Fiber Frequency Combs and Some Precision Measurement Applications

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Abstract: We discuss highly coherent fiber-based frequency combs and some of their applications to precision measurements in optical metrology, ranging, and spectroscopy.

Fiber-frequency combs work on the same principles as the original solid-state frequency combs [1, 2]. They take advantage of the fact that the output pulse train from a passively mode-locked laser forms a comb of lines in frequency space. By stabilizing only two degrees of freedom of this comb to a single microwave or optical reference, the entire frequency comb is stabilized with a frequency accuracy directly set by the underlying reference. If the comb is locked sufficiently tightly, then the comb lines can have very little (< 1 rad) phase noise with respect to an underlying optical reference and are, in that sense, highly coherent [3, 4]. Frequency combs were originally developed as an elegant solution to measuring the optical frequencies of optical clocks [1, 2, 5]. In addition, it is interesting to apply these broadband, coherent, highly accurate sources to other precision measurement problems.

One interesting setup that exploits the comb's broadband coherent output uses two coherent, phase-locked combs. One comb serves to interrogate a system, and the second serves as a Local Oscillator (LO) to measure the resulting signal. This system is exactly analogous to a cw laser heterodyne system except that instead of a single frequency, a comb of frequency lines is transmitted and detected. In the time domain, the system is equivalent to a very accurate time-domain optical sampling setup where the LO pulse train samples the returning signal pulse electric field. We have demonstrated that such a system can precisely measure absolute distance at long range and at a reasonably high update rate [6]. This dual-comb system can also provide very high accuracy, phase-coherent spectroscopic measurement of a sample [7, 8] with a frequency accuracy limited only by the reference underlying the combs. In contrast to normal absorption spectroscopy, this signal contains both the phase and amplitude of the absorption. Therefore, the signal can be inverse Fourier transformed to yield the time-domain signal, which is exactly the free-induction decay of the molecules after excitation by the incident pulse. (See Fig. 1.)

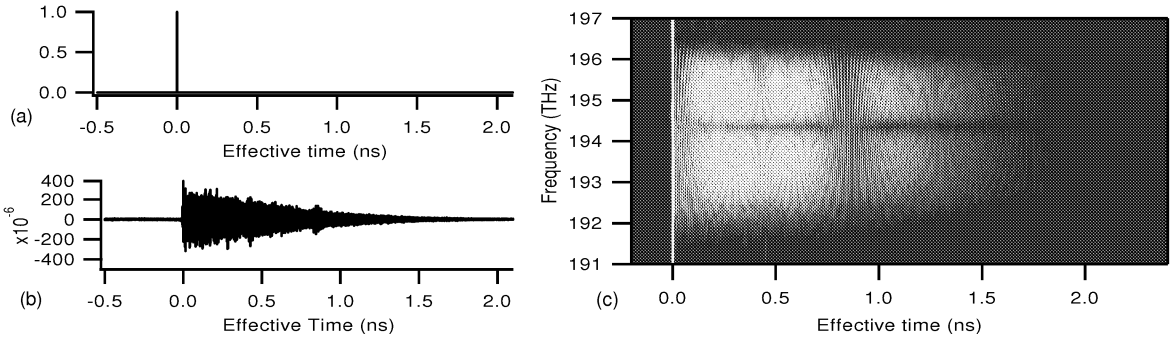

Fig. 1: (a) Time-domain free-induction decay of HCN molecules at 3 Torr. (b) Expanded version of the free induction decay. (c) Time-frequency plot of the same signal at 200 GHz resolution showing rotational recurrences as the rotating, vibrating molecules rephase.

References

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