Generalized Ramsey Methods in Precision Laser Spectroscopy: from Atomic Clocks to Interferometers

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Atomic clocks are based on high-precision laser spectroscopy of isolated quantum systems and are currently the most precise scientific instruments. Fractional frequency instabilities and accuracies at the level of 10^{-18} have already been achieved, with the goal of 10^{-19} on the horizon. Frequency measurements at such a level could enable new tests of quantum electrodynamics and cosmological models, searches for drifts of fundamental constants, and new types of chronometric geodesy.

For many atomic and ionic systems promising for development of high-accuracy optical clocks a key limitation is the frequency shifts due to the probe field itself, whose frequency is stabilized and is a reference point for atomic clocks. In particular, for ultra-narrow transitions (for example, for electro-octupole and two-photon transitions), the non-resonant Stark shift can be so large that achieving high accuracy and stability is almost impossible. For magnetically induced spectroscopy, field shifts (Stark and quadratic Zeeman shifts) can ultimately limit the attainable metrological characteristics. A similar restriction also exists for atomic clocks based on the direct use of the “frequency comb” (direct frequency-comb spectroscopy), due to Stark shifts induced by a huge number of non-resonant laser modes. In addition to optical frequency standards, the problem of field shifts is also critical for microwave frequency clocks based on the effect of coherent population trapping (CPT).

Over the past decade, significant progress has been made in solving these problems with the use of Ramsey spectroscopy methods. Unlike continuous-wave spectroscopy, the pulsed Ramsey spectroscopy has a large number of additional and well-controlled parameters (such as the durations of Ramsey pulses t1 and t2, the time of free evolution T, the “phase composition” of Ramsey pulses, etc.), by manipulating these parameters it is possible to solve various spectroscopic problems. The development of Ramsey field-suppression schemes in optical frequency standards began in, where the hyper-Ramsey spectroscopy method was proposed using so-called composite pulses. Soon this method was successful experimentally confirmed.

This report provides an overview of methods for suppressing field shifts in atomic clocks using various generalized Ramsey schemes. It turns out, that some methods are so universal that they can be successfully used both in optical clocks and in microwave frequency clocks based on the CPT effect, as well as in atom interferometers.

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