# Radiation hardness by design for mixed signal infrared readout circuit applications

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# Mixed Signal RHBD Presentation Overview

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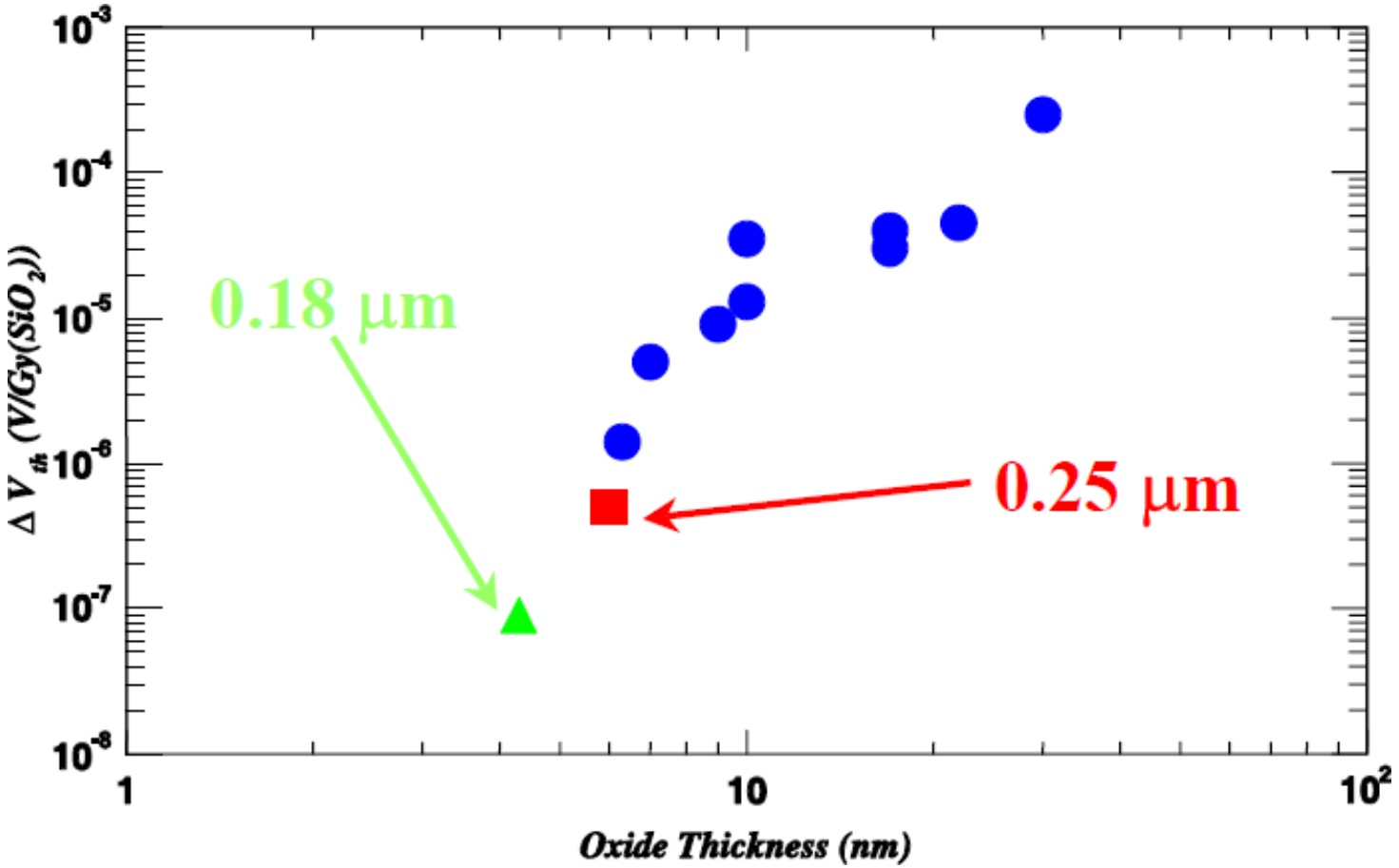
- Radiation tolerant ROICs to support space-based infrared detection applications
- Radiation Hardening by Design (RHBD) methodology
- Appl. #1: Thermopile ROIC for mission to Europa
- Appl. #2: LWIR PV  ROIC for spaced based sensing
- ROIC RHBD Capability and Conclusions

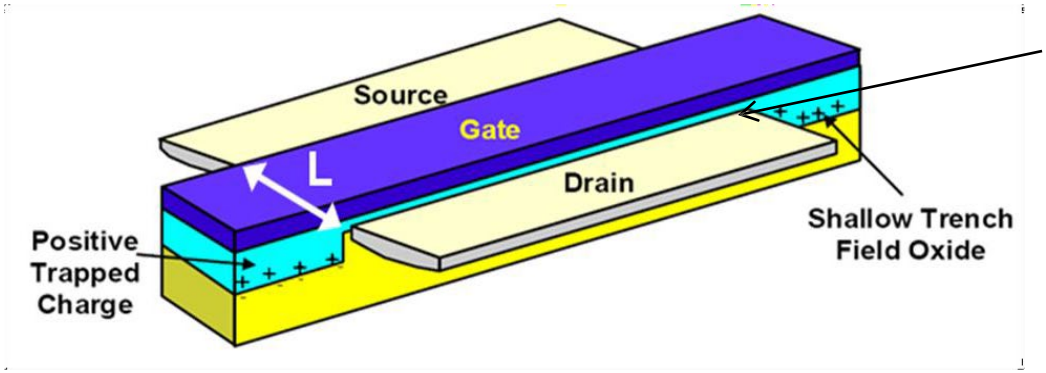
# FET $\Delta V_{th}$/TID versus gate oxide thickness -huge advantage for gate oxide thickness reduction-



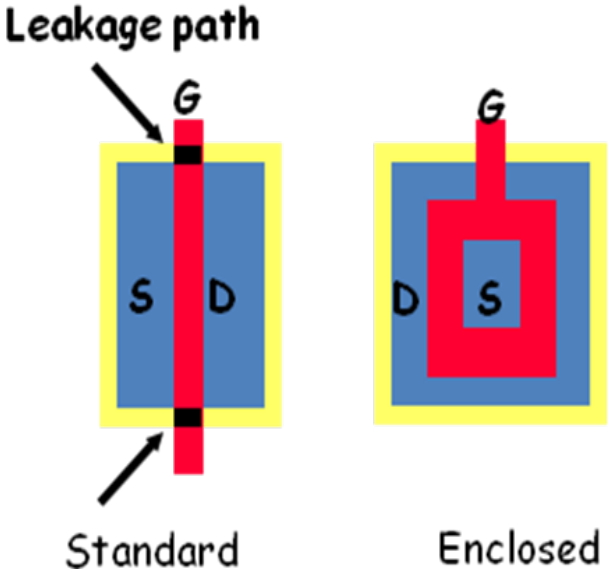

IEEE Trans. on Nuclear Science, Vol. 52, pp. 861-867 (2005).

# NFETS still not radiation tolerant
# -Enclosed NFETS provide large TID immunity-






NFET parasitic channel at STI
-increased leakage current
-increased 1/f noise-




Top view layout comparison
standard and enclosed (annular gate) FETs

# ROIC RHBD Methodology

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1. Thin gate oxide (<4.5 nm) FETs for both analog and digital circuitry to reduce TID related threshold voltage shift

2. Annular/enclosed gate NFETS to reduce TID dose related off current, maintain low 1/f noise, and provide long term reliability

3. Circuit biasing and design to compensate for total ionizing dose

4. Guard rings and low resistance well contacts to prevent latch up

5. Optimized ROIC circuitry to provide high S/N and operability in a high radiation environment (total dose and dose rate)

# BFE Thermopile ROICs support prior NASA Missions (NASA/JPL Thermopile linear IR array and BFE CMOS readout)

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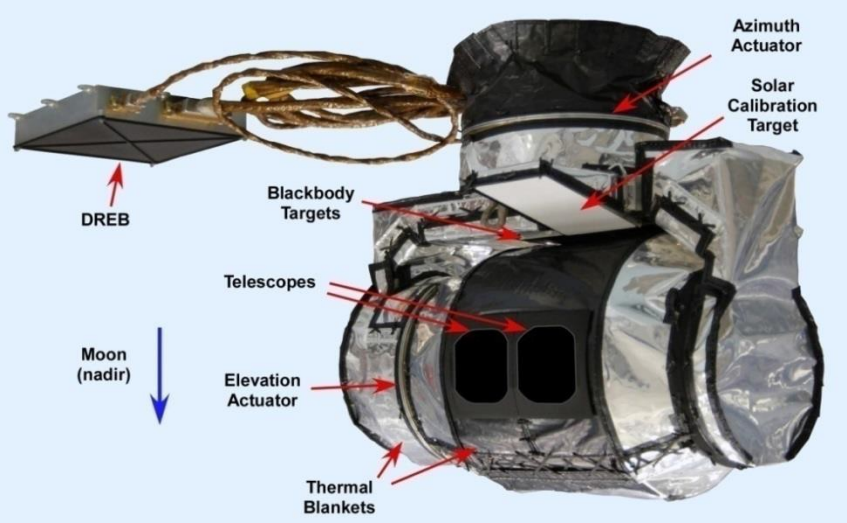
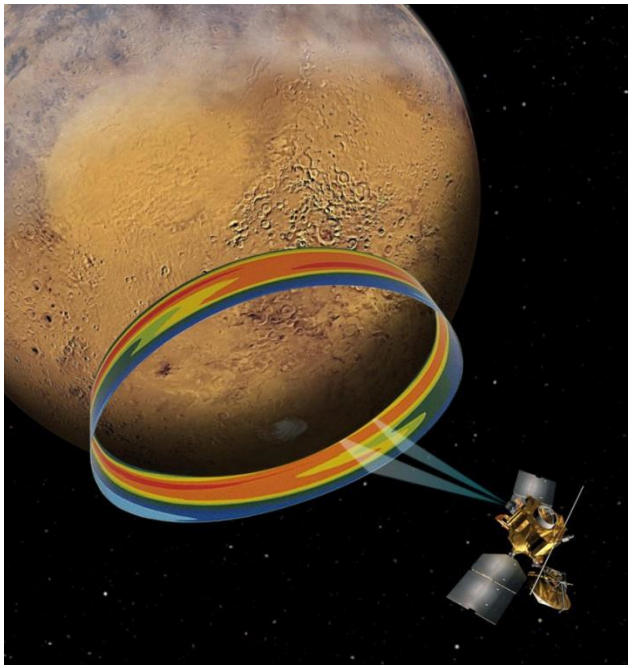



Diviner Lunar Radiometer Experiment
(Launched 18 June 2009)



Mars Climate Sounder is one instrument on the Mars Reconnaissance Orbiter Spacecraft, launched August 12, 2005,

# Future missions may need "rad-hard" ROIC - Example prior JEO mission concept-

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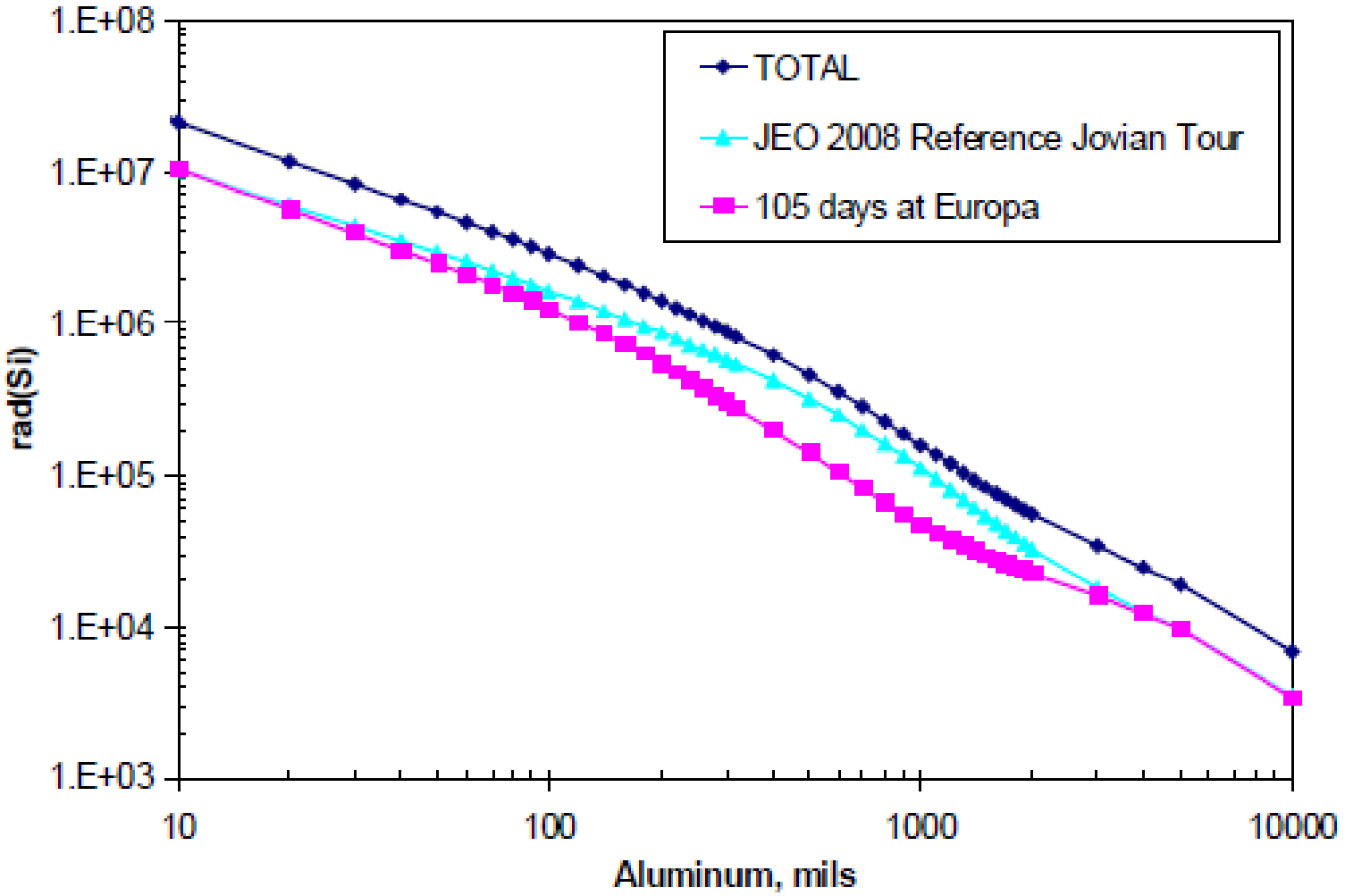


JEO 2008 conceptual mission study JPL D-48256

Note: Recent Europa Clipper mission concept has reduced TID requirements

# BFE333 RHBD ROIC for Thermopile Linear Arrays

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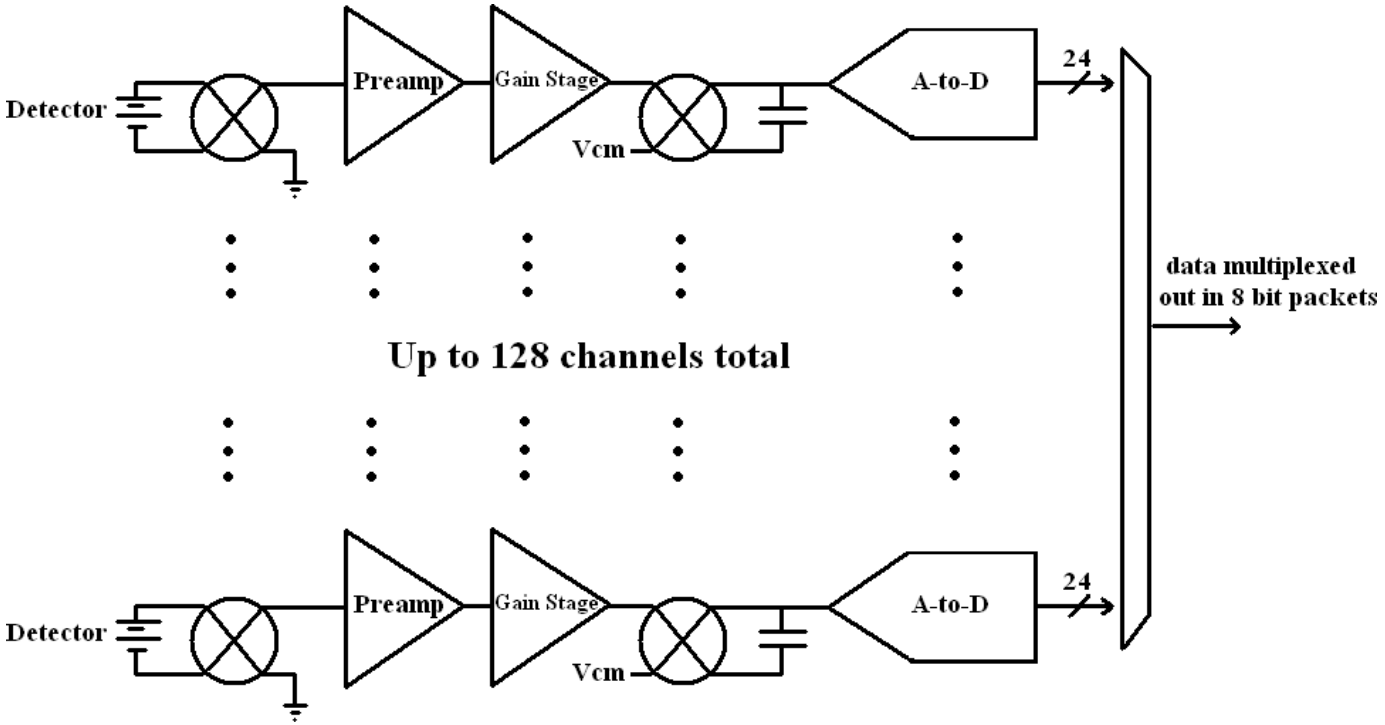


- 110 µm channel pitch, < 1 mW/channel
- Requires 2 bond pads per thermopile (improved S/N, polarity switching)
- On-ROIC ADC: 18-bits, LVDS output, system noise immunity
- Compatible with thermopiles of 10-150kΩ resistance
- RHBD: 4.5 nm Tox gates, enclosed NFETs, GR's,
- TID capability > 2 MRad

# BFE333 ROIC digital output
# -sine wave electrical input-

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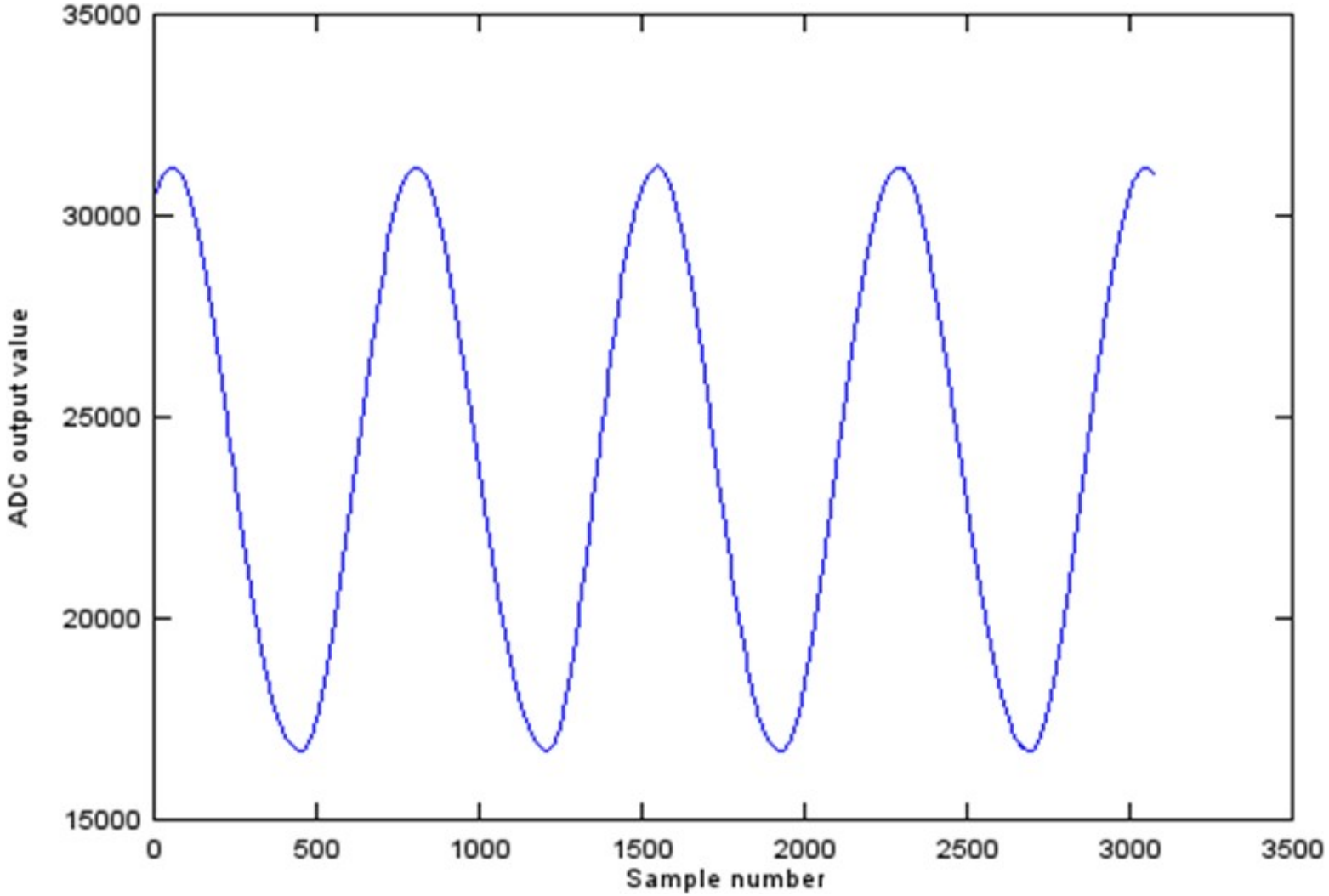

# BFE333 Raw output during radiation test

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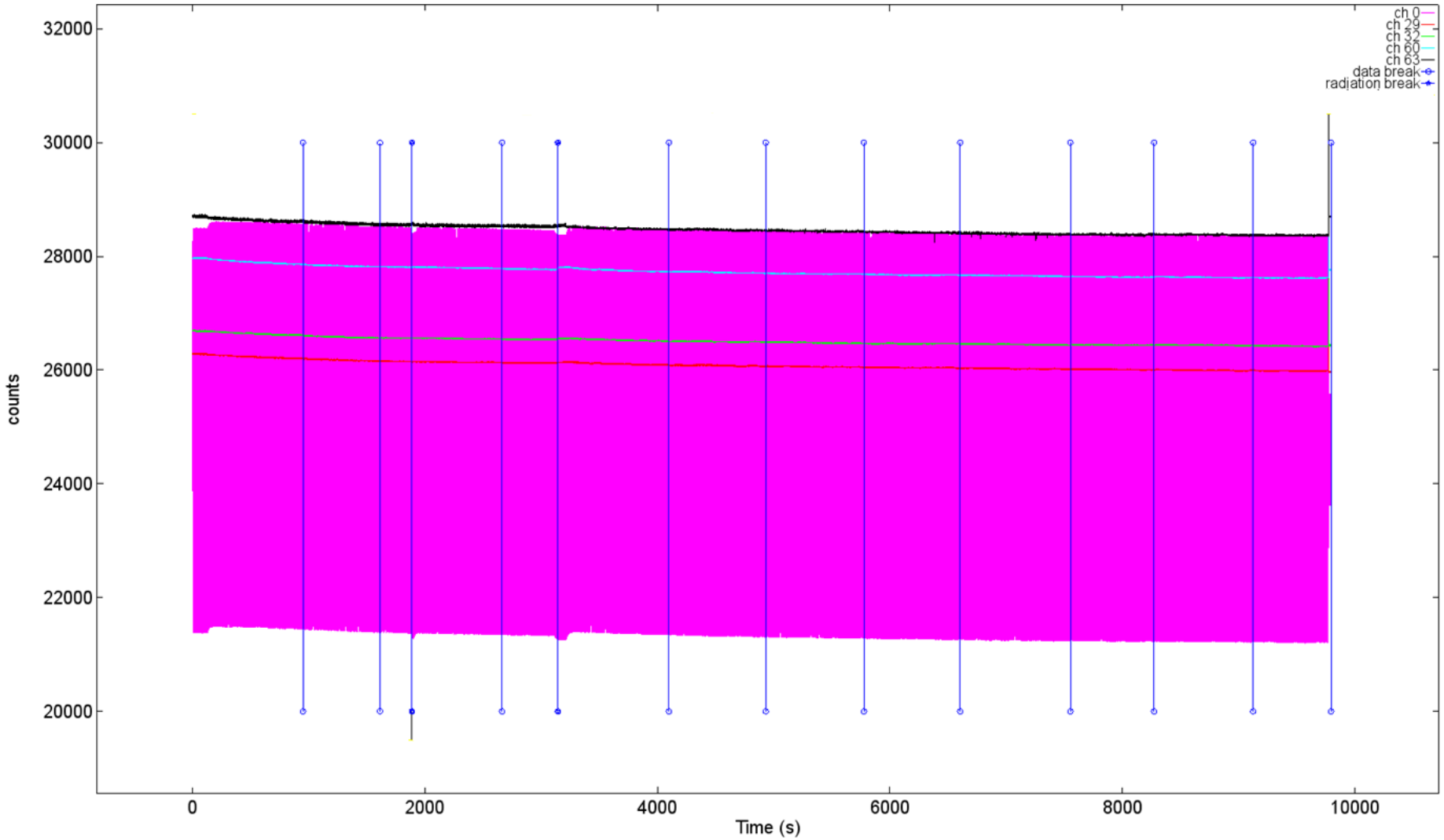

# Measured dc supply currents (VddP, VddA and VddD) versus TID in kRad

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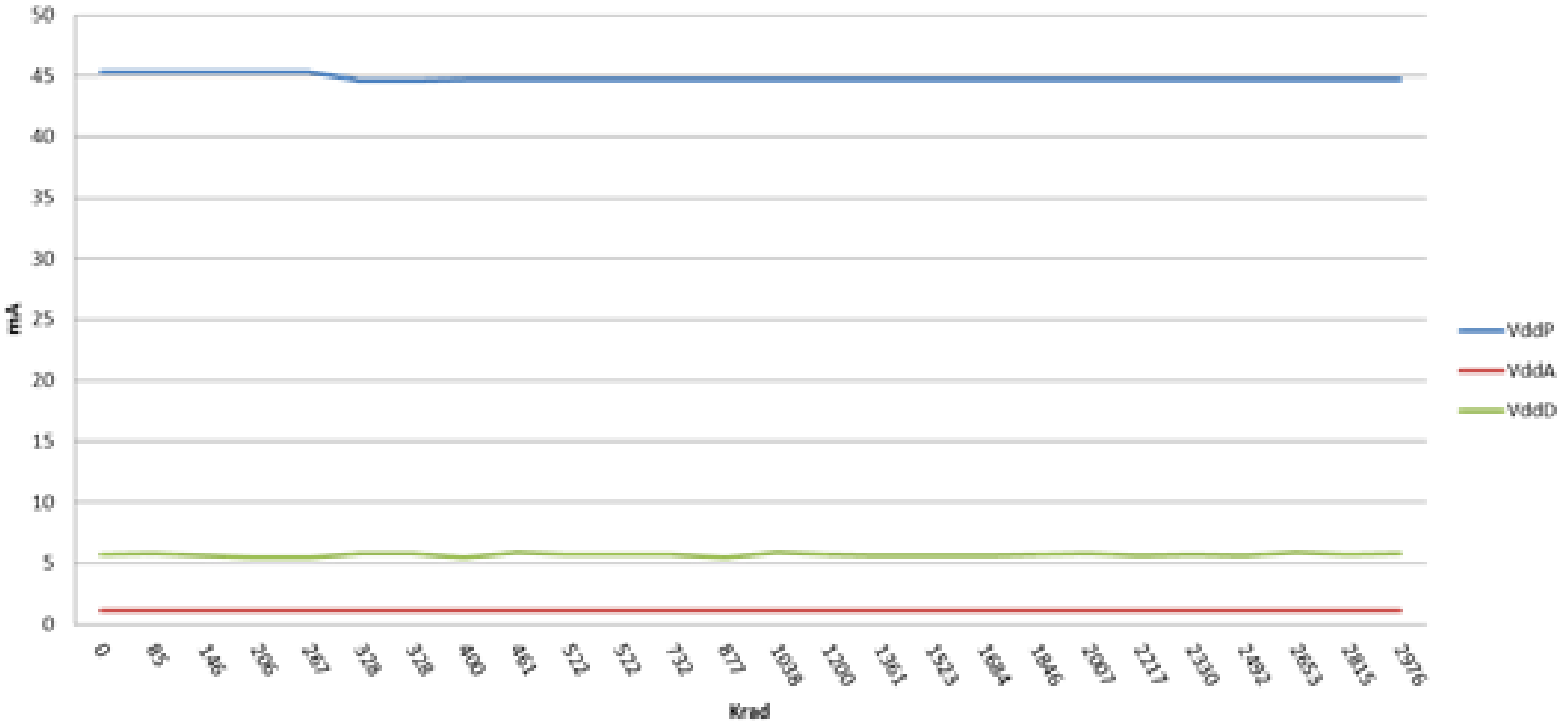
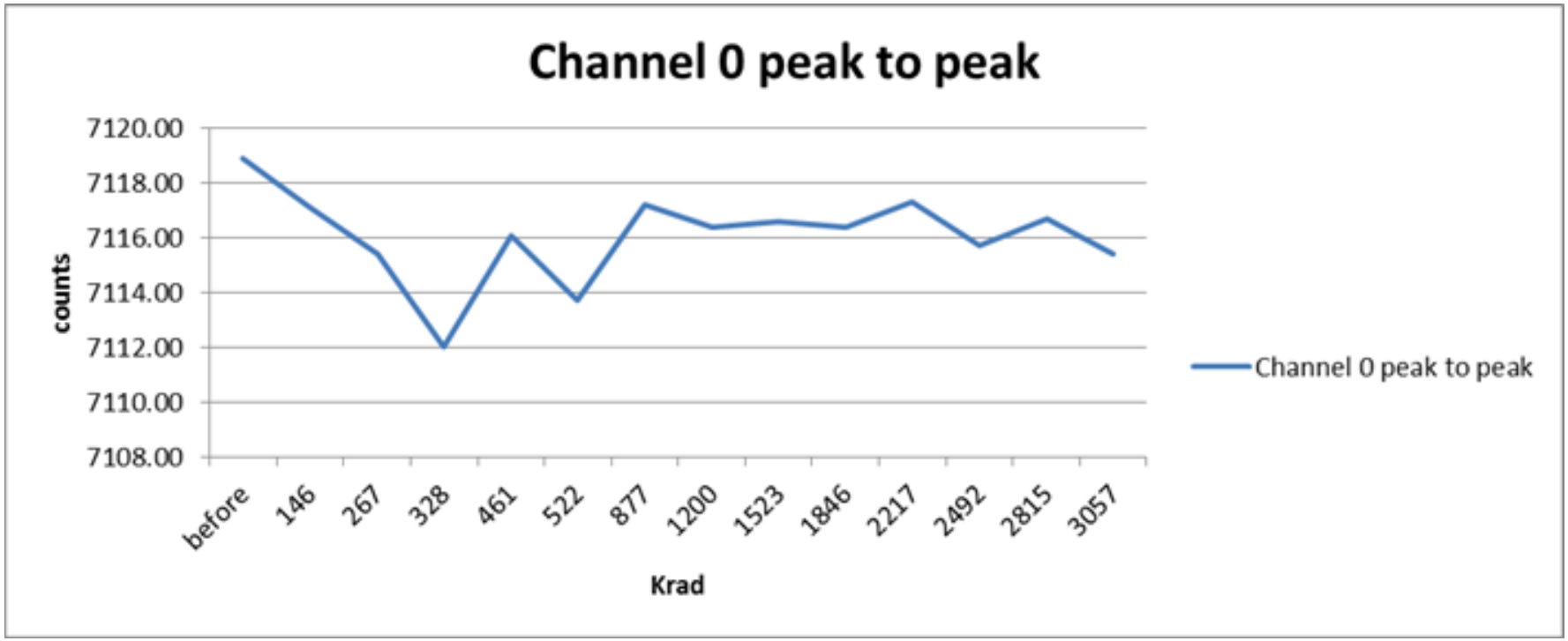


# Channel 0 signal amplitude ADC counts (1 mV peak to peak sine wave across 10 kΩ resistor)



# RHBD ROIC for space-based LWIR area arrays

1. ROIC format: 260 x 256 array on a 40 µm pixel pitch
2. 40-77 K operation temperature
3. >300 kRad TID capable
4. Per pixel detector bias optimization
5. CTIA pixel amp, snap-shot, integrate while read, anti-bloom
6. On-ROIC in-pixel CDS
7. Digital output or multiple analog outputs available
8. 180 nm CMOS process

# BFE315 Simplified block diagram illustrating the overall architecture

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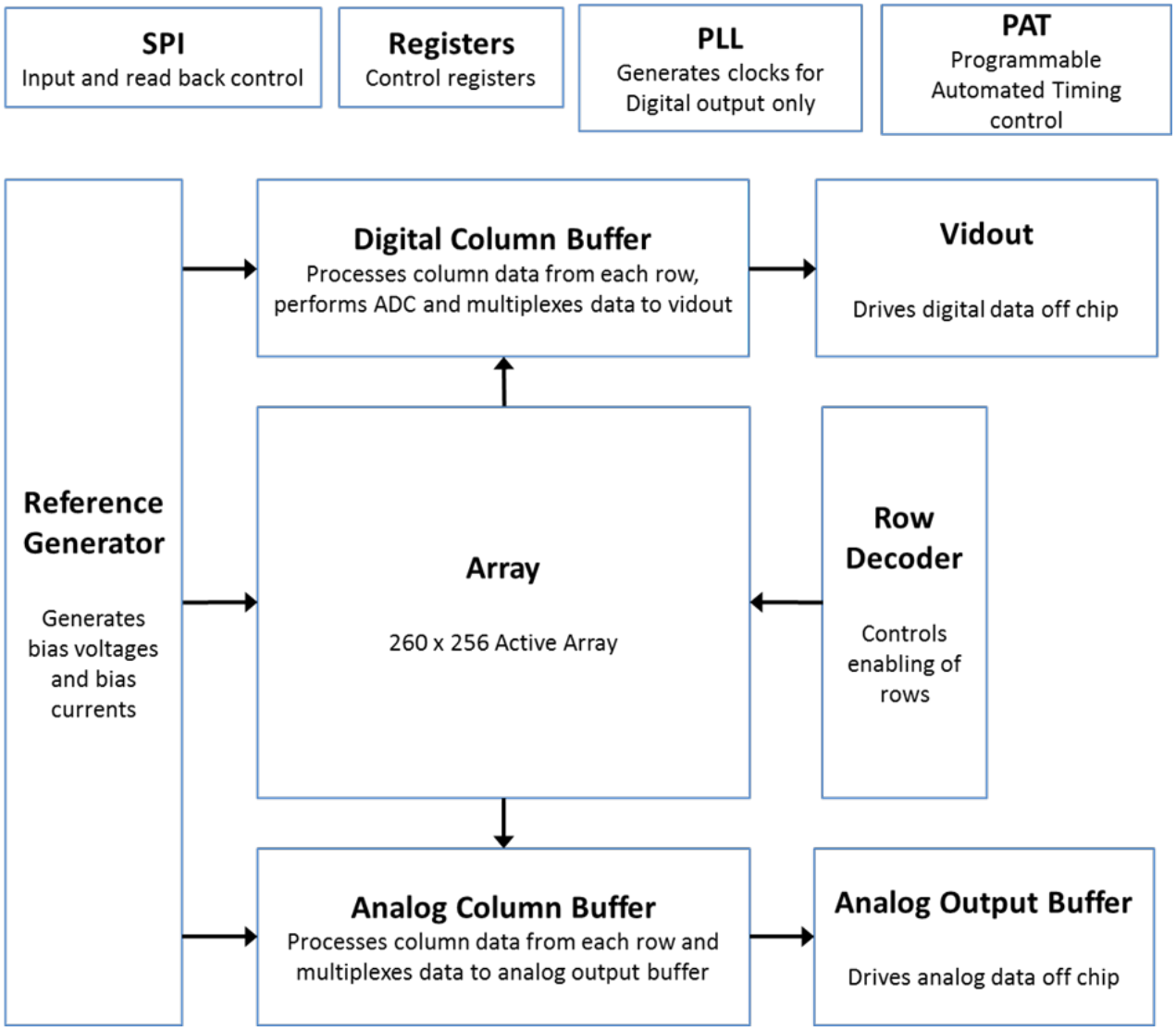

# Dewar without lid (left), Dewar and harness just before placement in (Cobalt 60) chamber

# Simplified pixel schematic and test signal

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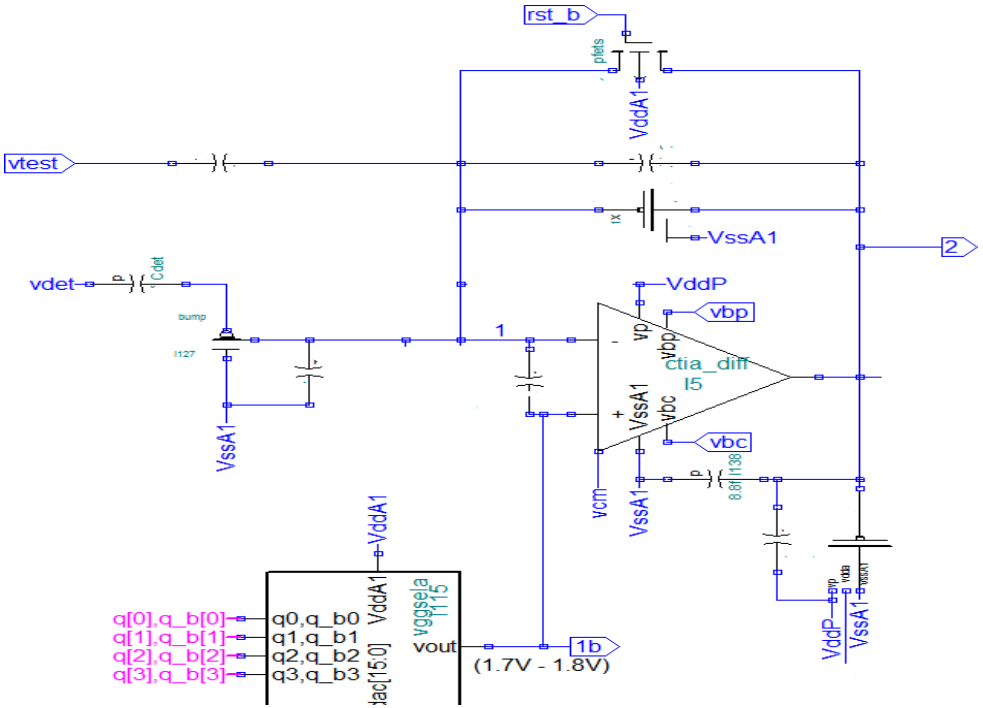
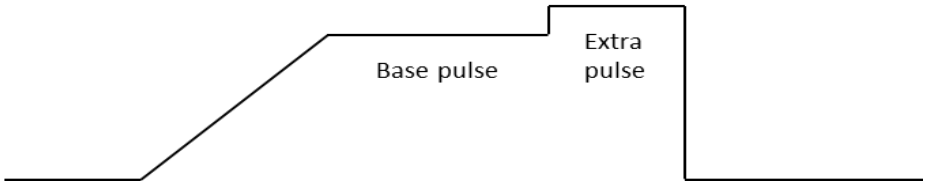



4 frames without extra pulse

4 frames with extra pulse



# BFE315 ROIC TID testing 77 K
# Slight increase in supply current with TID

## ROIC supply currents vs. temperature

| Supply | 300K mA | 76K mA | 40K mA |
|---|---|---|---|
| VddP | 14.5 | 11.4 | 12.0 |
| Vref | 0.9 | 0.9 | 0.6 |
| VddA | 7.2 | 8.9 | 7.9 |
| VddO | 1.7 | 1.9 | 2.2 |
| VddD | 73.6 | 70.8 | 71.0 |

## Supply currents during ROIC TID test @ 77K

| Test number | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Dose (kRad) | 0 | 10 | 20 | 50 | 100 | 200 | 300 | 400 |
| VddP (mA) | 12.1 | 12.1 | 12.0 | 12.1 | 11.8 | 12.3 | 12.0 | 12.1 |
| Vref (mA) | 0.9 | 0.9 | 0.7 | 0.8 | 0.7 | 0.8 | 0.9 | 0.8 |
| VddA (mA) | 7.4 | 7.9 | 7.3 | 8.9 | 8.4 | 6.3 | 8.4 | 8.2 |
| VddO (mA) | 2.1 | 2.4 | 2.1 | 2.2 | 2.3 | 2.4 | 2.4 | 2.3 |
| VddD (mA) | 66 | 66.8 | 67.0 | 70.1 | 66.9 | 68.3 | 70.0 | 82.7 |

# Conclusions and Acknowledgement

1. BFE RHBD approach using 180 nm CMOS achieved ~> 3 Mrad TID for thermopile ROIC and > 400 kRad TID for cryocooled PV ROIC.

2. Use of 130/90 nm CMOS is anticipated to further improve TID tolerance for mixed-signal applications

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