Development of Polarization Sensitive Multi-Chroic MKIDs for CMB Studies
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Project supported in part by a grant from NSF/ATI.
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.

See for example, Day et al. (2003) *Nature* 425, 817-821
Yates et al. (2011) *APL*. 99, 7
Photons absorbed in the aluminum CPW break Cooper pairs changing $L_k$ and $R$ and therefore the resonant frequency and the quality factor.

$$\nu_g = \frac{2\Delta}{\hbar} \approx 74 \text{ GHz} \times \frac{T_c}{1 \text{ K}}$$
Schematic for One CPW MKID

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\[ \nu_g = \frac{2\Delta}{h} \approx 74 \text{ GHz} \times \frac{T_c}{1 \text{ K}} \]
\[ S_{21} \approx 1 - \frac{Q_r}{Q_c} \frac{1}{1 + j 2Q_r x}, \quad x = \frac{f_r - f}{f_r}, \quad \frac{1}{Q_r} = \frac{1}{Q_c} + \frac{1}{Q_i} \]
Multiplexing the Array

Each niobium section has a unique length, so each resonator has a unique resonant frequency.

The transmission line width, the gap width, and the film thickness is the same for all MKIDS.

The aluminum section length is the same for each MKID in the array.

Hundreds of detectors can be read out with a single pair of coaxial cables.
Microstrip-to-CPW MKID Coupling Schematic


Development of Multi-Chroic MKIDs

Array Element Details

MKID resonant frequencies around 3 GHz

five-stub band-pass filter

hybrid

meandered CPW MKID

CPW for probe tones

microstrip-to-CPW transition
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

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
Development of Multi-Chroic MKIDs

![Graph showing quality factor vs. frequency for Q_i and Q_c](image)

- Preliminary data
- $Q_i$ and $Q_c$ markers
Schematic of Readout System

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

resonant frequencies around 3 GHz
Schematic of Experimental Setup

External Millimeter-Wave Source

LEKID Example: Measured Photon Noise

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

Optical Test Setup
LEKID Example: Measured Noise Spectra

1) low NET

2) low 1/f noise

3) lots of bandwidth

150 GHz

$\mu K/\sqrt{Hz}$

frequency [Hz]

attenuation [dB]

McCarrick et al. (2014) RSI, 85, 123117.
Dual-Polarization LEKIDs

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

see LTD17 poster PA-5
High quality factor manganese-doped aluminum lumped-element kinetic inductance detectors sensitive to frequencies below 100 GHz

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(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).