MKIDs for CMB Studies

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Why investigate MKIDs for CMB Studies?

- **High multiplexing factors** make them particularly suitable for instruments with 10,000 or more detectors (CMB-S4, for example).
- No membranes are required and arrays can be made with a comapratively **small number of processing steps**. Fabrication in commercial foundries is possible.
- **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** (~20 watts) is commercially available. Required LNAs are available. Required firmware is open-source.

But is the sensitivity and 1/f noise suitable?

REVIEW OF SCIENTIFIC INSTRUMENTS **85**, 123117 (2014)

Horn-coupled, commercially-fabricated aluminum lumped-element kinetic inductance detectors for millimeter wavelengths

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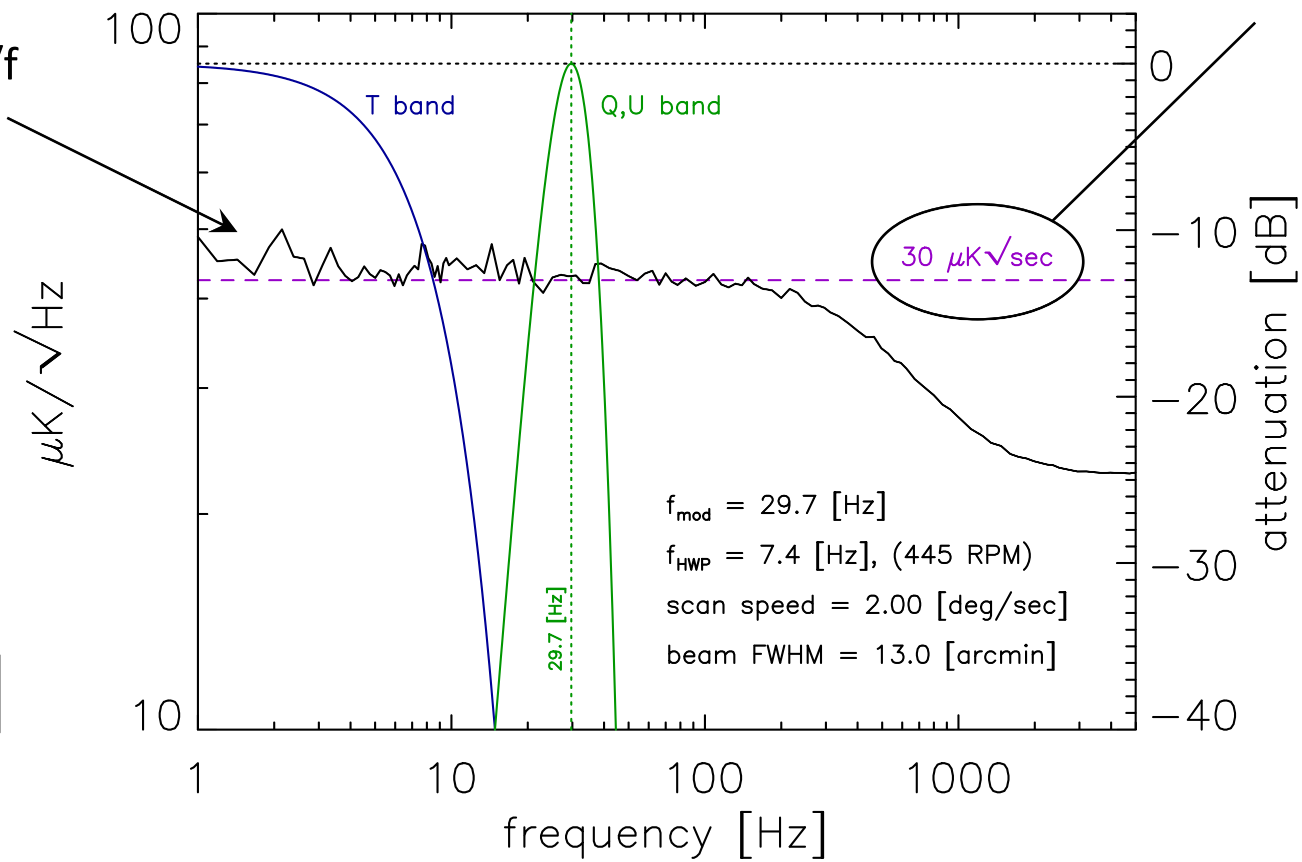
Project supported in part by a grant from the Research Initiatives for Science and Engineering program at Columbia.

Result: ***Measured*** LEKID Noise

1) low NET

2) low 1/f noise

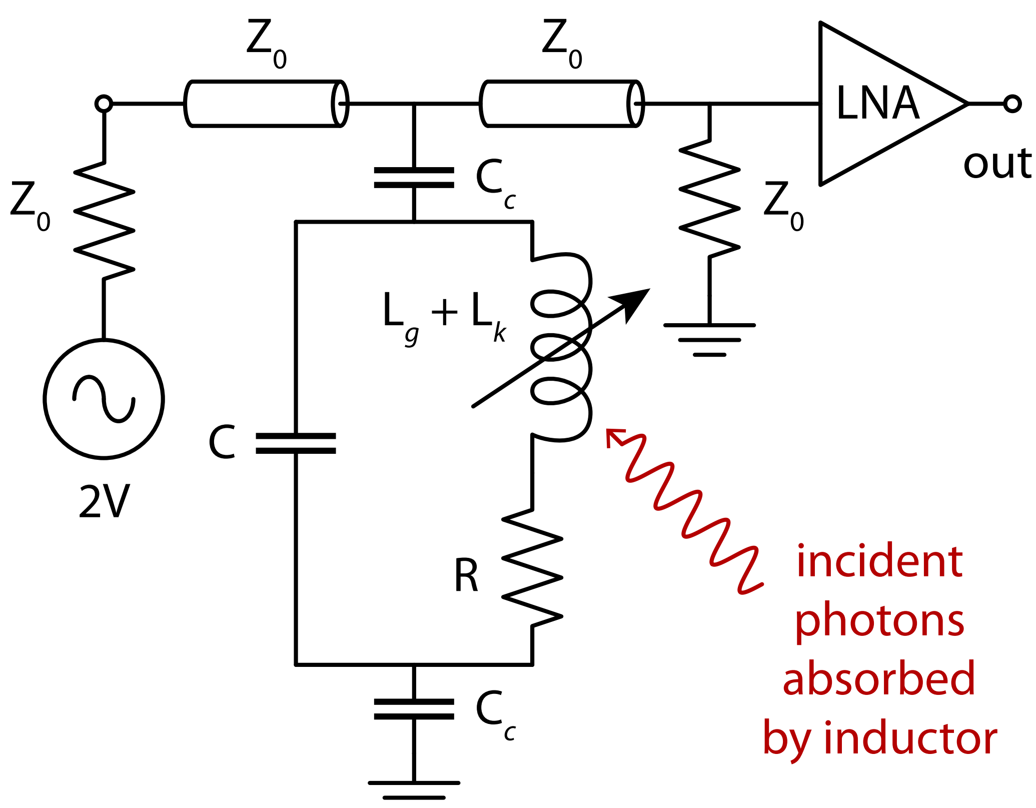


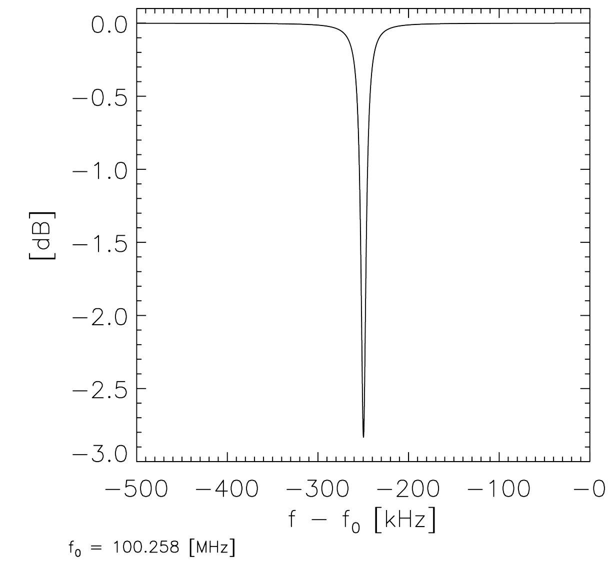
150 GHz

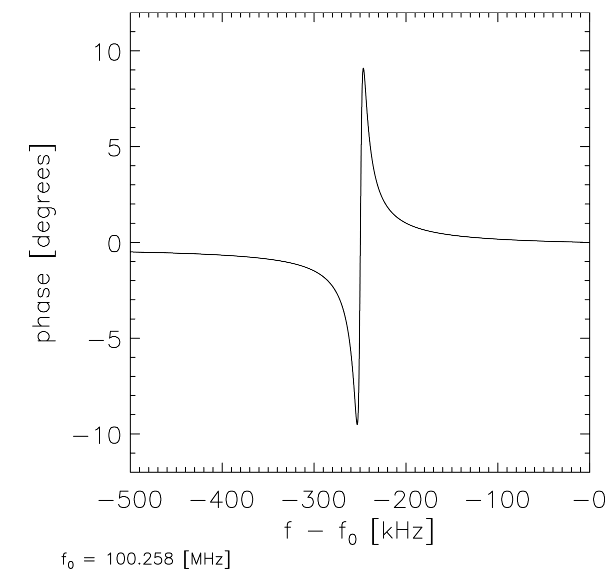
3) lots of bandwidth

4 K beam-filling load

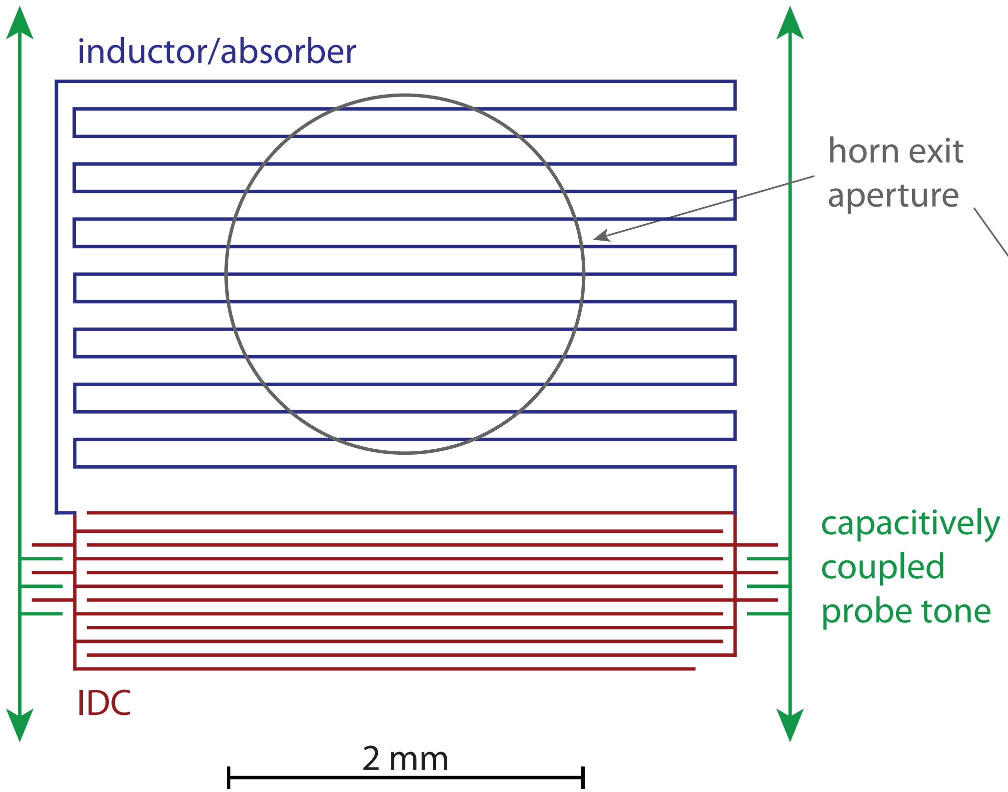
Circuit Schematic for One LEKID

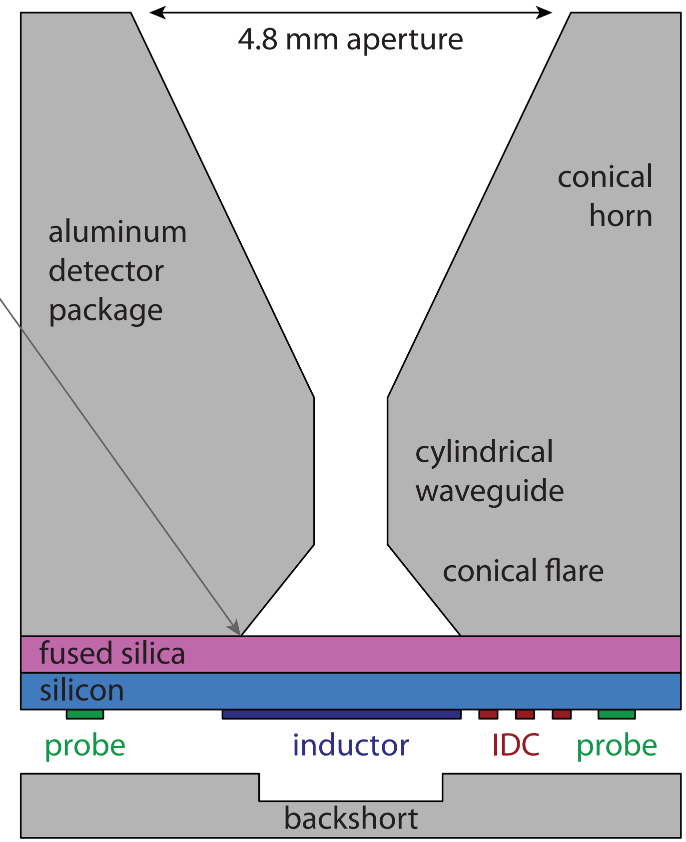




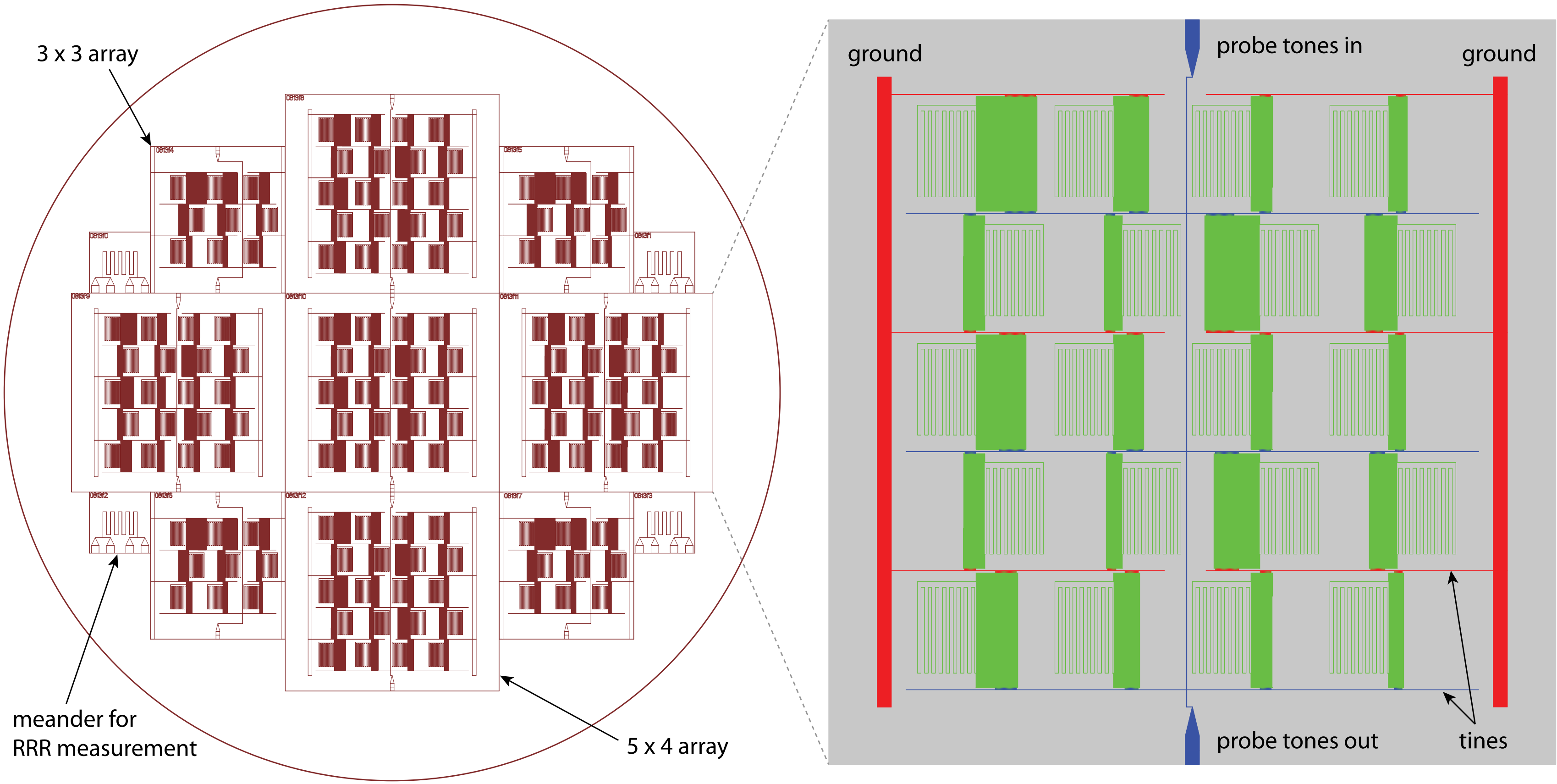


Pixel Design



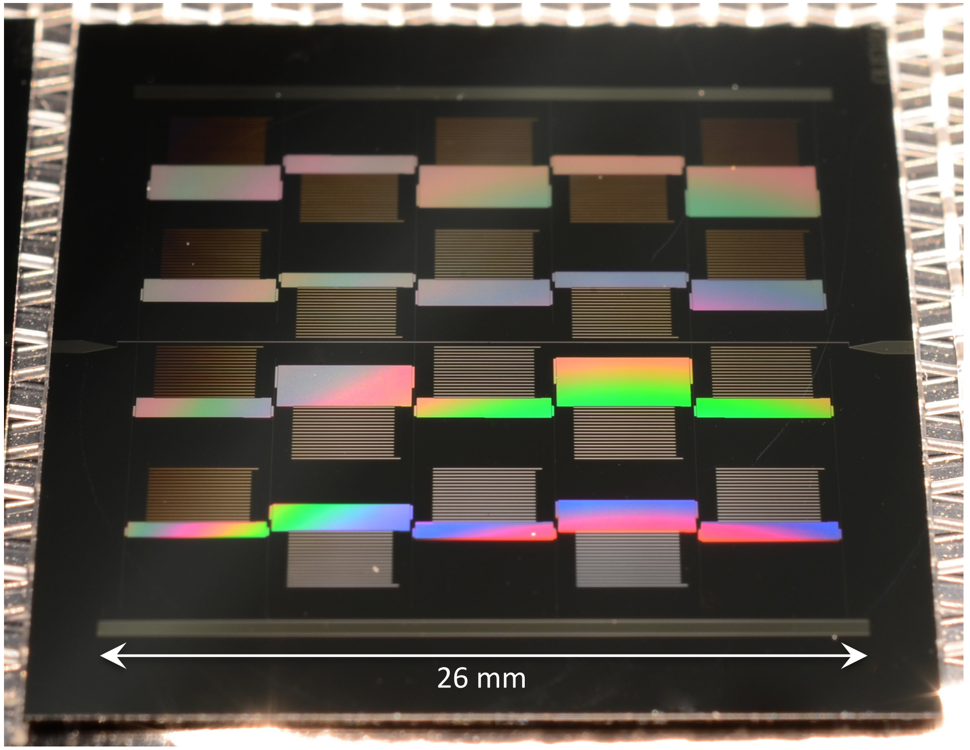


Prototype Array Design



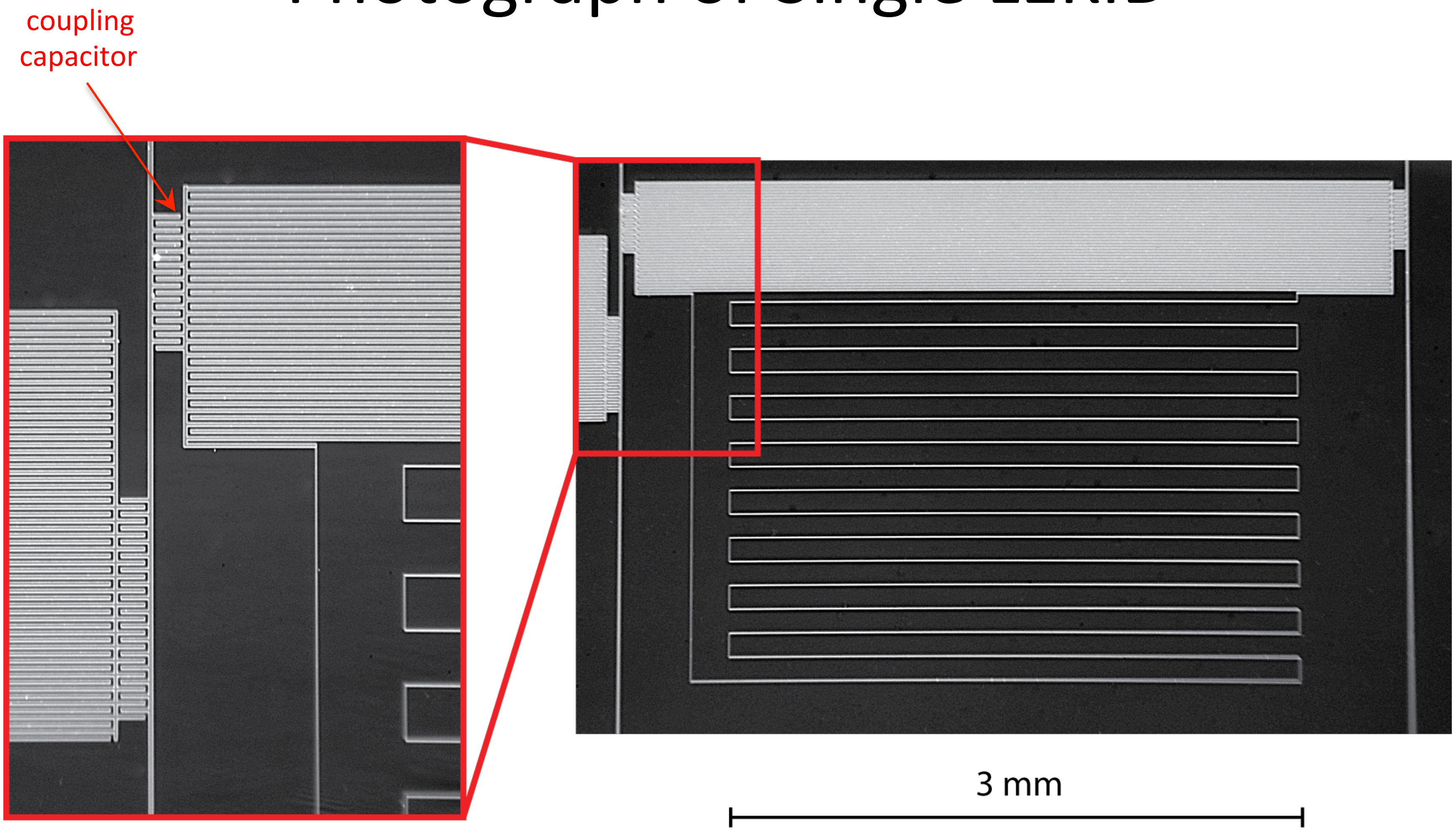
Photograph of Prototype Array

- Arrays fabricated on av100 mm **float zone silicon** wafer 300 microns thick.
- Devices processed from one **aluminum film 20 nm thick**.
- **Contact lithography** used -- one mask required.
- **Commercially fabricated** at STAR Cryoelectronics (~$2k per wafer)
- Processing took ~1 week.
- Plan was to fabricate and test 1 wafer per month for two years.
- Paper describes results from first wafer.

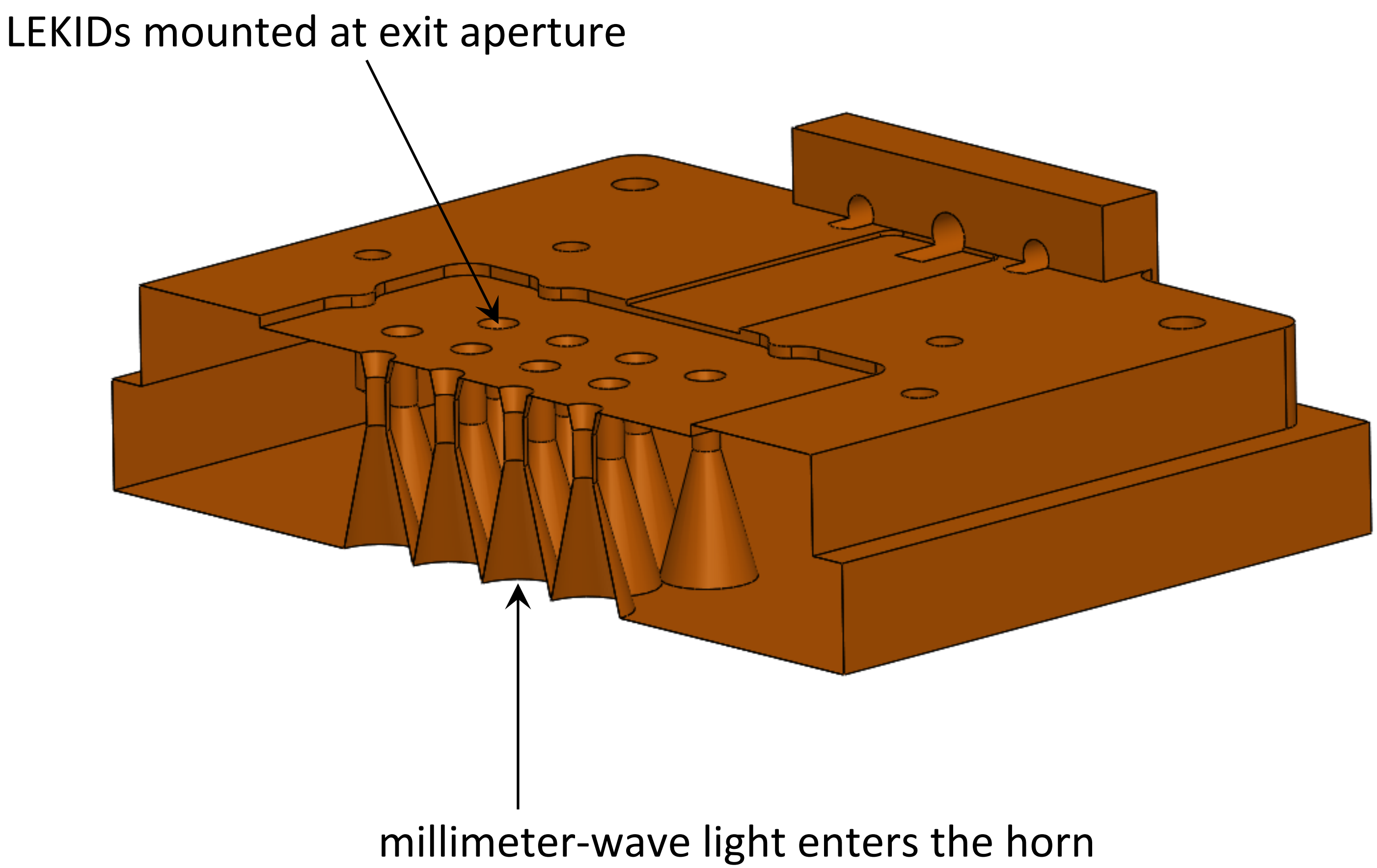


yield > 90%

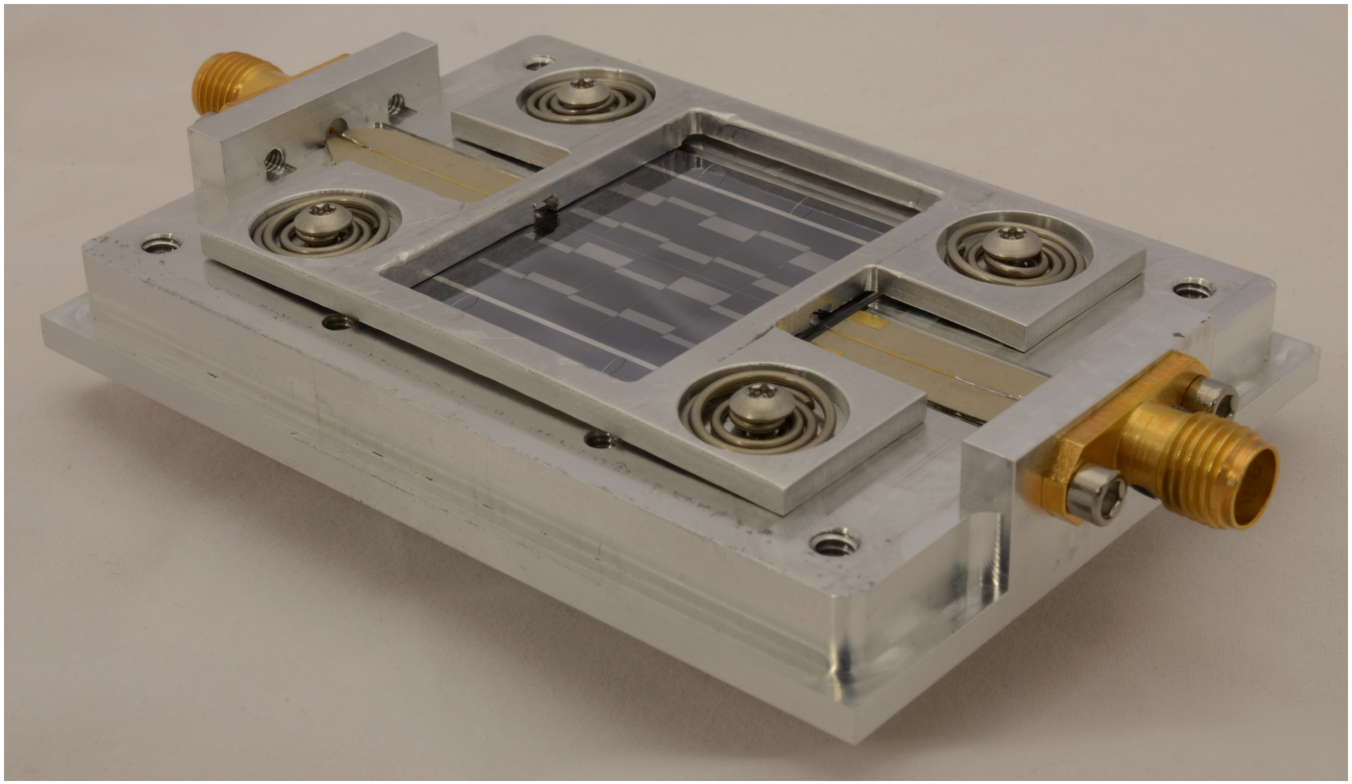
Photograph of Single LEKID



Cross Section of Detector Package



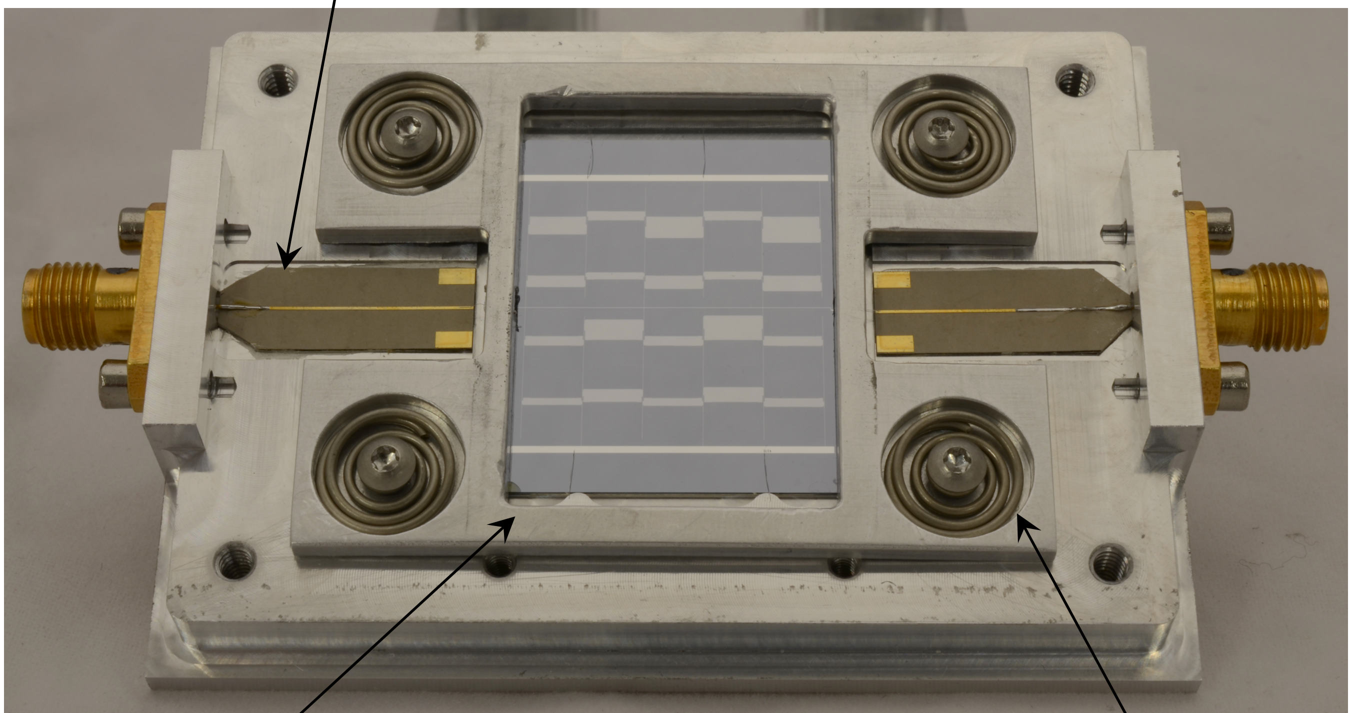
Prototype Array in Detector Package



Prototype Array in Detector Package

duroid boards connect probe tones to the array

probe comb in

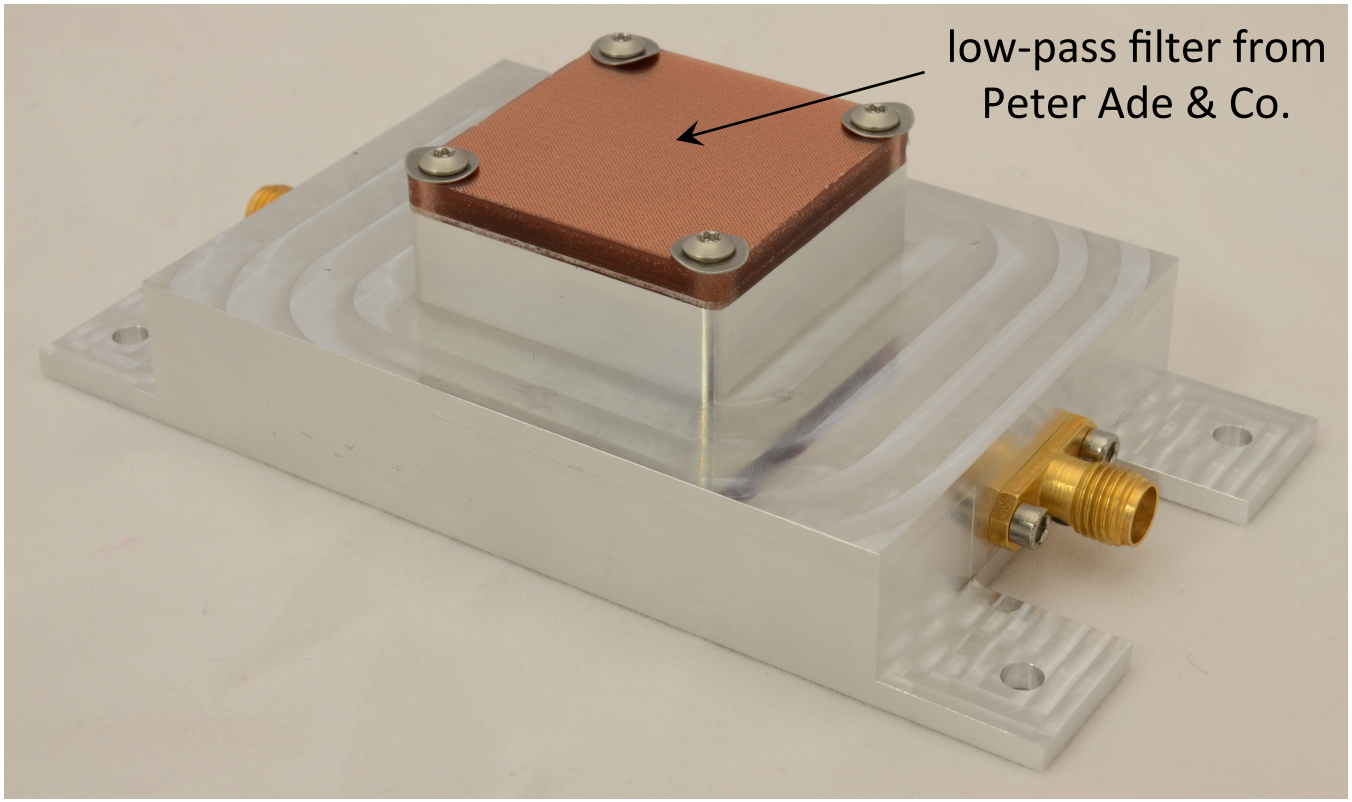


probe comb out

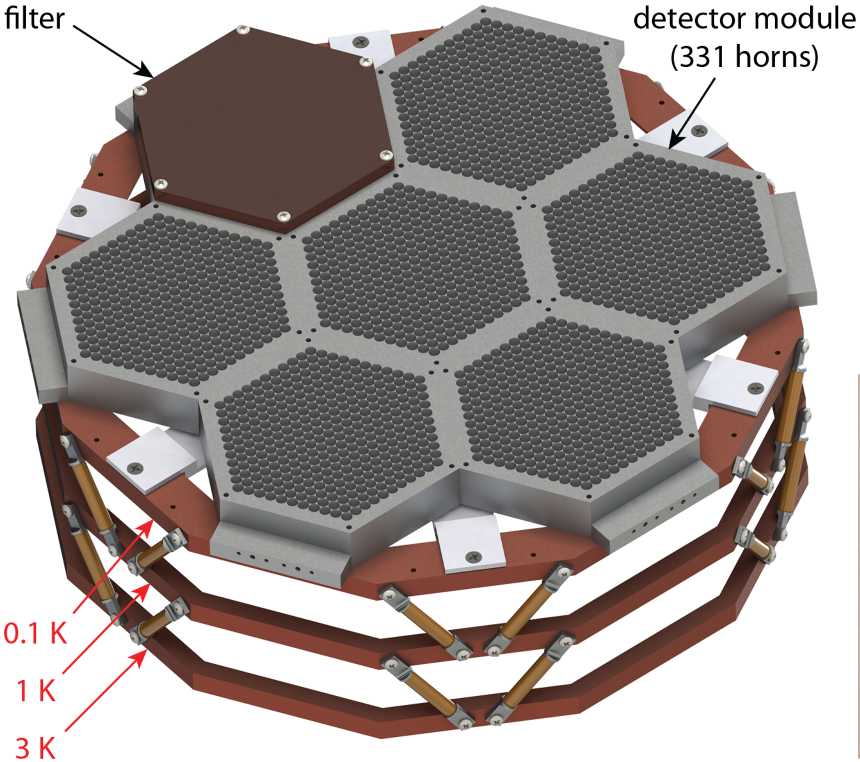
frame holds the chip in place

springs provide force and improve thermal conductivity

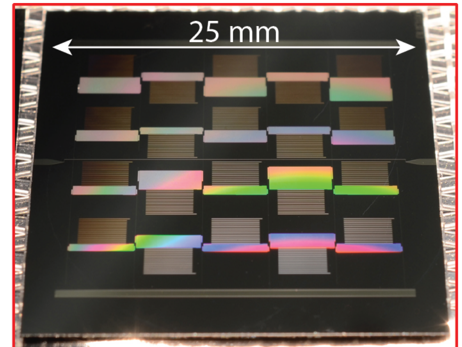
Prototype Array in Detector Package



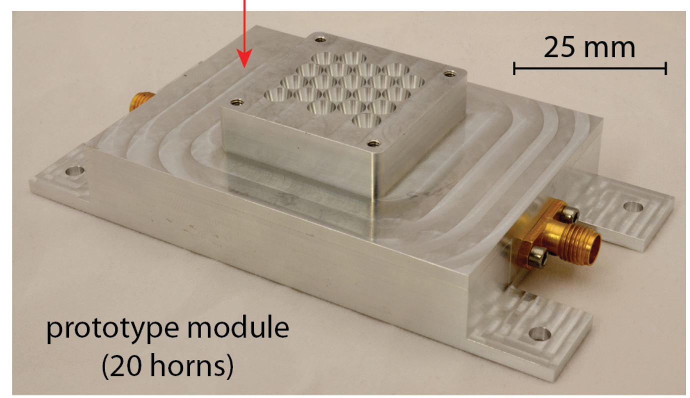
Detector Array Development Plan



2317 horns/single-pol detectors
4634 dual-pol detectors



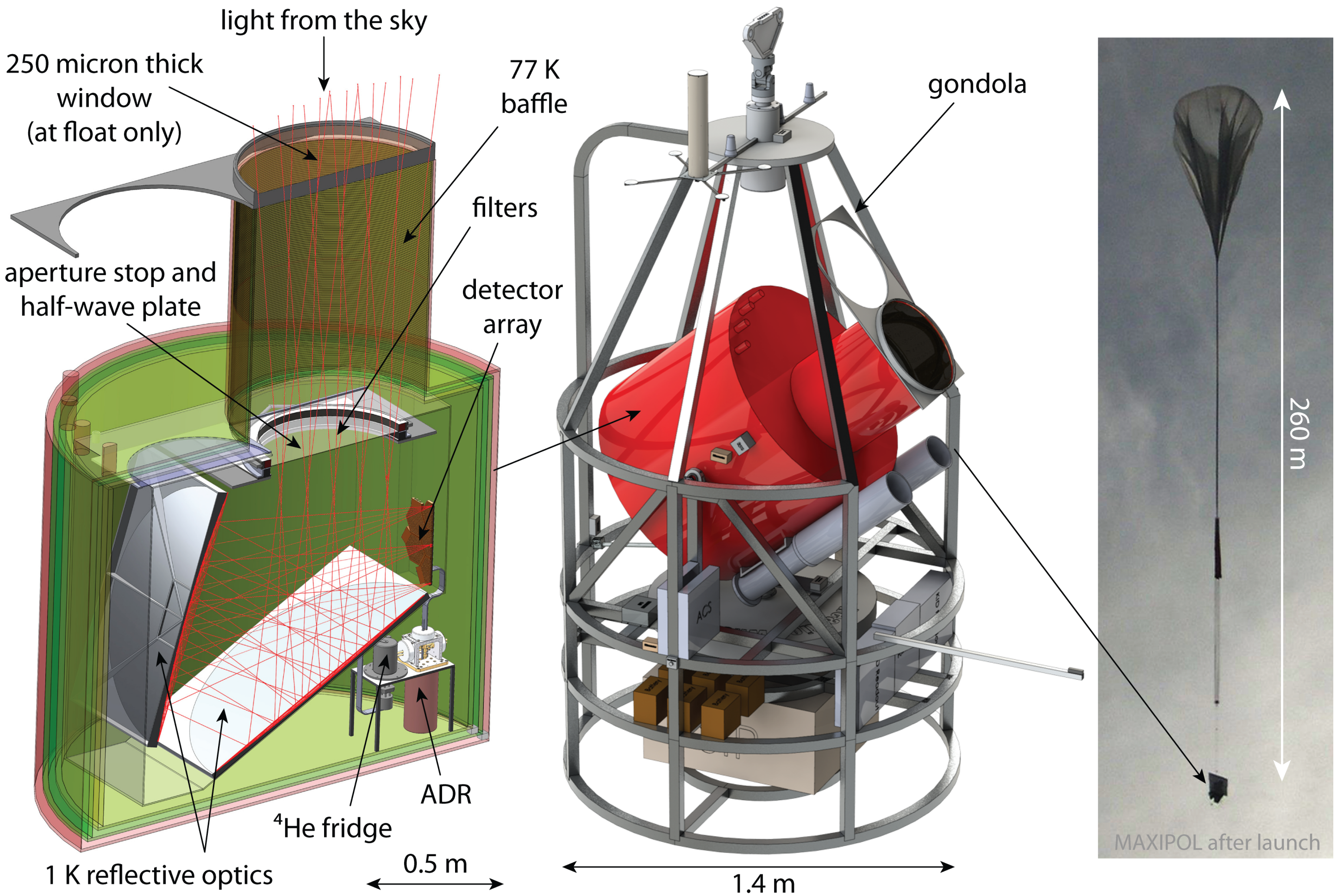
prototype
LEKID
array



start with scalable, 20-element
prototype module

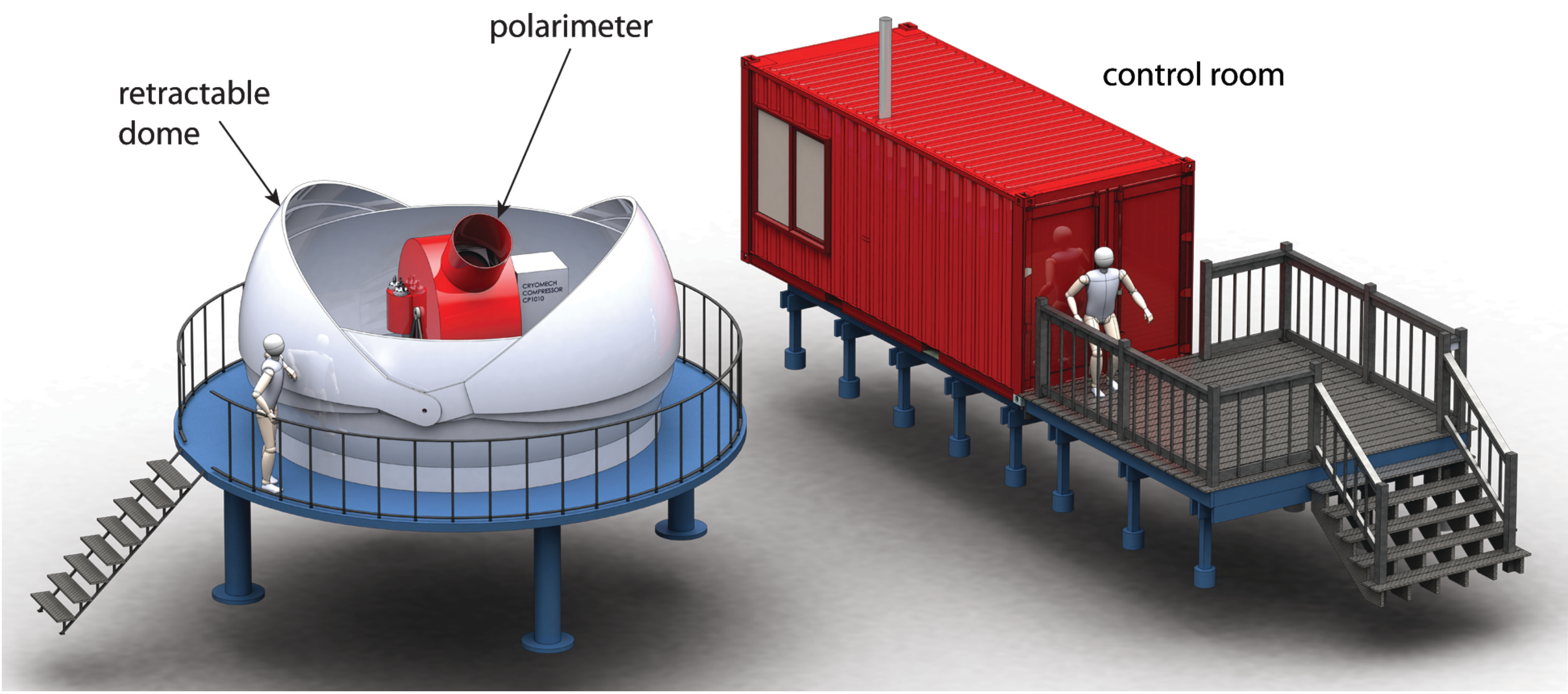
SKIP: Johnson et al. (2013) J. Low Temp. Phys.
GLP: Araujo et al . (2014) Proc. SPIE

SKIP



Johnson et al. (2013) J. Low Temp. Phys.

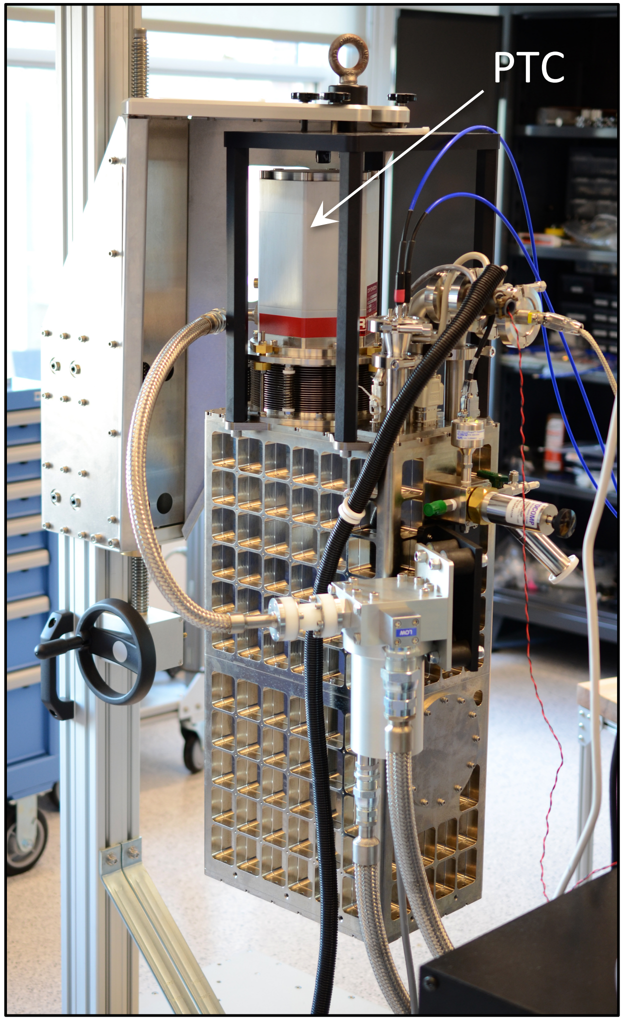
The Greenland LEKID Polarimeter



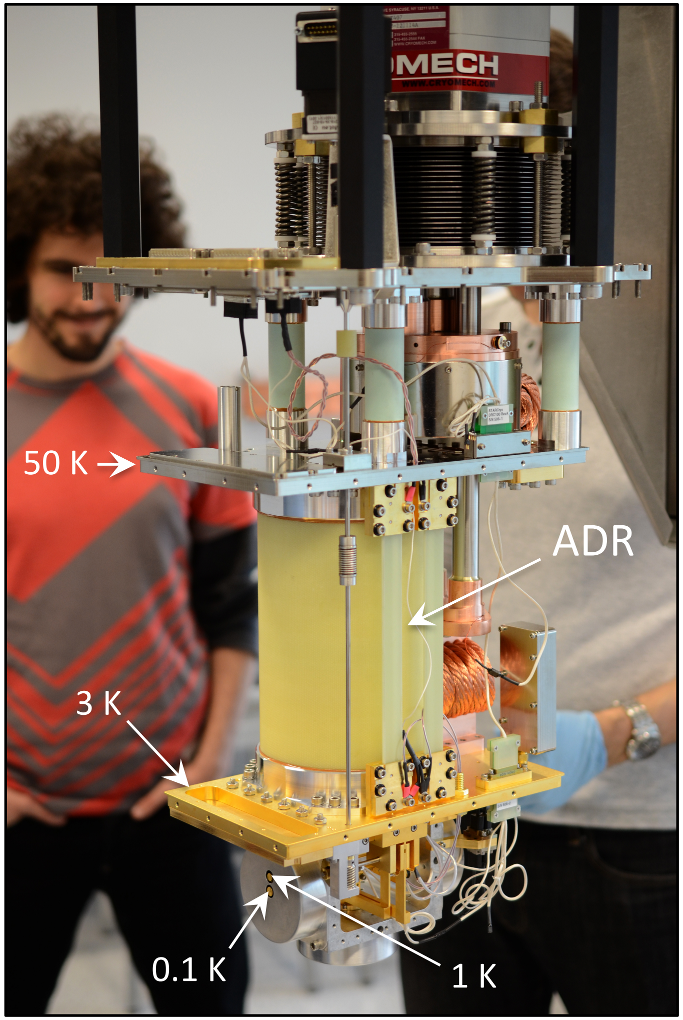
Araujo et al . (2014) Proc. SPIE

STAR Cryo DRC-102 ADR Cryostat

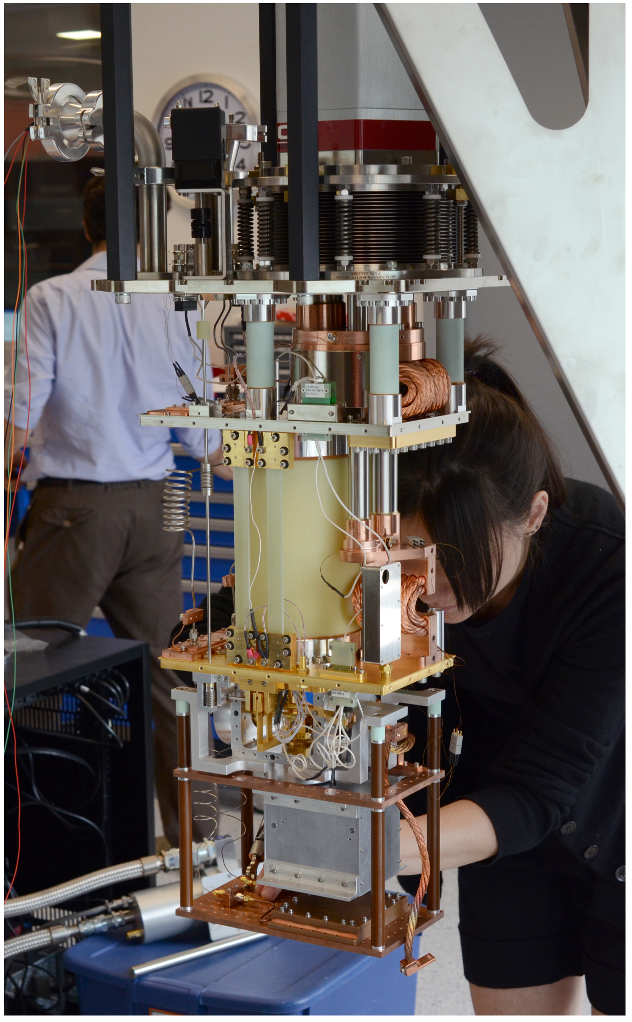
fully assembled



vacuum jacket, radiation shields off

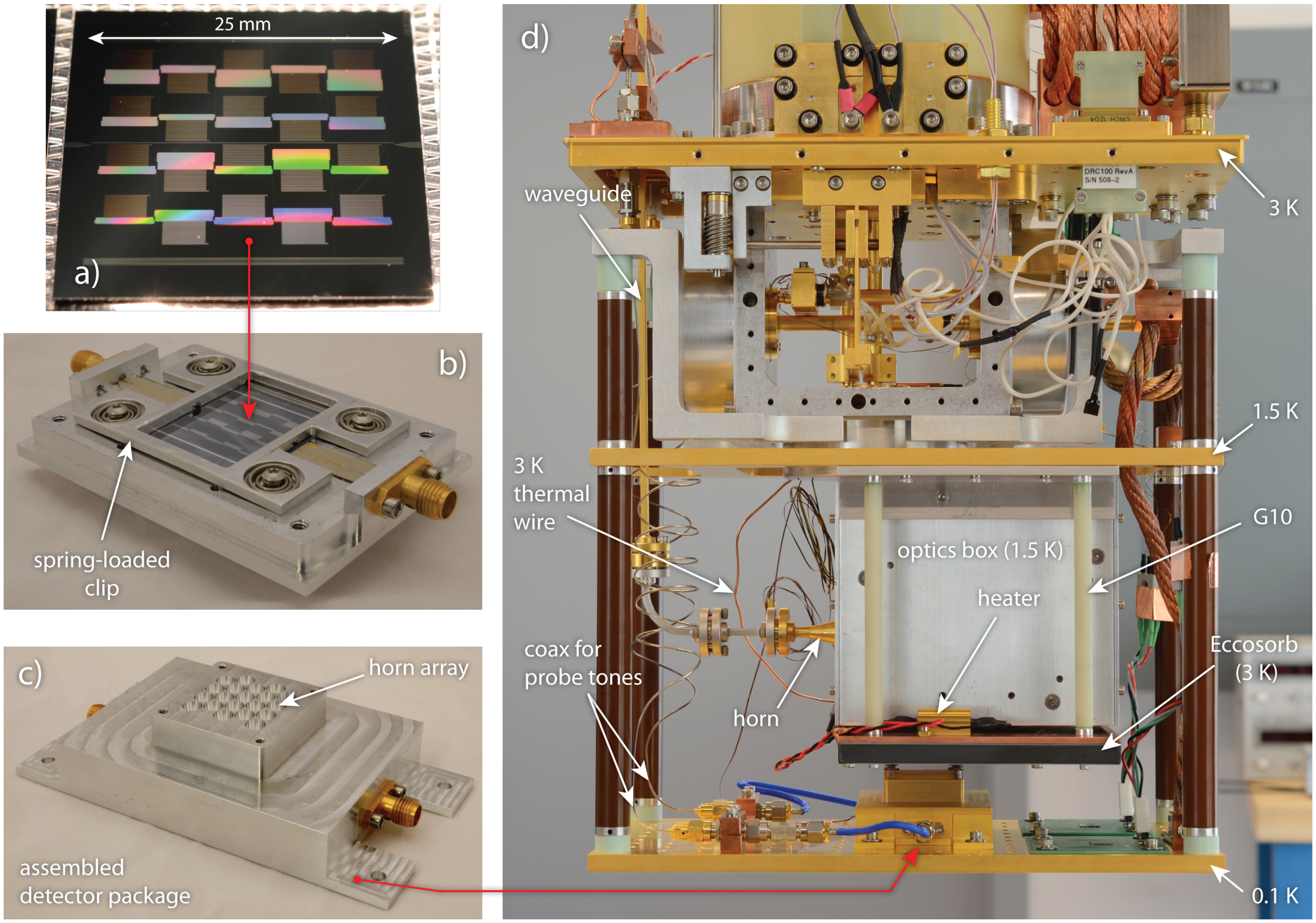


STAR Cryo DRC-102 ADR Cryostat

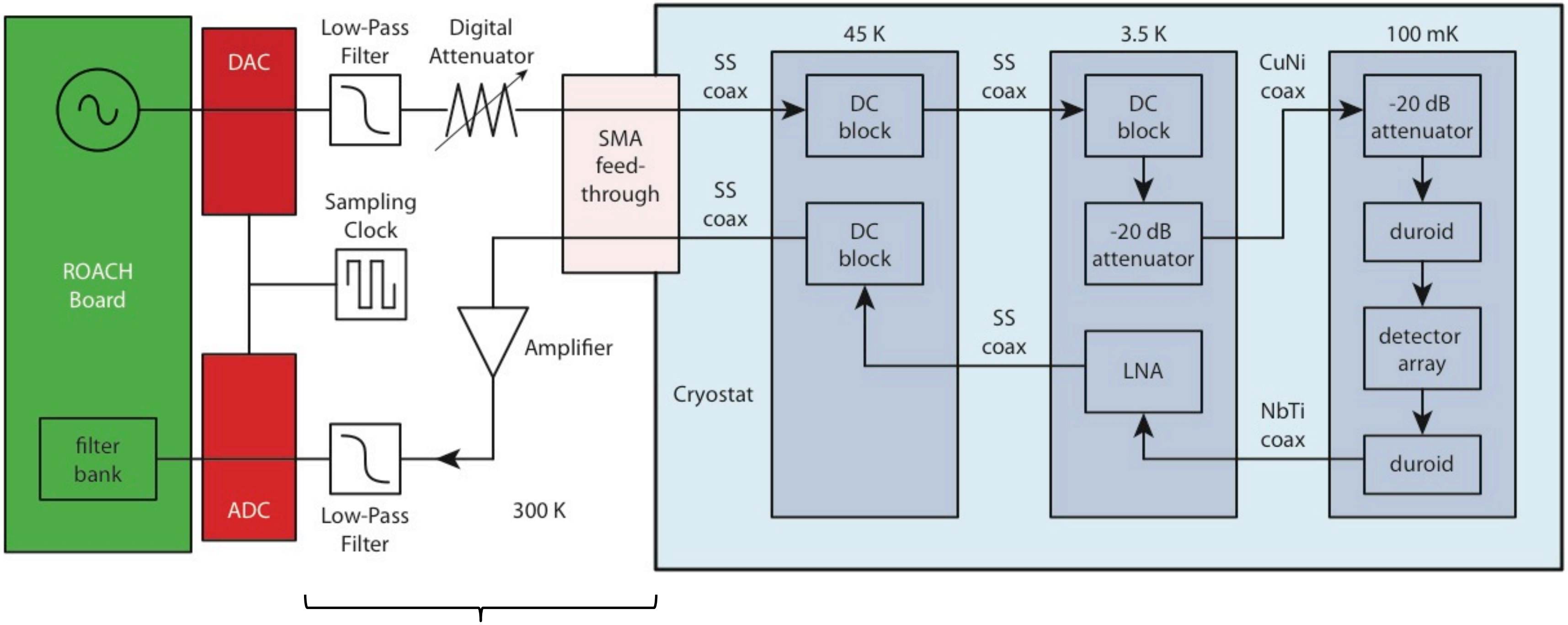


Star Cryo DRC-102 ADR Cryostat System

Optical Test Setup



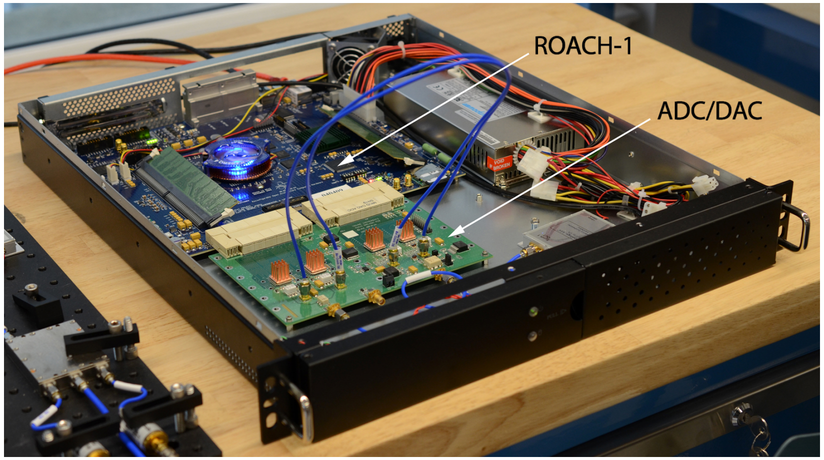
LEKID Readout



analog circuit

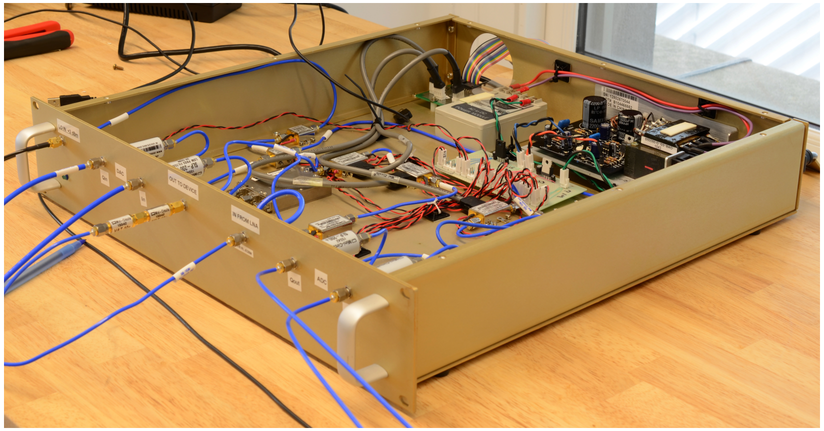
ROACH-Based Readout

ROACH-I and ADC/DAC



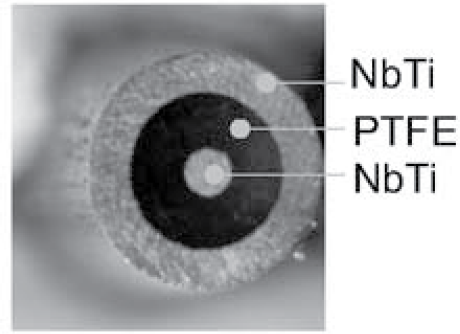
ROACH available from Digicomm
FPGA donated by Xilinx

analog circuit



components from Mini Circuits

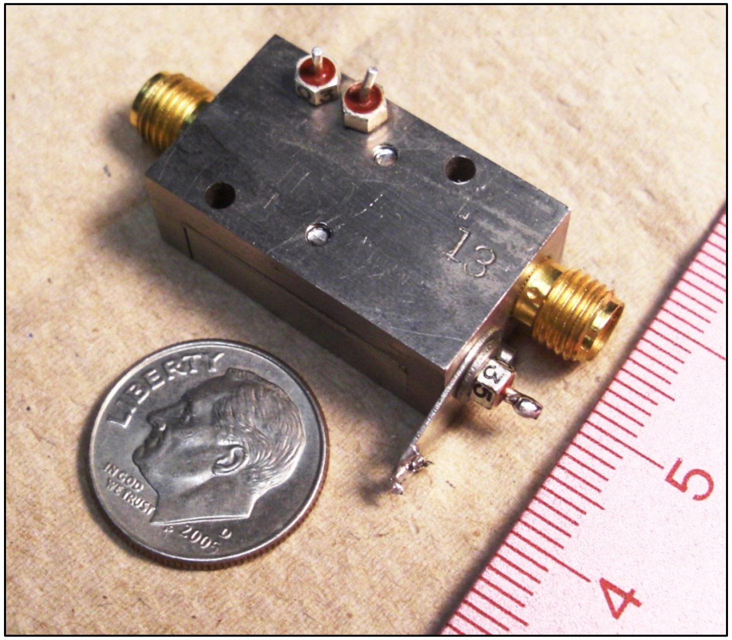
Niobium-Titanium Coax

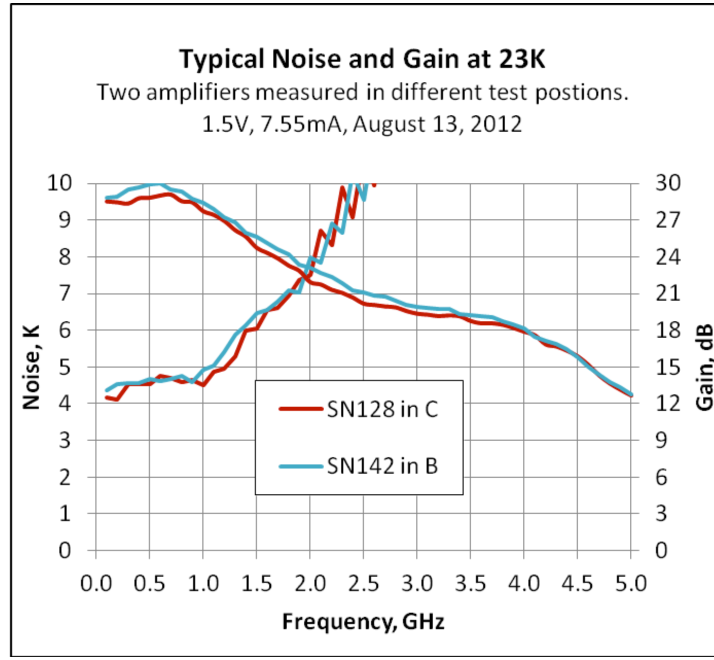


Outer conductor	Material	NbTi
	Diameter	1.60 ± 0.05 mm
Dielectric	Material	PTFE
	Diameter	1.05 ± 0.05 mm
Inner conductor	Material	NbTi
	Diameter	0.31 ± 0.025 mm
Characteristic impedance		50 ± 2.5 Ω
Minimum bending radius		10 mm
Average weight		9.1 g/m

http://www.coax.co.jp/

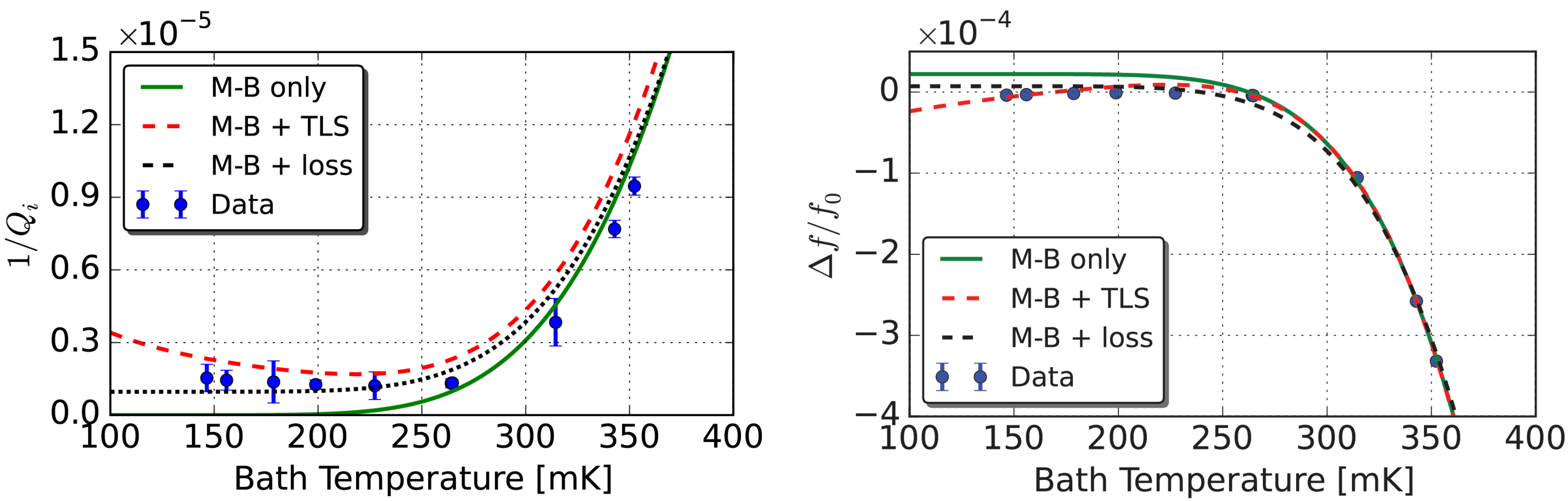
Cryogenic SiGe Low-Noise Amplifier





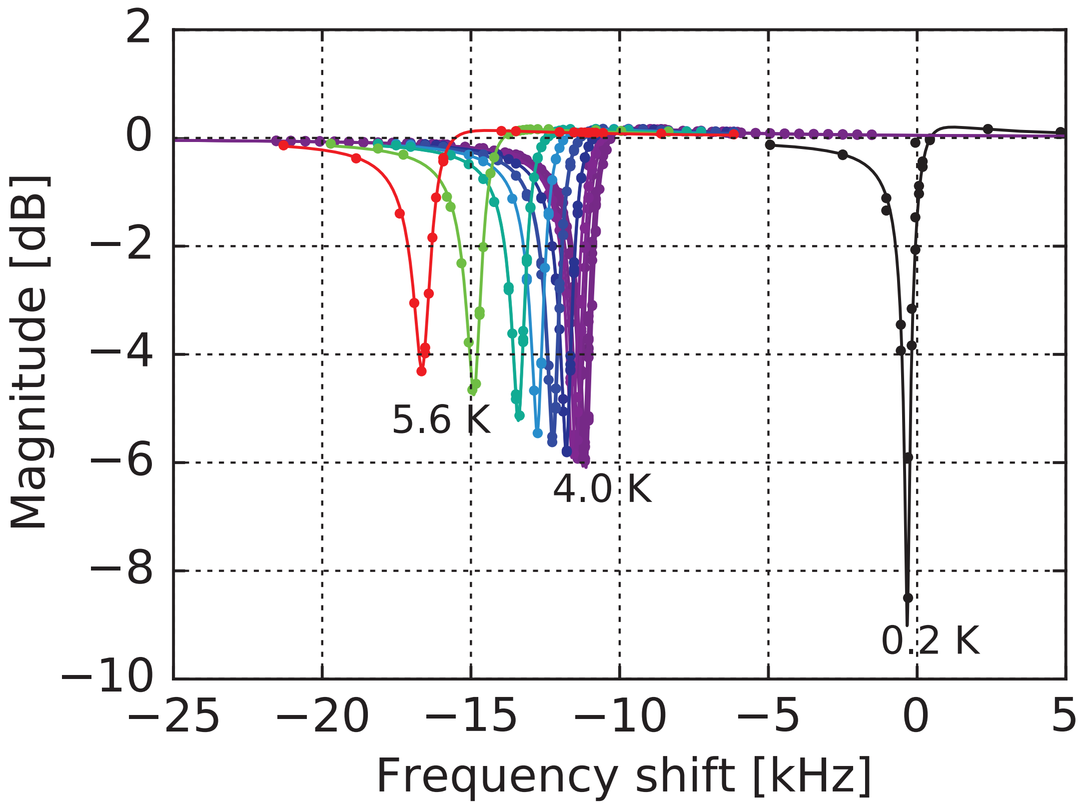
Parameter	@1.5V, 7.5mA Bias	@2.5V, 22mA Bias
Noise Temperature	< 5K	< 4K
Gain = -20 log|S21|	29 +/- 1.5 dB	34 +/- 2 dB
IRL = -20 log|S11|	> 10	> 10
ORL = -20log|S22|	> 15	> 13
Gain Compression, Output P1dB	-14 dBm	-4 dBm

Do the resonantors perform as expected?



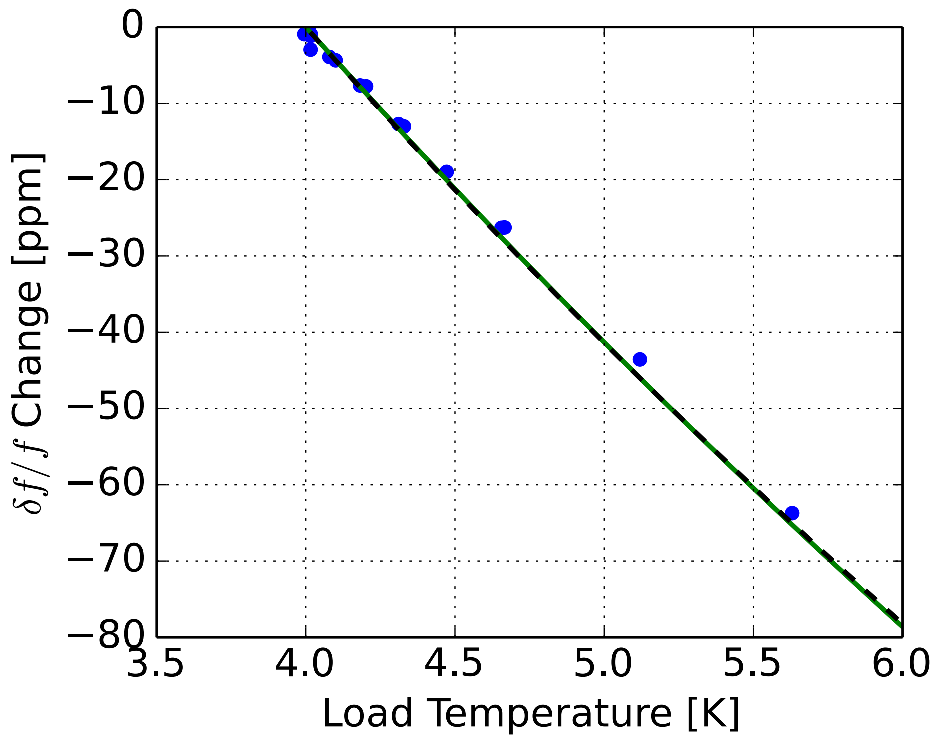
Bath temperature sweeps for a single resonator. The resonant frequency at 200 mK is 86.31195 MHz, and the probe power used was −111 dBm. The plot in panel (a) shows the inverse internal quality factor, and the plot in panel (b) shows measurements of the fractional frequency change. Joint fits to the data for three models are plotted: Mattis-Bardeen theory alone (solid green), M-B with temperature-dependent TLS loss (dashed red), and M-B with a fixed loss term (dotted black) .

Measured Resonances



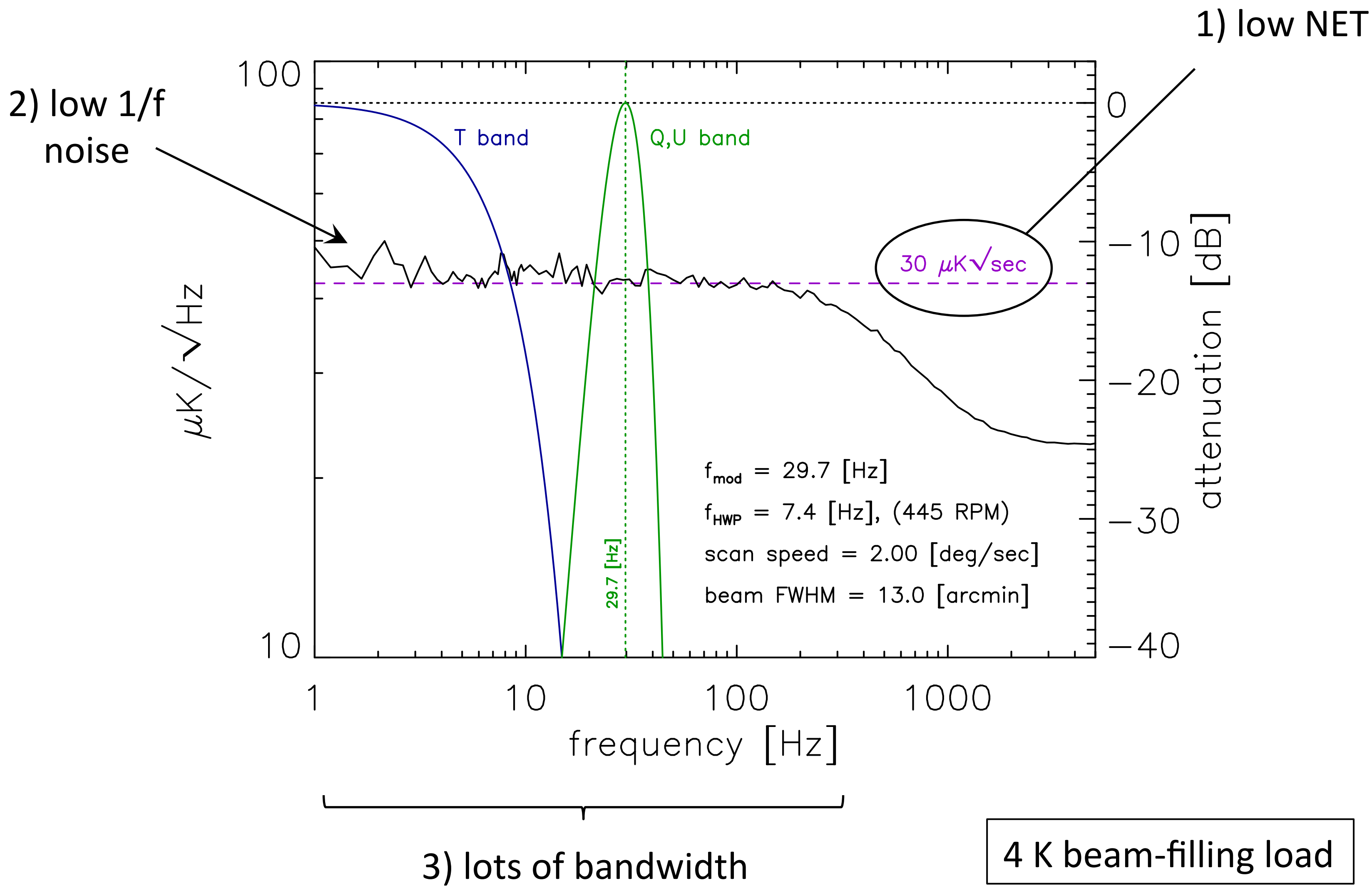
Resonance sweeps of a single resonator with changing optical load. The dots are measured points and the lines are fits. The resonant frequency at 200 mK is 86.31195 MHz. For these measurements the bath temperature was 200 mK. The measurement labeled 0.2 K was taken a the dark configuration.

Measured LEKID Responsivity



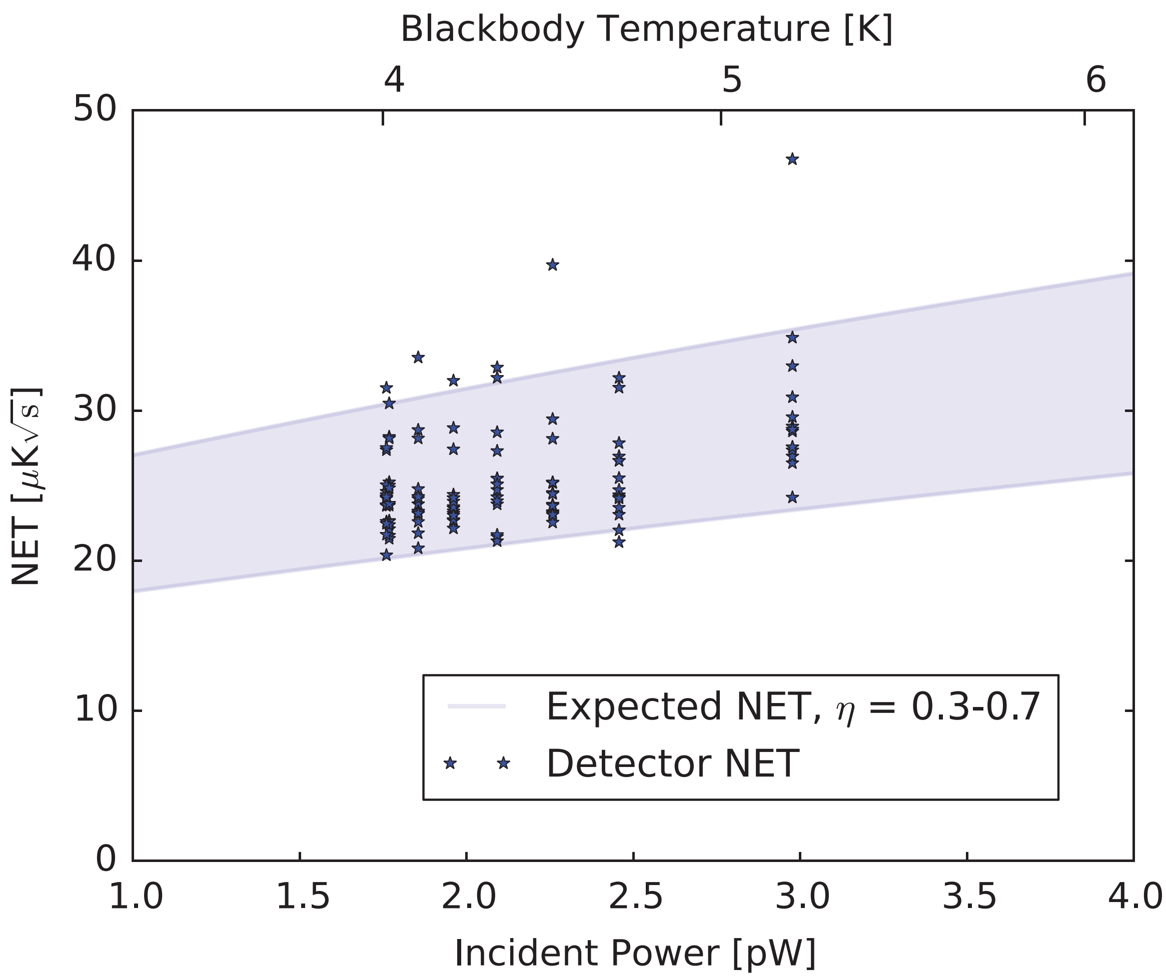
The measured frequency response has a slope of approximately **40 ppm/K**. This fractional responsivity is seen consistently across all resonators. The solid green line shows the expected response.

Result: ***Measured*** LEKID Noise



4 K beam-filling load

Measured Detector Noise



Future Work

Design of Dual-Polarization Horn-Coupled Kinetic Inductance Detectors for Cosmic Microwave Background Polarimetry

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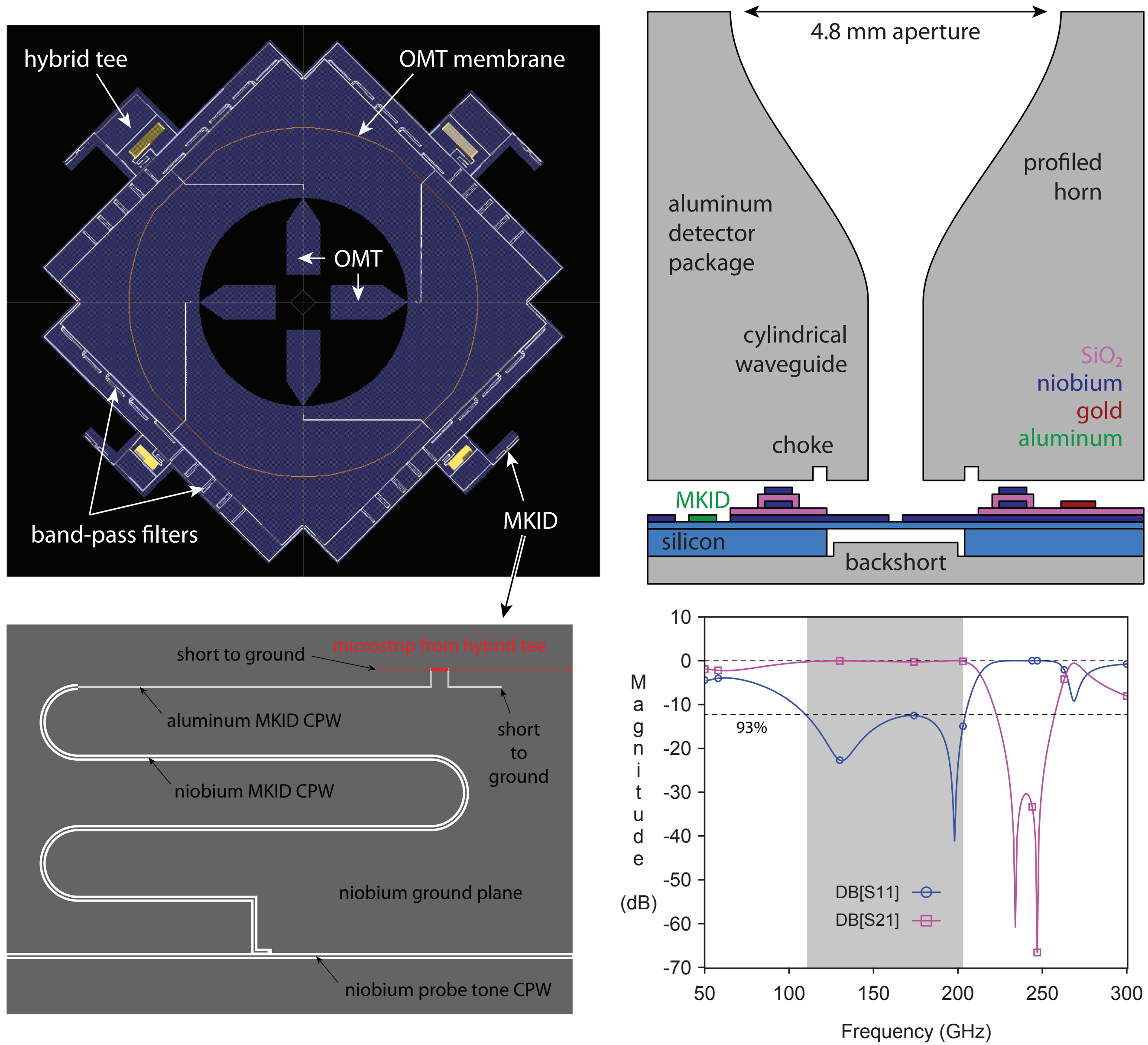
Columbia University
New York, NY, USA

Peter Day
Jet Propulsion Laboratory
Pasadena, CA, USA

2015 ISSTT Proceedings in preparation



hybrid tee
OMT membrane
OMT
band-pass filters
MKID
4.8 mm aperture
aluminum detector package
profiled horn
cylindrical waveguide
SiO_2
niobium
gold
aluminum
choke
MKID
silicon
backshort
short to ground
microstrip from hybrid tee
aluminum MKID CPW
short to ground
niobium MKID CPW
niobium ground plane
niobium probe tone CPW
10
0
-10
-20
-30
-40
-50
-60
-70
Magnitude (dB)
93%
DB[S11]
DB[S21]
50
100
150
200
250
300
Frequency (GHz)

WSPEC: A Waveguide Filter Bank Spectrometer

George Che[1*], Sean A. Bryan[1], Matthew Underhill[1], Philip Mauskopf[1], Christopher Groppi[1],
Glenn Jones[2], Bradley R. Johnson[2], Heather McCarrick[2], Daniel Flanigan[2], and Peter Day[3]
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[3] *Jet Propulsion Laboratory, Pasadena, CA 91109, USA*
**Contact: gche2@asu.edu*

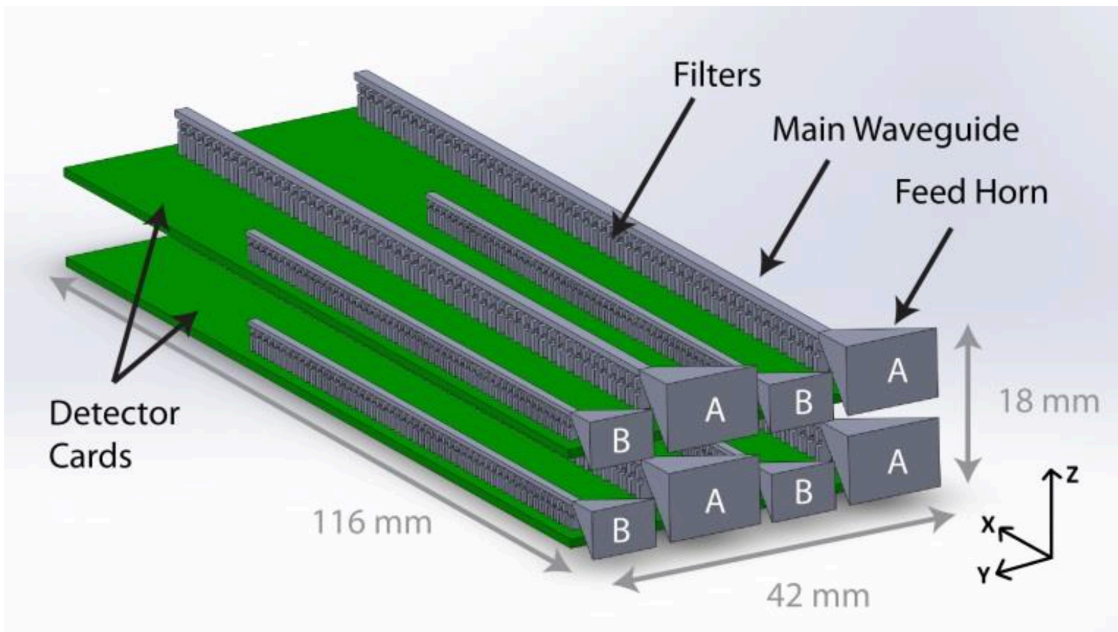


Fig. 4 Solidworks drawing of our horn-coupled 4-pixel focal plane array of filter banks.

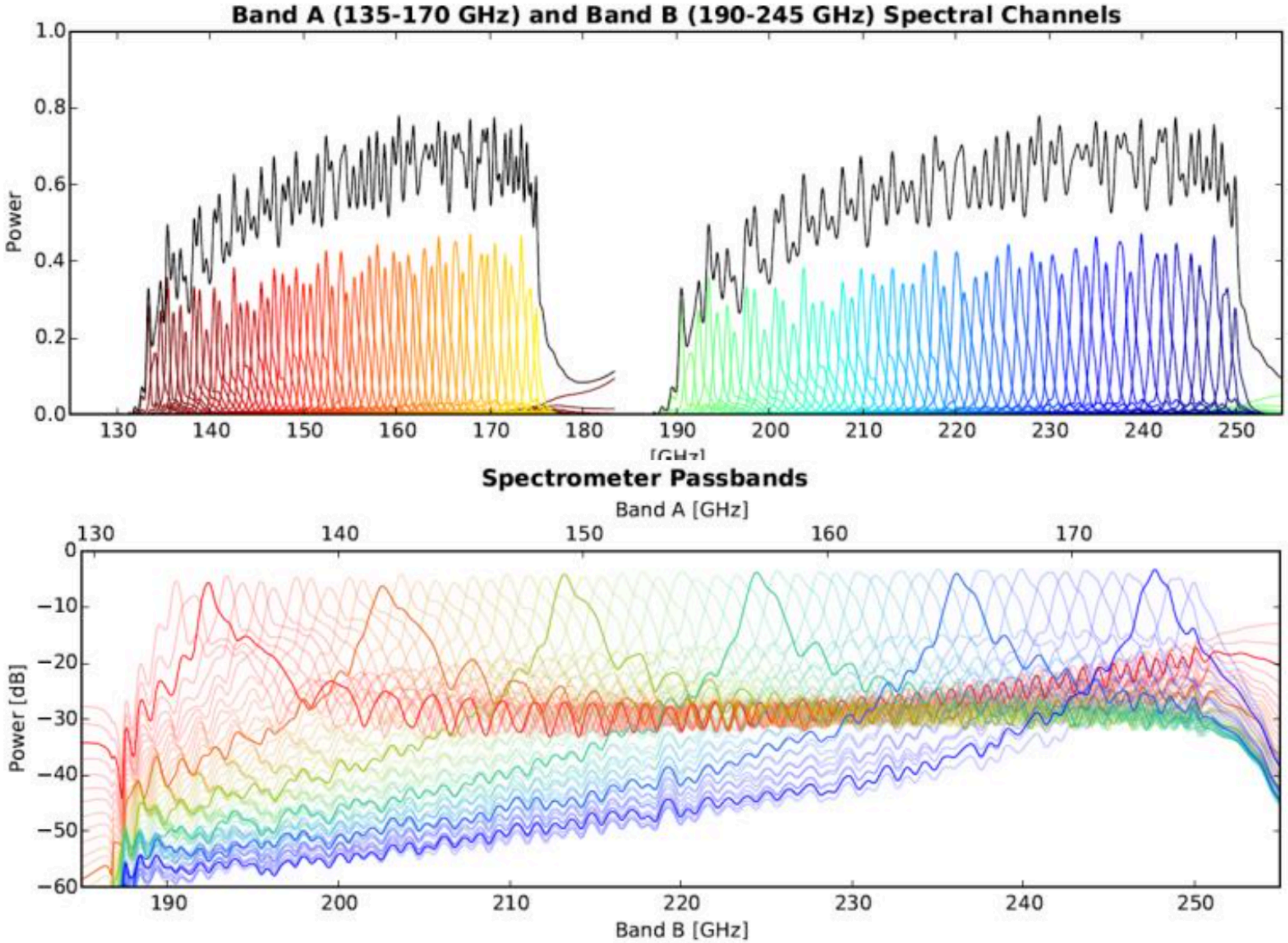
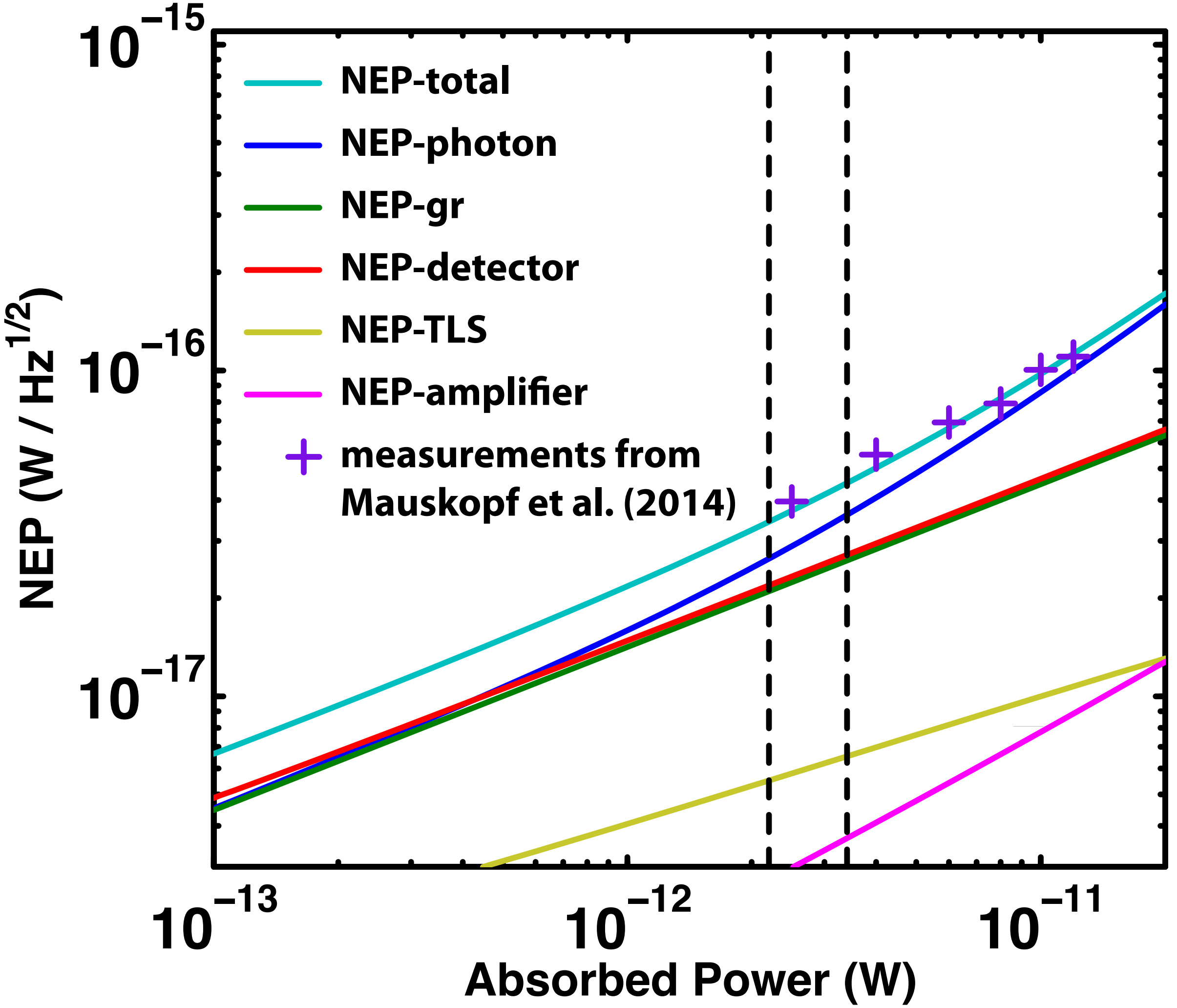


Fig. 5 HFSS-simulated passbands in linear units (top) and dB (bottom) for band A, which covers 135-170 GHz, and band B, which covers 190-245 GHz. The black curve in the top panel represents the sum total of all the passbands.

MKID Noise Sources



Future Testing