

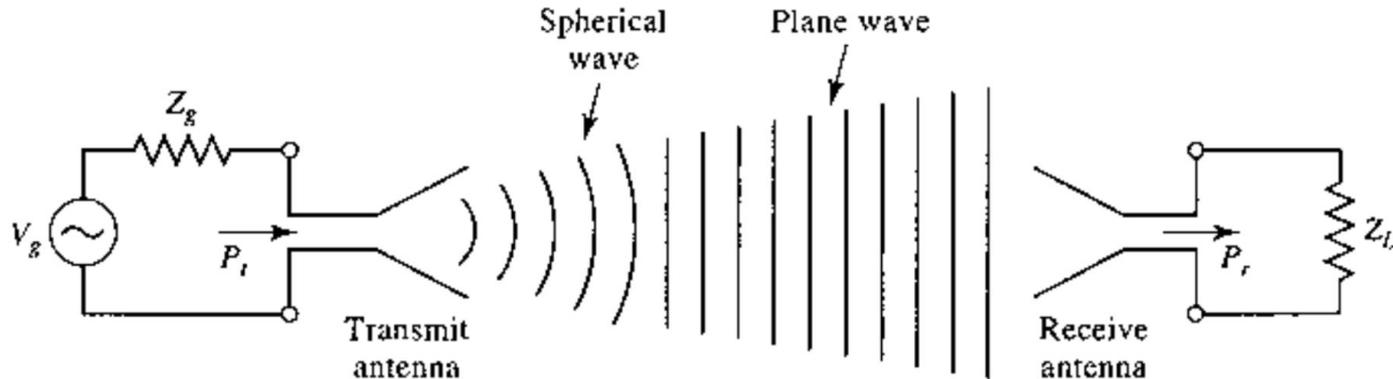


Antenna coupling to qubits

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What is an antenna?

A transmitting antenna can be viewed as a device that converts a guided electromagnetic wave on a transmission line into a plane wave propagating in free space. Thus, one side of an antenna appears as an electrical circuit element, while the other side provides an interface with a propagating plane wave. Antennas are inherently bidirectional, in that they can be used for both transmit and receive functions.





AC Josephson Effect

From the Josephson voltage-phase relationship: $\frac{\partial \varphi}{\partial t} = \frac{2\pi}{\Phi_0} \int \mathbf{E} \cdot d\mathbf{l}$

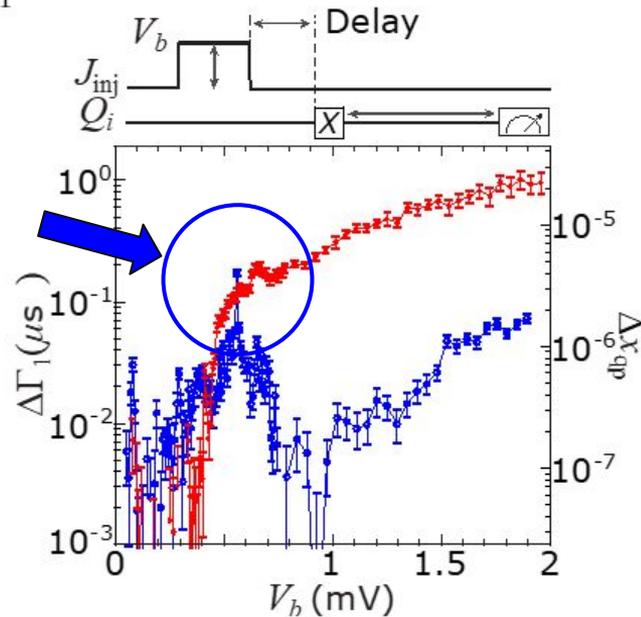
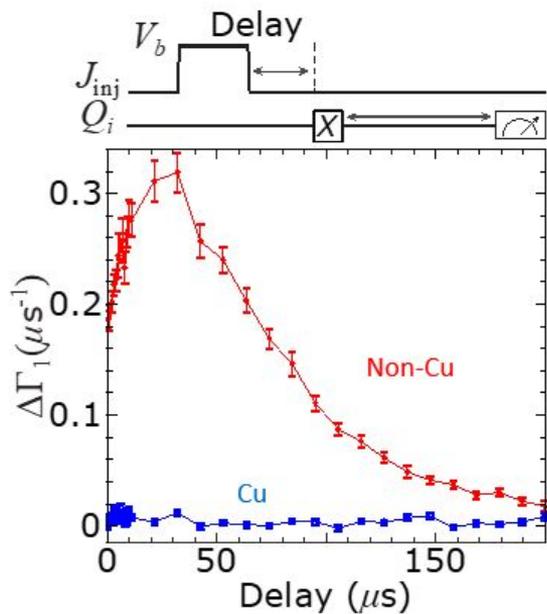
We know that the phase across a junction with DC voltage across it will be: $\varphi = \varphi_0 + \frac{2\pi}{\Phi_0} V_{dc} t$. Then, the current will be $i = I_c \sin \left(2\pi \frac{V}{\Phi_0} t + \varphi_0 \right)$. Notably, there is an AC current through the junction with frequency V/Φ_0 .



Early Experimental Evidence

Enhanced qubit relaxation from controlled phonon injection

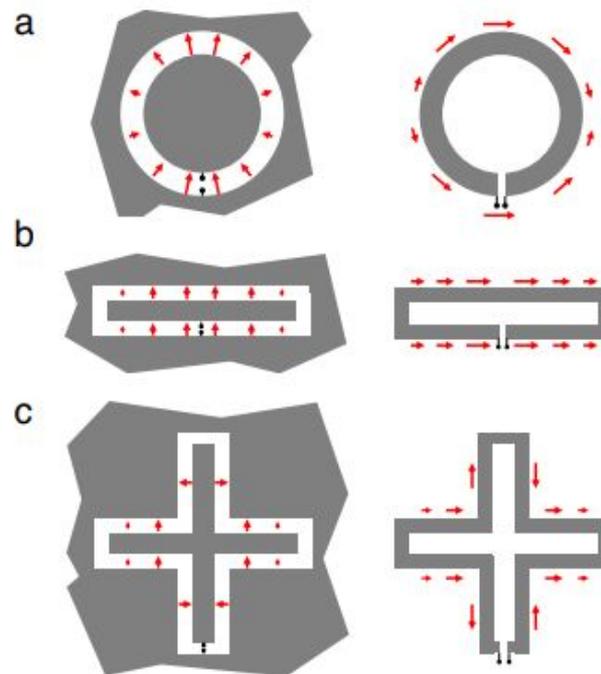
$$\Delta\Gamma_1 = \frac{1}{T_1} - \frac{1}{T_1^b}$$





Babinet's Principle

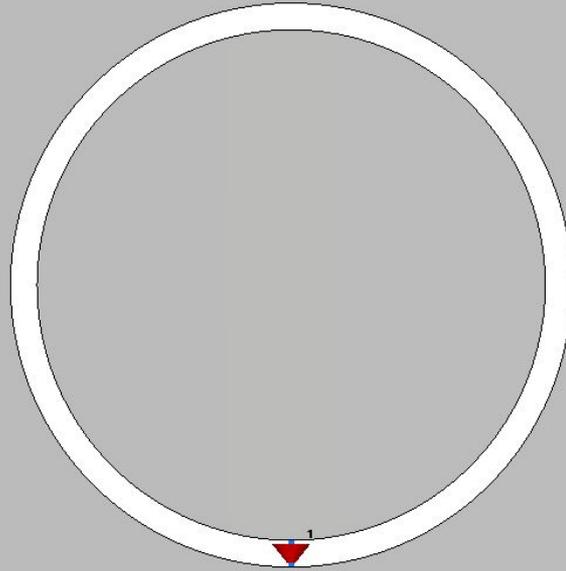
Babinet's Principle states that a planar antenna driven by a current source can be transformed into a dual by changing the antenna's conductor into free space and the free space surrounding the antenna in the plane into a conductor driven by a voltage source.



O. Rafferty et al. ArXiv (2021)

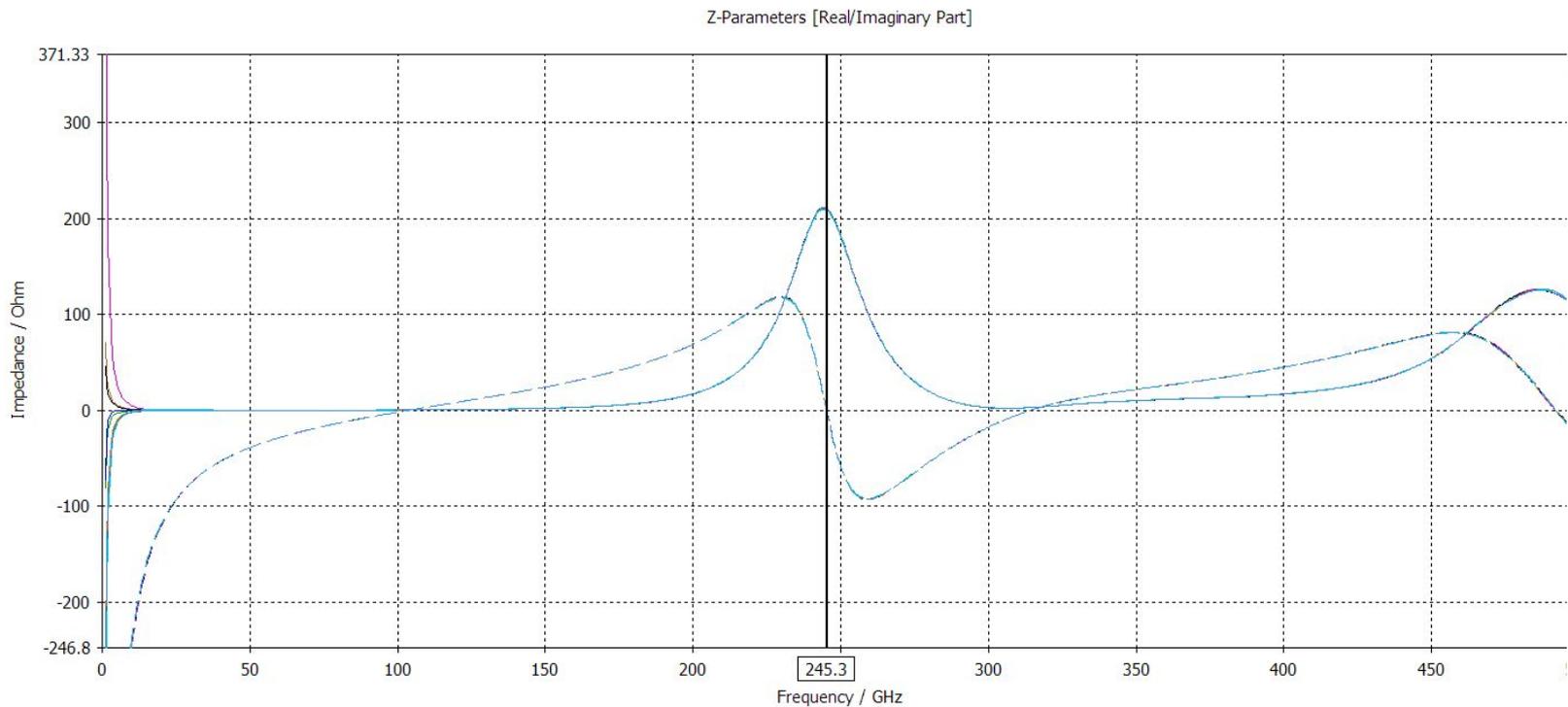


Simulation of antenna geometry

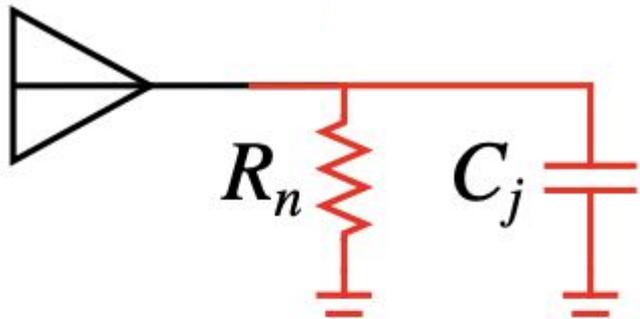




Impedance results

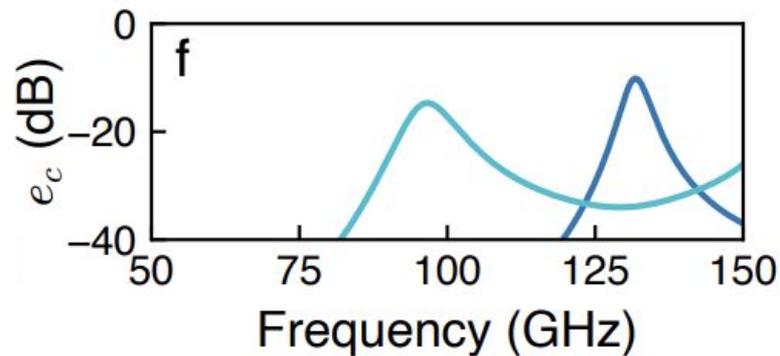
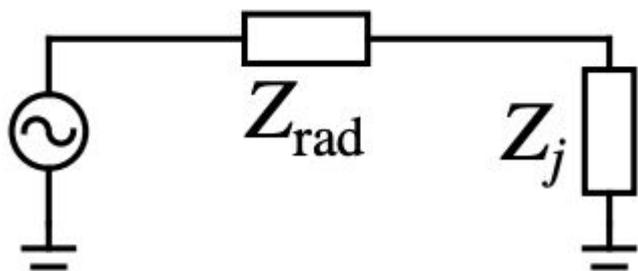


Coupling to the Josephson Junction



$$R_n = \frac{\pi \Delta}{2eI_0}, \quad Z_j = \frac{1 - j\omega\tau}{1 + \omega^2\tau^2} R_n,$$

$$\Gamma = \frac{Z_{\text{rad}} - Z_j^*}{Z_{\text{rad}} + Z_j}, \quad e_c = 1 - |\Gamma|^2,$$





Quasiparticle poisoning rate

$$P = \int S(f, T) e_c(f) df$$
$$\approx \frac{hf_0}{e^{hf_0/k_B T} - 1} \Delta f_N,$$
$$\Delta f_N = \int e_c df.$$

$$\Gamma_{\text{pa}} = \frac{\Delta f_N}{e^{hf_0/k_B T} - 1}.$$



T₁ times

$$T_1 = \frac{C}{\operatorname{Re}[Y_a(\omega_{01})]},$$

From Babinet's principle, we know that $Z_w Z_a = \frac{\eta^2}{4}$,
so $Y_a = \frac{4Z_w}{\eta^2}$

$$T_1 = \frac{\eta^2}{4} \frac{C}{\operatorname{Re}[Z_w(\omega_{01})]}.$$



Conclusion

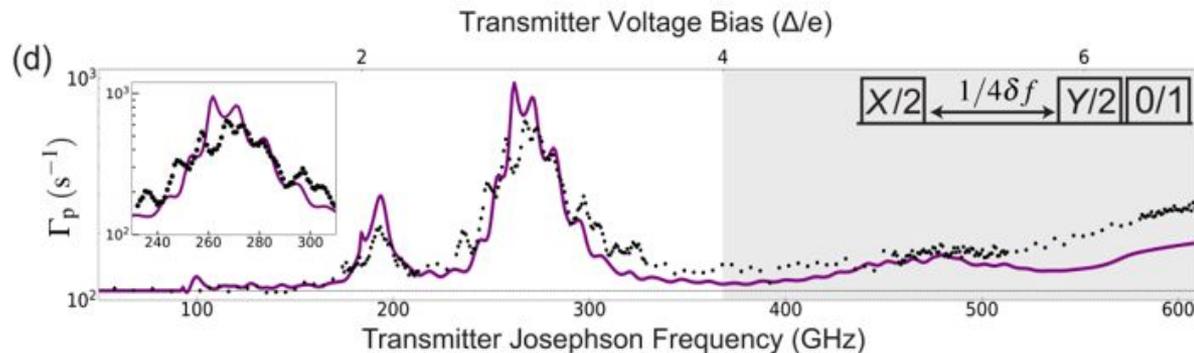
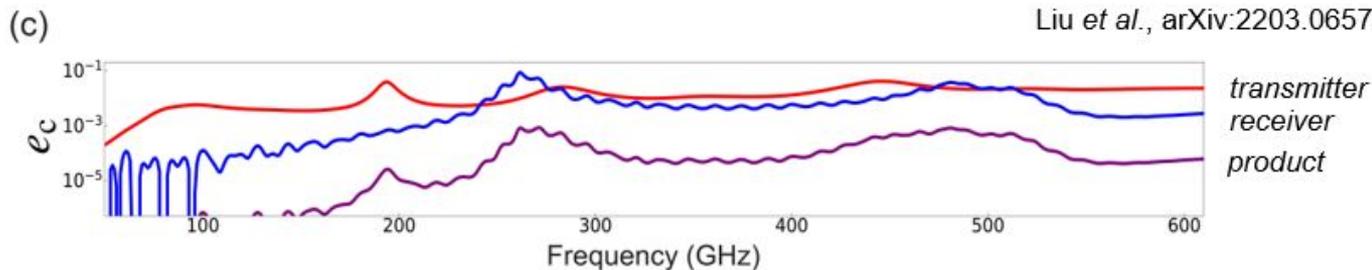
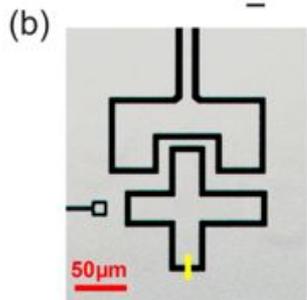
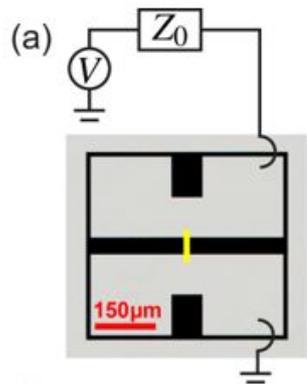
- By simulating transmon capacitive islands as antennas, we are accurately able to calculate qubit-antenna resonant frequencies, quasiparticles poisoning rates and T1 times
- Validate IR shielding by designing qubits with different antenna modes and comparing background rates to shielded rates



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Photon-mediated Quasiparticle Poisoning

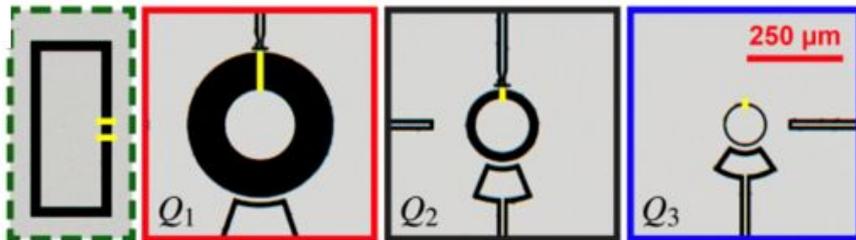
Liu et al., arXiv:2203.06577



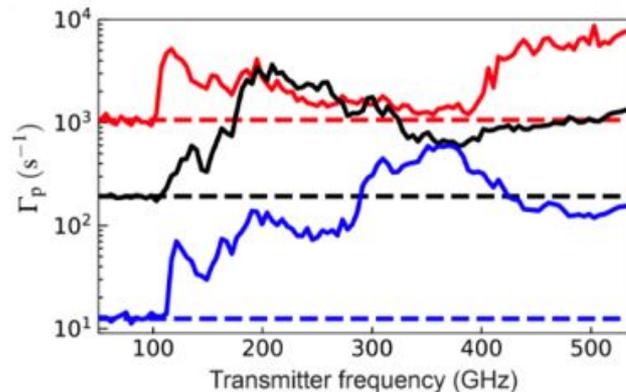
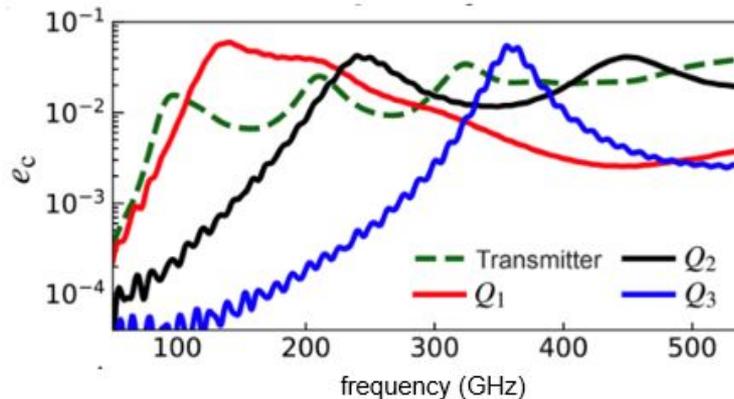
Mitigating photon-mediated QP poisoning:

- More compact shunt capacitor designs for higher frequency antenna modes
- Further improvements to filtering, shielding, thermalization to reduce effective blackbody temperature of photons in qubit environment

Photon-mediated Quasiparticle Poisoning



Liu *et al.*, arXiv:2203.06577



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