Ultra-low Phase Noise Frequency Synthesis for Optical Atomic Frequency Standards

D. A. Howe, A. Hati, C. W. Nelson
Time & Frequency Division, National Institute of Standards and Technology, Boulder, CO/USA
Email: dhowe@nist.gov

This paper discusses frequency synthesizer needs that are consistent with new high-accuracy optical atomic standards. Optical atomic standards achieve extremely low frequency uncertainty in only hundreds of minutes due to their unprecedented levels of phase stability and accuracy. Days are ordinarily required for laboratory Cs standards. Stabilization by a hi-Q cavity of an optical frequency comb effectively divides an optical atomic transition frequency and so also divides the intrinsically low optical phase noise down to a usable radio signal. This provides exciting opportunities and formidable challenges to metrologists faced with synthesizing frequencies for direct measurements of these new breeds of ultra-low phase noise (ULPN) signals from atomic standards.

Applications are presented that need ULPN fast-accuracy oscillators in the radio frequency (RF) range of 5 MHz to a few GHz. Techniques for cavity-stabilized optical-frequency division (OFD) to attain RF ULPN are reviewed. For several in-the-field applications, we address how and why accurate ULPN oscillators mitigate problems in the following areas: (a) the synchronization segment, (b) the effect of lag time, and (c) the limitations due to phase noise and frequency uncertainty. We present recent research and measurements at NIST of a chain of ULPN regenerative dividers whose input is a cavity-stabilized OFD and whose end output at 5 MHz has a phase noise of L(1 Hz) = -150 dBc/Hz. Importantly, this chain provides cascading intermediate, exceptionally low-noise frequencies suitable for synthesizing many ULPN signals at convenient RF and microwave frequencies. We outline current status and recent trends in size/weight/power of generating ULPN RF signals. We discuss pitfalls recently found in two-channel cross-correlation measurements that are needed to accurately make measurements of cavity-stabilized optical oscillators used in not only optical atomic standards but also other traditional devices that produce signals at RF. We also add the necessity and challenge of accurately measuring the vibration sensitivity of ULPN standards at required in-the-field levels below 10-11 /g at certain vibration frequencies. The paper concludes with a derivation showing that, for the lowest frequency uncertainty, ULPN frequency standards (atomic or cavity-stabilized) should be characterized by flicker-FM frequency stability, as determined by Allan deviation (ADEV) or more efficient statistics such as Total or Theo, over the widest possible range of averaging times.