Statistical Noise in Isolated Attosecond Pulse Retrieval

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Synopsis: Measurement of single isolated attosecond pulses suffers from low photoelectron counts in the streaked spectrogram, and is thus susceptible to shot noise. We show that the reconstructed spectrogram and attosecond pulse depend on the number of photoelectron counts at the peak of the spectrogram, and find that spectrograms with a peak count number of 50 or more can be reconstructed accurately.

Attosecond pulses can be reconstructed from a streaked photoelectron spectrogram using the CRAB (complete reconstruction of attosecond bursts) technique [1]. CRAB traces, unlike their optical FROG counterparts, suffer from low count numbers in the spectrogram. When the photon flux [2], photoabsorption probability, and efficiency of the optics and detector are considered, the number of photoelectrons detected is limited to ~1 per laser shot [3]. Maintaining high power carrier-envelope (CE) phase stabilized laser pulses over a long enough period to obtain enough counts such that shot noise is negligible is currently unachievable, and it is thus necessary to determine how many photoelectron counts are needed for accurate reconstruction of the attosecond pulse.

CRAB traces in the presence of shot noise were simulated [3]. The attosecond pulse was assumed to have a spectrum supporting a 90 as transform-limited pulse, and a linear chirp of 5000 as^2 was added. The streaking laser pulse was assumed to be 5 fs in duration with a peak intensity of 10^{12} W/cm^2. The retrieval was performed using a blind iterative algorithm.

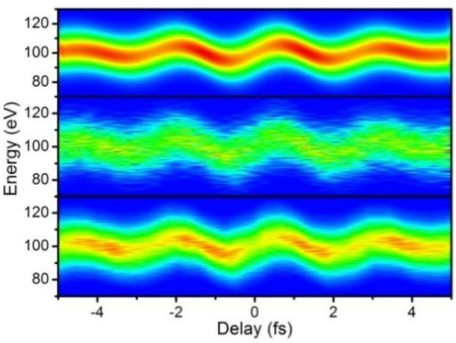

Fig. 1. Simulated CRAB traces with no noise added (top) and with shot noise (middle). Retrieved trace (bottom)

Figure 1 shows the results of the retrieval for the case when the photoelectron count at the peak of the spectrogram was 50. Clearly, the retrieved trace in Figure 1(c) matches the features of the noise-free trace in 1(a) more than the noisy trace shown in 1(b), which was given to the algorithm. In fact, for peak count numbers above 50, we found that the pulse duration and linear chirp could be retrieved within 5% of their actual values when the streaking intensity was greater than 5×10^{11}.

To further test the pulse retrieval with CRAB, experimental streaking data was used [4]. Because our data acquisition system saves the photoelectron energy spectrum recorded for each laser shot, we are easily able to select only a sample of data taken within a given time frame. By analyzing the data only from selected laser shots, we can observe what the resulting CRAB trace would be for accumulation times smaller than those used in the experiments. We found that all retrieved pulse durations for accumulation times of 4 seconds per delay step (corresponding to roughly 80 or more counts) and larger were within 5% of 141 as [3].

We have shown that shot noise has little effect on the retrieval of single attosecond pulses for traces with at least 50 photoelectron counts at the peak of the spectrogram. Such a result is significant as it suggests a lower limit to the number of counts necessary for CRAB retrieval. Due to the difficulty of maintaining CE phase stabilized laser pulses over a long period of time, this makes measurement of single attosecond pulses more accessible to laboratories without state-of-the-art lasers.

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References

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