National Aeronautics and Space Administration

Quanta Image Sensor

Principal Investigator: Shouleh Nikzad (389)
Eric Fossum (Thayer School of Engineering, Dartmouth)

Program: Innovative Spontaneous Concept

Project Objective:

Quanta Image Sensor is a novel photon counting image sensor that unlike other solid-state based photon counting detectors, does not rely on avalanche gain for its high signal to noise capability. QIS has zero dead time, low dark count, low power, low operating voltage. Because it is fabricated in the latest 3D CMOS image sensor fabrication lines, it is easily extendable to large format required for future large FPAs. These capabilities potentially overcome the shortcomings of other single photon counting detectors that are state of the art for NASA missions. To examine the extent that this device potential can be realized, we plan to further characterize and understand the noise behavior of QIS by low temperature characterization (-70° C) of existing devices in Prof Fossum's laboratory. In particular, we are trying to dissect out sources and mechanisms for noise.

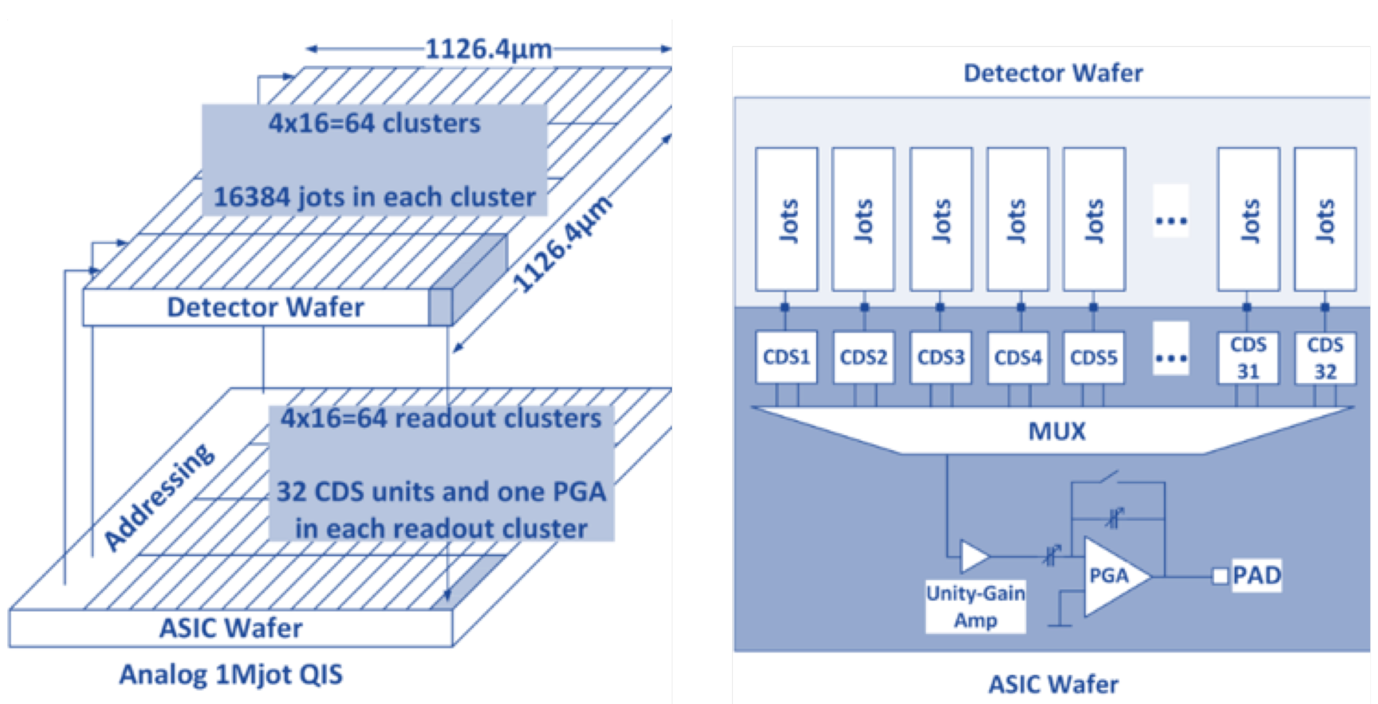
The objective for the scope of this ISC was to achieve a better understanding of the Quanta Image Sensor's (QIS) performance at lower temperatures in order to determine its viability for future JPL missions.

FY19 Results:

Temperature-related measurements of read noise, conversion gain, and dark current were performed via the photon-counting histogram (PCH) method on the 1Mjot stacked QIS chip, a buried-channel source follower with 0.14 μm channel width, using tapered pump-gate (TPG) jots. Amount of electrons collected by the pixel follows a Poisson distribution. The x-axis of the PCH shows the equivalent electron count, and the y-axis is the probability distribution.

Source-follower gain is proportional to its transconductance, which increases with higher electron mobility. The floating diffusion capacitance's partial dependence on the source-follower gate capacitance partly accounts for its temperature dependence. Direct relationship between average read noise (from 1,280 pixels over 20,000 frames) and temperature was demonstrated. The reduction of read noise demonstrated here appears to occur primarily as a result of the 1/f noise component decreasing. 1/f noise is historically attributed to a combination of carrier number fluctuation (e.g. due to trapping and release of carriers in the vicinity of the MOSFET channel) and carrier mobility fluctuation which is related to scattering centers and their variation. As temperature decreases, so too does the scattering of carriers near the Si-SiO2 interface – which is attributed as the main cause of 1/f noise in CMOS QIS. The lowest average read noise reported in these measurements occurs at -50° C and is 0.235 e- rms. The data points at -60° C and -70° C appear to be higher than that at -50° C, likely due to small instabilities of the test. Integration times at these low temperatures are very long and hence may have more measurement system variation than shorter tests.

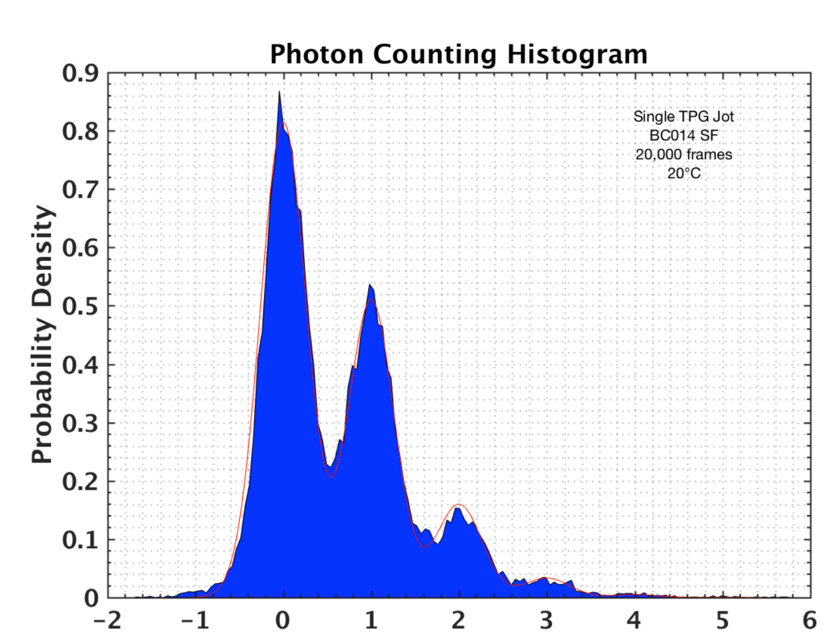
The dark current decreases exponentially with decreasing temperature from 60° C down to ~0.07e-/sec at 25° C. The data was scaled based on 25° C and 60° C data due to bias currents not having been adjusted for each higher temperature and the data should be revisited, although agrees with Gigajot. An additional measurement taken at -70° C yields a dark current of 0.001e-/sec, The activation energy for the measured trend in is roughly 0.6 eV. This value is indicative of midgap traps being the primary cause of dark current in the chip. In the QIS's pump-gate jots, thermally generated carriers from the surface (midgap traps) are directed to the floating diffusion (FD) instead of the storage well and removed prior to readout. This leads one to expect bulk (full bandgap) generation in the vicinity of the storage well. Nevertheless, it is possible there are some carriers that are not being 'pumped' to the floating diffusion and are causing the dark current we're seeing in these measurements.



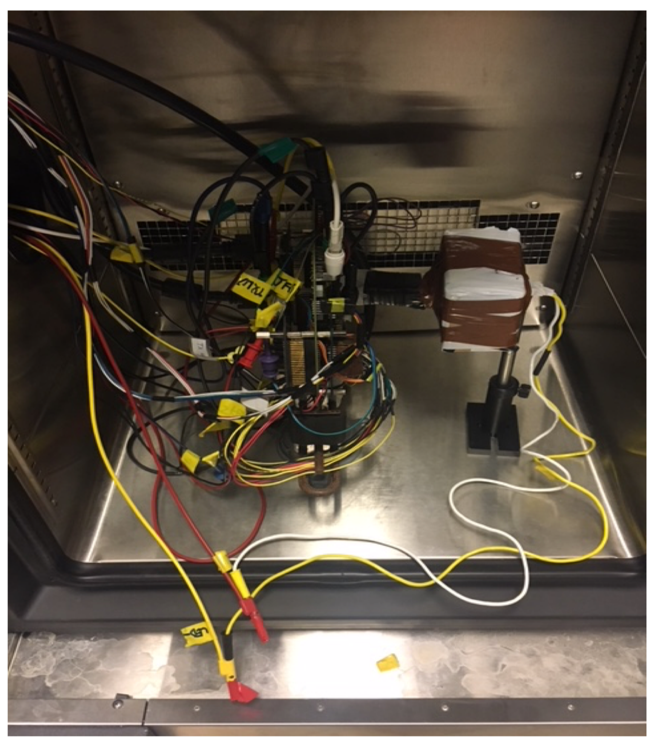
Simplified readout schematic of the QIS chip tested

Benefits to NASA and JPL (or significance of results):

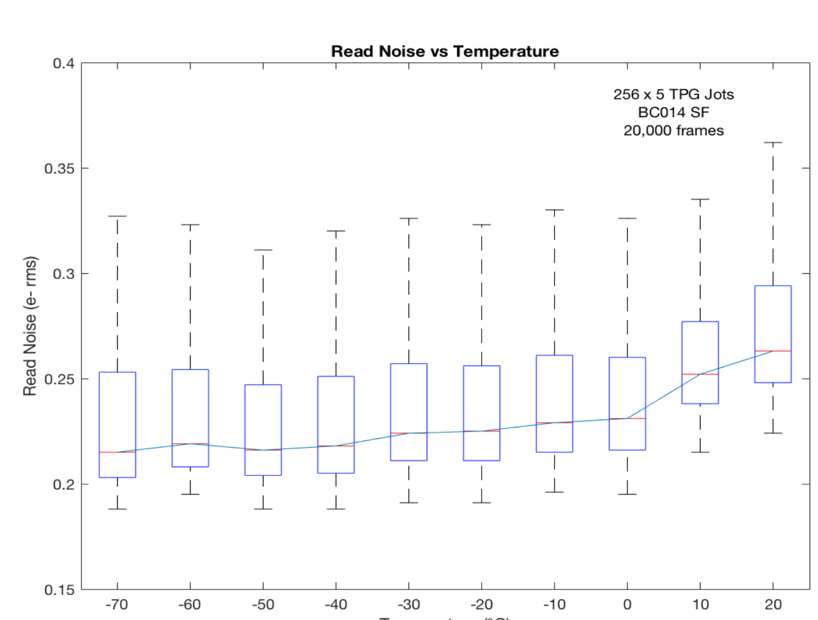
The research results from this study indicate no surprise obstacles to QIS's promising viability in future NASA missions due to its low-noise and high conversion gain characteristics, particularly for low-temperature applications. The data suggest that the noise performance of QIS will continue improving at even lower temperatures. Visible (and possibly UV) sensors and cameras will be improved by reducing read noise and/or exposure time using this low-power high-resolution photon-number resolving detector. Other imaging systems may also be improved such as navigation, optical communications, etc.



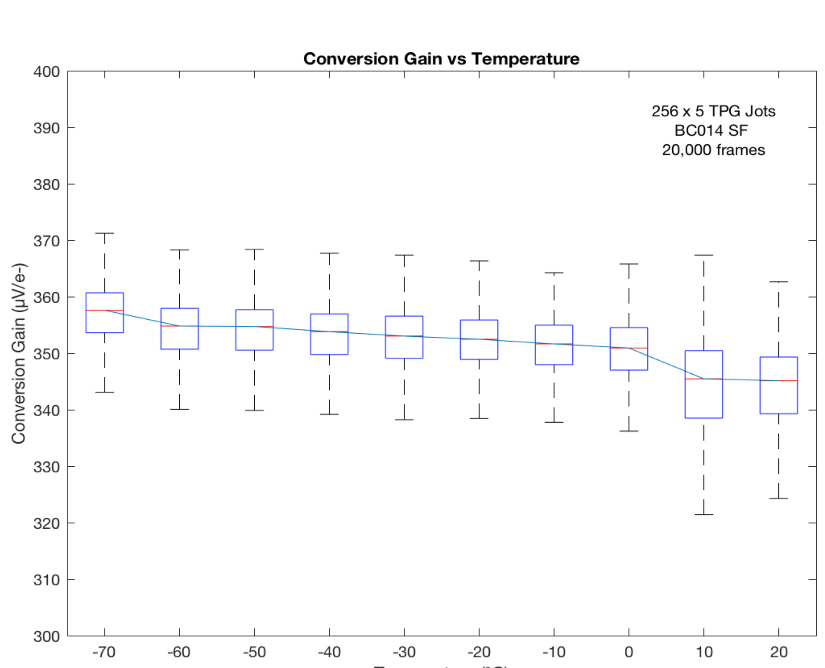
Example of a photon-counting histogram taken using experimental data.



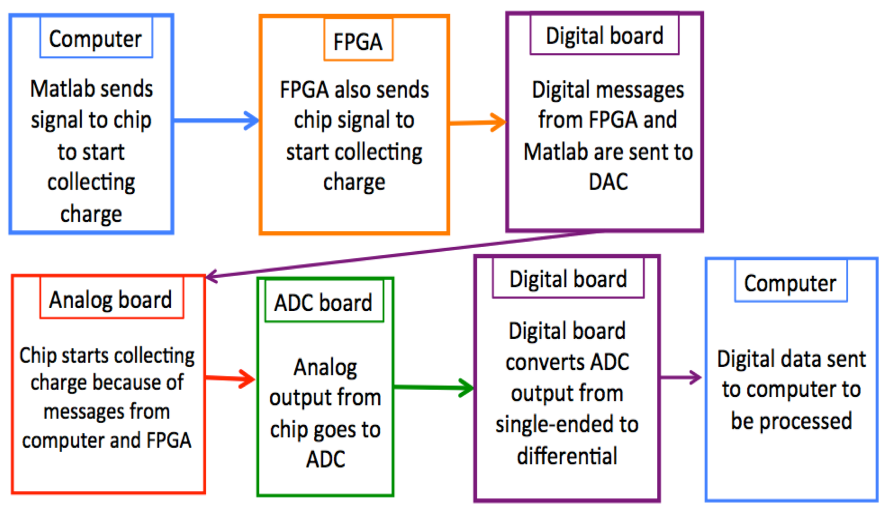
Side view of analog and digital board with light source in temperature chamber.



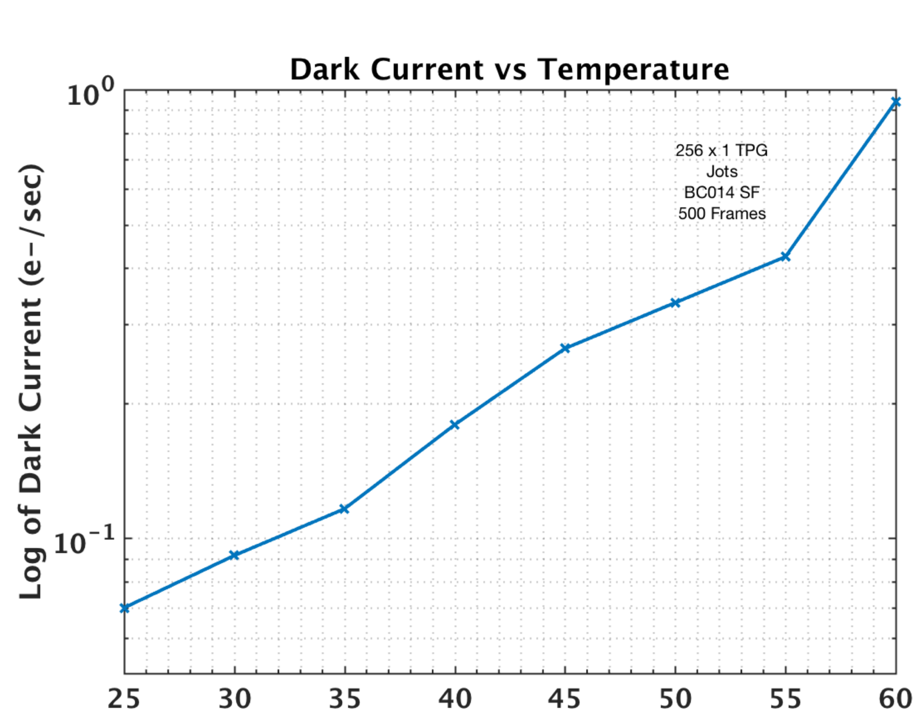
Average read noise vs. temperature



Average conversion gain vs. temperature.



A simple block diagram of the test setup



Average dark current vs. temperature.

Publications:

None.

PI/Task Mgr. Contact Information:

Shouleh Nikzad (818) 354-7496

Shouleh.Nikzad@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov