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Quantum-Enhanced Axion Searches Using Josephson Junction-Based Circuits

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***Abstract*–Quantum noise is the primary barrier hindering the rapid search for axion-induced RF signals at an unknown frequency. Specifically, it constrains the axion-sensitive bandwidth of the detector. However, this limitation can be overcome by employing quantum-enhanced sensing technology, thus unlocking the potential for accelerating the axion search. In this study [1], we demonstrate a prototype detector that comprises two microstrip modes coupled by a three-wave mixing element – Josephson ring modulator, with one mode serving as the science mode and the other utilized for readout purposes. By dynamically coupling these modes through simultaneous two-mode squeezing and state-swapping interactions, we achieve an increase in the axion-sensitive bandwidth, resulting in an eight-fold acceleration in the detection of a weak microwave tone compared to a quantum-limited detector. Furthermore, we discuss progress towards implementing this technique in a practical search for HAYSTAC**.

Keywords (Index Terms)– axion detection, RF, quantum sensing, three-wave mixing, Josephson ring modulator, squeezing, quantum-limited, HAYSTAC

[1] Y. Jiang, E.P. Ruddy, K.O. Quinlan, M. Malnou, N.E. Frattini, and K.W. Lehnert, Accelerated weak signal search using mode entanglement and state swapping, *PRX Quantum* 4, 020302 (2023).

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