Simple, Complete Characterization of Ultrafast Optical Pulse by Phase-Preservation Autocorrelation

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We present a novel nonlinear interferometric autocorrelation technique with unbalanced intensity, which preserves spectral phase information in the autocorrelation signal and enables the complete characterization of ultrafast optical fields without requiring any spectrally resolved measurements.

Nonlinear autocorrelation was one of the earliest and simplest tools for obtaining partial temporal information about an ultrashort optical pulse by gating it with itself. However, since the spectral phase is lost in a conventional autocorrelation measurement, it is insufficient for a full characterization of an ultrafast electric field. Thus, modern optical pulse metrology methods, such as frequency-resolved optical gating (FROG), require additional spectral information for phase retrieval. Besides adding experimental complexity, the requirement for spectroscopic measurements renders non-radiative optical fields, such as ultrafast plasmonic near-fields at metallic nanostructures, inaccessible to these methods, while a spectrally integrated autocorrelation can be easily obtained *via* nonlinear photoemission. Here, we present Phase-Enabled Nonlinear Gating with Unbalanced Intensity (PENGUIN), a novel technique for complete optical field retrieval from a nonlinear interferometric autocorrelation (IAC) signal alone without the need for spectral measurements, and validate it experimentally by comparison with the well-established FROG method.

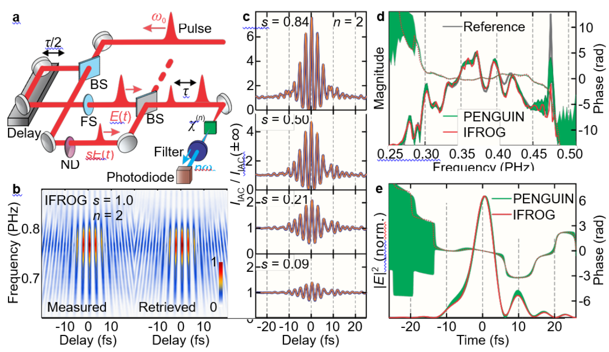

Figure 1: (a) Unbalanced Mach-Zehnder interferometer used for nth-order nonlinear IAC. ND: neutraldensity filter, BS: beam splitter, FS: fused silica plate for dispersion matching, $\chi^{(n)}$: nonlinear medium. (b) Measured (left) and retrieved (right) balanced IFROG spectrograms ($s = 1$). (c) Measured (dark blue) and retrieved (orange) IAC traces for various balance factors s using the PENGUIN technique. (d) Retrieved fields in the frequency domain for the IFROG measurement (red) and a series of PENGUIN measurements with balance factors between $s = 0.21$ and $s = 0.84$ bounded by the green bands. Magnitudes are shown as solid lines and phases as dotted lines. The independently measured fundamental spectral magnitude is shown in gray for reference. (e) Time-domain representation of the retrieved fields in (d) showing the intensity envelopes (solid lines) and temporal phases (dotted lines) with the linear part ($\omega_0 t$) subtracted

In order to validate the new PENGUIN technique, we performed a series of unbalanced-intensity IAC measurements with a varying balance factor s using few-cycle Ti:sapphire oscillator pulses and a 10 μm thin β-BaB_2O_4 crystal for second-order harmonic generation ($n = 2$). In addition, a balanced ($s = 1$) measurement was performed with a spectrally resolved detector for field retrieval with the interferometric FROG (IFROG) method, as shown in Fig. 1b. The spectrally integrated PENGUIN results for a large range of balance factors are shown in Fig. 1c. Both field retrieval methods are in excellent agreement with each other and with the independently measured laser spectrum (Fig. 1d-e), yielding a ∼6.4 fs pulse duration, which serves as a validation of our novel technique.