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Gauging pulse train instability and coherent artifacts with dispersion scan

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The stability of an optical pulse train is always an implicit assumption in multi-shot pulse characterization techniques, and in most cases this is a reasonable assumption. Yet, when the pulse train involved is unstable, some pulse characterization techniques fail to detect this problem and may only see a coherent artifact, leading to an erroneous underestimation of the pulse length. In particular, in the context of mode-locked semiconductor lasers, there are numerous questionable reports of allegedly mode-locked lasers without a clearly identified mode-locking mechanism. Currently no method is known to undisputably measure the degree of instability. Nevertheless, at least some of the more advanced pulse characterization techniques allow an identification of unstable operation under certain circumstances [1, 2].

Our newly suggested method builds on the dispersion scan (d-scan) technique, which is recently gaining attraction for being able to measure pulses in the single-cycle regime with a very simple collinear measurement setup [3]. The d-scan trace is a two-dimensional map of the nonlinear spectrum measured as a function of dispersion. Measuring a d-scan trace does not require splitting of the beam and can use tight focusing on the nonlinear medium, thus allowing the measurement of weak pulses. Similar to frequency-resolved optical gating (FROG), d-scan also requires the use of a retrieval algorithm to extract the pulse characteristics from the trace. While single-shot configurations for d-scan also exists [4], they cannot be applied to weaker pulses, e.g., from semiconductor lasers. The common d-scan configuration involves the averaging of multiple shots; hence it also appears vulnerable to the problem of the coherent artifact.

In order to study the influence of a coherent artifact, we performed an extensive numerical study for second harmonic generation (SHG) d-scan, using multiple sets of numerically-generated pulse trains with varying degrees of instability. It is shown that similar to FROG, d-scan is also perfectly able to detect the presence of pulse instabilities due to the noticeable mismatch between the recorded and the retrieved traces. Here we go a decisive step beyond and modify the retrieval algorithm for being able to simultaneously gauge the instability of the pulse train. Following a similar method as was suggested as the self-calibrating d-scan technique [5], the amount of dispersion used for recording the trace can be retrieved by the algorithm. In the presence of pulse instabilities, the retrieved dispersion deviates from the expected one. This deviation is shown to be correlated to the degree of instability, thus allowing the measurement of the pulse train's complexity. The ability to not only detect but also measure pulse instabilities greatly expands the potential applications of d-scan as a pulse characterization technique. We further believe that our method will enable to finally resolve the issue of self-mode-locked semiconductor lasers and other questionable reports of femtosecond pulse generation.

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