Disk Resonator Format for Kinetic Inductance Detectors

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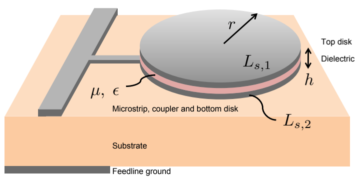
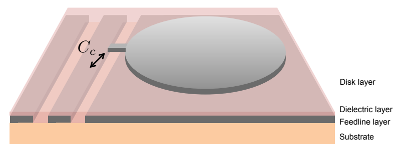
Motivation

- We are interested in resonators that allow for higher power readout. Higher readout powers may improve the signal to noise ratio by saturating two level systems.
- The base design is simple and avoids detailed lithography.
- Disks are well suited for detectors where the event energy spot size is large (e.g. phonon mediated membrane suspended devices).
- Disk resonators are analytically solvable as microwave circuit elements.



- Inductively coupled
- Disk does not share feedline ground

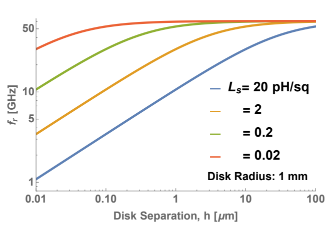


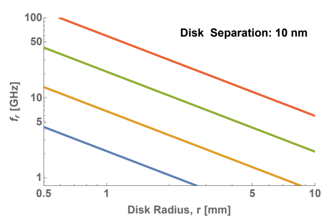
- Capacitively coupled
- Disk shares feedline ground

Design Equations

A disk resonator's resonant frequency depends on its size, disk separation and its surface inductance. High surface inductance materials and small disk separations are needed to bring the resonant frequency into a usable range. Resonator footprints of 500 x 500 µm to 1000 x 1000 µm can be realized in the 1 – 10 GHz range.

Resonant frequencies are related to Bessel function zeros. $j_{1,1}$ is the first zero of the first Bessel function.





Signal To TLS Noise

$$\mathrm{SNR} \propto r\ \alpha_{\mathrm{ki}}\ \epsilon\ P_{\mu w}^{1/4} \sqrt{QQ_i}\ \frac{\delta E}{T_c^2 V_{\mathrm{metal}}}$$

Kinetic Inductance Fraction

$$\alpha_{\mathrm{ki}} = \frac{1}{1 + \frac{\mu h}{L_{s,1} + L_{s,2}}}$$

Resonant Frequency

$$f_r = \frac{j_{1,1}}{2\pi r \sqrt{\mu\epsilon} \sqrt{1 + \frac{L_{s,1}+L_{s,2}}{\mu h}}}$$

Lumped Element Approximation

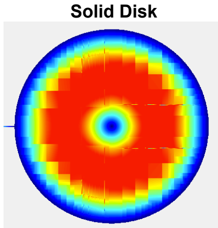
$$C = \frac{\epsilon \pi r^2}{h} \qquad L = \frac{\mu h}{\pi j_{1,1}^2} \sqrt{1 + \frac{L_{s,1} + L_{s,2}}{\mu h}}$$

Coupling Q

$$Q_c = \frac{2\sqrt{L(C + C_c)^3}}{Z_0\ C_c^2}$$

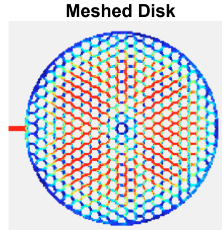
Simulations

Solid Disk



- Sonnet® E&M Simulation of TM_{02} resonance mode
- $f_r = 4.13\ \mathrm{GHz}$
- $r = 0.5\ \mathrm{mm}$

Meshed Disk



- Resonance still exists after meshing
- Reduces resonance frequency by up to ~17%
- Reduces metal volume
- Avoids vortex losses from magnetic flux penetration

Challenges and Ongoing Development

- Meshing is being explored as a way to reduce the resonator volume and vortex penetration.
- Nearby disk modes could interfere with reading out large numbers of resonators on the same feedline. Slits in the disk may suppress some of these modes.
- ~10 nm thick dielectrics are needed to reduce the resonator size. We've currently reached internal quality factors of ~40,000.
- See Grégoire Coiffard's talk (Thursday 12:45 O-65) for another example of a parallel plate resonator geometry that we are exploring.