Room Temperature Rubidium Atom Spectroscopy of a Terahertz Frequency Comb

Wiktor Krokosz
Jan Nowosielski, Bartosz Kasza, Sebastian Borówka, Mateusz Mazelanik, Wojciech Wasilewski, Michał Parniak

University of Warsaw, Krakowskie Przedmieście 26/28, Warsaw, Poland

w.krokosz@cent.uw.edu.pl

Terahertz (THz) and millimeter-wave radiation is a rapidly expanding frontier for communications, sensing, and spectroscopy, yet it remains constrained by a lack of practical hardware.

We employ a room-temperature Rydberg-atom sensor that exploits strong electric-dipole transitions between highly excited atomic states to couple efficiently to THz fields.

To push sensitivity into the regime relevant for quantum THz measurements, we combine (a) Autler--Townes (AT) splitting as an absolute, atom-referenced field calibration method with (b) parametric RF-to-optical upconversion via six-wave mixing in warm rubidium vapor.

This hybrid strategy links a traceable calibration scheme (AT splitting) to an optical photon-counting readout, which has been shown to achieve sensitvities down to the thermal limit, all in one optical setup.

Our sensor performs mode-selective spectroscopy of the comb by scanning the relevant atomic resonance condition with optical detunings, thereby addressing individual comb teeth with MHz-scale selectivity while still allowing GHz-scale scans.

To support robust coupling and reproducible calibration across different frequency regions, the setup integrates custom metamaterial components for collimation, controlled attenuation, and polarization management, and uses a commercial mmWave radar chip as an auxiliary reference in the calibration chain.

Figures

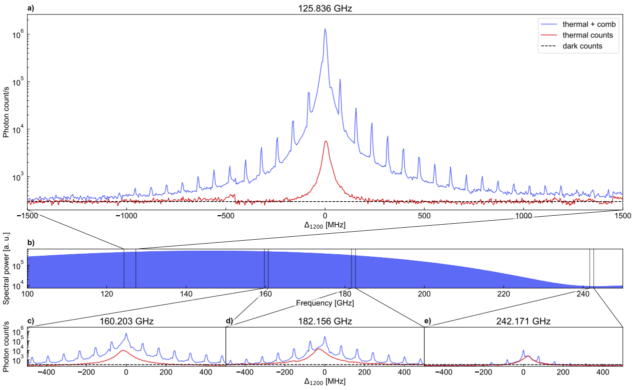

Figure 1: Mode-resolved detection of a THz frequency comb. By scanning the laser, the sensor addresses individual comb teeth spaced by frep ≈ 80 MHz. GHz-scale scans access multiple teeth and map different spectral regions of the comb while retainingsingle-mode resolution.

Using this platform, we can access distinct regions by tuning our lasers to a given Rydberg transition (we show examples for 125 GHz, 160 GHz, 182 GHz, and 242 GHz) and achieve an octave-spanning scan bandwidth with MHz resolution, allowing us to view individual comb modes.

This opens a path for THz spectroscopy and sensing to inherit key benefits that optical frequency combs unlocked in the visible and infrared: precision, accuracy, and multi-parameter readout across wide bandwidths, now extended into a spectral region where detector performance has historically limited the adoption of comb techniques.

References

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