Spectral Resolution Diagnostic Studies of the Microwave Kinetic Inductance Detector

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Introduction

The microwave kinetic inductance detector (MKID) is a new type of low-temperature astronomical detector. With the ability to record energies of individual photons at microsecond resolution, this detector is a great candidate for the next generation astronomical detector, especially for the use of studying dark energy. There has already been success in designing and comissioning a small 2024 pixel detector for astronomical observations (Figure 2). We present the results of the spectral resolution diagnostics of the MKID device at Fermilab.

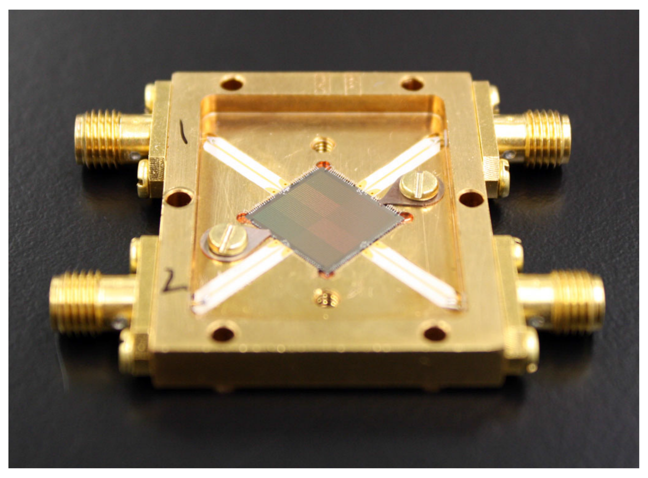


Figure 1. The MKID.

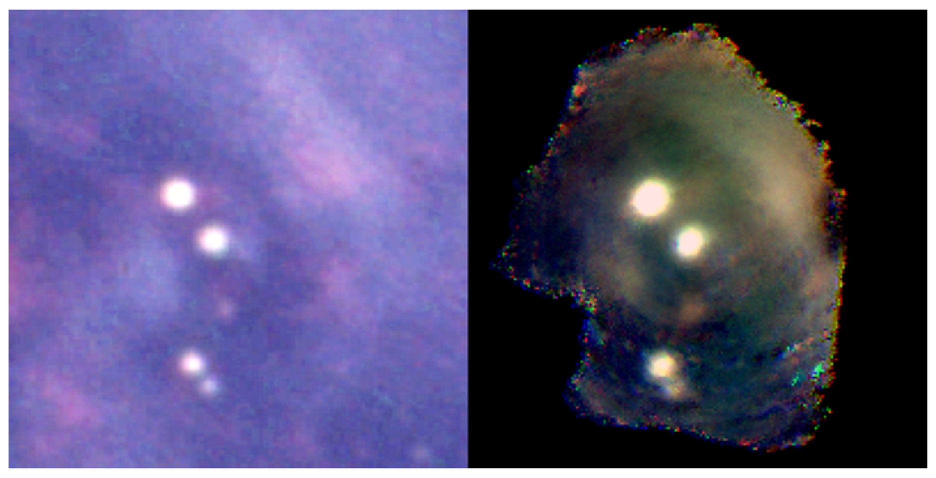


Figure 2. *Left:* An image of the crab region from the Kitt Peak telescope. *Right:* The same region captured by the MKID.

Mechanics of MKIDs

- The MKID device at Fermilab is a 2024 pixel detector, where each pixel is a resonant circuit.
- The device is cooled to 100 mK using an adiabatic demagnetization refrigerator.
- When a photon hits the inductor (Figure 3), the resonant frequency of the pixel shifts.
- This, in turn, induces a phase shift in the microwave input signal. By measuring this shift, the energy of the photon is recorded.
- Each pixel in the array has a unique resonant frequency; therefore the pixels can be multiplexed on a single signal that can be quickly read out.
- The observational data for every pixel is stored in a file, which can later be used for analysis.

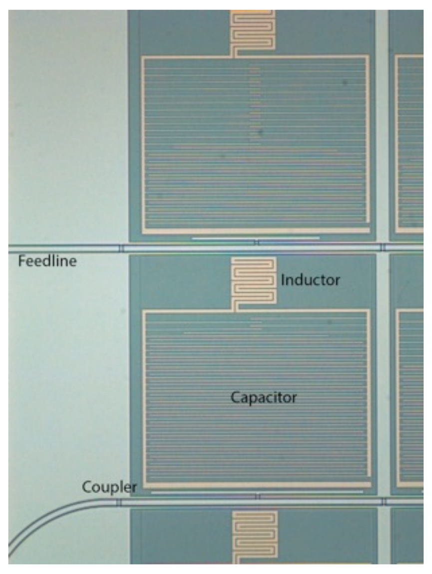


Figure 3. Pixel schematic.

Setup

1. Variable current lamp
2. 400 nm filter
3. Spherical integrator
4. Observational window of ADR
5. MKID (inside ADR)

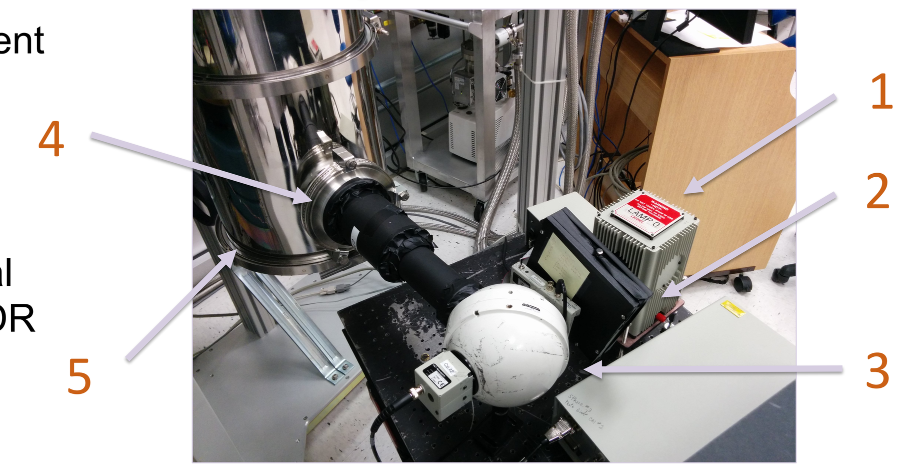


Figure 4. The data collection setup at Fermilab.

Strengths of MKIDs

- Microsecond time resolution (many orders of magnitude better than charge-coupled devices)
- No read noise or dark current due to 100 mK operating temperature
- No loss of observation time due to data readout
- Ease of multiplexing in the resonant frequency domain
- Simultaneous collection of time resolution and spectroscopic data

PeakFinder

Robust Python analysis package for spectrogram analysis:

- Plotting
- Fitting (various methods)
- Find resolution
- Find one sigma contribution of Gaussian
- Various veto parameters
- Intelligent parameter guessing
- Intelligent dead/bad pixel detection

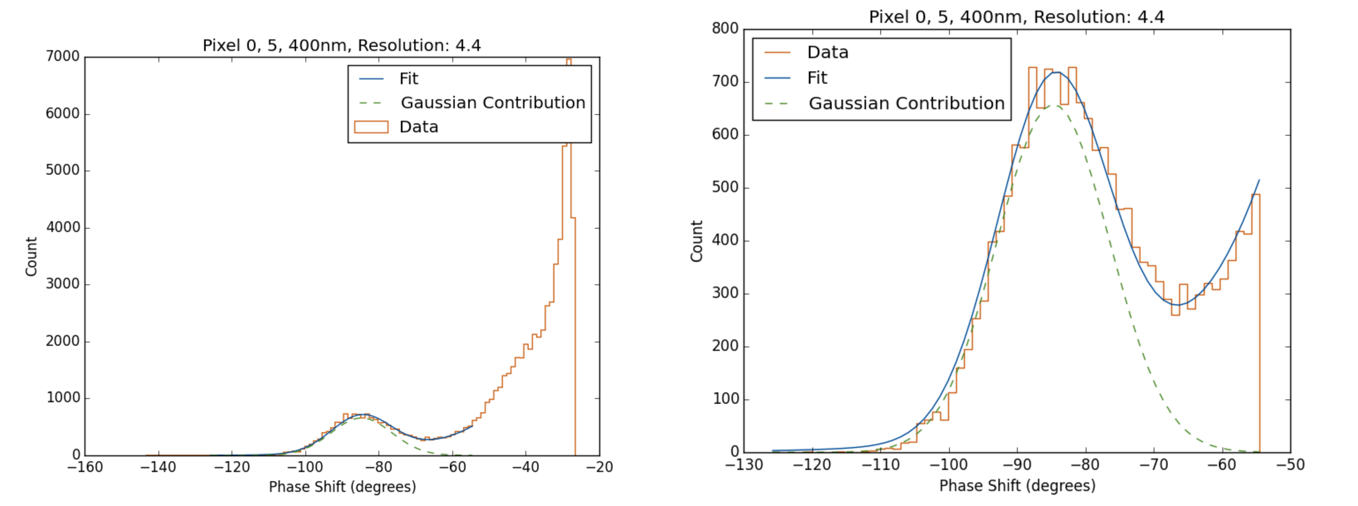
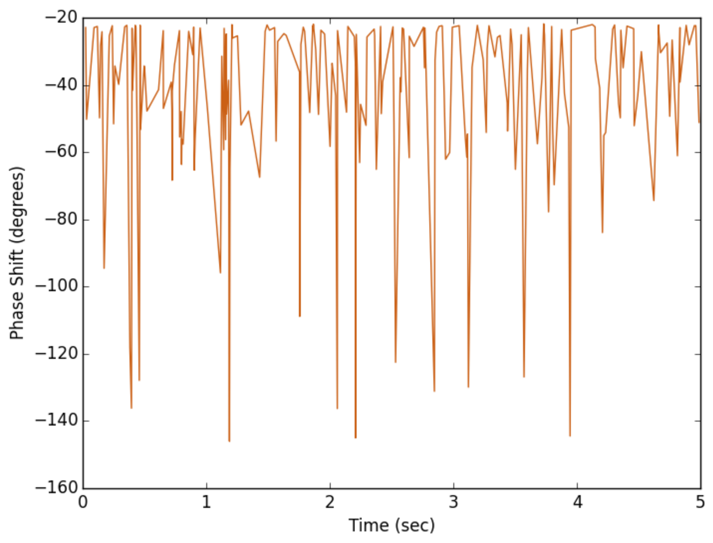


Figure 6. *Left:* The spectrogram from a good pixel. *Right:* Zoomed in on the photon peak.

Spectroscopy

- The observational data file contains lists of timestamps and phase shifts (Figure 5).
- A histogram of phase shifts results in a spectrogram (Figure 6).

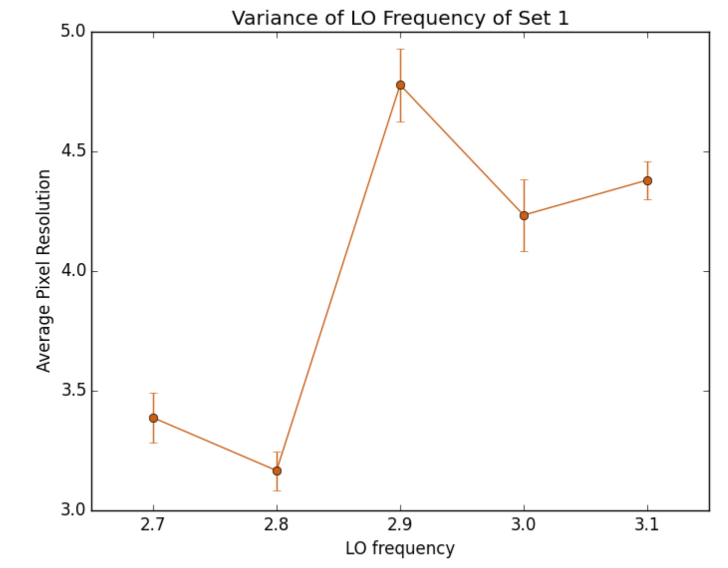
Figure 5. The phase shifts and timestamps from the observational data.



Local Oscillator Frequency

- The input microwave signal is combined with a local oscillator (LO) frequency during data collection.
- Under ideal conditions the pixels should behave identically in all LO frequencies, but preliminary inspection showed this was not true.
- 400 nm light was observed for 120 seconds at LO frequencies from 2.7 to 3.1 GHz at 0.1 GHz intervals.

Figure 8. Average resolution of pixels in the array at various LO frequencies.



- At 2.9 GHz, the average resolution of the pixels was highest.

Resolution Testing

- A Gaussian can be fit to the photon peak (Figure 6).
- Resolution = mean / FWHM

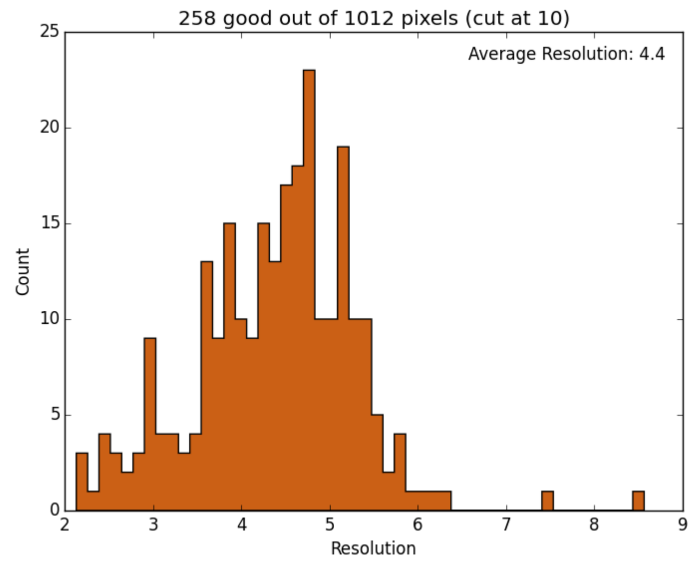


Figure 7. The histogram of pixel resolutions for the first feedline of the Fermilab MKID detector.

- Out of the 1012 pixels in feedline 1, about 25% behave well.
- Analysis was done by dividing pixels into four sets in resonant frequency domain.
- Sets 1 and 2 (2.5–3.9 GHz) contained most of the good pixels.
- Sets 3 and 4 (3.9–5.1 GHz) contained almost no usable pixels.

Further Research

- What causes the behavior of pixels in Sets 3 and 4 to be so poor?
- What factors determine the best LO frequency?
- Pixel behavior and quality when observing other wavelengths of light

Optical Power

To better characterize pixel behavior with regards to noise, one sigma contribution of Gaussian to fit was calculated. At one sigma to the right of the mean, what percentage of the fit is the Gaussian instead of the noise?

- Using the variable current lamp, 400 nm of light was observed for 120 seconds at 0.1A intervals from 2 to 3A.
- Since lamp current is not linearly related to actual optical power, the one sigma contribution was plotted against photons observed per second.

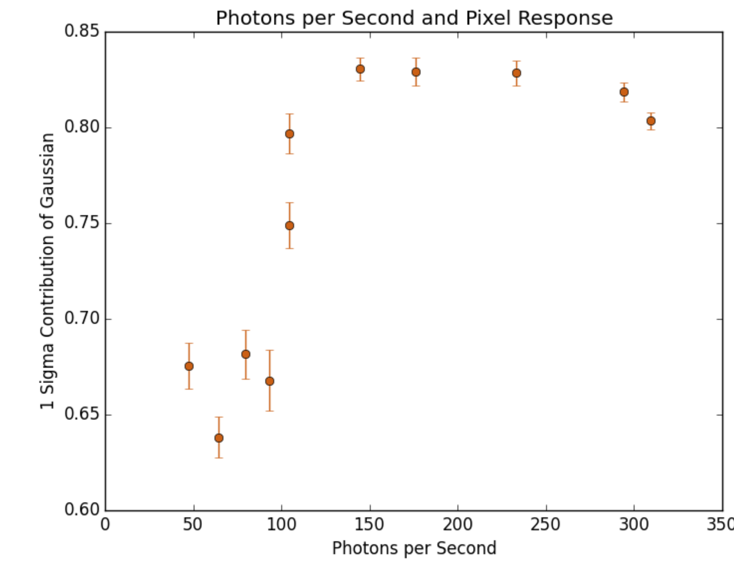


Figure 9. The average 1 sigma contribution of Gaussian against photons per second.

- At approximately 150 photons per second, the pixel behavior "tops out." This is believed to be due to the time between incident photons becoming too small, thus overlapping with the recovery time of the resonant frequency shift.

Acknowledgments

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