HIGH Q TRANSMISSION LINE RESONATORS

Low Temperature Effects on a Scaled Up Coplanar Waveguide Resonator

PHSX 501: Honors Undergrad Research

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Outline

- An Introduction to Quantum Computing
- Applications of TLRs
- Quality Factor
- Design and Fabrication
- Some Results
- More Experimentation

A Brief Intro

- Classical computers store information as 1s and 0s
  - Computers handle information 32 units at a time (32 bits)
- Quantum computers store information on single particles called qubits
  - Qubits are both 1 and 0 together
  - Qubits store multiple numbers at the same time
    - You could store 4 billion numbers at a time using a 32 qubit computer
- Calculations can be done very quickly on a QC

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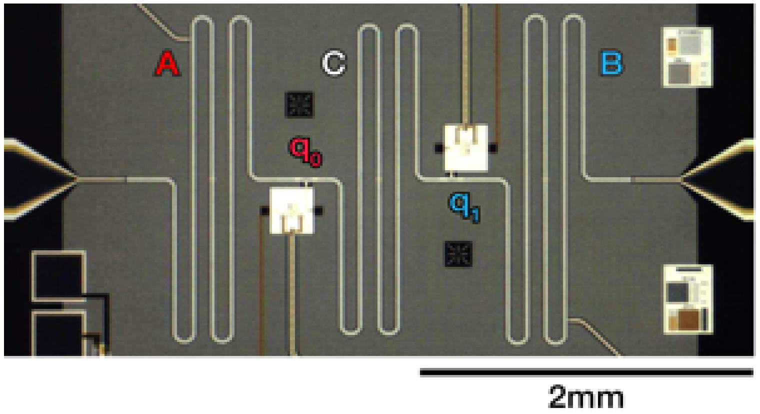
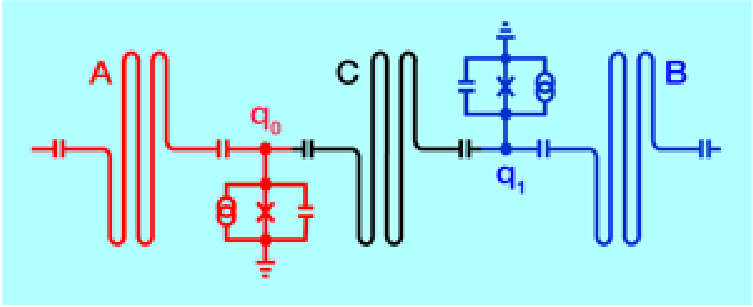
Applications

- Filters
- Single photon detectors
- Inter-qubit information transfer
- Qubit information storage
- Novel uses invented everyday

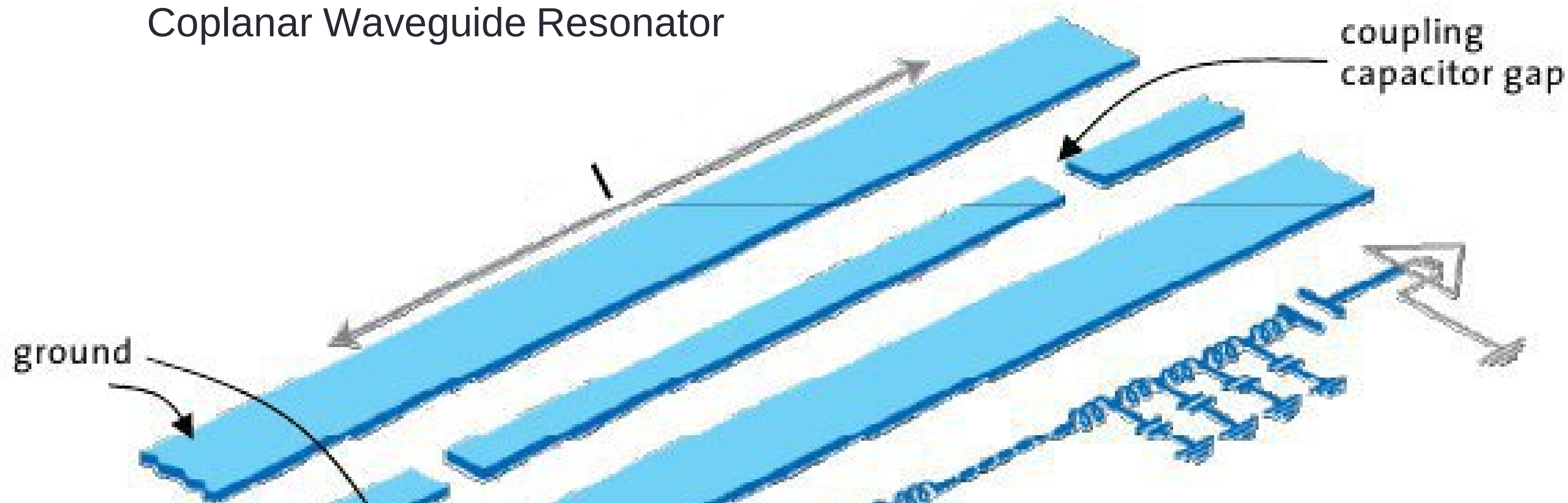


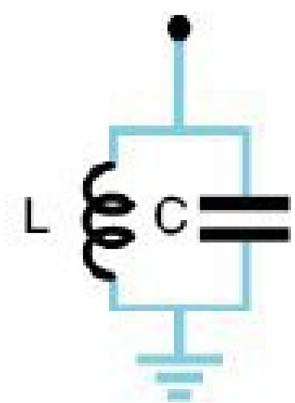


Credit: Wang et al. 2011

Device

Coplanar Waveguide Resonator





- l is chosen to establish standing waves at the resonant frequency
- W, S, and ε_{eff} determine the characteristic impedance

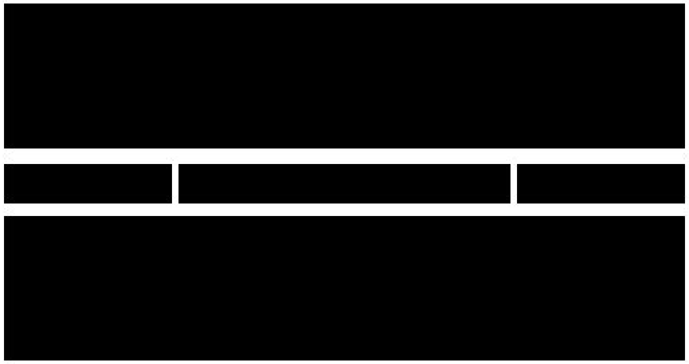
Design

- Aiming for a long decay time (high quality factor)
  - Stored information must last as long as possible
  - Minimize losses
- Able to handle extremely low power conditions
  - Each qubit will emit a single photon
- Ease and cost of manufacture

Fabrication

Toner-Transfer method of PCB manufacture

- w = 2.0 mm
- s = 0.92 mm
- ε_{eff} = 2.8
- l = 17 mm



- l is chosen for ½ the wavelength at a resonant frequency of 5 GHz
- ε_r estimated using $C = \varepsilon_r \frac{A}{4\pi d}$
- Coupling gaps are as small as possible
- Substrate material is a fiberglass material called FR-4

Losses in a TLR

- Conductor
  - Resistance of the copper, R
  - Surface roughness
- Substrate
  - FR-4 loss tangent ($\tan\delta$)
    - Between .02 and .008
  - Moisture absorption
    - Loss tangent ~.16

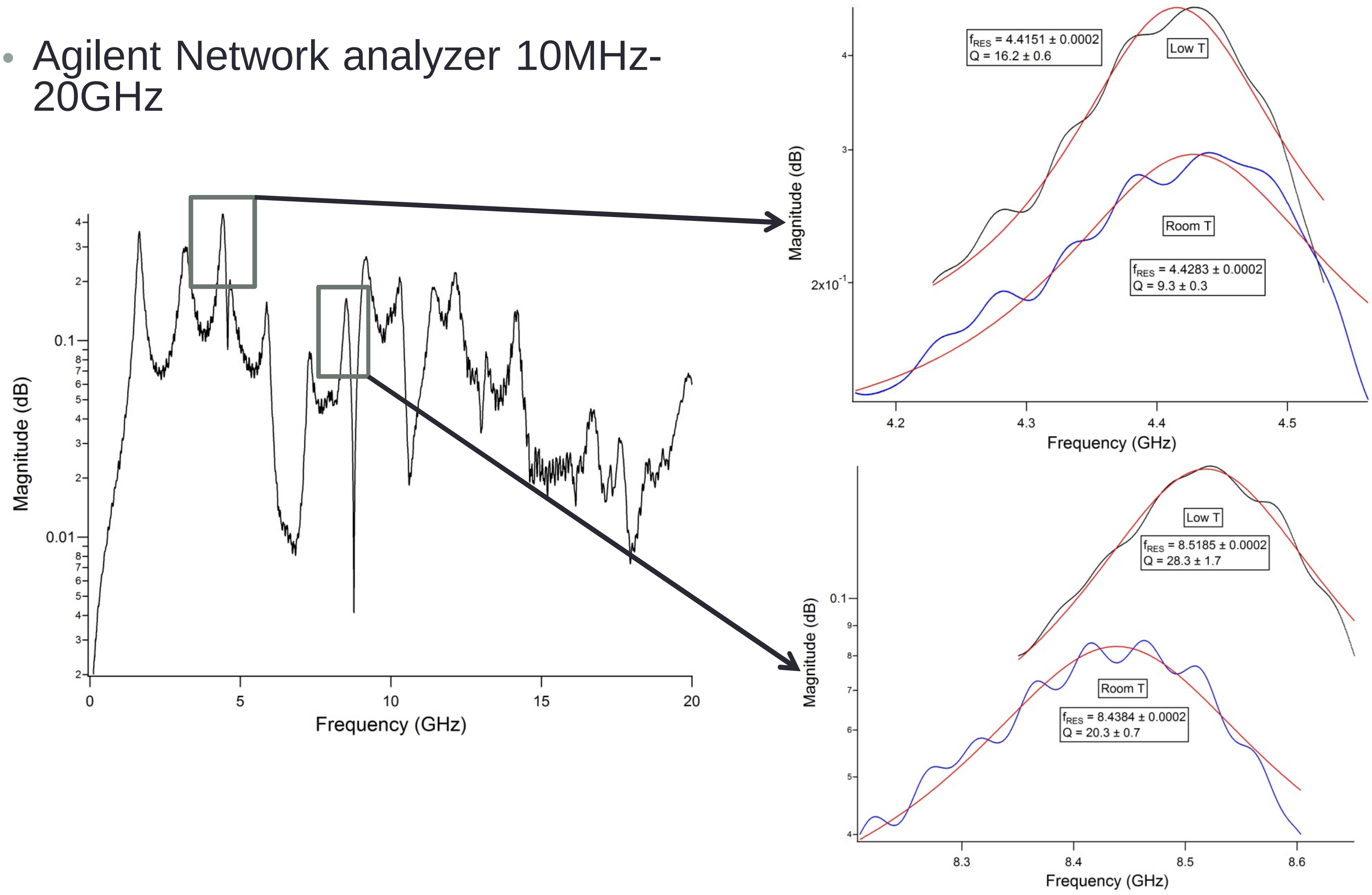
$$Q \leq \frac{1}{\tan\delta}$$

$$Q \propto \frac{1}{\delta}$$

$$Q \propto \frac{1}{R}$$

Testing

- Agilent Network analyzer 10MHz-20GHz



Results

- As expected $Q \propto \frac{1}{T}$
  - Indicates that conductor losses are dominant
- $\varepsilon_{eff} \cong 3.6$
- Temperature and frequency dependence of ε_R?
  - 5.1% frequency shift down at room temp.
  - 3.6% frequency shift down at low temp.
  - Coupling induced frequency shift?

Further Investigation

- Isolate dielectric and conductor losses
- Power dependent Q-factor
- Overcoupled
  - $Q_{INT} + Q_{EXT} = Q_L$
- FR-4 not suitable for high frequency
  - Q-factors on the order of 10^6 are achievable on other substrates using superconducting materials

Bibliography

- M. Goeppl *et al.*, Coplanar Waveguide Resonators for Circuit QED, *Journal of Applied Physics* **104**, 113904 (2008)