Cryogenic Infrared Filtering

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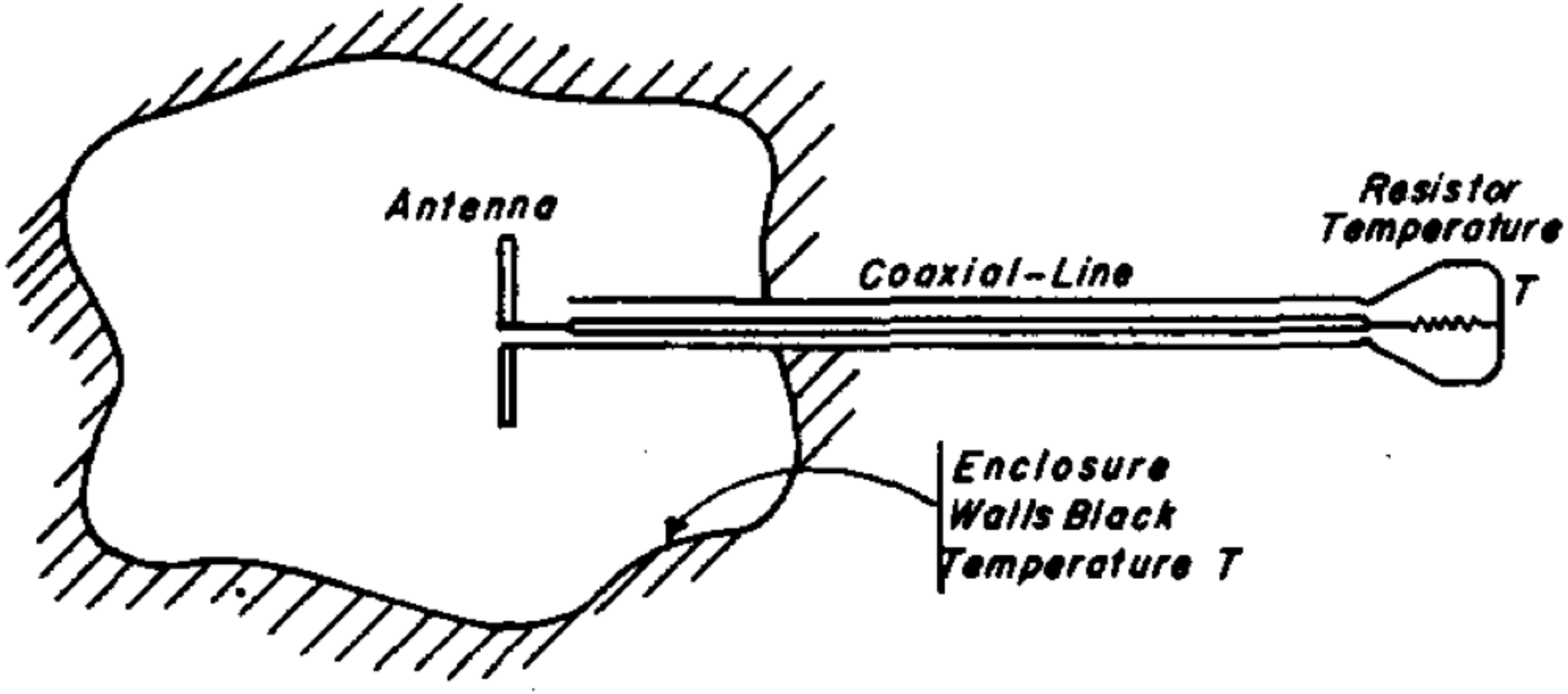
Why do we spend time arguing about attenuation in the fridge?

- During commissioning, we spend a lot of time installing cryogenic attenuators at multiple fridge stages. This is mechanically fussy and may feel counterintuitive

Start with a thought experiment.



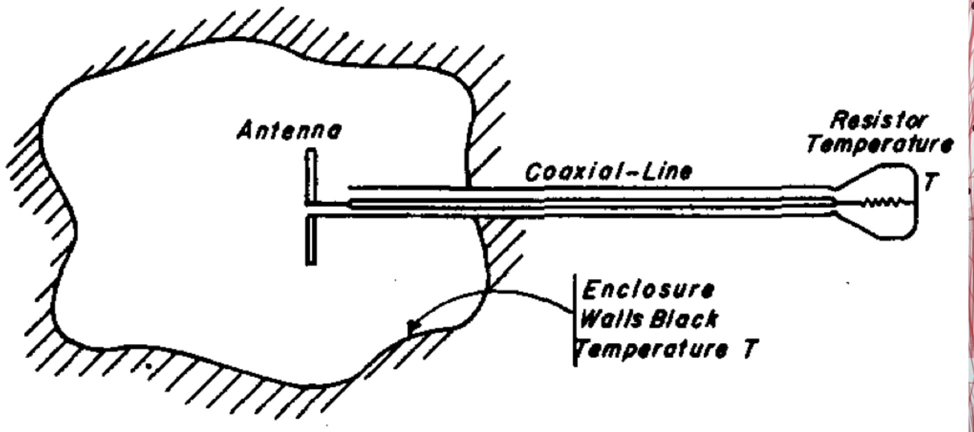
Johnson-Nyquist Noise

THE REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 17, NUMBER 7 JULY, 1946

The Measurement of Thermal Radiation at Microwave Frequencies

R. H. DICKE*
*Radiation Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts***

(Received April 15, 1946)



- Thermal activity of charge carriers —> measurable current flow
- Connection to thermal radiation emphasized by Dicke in above paper.
- Equipartition theorem leads to:

$$\langle E \rangle = \frac{\langle V^2(t) \rangle}{4R} = \frac{h\nu}{e^{h\nu/kT} - 1}$$

And in the low-frequency limit, $$\lim_{h\nu \ll kT} \langle E \rangle = kT$$

Distinguishing coherent and thermal photon noise in a circuit QED system

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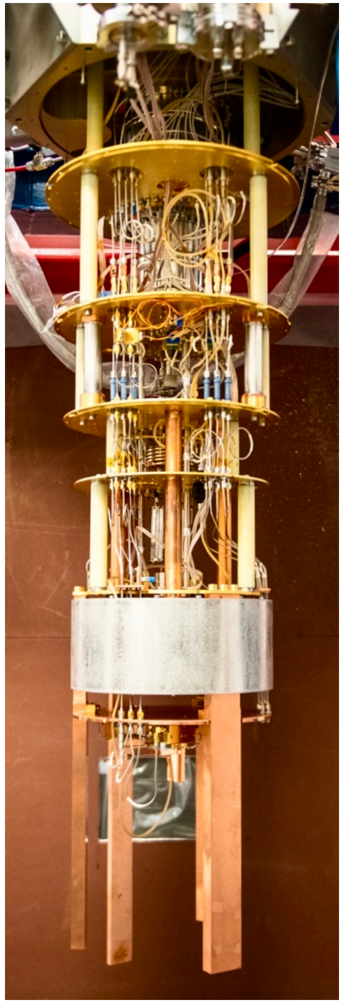
$\omega_q/2\pi = 4.7\,\text{GHz}$, $T_1 = 35-55\,\mu\text{s}$ and $T_{2\text{Echo}} = 40\,\mu\text{s}$ [8]. Fig. 4a shows the spin-locking noise spectroscopy results, which again demonstrate the characteristic factor of 2 difference between the HWHMs of injected coherent and thermal photons. We also found that the spectrum measured without added noise (blue) has a -3 dB point consistent with thermal photon noise. Therefore, we suspected that thermal radiation from higher-temperature stages in the DR were responsible for the residual cavity photons and the resulting dephasing. By measuring the dependence of the dephasing rate on the average number of engineered thermal-noise photons, we extrapolated the average residual thermal photon number in the absence of externally applied noise to be around 0.006, corresponding to an 80 mK equilibrium temperature [8]. During a subsequent thermal-cycling of the dilution fridge, we increased the attenuation at the mixing chamber (20 mK) from 23 dB to 43 dB in order to reduce the thermal photons reaching the cavity (see details in supplement [34]). This modification significantly increased $T_{2\text{Echo}}$ to $80\,\mu\text{s}$ (Fig. 4b), while T_1 did not change. The new attenuator configuration effectively suppresses the residual thermal photons in our cavity to $\bar{n} < 0.0006$ [34], ten times lower than the previous level. This corresponds to an equivalent equilibrium temperature of 55 mK. Due to temporal spread of coherence times and measurement uncertainty, we could not confirm a lower bound, though measurements of the excited-state population of several qubits tested in the same dilution fridge found an effective temperature of 35 mK [35].

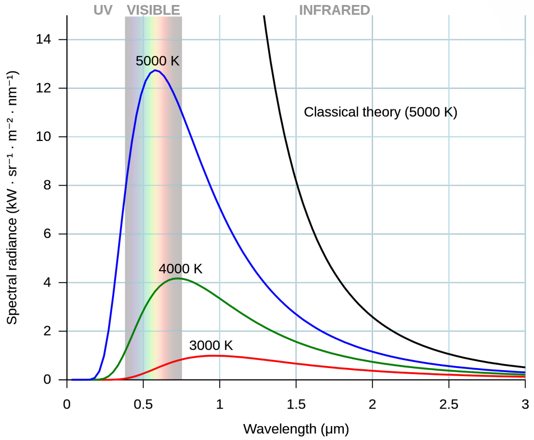
To conclude, we developed a spin-locking ($T_{1\rho}$) technique for performing non-classical noise spectroscopy and demonstrated it using engineered photon noise applied to a superconducting circuit QED system. The measured noise spectra were used to distinguish between

Experimental payloads see thermal photons from each fridge stage.



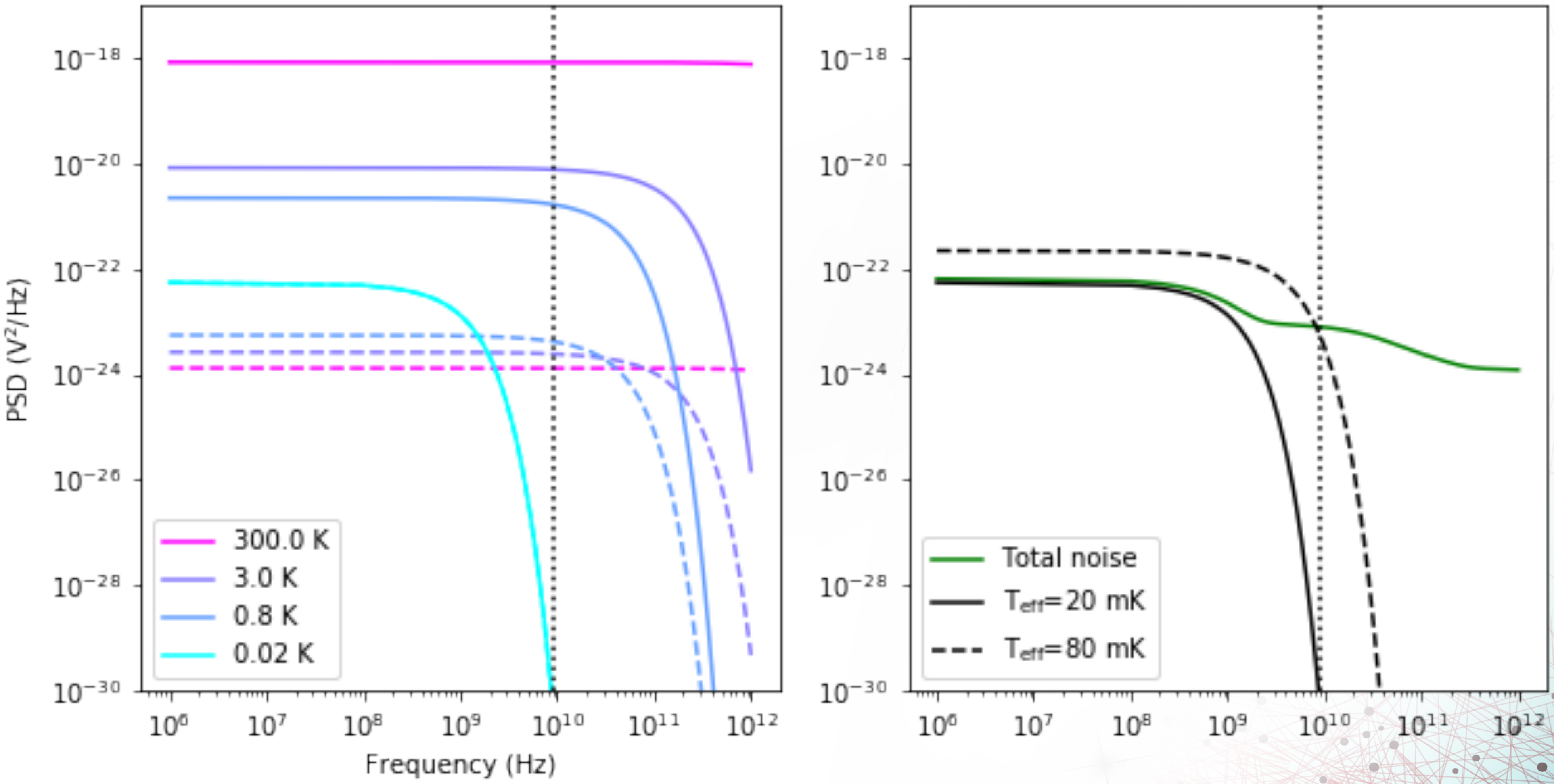
$$S_{VV}(f;R,T) = 4R\frac{hf}{e^{hf/k_BT}-1}$$

$$S_{VV}(f_c) \to \sum_n A^{(n)} S_{VV}(f_c;R^{(n)},T^{(n)})$$



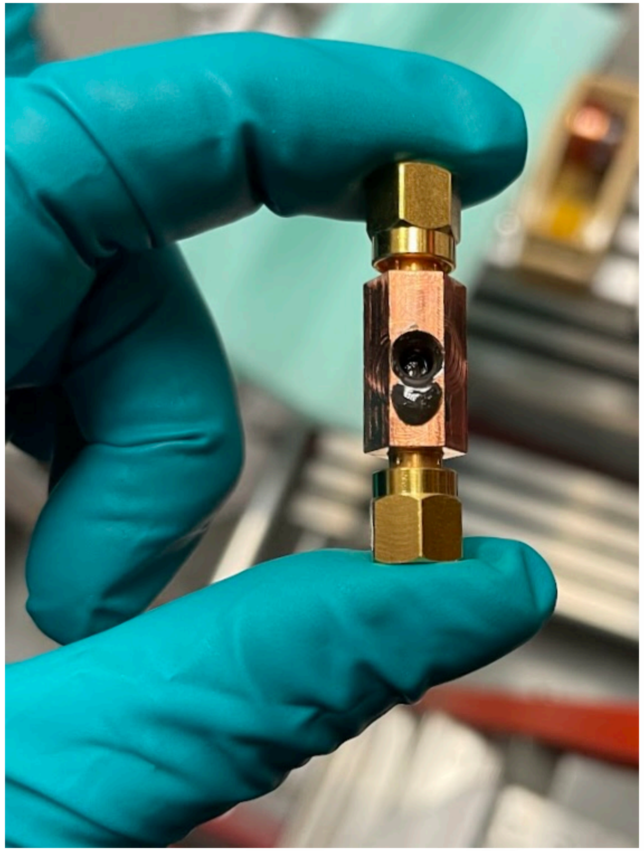
$A^{(n)}$ in this context is the attenuation at a specific fridge stage.

Noise contributions with and without added attenuation:

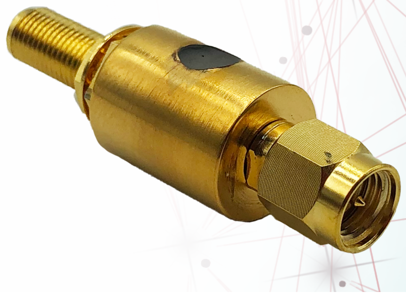


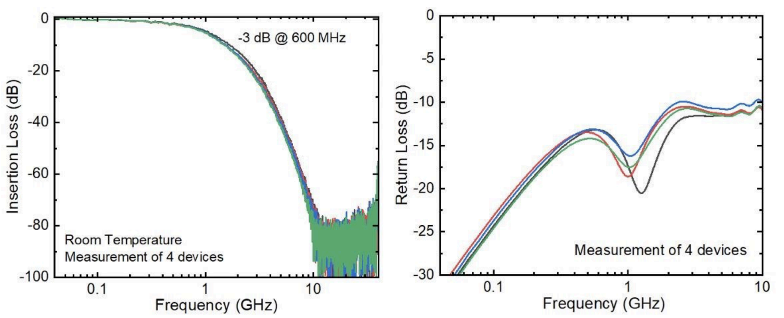
What's a good, broadband IR absorber?

We've used [Eccosorb CR-110](https://www.laird.com).



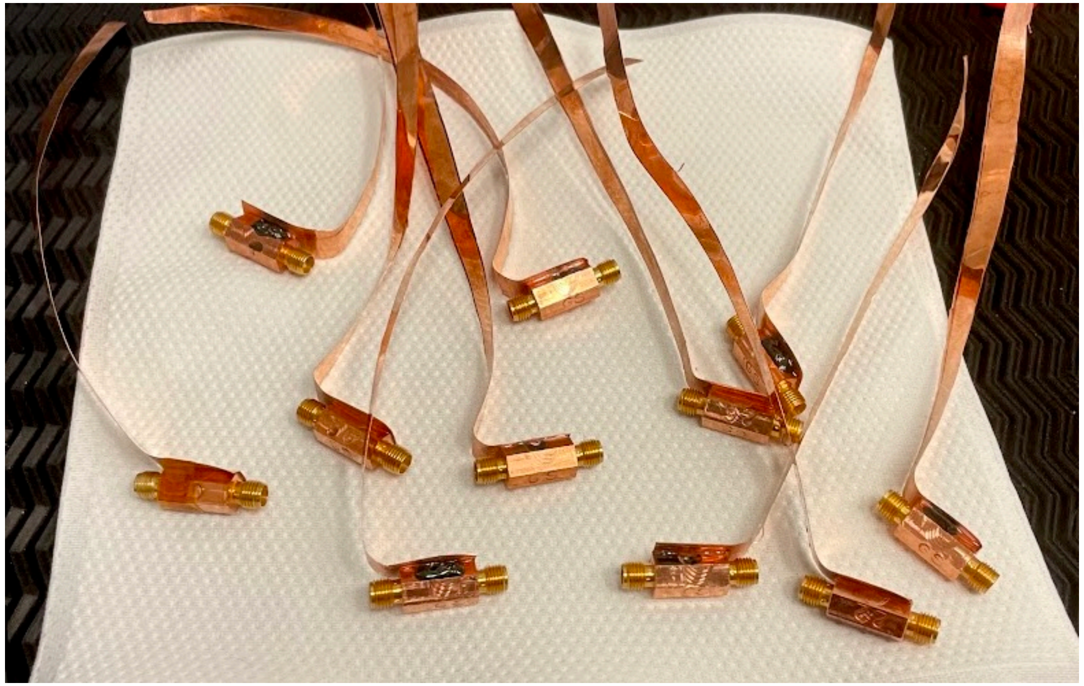
Thanks, G. Spahn (NWU)

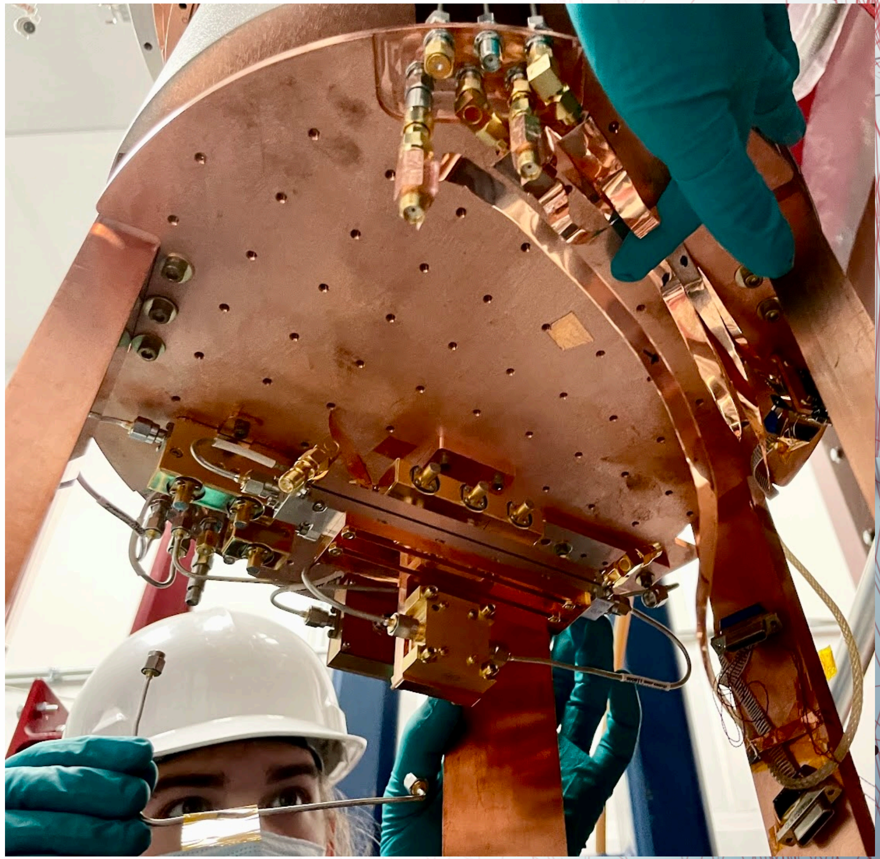




Quantum Microwave. makes a version of this too.

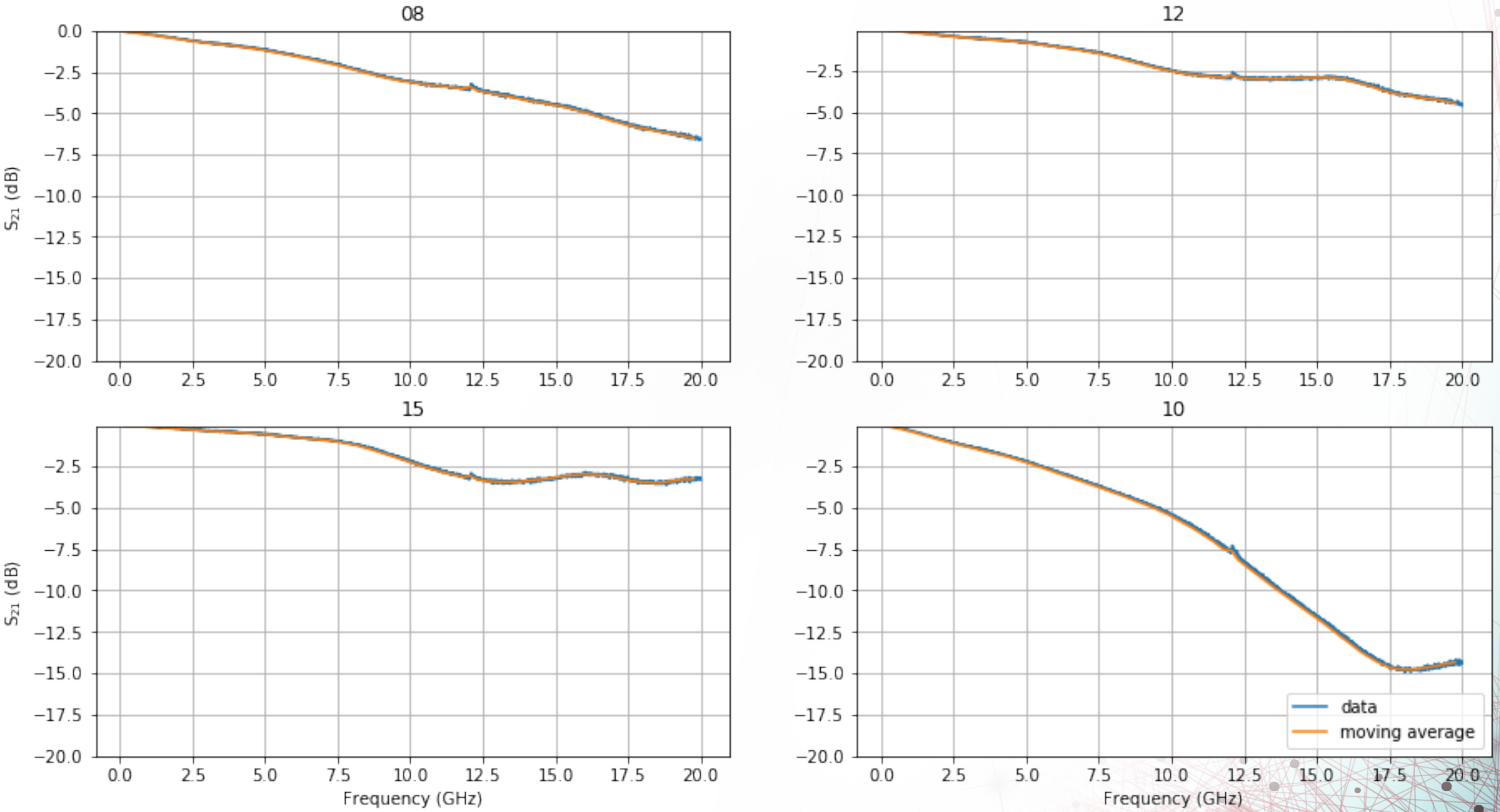
Broadband IR absorbing filters exist.





- G. Spahn & N. Kurinsky made a batch of these recently.
- Rumor: well-thermalized commercial filters are on their way…
- Photo credit: S. Lewis

S21 measurements of selected filters (G. Spahn)



Parting Thoughts

- For the 4-qubit UW package in NEXUS, we were given a spec of reducing charge noise to $\gtrsim$ 100 pC.
- Your experiment may have different requirements, necessitating a different arrangement of attenuators.
- This also motivates serious thought about how to thermalize the various components in your fridge! Magnetic shields, e.g.

Acknowledgements

Thanks to the people whose work is directly referenced in this talk:

- Sami Lewis (FNAL)
- Noah Kurinsky (SLAC)
- Gabe Spahn (U. Wisconsin-Madison)

References for those interested

- https://bingweb.binghamton.edu/~suzuki/Math-Physics/LN10S_Jphnson-Nyquist_noise.pdf
- https://123.physics.ucdavis.edu/week_2_files/Johnson_noise_intro.pdf
- https://wiki.physics.wisc.edu/ObsCos/images/c/c8/Dicke_Detection_of_Thermal_Radiation_RSI_1946.pdf
- https://arxiv.org/pdf/1801.00467.pdf