# Strong Photon-Magnon Coupling Using a Lithographically Defined Organic Ferrimagnet

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Hybrid quantum systems are attractive for emerging quantum technologies because they take advantage of the distinct properties of the constituent excitations. This is important because no single quantum system is ideal for every task, e.g., scalable quantum information processing, quantum sensing, long-lived quantum memory, and long-range quantum communication all have different requirements. In creating hybrid systems, it is advantageous to operate in the strong-coupling, low-loss regime, where the relaxation rates of the two distinct quantum systems are exceeded by the coupling rate between them. This allows the hybrid system to operate as a quantum interconnect, wherein quantum information can be passed from one excitation to another. Thus, a central challenge is to couple distinct quantum systems strongly, with all elements maintaining long coherence times. An equally critical challenge is to fabricate the hybrid quantum devices using scalable and integrable approaches so that their engineered properties can be used in applications.

Here we demonstrate a cavity-magnonic system composed of a superconducting microwave resonator coupled to a magnon mode hosted by the organic-based ferrimagnet vanadium tetracyanoethylene (V[TCNE]x) [1]. This work is motivated by the challenge of scalably integrating a low-damping magnetic system with planar superconducting circuits. V[TCNE]x has ultra-low intrinsic damping, can be grown at low processing temperatures on arbitrary substrates, and can be patterned via electron beam lithography. The devices operate in the strong coupling regime, with a cooperativity exceeding 1000 for coupling between the Kittel mode and the resonator mode at $T \approx 0.4$ K, suitable for scalable quantum circuit integration. This is critically enabling for integration and scaling, permitting future designs in which magnonic waveguides can be tailored as couplers or can mediate interactions between different quantum excitations in a planar superconducting circuit. Focusing on the 3.6 GHz device, we present a detailed microwave transmission spectrum that reveals not only the expected avoided level crossing of the resonator mode and the uniform magnon mode (the Kittel mode, or simply magnon mode unless otherwise stated) but also the resonator mode is hybridized with a discrete spectrum of higher-order magnon modes that show a much narrower linewidth than the uniform mode (Fig. 1). This work paves the way for future hybrid magnonic quantum systems by establishing an integrated and scalable platform enabling arbitrary design of the magnonic elements.

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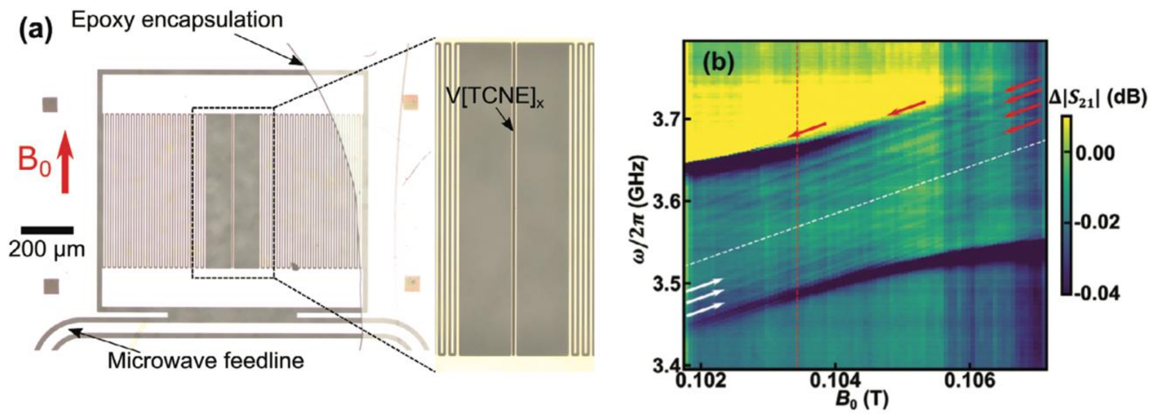


**Figure 1. (a)** Optical microscopy of a superconducting LC resonator capacitively coupled to a microwave feedline. Zoomed image reveals a V[TCNE]x magnetic resonator deposited on top of the inductive wire of the resonator, allowing coupling to the Oersted fields generated by the oscillating current. **(b)** Microwave absorption as a function of applied magnetic field revealing hybridization and strong coupling between the Kitttel mode of the magnetic resonator and the superconducting resonator (dark black lines) as well as higher order modes in the gap opened up by the strong coupling (light black lines marked by red and white arrows).