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Multi-frequency THz Heterodyne Spectroscopy using Electro-Optic Sampling

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Multi-frequency heterodyne spectroscopy, developed by two groups (Schiller as well as van der Weide, Keilmann and co-workers) uses one optical femtosecond frequency comb (FFC) to probe a sample. A second FFC with a slightly detuned spacing is used as a multi frequency local oscillator to uniquely map the broadband optical spectroscopic information to the RF domain where it can be easily analyzed. Researchers at NIST (Coddington et al) have realized the full potential of this technique by tightly locking the detuned combs together using optical locking techniques. It is of considerable interest to extend such capabilities to access the so-called molecular vibrational "fingerprint" range of approximately 10 to 100 THz (300 to 3000 cm^{-1}). A transfer of the direct heterodyne detection approach used in the optical regime down to this frequency range is fraught with difficulties including significantly lower power of the probe THz frequency comb. In addition, a low noise detector with a relatively fast RF response ($>$ 100 MHz at a minimum) is required. An alternative, indirect detection technique for detecting THz signals is electro-optic sampling (EOS). It has employed for time domain THz spectroscopic applications for a number of years with a demonstrated spectral detection ranging from 0.5 THz range to over 100 THz. Through careful analysis of the EOS we show how electro-optic sampling of THz frequency comb by a detuned optical FFC followed by direct optical detection of the optical sampling beam enables conversion of the THz spectroscopic data directly to the RF domain. In particular, we show there is a one-to-one correspondence between a detected RF heterodyne beat and THz comb element. Numerical simulations predict excellent signal to noise ratio of the RF beats (20 dB) with modest acquisition times (10 μs). We will also summarize our progress toward experimental realization of such a system.