National Aeronautics and Space Administration

# Large Array of Single Photon Detecting Quantum Capacitance Detectors (QCDs) with Low Frequency Readout

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## Objectives:

Demonstrate an array of small volume far-Infrared Kinetic Inductance Detectors with Noise Equivalent Power (NEP) lower than 1x10$^{-19}$W/Hz$^{1/2}$ at 1 atto Watt of loading and with a dynamic range larger than 10$^4$ as required by PRIMA, a concept for a probe class mission currently under development.

## Background:

The Kinetic Inductance Detector (KID) is being developed for a proposal for a probe class mission current in preparation. Since the objectives of the proposal include observing very faint objects at large red shift but also bright objects within the local galaxy, not only it requires NEP of the order of **1x10$^{-19}$**W/Hz$^{1/2}$but also a large dynamic range. This precludes the use of the Quantum Capacitance Detector which was being developed in this task. Instead the focus was changed to the Kinetic Inductance Detector (KID), which already has a large dynamic range, but requires improvement of the NEP at low optical loadings.

## Approach and Results:

In a KID, radiation is absorbed on a superconducting inductor which is a part of a resonator. Radiation breaks Cooper-pairs thereby changing the surface inductance and resistance on the inductor. As a result the resonant frequency decreases as a function of optical loading and so does the quality factor (Figure1).

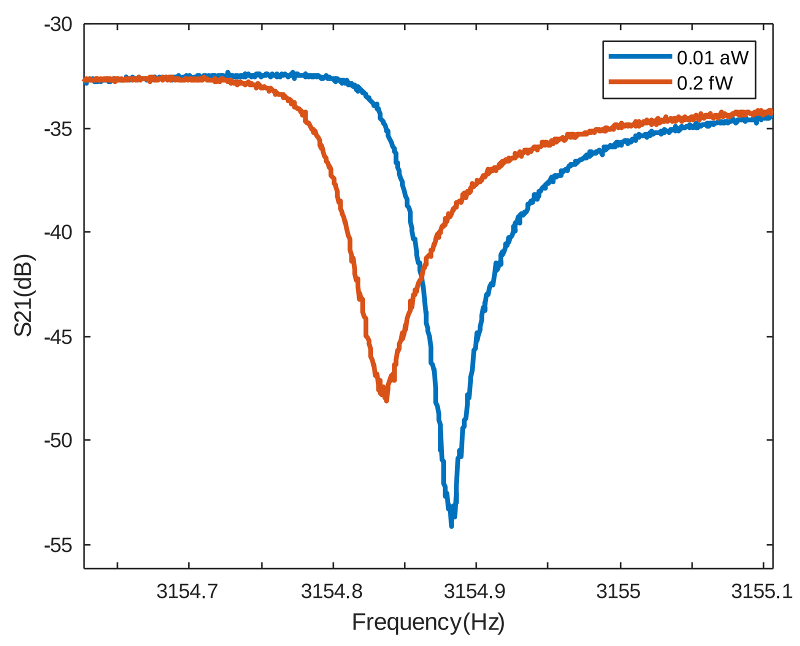


Figure 1. Change in resonance frequency
And quality factor on a KID resonator for
Low and high optical loading

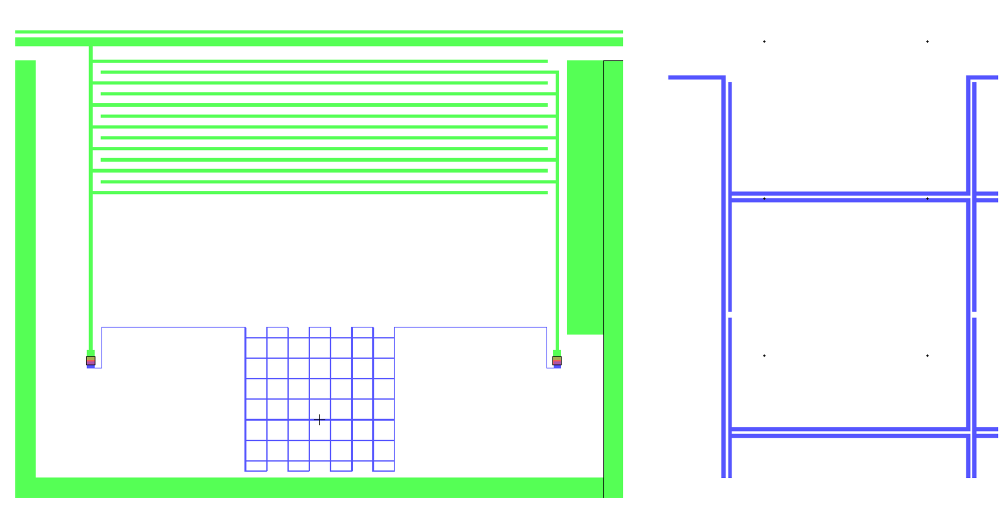

Figure 2. Design of a small Volume KID. The aluminum inductor (blue) is also the absorber. The shape is optimized to couple two polarizations while maintaining a small volume. The interdigitated capacitor (niobium) completes the resonator and acts to trap generated quasiparticles in the inductor.

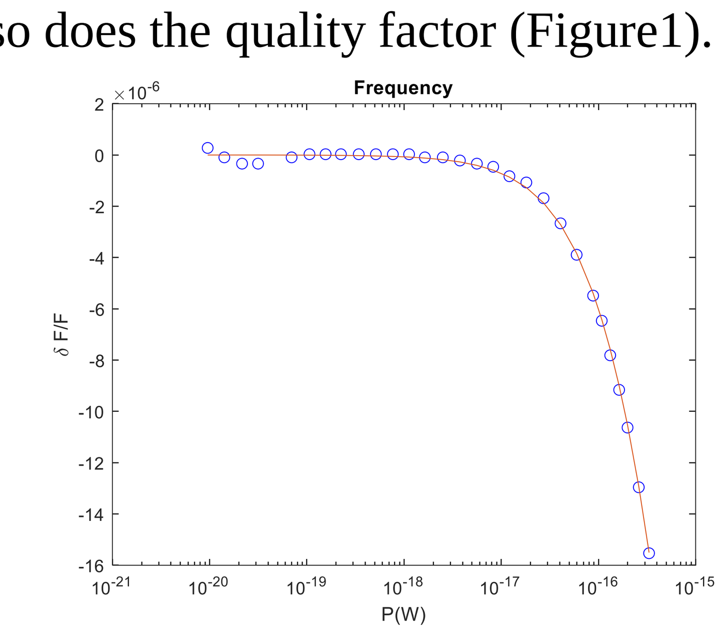


Figure 3. Fractional frequency response as
A function of optical loading

In order to obtain the required NEP at low optical loading the volume of the inductor/absorber has to be reduced relative to previous devices. Figure 2 shows the latest design of our small volume KID. The inductor is designed to absorb both orthogonal polarizations. The absorber volume is 20 cubic micron and will be reduced further to below 10 cubic micron in the next iteration. Figure 3 shows the fractional frequency change of the resonator showing response down to 1 aW of loading at a temperature of 200mK. Figure 4 shows the fractional frequency noise for various optical loadings (blue – low illumination level, red – high illumination level). At low optical loadings a 1/f component is seen due to two level system noise (TLS). At 200 mK the 1/f component is greatly diminished compared to 100mK. The flat noise above 10Hz indicates that generation recombination noise is the dominant noise source. This allows extraction of the quasiparticle lifetime as shown in figure 5, showing it saturates at about 280 µs. Figure 6 shows the NEP corresponding to frequencies between 1 a 10Hz as a function of optical power. The square root of power dependence implies photon noise limited performance. However, since the NEP falls below the photon noise means more power is reaching the detector than calculated probably due to crosstalk (radiation from neighboring pixels). We will remedy this in the next iteration by introducing a titanium grid on the back of the detector wafer. Holes above the detector will allow radiation from the lens above it to reach the detector but block radiation coming from neighboring pixels.

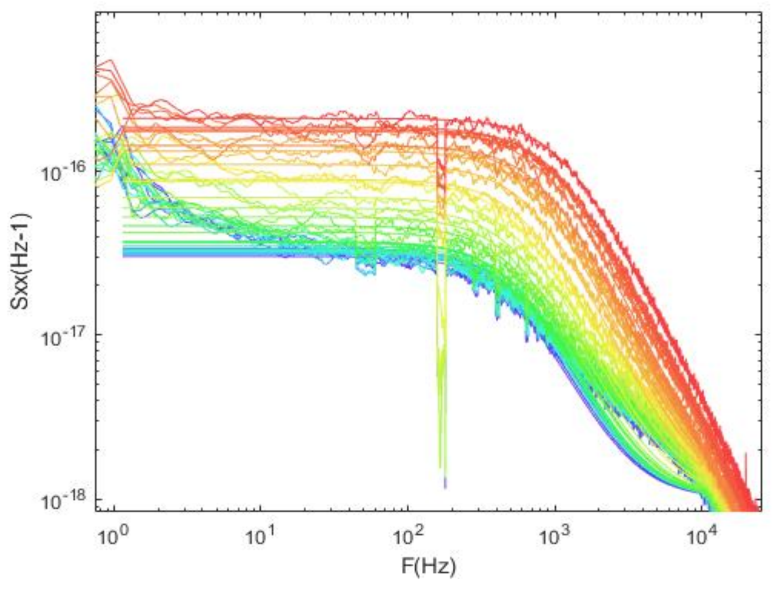


Figure 4. Fractional frequency noise
For various levels of optical illumination

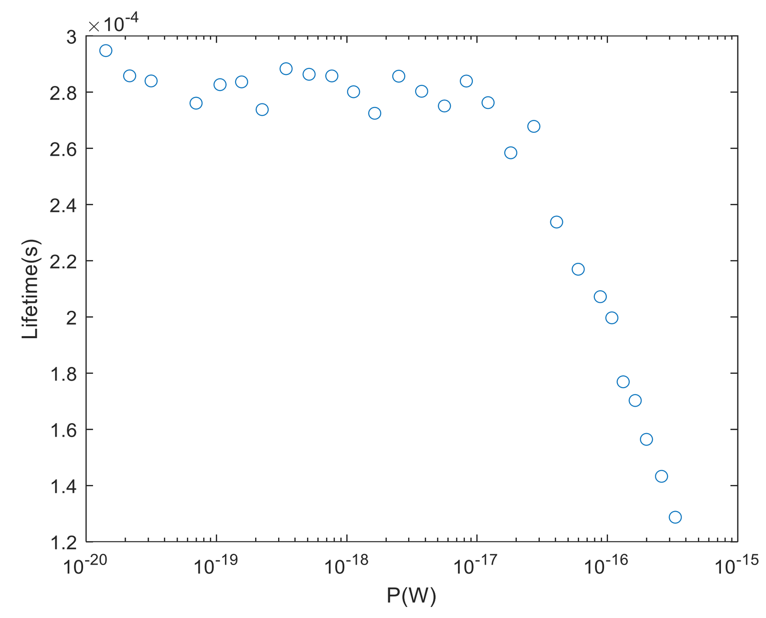


Figure 5. Quasiparticle lifetime inferred from
roll off of fractional frequency noise

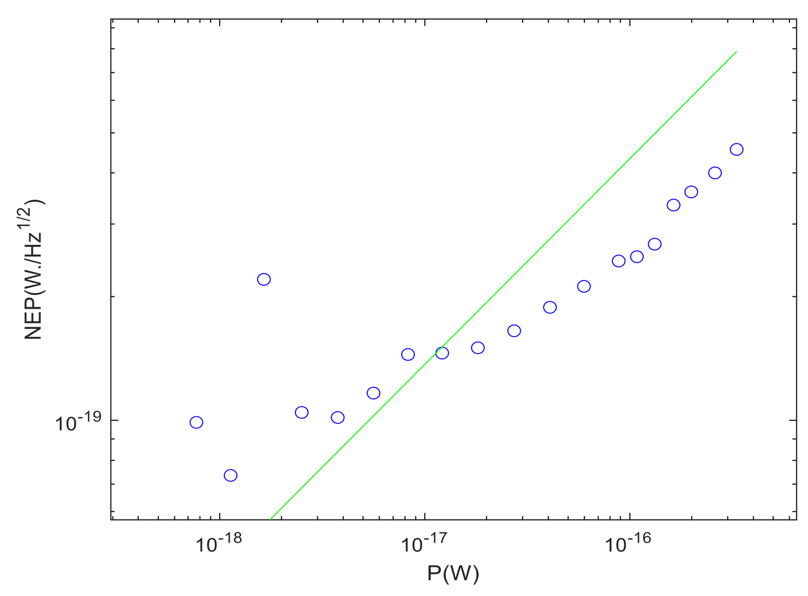


Figure 6. Device NEP as a function of optical
power. Green curve is photon shot noise

## Significance/Benefits to JPL and NASA:

Demonstration of small volume KIDs will make the PRIMA proposal being prepared in anticipation of an AO for a probe class mission very competitive.

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