Cryogenic microwave frequency combs based on quantum paraelectric superconducting resonators.

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Abstract

A frequency comb is a spectral structure consisting of discrete, evenly spaced spectral lines, often described as an "optical ruler" due to its remarkable precision. They have become essential in fields such as astronomical spectrograph calibration, high-precision metrology, optical atomic clocks, frequency synthesis and spectroscopy. These combs are indispensable across various quantum technologies and essential due to the growing need for free-space quantum communication and circuit-based quantum devices—such as quantum electrical metrology, quantum sensing, and solid-state quantum information processors including semiconducting and superconducting qubits—has made the development of microwave frequency combs of paramount importance. Despite their significance, microwave frequency combs remain relatively underexplored compared to their optical counterparts. Current methods mostly rely on complex, high-power optical systems that are incompatible with the low-power, cryogenic on-chip quantum technologies. Additionally, the limited tunability of comb lines also restrict their adaptability for advanced applications. In this experiment we realize a tunable on-chip micro-comb using a coplanar waveguide resonator on $SrTiO_3$ (STO) leveraging its high Pockels coefficient in its quantum paraelectric phase. Our device exploits a superconducting microwave cavity on STO and the frequency comb is generated as a result of the cavity phase modulation enabled by the linear electro-optic effect present as a result of field induced effective $\chi^{(2)}$, on STO. The on-chip, all-electrical approach with voltage tuneable comb-lines makes our approach a suitable choice for various applications in quantum technology.

References

[1] C. P. Anderson et al., Quantum critical electro-optic and piezo-electric nonlinearities, Science **390**, 394 (2025)

[2] D. Davidovikj, N. Manca, H. S. J. van der Zant, A. D. Caviglia, and G. A. Steele, PHYSICAL REVIEW B 95, 214513 (2017).

Figures

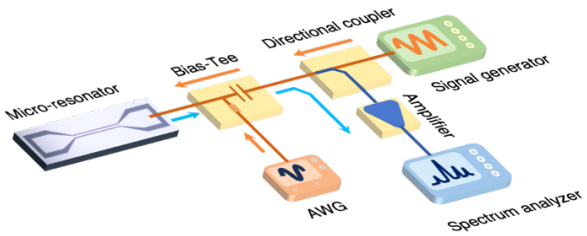

Figure 1: Schematic diagram of the measurement setup.

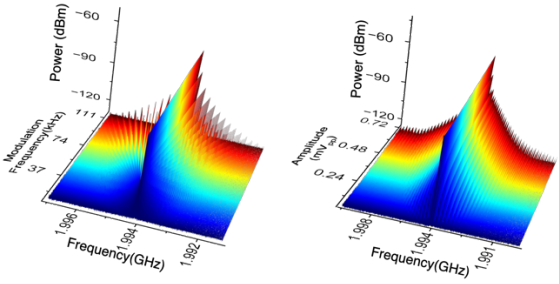

Figure 2: represents the 2D plots of combs generated varying modulation frequency and modulation amplitude