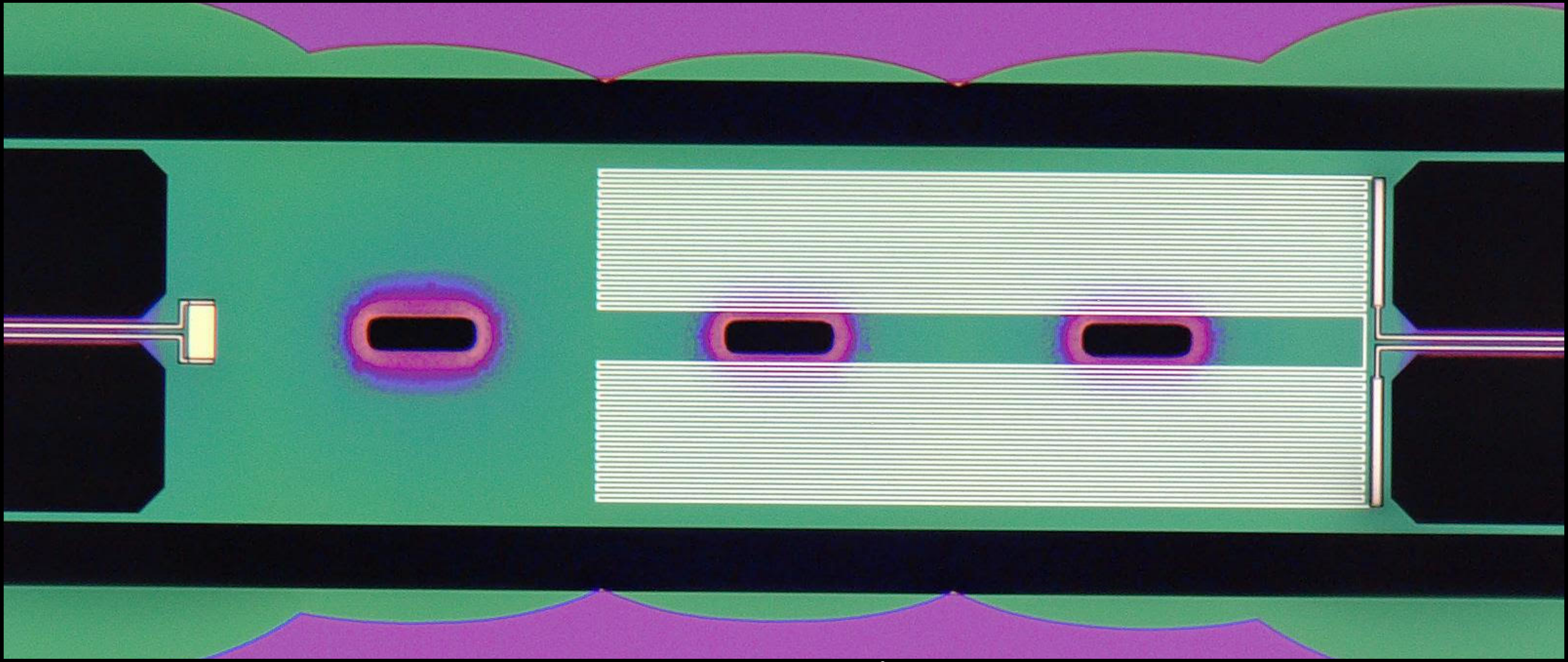
TKIDs for CMB Polarimetry and submillimeter observations



Roger O'Brient
Jet Propulsion Laboratory,
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July 26, 2019

Team Members

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Outline

- Motivation
- Sensitivity
- Simple Prototypes
- Antenna compatible TKIDs
- Antenna coupled TKIDs

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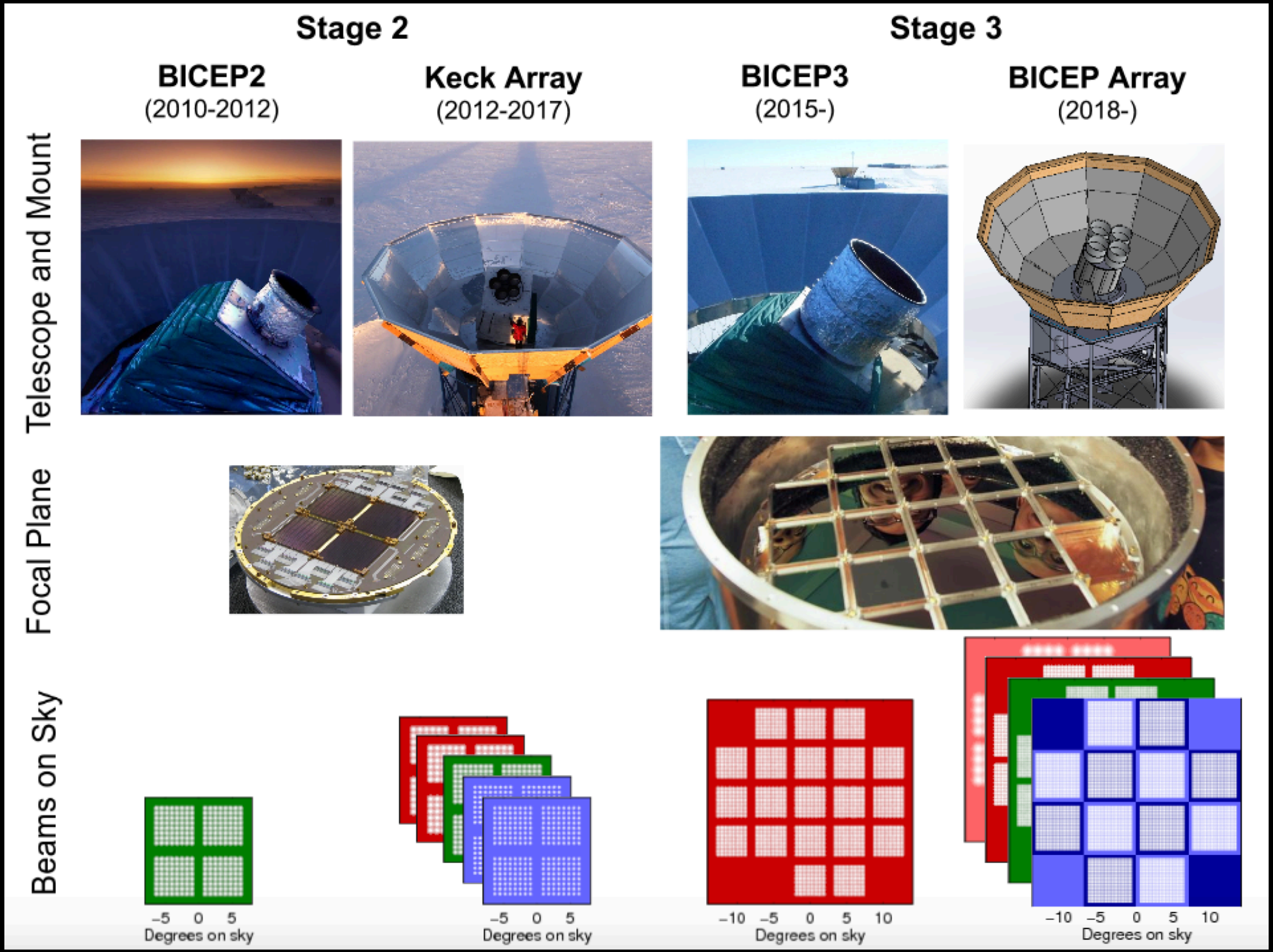
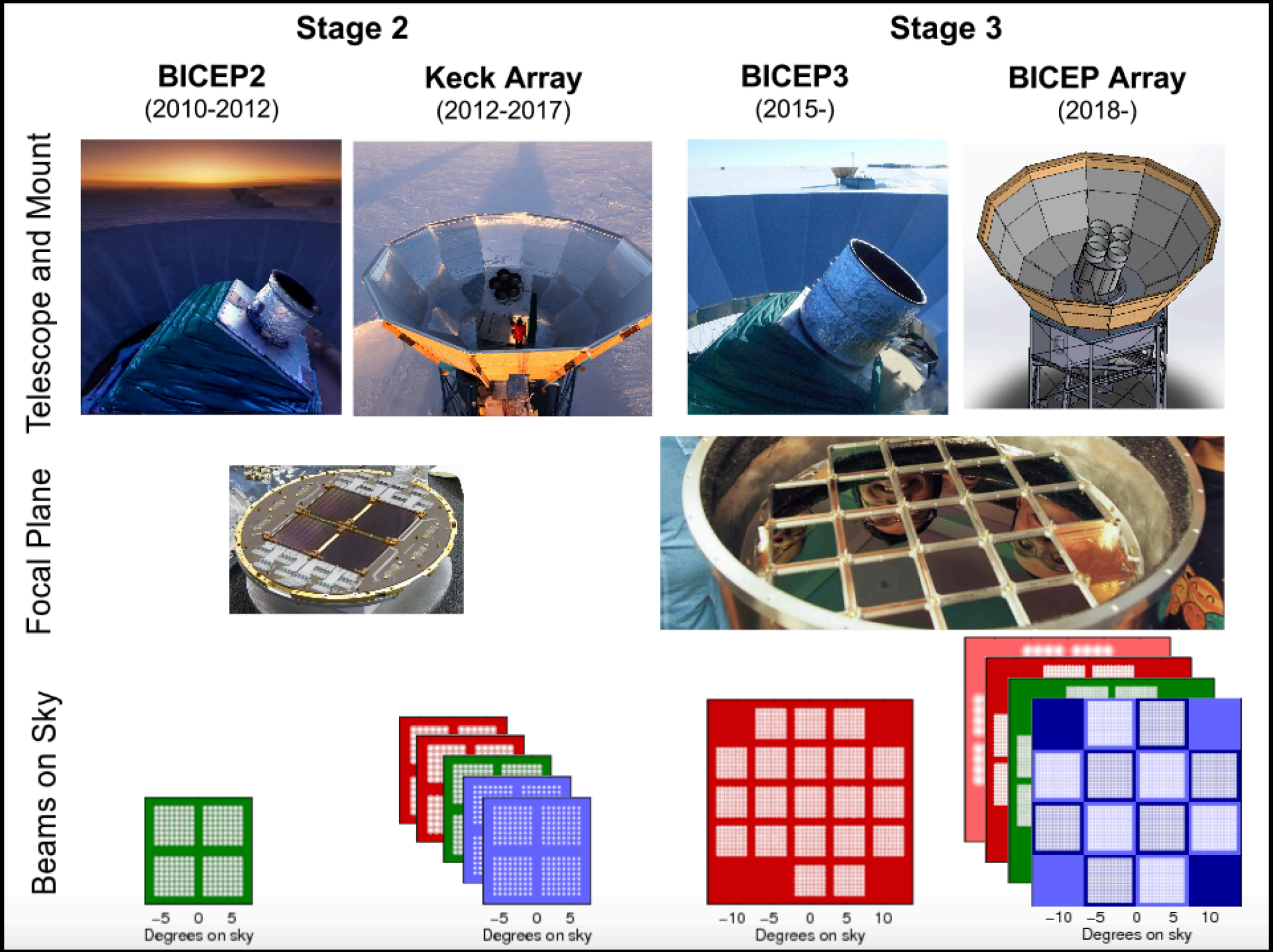
Motivation


Stage 2
Stage 3
BICEP2
(2010-2012)
Keck Array
(2012-2017)
BICEP3
(2015-)
BICEP Array
(2018-)
Telescope and Mount
Focal Plane
Beams on Sky
−5 0 5
Degrees on sky
−5 0 5
Degrees on sky
−10 −5 0 5 10
Degrees on sky
−10 −5 0 5 10
Degrees on sky

Motivation



- BICEP Array 150GHz: ~7,000 detectors
- BICEP Array 250GHz: ~20,000 detectors

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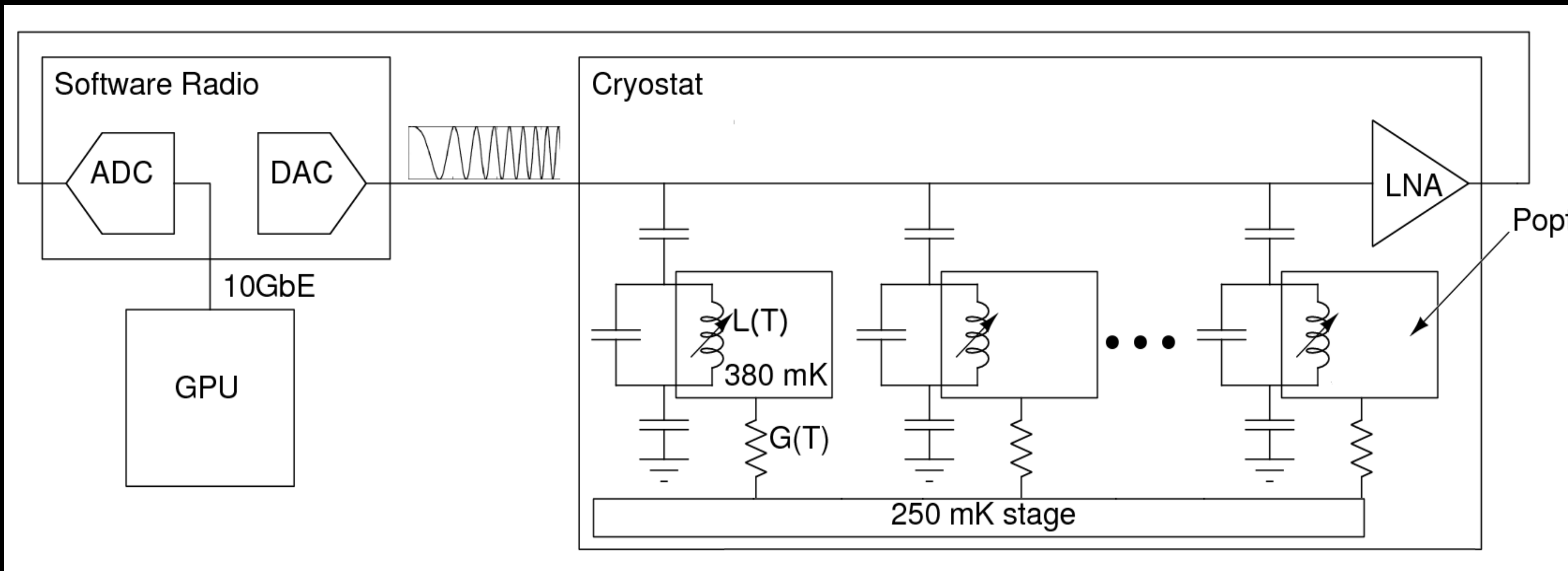
KID challenges

- Inductor and absorber are same:
  - Must absorb mm-waves well
  - Must provide high resonsivity
- Limited design parameters
- Fundamental GR noise inspires small volume inductors:
  - large capacitors
  - higher readout frequencies

Thermal Kinetic Inductance Detectors



Motivation

- Inherits ease of integration and multiplexing from KIDs
- More design parameters:
  - Absorber distinct from inductor
  - Leg Conductance
  - Bolometer Island temperature
  - Inductor Volume
- Bonus: ease of calibration

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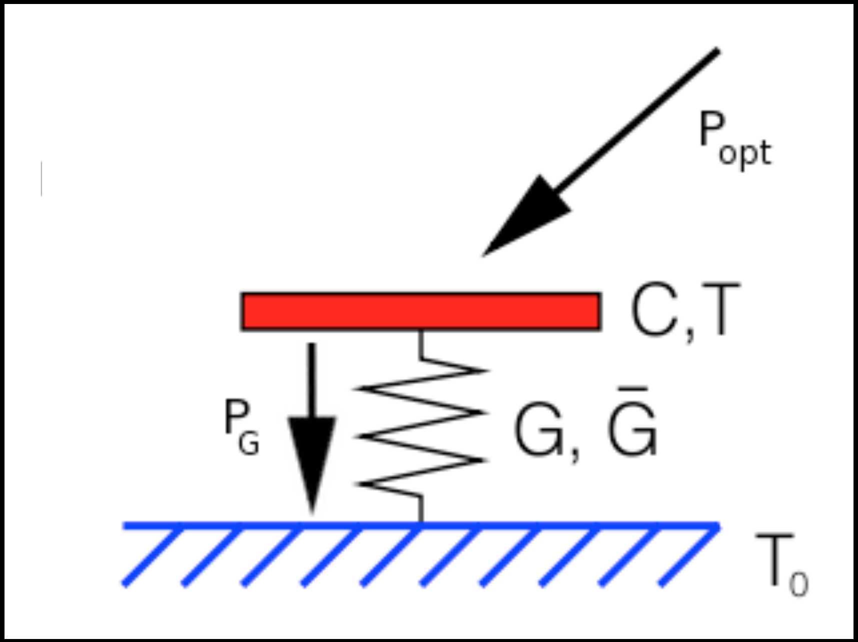
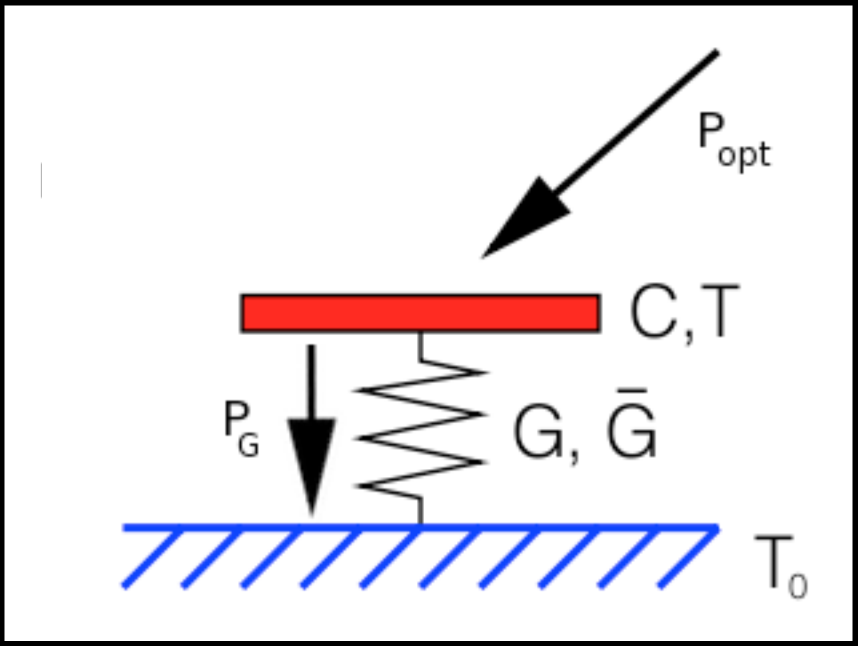
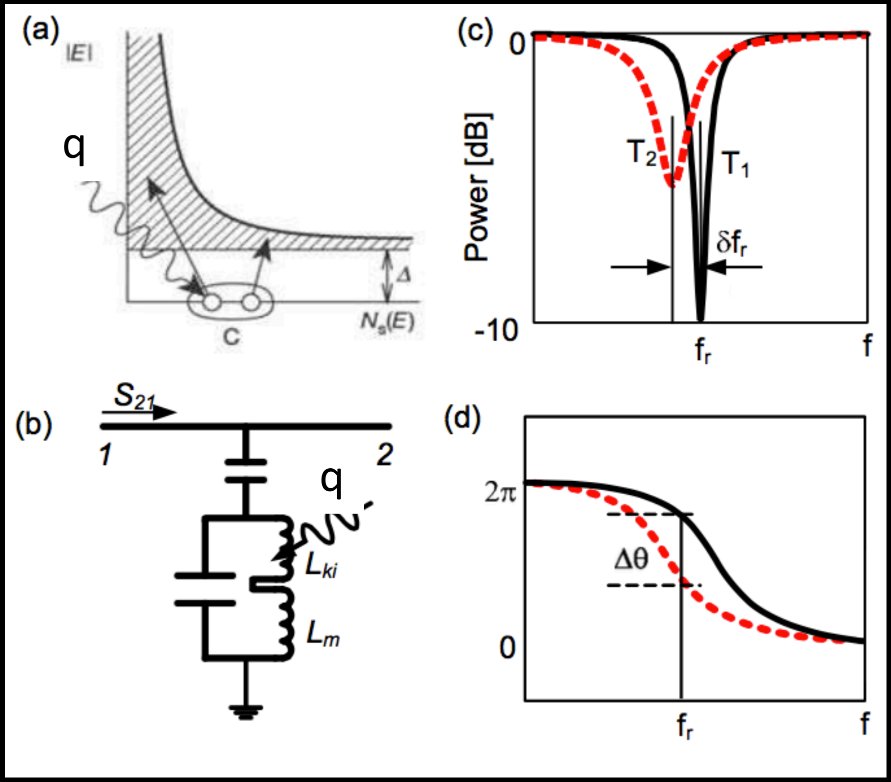
Sensitivity



$$\partial T(\nu) = \frac{\partial P(\nu)}{G} \frac{1}{1 + j2\pi\nu\tau}$$

Sensitivity

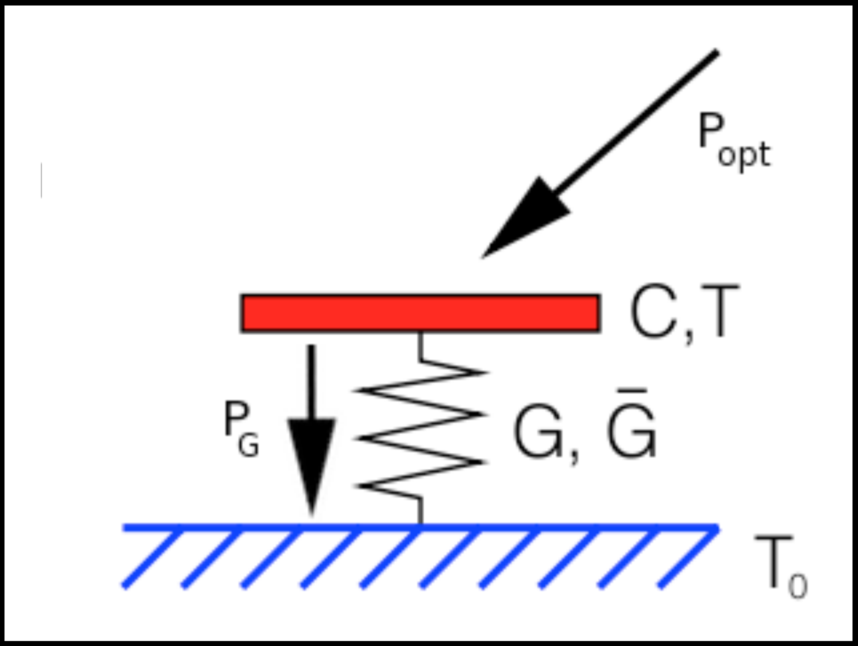


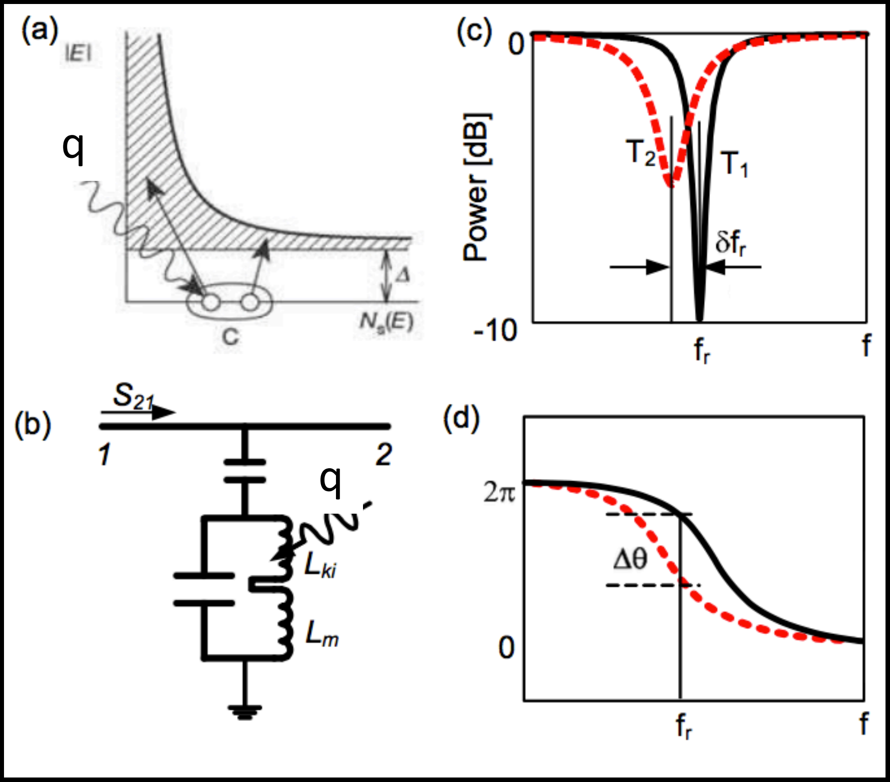


$$\partial T(\nu) = \frac{\partial P(\nu)}{G} \frac{1}{1 + j2\pi\nu\tau}$$

$$n_{th}(T) = 2N_o\sqrt{2\pi k_B T \Delta} e^{-\Delta/k_B T}$$

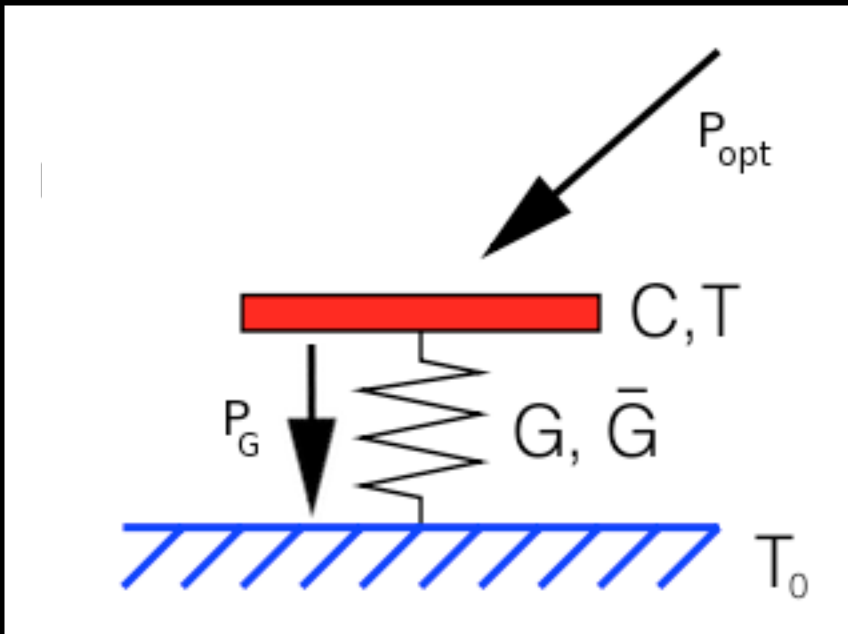
Sensitivity

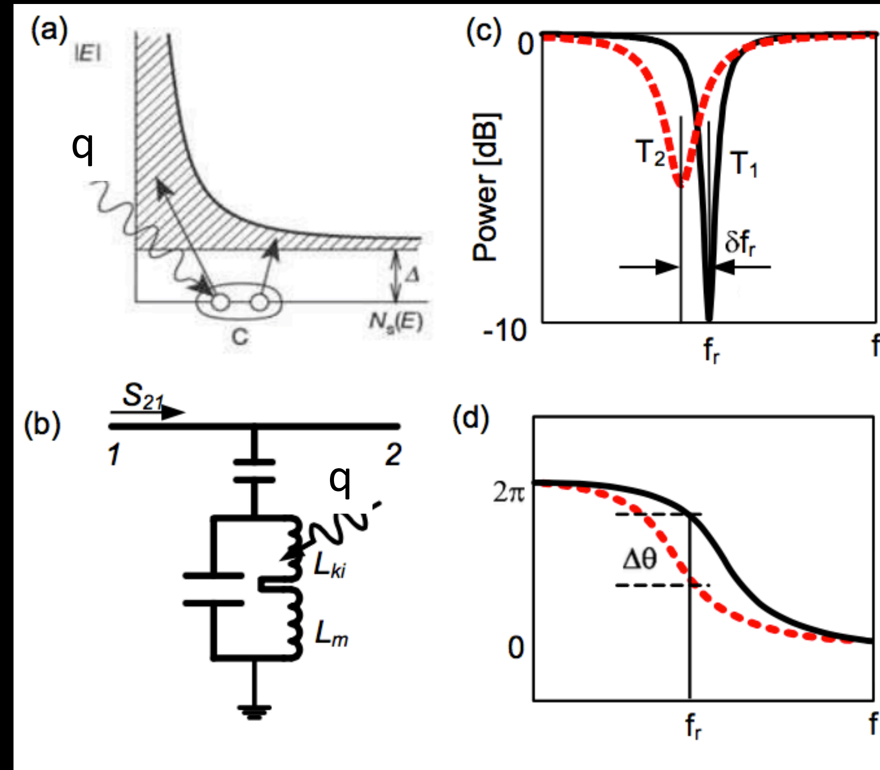




$$S \equiv \frac{\partial x_{qp}}{\partial P_{opt}} = \frac{\partial x_{qp}}{\partial N_{qp}} \frac{\partial N_{qp}}{\partial T} \frac{\partial T}{\partial P_{opt}} = -\frac{\beta(\nu, T)\kappa(T)}{2Q_i G(T) T}$$

Sensitivity





- No feedback to linearize
- 10-50fW loading change during elevation nod (on 2-7pW background).
- Gain compression: responsivity changes 0.2%

Internal Noise

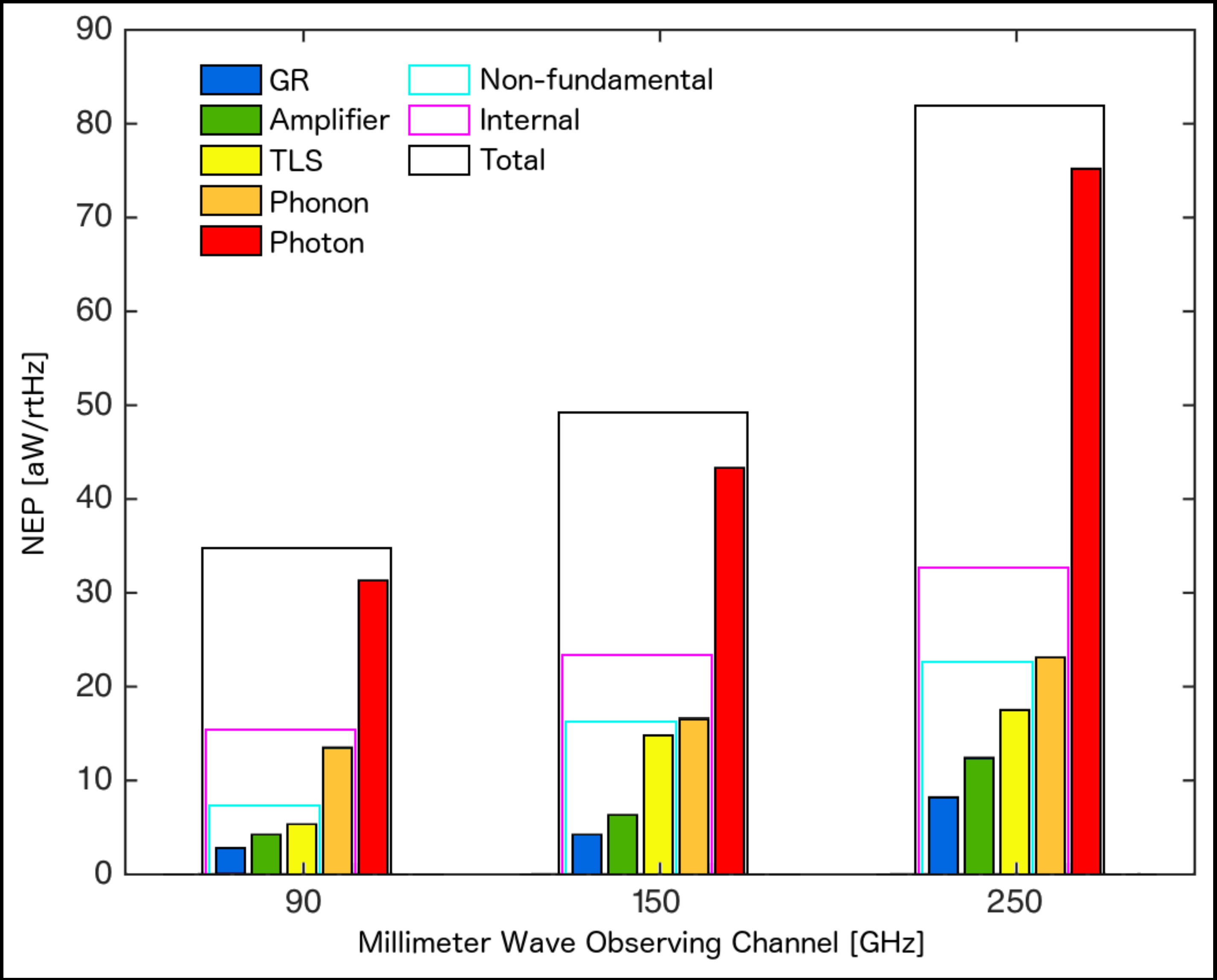
- Needs to be photon noise limited
- Fundamental noise is phonons in legs (G)
- Suppress other noise sources with responsivity

$$NEP_*^2 = \frac{|\delta x_*|^2}{S^2}$$

$$NEP_{TLS,amp}^2 \propto (GT)^2 \quad NEP_{GR}^2 \propto \frac{(GT)^2}{V_{sc}}$$

- Constraint: high *S* can limit channel count in finite bandwidth

Expected Noise



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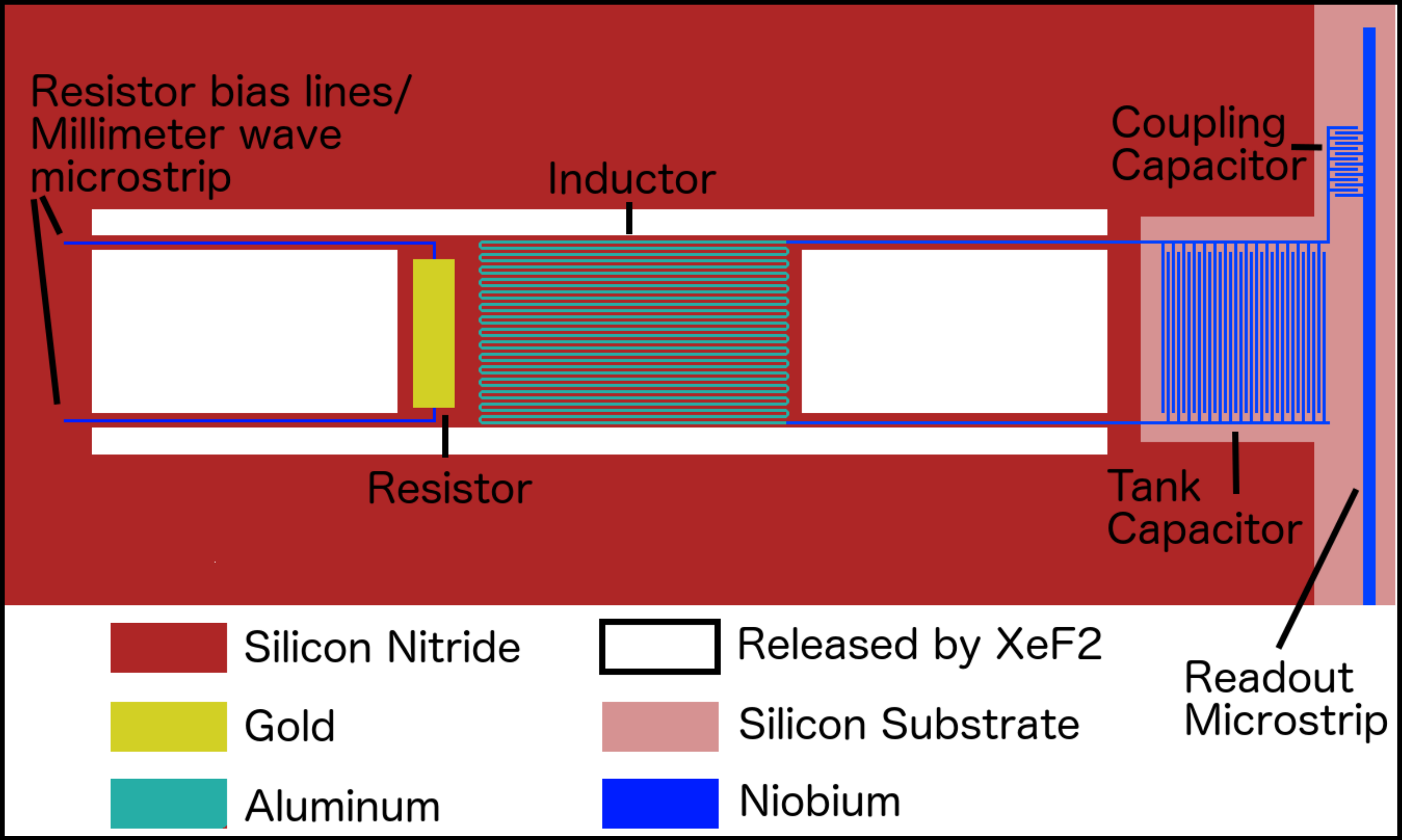
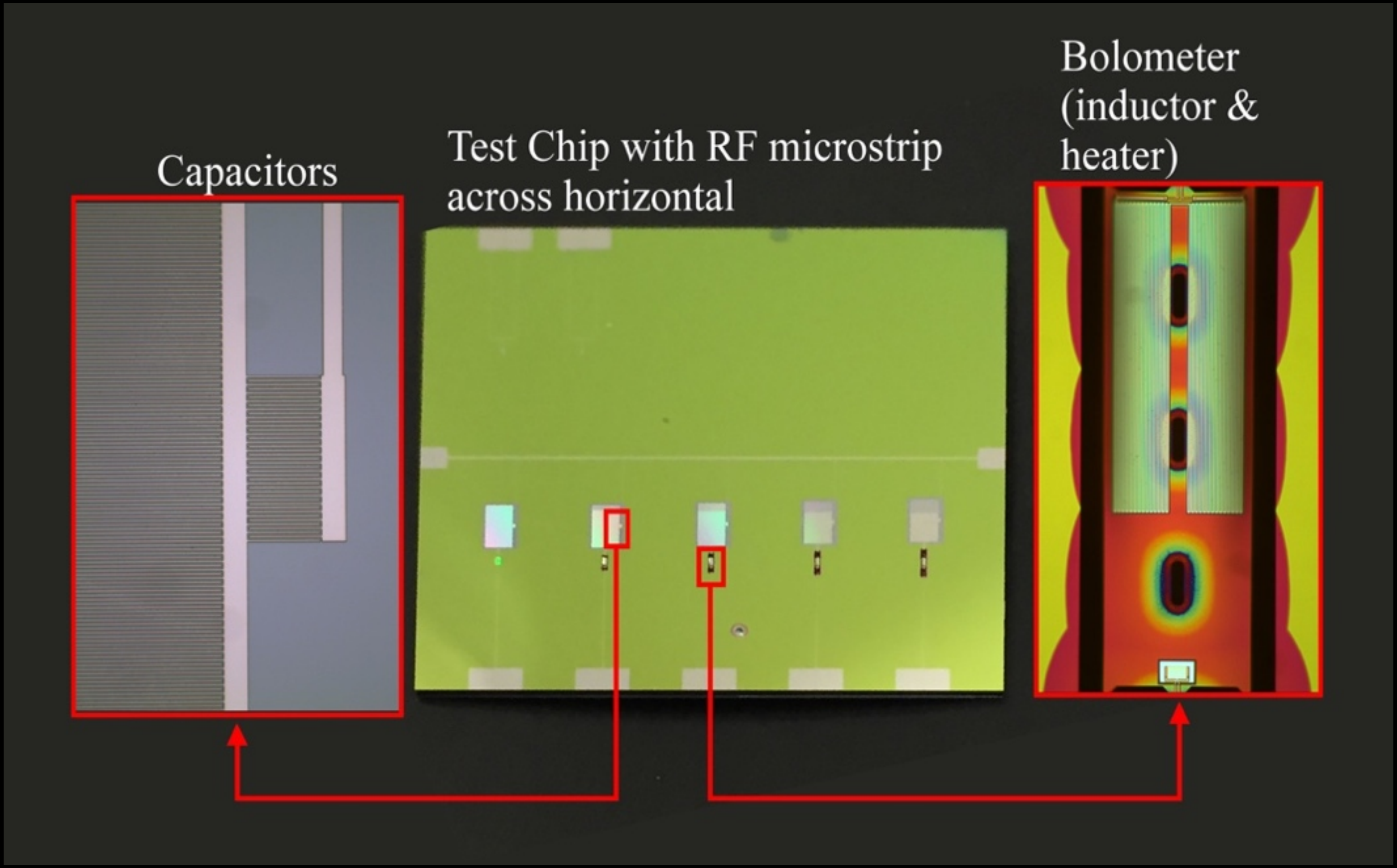
Prototypes

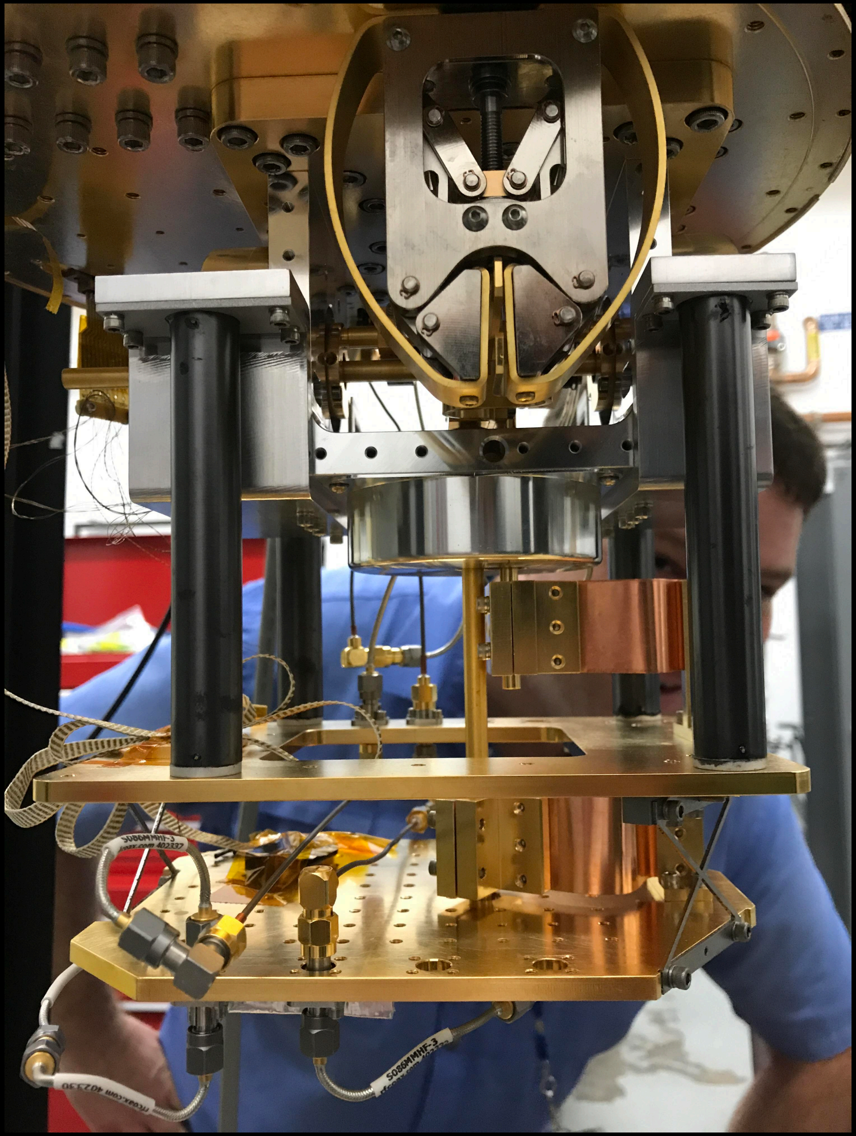


Resistor bias lines/
Millimeter wave
microstrip
Inductor
Coupling
Capacitor
Resistor
Tank
Capacitor
Silicon Nitride
Gold
Aluminum
Released by XeF2
Silicon Substrate
Niobium
Readout
Microstrip

Prototypes


Capacitors
Test Chip with RF microstrip across horizontal
Bolometer (inductor & heater)

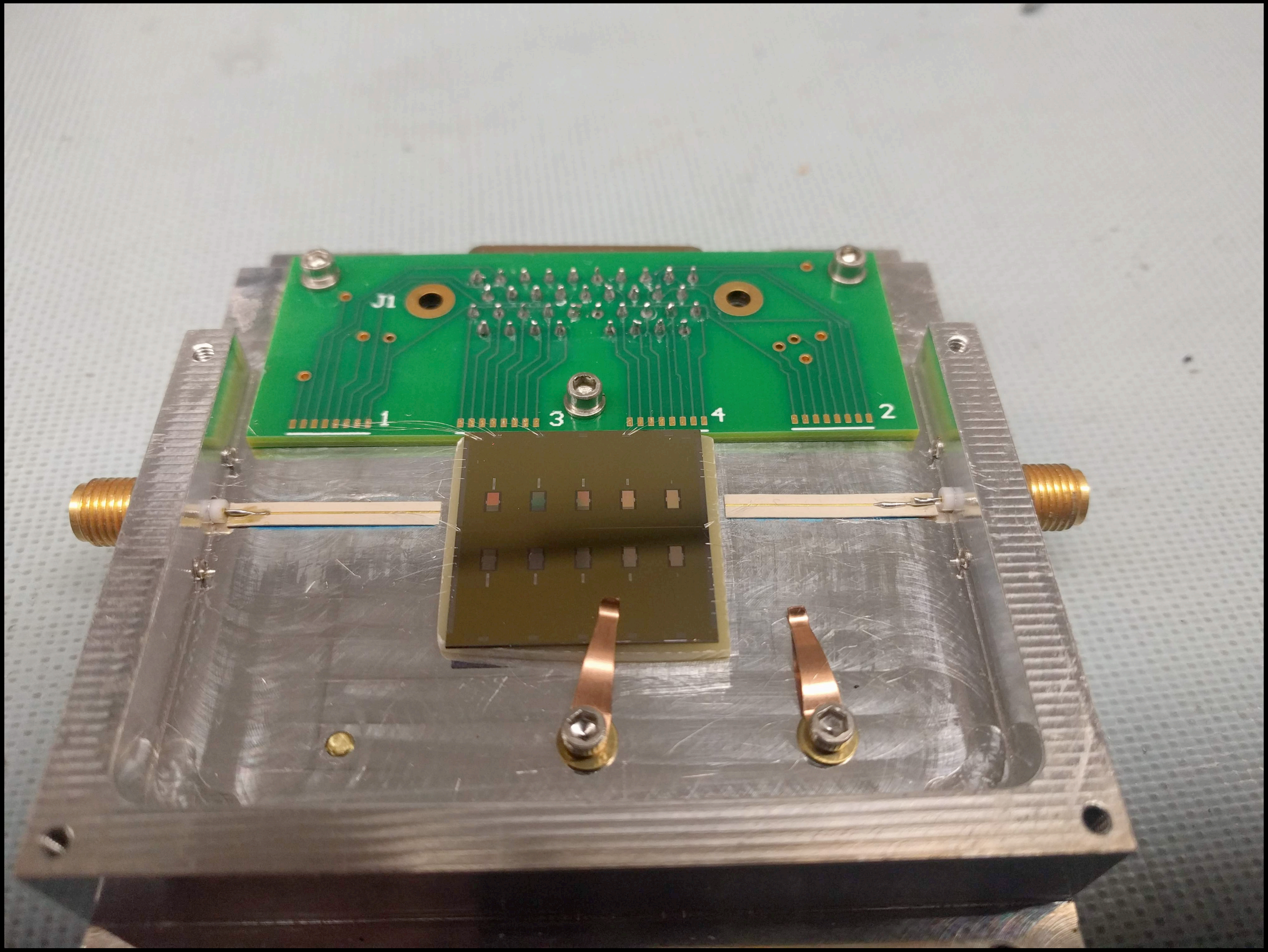
Testbed



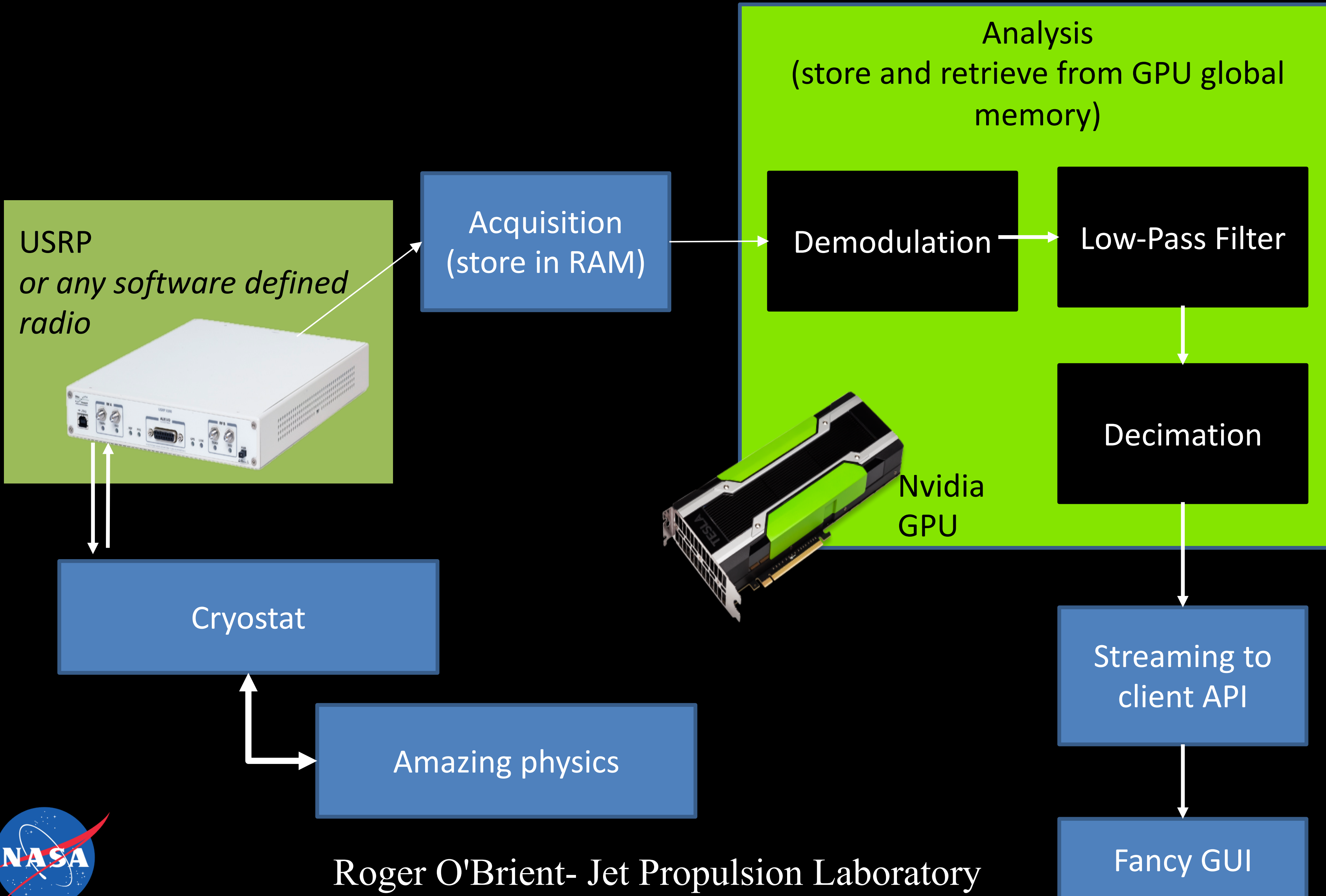
HPD cryostat:
- Pulse-tube
- ADR

Thanks to Matt Holister for the cold-stage design

Chip holder



Software Radio Readout system



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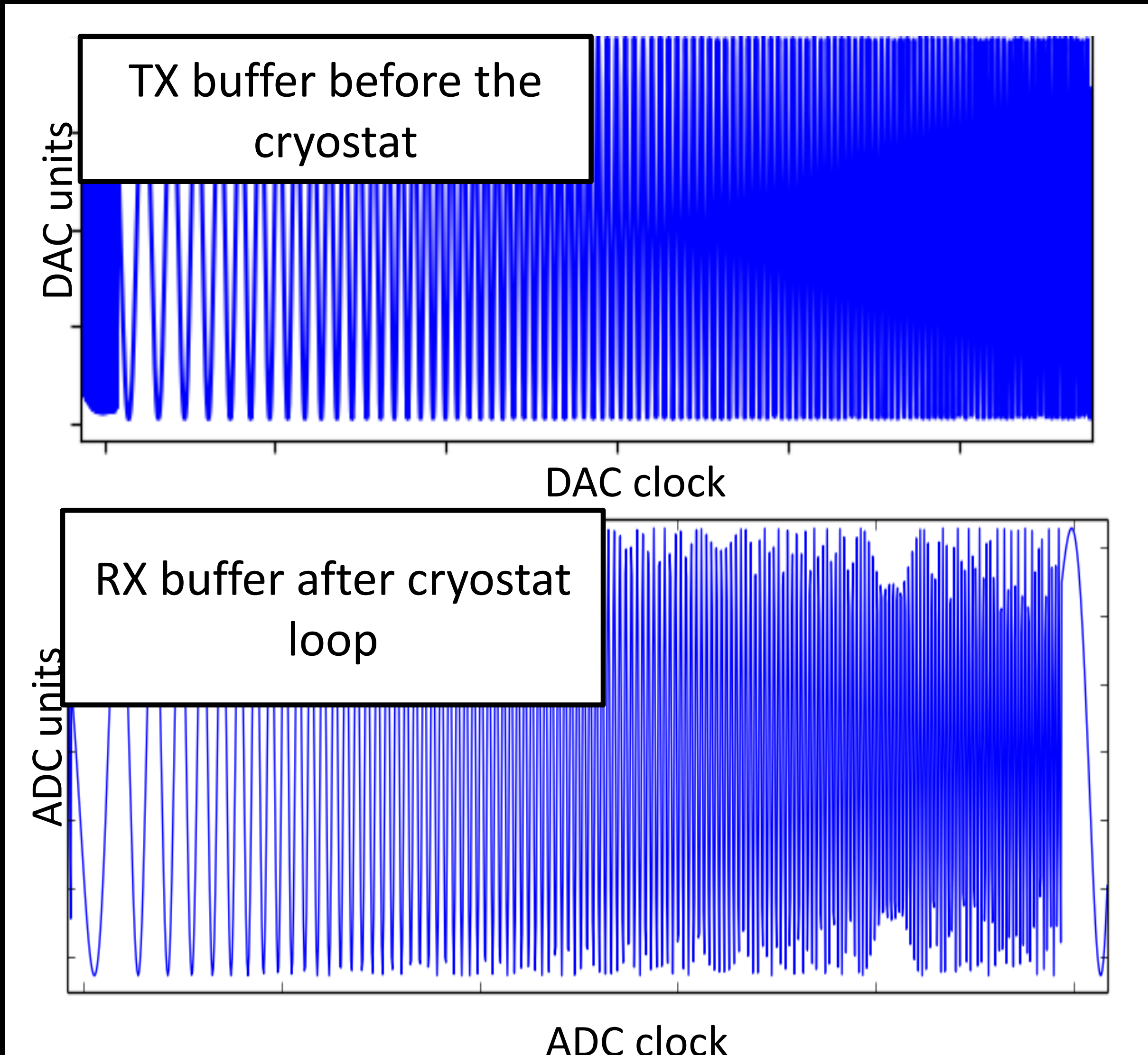
Chirped readout mode



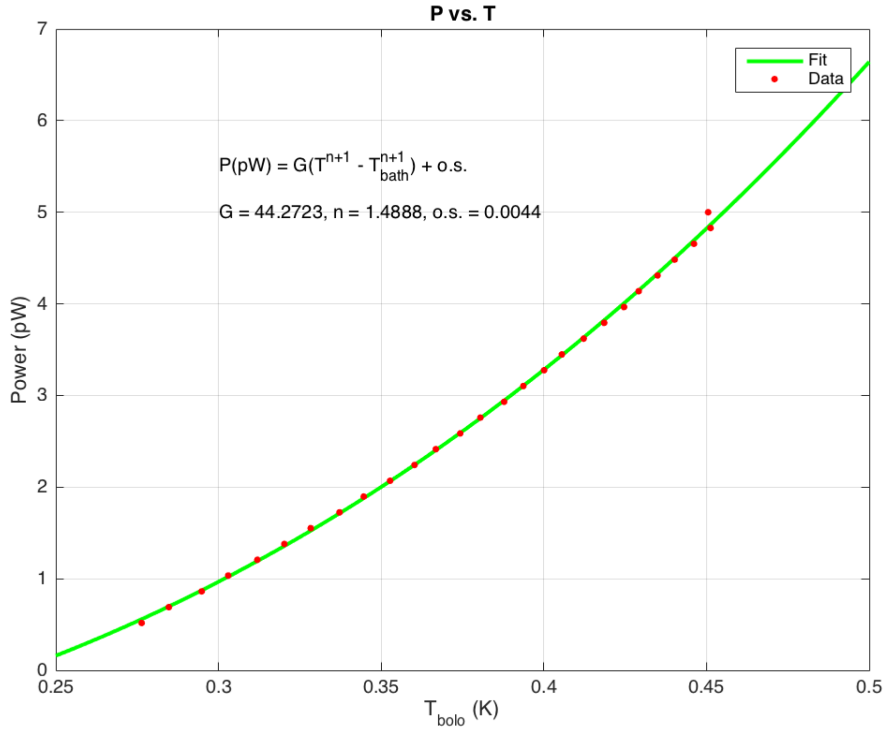
Chirp signal:

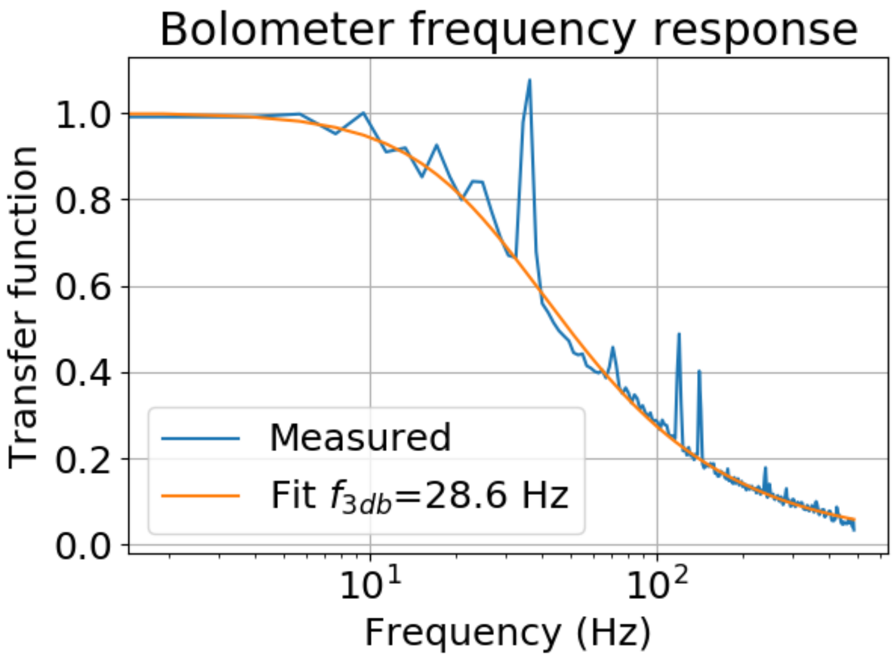
$$Ae^{-jk(f_1,f_2)t^2}$$

detector S_{21}

1. Chirp for ~5us
2. Record ringdown for ~50us
3. Repeat

Bolometer G and τ





- No electrothermal feedback
- τ~5ms for T_{bath}=250mK
- 30Hz is ample bandwidth for ground observations
- Faster at lower operating temperatures

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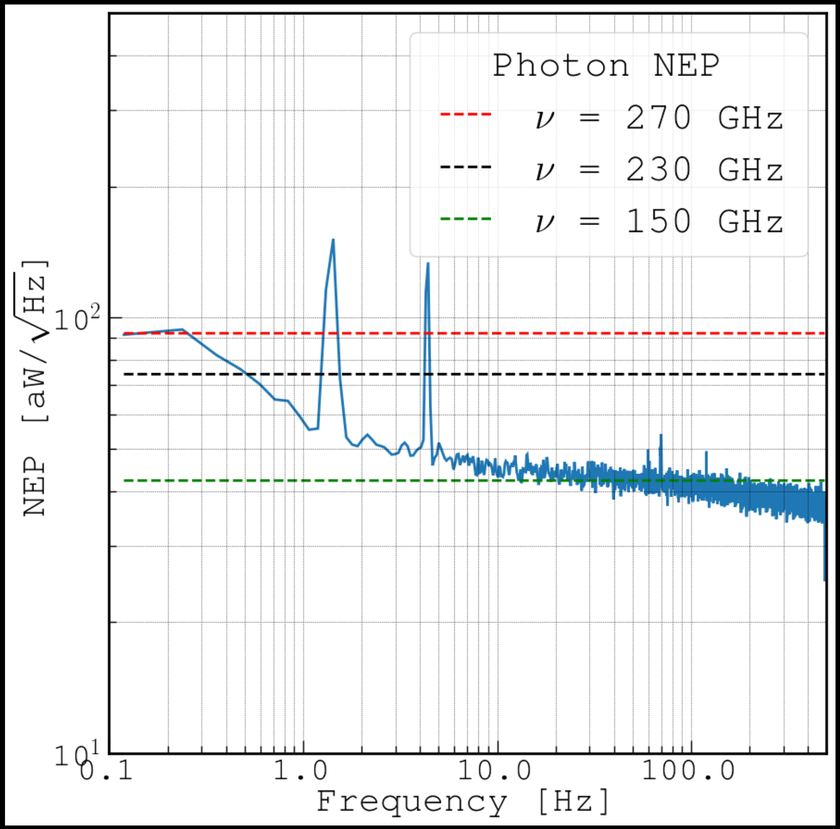
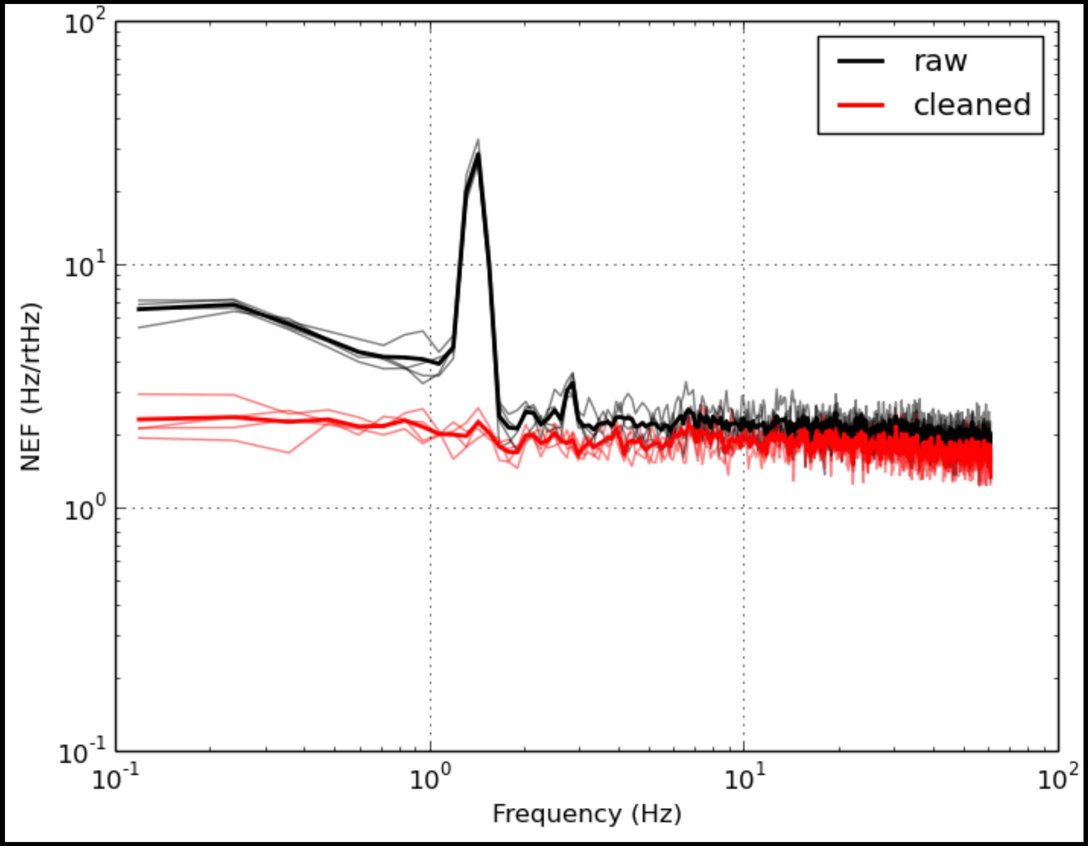
Noise measurements



- ~7pW loading from heater
- ~60aW/rtHz "white" noise
- 1/f knee ~ 1Hz.
- Non-white behavior from stage stability or transmit gain

Common mode cleaning



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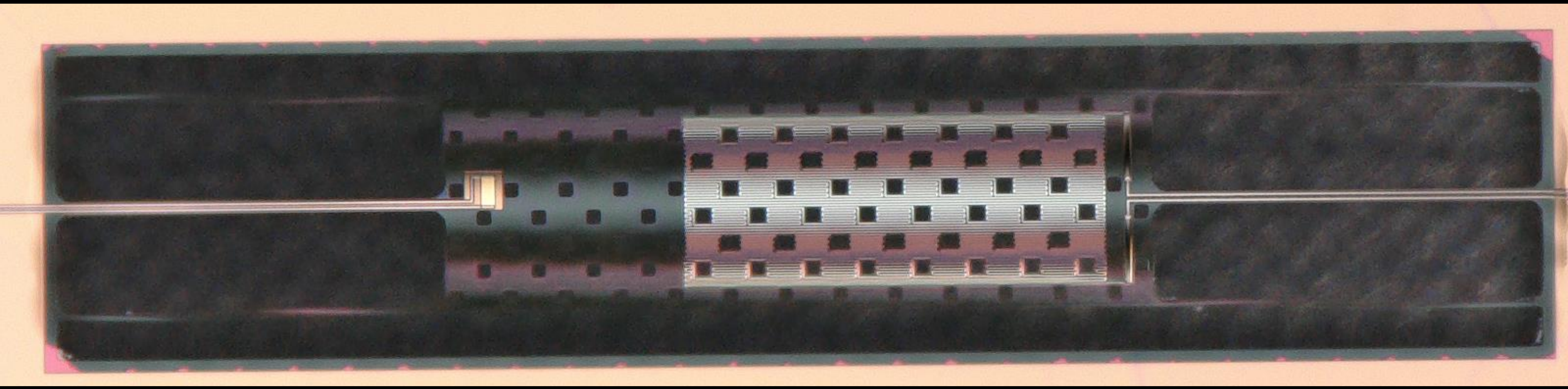
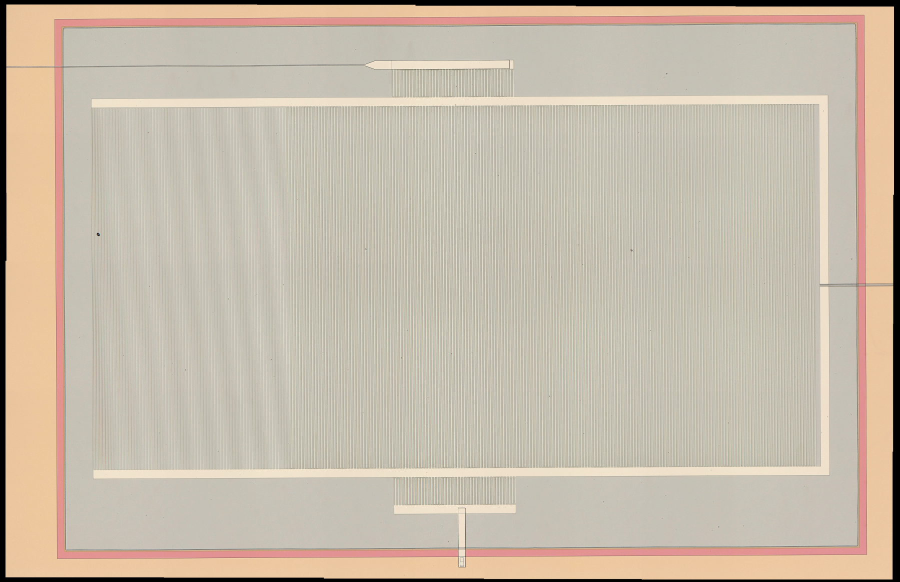
Antenna compatible design





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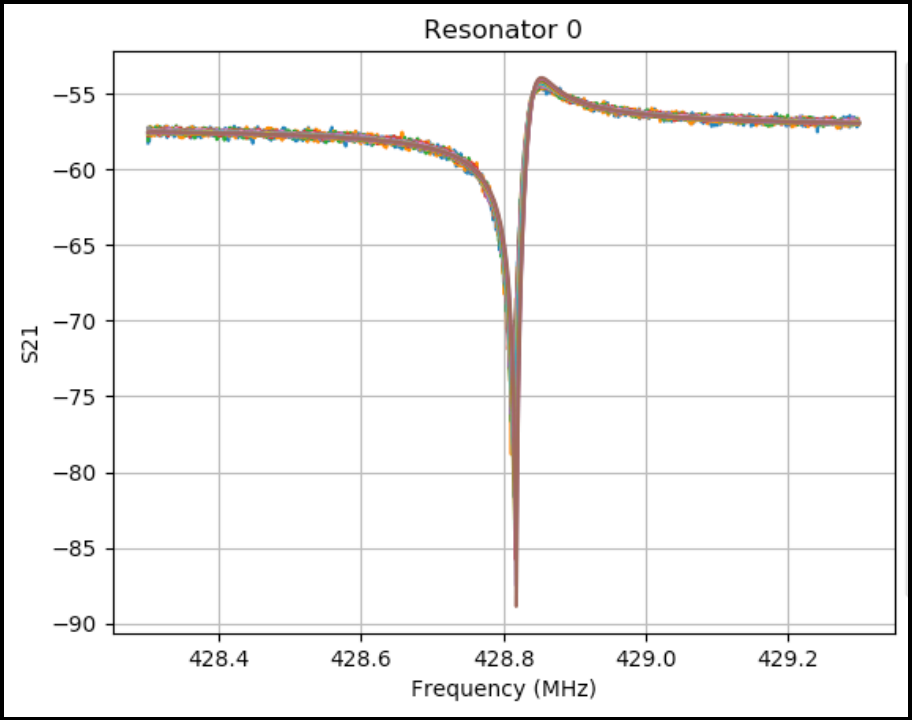
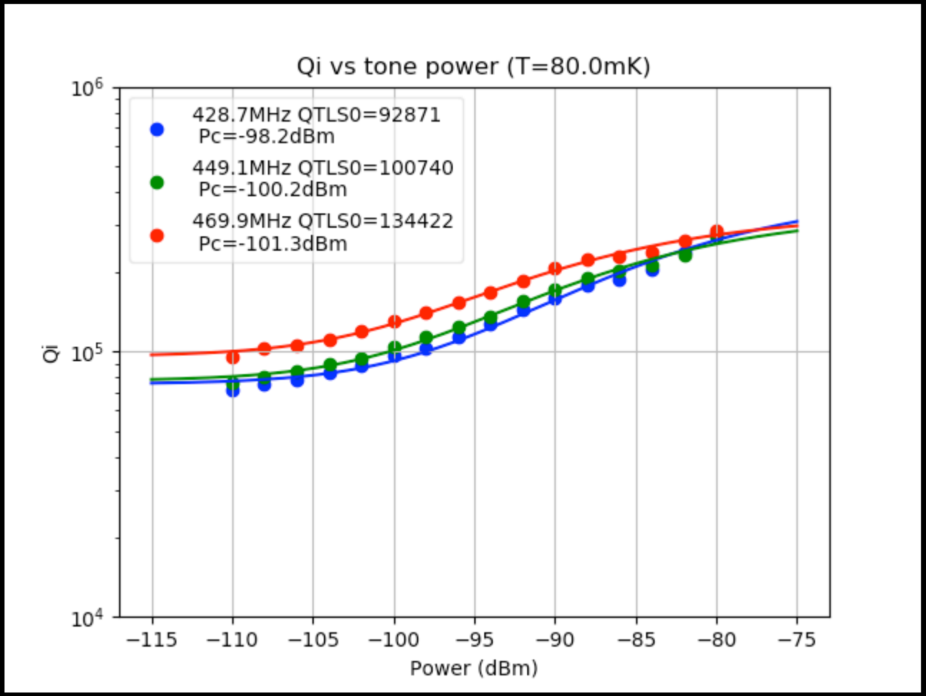
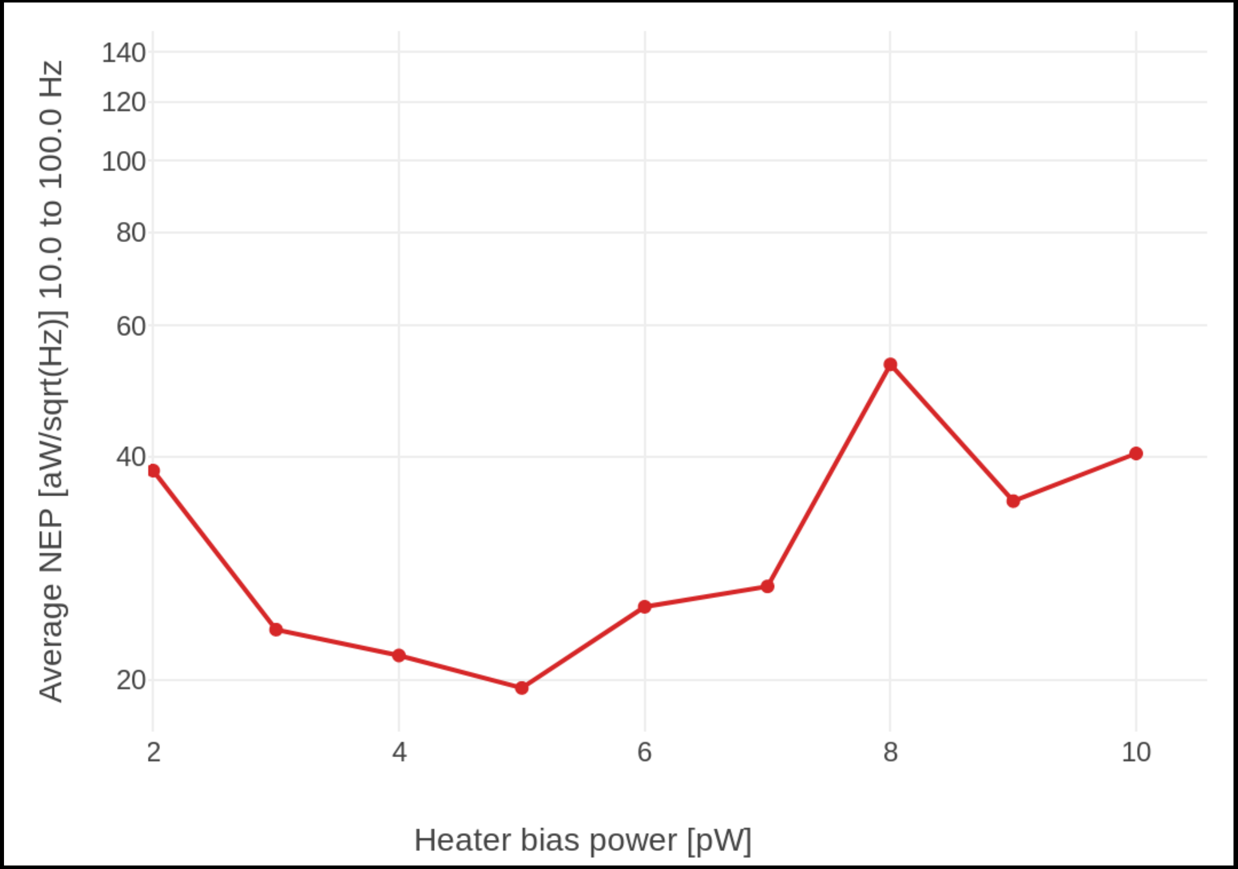
Resonator Qs





- Q_c is close to design 20,000
- Q_i is consistently high

Noise vs loading



- Would be background limited for 90GHz, 150GHz, and 220GHz at South Pole

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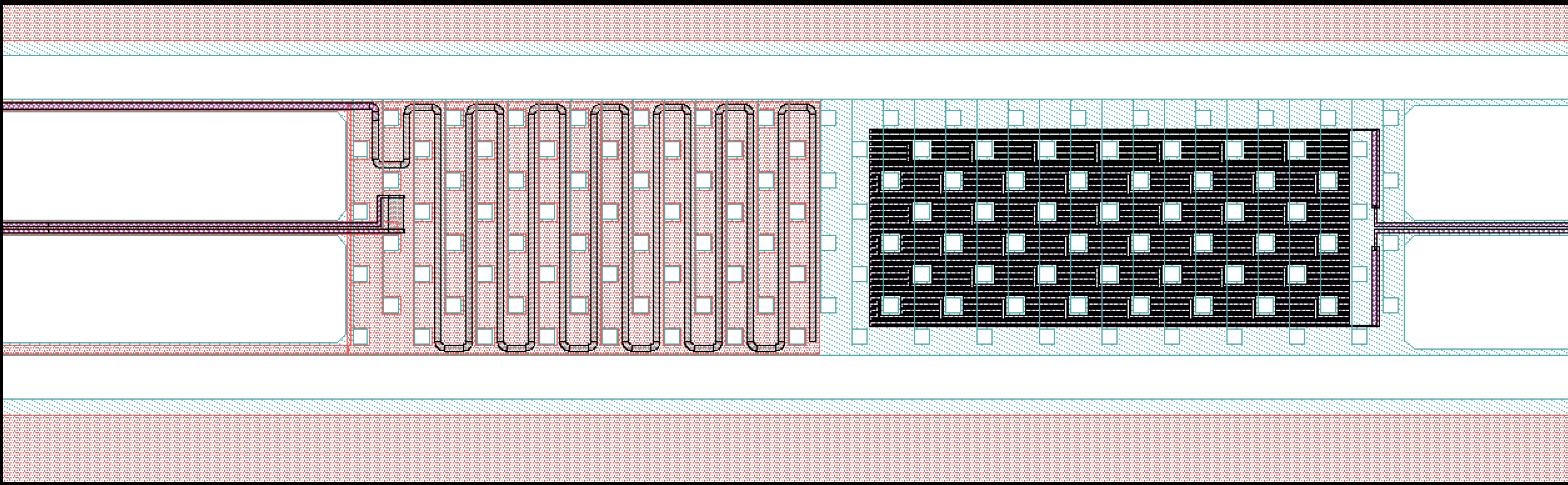
Antenna coupling



- Retain heater for calibration
- Add microstrip termination (gold)
- Drop-in replacement for antenna-coupled TESes:
  - Horn/OMTs
  - lens-coupled antennas
  - antenna arrays

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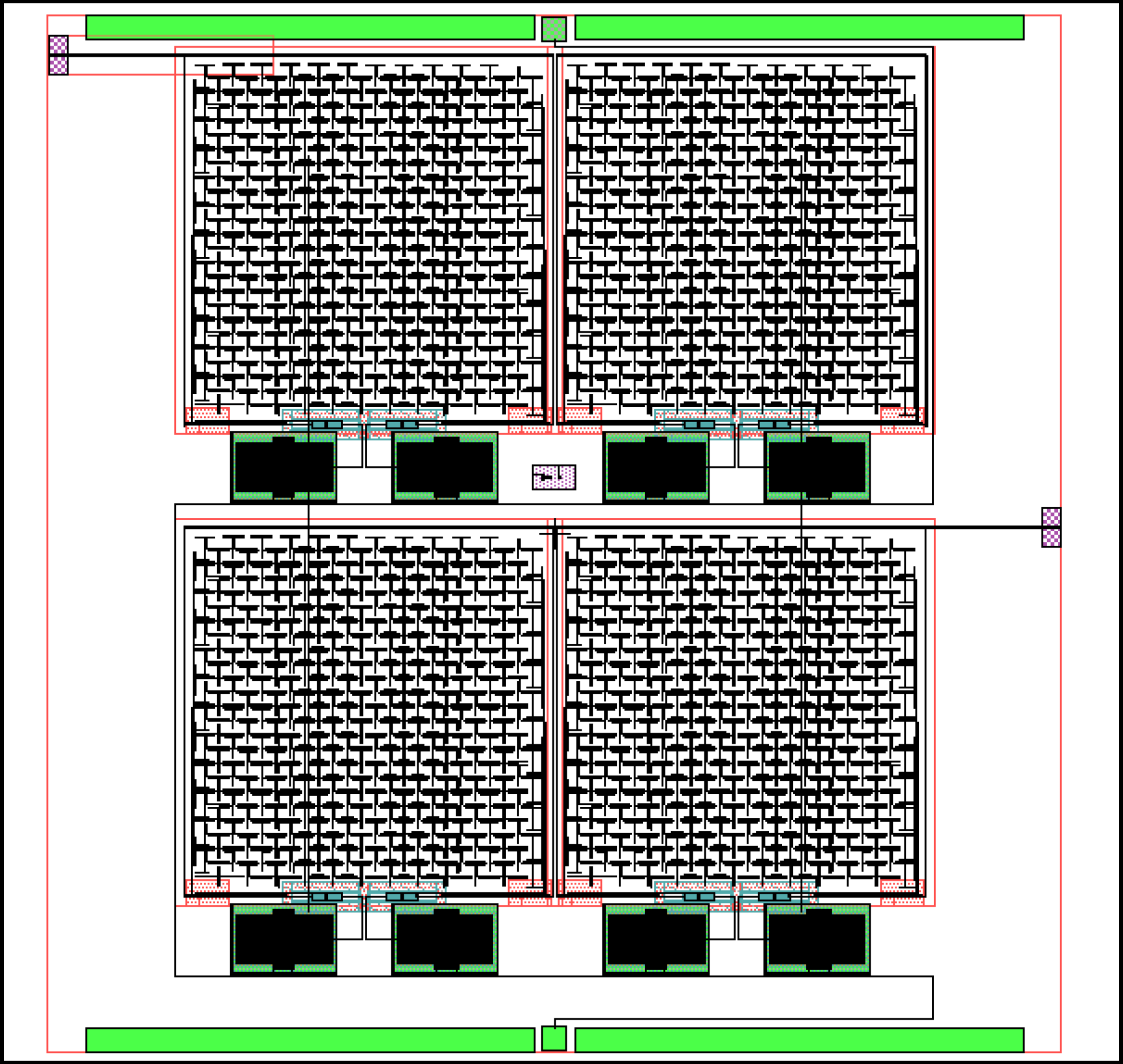
Antenna Coupled Design



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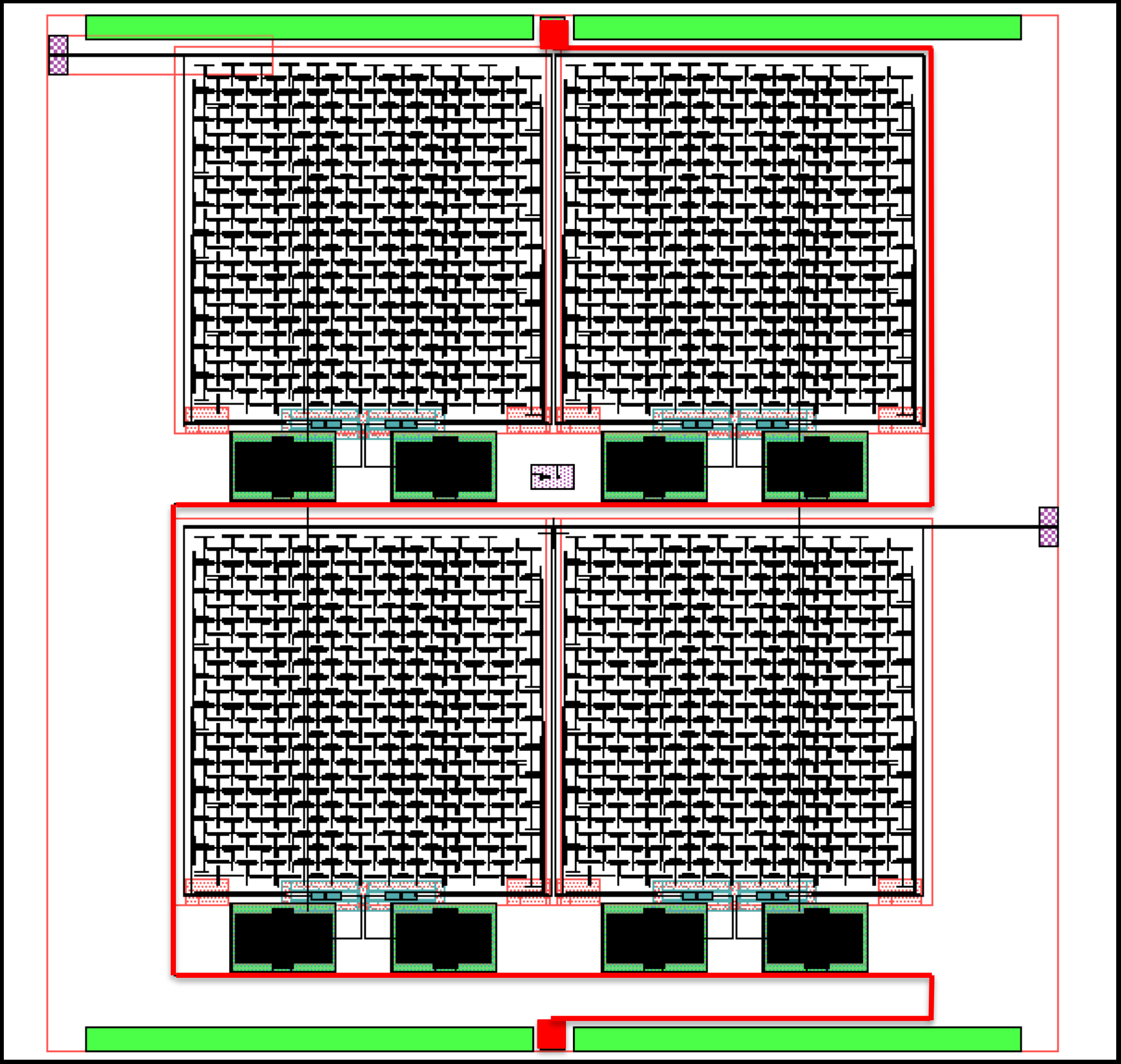
Antenna Coupled Design



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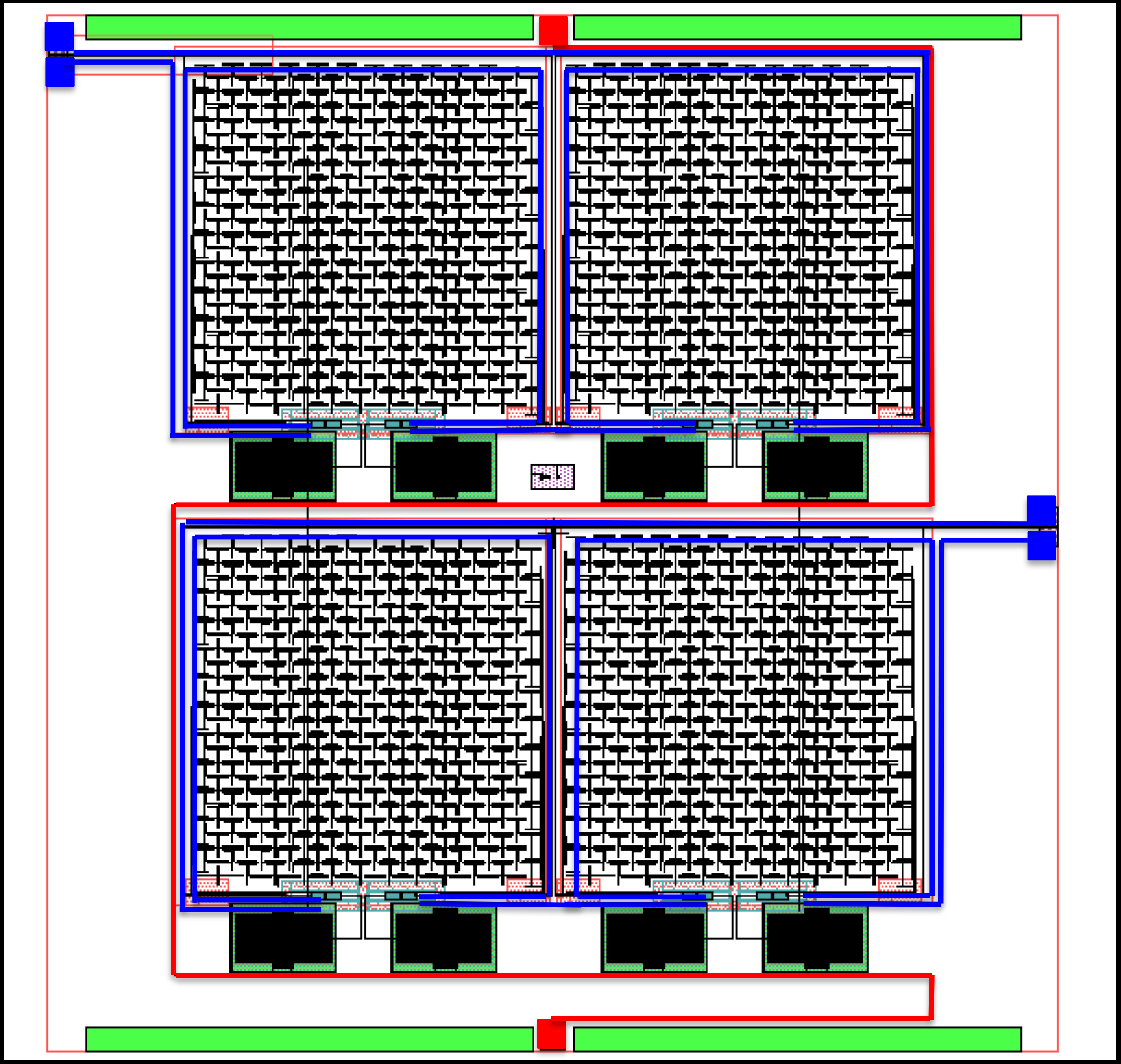
Antenna Coupled Design



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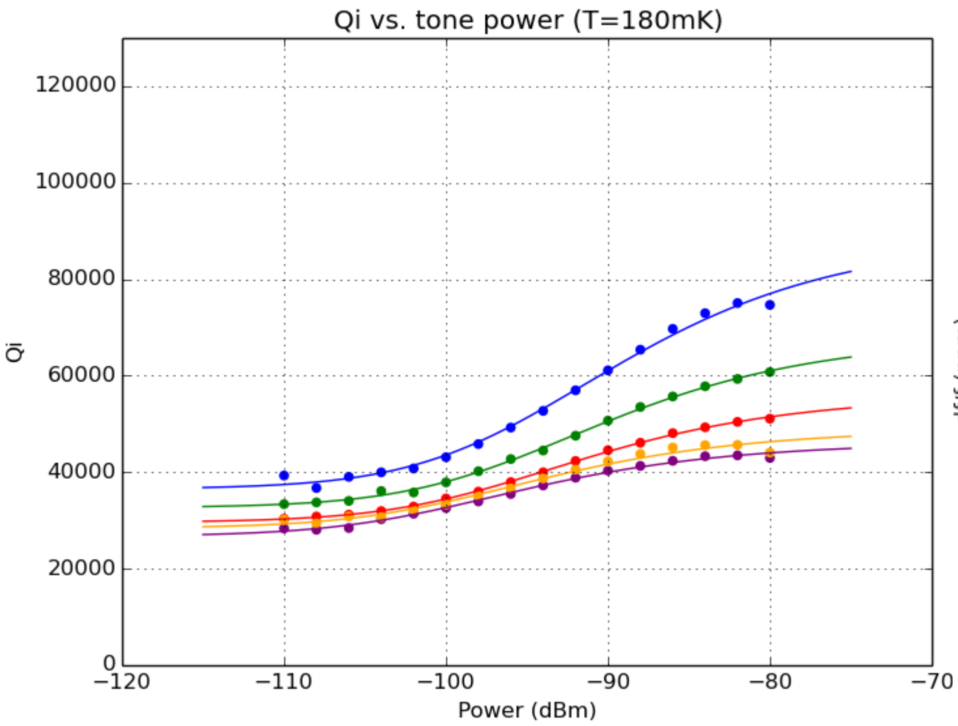
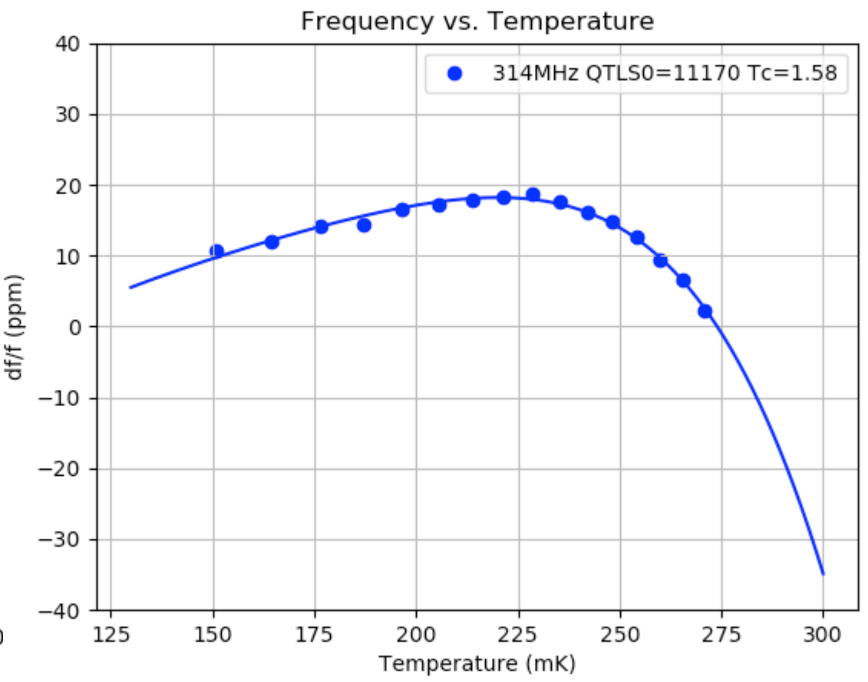
Conclusions

- TKIDs offer simple integration, but much needed design flexibility
- Dark but heater loaded measurements demonstrate background limited performance suitable for 90, 150, 250GHz ground observing
- Detectors stable to 100mHz
- Time constant low enough for simple transfer functions
- Clear pathway to antenna coupled designs- currently under fabrication

Extra slides

TLS Effects





- Our Responsivity ~10kHz/pW
- Typical S_{TLS}^2~1e-17 Hz
- Expect NEP_{TLS}~15aW/rtHz

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