Fast photonic temporal differentiator based on fiber Mach-Zehnder interferometer

Radan Slavík and David Krčmařík
Institute of Photonics and Electronics AS CR, v.v.i.
CESNET a.l.e.
Prague, Czech Republic
slavik@ufe.cz

Yongwoo Park and José Azaña
Institut National de la Recherche Scientifique (INRS)
Montreal, Quebec, Canada
azana@emt.inrs.ca

***Abstract*—A novel configuration of all-fiber photonic differentiator optimized for tens-of-gigahertz processing speeds is suggested. This device covers the gap in terms of processing speeds between fiber Bragg grating based differentiator (< 20 GHz) and that based on long-period fiber gratings (>100-200 GHz).**

Keywords-optical pulse shaping, optical fiber filters, passive filters, gratings.

I. Introduction

Temporal differentiation is a fundamental signal processing functionality. Although this basic operation can be easily implemented in electric domain, all-optical temporal differentiators have been demonstrated only very recently [1-3].

A photonics temporal differentiator is essentially a linear optical filtering device providing a spectral transfer function of the form $H(\omega-\omega_0)=i(\omega-\omega_0)$, where ω is the optical frequency variable and ω_0 is the carrier optical frequency of the signals to be processed.

Differentiators were demonstrated using fiber Bragg gratings, FBG [2], uniform long-period fiber gratings, LPFGs [1], and bulk-optics based Michelson interferometers [3]. The required filtering characteristics are obtained around the resonance wavelength (wavelength at which the transmission reaches zero). Differentiators based on a phase-shifted FBGs were found to provide relatively limited bandwidth (typically <20 GHz), while differentiators based on uniform LPFGs operating in full coupling condition have bandwidth typically of >200 GHz. Although it is possible to process lower-bandwidth signals using the reported uniform LPFG-based differentiators, it would result in a very poor energetic efficiency (EE), as EE decreases quadratically with the signal bandwidth (maximum EE is thus reached when the signal bandwidth matches the maximum processing speed of a given differentiator). The processing window of ~20-200 GHz can be easily covered by a differentiator based on a 50/50 splitter-based Michelson interferometer operated around the destructive interference wavelength, however, it consists of a bulk-optics based components and generally require a feedback-loop for robust operation [4].

Here, we propose a new structure for all-fiber photonic differentiator that is based on two 50/50 splitters based fiber Mach-Zehnder (MZ) interferometer operated at the destructive interference point. The transfer function of such MZ is identical with that of the Michelson interferometer demonstrated earlier to operate as an optical differentiator. Besides demonstrating a new scheme we show that this scheme is particularly suitable for covering the tens-of-gigahertz processing speeds that were difficult to process with previous all-fiber implementations. Previously, we proved that the presented device is suitable for various pulse shaping functionalities like flat-top or parabolic-like pulse synthesis. However, for these functionalities, positive interference in the MZ was used, as opposed to destructive interference used for optical differentiation.

II. Principle of Operation and Prepared Differentiator Samples

The proposed device is based on a cascade of two LPFGs that form an imbalanced symmetric MZ interferometer, Fig. 1.

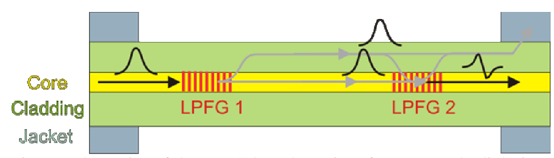

Fig. 1. Schematics of the LPFG-based MZ interferometer. The light is split by the first LPFG, then propagates in the core and cladding modes with different speeds and is superimposed coherently using the second LPFG.

The key in obtaining optical differentiation is a precise symmetry of the MZ interferometer in terms of the splitting ratios in order to obtain full destructive interference. The first LPFG couples 50% of light into a cladding mode. Subsequently, 50% of energy propagates in the cladding mode while the other 50% propagates in the core mode. The light propagating in the core mode accumulates (in respect to the cladding-propagating portion of the signal) a delay due to the difference in the effective refractive indices between the core and cladding modes. As both modes propagate within the same fiber and as the interferometer length is typically of the

This project was supported by the GA AS CR under contract KJB200670601 and Czech Science Foundation under contract 102/07/0999.

order of a few to tens of centimeters, any environmental change influences both modes in nearly the same manner, which results in a very robust device operation. Moreover, the performance of LPFGs is almost independent on the input polarization. Thus, the filter is very weakly polarization dependent.

We prepared various samples that yield MZ with spectral periods of 1.2-6.5 nm. The typical LPFG length was 5-15 mm, the LPFG separation 5-25 cm, the LPFG period of 490 μm (samples made in SMF-28 fiber) and 390 μm (samples made in SM980 (4.5/125) from FiberCore Inc.).

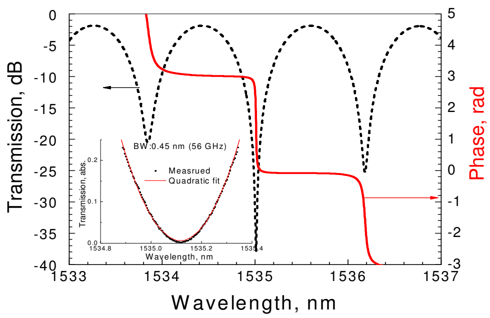

Fig. 2. Sample made in SM980 fiber; LPFGs are separated 25 cm and have 50 periods each. Inset: Measured and differentiator-required transmission. Differentiation bandwidth: 56 GHz.

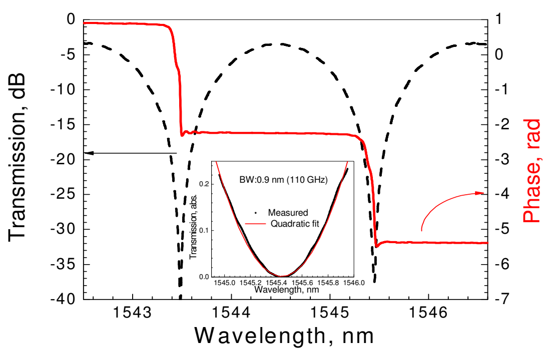

Fig. 3. Sample made in SM980 fiber; LPFGs are separated 16 cm and have 50 periods each. Inset: Measured and differentiator-required transmission. Differentiation bandwidth: 110 GHz.

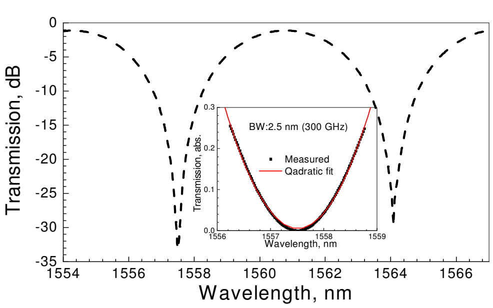

Fig. 4. Sample made in SMF-28 fiber; LPFGs are separated 10 cm and have 11 periods each. Inset: Measured and differentiator-required transmission. Differentiation bandwidth: 300 GHz.

III. Results

For a proof-of-principle experiment, we chose the 300-GHz differentiator, as the available source (mode-locked fiber laser) emits pulses of 2.5 ps temporal FWHM corresponding to spectral full bandwidth (taken at 10% of the peak intensity) of 300 GHz. This pulse was subsequently propagated through our MZ filter. To obtain amplitude and phase of the output signal, we used a fiber-based Fourier-transform spectral interferometry setup (in this setup, the input pulse was used as the reference pulse) [5]. The result is shown in Fig. 5. The π-phase jump between the two lobes of the output waveform expected theoretically was clearly observed.

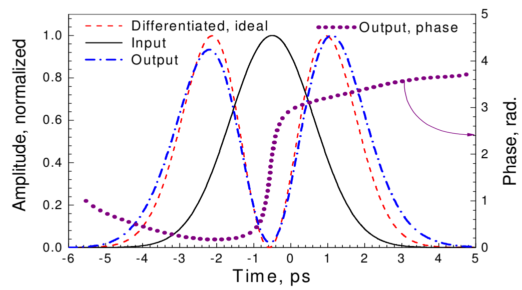

Fig. 5. Temporal characteristics – input pulse, output pulse and ideal differentiation of the considered input pulse.

IV. Conclusions

We demonstrated a new configuration for photonic differentiation that is based on all-fiber technology. The demonstrated devices have processing bandwidths of 56, 110, and 300 GHz, covering the tens-of-gigahertz window, which was not reported so far. In the proof-of-principle experiment, 2.5-ps pulses are successfully processed with the 300 GHz device. In the near future, we plan to characterize also the 56 and 110-GHz differentiators – results will be presented at the conference.

References

[1] R. Slavík, Y. Park, M. Kulishov, R. Morandotti, and J. Azaña, "Ultrafast all-optical differentiators ," Opt. Express **14**, 10699-10707 (2006).

[2] N. K. Berger, B. Levit, B. Fischer, M. Kulishov, D.V. Plant, and J. Azaña, "Temporal differentiation of optical signals using a phase-shifted fiber Bragg grating," Opt. Express **15**, 371-381 (2007).

[3] Y. Park, J. Azaña, and R. Slavík, Ultrafast all-optical first and higher-order differentiators based on interferometers, Optics Letters **32**, 710-713 (2007).

[4] Y. Park, T.-J. Ahn, and J. Azaña, "Stabilization of a fiber-optic two-arm interferometer for ultra-short pulse signal processing applications," Appl. Opt. **47**, 417-421 (2008).

[5] Y. Park, F. Li, and J. Azaña, "Characterization and optimization of optical pulse differentiation using spectral interferometry," IEEE Photon. Technol. Lett. **18**, 1798-1800 (2006).