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Temporal Talbot Effect in Birefringent Optical Filters for Multiplying Pulse Repetition Rates

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Summary: We propose a pulse rate multiplier based on the temporal Talbot effect using a phase-only birefringent optical filter. The Opto-geometrical parameters of the filter are obtained by an optimization algorithm to achieve the desired spectral response. Preliminary results show excellent agreement with those anticipated by theory.

Keywords: Periodic quadratic phase birefringent filter, Temporal Talbot effect, Pulse repetition rate multiplication.

1. Introduction

Since the first description in 1981 by T. Jansson and J. Jansson [1] of the temporal Talbot effect (TTE) by propagating a temporal pulse train in the first-order dispersion approximation, this phenomenon has become attractive in various applications, such as sub-harmonic clock recovery, optical passive amplification and optical real-time discrete Fourier transformer [2-4]. Besides these applications, pulse repetition rate multiplication (PRRM) techniques induced by TTE have drawn attention throughout the years, because of their simple all-passive realization, with much lower complexity than other PRRM methods. Most importantly, this technique depends on a phase-only filtering process, which can conserve most energy spectrum available from the input signal [5].

In this work, for the first time to the best of our knowledge, we present a new type of pulse repetition rate multiplier based on TTE using birefringent optical filters, which naturally have a periodic quadratic phase and a flattened transmittance. An optimization algorithm is used to determine the Opto-geometrical parameters of the filter. Preliminary results show extremely high fidelity in multiplying a 10 GHz input pulse rate by a factor m without affecting the individual pulse characteristics.

2. Filter design, results and discussion

When a periodic train of optical pulses with a repetition period T_{rep} (or equivalently f_{rep} is the frequency repetition rate), propagate through a continuous quadratic phase filter satisfying the temporal Talbot condition,

$$\ddot{\Phi} = \frac{s}{m} \frac{T_{rep}^2}{2\pi} \quad (1)$$

with s and m are mutually prime integer numbers and

$\ddot{\Phi}$ is the first-order dispersion coefficient, a copy of the original temporal sequence reappears but with a frequency repetition rate multiplied by a factor m [6]. It's worth noting that the TTE may be achieved with periodic phase filtering as well [7]. This property allows us to take advantage of the periodic nature of the transfer function of the birefringent optical filter. Specifically, our filter should have a free spectral range (FSR) of $m \cdot f_{rep}$, a first-order dispersion coefficient satisfying the TTE condition given by Eq. (1) for each period, and a flattened transmittance.

Fig. 1 illustrates the proposed design of the N -stages birefringent phase filter. The filter consists of N -hybrid stages placed between an input polarizer (P) parallel to the laboratory x -axis and an analyzer (A) oriented at an angle φ_p . Each stage is composed of a birefringent plate (BP) as the identical section associated with a liquid-crystal cell (LCC) as the variable section [8]. The slow (S) and fast (F) axes of each section are parallel to each other and orientated at an angle φ_i ($i = 1, 2, \dots, N$).

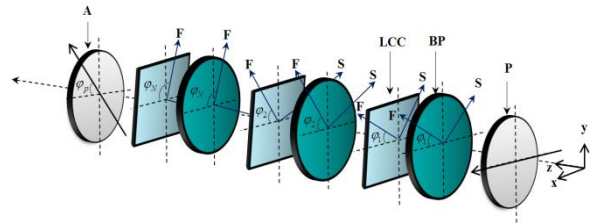


Fig. 1. The configuration of the N -stages birefringent periodic phase filter.

Assuming we have a periodic sequence of Gaussian laser pulses with a repetition period $T_{rep} = 100$ ps, ($f_{rep} = 10$ GHz), each pulse has an FWHM pulse duration of 5 ps. We design a birefringent filter to increase this repetition rate by a factor of $m = 4$

(with $s = 1$) to generate a pulse train with a frequency repetition rate of $f_{rep} = 40$ GHz. Referring to the procedure shown in our previous work [8], and relying on optimization algorithms, for instance, the Genetic Algorithm, the absolute angles and the phase shifts introduced by the LCCs for each stage have to be determined. For our case of $m = 4$, 12 stages-filter of Rutile (Titanium dioxide, TiO₂) birefringent plates having a birefringence of 0.25 at $\lambda = 1550$ nm associated with liquid crystal cells (LCC) are required.

The results obtained for the amplitude and phase responses of the proposed filter with the input and output pulse train are depicted in Fig. 2. As shown in Fig. (2a), the amplitude response has a flattened transmittance with a negligible normalized power loss of 0.08 and a peak-to-peak amplitude ripple of 0.08. Fig. (2b) shows the periodic quadratic phase with an FSR of $m \cdot f_{rep}$ (40 GHz) and a first-order dispersion coefficient $\ddot{\Phi} = 397.8874\text{ps}^2$.

Fig. (2c) represents the normalized temporal intensity for the input and output Gaussian pulse train before and after propagating through the birefringent optical filter. As predicted by theory, the output pulse train is a distortionless replica of the input pulse train in terms of shape and FWHM pulse duration of 5 ps, but with four times the original frequency repetition rate and a perfect 1/4 less intensity.

Since the FSR depends upon the factor m , and in order to obtain higher multiplication factors, more stages are needed to cover the entire operation bandwidth and ensure high-fidelity results with minimal errors.

3. Conclusions

In this work, we have demonstrated, for the first time to the best of our knowledge, a pulse repetition rate multiplier based on TTE using a birefringent optical filter. The filter has a periodic quadratic phase and a flattened transmittance. An optimization

algorithm is used to determine the Opto-geometrical parameters of the 12-stages filter. Preliminary results show extremely high fidelity in multiplying a 10 GHz input pulse rate by a factor $m = 4$ to achieve an output pulse train of 40 GHz without affecting the individual pulse characteristics.

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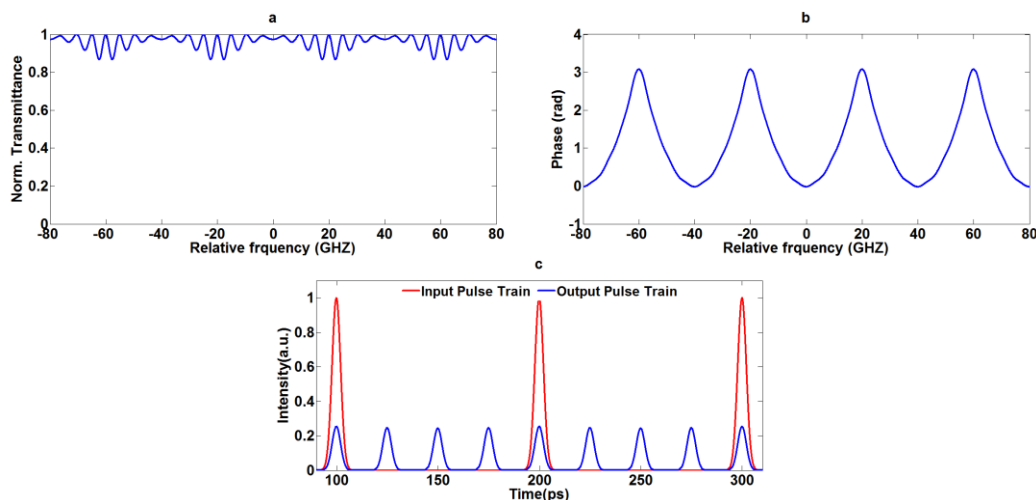


Fig. 2. PRRM by the designed 12-stages birefringent filter. (a) Amplitude response (b) Phase response (c) The output pulse train with a multiplication factor of $m = 4$. The frequency repetition rate of the input pulse train is 10 GHz. The frequency repetition rate of the output pulse train is 40 GHz.