Development of Polarization Sensitive Multi-Chroic MKIDs for CMB Studies

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Development of Polarization Sensitive Multi-Chroic MKIDs for CMB Studies

B. R. Johnson (PI), D. Flanigan, M. H. Abitbol, P. A. R. Ade, S. Bryan, H.-M. Cho, R. Datta, P. Day, S. Doyle, K. Irwin, G. Jones, S. Kernasovskiy, D. Li, P. Mauskopf, H. McCarrick, J. McMahon, A. Miller, G. Pisano, Y. Song, H. Surdi, C. Tucker

Project supported in part by a grant from ***NSF/ATI***.

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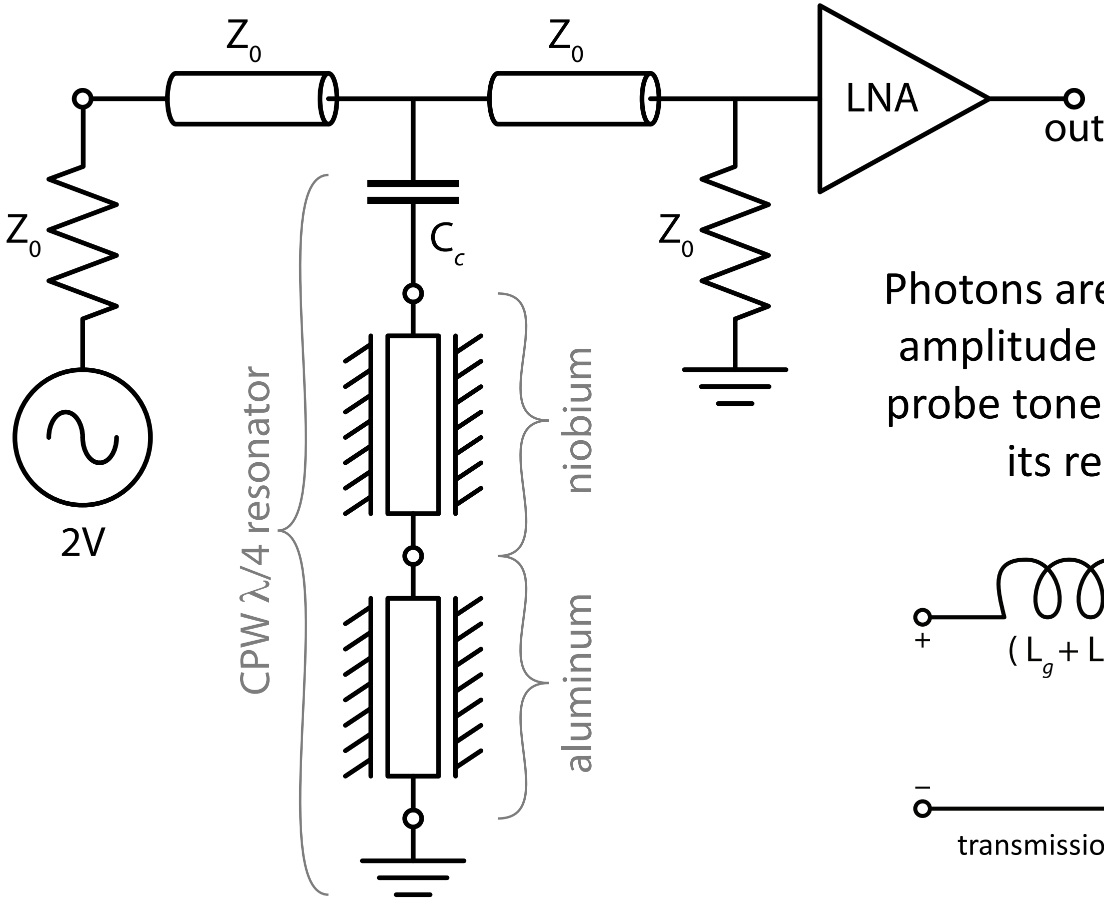
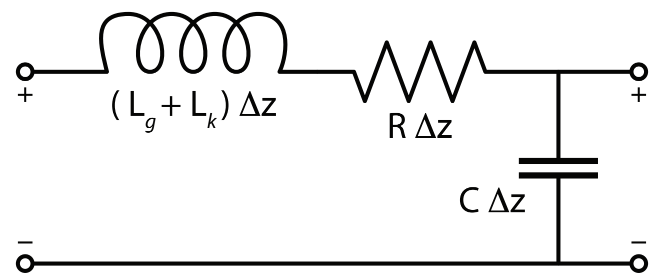
Overview

- We are developing scalable modular arrays of **horn-coupled, polarization-sensitive MKIDs** that are each sensitive to **two spectral bands between 125 and 280 GHz**.
- These MKID arrays are **tailored for future multi-kilo-pixel experiments** that will observe both the cosmic microwave background (CMB) and Galactic dust emission.
- Detector modules like these could be a strong candidate for a **future CMB satellite mission and/or CMB-S4**.
- Our device **design builds from successful transition edge sensor (TES) bolometer architectures** that have been developed by the Truce Collaboration and demonstrated to work in receivers on the ACT and SPT telescopes.

Schematic for One CPW MKID



Photons are detected by measuring amplitude and phase changes in a probe tone driving the resonator at its resonant frequency.



transmission line model for CPW element

See for example, Day et al. (2003) *Nature* 425, 817-821
Yates et al. (2011) *APL*. 99, 7

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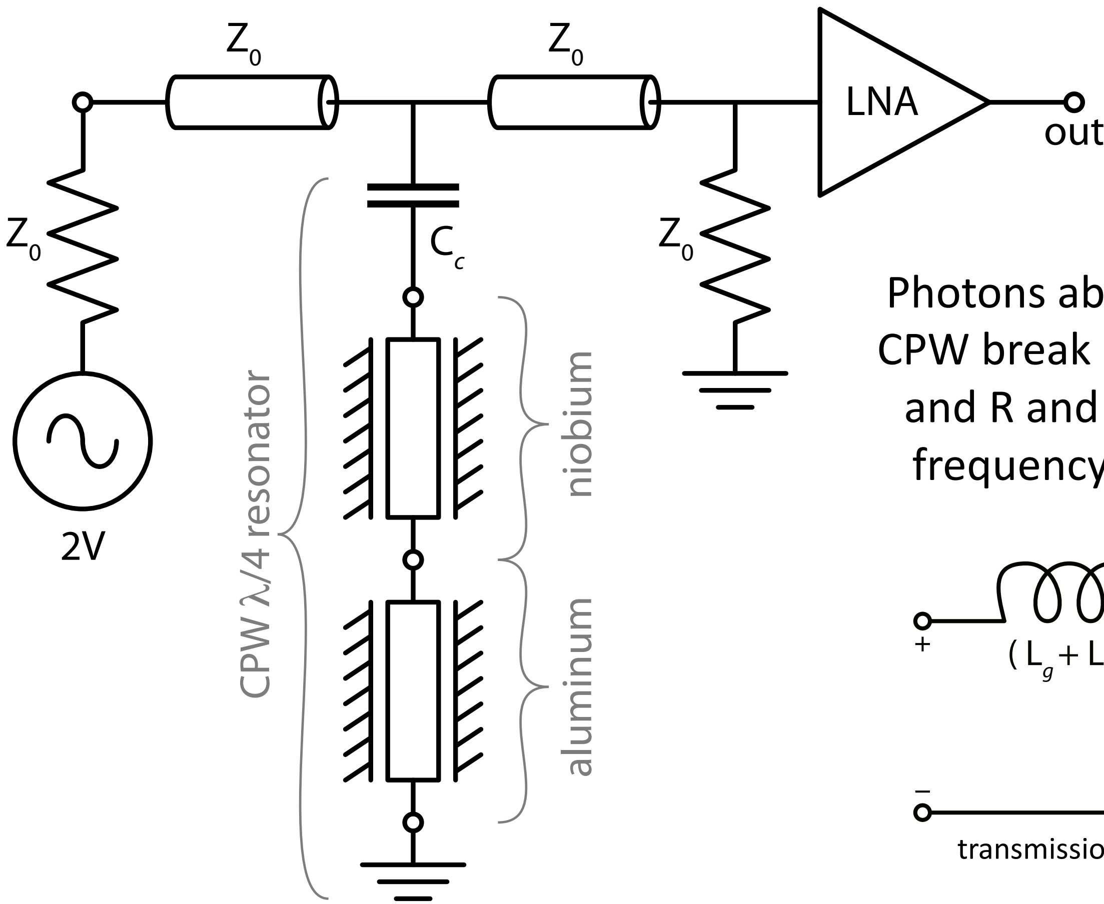
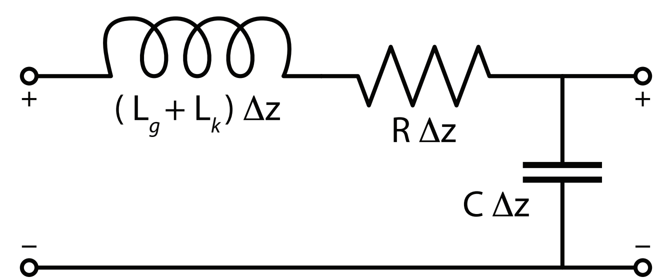
Schematic for One CPW MKID



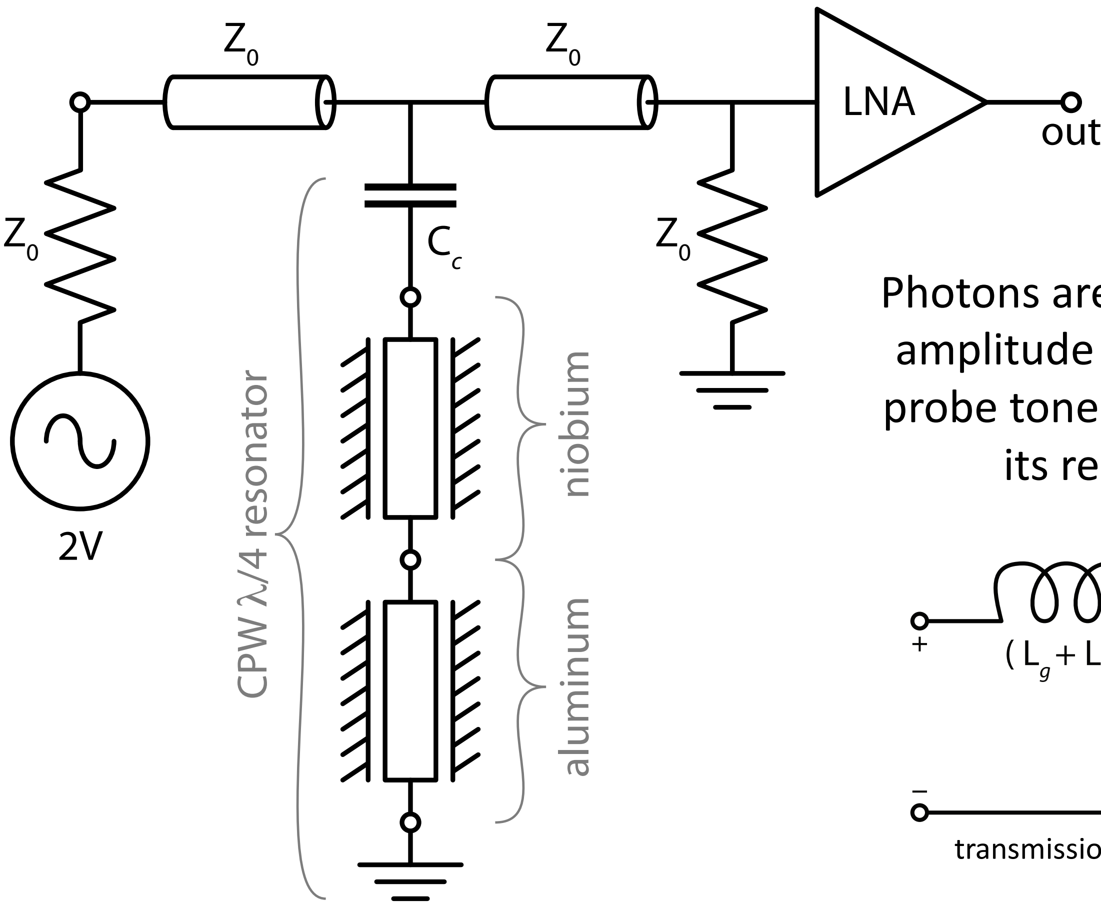
Photons absorbed in the aluminum CPW break Cooper pairs changing L_k and R and therefore the resonant frequency and the quality factor.



transmission line model for CPW element

$$\nu_g = \frac{2\Delta}{h} \approx 74\ \mathrm{GHz} \times \frac{T_c}{1\ \mathrm{K}}$$

Schematic for One CPW MKID



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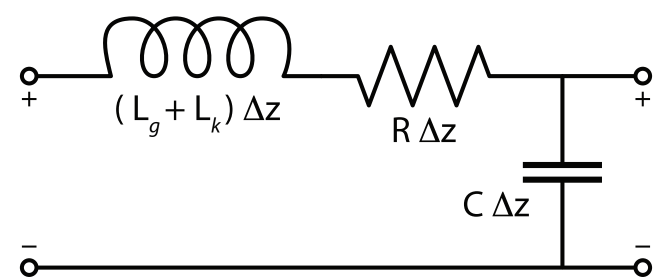
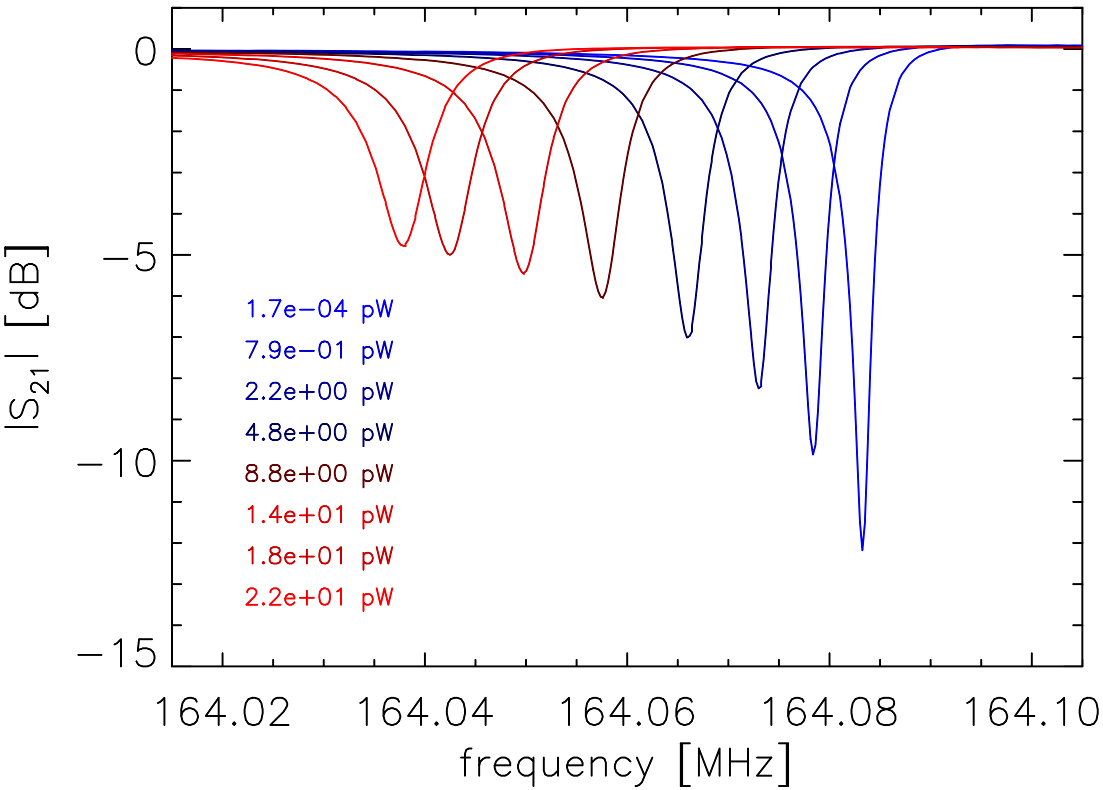


transmission line model for CPW element

$$\nu_g = \frac{2\Delta}{h} \approx 74\ \mathrm{GHz} \times \frac{T_c}{1\ \mathrm{K}}$$

Resonances



$$S_{21} \approx 1 - \frac{Q_r}{Q_c}\frac{1}{1 + j\,2Q_r x}, \;\; x = \frac{f_r - f}{f_r}, \;\; \frac{1}{Q_r} = \frac{1}{Q_c} + \frac{1}{Q_i}$$

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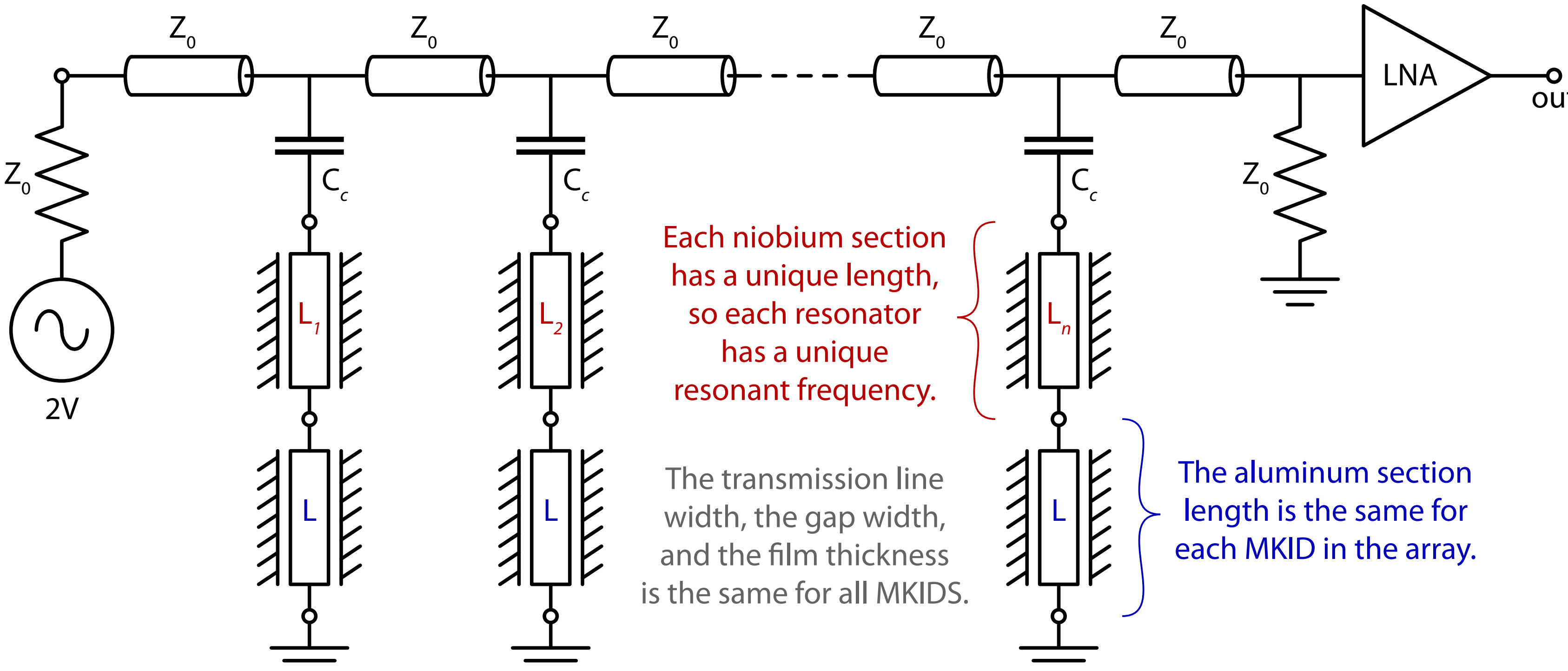
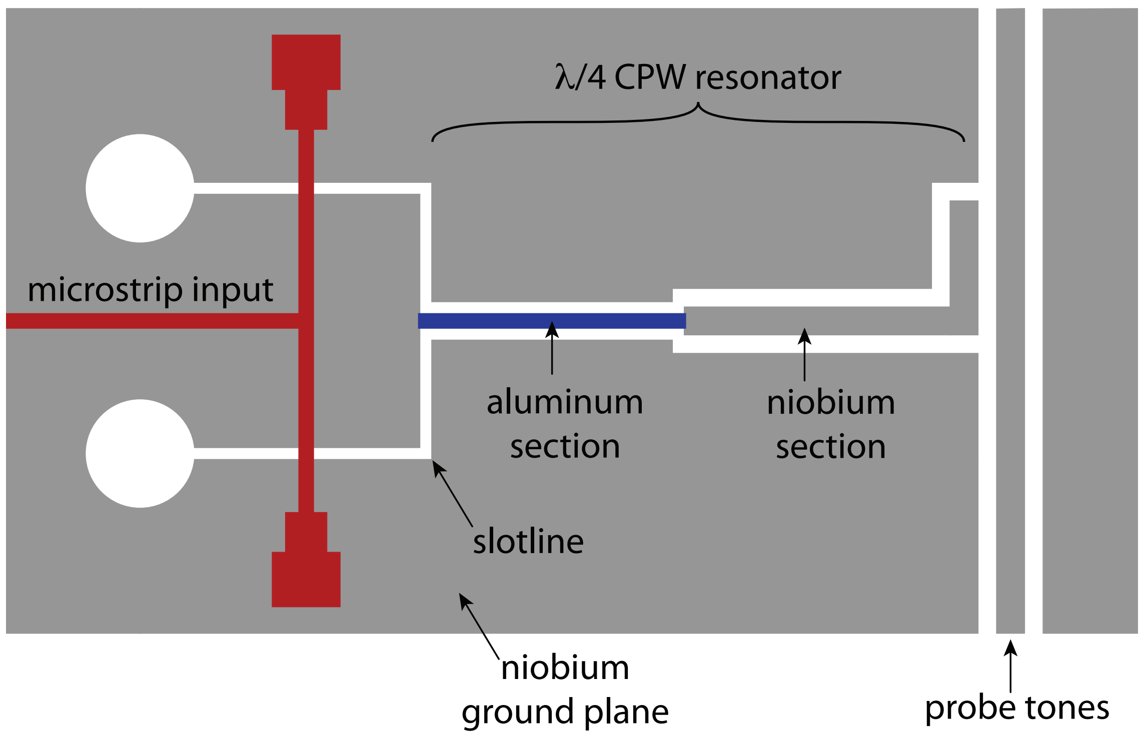
Multiplexing the Array



Hundreds of detectors can be read out with a single pair of coaxial cables.

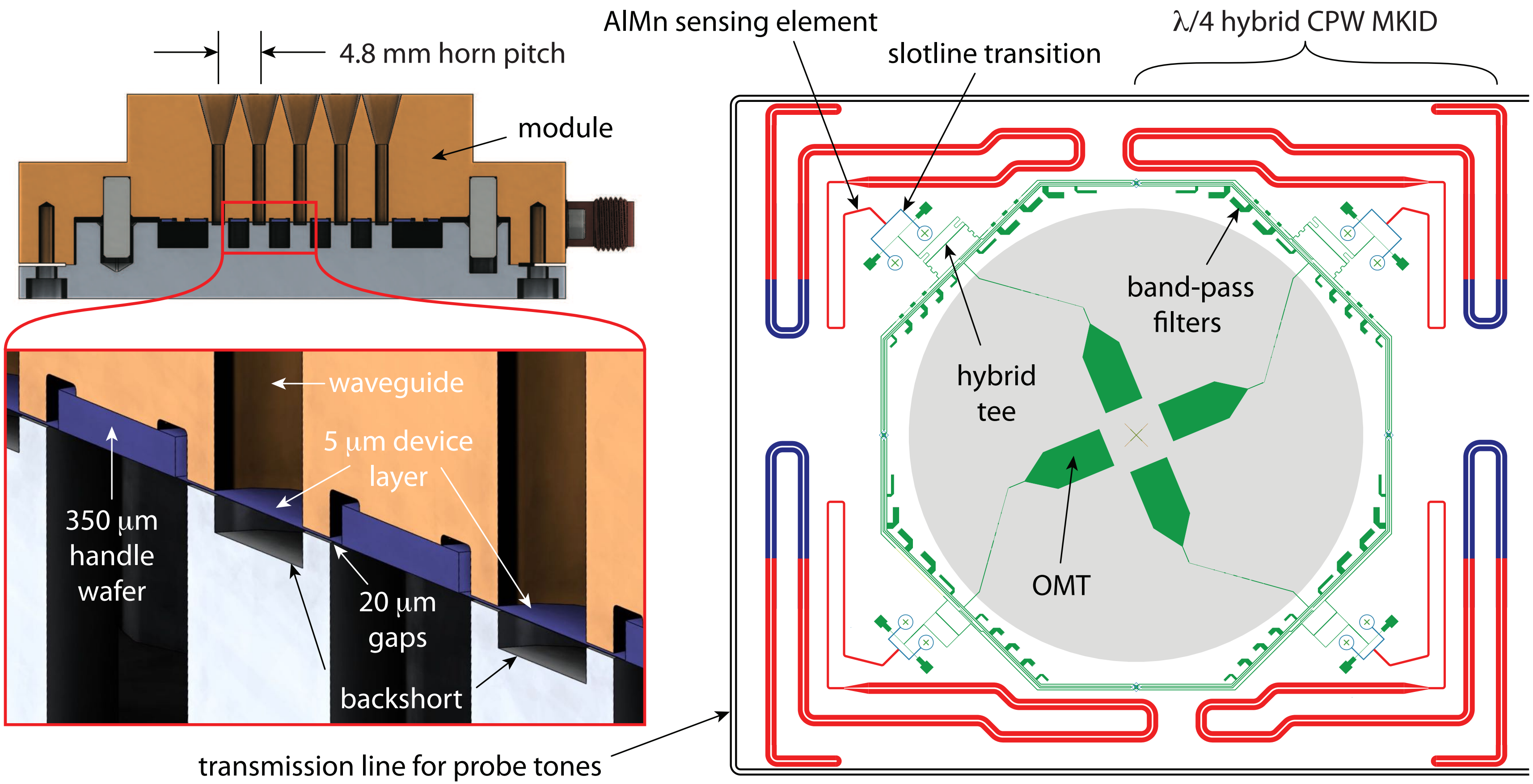
Microstrip-to-CPW MKID Coupling Schematic



Surdi, H. (2016) "*Applications of Kinetic Inductance: Parametric Amplifier & Phase Shifter, 2DEG Coupled Co-planar Structures & Microstrip to Slotline Transition at RF Frequencies*." Dissertation at ASU.

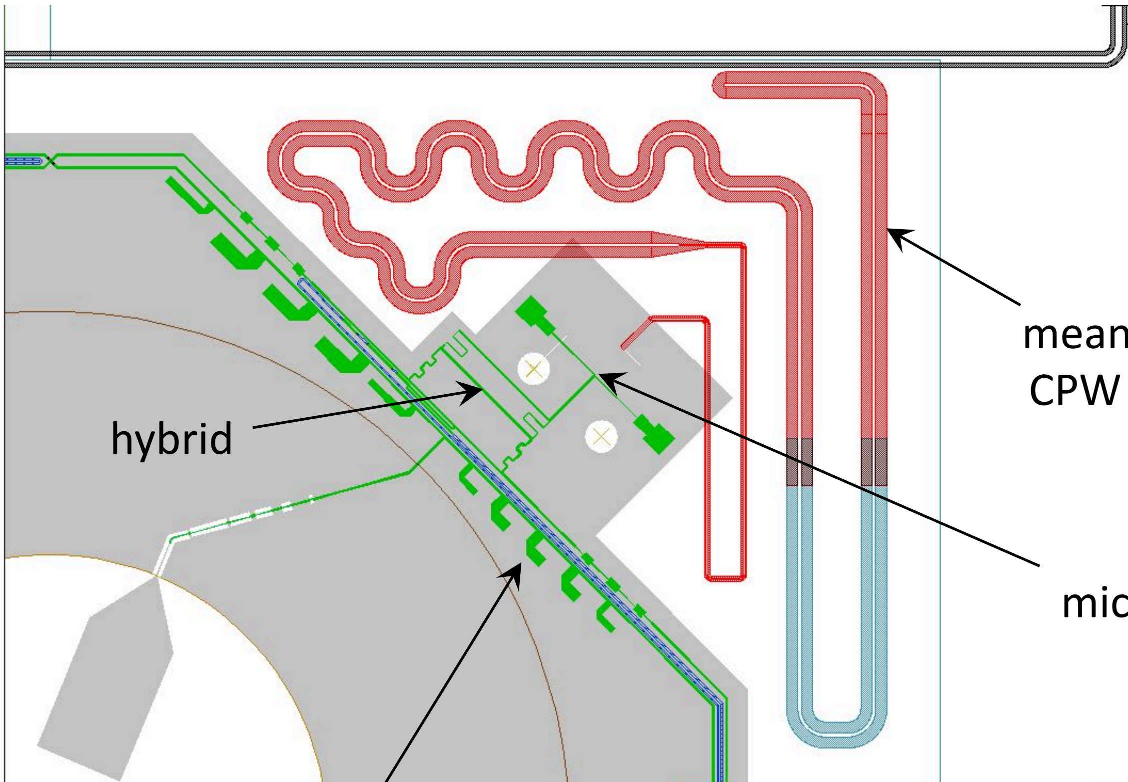
Johnson et al. (2016) *Proc. SPIE*, 9914, 99140X

Development of Multi-Chroic MKIDs



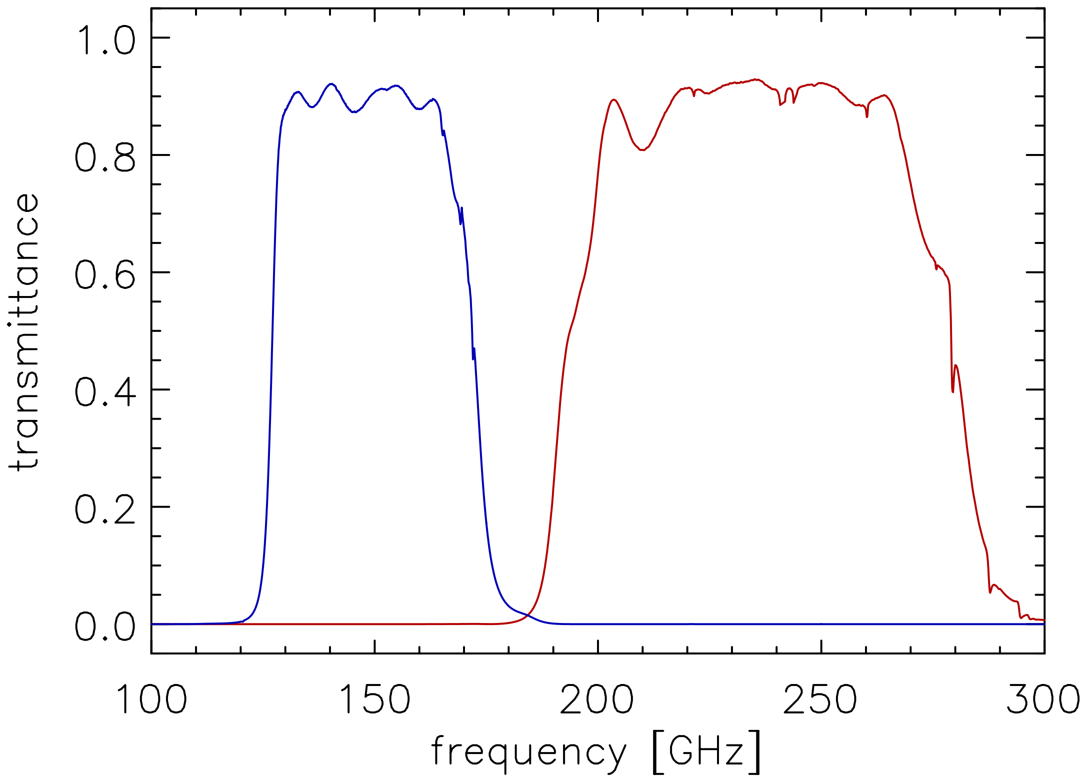
based on: Datta et al. (2014) *J. Low Temp. Phys.* 176, 670–676

Array Element Details



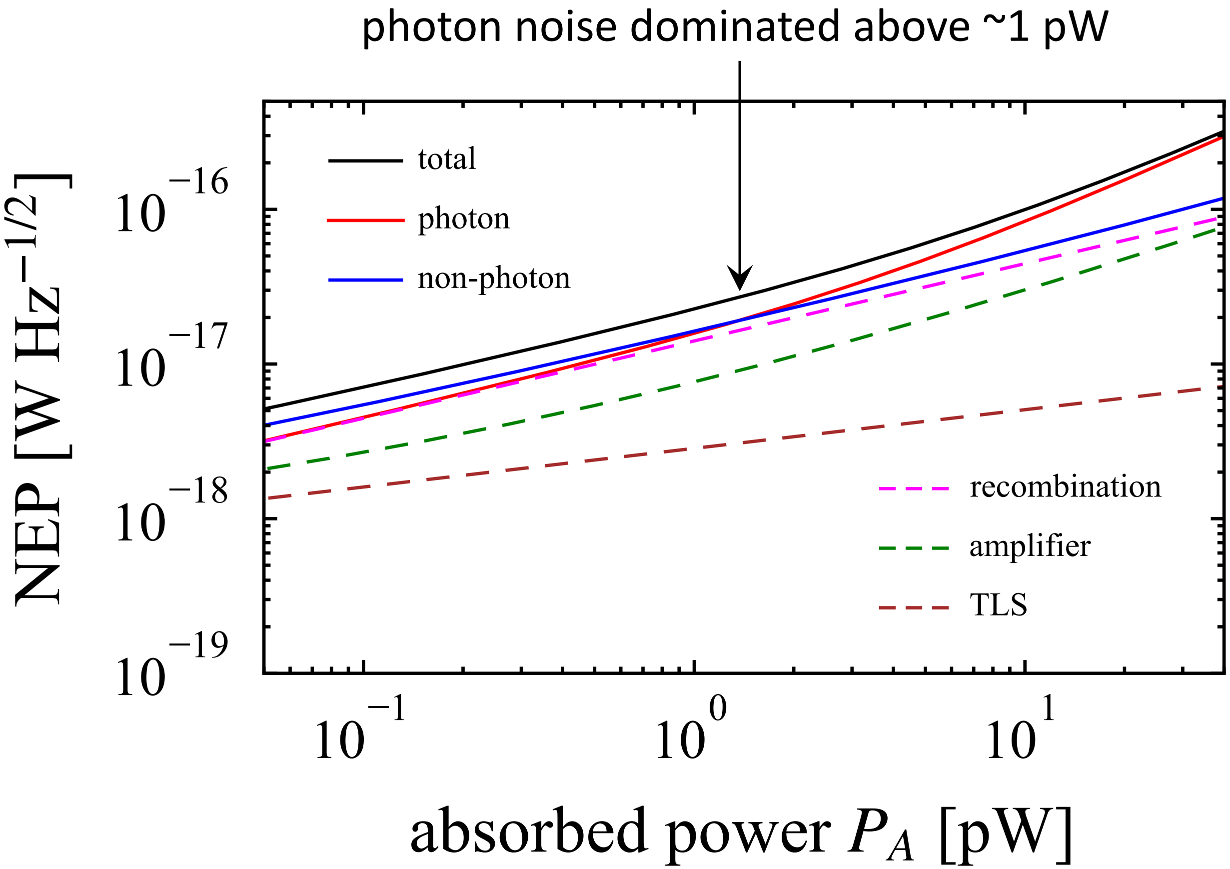
MKID resonant frequencies around 3 GHz

Simulated Spectral Bands



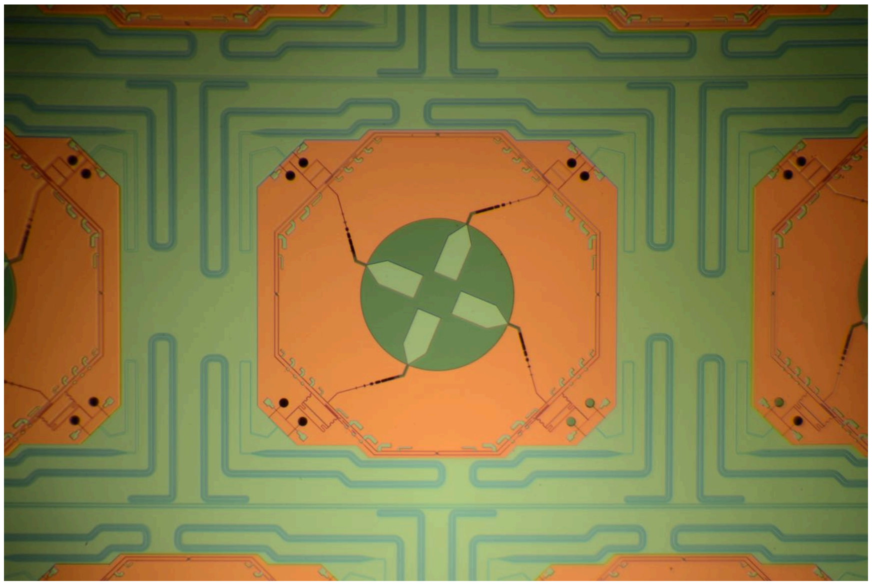
HFSS/Sonnet simulation results show the expected absorption efficiency is approximately 90% taking into account all of the elements in the circuit except the OMT probes.

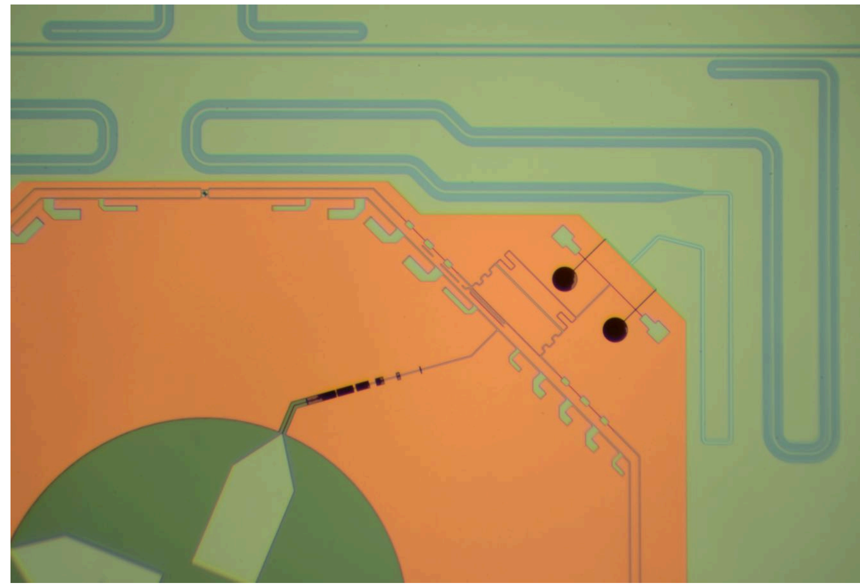
Noise Sources and Expected NEP @ 150 GHz



We have **plans to fabricate aluminum manganese sensors**, which will make the MKIDs photon-noise dominated at lower absorbed power levels.

Photographs of First Devices

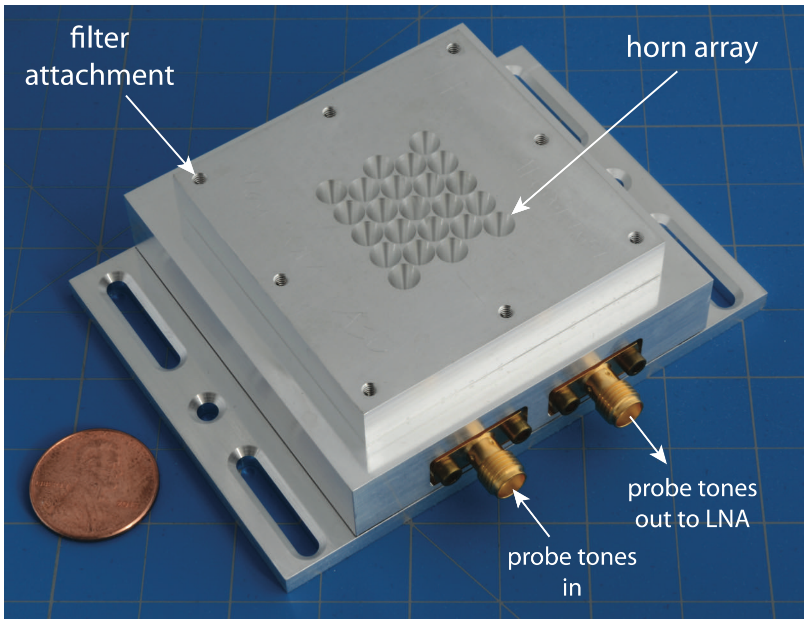


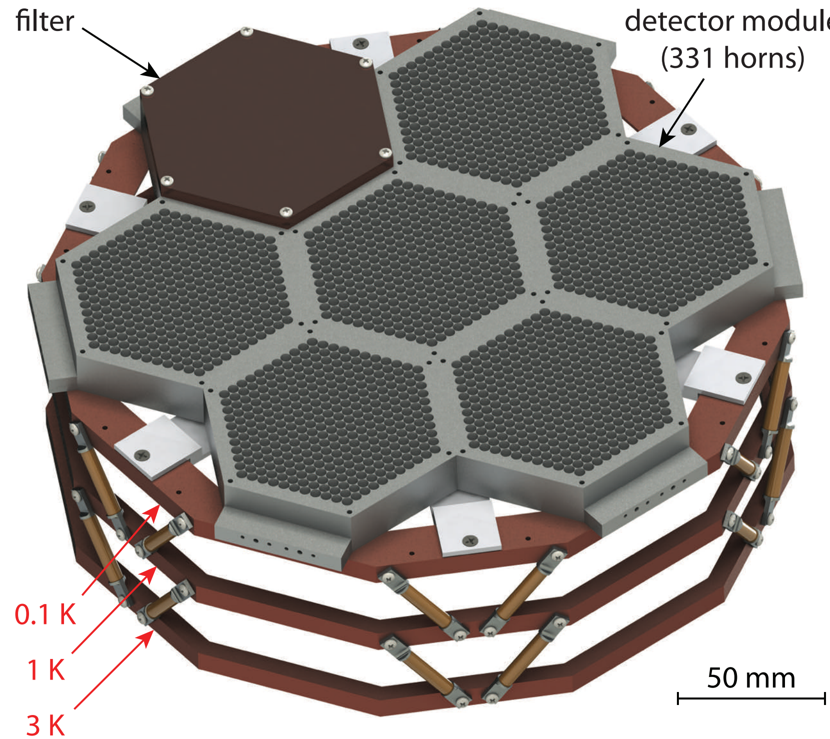


Fabricated at Stanford

Multi-Chroic MKID Array Goal

prototype module (23 horns)

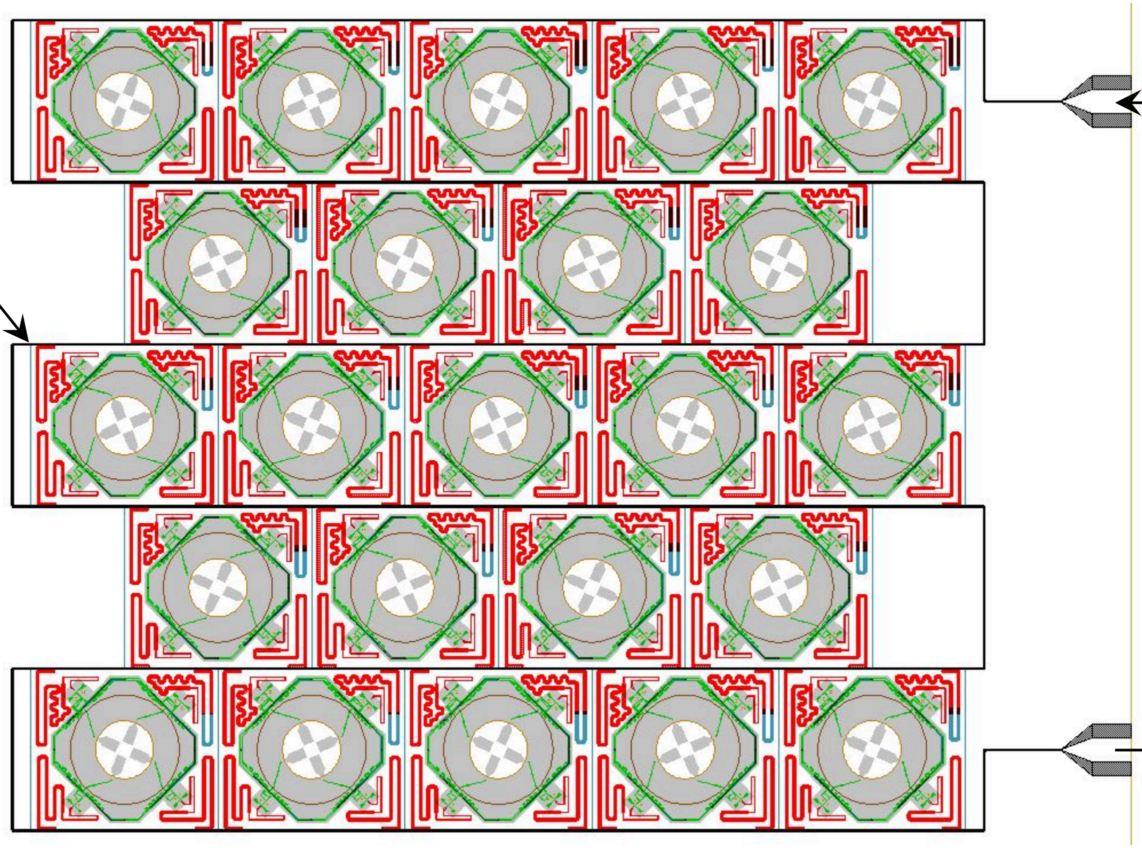




start with scalable, 23-element prototype module …

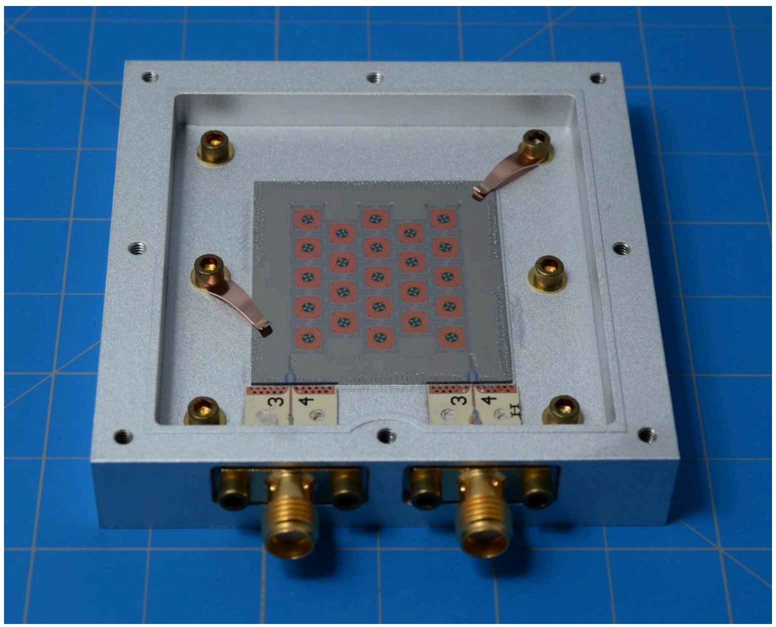
… scale up to 2317 horns or 9268 detectors

Layout of Prototype Array

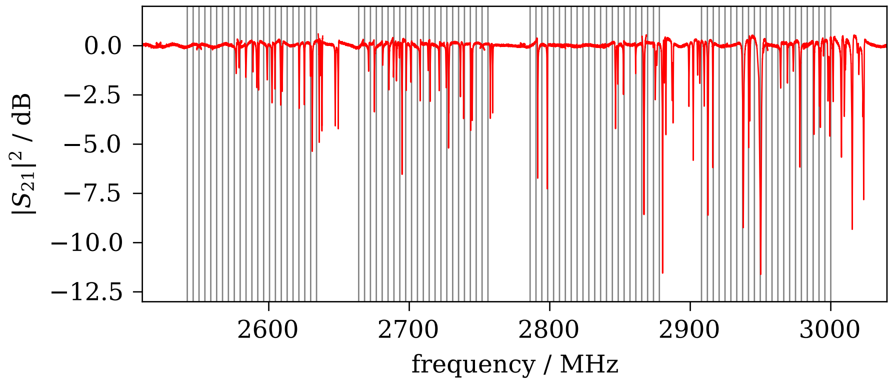


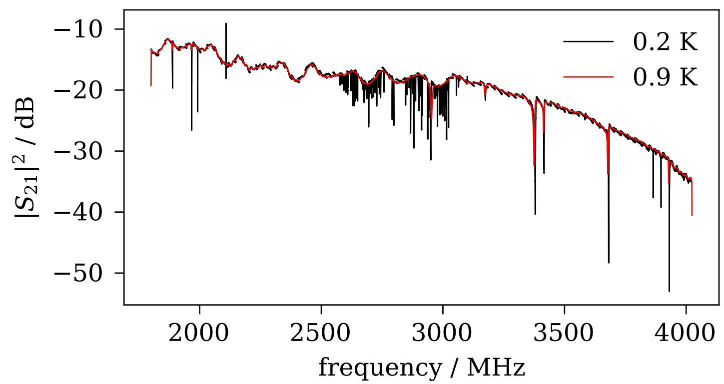
23 elements in the array

Development of Multi-Chroic MKIDs

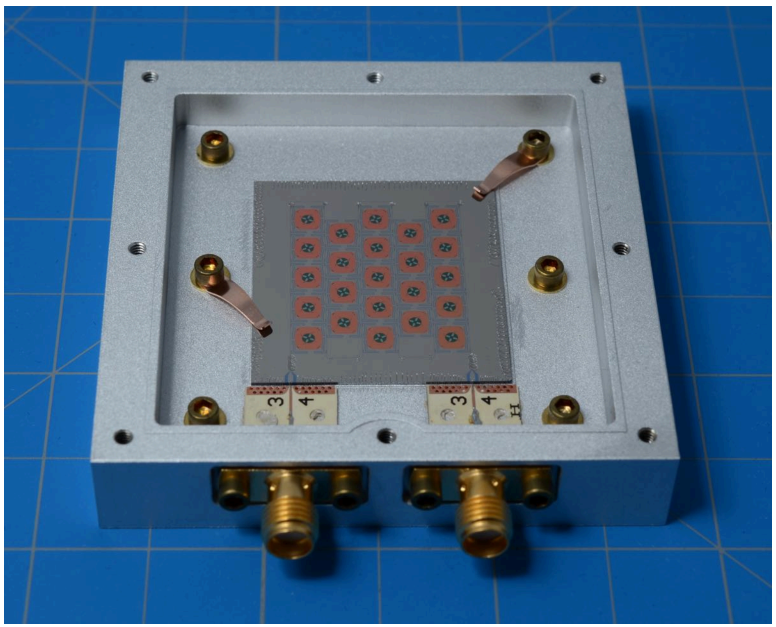


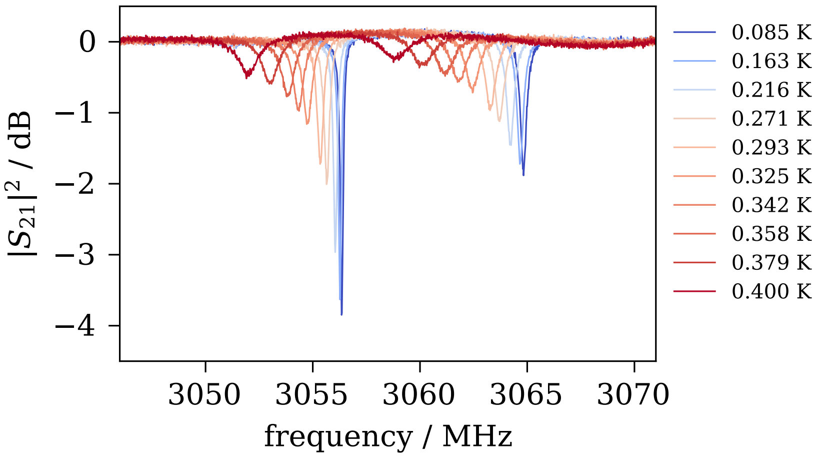
92 of 92 resonators found

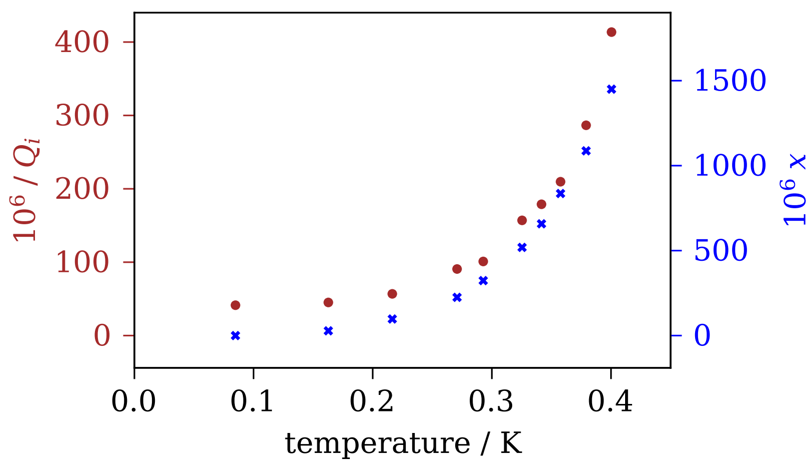




Development of Multi-Chroic MKIDs







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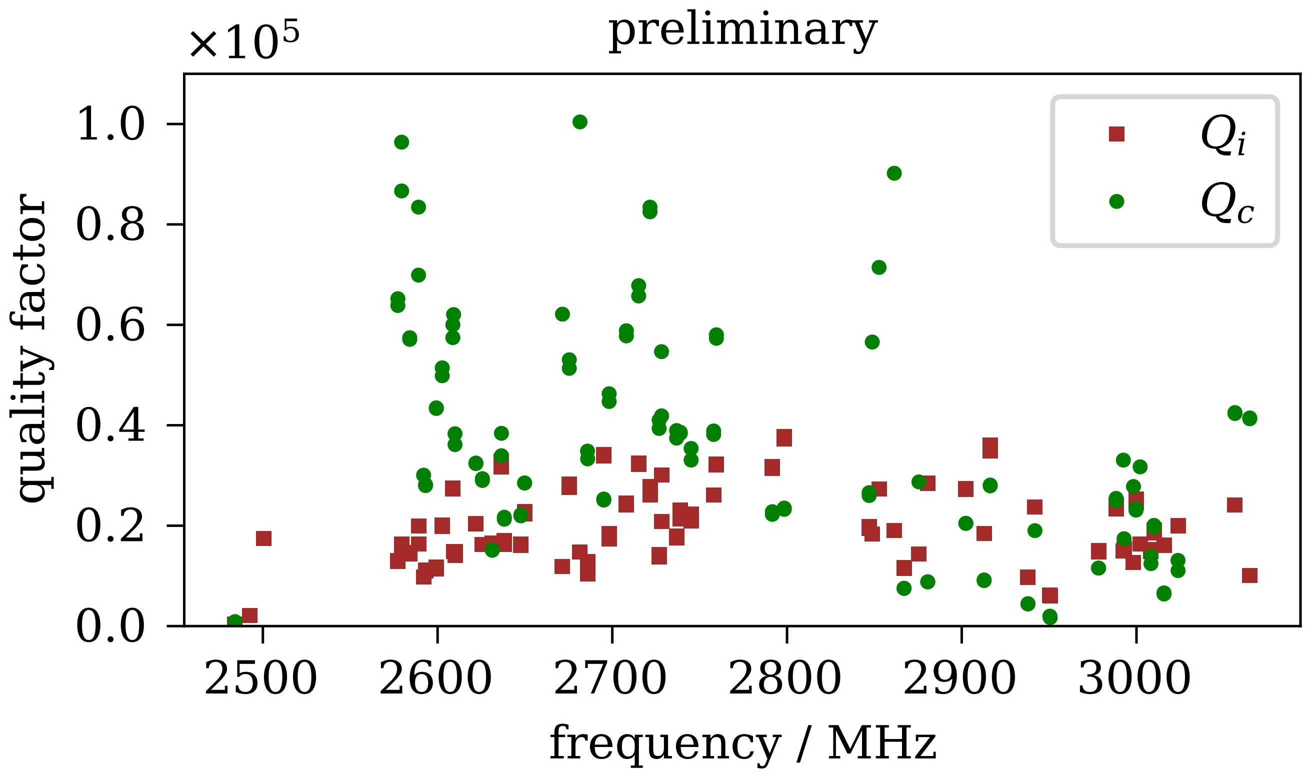
Development of Multi-Chroic MKIDs



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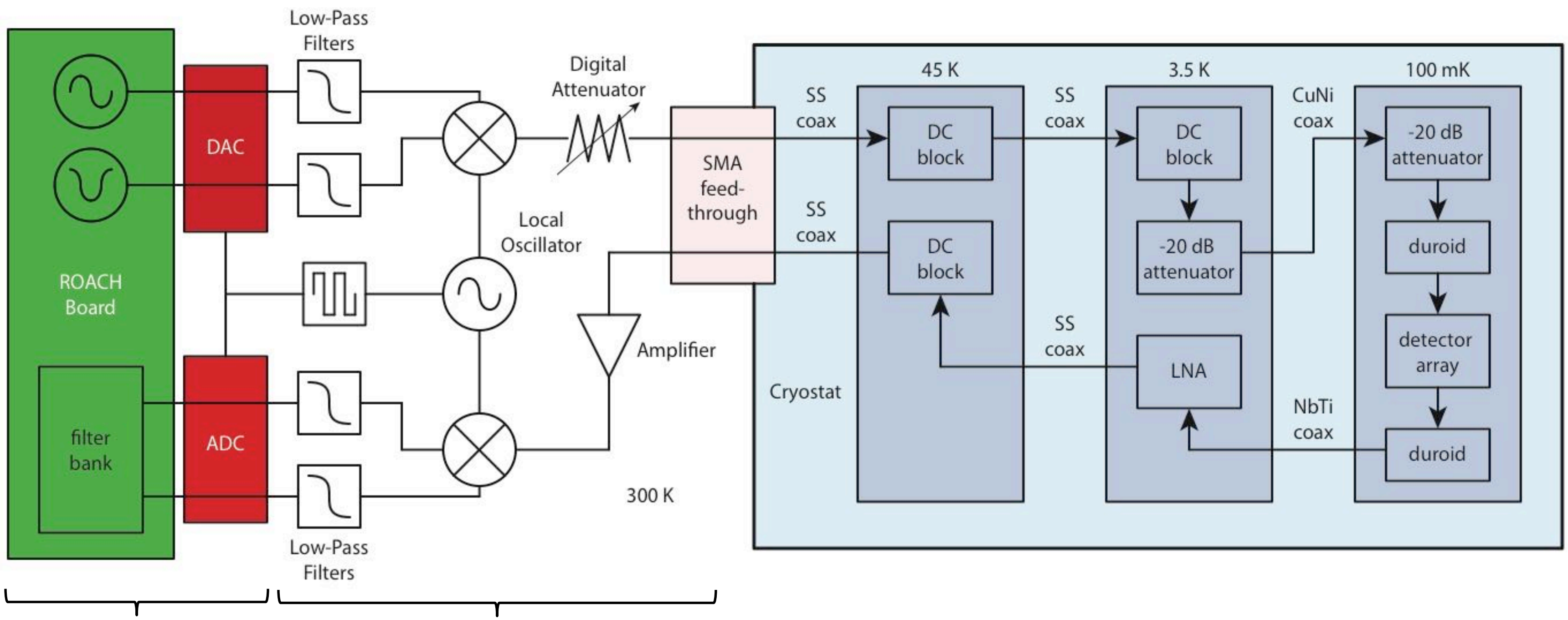
Schematic of Readout System

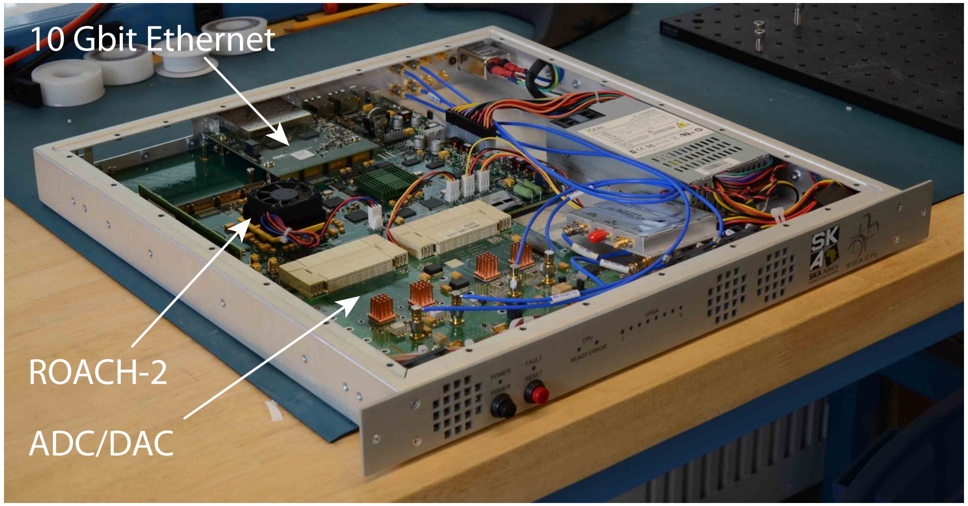


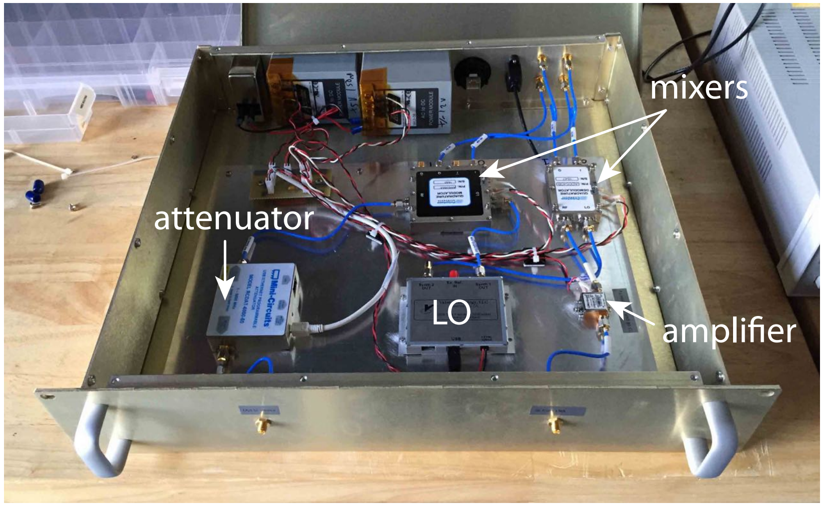
ROACH and ADC/DAC

analog circuit

Note: This design requires a vacuum feedthrough with just two SMA connectors and two pins for LNA bias.

ROACH-2, ADC/DAC, and Analog Circuit

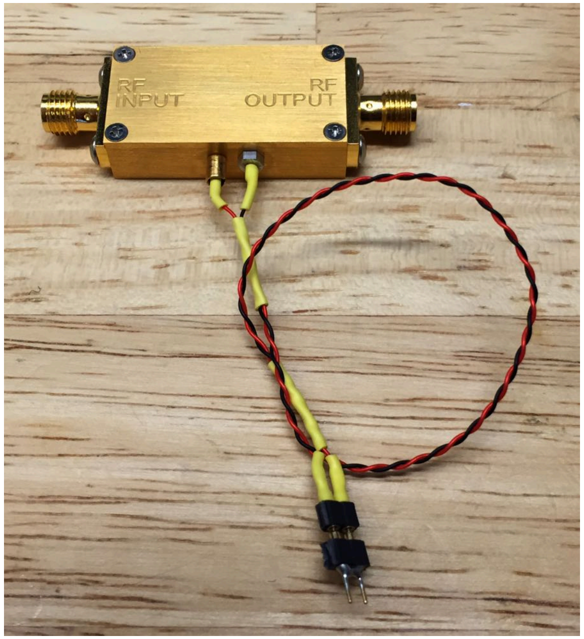


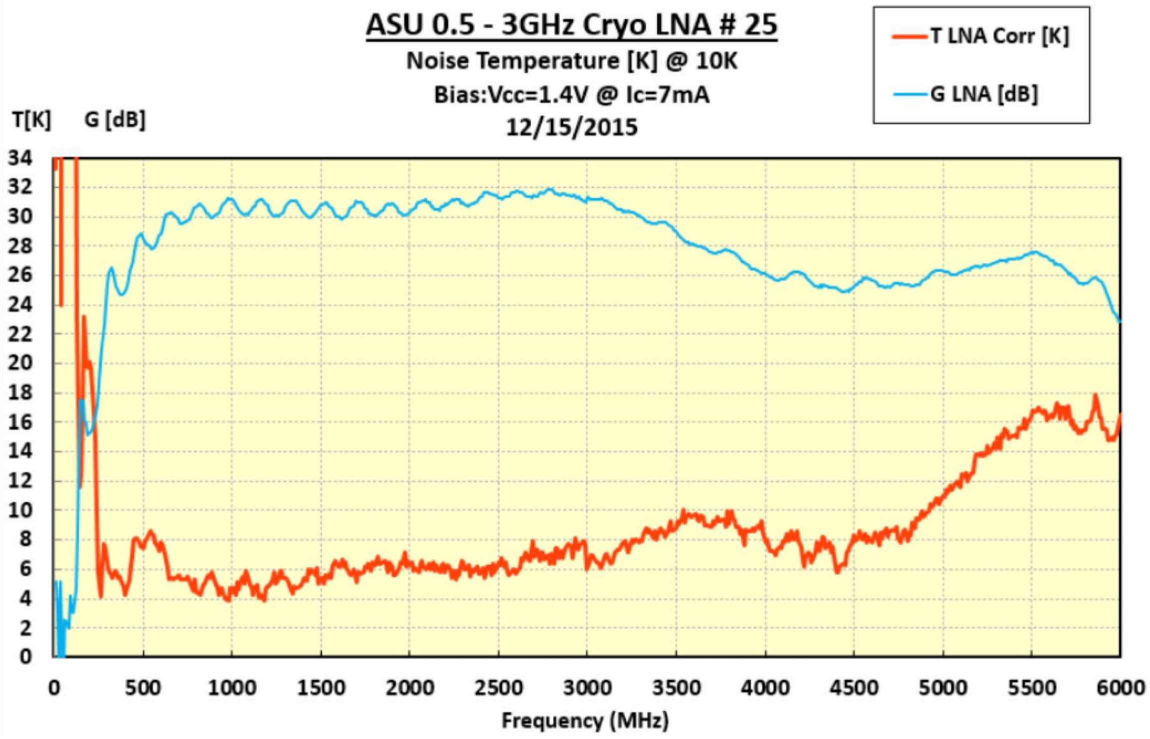


Analog signal conditioning system based around Polyphase Microwave quadrature modulators and demodulators is used to convert the baseband signals generated and analyzed by the ROACH-2 to the target ~3 GHz readout band.

SiGe LNA from ASU

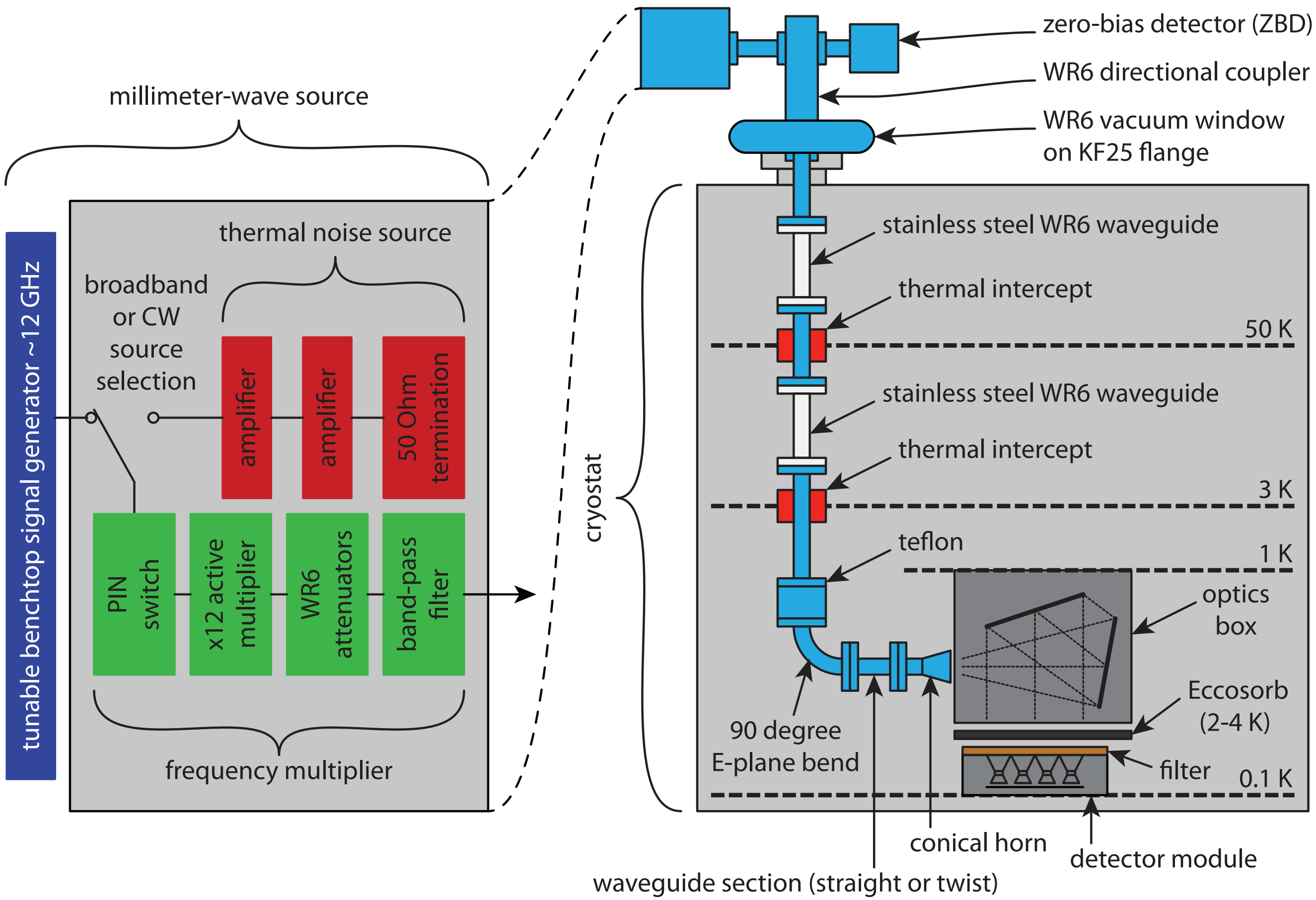
SiGe LNA from ASU





resonant frequencies around 3 GHz

Schematic of Experimental Setup



See Flanigan et al. (2016) *APL*, 108, 083504.

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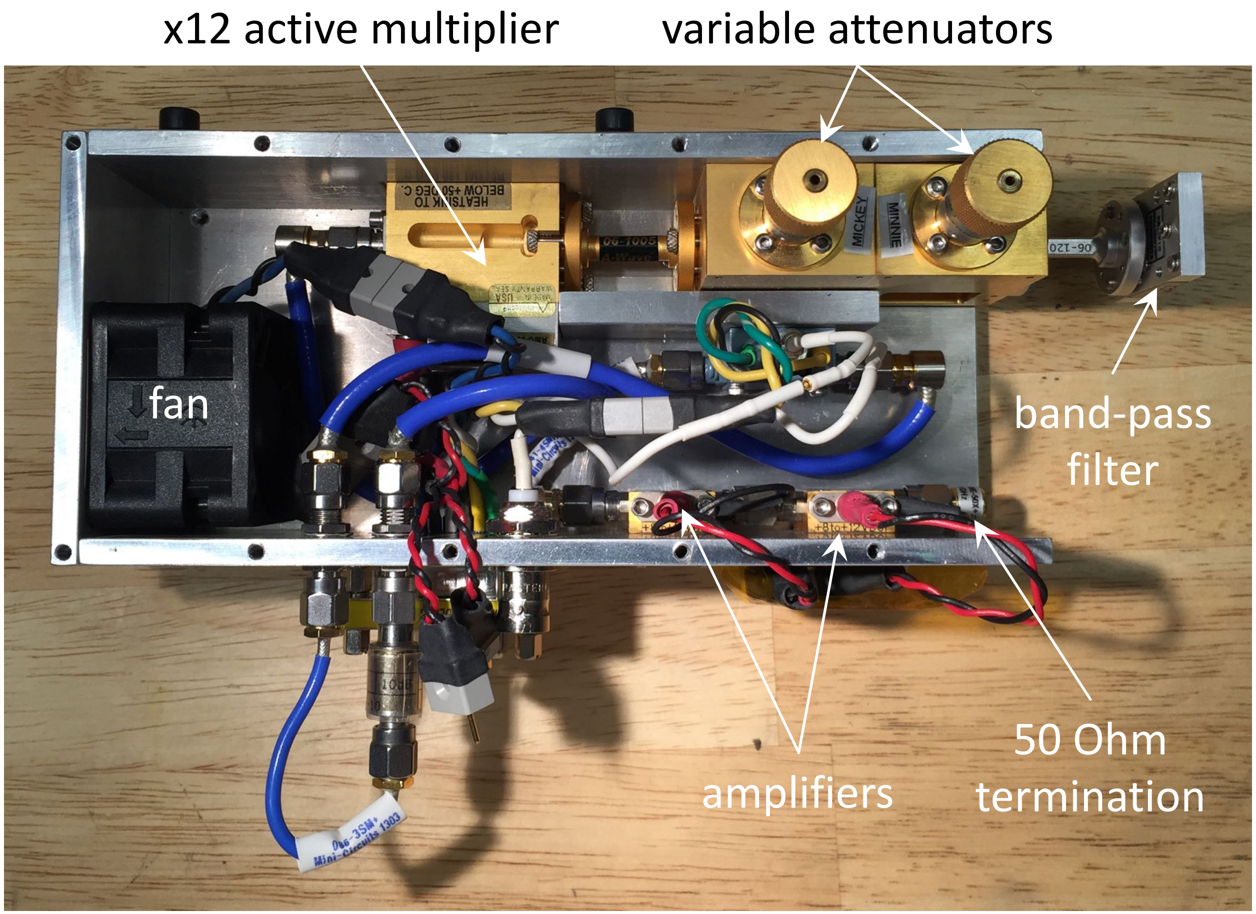
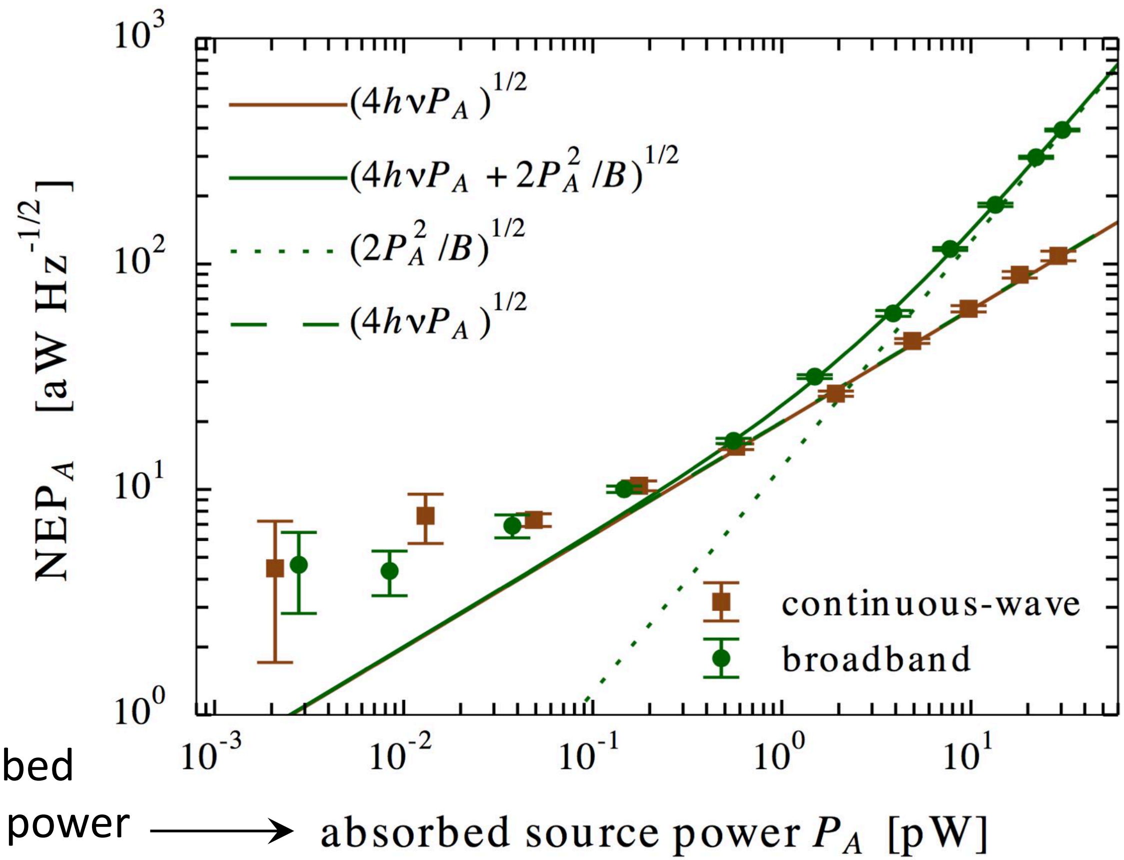
External Millimeter-Wave Source



See Flanigan et al. (2016) *APL*, 108, 083504.

LEKID Example: Measured Photon Noise



detecting photon noise and able to differentiate between shot and wave noise above ~1 pW

absorbed incident power from our source →

See Flanigan et al. (2016) *APL*, 108, 083504.

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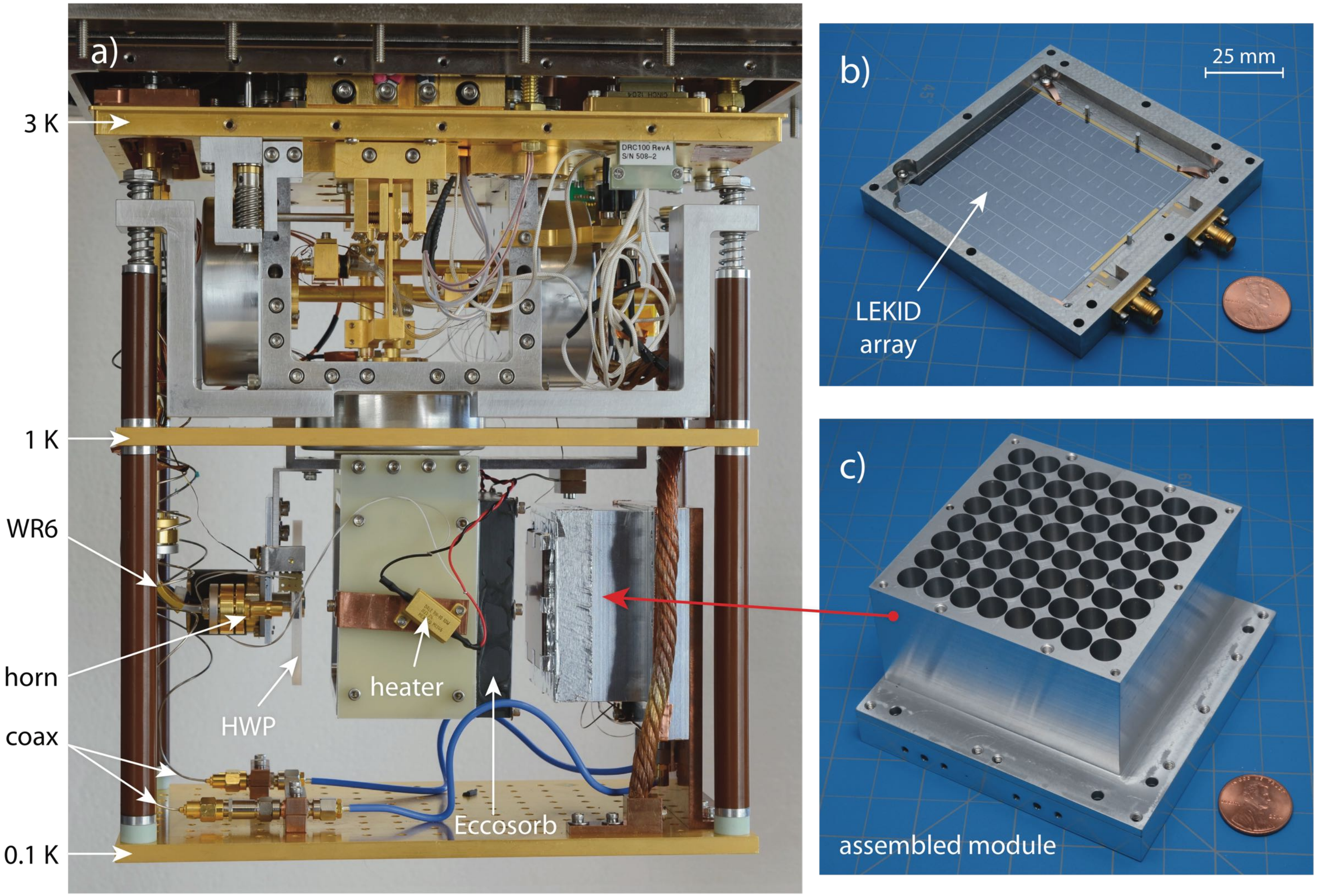
Optical Test Setup



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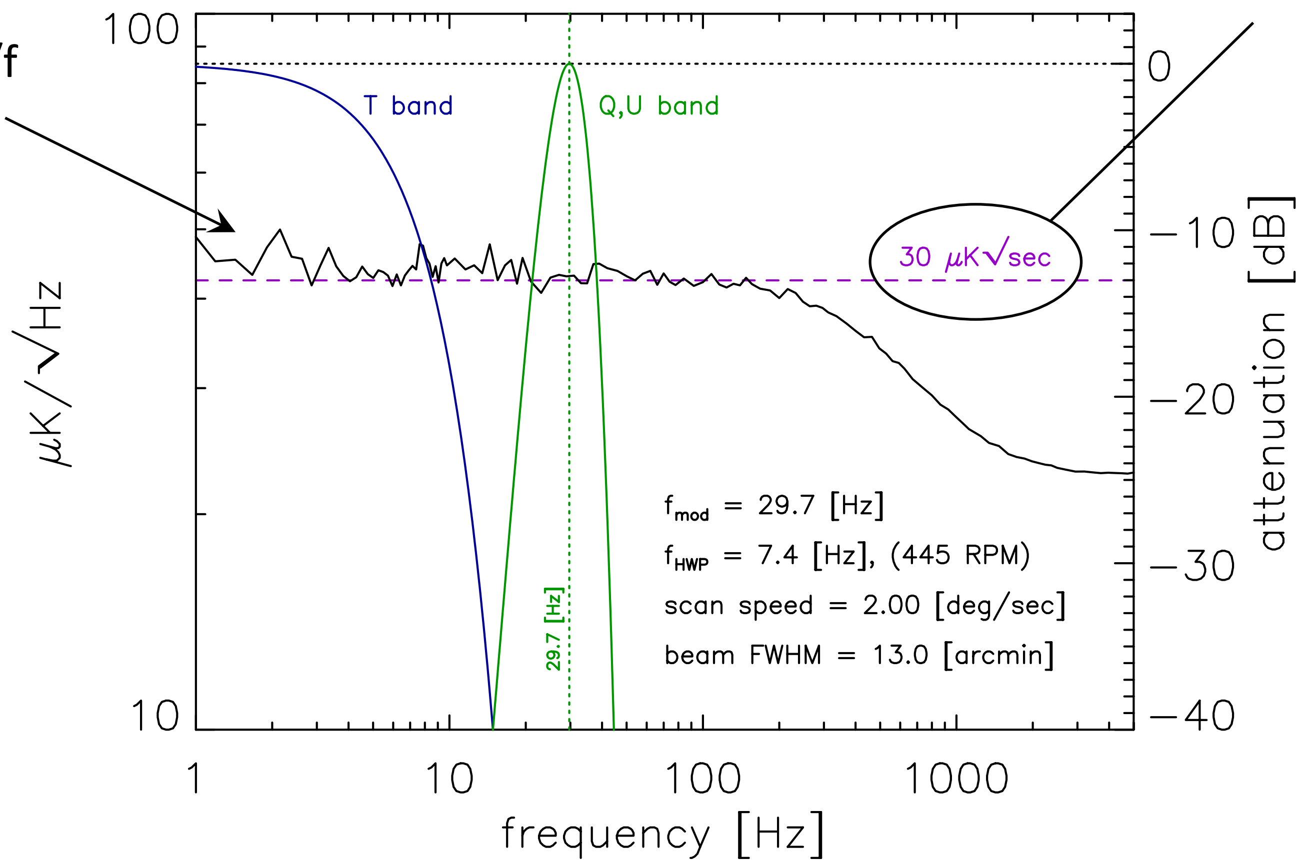
LEKID Example: Measured Noise Spectra

1) low NET

2) low 1/f noise



150 GHz

3) lots of bandwidth

4 K beam-filling load

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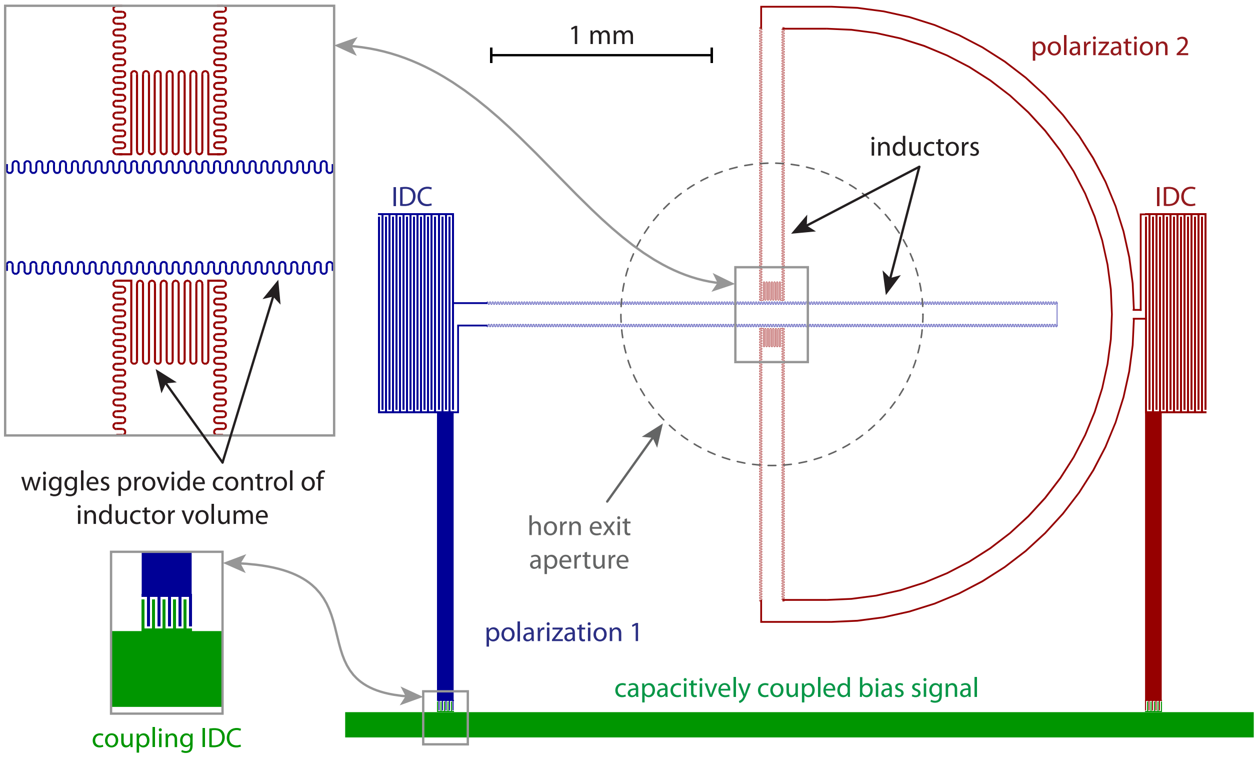
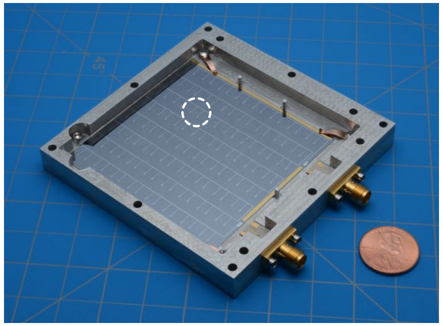
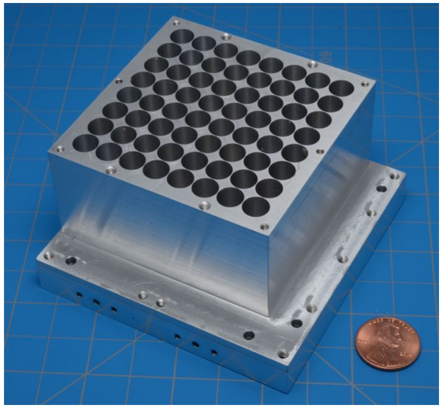
McCarrick et al. (2014) *RSI*, 85, 123117.

Dual-Polarization LEKIDs







McCarrick et al. (2017) *in preparation*.

see LTD17 poster PA-5

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High quality factor manganese-doped aluminum lumped-element kinetic inductance detectors sensitive to frequencies below 100 GHz

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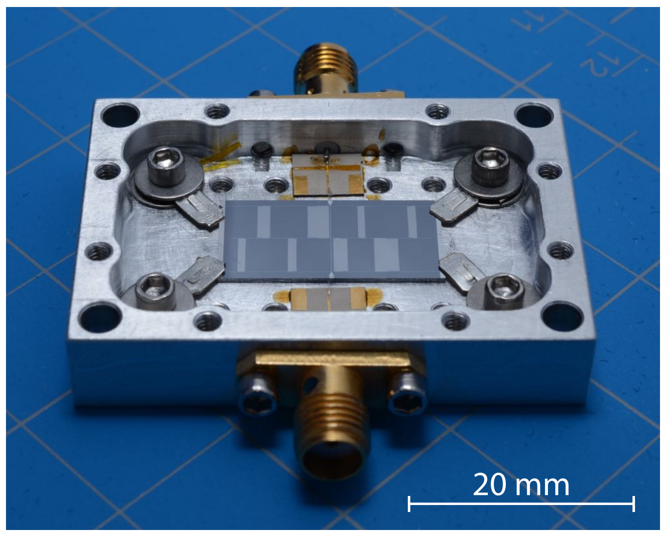
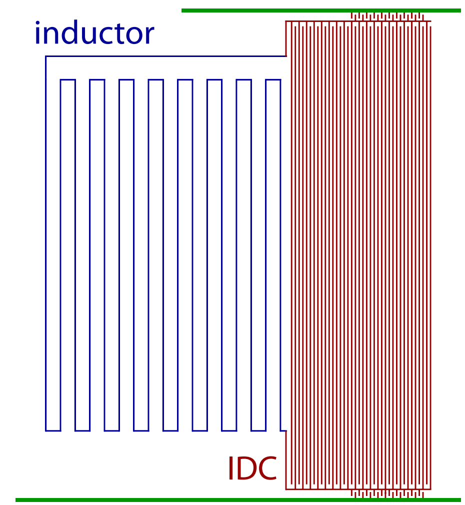
[5)] *NASA, Jet Propulsion Laboratory, Pasadena, CA 91109, USA*
[6)] *Department of Physics, Stanford University, Stanford, CA, 94305-4085, USA*
[7)] *Department of Physics and Astronomy, University of Southern California, Los Angeles, CA 90089, USA*

(Dated: 31 January 2017)

see LTD17 poster PA-12





Jones et al. (2017) *APL*, 110, 222601.

Summary

- We are developing scalable modular arrays of **horn-coupled, polarization-sensitive MKIDs for CMB studies** that are each sensitive to **two spectral bands: 150 and 235 GHz**.
- Array layout is almost complete. Module **fabrication will finishing this summer.**
- We anticipate **photon noise limited performance** above ~1 pW of loading.
- **ROACH-2 readout** system has been developed.
- We have plans to fabricate **aluminum manganese sensors**, which will make the MKIDs photon-noise dominated at lower absorbed power levels (see LTD17 poster PA-12).
- We are **also developing dual-polarization LEKIDs** (see LTD17 poster PA-5).