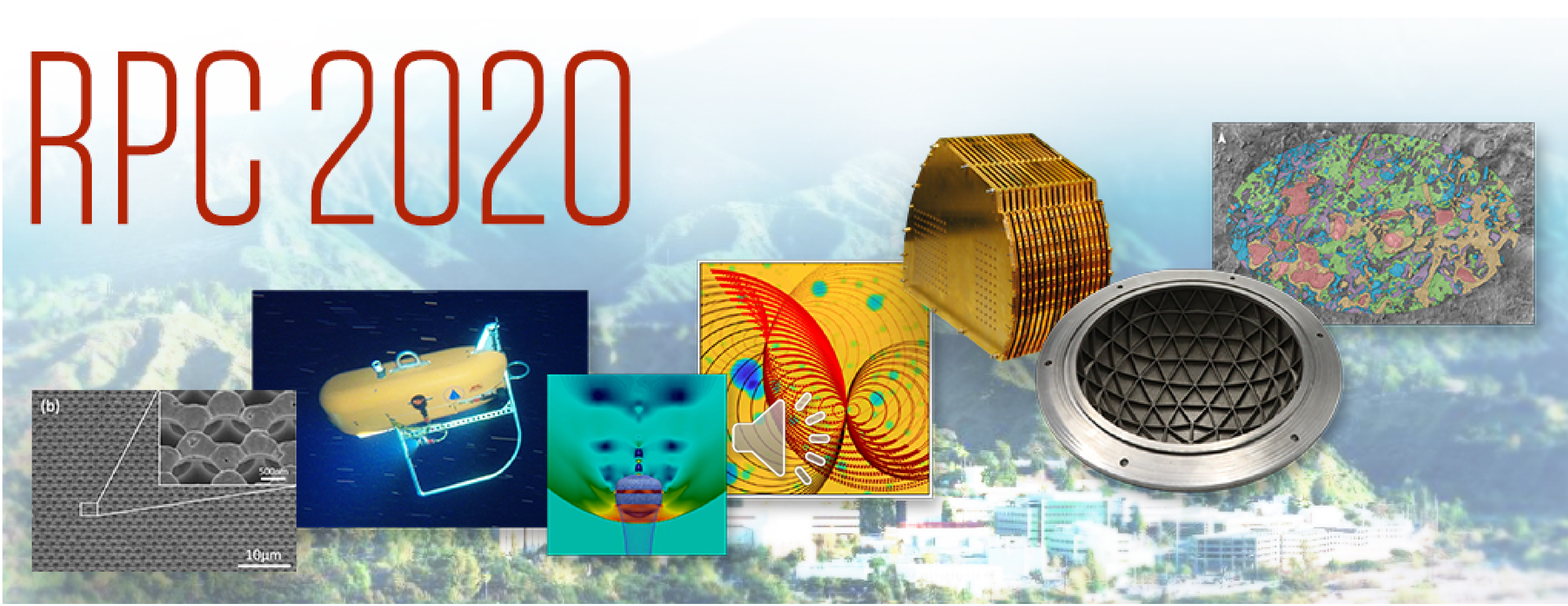


Virtual Research Presentation Conference

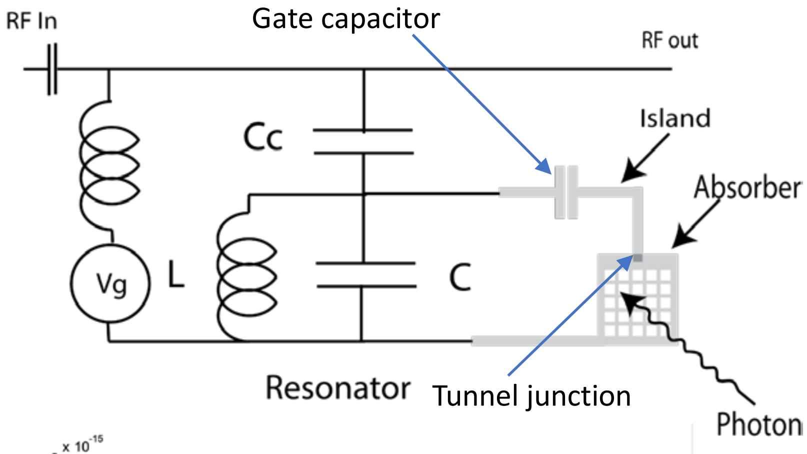
Large Array of Single Photon Detecting Quantum Capacitance Detectors (QCDs) with Low Frequency Readout

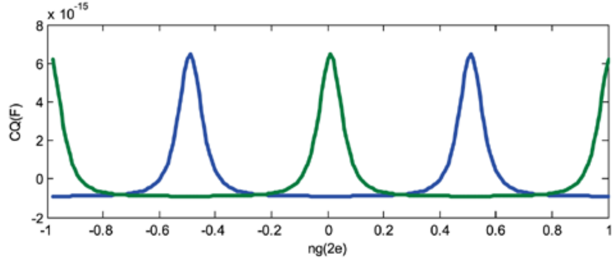
Principal Investigator: Pierre Echternach, 389
Co-Is: C. Matt Bradford, 326; Andrew D. Beyer, 389
Program: Strategic Initiative

Assigned Presentation #RPC198

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction





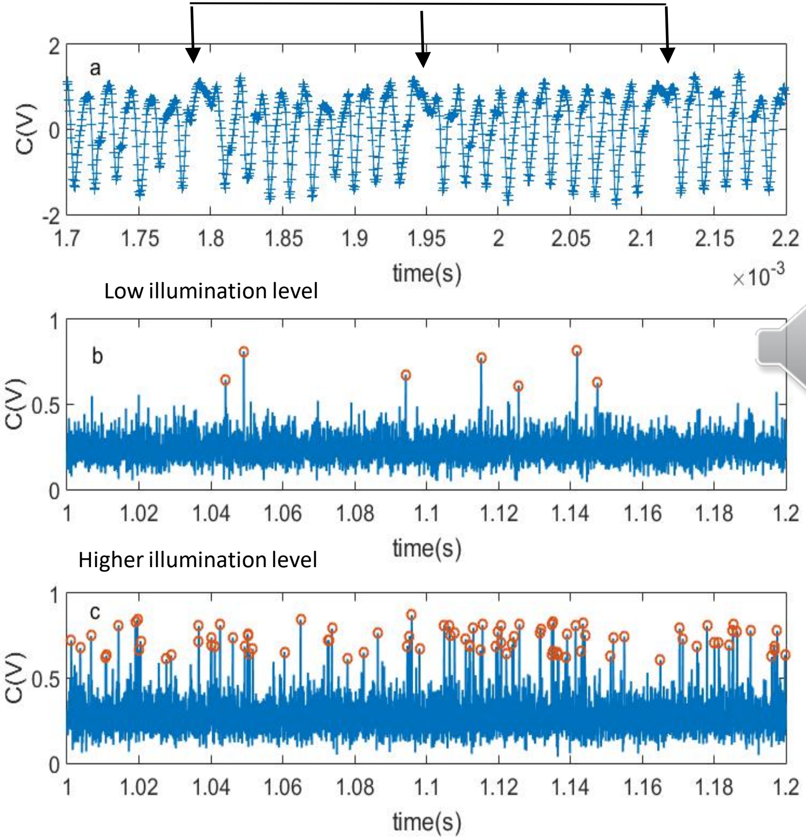
- Small island of superconducting material connected to a superconducting absorber via a small tunnel junction and biased by a gate capacitor
- The device capacitance as a function of gate voltage features peaks with periodicity 2e/Cg where e is an electron charge and Cg the gate capacitance
- If an unpaired electron tunnels to the island, this capacitance trace shifts by an amount e/Cg
- When a photon strikes the absorber, it can break a Cooper pair (a pair of electrons bound together in the superconducting state)
- This unpaired electron tunnels to the island and changes the device capacitance which shifts the resonance frequency of the resonator
- The resonance frequency shift is measured by standard RF techniques

The Quantum Capacitance Detector- Single 1.5THz Photon Detection

Single Photon absorption events in raw data

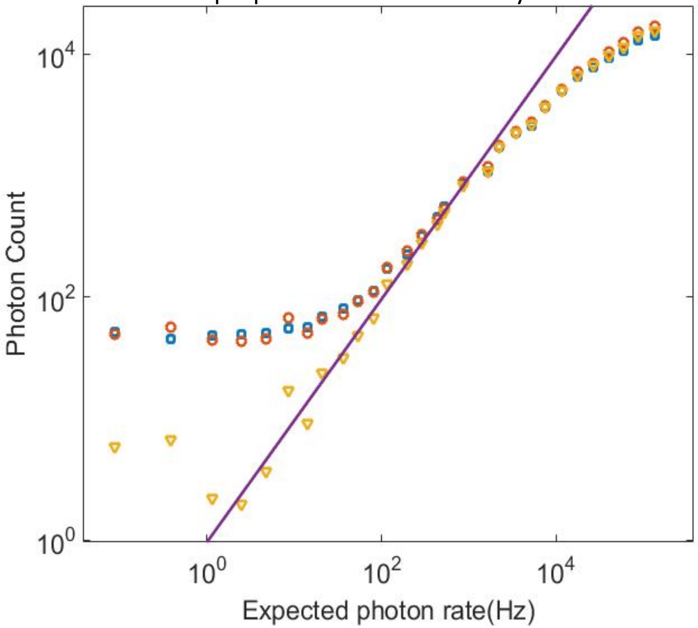
Low illumination level

Higher illumination level



Circles mark single photon events in processed data

Expected photon rate x measured photon rate (gold triangles) – purple line = 96% efficiency



Problem Description

a) Context (Why this problem and why now)

Origins Space Telescope -- Far-IR flagship under study for NASA submission to 2020 Decadal. Key tall pole is detectors. NEPs of the order of 10^{-20}W/Hz$^{1/2}$ are needed. JPL technology and science experience positions us for instrument and/or mission leadership. Start 2020s, launch 2030s.

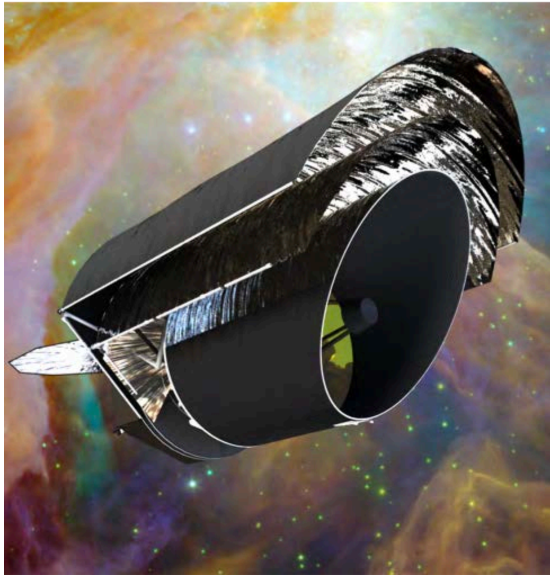
a) SOA (Comparison or advancement over current state-of-the-art)

- Kinetic Inductance detectors – best NEP 3x10^{-19}W/Hz$^{1/2}$in a kilopixel array
- Transition edge sensors - best NEP 1x10^{-19}W/Hz$^{1/2}$in single pixel
- QCD 2x10^{-20}W/Hz$^{1/2}$ in single pixel demonstration

a) Relevance to NASA and JPL (Impact on current or future programs)

Our work will ready JPL and NASA for an OST-like mission and a potential far-IR probe-class mission.

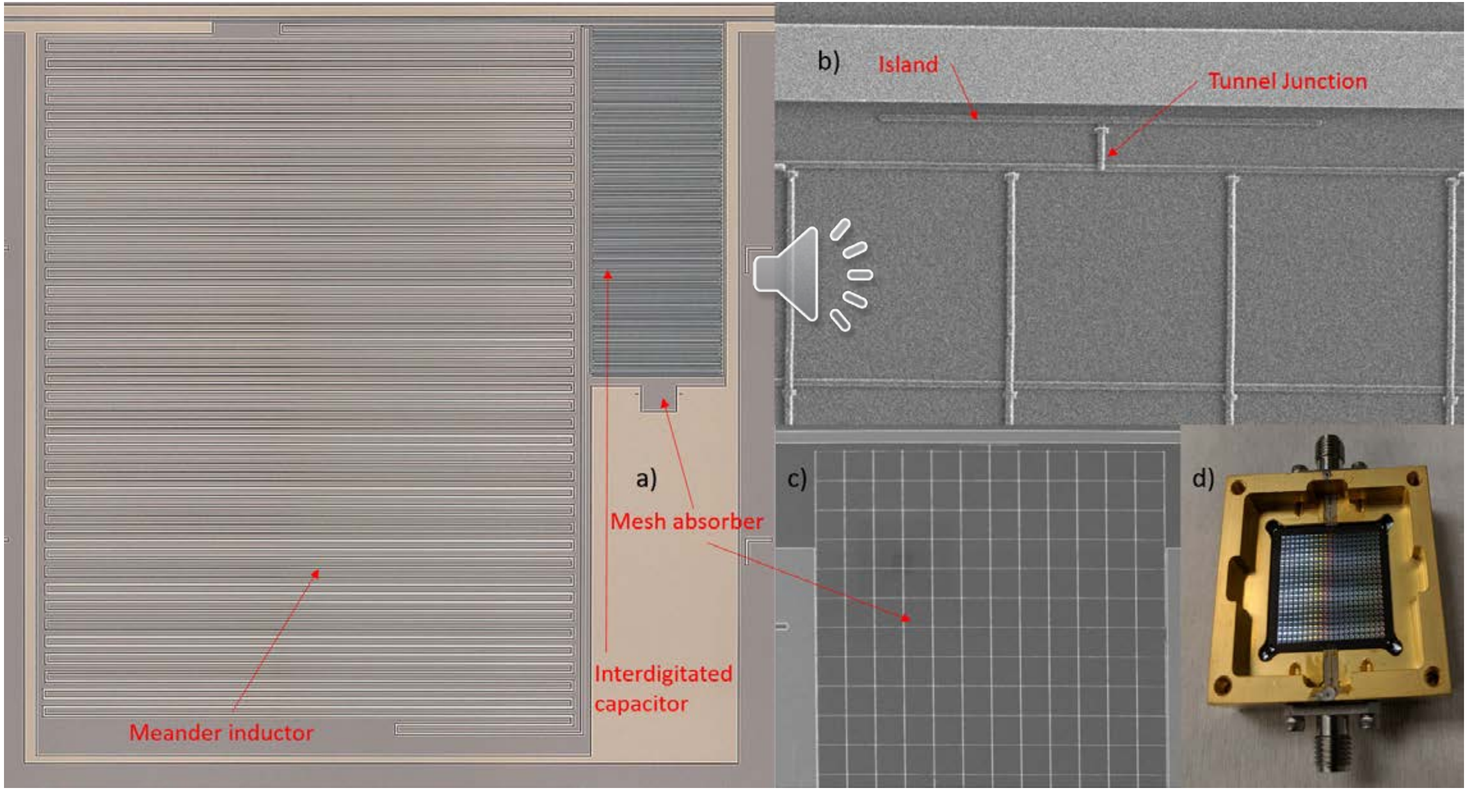
OST



Results

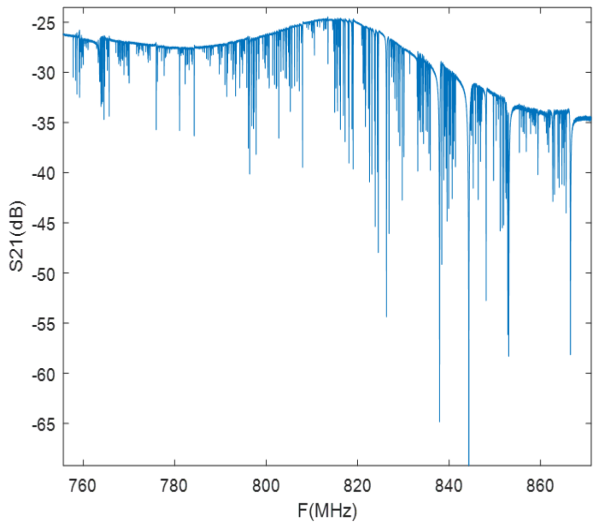
- Design and fabrication of low frequency readout 21x21 completed
- Resonance frequencies between 750 and 870MHz
- Measured NEPs – clustered around $5x10^{-20}W/Hz^{1/2}$
- Developing fully multiplexed readout system based on Xilinx ZCU111 RFSoC

Lens coupled mesh absorber lumped element low frequency readout QCD

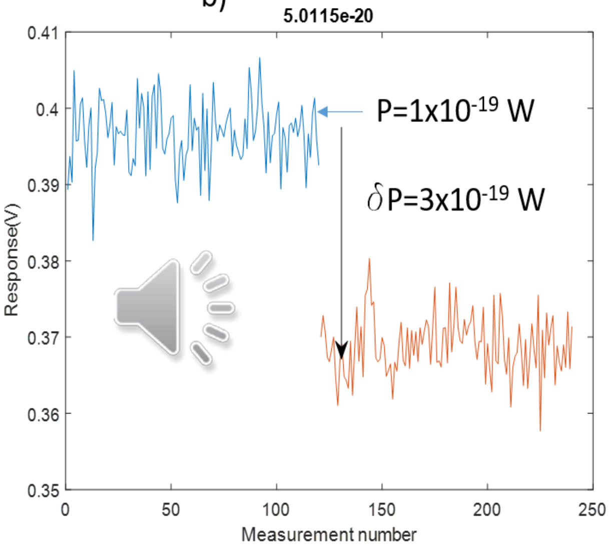


21x21 array of low frequency readout QCDs

a)



b)

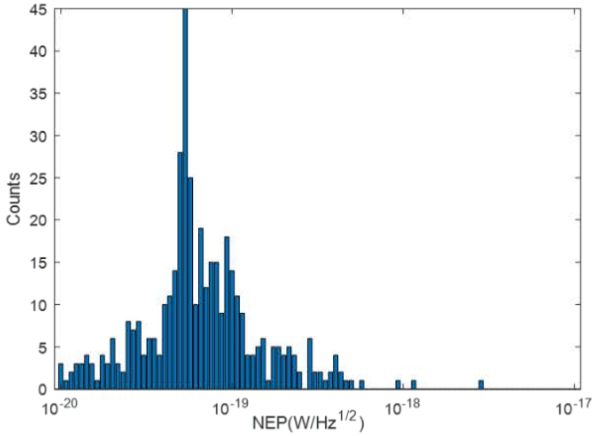


- No lens array, but can get up to 10^{-18} W of optical power
- Each point corresponds to a measurement 0.5s long (measurement bandwidth 1Hz)
- Power is stepped
- NEP is the power step divided by the signal to noise ratio

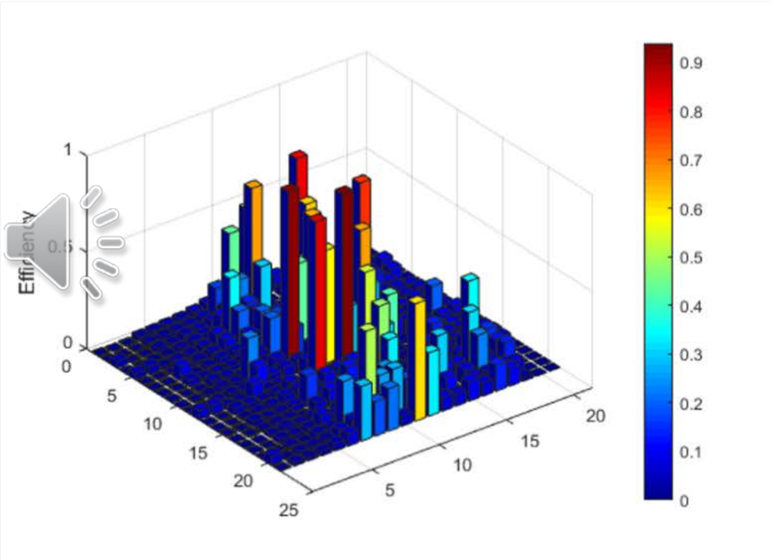
Transmission through QCD feedline, (b) example of a Noise Equivalent Power measurement

21x21 array of low frequency readout QCDs

a)

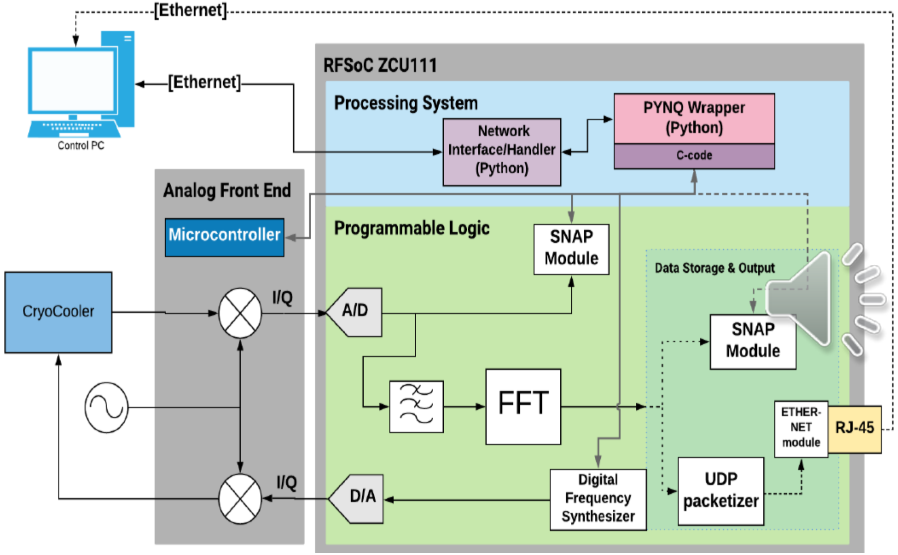


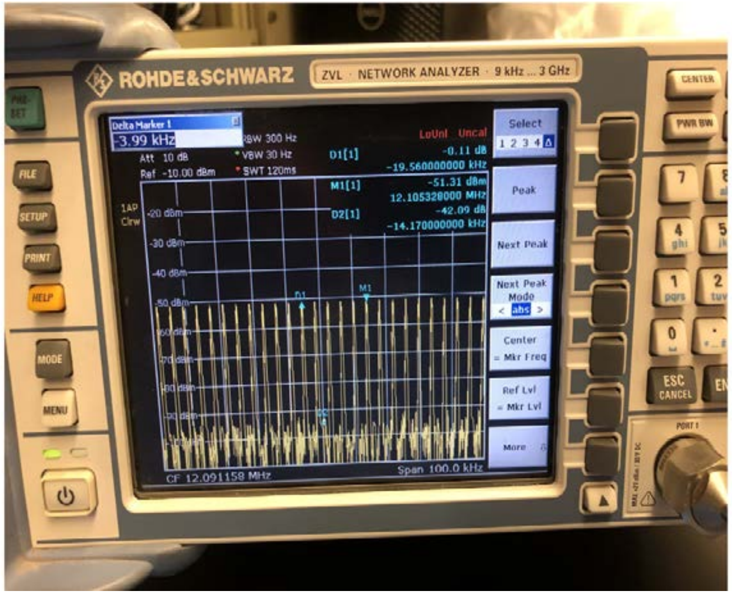
b)



Histogram of measured NEPs, (b) Map of efficiencies calculated by comparing the measured NEPs with photon shot noise NEP.

Multiplexed readout under development





Overview of what the end result firmware system should contain. Right: Zoom in of the DAC output from a 1000-tone frequency comb over 3 MHz. showing a 3 kHz tone spacing, generated using a single channel 12bi LUT.

Next steps

- Fabricate new 21x21 arrays – both low frequency and high frequency readout
- Characterize integrated array-lens array system using analog channel by channel approach
- Characterize both arrays using the ZCU111 set up
- Design, fabricate and characterize antenna coupled devices with the aim of increasing the dynamic range

Publications and References

P.M. Echternach, B.J. Pepper, T. Reck, and C. M. Bradford, "Single Photon Detection of 1.5THz radiation with the Quantum Capacitance Detector", Nature Astronomy 2(1), 90-97, (2018). [https://doi.org/10.1038/s41550-017-0294-y]

P.M. Echternach, A.D. Beyer, and C.M. Bradford, “Large Array of Low Frequency Readout Quantum Capacitance Detectors” to be published in Journal of Astronomical Telescopes, Instruments, and Systems.