Development of KIDs for CMB Polarization Studies

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Assistant Professor
Columbia University

KID = kinetic inductance detector
MKID = microwave kinetic inductance detector
LEKID = lumped-element kinetic inductance detector

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Why investigate KIDs for CMB Studies?

- **High multiplexing factors** make them particularly suitable for instruments with 10,000 or more detectors (CMB-S4, for example).
- Comparatively **small number of wires** needed to sub-kelvin stage, and no additional sub-kelvin multiplexing circuitry is needed (**no SQUIDs**).
- **No delicate membranes are required** and arrays can be made with a comparatively small number of processing steps. **Some architectures have been fabricated in commercial foundries**.
- **Fast time constants** (~100 μs) provide a lot of bandwidth for modulation schemes – like half-wave plate modulation – and they help with cosmic ray hits.
- **Low power consumption readout** (< 50 watts per comb) is commercially available. Required LNAs are available. Required firmware is open-source.
- Some TES bolometer architectures are hard to make with < 1 pW saturation power, and MKIDs might actually be more straightforward.

Organization of Presentation

1) Dual Polarization LEKIDs
 - McCarrick et al. (2017) *A&A accepted*. arXiv:1710.02239

2) Multi-Chroic Dual-Polarization MKIDs
 - Johnson et al. (2017) *JLTP submitted*. arxiv:1711.02523
 - optical response of first prototype array

3) Aluminum-Manganese LEKIDs
 - Jones et al. (2017) *APL*, 110, 222601.

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November 17, 2017

Design and performance of dual-polarization lumped-element kinetic inductance detectors for millimeter-wave polarimetry

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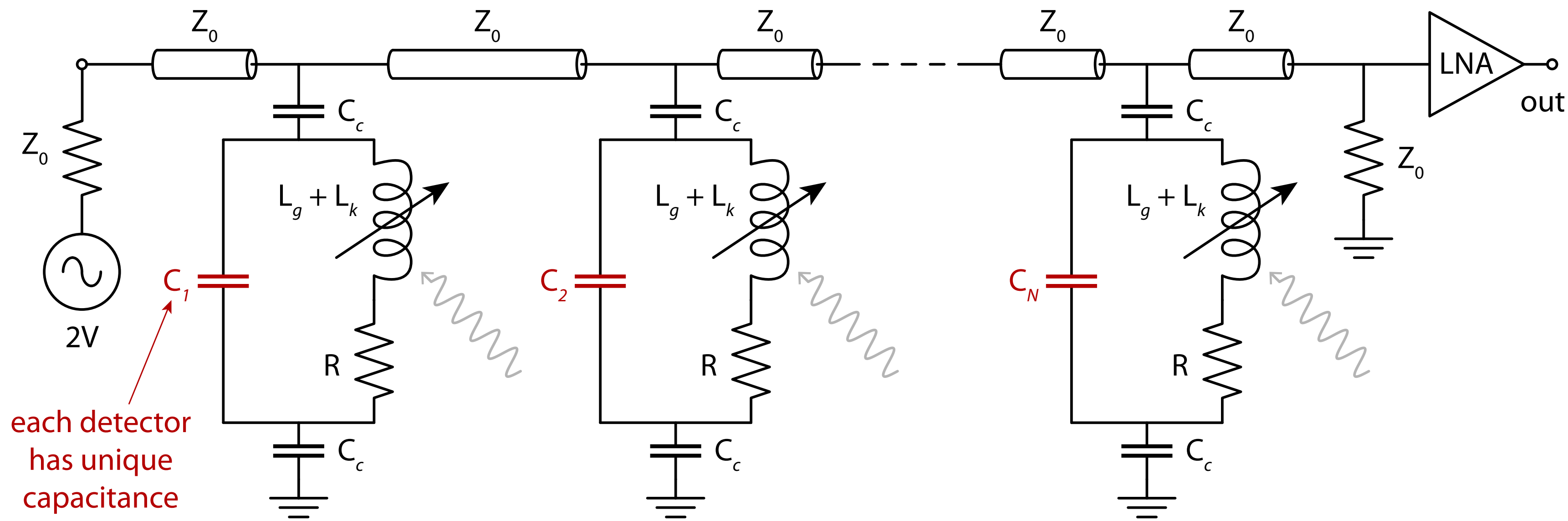
Received 4 October 2017

Project supported in part by a ***RISE*** grant, ***ONR*** grant and ***NASA/NESSF***.

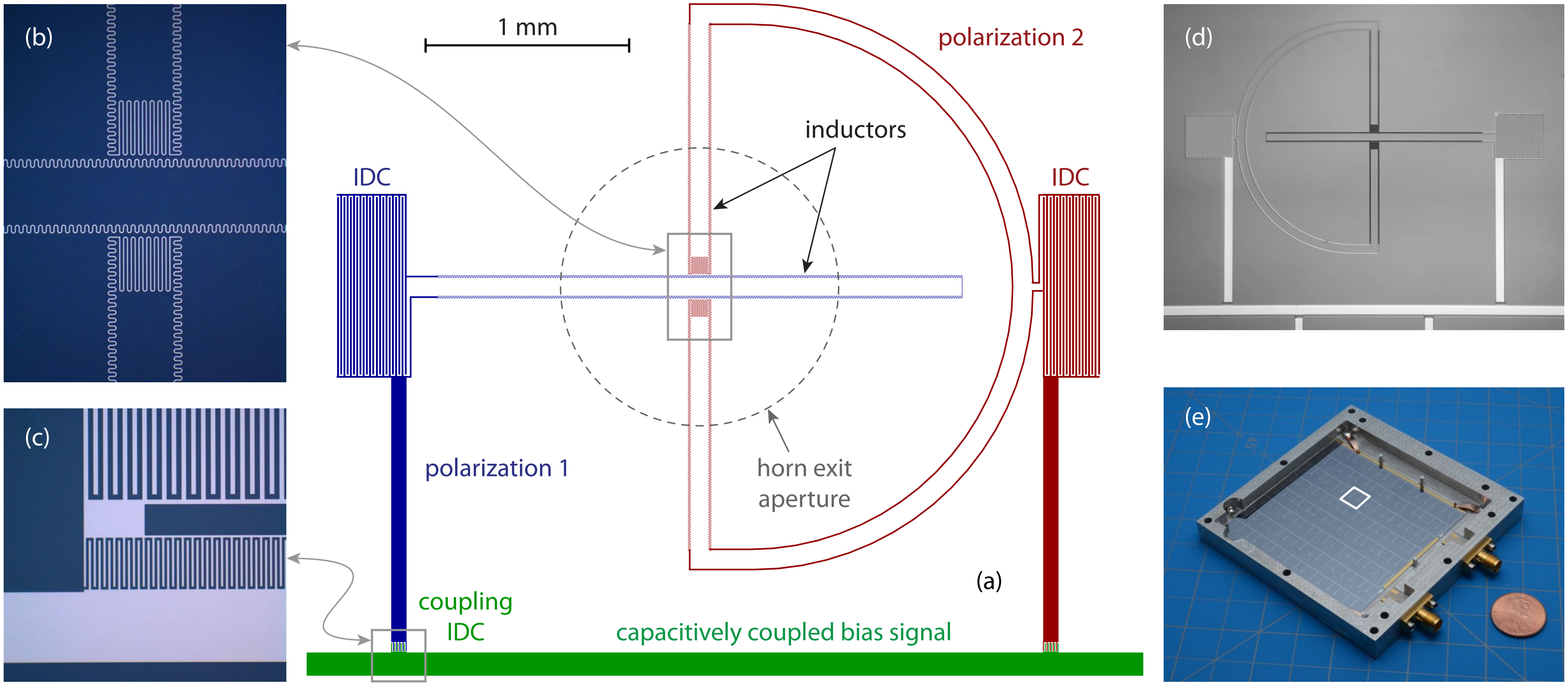
McCarrick et al. (2016) *A&A accepted*. arXiv:1710.02239

Multiplexing Strategy



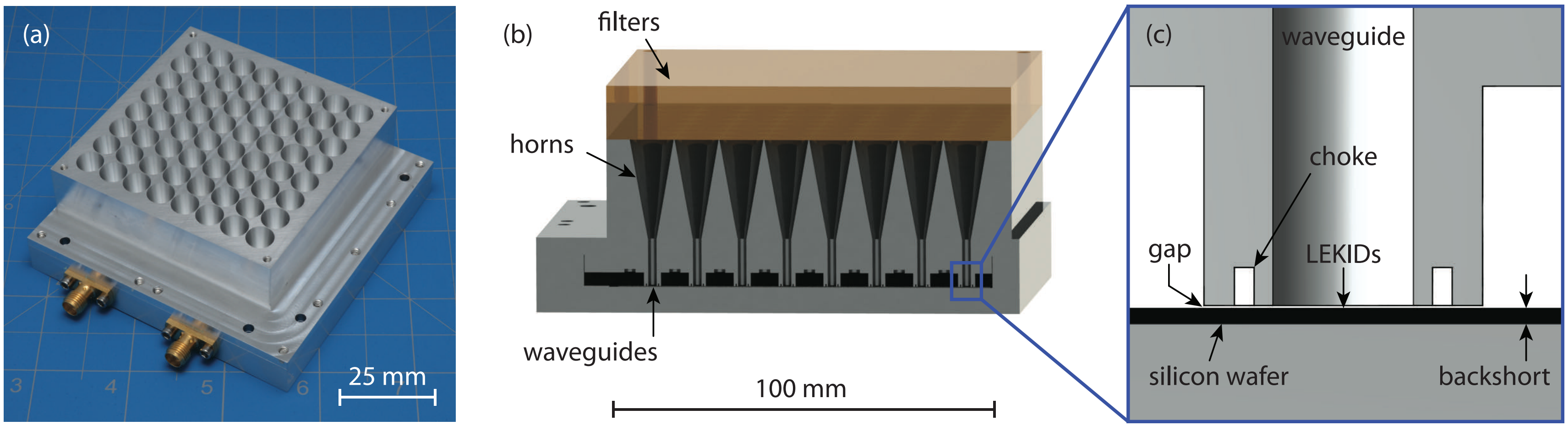
Hundreds of detectors can be read out with a single pair of coaxial cables.

Dual-Polarization LEKID Development



McCarrick et al. (2017) *A&A accepted*. arXiv:1710.02239

Dual-Polarization LEKID Development



McCarrick et al. (2017) *A&A accepted*. arXiv:1710.02239

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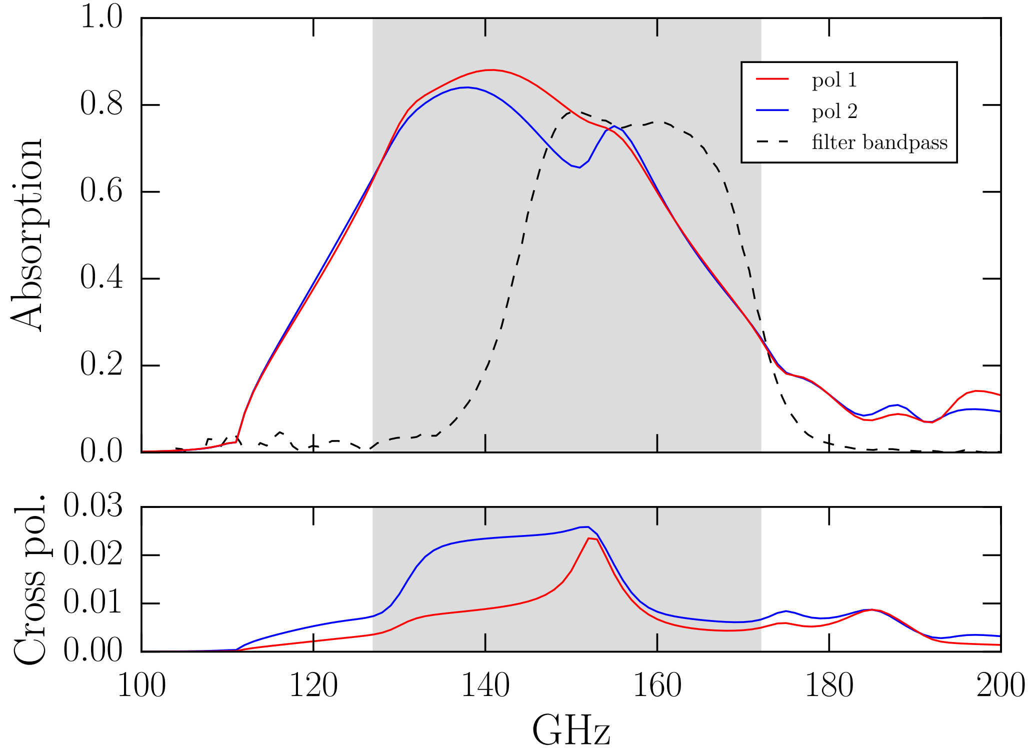
Simulated Coupling Performance

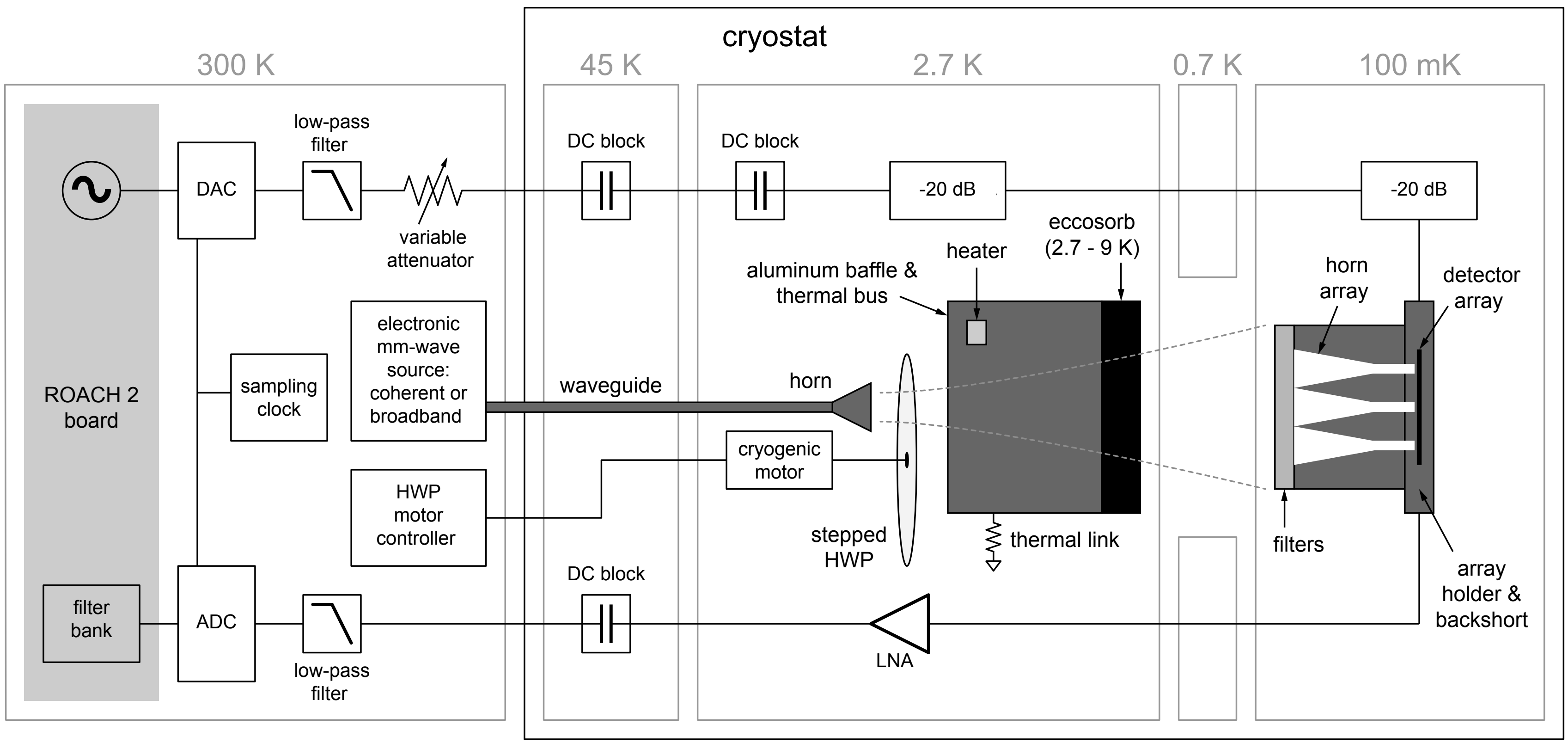


McCarrick et al. (2017) *A&A accepted*. arXiv:1710.02239

see also: McCarrick et al. (2016) *Proc. SPIE*, 9914, 99140O

see also: Bryan et al. (2015) *Proc. ISSTT*, T3-4.

Test Setup with Half-Wave Plate



McCarrick et al. (2017) *A&A accepted*. arXiv:1710.02239

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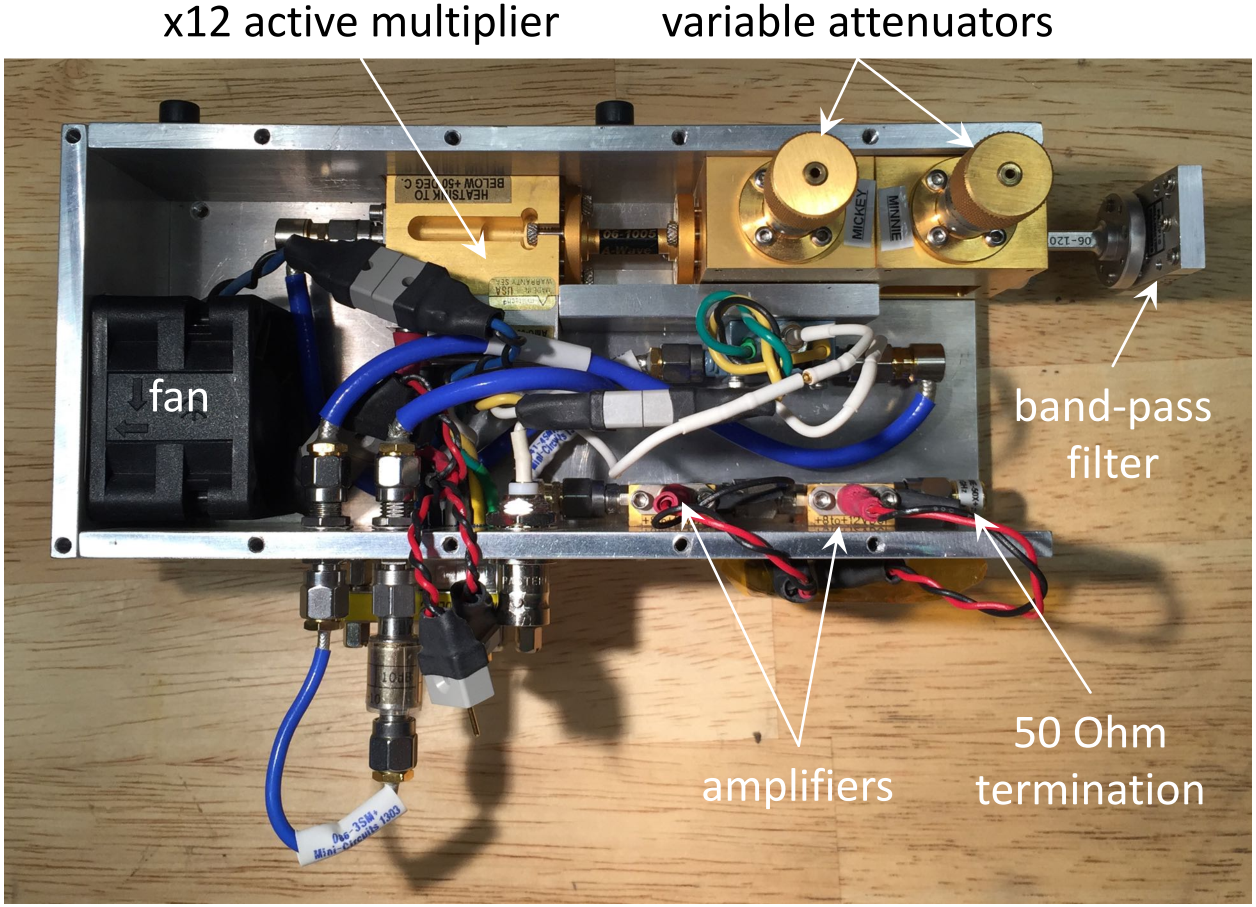
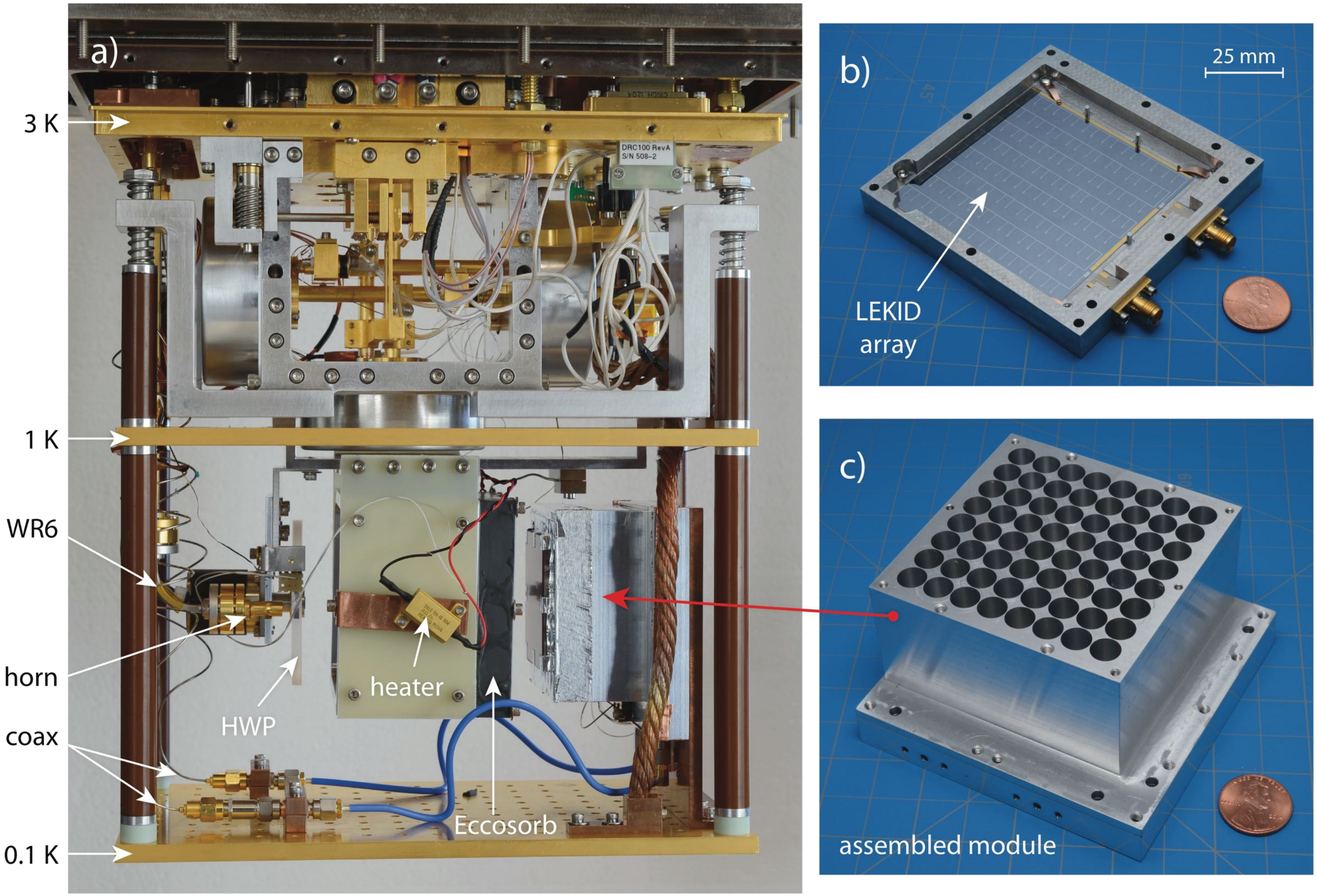
Millimeter-Wave Source



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

Test Setup with Half-Wave Plate



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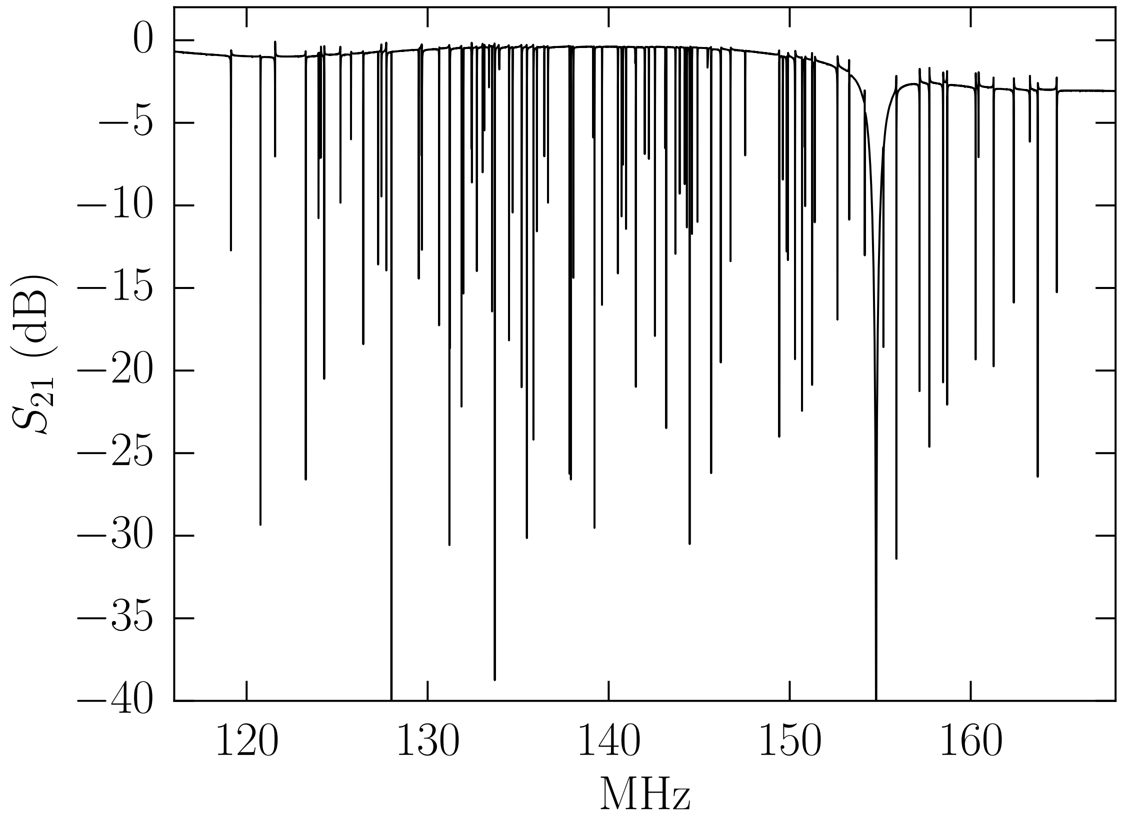
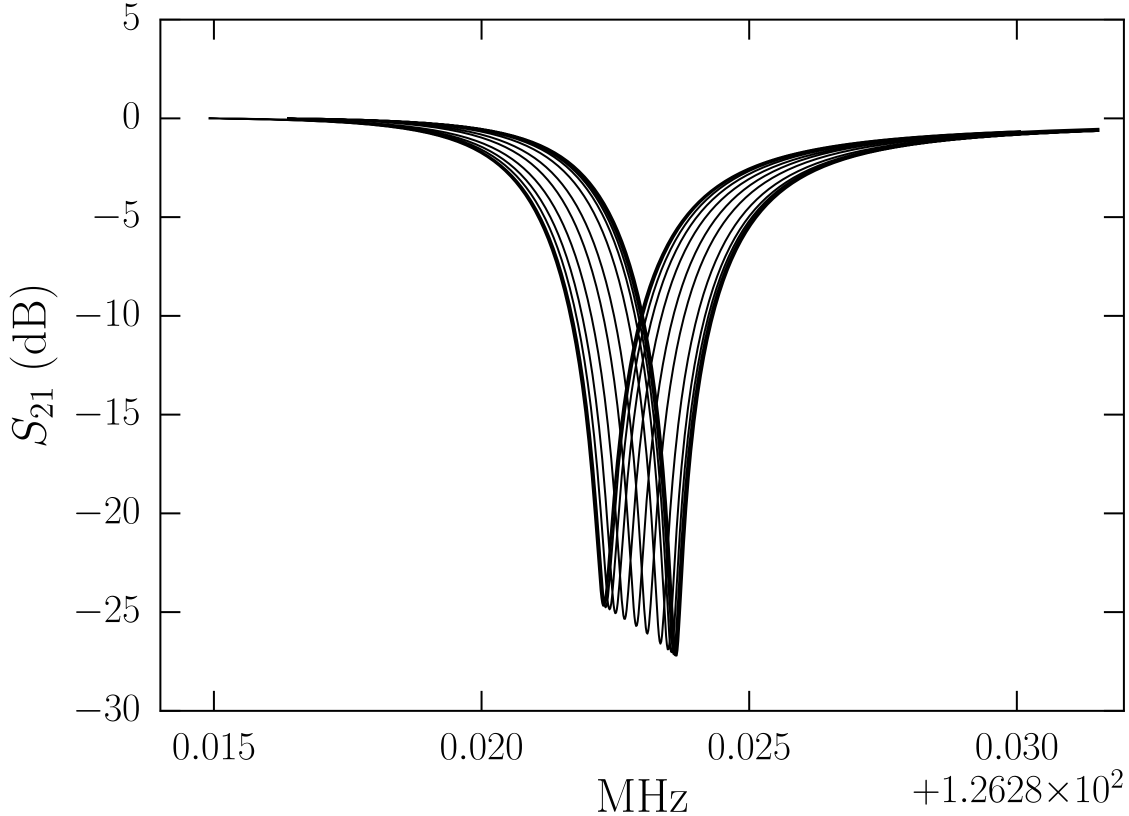
Multiplexing Factor of 128 Demonstrated



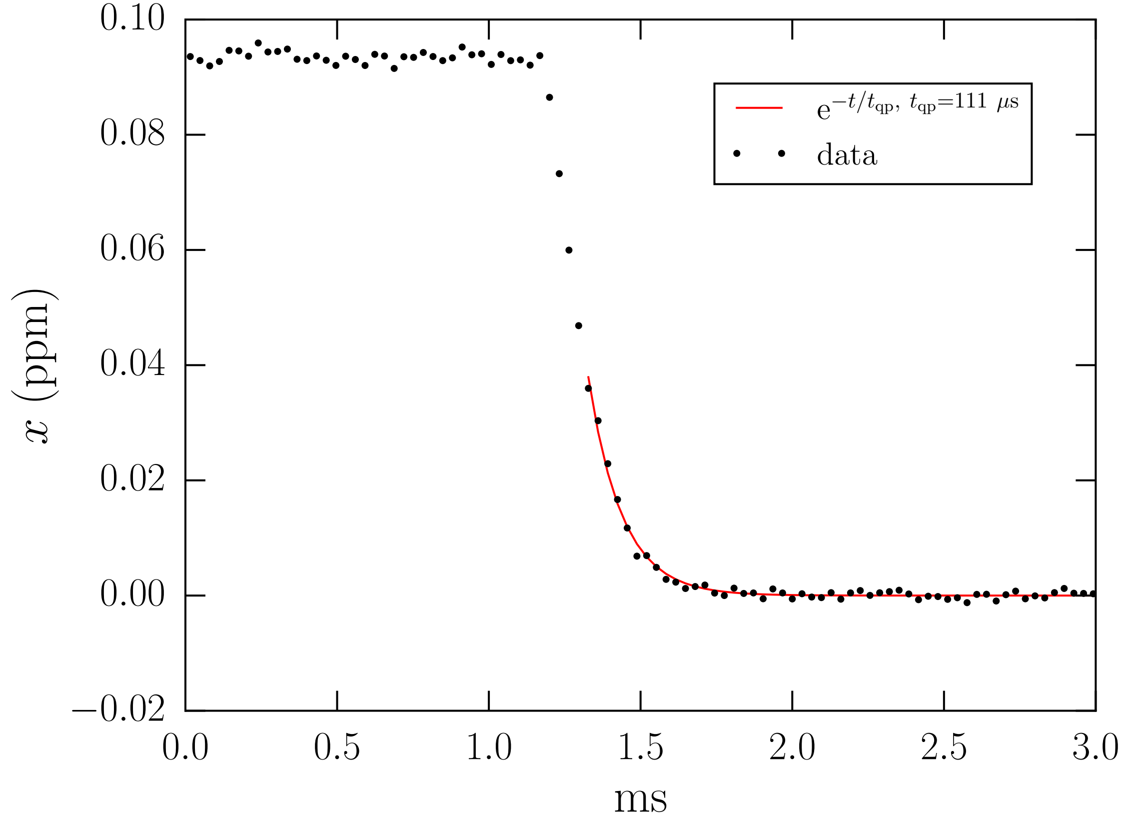
McCarrick et al. (2016) *A&A accepted*. arXiv:1710.02239

Resonators Behave as Expected



McCarrick et al. (2016) *A&A accepted*. arXiv:1710.02239

Measured Quasiparticle Lifetime



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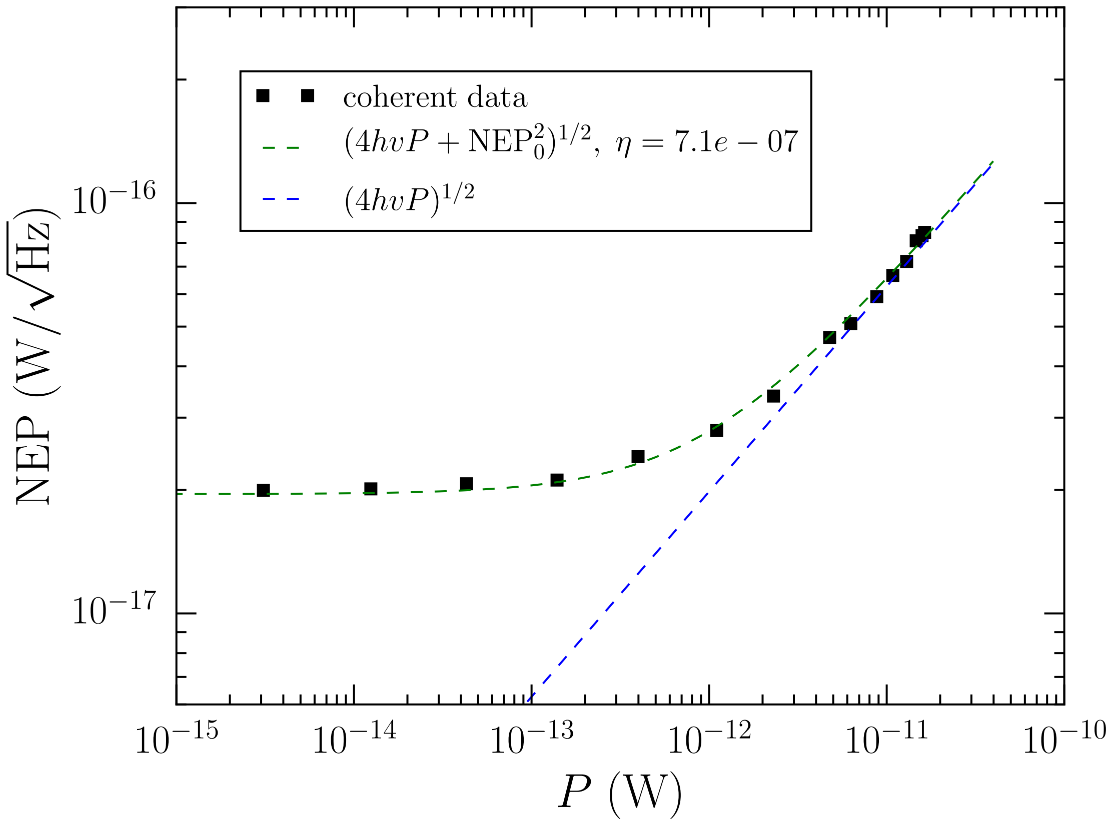
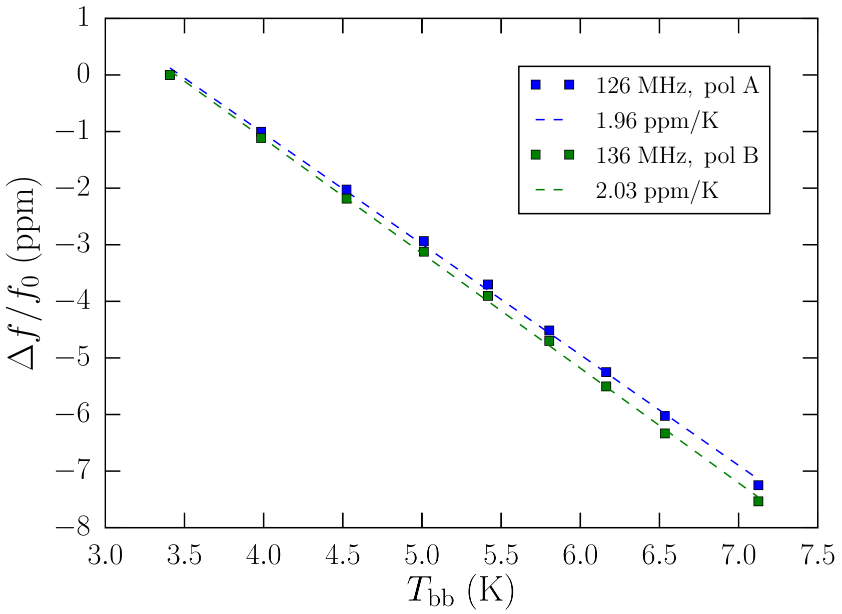
Measured NEP versus Absorbed Power

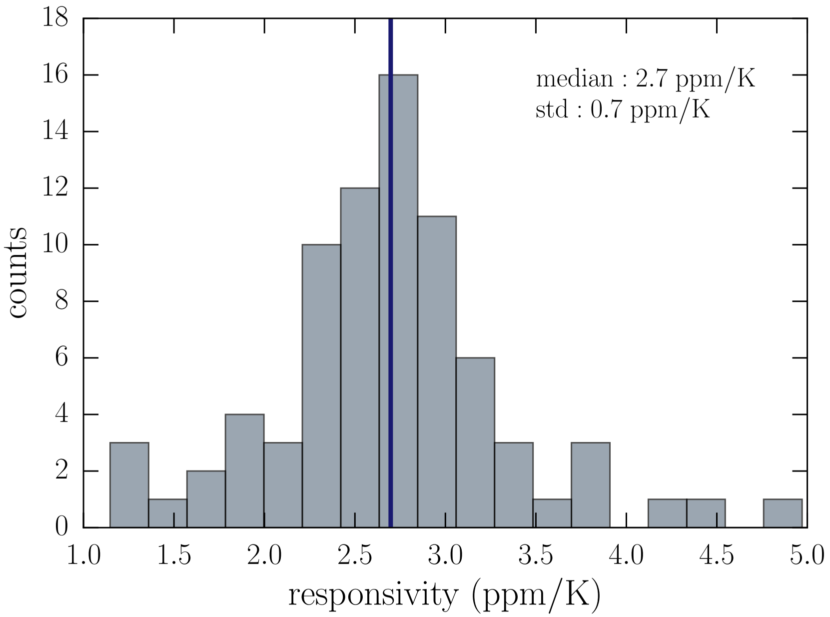


McCarrick et al. (2016) *A&A accepted*. arXiv:1710.02239

see also: Flanigan et al. (2016) *APL*, 108, 083504.

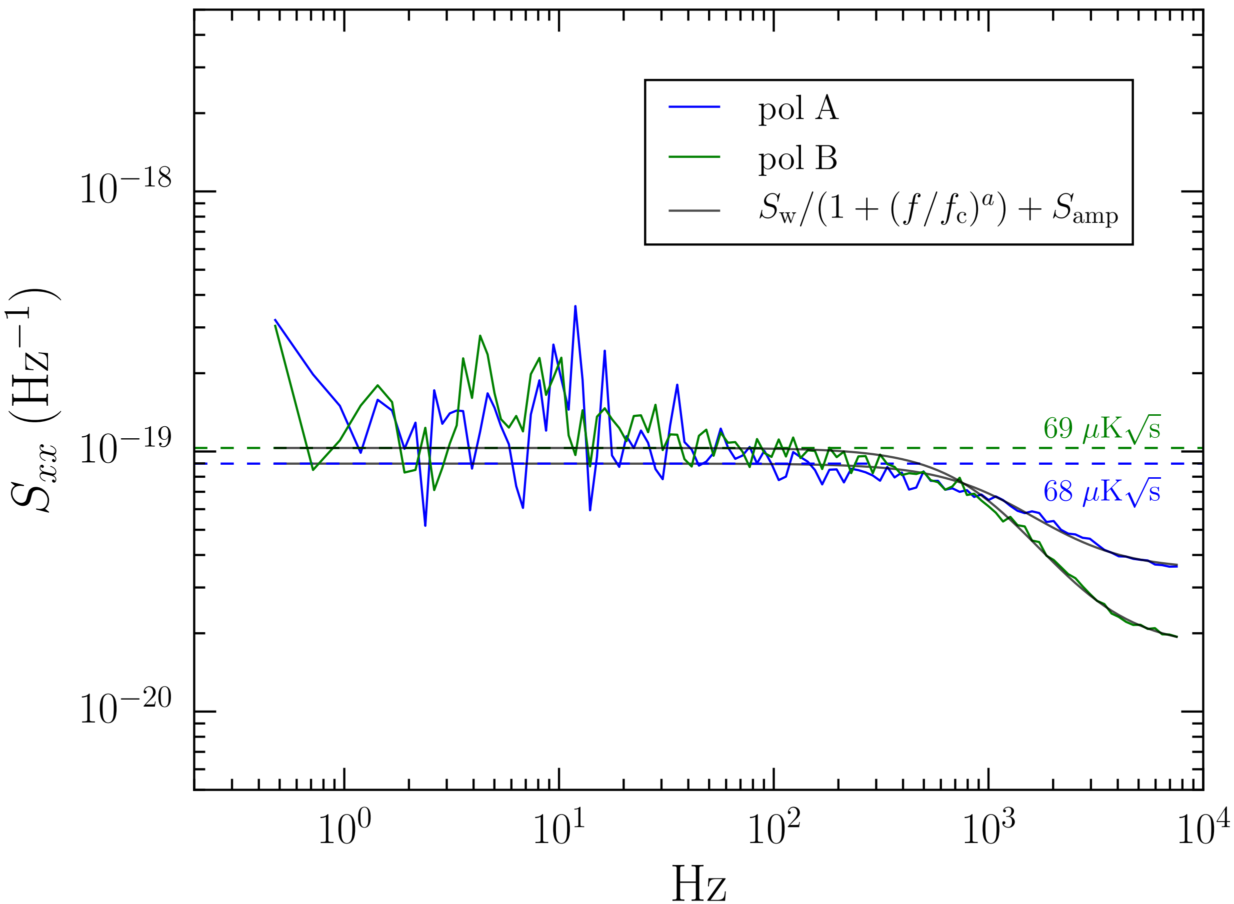
Measured Responsivity





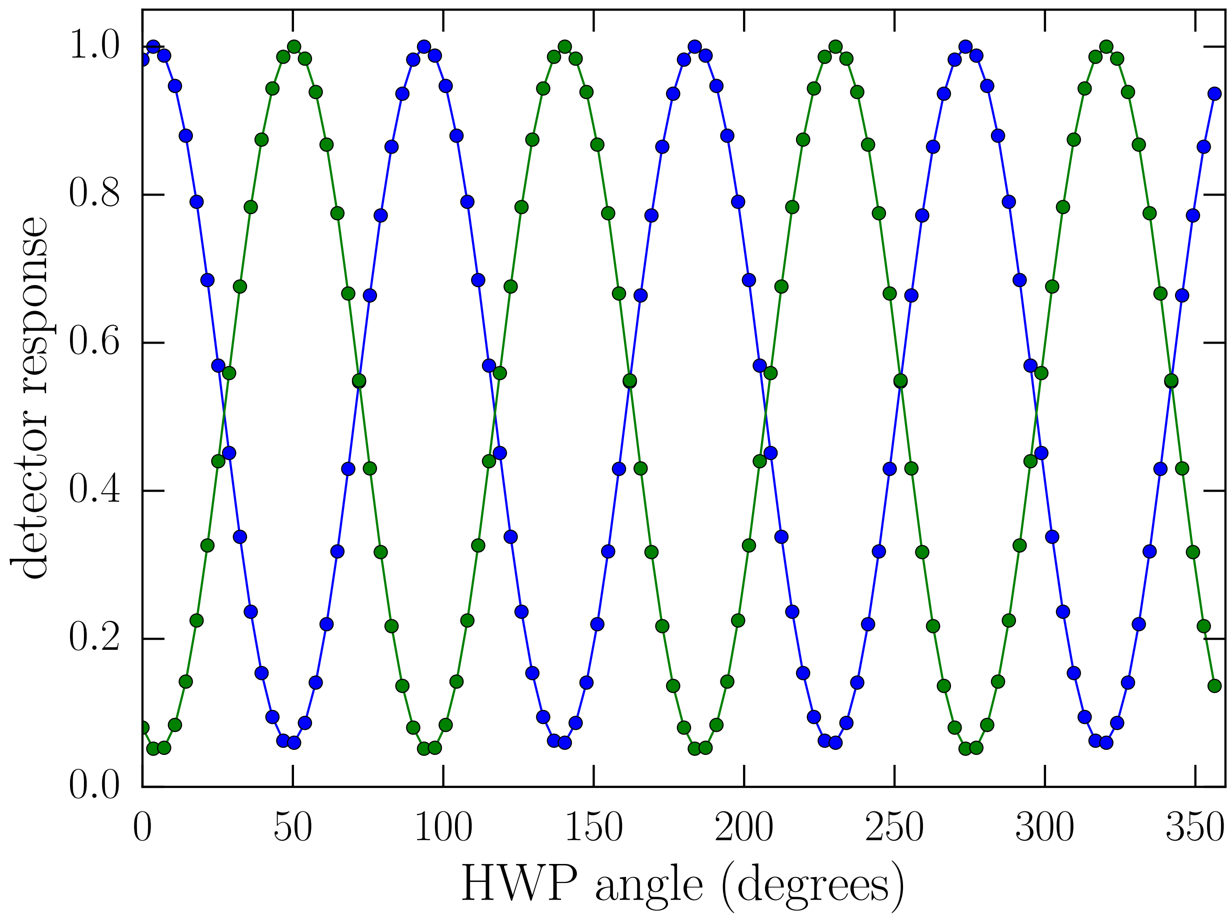
McCarrick et al. (2016) *A&A accepted*. arXiv:1710.02239

Measured Noise (Calibrated)



McCarrick et al. (2016) *A&A accepted*. arXiv:1710.02239

Measured Polarization Response



McCarrick et al. (2016) *A&A accepted*. arXiv:1710.02239

Multi-Chroic Dual-Polarization MKIDs

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

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Journal of Low Temperature Physics manuscript No.
(will be inserted by the editor)

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M. H. Abitbol[a] · P. A. R. Ade[b] · S. Bryan[c] ·
H.-M. Cho[g] · R. Datta[e,h] · P. Day[f] ·
S. Doyle[b] · K. Irwin[d,g] · G. Jones[a] ·
D. Li[g] · P. Mauskopf[c] · H. McCarrick[a] ·
J. McMahon[e] · A. Miller[a] · G. Pisano[b] ·
Y. Song[d] · H. Surdi[c] · C. Tucker[b]**

Development of Multi-Chroic MKIDs for Next-Generation CMB Polarization Studies

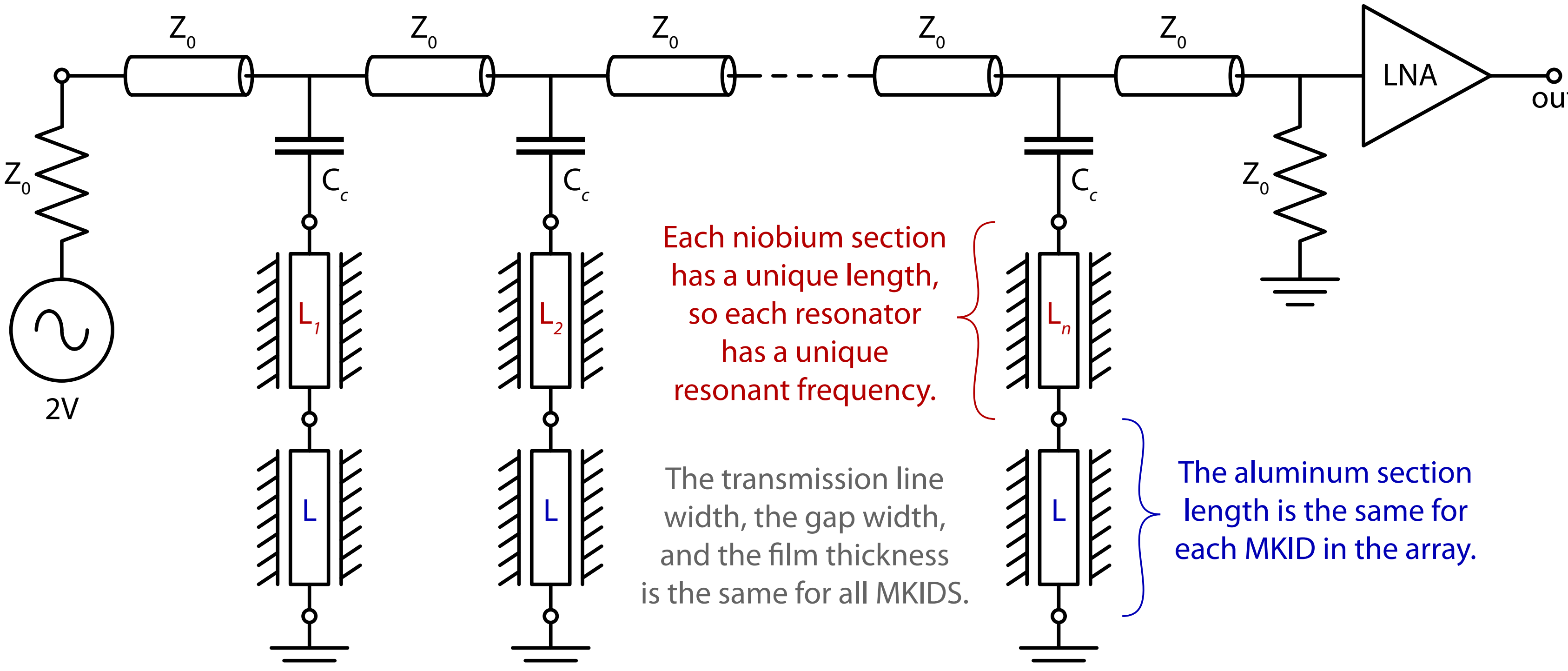
Johnson et al. (2017) *JLTP submitted*. arxiv:1711.02523

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

Overview of Multi-Chroic MKID

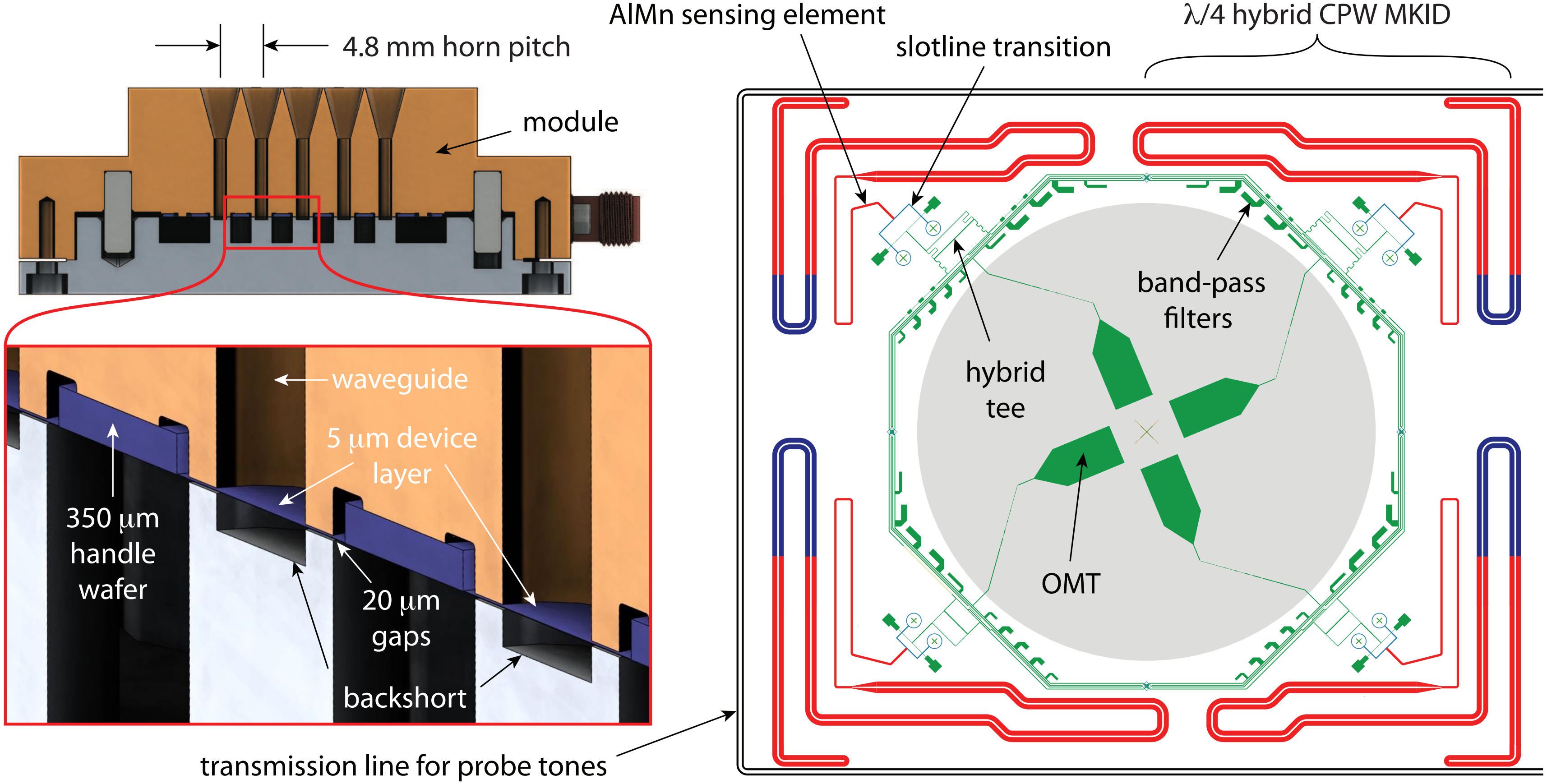
- We are developing scalable modular arrays of **horn-coupled, polarization-sensitive MKIDs** that are each sensitive to **two spectral bands between 125 and 280 GHz (150 GHz and 235 GHz)**.
- These MKID arrays are **tailored for future multi-kilo-pixel experiments** that will observe both the cosmic 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.

Multiplexing Strategy



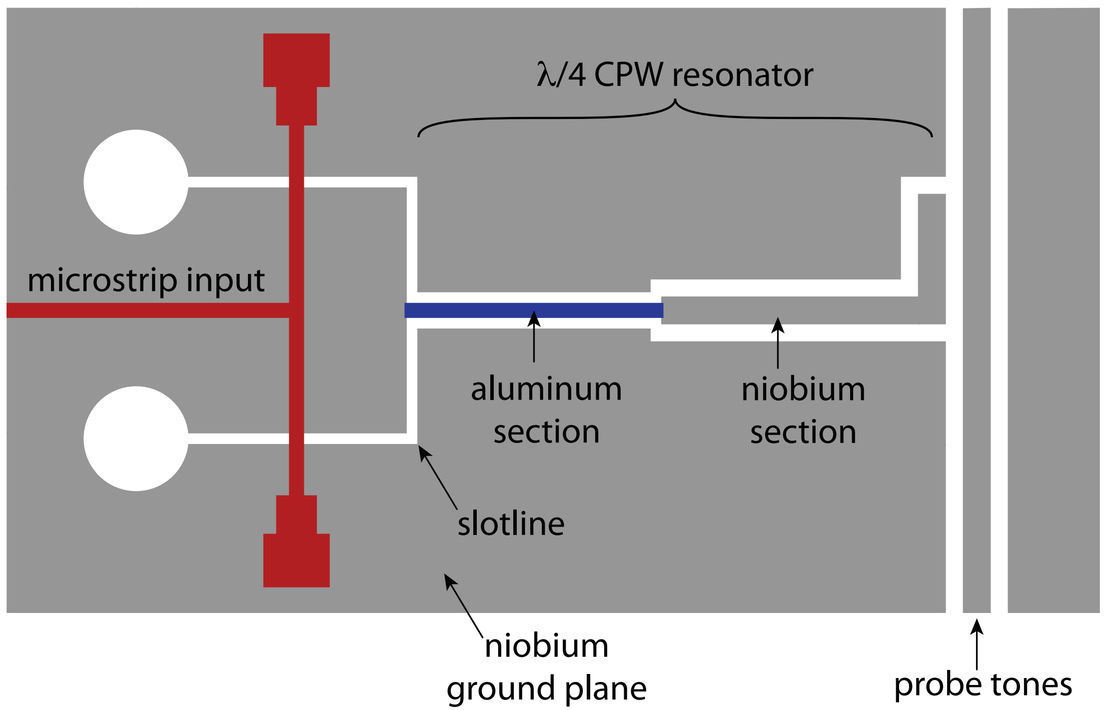
Hundreds of detectors can be read out with a single pair of coaxial cables.

Development of Multi-Chroic MKIDs



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

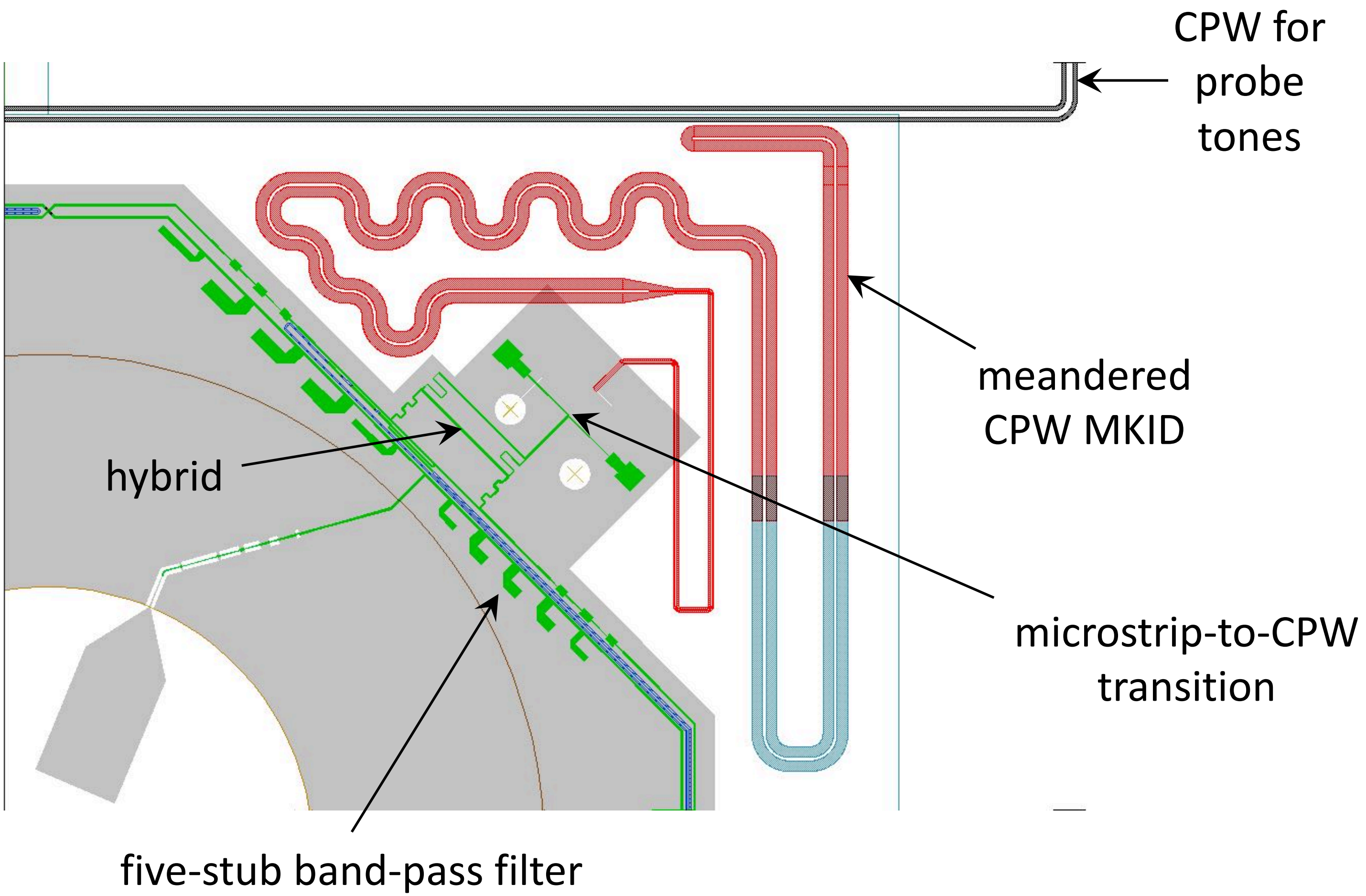
Microstrip-to-CPW MKID Coupling Schematic



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

Array Element Details



MKID resonant frequencies around 3 GHz

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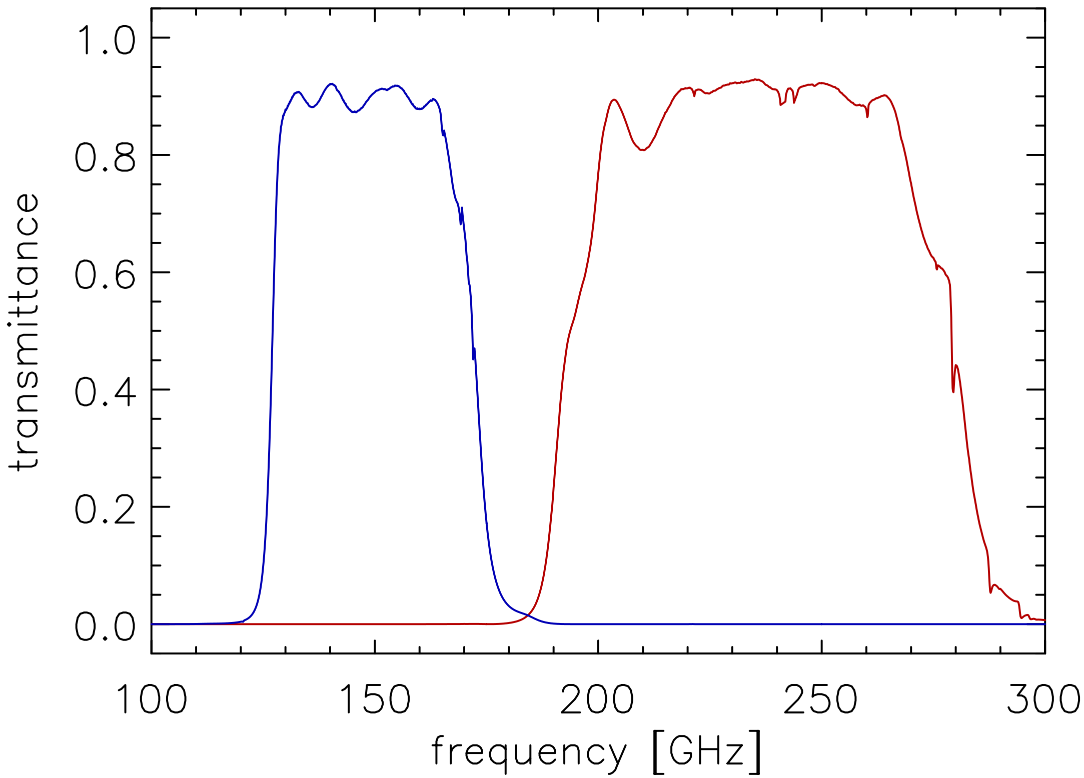
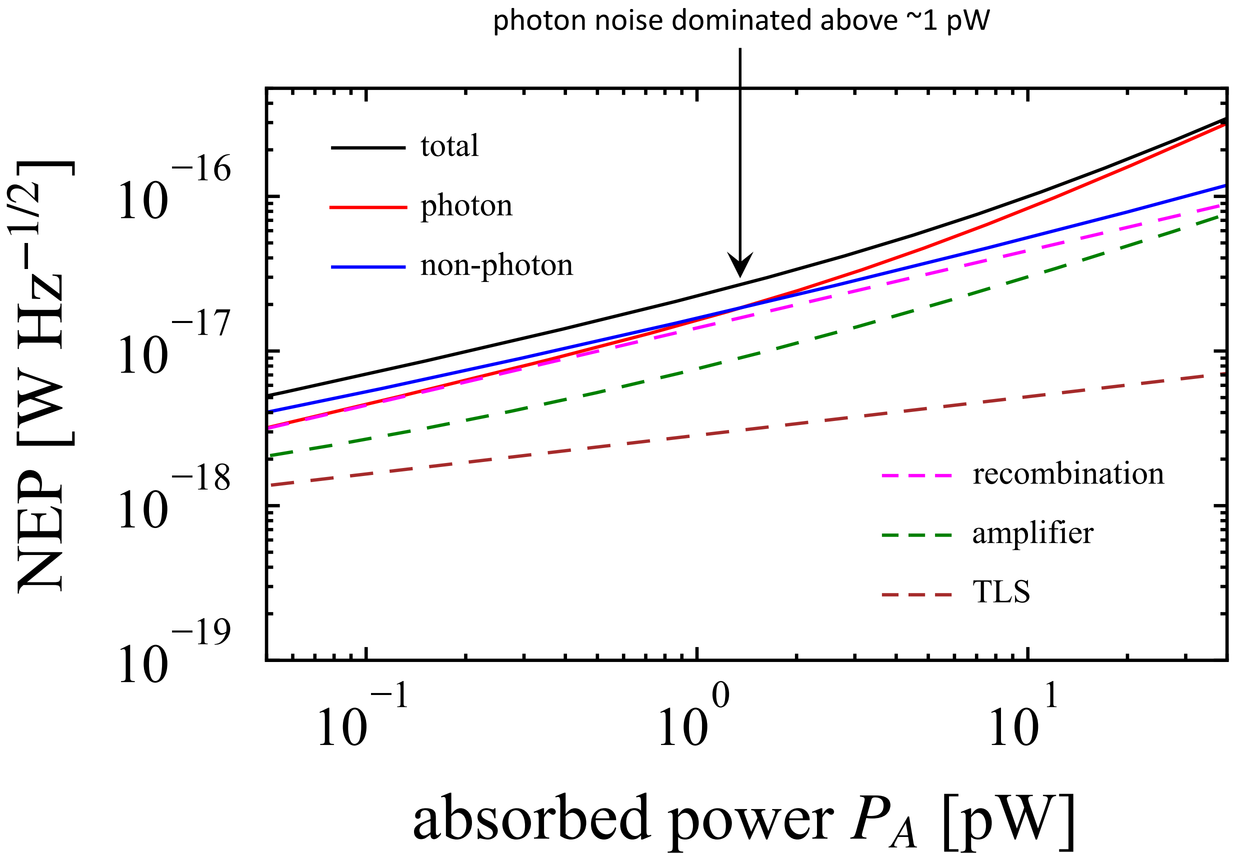
Simulated Spectral Bands



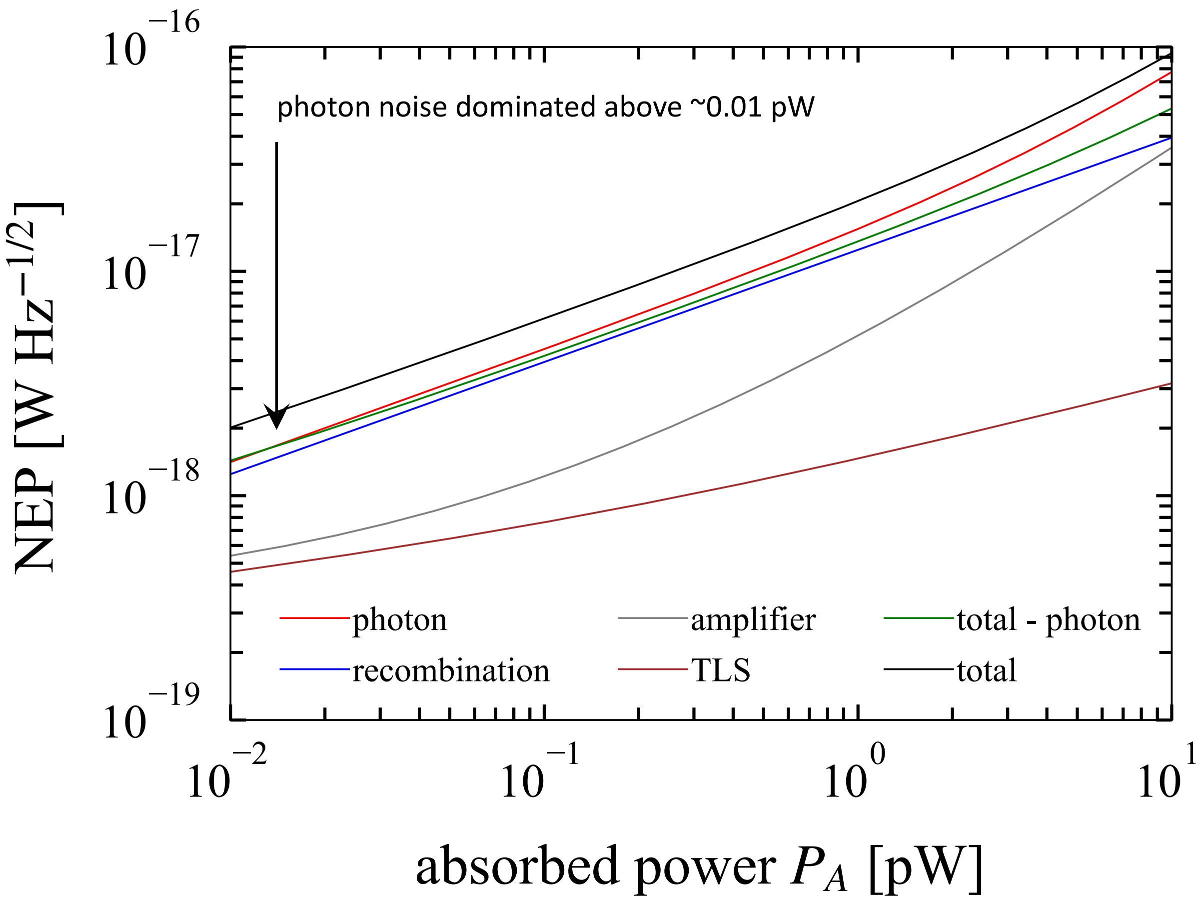
HFSS/Sonnet simulation results show the expected **absorption efficiency is approximately 90%** taking into account all of the elements in the circuit except the OMT probes.

Noise Sources and Expected NEP @ 150 GHz



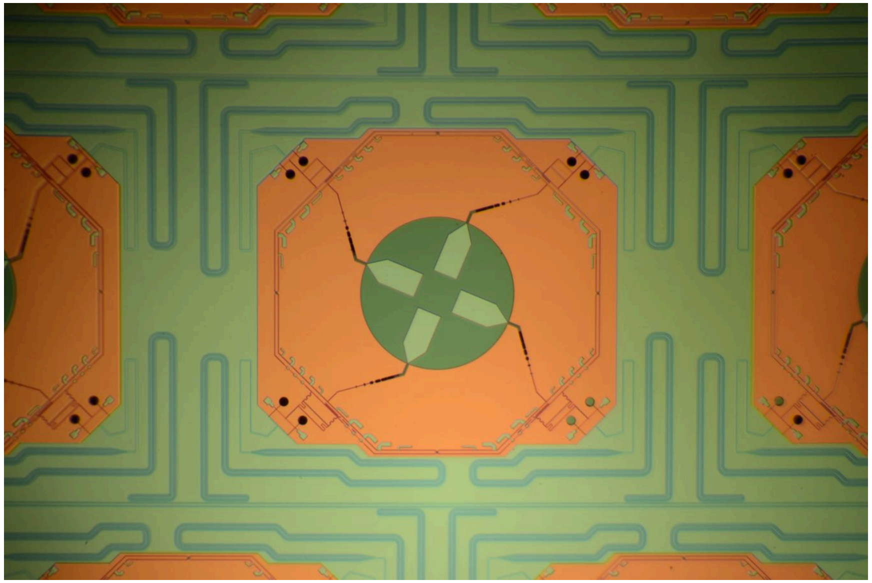
forecasted NEP with **aluminum sensors**

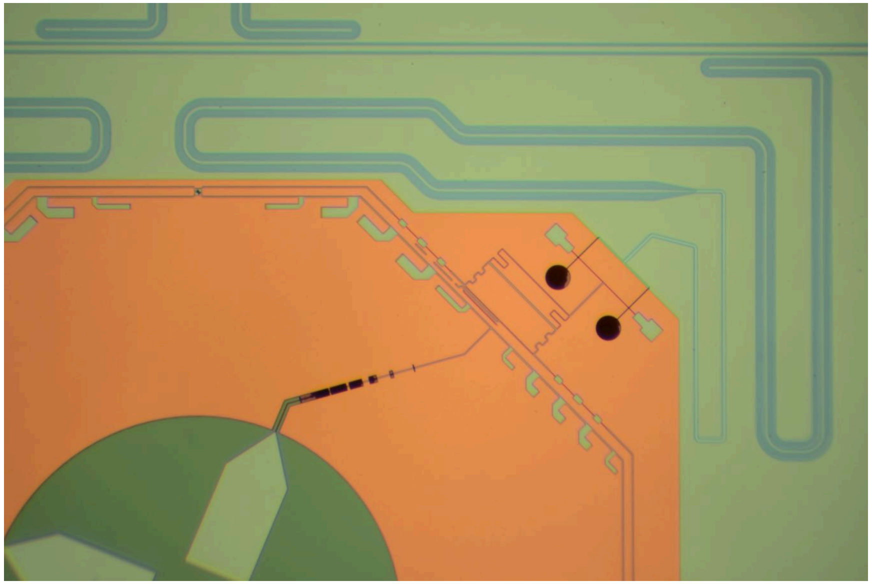
Noise Sources and Expected NEP @ 150 GHz



forecasted NEP with **aluminum-manganese sensors**

Photographs of Engineering Array

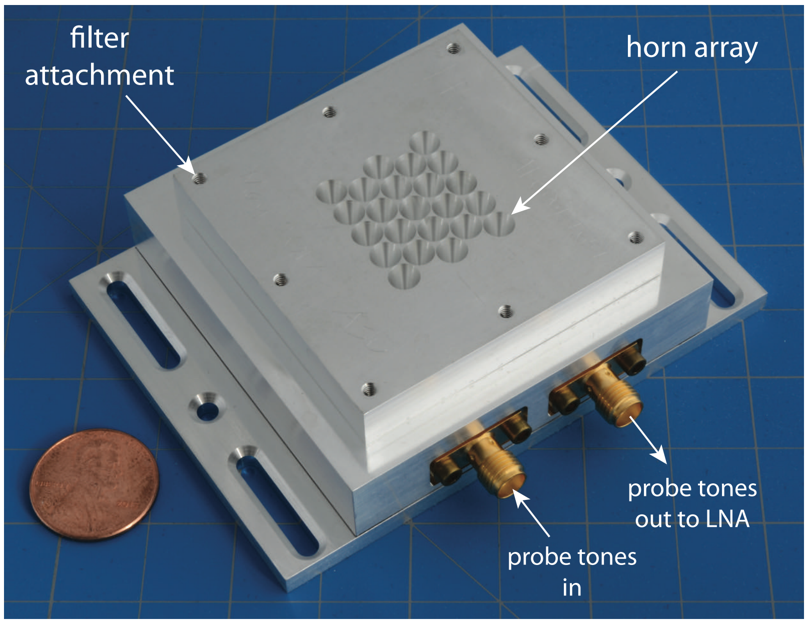


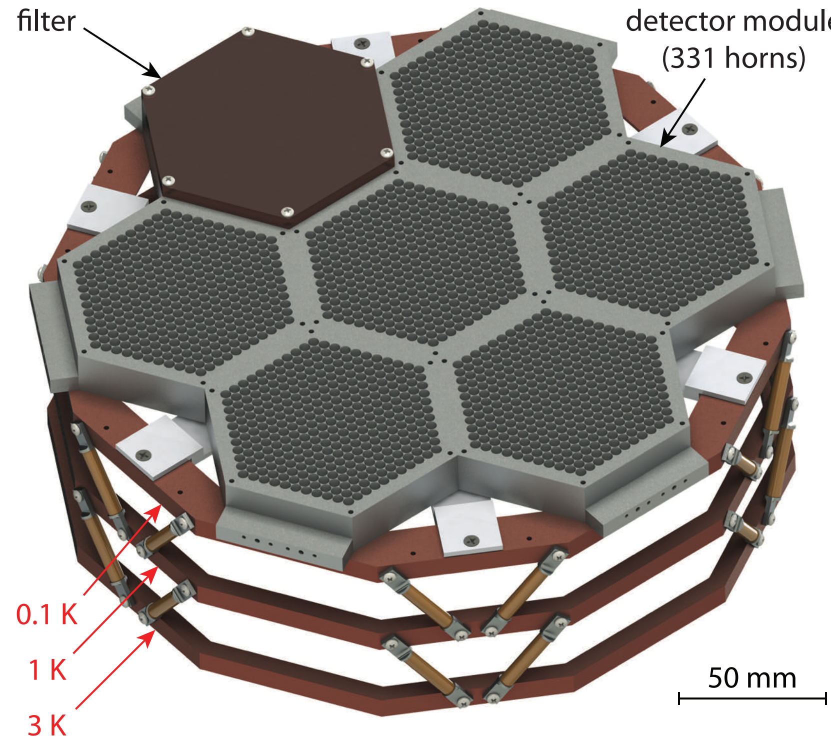


Fabricated at Stanford

Multi-Chroic MKID Array Goal

prototype module (23 horns)





start with scalable, 23-element prototype module …

… scale up to 2317 horns or 9268 detectors

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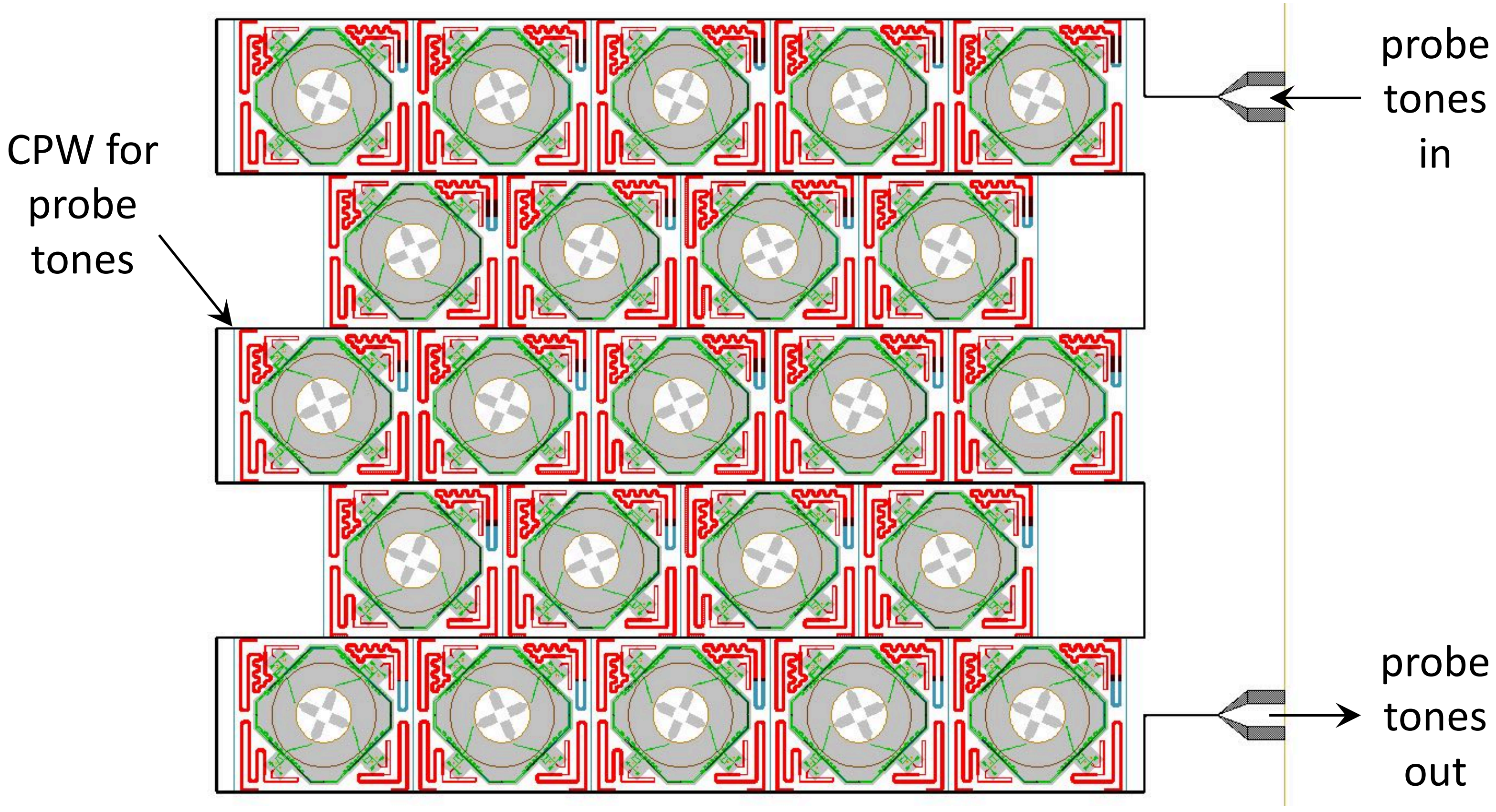
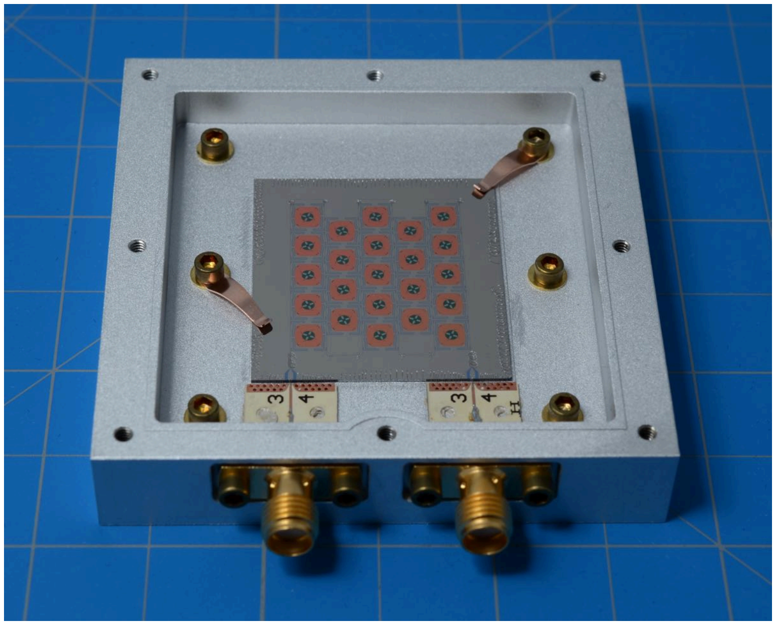
Layout of Prototype Array

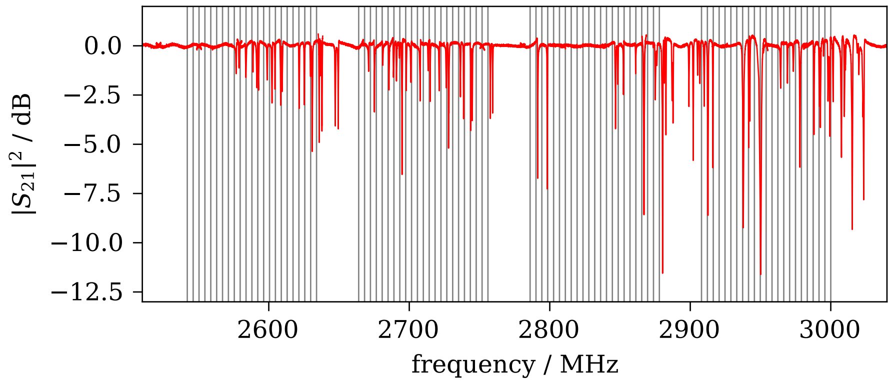


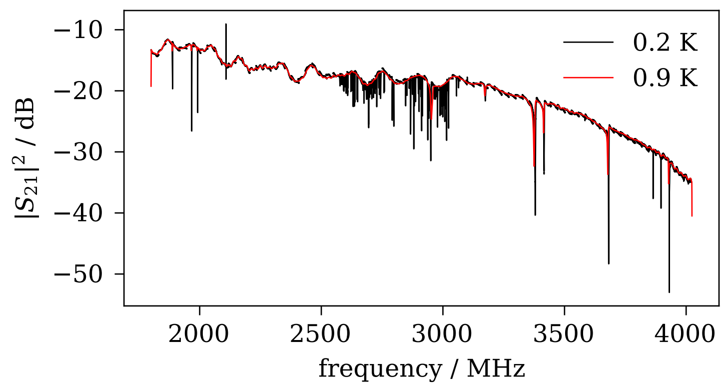
23 elements in the array

Engineering Array Performance



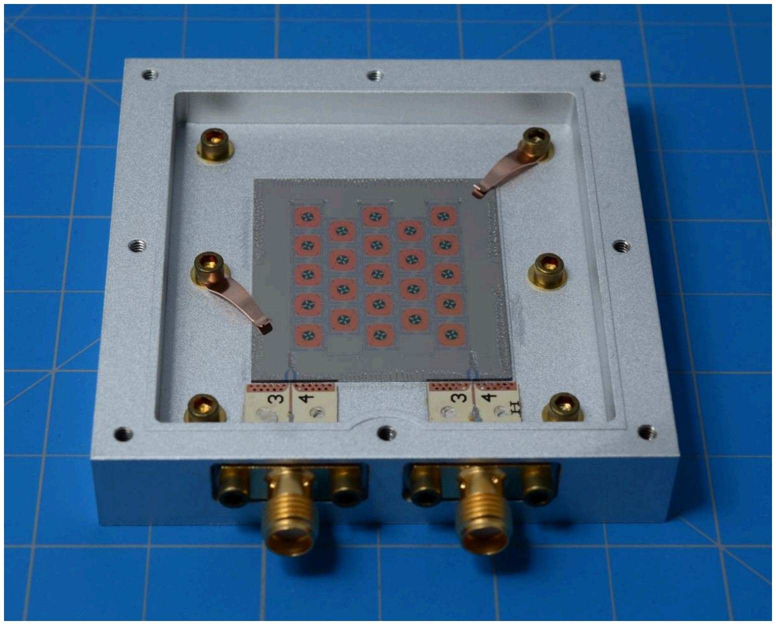
92 of 92 resonators found

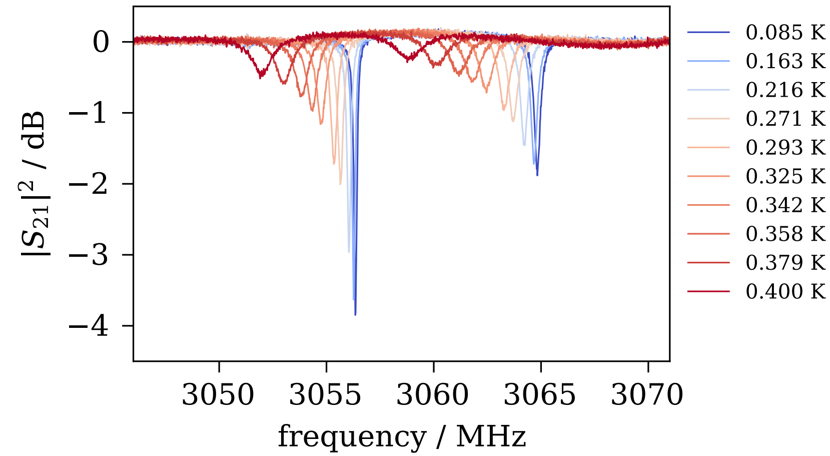


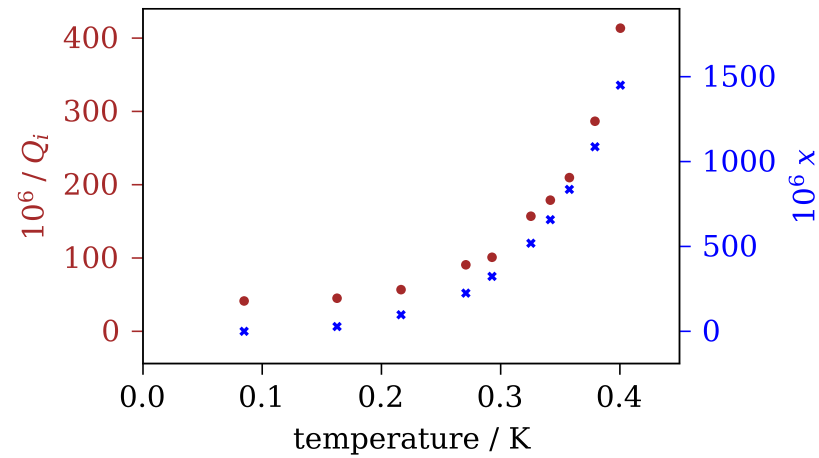


fabricated on silicon wafer

Engineering Array Performance







fabricated on silicon wafer

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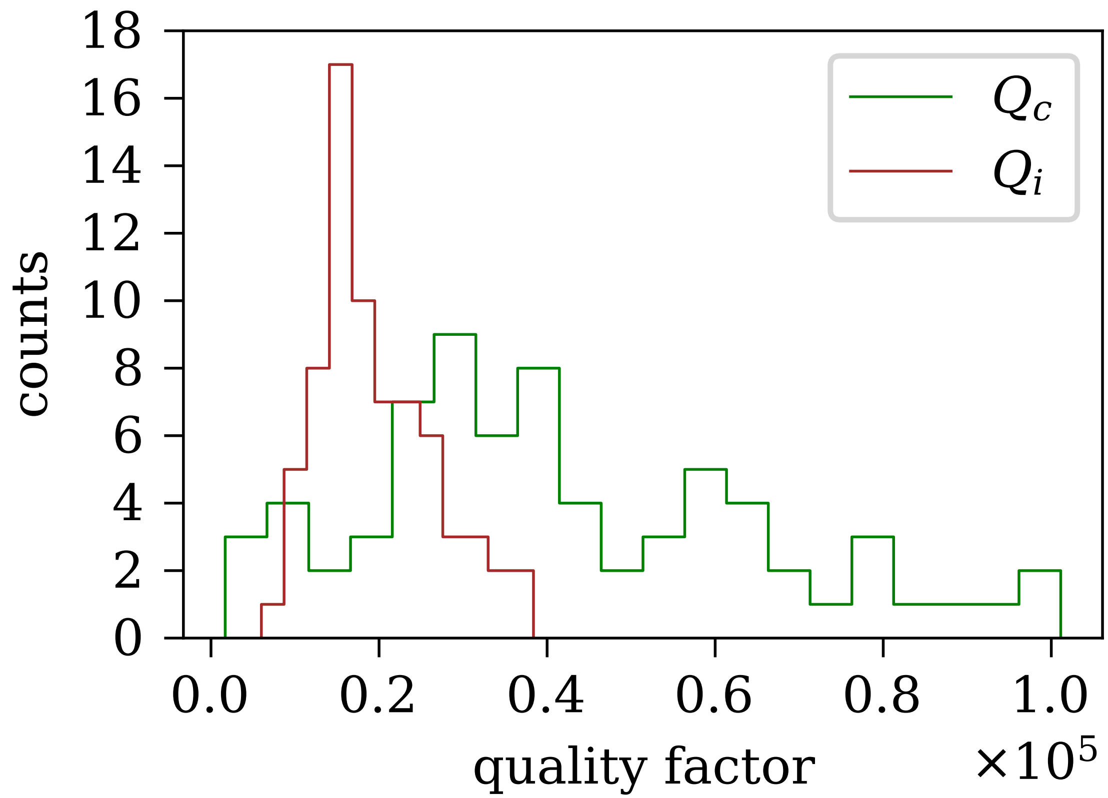
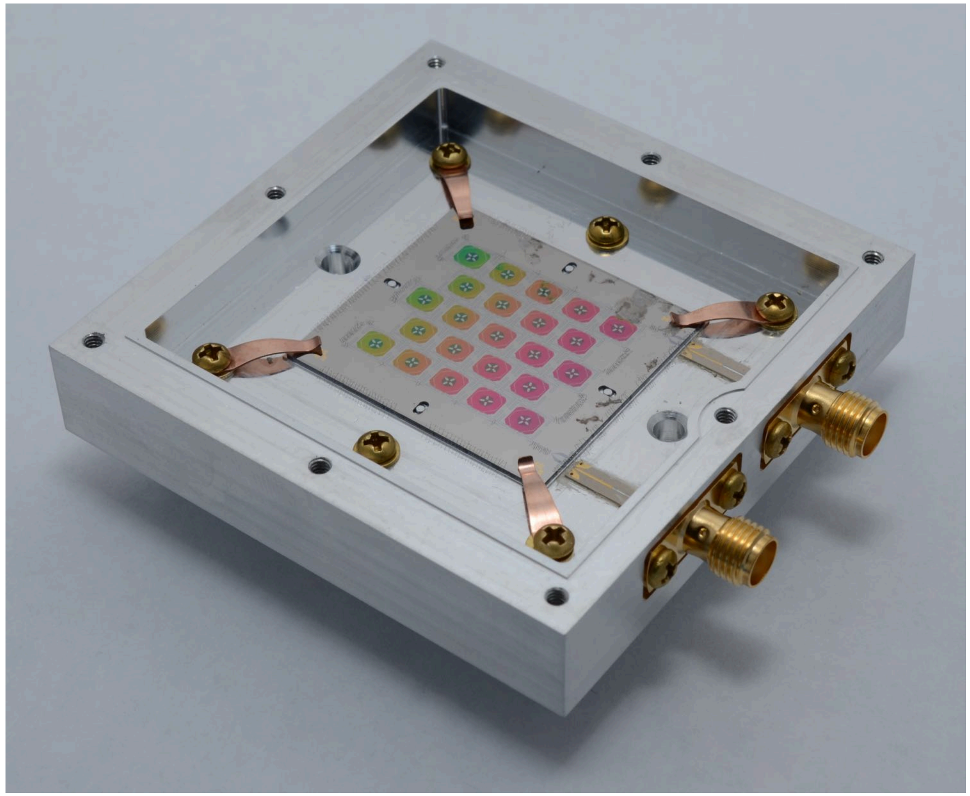
Engineering Array Performance

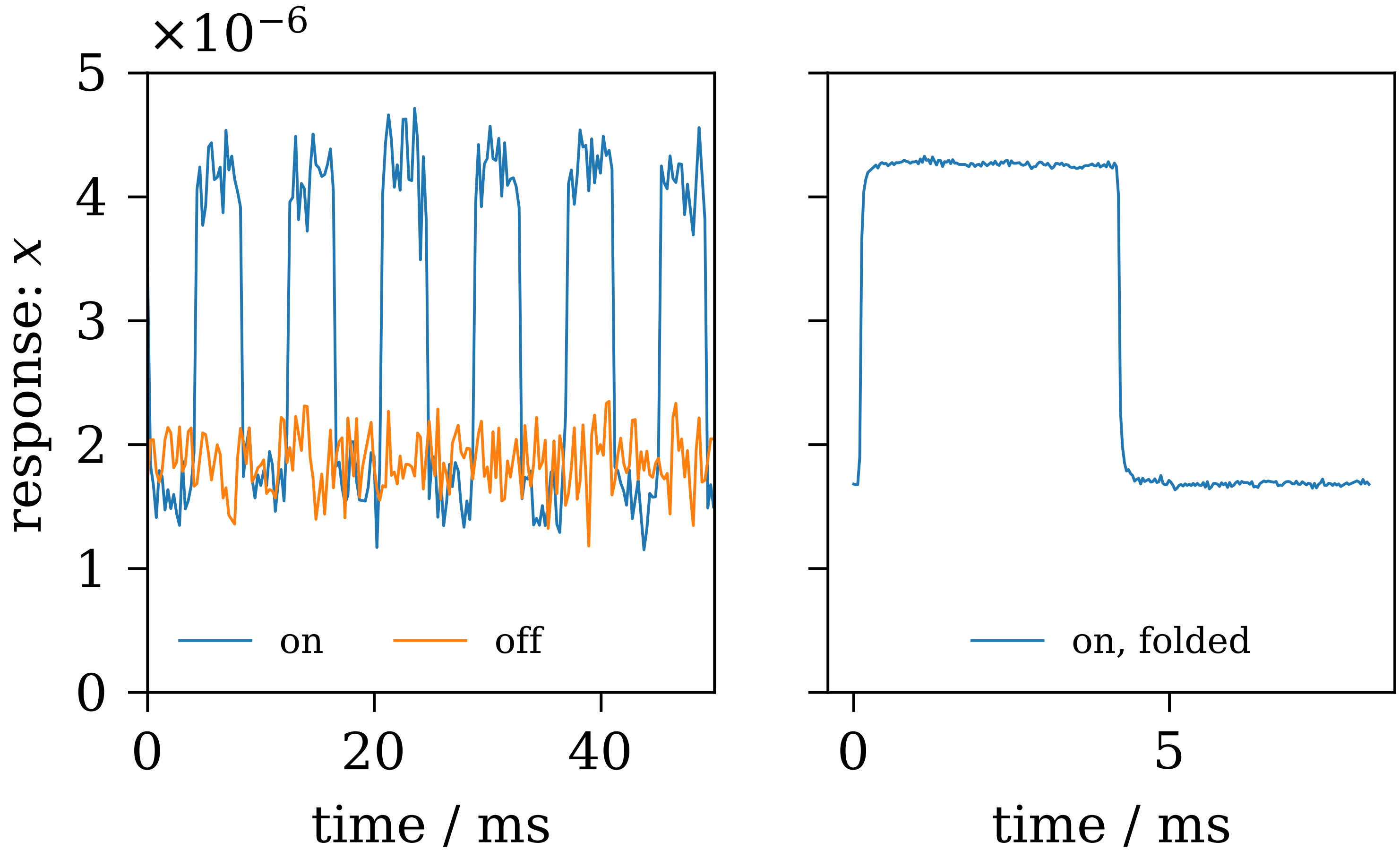


First Complete Prototype Array



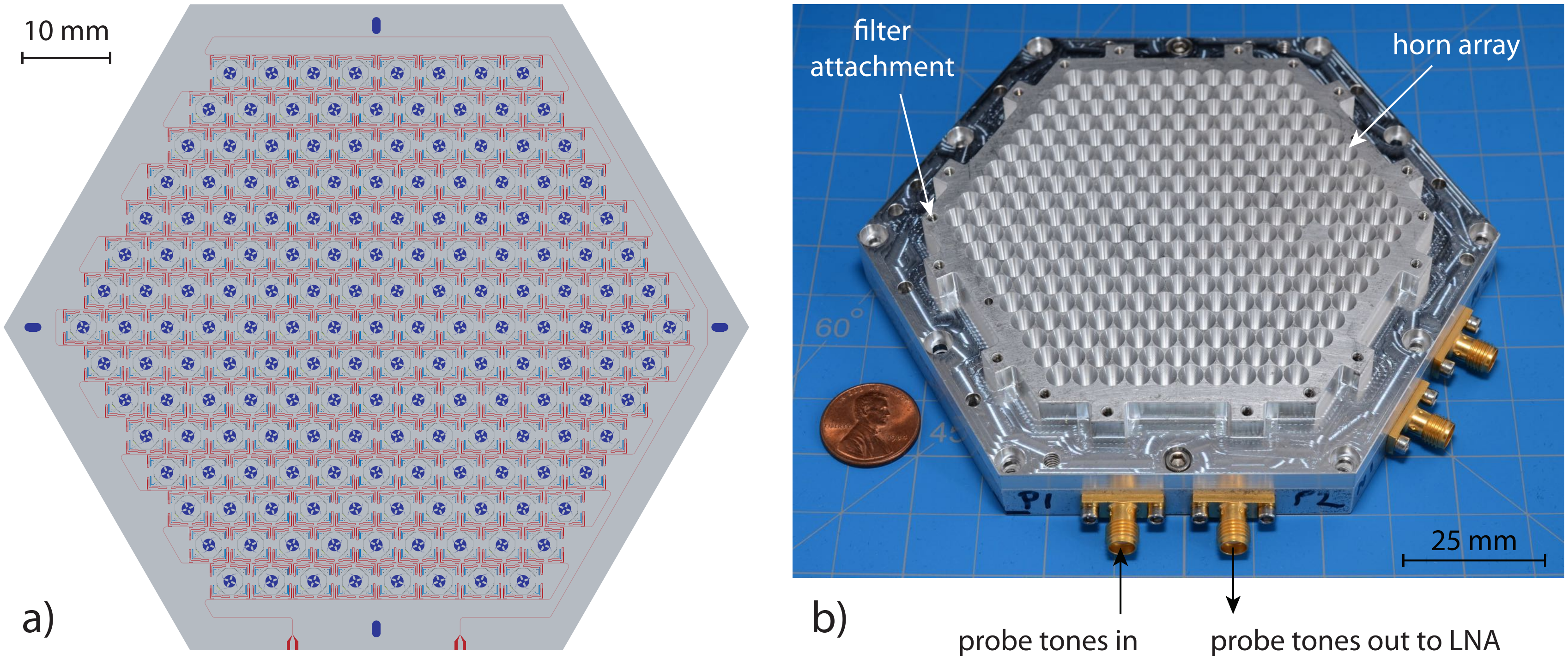
fabricated on SOI wafer

Optical Response of Prototype Array



More data coming soon!

Future Plans: Scale up the Array



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

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

G. Jones,[1, a)] B. R. Johnson,[1] M. H. Abitbol,[1] P. A. R. Ade,[2] S. Bryan,[3] H.-M. Cho,[4] P. Day,[5] D. Flanigan,[1] K. D. Irwin,[6,4] D. Li,[4] P. Mauskopf,[3] H. McCarrick,[1] A. Miller,[7] Y. R. Song,[6] and C. Tucker[2]
[1)] *Department of Physics, Columbia University, New York, NY 10027, USA*
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[3)] *School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287, USA*
[4)] *SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA*
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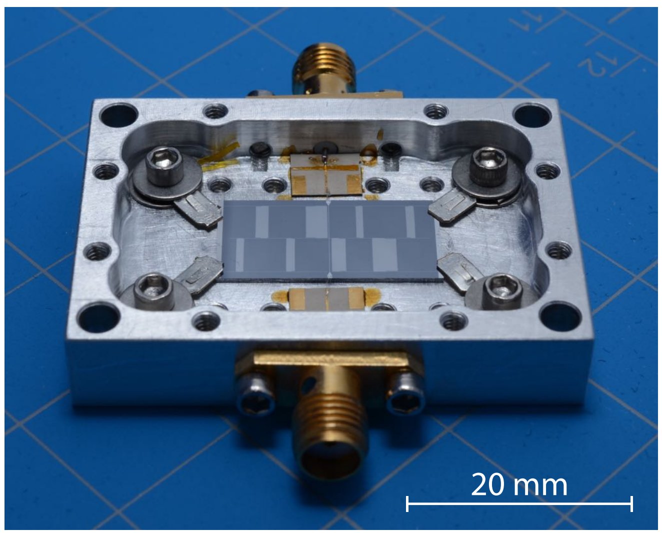
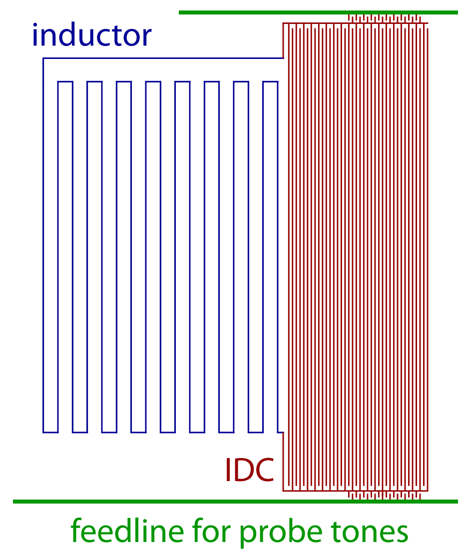
[6)] *Department of Physics, Stanford University, Stanford, CA, 94305-4085, USA*
[7)] *Department of Physics and Astronomy, University of Southern California, Los Angeles, CA 90089, USA*

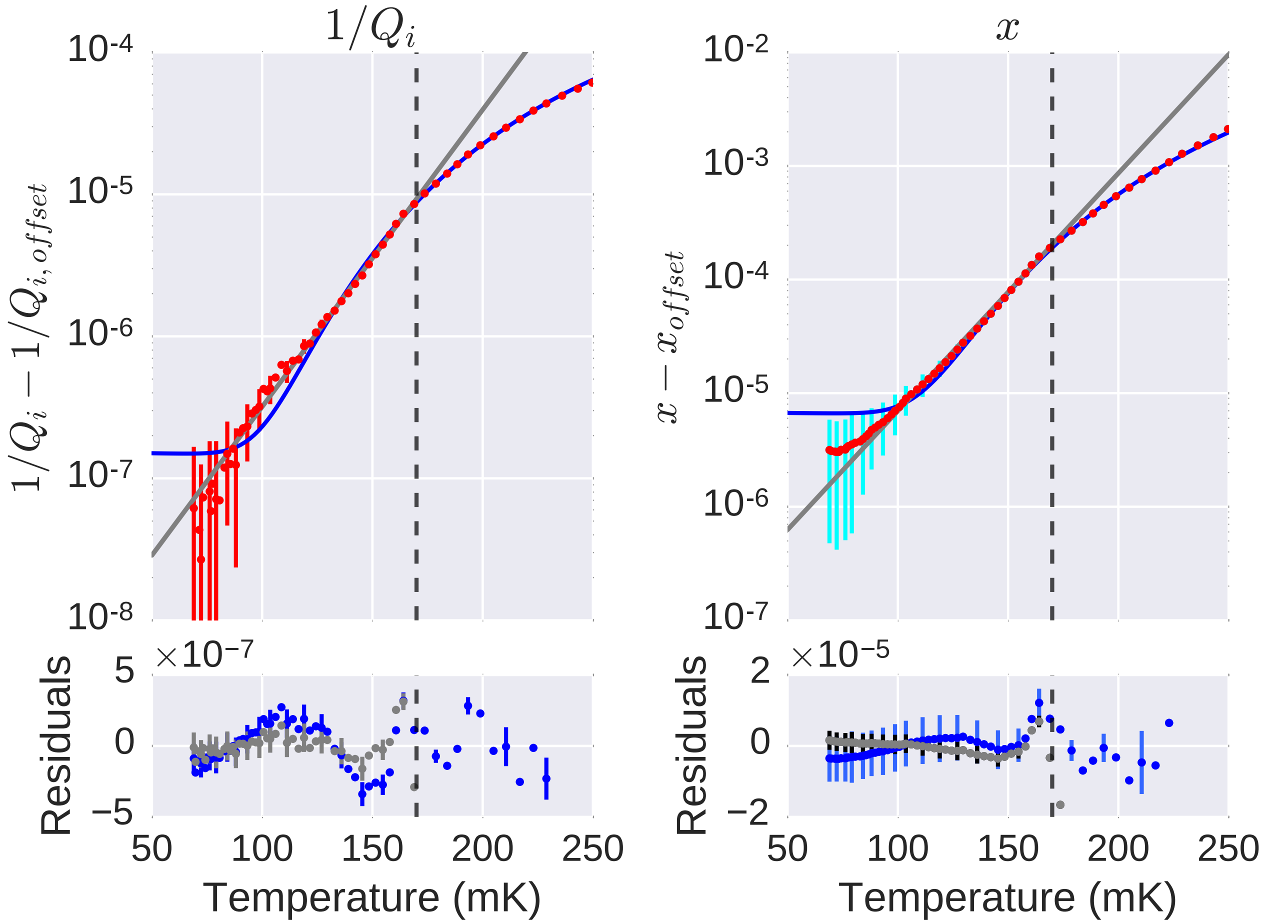
(Dated: 31 January 2017)





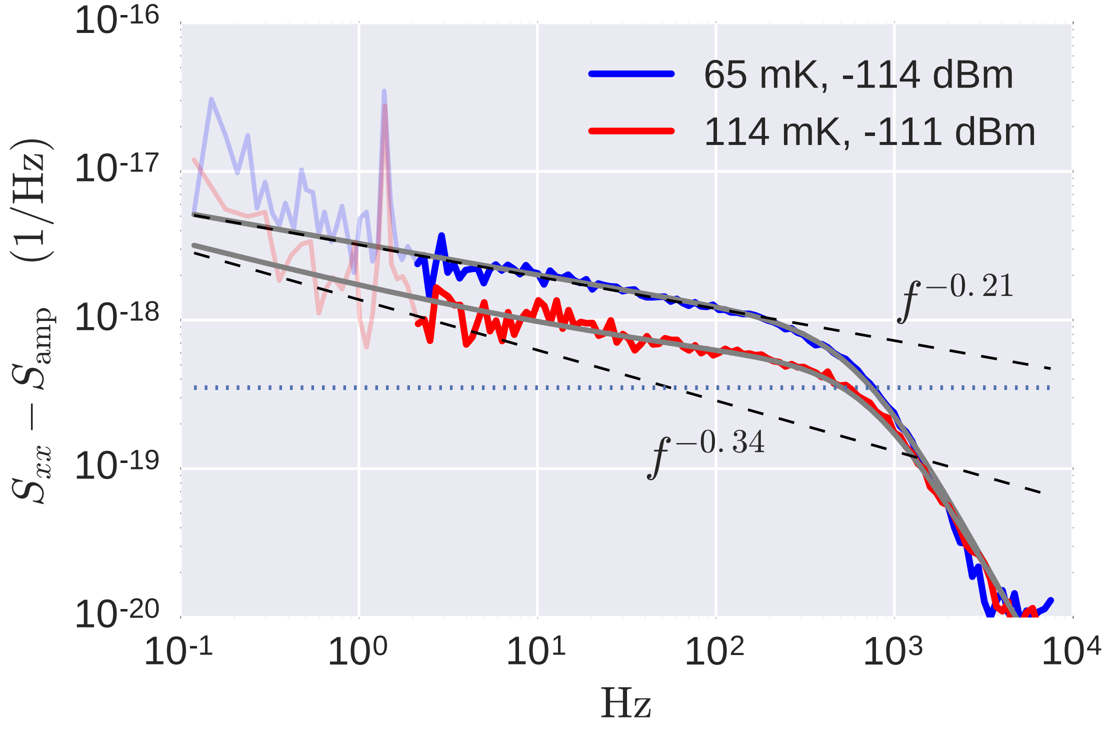
Jones et al. (2017) *APL*, 110, 222601.

High Q_i AlMn LEKIDs



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

High Q_i AlMn LEKIDs



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

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Summary

MKIDs have characteristics that could be useful for CMB studies:

- high multiplexing factors
- no SQUIDs
- no delicate membranes
- Fast time constants
- Low power consumption readout
- Some architectures have been fabricated in commercial foundries.

We are developing two different KID varieties:

- dual-polarization LEKIDs (supported by ONR, NASA/NESSF, RISE)
- multi-chroic dual-polarization MKIDs (supported by NSF/ATI)

AlMn appears to be a suitable sensor material.

Measured LEKID noise properties look promising. MKID noise results soon.

Readout system based on ROACH-2 has been developed.