Precision Metrology with Coherent Dual Frequency Combs

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Frequency combs have enabled a wide range of applications because of their unique combination of coherence and broad bandwidth. The comb provides 100,000's of comb teeth at precise, well-known optical frequencies that can support broadband accurate spectroscopy or multi-wavelength interfometric ranging. However, the full advantages of the comb can be realized as a source for these and other applications only with a matched detection approach. In other words, the detection must fully resolve each individual transmitted comb tooth. It is possible to achieve this tooth-by-tooth detection through multi-heterodyne interference against a second, or dual, coherent frequency comb [1, 2].

Dual comb systems for spectroscopy have been pursued for several years now in different implementations [1-7]. When implemented with fully coherent frequency combs over sufficiently long integration times, dual comb spectroscopy enables measurements of the absorbance and phase spectra from a gas with a resolution limited only by the comb teeth linewidth (and any system nonlinearities), yielding a frequency accuracy and precision far in excess of conventional FTIR systems and a bandwidth far in excess of tunable laser spectrometers [1, 3, 6, 7]. In our recent work, we have moved beyond the 1550-nm region to demonstrate coherent dual-comb spectroscopy over much broader near-infrared spectra and even into the mid-infrared [3, 7, 8]. Figure 1 shows the setup and an example spectrum acquired over the near infrared. This system has enabled precise and accurate line-center measurements of methane, acetylene and water. In the future, coherent dual-comb spectroscopy is promising for very precise, accurate and broadband lineshape measurements, which can support accurate measurements of trace gas concentrations in air.

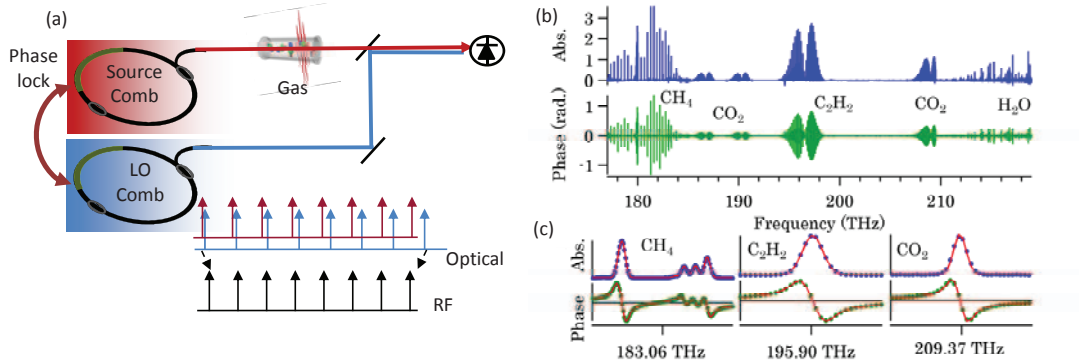


Fig. 1 (a) Setup for spectroscopy based on two coherent frequency combs. Interference between the two combs in the frequency domain results in a comb in the rf domain that has a one-to-one mapping back to the optical comb teeth. (b) Broadband amplitude (blue) and phase (green) spectra across 400,000 combs lines at 100 MHz spacing and kHz-level accuracy. (c) Expanded view of the fit (red line) to phase and absorbance of individual lines.

This basic approach of coherent detection of one comb via a second comb can be applied to other applications as well, such as ranging or free-space frequency-time transfer. In these applications, a time domain picture is more apt as the goal is precise and accurate measurements of the time-of-arrival of the incoming pulses from the source comb. We have demonstrated time-of-arrival measurements at the femtosecond level. When implemented with a two-way geometry, this system should allow for free-space time-frequency transfer between the next generation of optical atomic clocks at accuracies or 10^{-18} and below [9].

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