Microwave mode cooling with room temperature diamonds

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Microwave (MW) measurements are plagued by Johnson-Nyquist noise at room temperature, making the detection of weak microwave signals an exceptionally difficult task. To reduce the microwave thermal noise detectors must be cooled to cryogenic temperatures, which restricts their wide-spread application. Devising techniques to reduce the amount of noise in microwave circuits at room temperature would have far-reaching uses in areas as diverse as electron spin resonance (ESR) spectroscopy, deep space satellite communication and radar.

Recent results [1,2] have demonstrated that polarized ensembles of nitrogen vacancy (NV) centres in diamond can be used as a cold spin bath to absorb thermal photons in a microwave cavity, lowering the effective temperature of its mode. The cold mode can be used to cool the microwave temperature of an external transmission line and hence increase the signal to noise ratio of measurements (see Fig. 1). Such a system also provides a testbed to probe cavity quantum electrodynamics (CQED) effects in a solid-state system at room temperature [3].

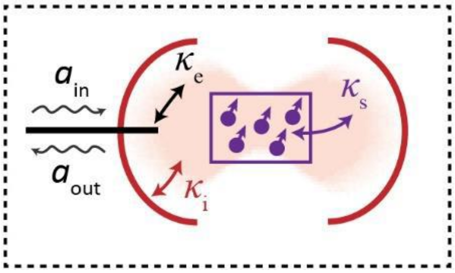

Figure 1: Thermalisation channels between the microwave mode (pink), room temperature cavity (red), and NV spins (purple).

Currently reported implementations operate at or near the NV centre zero-field splitting frequency of 2.87 GHz and have reduced/cooled noise levels by approximately 2 dB over bandwidths below 1 MHz [2]. Here we demonstrate microwave mode cooling at X-band frequencies (9.7 GHz) in a magnetic field of 244 mT (Fig. 2). We observe 1.6 dB of cooling over 2.6 MHz and discuss improvements to the setup to enhance both the cooling power and bandwidth. These results demonstrate that the cooling of room temperature X-band microwaves is practical, which is a key frequency range for satellite communications and ESR spectroscopy.

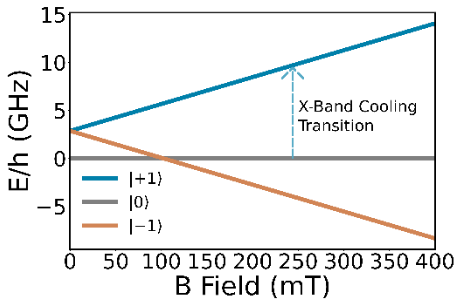

Figure 2: Eigenfrequencies of the NV centres aligned parrallel to a magnetic field. The cooling transition from the |0⟩ to |+1⟩ states is labeled.

[1] W. Ng, H. Wu and M. Oxborrow, Applied Physics Letters **119** (23), 234001 (2021).

[2] D. P. Fahey et al., arXiv preprint arXiv:2203.03462 (2022).

[3] Y. Zhang et al., Physical Review Letters **128** (25), 253601 (2022).