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Transmon-based single microwave photon detectors for QCD axion searches in the classical window

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The post-inflationary QCD axion is a sharp BSM theory target that spans a frequency range from 5 to 50 GHz known as the classical window. At these higher frequencies, linear amplifiers as cavity haloscope receivers are severely degraded in sensitivity by the standard quantum limit: $P_{\mathrm{bkgd}} = h\nu\Delta\nu$. For calorimetric measurements, this limit can be evaded through the use of direct photon counting. The background power from thermal photons is $P_{\mathrm{bkgd}} = \bar{n}_{\mathrm{th}} h\nu\Delta\nu = \frac{1}{1-e^{h\nu/kT}} h\nu\Delta\nu$, where $\bar{n}_{\mathrm{th}}$ is the thermal photon population. At mK temperatures, the occupation number can be suppressed by three to four orders of magnitude below 1, providing remarkable enhancement to QCD axion scan rates.

We present on our work to develop a tunable single microwave photon detector (SMPD) that could be used in a cavity haloscope experiment in the 6 to 7 GHz range. The detector architecture is modeled after an existing transmon-based design, initially developed by the Quantronics group at Paris-Saclay University. We describe the design's fundamental working principles, which include four-wave mixing, dispersive readout, and cyclic readout operation. We also detail the effort to make a tunable SMPD from 6 to 7 GHz, chosen to line up with existing high-volume cavity haloscopes (this work is a subproject of the ADMX-VERA R&D working group). Lastly, we report $T_1 = 1.2\,\mu s$ for a prototype device, hypothesize what it may be limited by, and project how this low T_1 will limit overall detector efficiency.

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