Designing a Microwave Cavity to Enable Magneto-Optic Transduction in Quantum Networking

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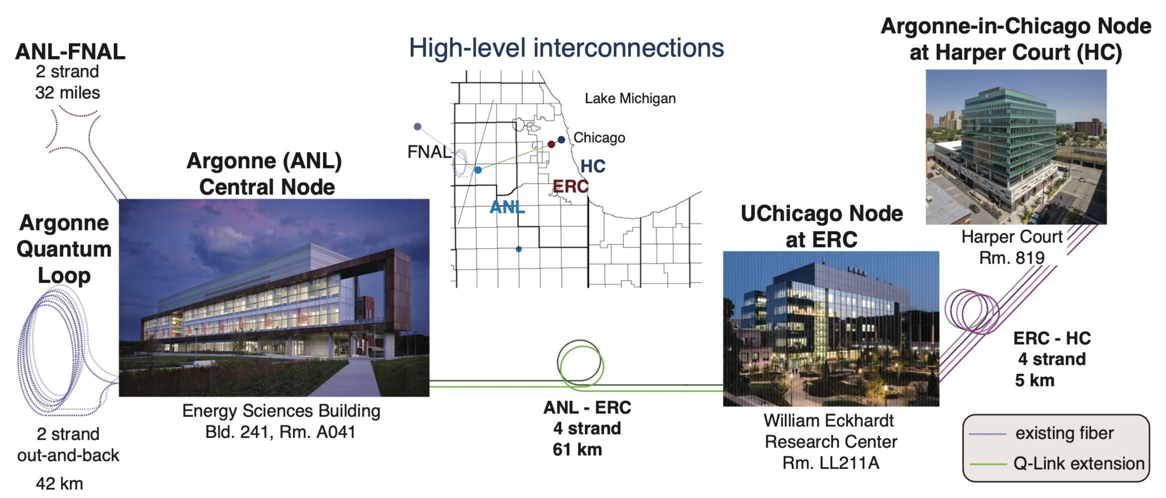
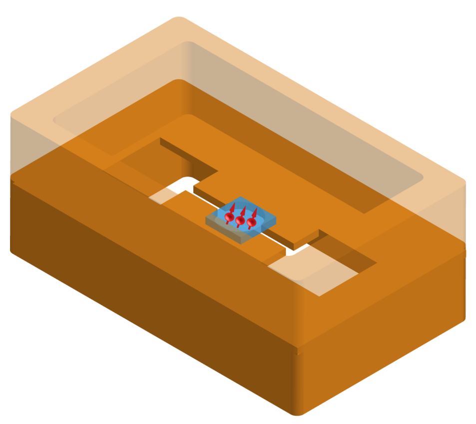
Background

- Quantum networks, like that connecting UChicago and Argonne, are testbeds for quantum communication and security technology.
- Quantum transduction involves converting entangled microwave photons into entangled optical photons that can travel through fiber-optic cables—essential for building quantum networks.
- Erbium ions (Er^{3+}) produce optical wavelengths in the telecommunications band (around 1540 nm), which allows for low-loss transmission in standard optical fibers, thus enabling efficient and practical long-distance quantum communication.
- The strong magneto-optical coupling of Erbium ions ensures high-fidelity conversion between microwave and optical signals, which is essential for preserving quantum states during transduction in the quantum network.



Goals

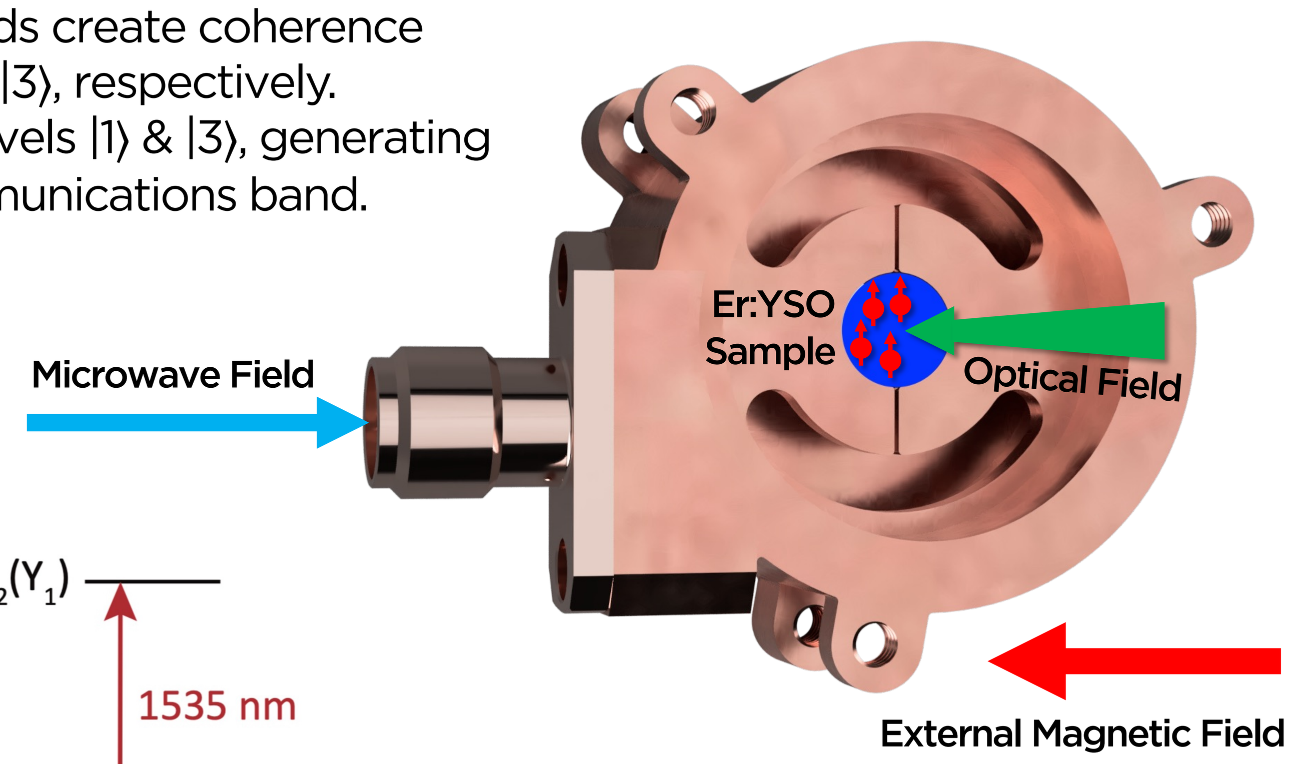
1. Make resonator more compact than initial design
2. Ensure resonator matches required parameters
   1. Eigenmode frequency of 5-6 GHz
   2. Strong magnetic field in center of resonator
   3. Sufficient Q-value (greater than 6000)
   4. Driven frequency of 5-6 GHz

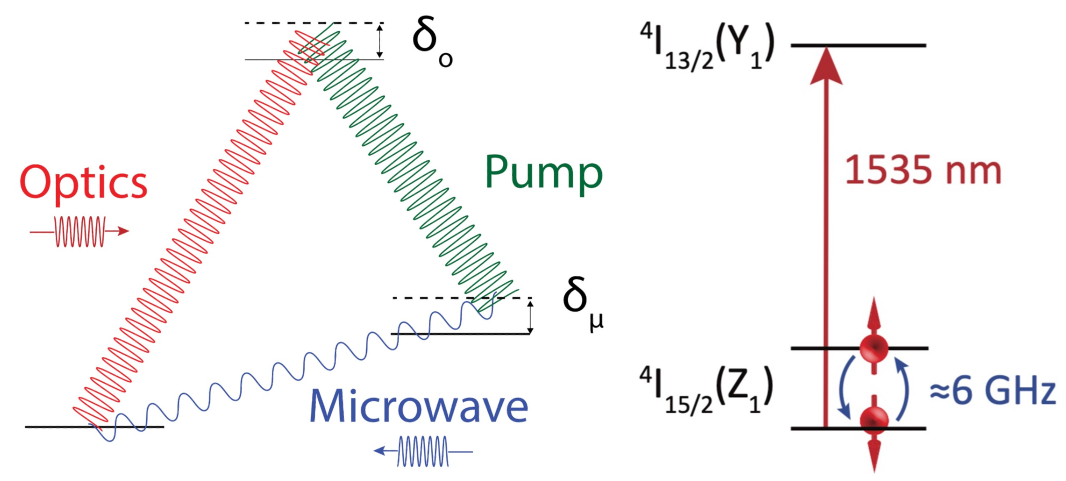


Initial Design

Cavity Operation

- $^4I_{15/2}$ and $^4I_{13/2}$ level of Er:YSO Zeeman split under magnetic field, transition resonant with cavity.
- Input microwave and optical fields create coherence between levels |1⟩ & |2⟩ and |2⟩ & |3⟩, respectively.
- Produces coherence between levels |1⟩ & |3⟩, generating output optical signal in telecommunications band.

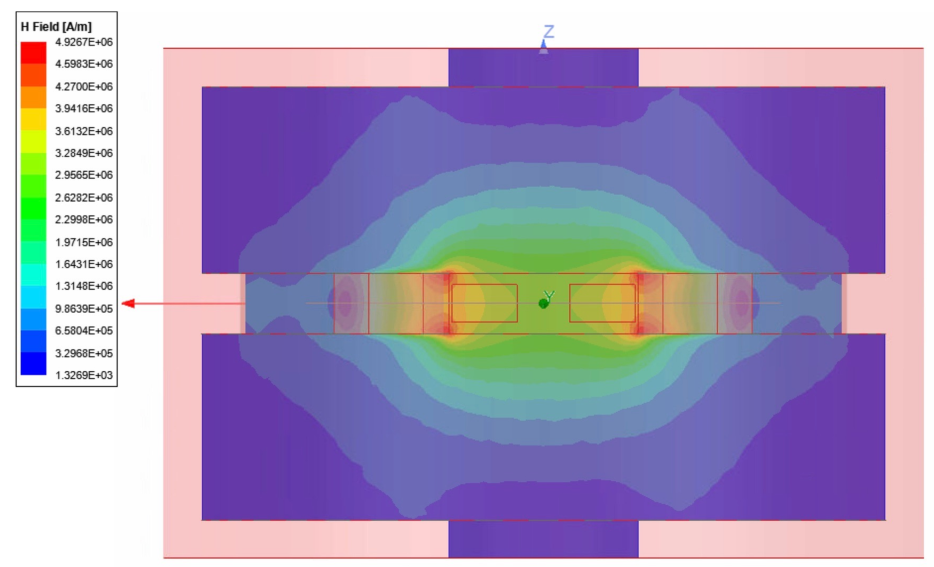




Simulations

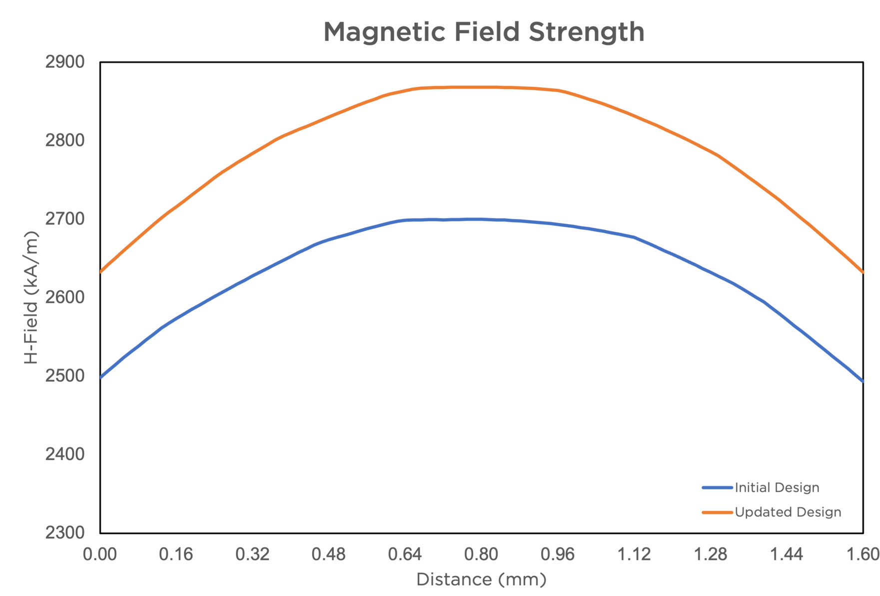
Eigenmode

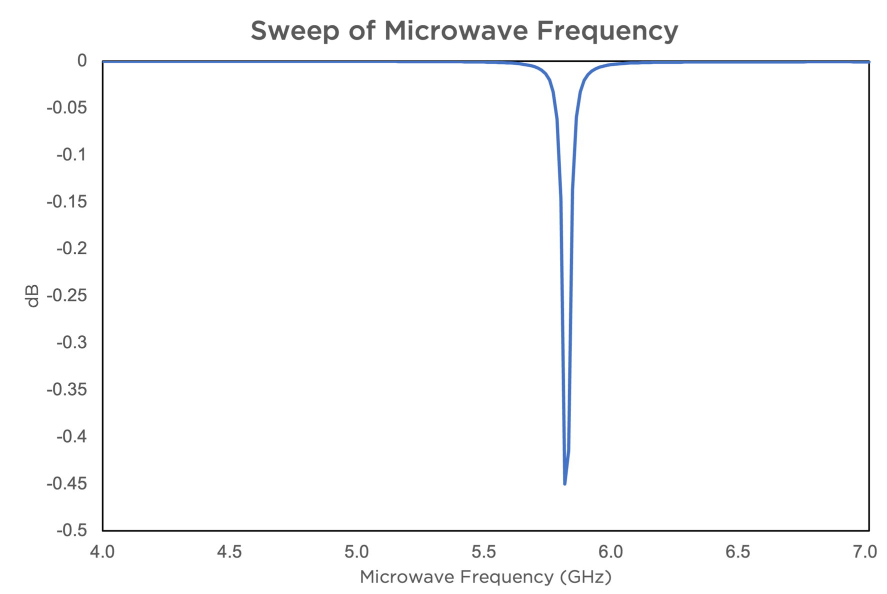
- Frequency: 6.0 GHz
- Q-value: 7216
  - **21% increase** from initial of 5961
- Maximum magnetic field strength: 2868 kA/m
  - **6.2% increase** from initial of 2700 kA/m



Driven

- Frequency: 5.8 GHz





Cavity Design

Loop-Gap Resonator

- This design uses a 3-loop, 2-gap resonator design. The outer loops are curved around the central bore to reduce space requirements.
- Loop-gap resonators act as an LC-circuit, producing a magnetic field through the central bore of the resonator.

Updated Design

- 12 mm radius & 15.4 mm height
- **83% less internal volume** than initial design
- Increase in Q-value and generated magnetic field strength

Future Directions

- Machine physical cavity
- Determine the resonant magnetic field strength, which involves varying the magnetic field to determine the maximum output signal power
- Conduct tests using the dilution refrigerator, with a focus on the efficiency of the transduction process

Raman Heterodyne Spectroscopy

- Vary both the magnetic field strength and optical field frequency to find the magnetic field strength that causes resonance and the optical field frequencies where the transitions occur