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Fabrication and performance verification of a 961 pixel Kinetic Inductance Detector system for future space borne observatories 9914-138

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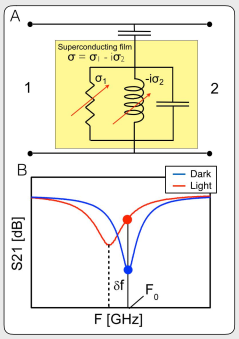
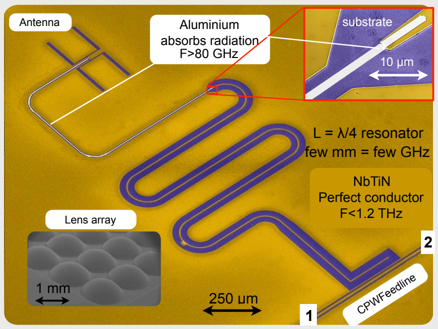
9914-138

Astronomical observations at infrared, sub-millimetre, and millimetre wavelengths are essential for addressing many of the key questions in astrophysics. Future ground- and space based observatories need large detector arrays with a sensitivity limited only by the noise of the radiation background. We demonstrate that antenna coupled Microwave Kinetic Inductance Detectors allow us to create kpixel large arrays with background limited sensitivity over the entire FIR/mm-wavelength range. We discuss in detail the readout system and experimental results of a 961 pixel array, optimised for 850 GHz radiation that is read out with a single readout chain.

The Microwave Kinetic Inductance Detector, MKID

A MKID is a superconducting resonance circuit that is constructed such that radiation is absorbed with high efficiency. This changes the complex surface impedance of the superconductor, modifying the resonance feature.
The devices we discuss are λ/4 CPW antenna coupled MKIDs[1]
- The antenna properties determine the signal frequency.
- Each antenna is coupled to a lens. For large arrays we use flies eye lens arrays

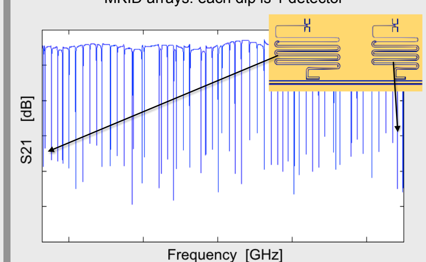




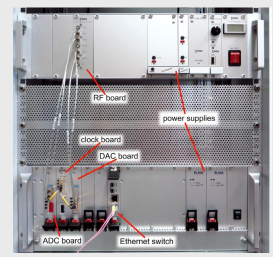
MKID arrays and readout

- Large arrays of MKIDs are made by changing the length (resonance/readout frequency) of the individual MKIDs while maintaining the same antenna geometry. Up to 2000 detector/GHz readout bandwidth are possible in principle
- The 'SpaceKIDs' readout system[2] can measure up to 4000 detectors simultaneously in a 2 GHz band centred around 5-7 GHz
- The devices are operated at 0.1K in a cryogenic test facility
- A single readout cable pair (2 coax cables) and a single cryogenic amplifier are needed to read out an array of up to 8000 pixels

MKID arrays: each dip is 1 detector



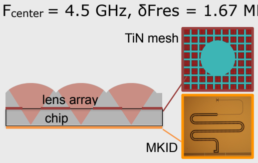
Readout system



850 GHz demonstrator: a 961 pixel large imaging array read-out with 1 readout system

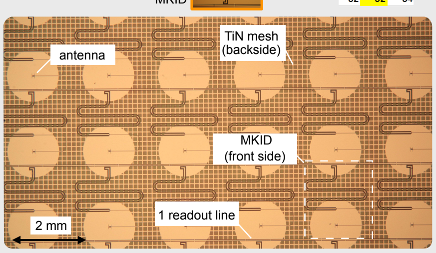
961 pixel array for 850 GHz radiation

- Sapphire C plane substrate: birefringent
- Metal layer thickness: 500 nm NbTiN, 40 nm Al
- 63 nm TiN mesh (T_c ~ 0.8K): stray light absorption
- Reducing cross talk[3]: F_{KID} = F_{center} + δFres·**M**
- F_{center} = 4.5 GHz, δFres = 1.67 MHz



M =

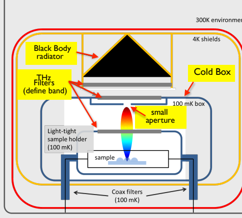
58	-56	56
-47	47	-45
37	-35	35
-37	33	-33
39	-39	41
-52	51	-51
62	-62	64

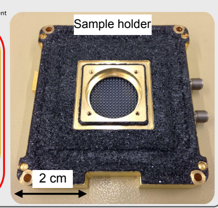


experimental system

- 100 mK test setup:
  - array in 100 mK cold box
  - central pixels coupled to 3-20 K thermal radiator
  - 3 filter stacks provide v = 850 ± 30 GHz band
- Calculate power coupled to each detector: P_{calc}
  - radiator temperature
  - CST calculation of lens-antenna-aperture coupling: η_{opt}= 0.304
  - Filter frequency band
- We can calculate the *source* NEP(P_{calc})

$$NEP_{BLIP}^2 = 2P_{calc}h\nu(1+\eta_{opt}B) + 2\Delta P_{calc}/\eta_{pb} \quad (1)$$





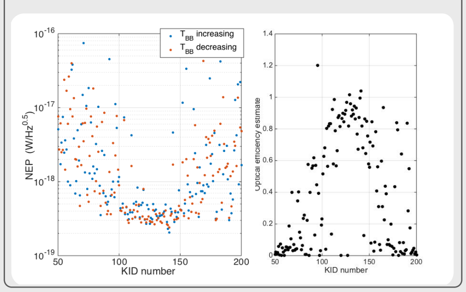
Sensitivity: NEP ≥ 2.5·10^{-19} W/√Hz

Measure the noise (S_θ), response to radiator power ($d\theta/dP$) and lifetime τ_{qp}:

$$NEP = S_\theta \left(\frac{d\theta}{dP}\right)\sqrt{1+(2\pi\tau_{qp})^2}$$

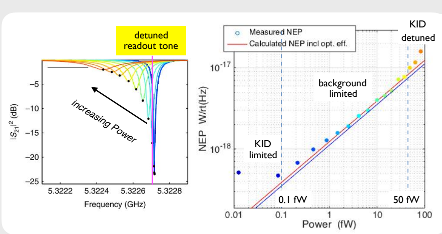
- Obtain NEP ≥ 2.5·10^{-19} W/√Hz
- independent of T_{BB} sweep direction

Optical efficiency from eqn. (1)
- between 80-100% of calculated BLIP value



Dynamic range: 1.7·10^5

We read-out each MKID with a single tone, slightly detuned to lower frequency
NO retuning
- max power: P_{max} = 50 fW
- dynamic range = P_{max}/NEP = 1.7·10^5
- background limited 0.1 - 50 fW

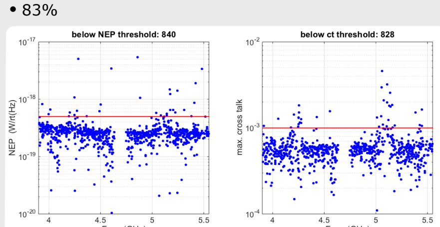


Array yield: 83%

Obtain the dark NEP for all pixels[4]
- From temperature response, noise, lifetime and Tc

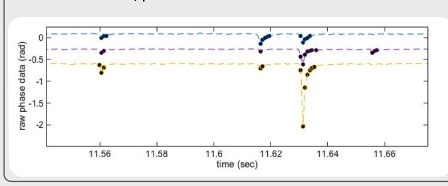
Obtain the cross talk between pixels
- from direct measurements and model analysis

Yield:
799 pixels: NEP < 5·10^{-19} W/√Hz *and* cross talk<-30dB
- 83%



Cosmic Ray impact: 1.5% dataloss

Cosmic rays affect MKID timeline[5]
- Sampling at 1.2 kHz we flag all datapoints with a value > 5 σ_{RMS}
- time constant: 1.2 msec
  - so we resolve all cosmic ray glitches
- <Dead time/pixel> = 0.032% of timeline
- obtained event rate on the chip:420 sec^{-1}m^2
- @L2 operation event rate = 2·10^4 sec^{-1}m^2
  - <dead time/pixel> = 1.5% of timeline



We have demonstrated a 961 pixel array + readout system multiplexing all pixels with a single readout chain with one 4K amplifier and 300K back-end. This system combines very high sensitivity, high dynamic range, low cross talk, low cosmic ray susceptibility and high yield and demonstrates the next step in technological readiness of MKID technology.

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4:Janssen et al. 2014, Appl. Phys. Lett. 105 193504, DOI: 10.1109/TMTT.2016.2544303
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