrate a programmable bandwidth-variable second-order optical temporal differentiator based on a linearly chirped fiber Bragg grating (LCFBG) and a digital controlled thermal print head (TPH). The relationship between the 3dB spectrum bandwidth of the input pulse and the OTD's operational bandwidth is experimental analyzed and verified. Optimized parameters of OTD are found to provide second order differentiation for arbitrary input pulse with the 3dB bandwidth 0.55 nm~0.8 nm.

2. Principle and System Configuration

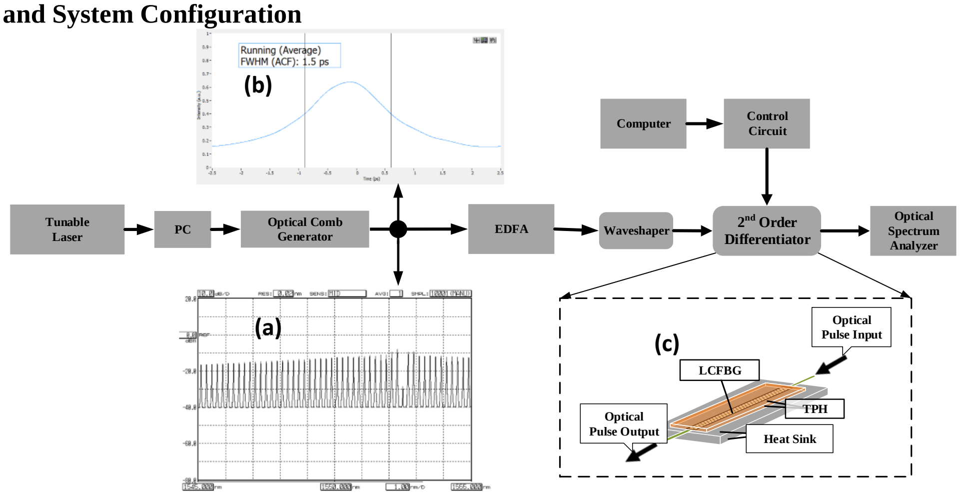


Fig. 1: Experimental setup of the 2nd order optical temporal differentiator, (a) optical comb generator output spectrum, (b) optical comb generator time-domain pulse waveform, (c) construction of the second-order differentiator

The spectra response of the ideal Nth-order differentiator is illustrated in Eq (1), where ω and ω_0 are the optical frequency variable and the central optical frequency, respectively. To implement the second-order (N=2) differentiator, it can be easily seen that only the optical signal's amplitude needs to be modified.

$$H_{diff}(\omega) = F(\omega)_{out} / F(\omega)_{in} = [j(\omega - \omega_0)]^N \tag{1}$$

Our experimental system to realize the second-order OTD is shown in Fig. 1. A tunable CW laser with line-width <100 kHz (IDPhotonics, CBDX4) acts as the laser source, the tunable frequency range is 1525.5 to 1556.5nm. Via a polarization controller (PC), the continuous wave laser source is connected with an optical comb generator (OCG) (OptoComb, WTAS-02) with a fixed repetition frequency is 25 GHz. Pico-second (around 1.5 ps) optical pulses with 25 GHz repetition rate are obtained after the OCG. The spectrum and the time-domain pulse waveform are shown in the inset (a) and (b) of Fig. 1. The time-domain pulse waveform is observed by autocorrelator (APE, Pulse-Check50). After an erbium-doped fiber amplifier (EDFA), we use a waveshaper (Finisar， Waveshaper1000s) to carve the spectrum of pulse generated by the OCG into a Gaussian-like pulse with variable spectrum bandwidth. It will serve as the input signal for our bandwidth variable second-order differentiator. Since the bandwidth of optical pulse under test is beyond the bandwidth of our photodetector and oscilloscope, an optical spectrum analyzer (OSA) (YOKOGAWA, AQ6370C) with the best resolution of 0.02 nm is used to monitor the output spectrum.

The block diagram of the second-order OTD is shown in the inset (c) of Fig. 1. A thermal print head (TPH) (Fujitsu, FTP628MCL701) is driven by our inhouse built controlled circuit. The TPH we used has a 48 mm long heating array that consists of 384 heating elements. The heating element spacing is 0.125mm, and each element can be heated independently. To implement the programmable spectrum response of second-order OTD, The TPH is fixed tightly to a linearly chirped fiber Bragg grating (LCFBG). By using the thermo-optic effect of the LCFBG together with TPH, we can realize a flexible bandwidth-variable optical spectrum filter [7] for different wavelength. When two separated local regions (9 elements respectively) are heated simultaneously with suitable widths (6 unheated elements), the notch between the two heated regions can be formed and it can be digitally adjusted until suitable for second-order optical temporal differentiation, as shown in Fig. 2. With different 3dB bandwidth of the incoming pulse, we can reconfigure the separation between two heated regions to modify the shape of the notch thus to find the optimized operation bandwidth of the second-order OTD, as inserted figure shows, the 3dB bandwidth is 0.8nm.

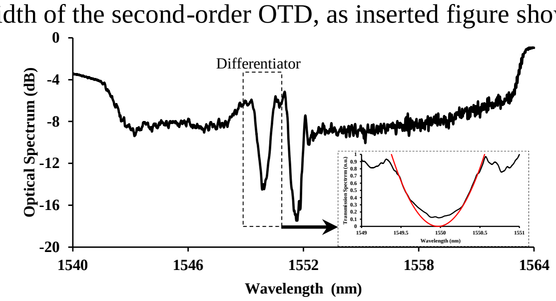


Fig.2: Transmission spectrum of the LCFBG and the local transmission spectrum (solid curve) compares with the ideal transmission function of the 2nd order differentiator (red curve).

3. Experimental Result and Analysis

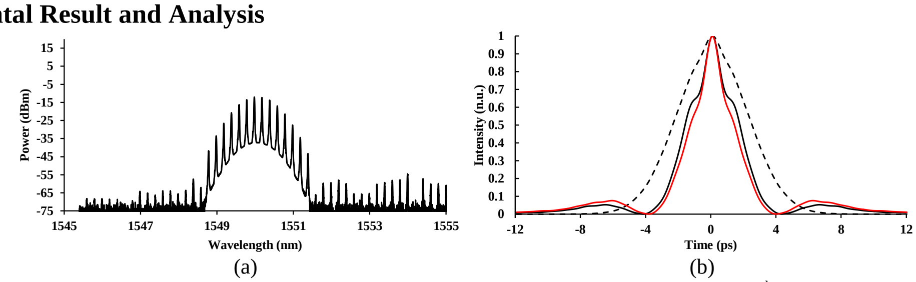
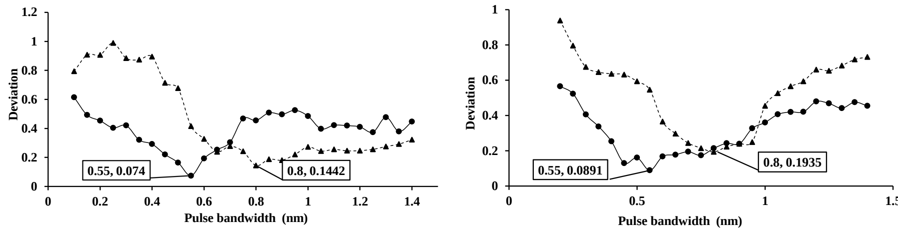


Fig.3 (a) Optical spectrum of the input signal and (b) Input and output time-domain waveform of the 2nd order optical differentiator. Input Gaussian-like pulse (dashed black curve), experimental (solid black curve) and ideal (red curve) output waveform of the 2nd order differentiator.

Fig. 3 (a) shows the output optical spectrum of the waveshaper when the central wavelength is 1550 nm and the 3dB spectrum bandwidth is 0.8 nm, as the input pulse signal for the second-order differentiator. With fixed central wavelength the 3dB spectrum bandwidth, we adjust the spacing between two heated regions from 3 elements to 15 elements to find the optimized second-order differentiator profile for the input pulse. We find that when the spacing is 6 elements, the deviation between the experimental time-domain differentiated pulse and the ideal second-order differentiation of the input pulse is minimized. Through inverse Fourier transform, the input optical pulse and output differentiated optical pulse in time domain can be obtained, as shown in Fig. 3 (b). The deviation is 0.1442.

To find the relationship between input pulse 3dB spectrum bandwidth and the differentiation deviation, we fixed the central wavelength at 1550 nm, adjust the input pulse 3dB spectrum bandwidth and the operation bandwidth of the second-order OTD simultaneously, the measured results as shown in Fig. 4 (a). It can be seen that the when the spacing between two heated regions is 6 elements, the optimized 3dB bandwidth of input pulse optical spectrum is 0.8 nm. When the spacing is 3 elements, the optimized 3dB bandwidth of input pulse optical spectrum is 0.55 nm when the deviation is minimized of 0.074.



(a) (b)

Fig.4 Relationship between 2^{nd} order differentiator deviation and the 3-dB bandwidth of the input pulse, the input pulse central wavelength is (a) 1550 nm (spacing between two heated regions is 3 elements for the dot and 6 for the triangle) (b) 1549nm (spacing is 4 and 7 elements)

To further investigate the performance of our second-order differentiator at different input pulse wavelength, we configure the central wavelength of the input Gaussian-like pulse at 1549 nm by adjusting the tunable laser and the waveshaper. The operation wavelength of the second-order OTD is simply adjusted by using computer software to shift the two heated regions along the TPH without moving any components. By controlling the number of unheated elements between two heating regions, from 1 element to 15 elements, the measured result indicates that the optimized separation is 4-elements for the input pulse with 0.55nm 3dB bandwidth and the deviation is 0.0891. On the other hand, 7-element was found for the input pulse with 0.8nm 3dB spectrum bandwidth and the deviation is 0.1935, as Fig. 4(b) shows. When the 3dB spectrum bandwidth of input pulse is between 0.55nm to 0.8nm, we can adjust the separation between two heated regions to acquire the optimized second-order differentiation result.

4. Conclusion

In this paper, we experimentally demonstrated a programmable all-fiber structured second-order optical temporal differentiator based on LCFBG and TPH. The operational bandwidth of the differentiator is programmable to realize the minimized differentiation deviation for incoming high speed optical pulses (25 GHz repetition rate) with the spectrum bandwidth 0.55 nm~0.8 nm. Meanwhile, the operation wavelength of the second-order differentiator can be easily configured. The relative larger deviation for shorter pulse-width (larger spectrum bandwidth) can be attributed to the imperfection of the LCFBG. It can be improved by using a better quality grating in our future work.

5. Acknowledge

This work is supported by the National High-tech R&D Program of China (863 Program) (Grant No. 2013AA013402), the National Natural Science Foundation of China (Grant No. 61331010, 61107087), the Fundamental Research Funds for the Central Universities', HUST: 2013TS052 and the Program for New Century Excellent Talents in University (NCET-13-0235). .

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