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Recent progress in carrier-envelope phase stabilization: towards zeptosecond timing jitters

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Carrier-envelope phase (CEP) stabilization of lasers plays an integral part for precision frequency metrology and attosecond spectroscopy. Ultimately, CEP stabilization schemes rely on a phase-locked loop. Considering that optical frequencies are in the hundreds of terahertz range, with carrier oscillation periods of a few femtoseconds, one would typically expect to see timing jitters in the sub-attosecond ($<10^{-18}$ s) regime, which are equivalent to phase jitters of a milliradian. However, all demonstrations of CEP control have performed far worse, and residual phase jitters of 10 milliradian are already considered heroic.

The question therefore arises why it is so much more difficult to stabilize and synthesize optical frequencies compared to their microwave counterparts at thousand times lower frequencies. The answer to this question seems to be twofold: first, microwave frequency synthesis heavily relies on frequency division, i.e., an operation that is not easily implemented in optics. Therefore, one has to resort to spectral supercontinuum generation to generate broadband spectra that contain frequency components at suitable integer ratios. And this process comes with a caveat as the coherence between widely separated spectral components is easily lost [1]. A second problem of the optical PLL is the absence of gain in optical schemes. While conversion losses in electronics can be readily overcome by using transistor based amplifiers, there is no practical optical transistor available.

Here we discuss new approaches to tackle this problem [2]. It is shown that the inclusion of laser gain in the optical PLL substantially improves the signal-to-noise ratio in the beat note detection. In turn, we have been able to reduce the phase noise in the CEP stabilization substantially, with equivalent timing jitters down to 3 attoseconds. To the best of our knowledge, this constitutes the best timing stabilization ever reported to date. While we certainly agree that optical PLLs will never reach the performance of their microwave counterparts, we do think that there is reason to believe that all-optical frequency synthesis can be very much improved if the two problems of the lack of optical dividers and transistors can be suitably circumvented.

References

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