Week 10 – Week commencing 25/4/2022

Week Outline

Online meeting. This week focused on feedback from both my PowerPoint slides and my approach to presenting my PowerPoint. During the meeting, I went through the slides and my supervisor gave feedback on the presentation. This was the main theme of the meeting for this week.

Outline of Tasks

- Amend the presentation based on the recommendations of my supervisor
- Prepare for presentation and questions
- Create a plan for report

Recommendations

The following are recommendations given by my supervisor on the presentation slides:

- Add more detail on what you have done
- Fix few errors on terminology
- Fix wavelength ranges for detectors
- Add plots to aid explanations
- Explain more detail on superconductivity and how it works for a KID

Presentation

Before the meeting I created a PowerPoint for a presentation where I started with introducing the background of KIDs and its relevance, and then moving on to discussing detector properties, aims and objectives and findings. The slides were amended based on the recommendations and are attached below:

CHARACTERIZING ARRAYS OF KINETIC INDUCTANCE DETECTORS

ASHLEY THEAN

3RD YEAR BSC PROJECT PRESENTATION – 29TH APRIL 2022

WHAT IS THE MOTIVATION FOR DEVELOPMENT?

Challenges faced in longer wavelength detection:

1) **Limited pixel count**:

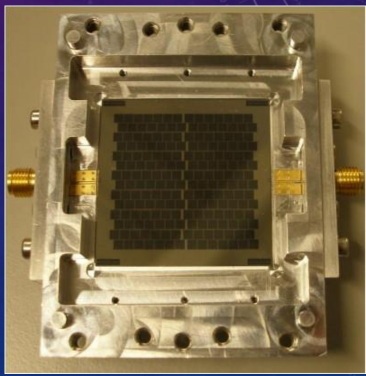
- Semiconductor tech (e.g. mobile cameras): Fit 10s of mega-pixels in a tiny square
- Best mm-wave cameras: Struggle to fit orders of thousands of pixels
- Detector physics tells us: $\boxed{Area\ of\ Detector \propto Wavelength^2}$
- Longer wavelength, larger detectors (Fewer pixels per area)

2) **Limited wavelength range**:

- Semiconductor physics: $\boxed{Photon\ Energy\ must\ be\ greater\ than\ band\ gap\ energy}$
- Lowest band gap energy semiconductor ~0.04 eV (Wavelength limited ~30 μm)

KINETIC INDUCTANCE DETECTORS (KID)

- Uses principles of superconducting-pair breaking
- Energy gap less than 1meV (wavelength up to 3mm)
- Developed for airport security cameras and in astronomy
- Compact: makes it easier for large arrays of detectors
- High sensitivity detector



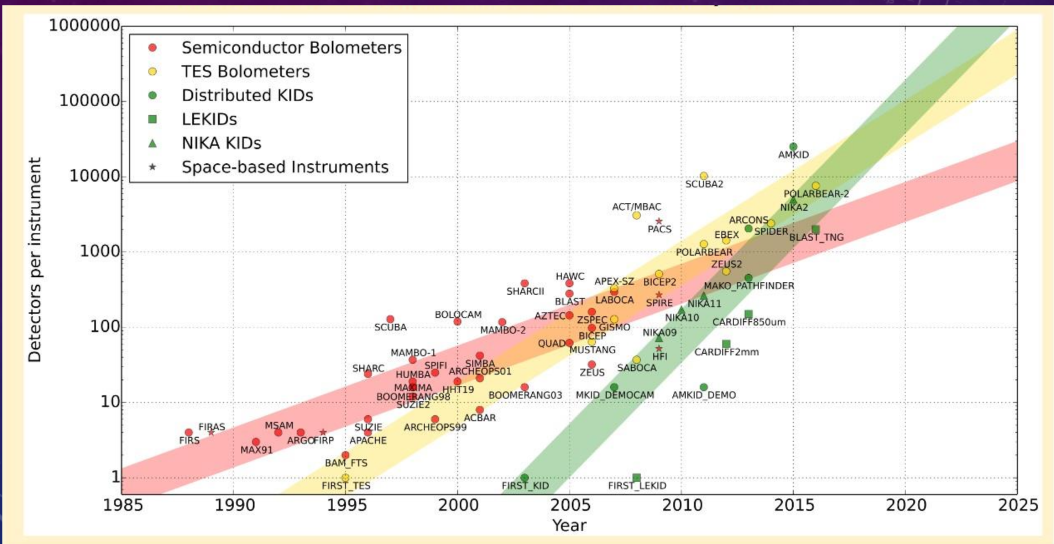
Source: Dr. Simon Doylés slides on intro to KIDs

COMPARISONS WITH COMMON DETECTORS WITHIN THE WAVELENGTH RANGE

Detector	**Limitation**	**Comparing with KIDs**
Semi-conductor technology	Limited to wavelengths of order $30\mu m$	Wavelengths up to 3mm
Heterodyne receivers	Typically noisy and not practical for large format imaging arrays	Compact, easy to create larger arrays
Bolometers	Have sensitivity but poor multiplexing ratios	Excellent multiplexing and sensitivity

Source: Dr. Simon Doyle's slides on introduction to Kinetic Inductance Detectors

PIXEL COUNTS IN ASTRONOMICAL RECEIVERS OVER THE YEARS



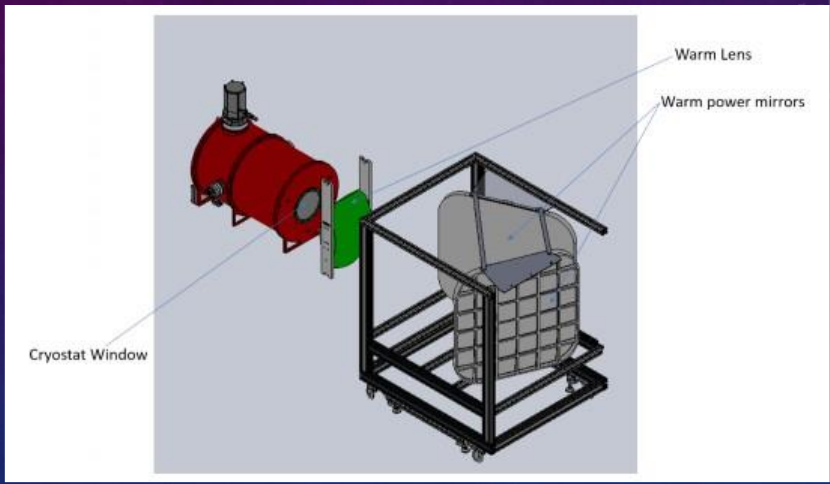
Source: Graph created by Dr. Sam Rowe

DETECTOR USED IN THIS PROJECT

- SFAB Security Imaging System
- Being developed in Cardiff University
- KID system developed for use as an airport security camera
- Range of frequencies used– transparent to bodies and clothing but not metals
- Detector kept at ~280mK

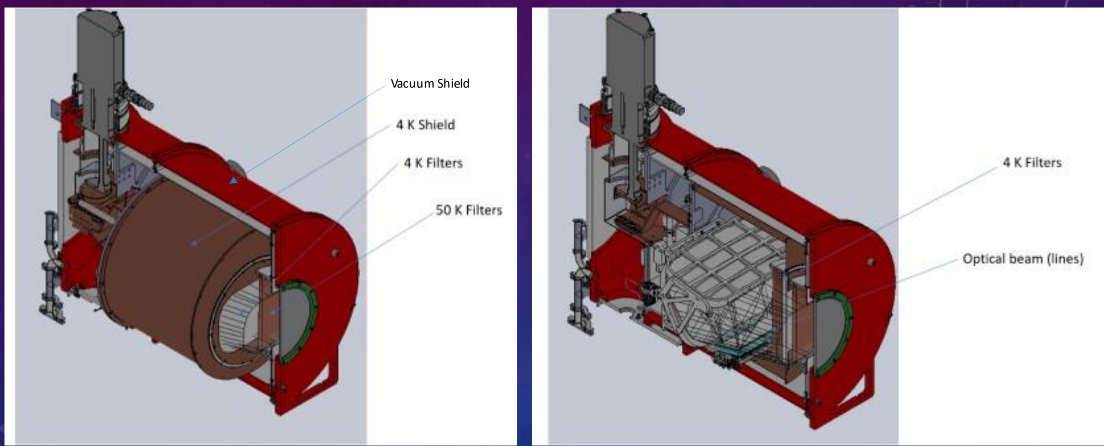
Source: Dr. Simon Doyle's slides on intro to KIDs

SCHEMATIC OF THE SFAB SECURITY IMAGING SYSTEM SET UP



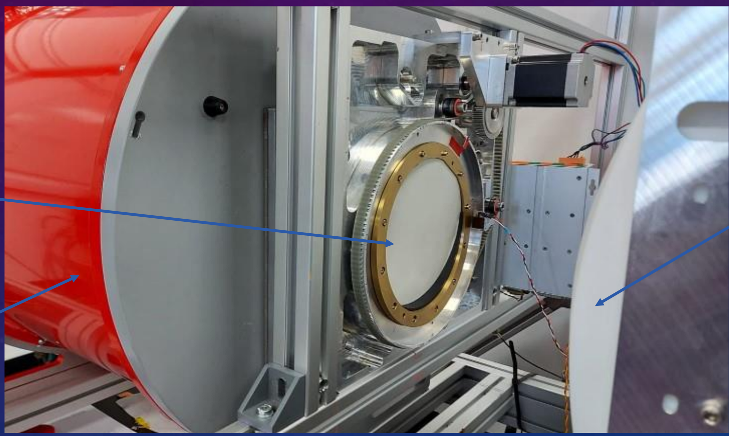
Source: System schematic by Dr. Tom Brien

SCHEMATIC OF THE CAMERA INTERIOR



Source: Schematics created by Dr. Tom Brien

PHOTOGRAPH OF THE SFAB SECURITY IMAGING SYSTEM



AIMS AND OBJECTIVES

1. Explore and understand the basic **principles of superconductivity** and its **application to KIDs**
2. Create a simple simulation of an ideal KID for a change in temperature
3. Read and analyze real KID data
4. Use experimental data to characterize the noise and detector properties

CHARACTERIZING DETECTOR PROPERTIES

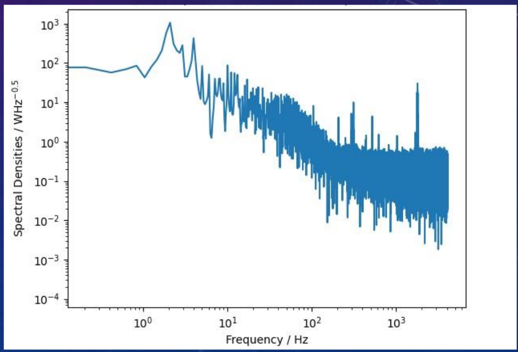
- Many performance metrics to compare between detectors
- In this report we focused on 4:

1. Responsivity:
Quantifying how the detector responds to a signal

2. Noise-Equivalent-Power (NEP):
Measure of sensitivity of a detector. Minimum detectable power

3. Detector System Yield:
Characterize losses throughout the system

4. Noise Spectrum:
Spectral density of the noise across the frequency



HOW DOES A KID WORK?

Superconductivity principles:

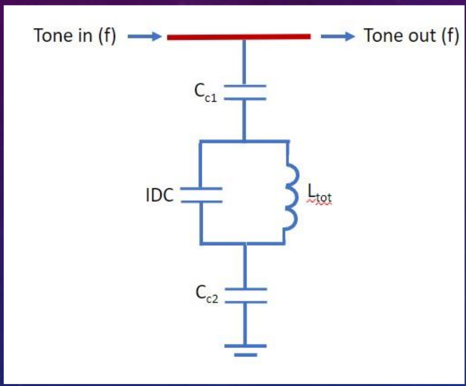
- At temperatures below T_c (depends on material), electrons start to pair up into superconducting electron -pairs
- When number of pairs varies, inductance will vary

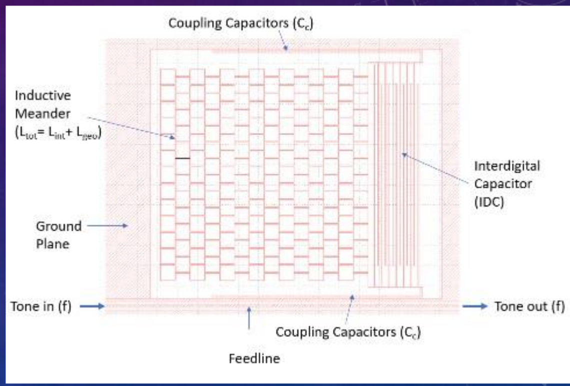
KID circuit:

- KID based on LC circuit
- LC circuit produces resonance when a signal (tone) is placed
- Inductor - superconductor and photon absorber
- Incident photons causes inductance to vary (energy absorbed to break pairs)

Able to detect photons from changes in resonance curve features!

CIRCUIT DIAGRAM OF KID

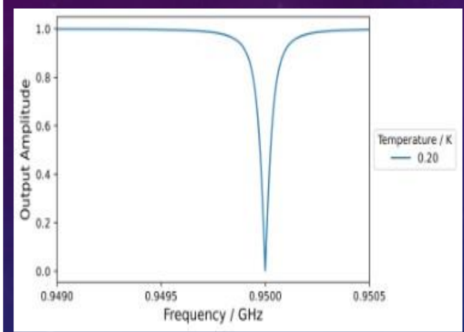




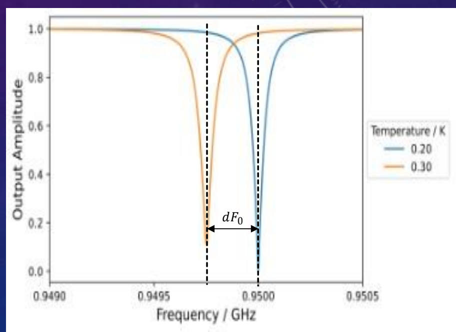
Source: Circuit diagram created by Dr. Simon Doyle

SIMULATION FOR CHANGE IN TEMPERATURE

Change in temperature has same effect as incident photons (energy break electron pairs)



Change in Temperature

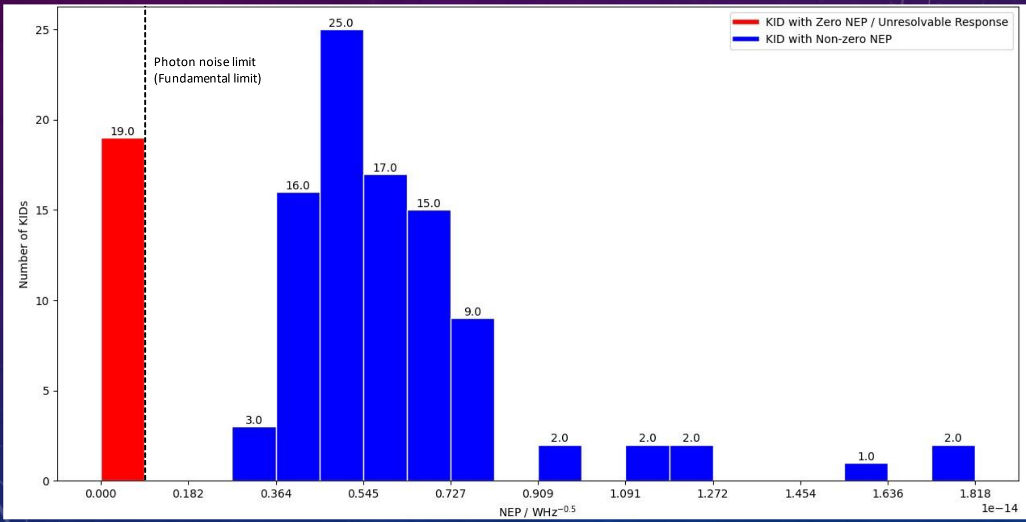


- Modelled using superconductivity theory
- Change in temperature causes resonance curve to shift position by dF_0

ANALYSIS OVERVIEW

1. Set up detector to measure a hot bar of known temperature
2. Scanned the hot bar to get detector response (hot bar power modelled as blackbody emission)
3. Compared this response to detector noise to determine minimum signal detectable (NEP)
4. Plot a histogram of sensitivity of all the KIDs in the array and compared it to the fundamental noise limit

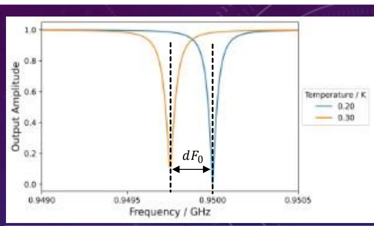
NEP DISTRIBUTION OF AN ARRAY OF KID

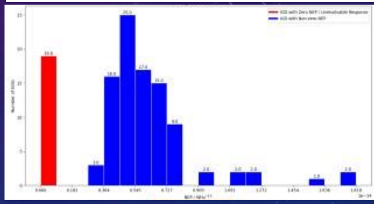


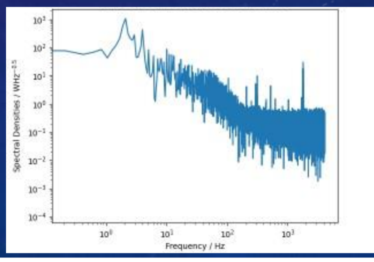
Total KIDs = 113

SUMMARY OF REPORT

1. Understood superconductivity and KIDs
2. Modelled the KID for a change in temperature
3. Took measurements of a hot bar of known temperature
4. Obtained analysis of the response, Noise Spectrum, NEP distribution
5. Found that NEP makes sense and only slightly above the fundamental limit. Relatively sensitive
6. Noise spectrum has all the right characteristics from the expected noise sources







THANK YOU FOR LISTENING!