Microwave-optical quantum transduction with a 3D cavity

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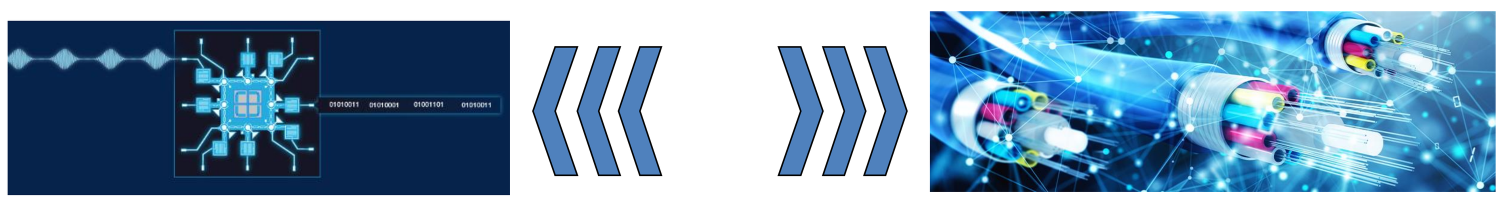
Microwave-optical quantum transduction

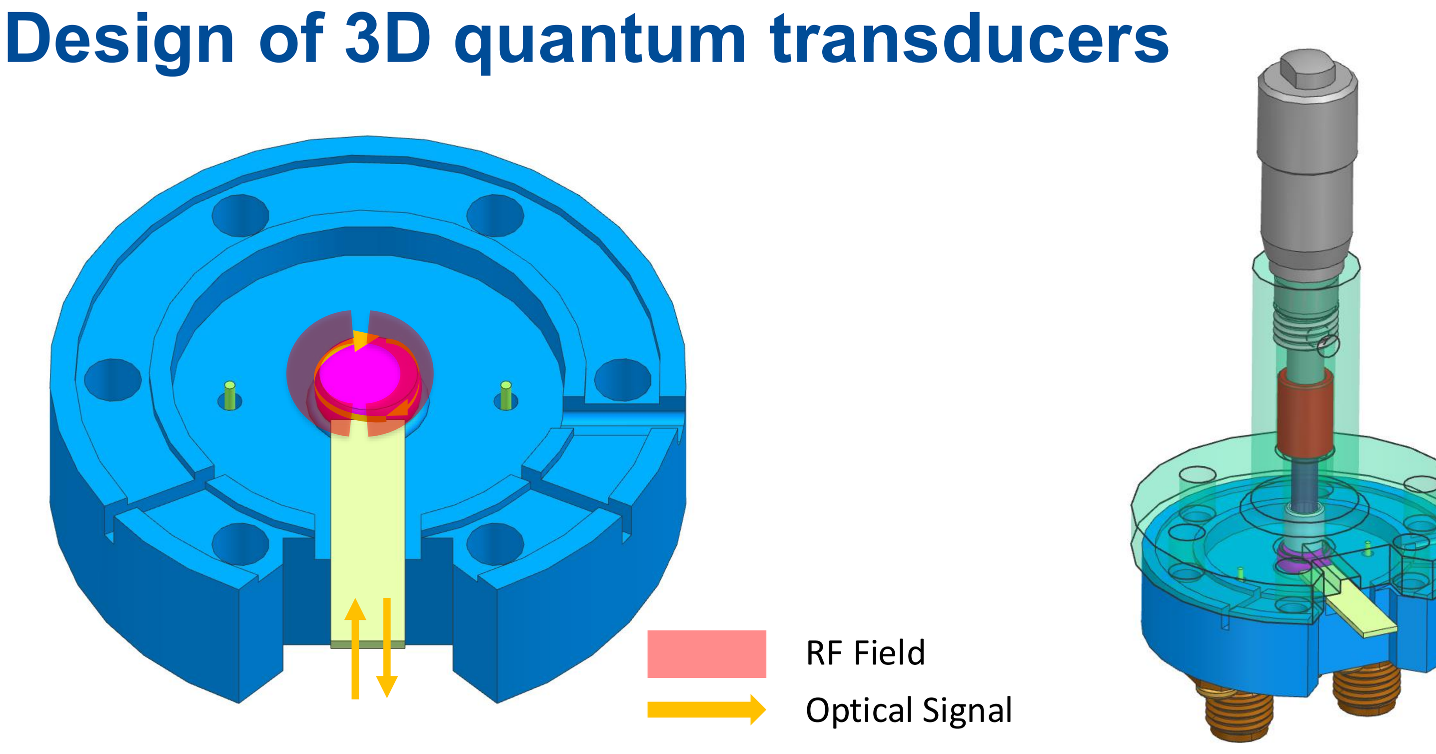


Superconducting qubits — Optical communication

Microwave (GHz) — Optical (200 THz)

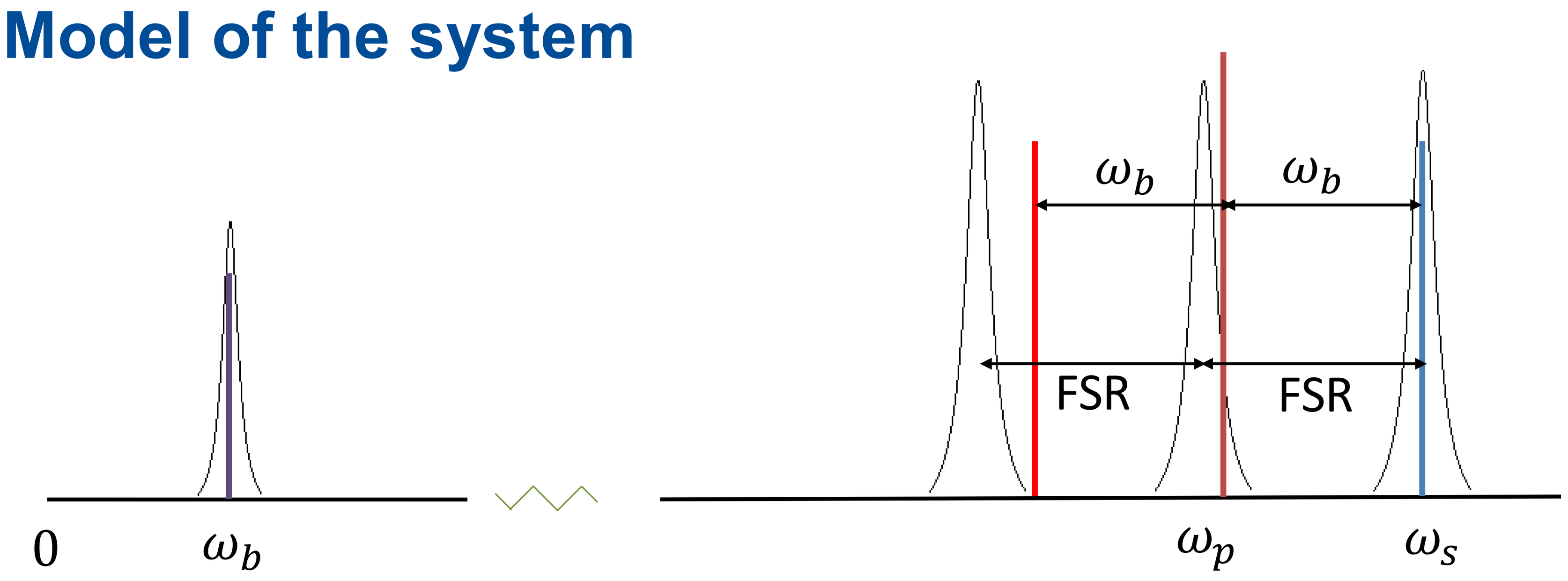
In a quantum network, we process quantum information with qubits and transmit quantum information over long distance through low-loss optical fiber. Microwave-optical transduction enables high-fidelity transfer of quantum state between microwave and optical frequency.

Design of 3D quantum transducers



3D hybrid quantum system: a tunable SRF cavity embedded with a lithium niobate ($LiNbO_3$) optical resonator. A laser pump is coupled to the $LiNbO_3$ WGM resonator via lensed fibers and a waveguide chip coupler.

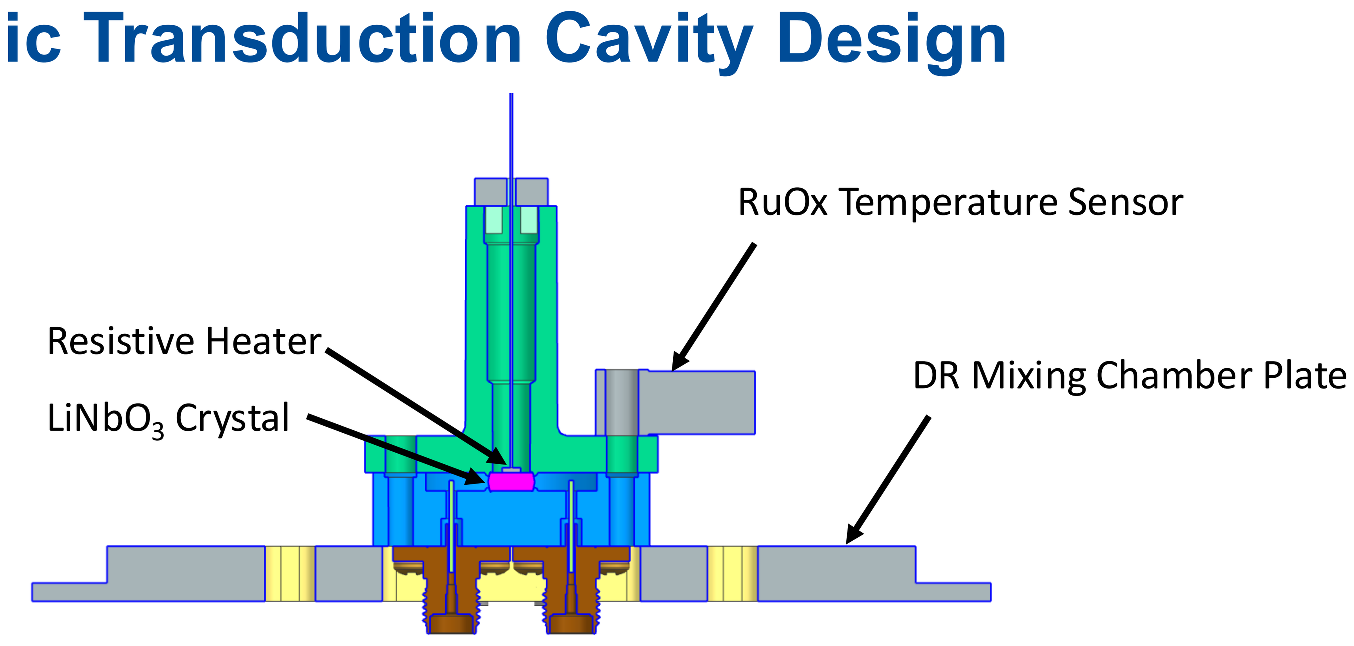
Model of the system



Electro-optic transduction provides a direct conversion through the three-wave mixing.

$$H = \hbar g_{eo}\left(a_p a_s^\dagger b + a_p^\dagger a_s b^\dagger\right).$$

Cryogenic Transduction Cavity Design



The quantum transduction cavity is mounted in a Dilution Refrigerator (DR) at mK with temperature sensors and a resistive heater epoxied to the $LiNbO_3$ optical resonator to simulate laser pump heat loads and pumping schemes. Experiments will inform design to reduce thermal noise from laser pump.

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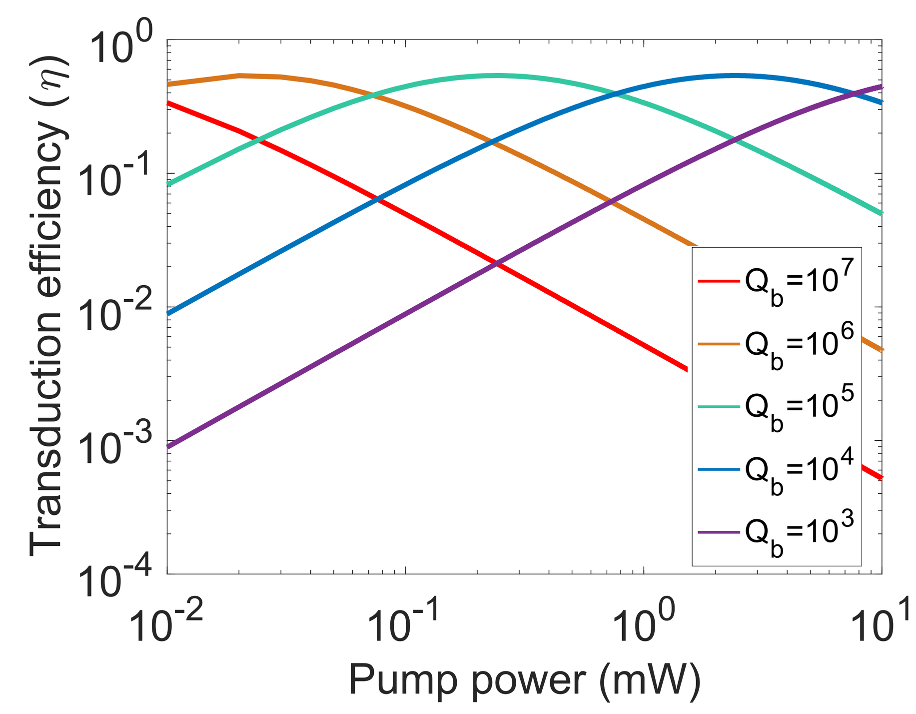
Fermilab

References:

S. Zorzetti, et al. Phys. Rev. B 107, L220302 (2023)

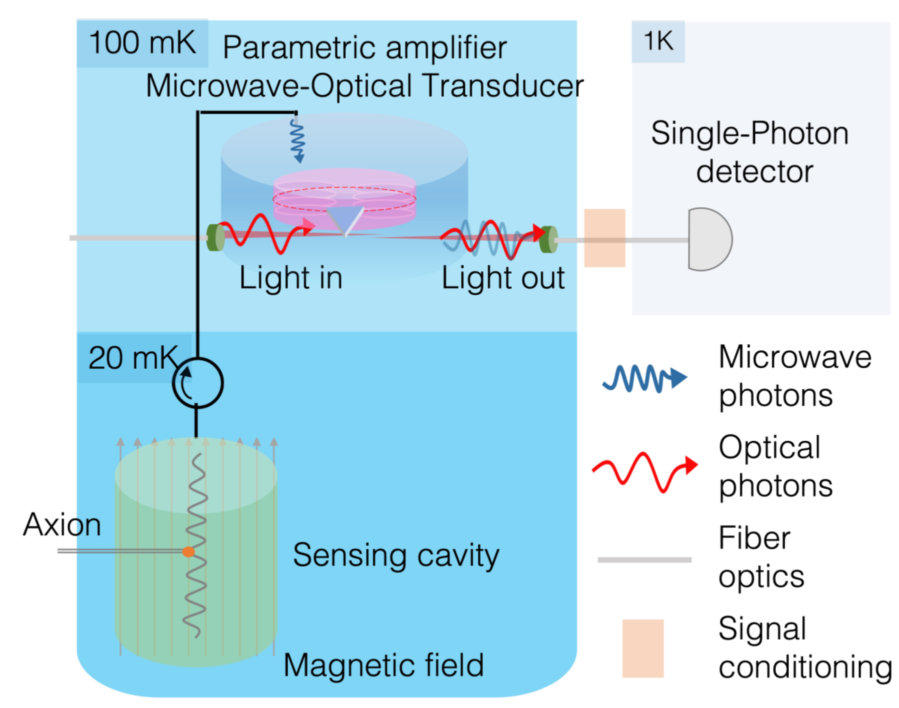
C. Wang, et al. npj Quantum Information, 8, 149 (2022)

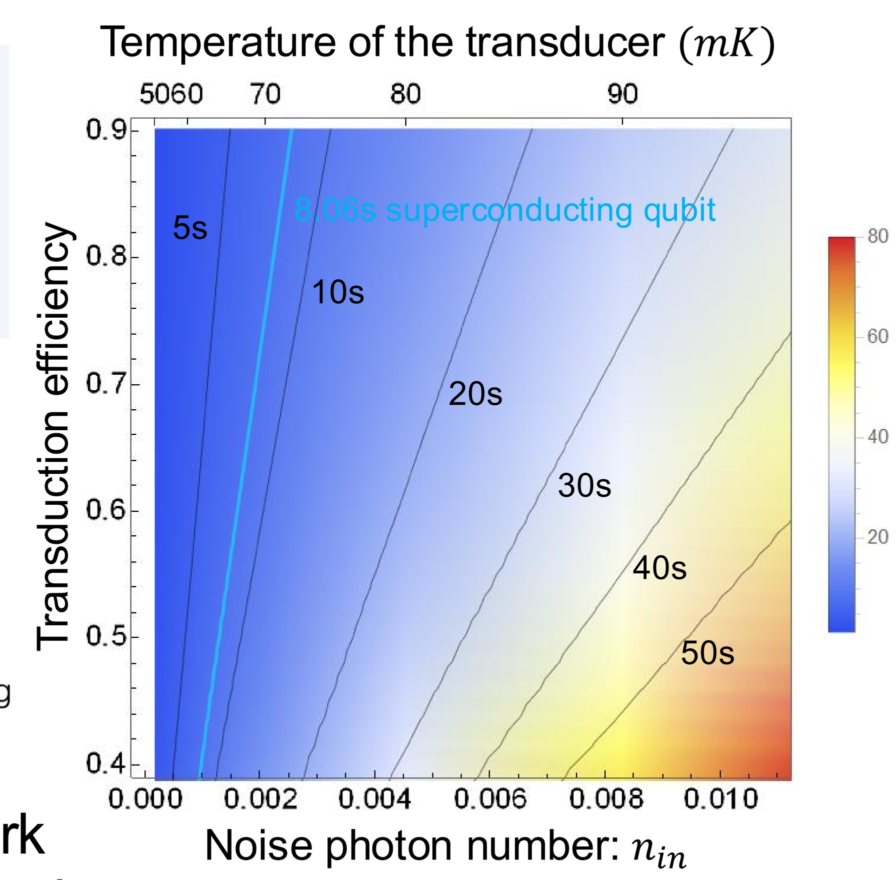
Figure of merit for quantum transduction



- Larger pump power leads to higher efficiency but more thermal noise.
- Our design yields 50% transduction efficiency at low pump power.

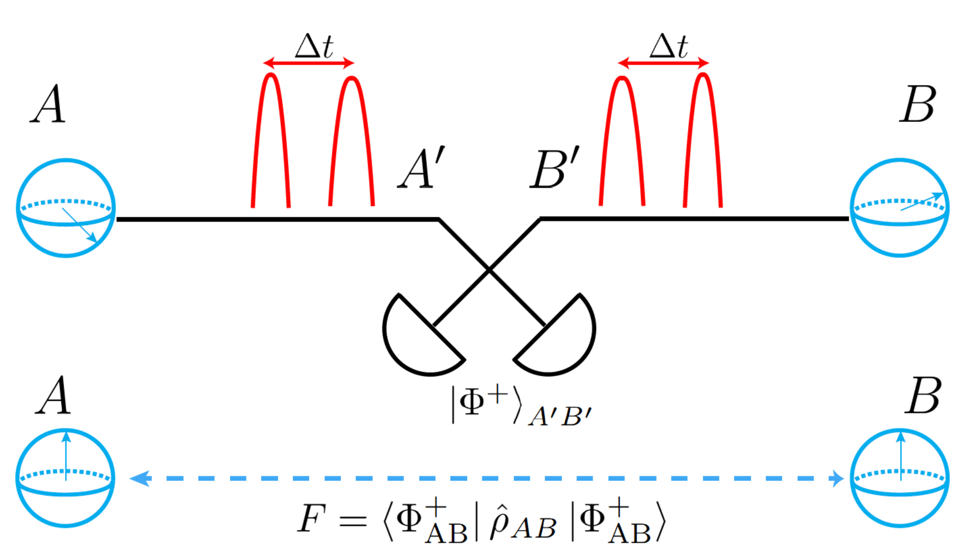
Application 1: Optical readout of weak field (axion)





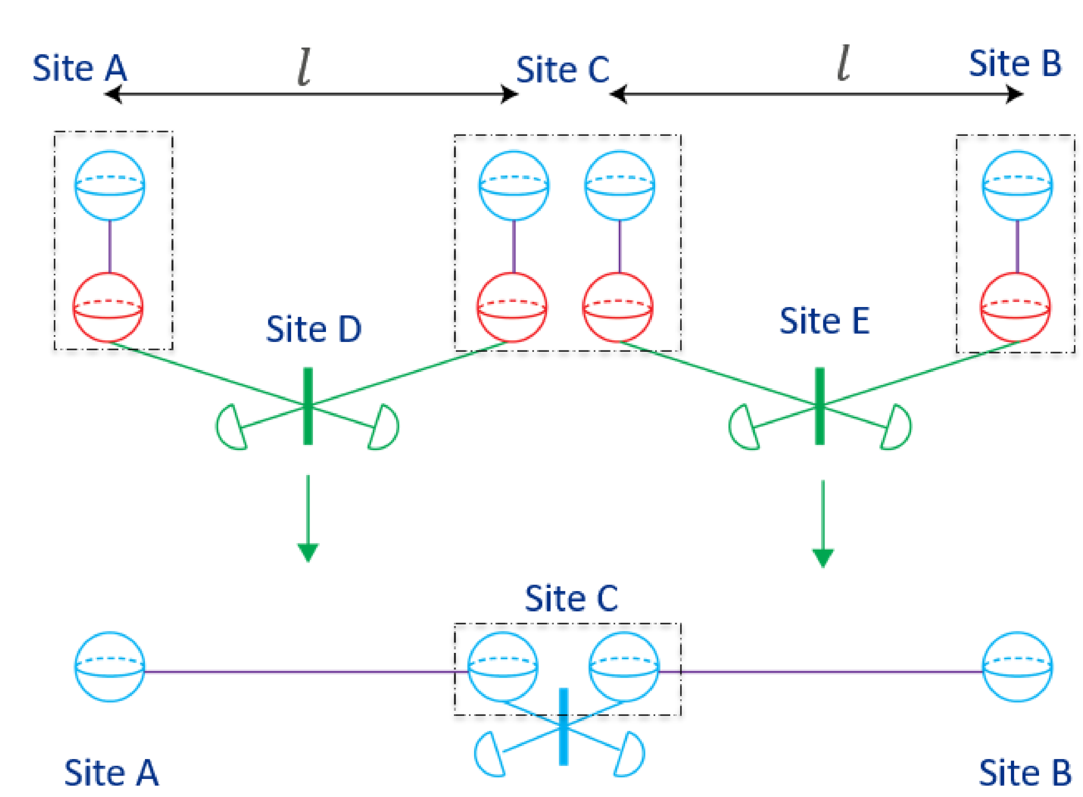
Due to high efficiency and low dark count rate of SNSPD, the transduction-based detection has potential to reduce measuring time.

Application 2: Entangling two distant qubits



Time-bin Bell state measurement at $A'B'$ can herald entanglement between the two superconducting qubits AB.

Application 3: Hybrid quantum repeater



Compared to a full optical quantum repeater design, the hybrid design performs quantum swaps at site C with significantly higher efficiency than 50%.

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