Heterodyne receiving with frequency combs: towards simultaneous ultrabroadband spectroscopy

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A fundamental problem is detecting the spectrum of a remote source, and heterodyne spectroscopy is a powerful technique for high-resolution measurements. However, performing these measurements over a wide range requires a widely tunable local oscillator. In THz quantum cascade lasers, this typically requires moving parts [1] and requires nontrivial amplitude and frequency calibration.

One potential alternative is the use of optical frequency combs as LOs. Frequency combs are light sources whose lines are perfectly evenly spaced [2], and in THz QCLs have achieved bandwidths exceeding 1 THz. For local measurements, the dual-comb spectroscopy technique—a multiheterodyne technique in which two different combs are beat together [3]—has become essential. However, measuring the spectrum of a *remote* source with a comb is more challenging. Though one can beat a comb LO with a signal, the resulting beating is ambiguous in the sense that the resulting beatings cannot be attributed to a specific line.

We will show that a new kind of dual-comb spectrometer, in combination with a fast analyzer, can be used to unambiguously determine the spectrum of a remote source over the comb's bandwidth. By beating the signal with two different combs, the original signal can be unambiguously retrieved, merely by computing the Fourier transform of the correlation between the spectrum of the two signals. (Alternatively, one comb can be used if a delay element is introduced.) This approach is suitable for any remote signal, even incoherent ones. In addition, the presence of multiple LOs allows for the double-sideband ambiguity to be resolved even when a double-sideband mixer is used.

Figure 1 simulates this process for a pair of LO combs spanning 4 to 5 THz at 10 GHz increments and a signal with lines at 4.211 THz, 4.558 THz, 4.783 THz, and 4.883 THz. Fig. 1a shows the beating with the first comb alone, showing components at 1, 2, and 3 GHz. Though beatings are present, which comb line they correspond to is ambiguous. However, by beating the signal with the second comb and calculating the Fourier transform of the correlations between the two spectra, one can determine which comb line each beating belongs to. These are shown below for the comb lines at 4.21 THz, 4.56 THz, 4.78 THz, and 4.88 THz. The true signals (shown in red) are reproduced, showing the four components at offset frequencies of 1 GHz, -2 GHz, 3 GHz, and 3 GHz, respectively. Note that both negative frequencies and overlapping frequencies in the IF were correctly reproduced, even though a double-sideband mixer was used.

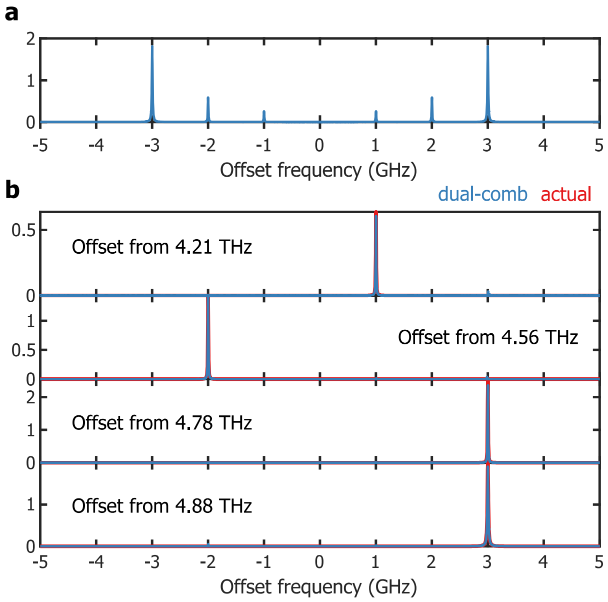

Fig. 1. a. Beating of a signal with four lines with a 4-5 THz comb. All beatings are present, but the result is ambiguous. b. Signal retrieved by a Fourier transform of the frequency-domain correlation at four comb frequencies. The signal is reproduced.

In principle, this system can be compact, monolithic, and self-calibrated—both in amplitude and frequency. We will also show that under certain conditions (the case of a signal whose IF components do not overlap), such systems can inherit the sensitivity of an equivalent system with a tunable LO. Thus, this scheme can act as an alternative route for ultrasensitive, ultrabroadband, high-resolution spectroscopy.

REFERENCES

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