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Measuring ultrafast vector pulses with amplitude swing

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Abstract: The amplitude swing technique is demonstrated theoretically and experimentally to measure time-varying polarization ultrashort laser pulses, using a simple setup. The reconstruction strategy extracts all the vector pulse information from a single trace measurement.

Ultrafast laser pulses interest is continuously increasing, simultaneously with a growth in their complexity. In consequence, the development of new characterization techniques and experimental implementations has been a subject of interest over the last decades. In particular, ultrafast vector laser pulses, which exhibit time-dependent polarization, are demanded in many technological and scientific fields, as material science, attoscience, or biotechnology. These applications can benefit versatile techniques adaptable to multiple experimental conditions. Recently, the technique amplitude swing (a-swing) was demonstrated for characterizing scalar pulses [1]. It presents a robust and compact inline set-up (Fig. 1), with typical optical elements, and it can operate at different pulse chirps and durations, spectral bandwidths, and spectral regions [2], as well as exhibiting a marked resilience to experimental noise [3].

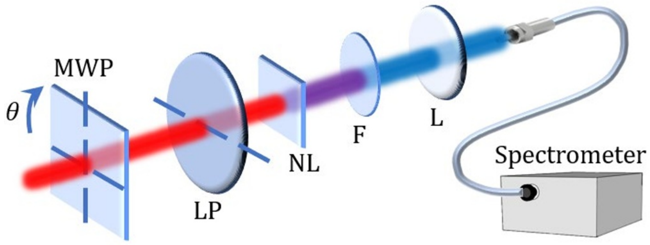

Fig. 1. Experimental a-swing setup: rotating multiple-order waveplate (MWP), linear polarizer (LP), nonlinear crystal (NL), filter (F) to remove the remnant fundamental signal, and convergent lens (L) to enhance the detected signal by the fiber-coupled spectrometer.

Here, it is proven the a-swing capability to characterize time-varying polarization pulses [4], showing that the implementation simplicity is kept. Firstly, we analytically examine how the information of the vector pulse is codified in the a-swing trace, identifying the terms of the nonlinear signal with their corresponding information. In these types of techniques, called spectrographic, the extraction of the pulse information cannot be analytical, and needs the use of an iterative algorithm. Benefiting from the previous analytical analysis, we design a dedicated reconstruction strategy to extract the phases of two polarization projections, including their relative phase, thus the vector pulse is fully characterized. This strategy performs several optimizations by using the Levenberg-Marquardt algorithm (any other could be used in principle) to minimize a merit function, which is the difference between the experimental and simulated traces. In a first stage, this strategy was validated by reconstructing a-swing simulated traces of different vector pulses, observing that the reconstructed vector pulses highly agree with the simulated pulses.

Subsequently, the technique was experimentally tested with the conventional a-swing implementation (Fig. 1.). The vector pulse to be measured propagates through a rotating multiple-order waveplate (MWP), where each polarization component is split into two delayed replicas corresponding to the MWP neutral axes projections. These four replicas, whose amplitude modulation is achieved with the MWP rotation, are projected to a common polarization direction by the following horizontal linear polarizer. The resulting interference pulse then produces a nonlinear signal, in this case second-harmonic generation in a nonlinear crystal (BBO). The spectrum of this signal (the remaining fundamental signal is filtered out) is measured for each MWP angle, obtaining a 2D a-swing trace. In this experiment, prior to the a-swing setup, the vector pulses to be measured are generated by propagating linearly polarized laser pulses by an accurately calibrated retarder plate (Fig. 2). These scalar input pulses, whose Fourier-limited duration is ~60 fs, were measured with a scalar characterization method, and, since the retarder plate is also characterized, the vector pulses to be measured were known. Thus, the subsequent a-swing retrievals can be validated by comparing with these known pulses. We repeated this process with different input pulses and retarder plates, i.e., producing diverse vector pulses.

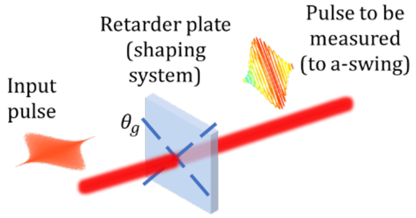

Figure 2. Scheme of the vector shaping system, which consists of a retarder plate.

Fig. 3 shows the results obtained with a vector pulse generated with a 5-mm quartz retarder plate, oriented at 45° with respect to the polarization direction of the input scalar pulse. The resultant vector pulse polarization components are highly temporally delayed, so the temporal overlap between them is small. The agreement between the simulated and retrieved pulses is high in all the analyzed cases, proving the capability of a-swing to work in vector pulse operation mode. Furthermore, the advantages of the scalar a-swing are maintained, since the setup is the same: easy adaptability to measure across a wide spectral region, pulse durations ranges, and robustness against experimental noise.

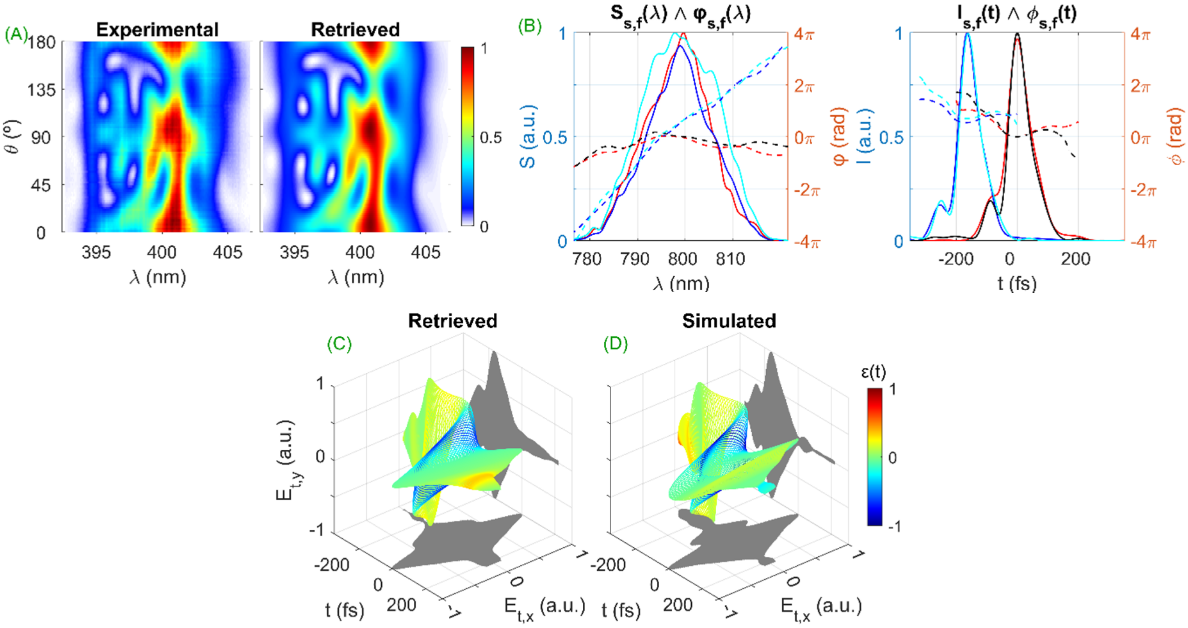

Fig. 3. (A) Experimental and retrieved a-swing traces; (B) experimental spectra and reconstructed and simulated phases in the spectral (left) and temporal (right) domains of two polarization components; (C) reconstructed and (D) simulated vector pulses in temporal domain, presenting the electric field components (E_x, E_y) evolution on time. In (B): red: retrieved E_x; blue: retrieved E_y; black: simulated E_x; cyan: simulated E_y. The simulated horizontal and vertical spectra are equal. The color scale in (C, D) indicates the ellipticity, being -1 and +1 left- and right-handed circular polarization, respectively, and 0 linear polarization.

In conclusion, we have comprehensively characterized the time-dependent polarization state of ultrafast pulses with a-swing, demonstrating both theoretically and experimentally its capability to measure vector pulses. A single a-swing trace codifies all the necessary information to reconstruct a vector pulse, which is effectively extracted by an upgraded retrieval algorithm. We hope it can benefit the progress in the field of ultrashort vector pulses and their multiple applications.

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