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A LINEAR MODE PHOTON-COUNTING (LMPC) DETECTOR ARRAY IN A CUBESAT TO ENABLE EARTH SCIENCE LIDAR MEASUREMENTS

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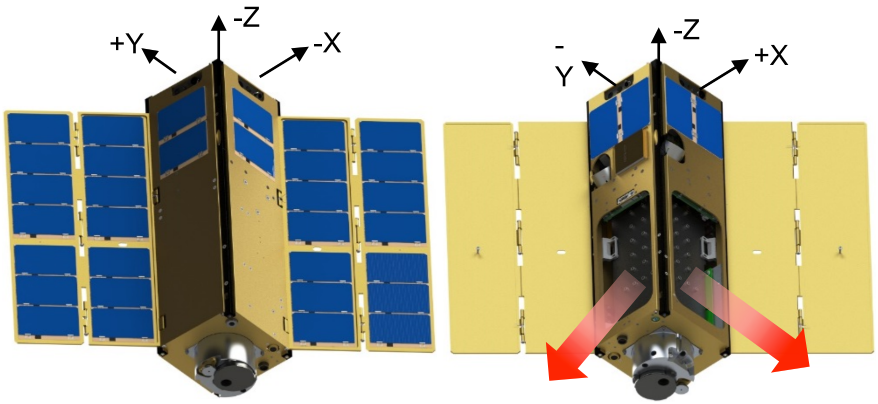
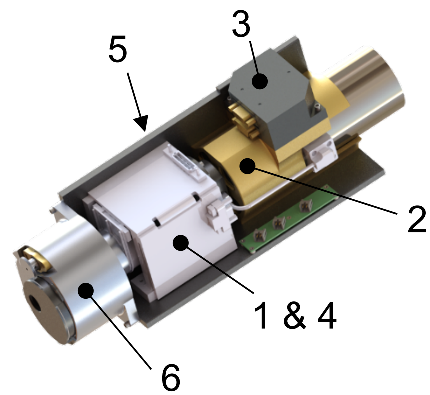
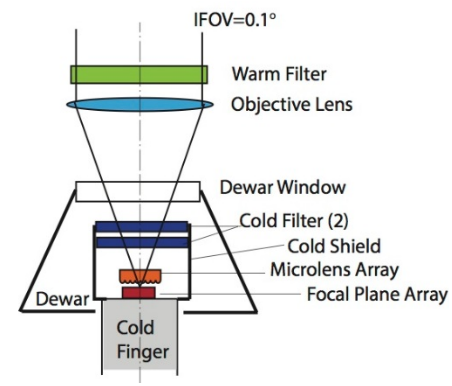
LMPC CubeSat – Aerospace AeroCube-9 (AC-9)

AC9
LMPC







BUS

- HgCdTe responds from 0.4 to 4 microns to single photons (1000 electrons per photon)
- AC9 will use narrowband filters to pass 1.06, 1.55 and 2.06 microns for daylight operation
- Launch Nov 2016 (delivery Aug 2016)

Optical Path

1. Dewar
2. Stirling cycle cooler
3. IDCA controller
4. FPA conditioning circuits
5. Radiator structure
6. Warm filter and objective lens

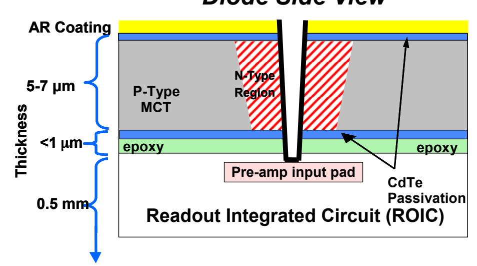
Optical Path

- Filter wheel with 5 settings
- 3 Bandpass filters
- 1 blank (opaque)
- 1 open

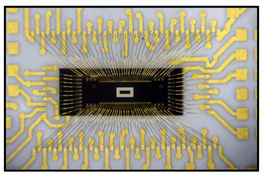
HgCdTe electron initiated avalanche photodiode (e-APD) array

- Developed by DRS Technologies in Dallas TX
- 2x8 pixels with built in read-out integrated circuit (ROIC), 20 μm diameter active area, 64 μm pitch, with μ-lens array F/7 optical path, 7 mm diameter entrance aperture
- 90% quantum efficiency
- >1000 APD gain, more than sufficient to override ROIC noise
- Linear mode photon counting (LMPC) detectors from visible to mid-wave infrared (VIS/MWIR) wavelength range.

Diode Side View



Top View



Why Fly a Linear Mode Photon Counting Detector?

	Tier 1						Tier 2					Tier 3			
Decadel Survey Missions	ICESat-II	CLARREO	SMAP	DESDynI	HyspIRI	ASCENDS	SWOT	GEO=CAPE	ACE	LIST	PATH	GRACE=II	SCLP	GACM	3D=Winds
LMPC Impact	☒ ☒	☒	0	☒ ☒	☒	☒ ☒	0	☒	☒ ☒	☒ ☒	0	0	0	☒	☒

At least three Tier 1 missions are strongly driven in science capability by photon detection sensitivity

- LIST which is strongly related to ICESat & DESDynI will not reach threshold goals without single photon response matched to high power efficient transmitters that respond to 1 micron
- While threshold science can be achieved with photomultipliers for CO2 at 1.5 and 2 microns, single photon response will significantly extend the science
- The potential for high sensitivity passive arrays across the 0.4-4 micron HgCdTe response shows potential for many other missions as this technology and its support elements mature

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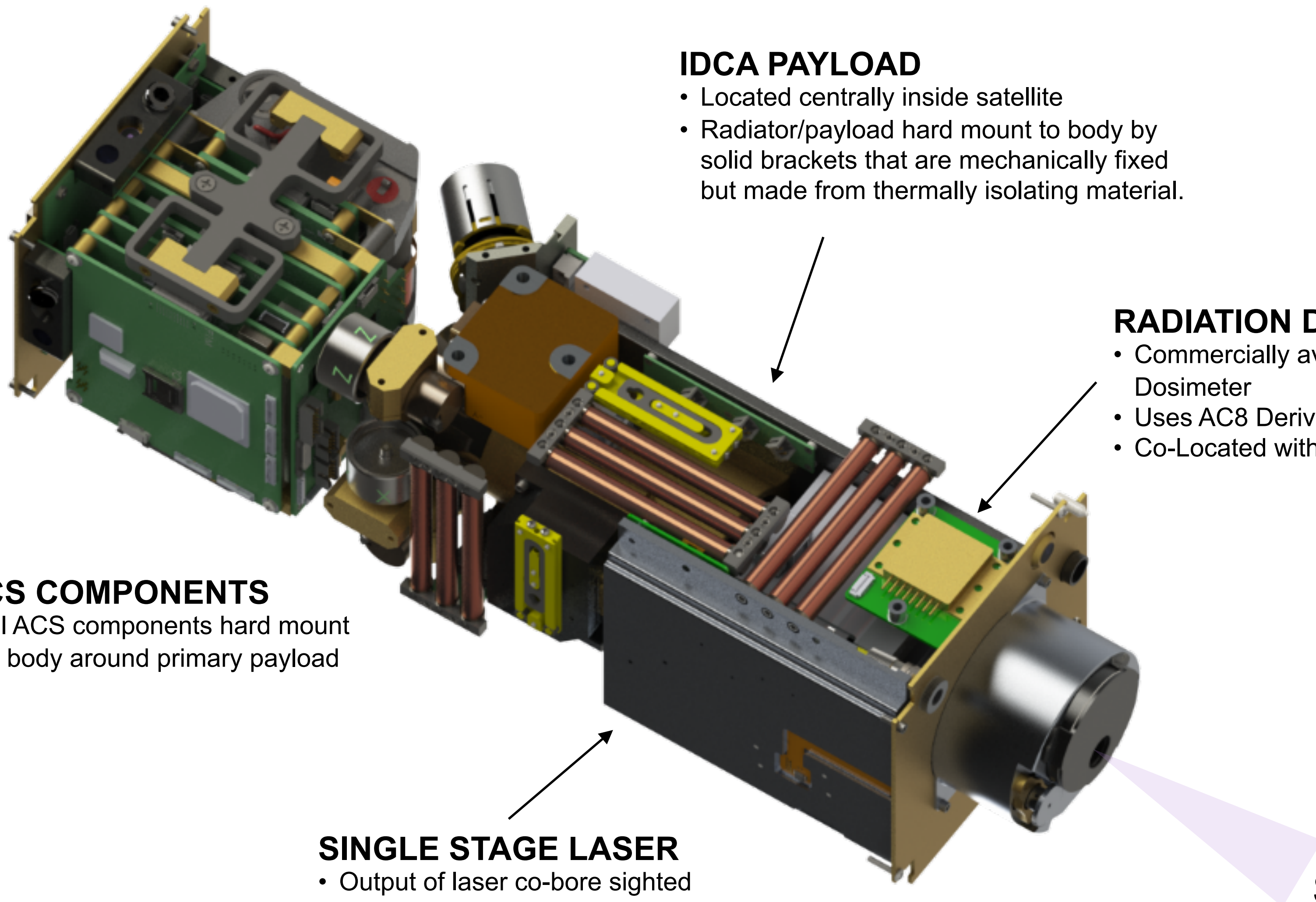
Packing Density View



IDCA PAYLOAD
- Located centrally inside satellite
- Radiator/payload hard mount to body by solid brackets that are mechanically fixed but made from thermally isolating material.

RADIATION DETECTOR
- Commercially available Teledyne Dosimeter
- Uses AC8 Derived daughter PCB
- Co-Located with IDCA sensor

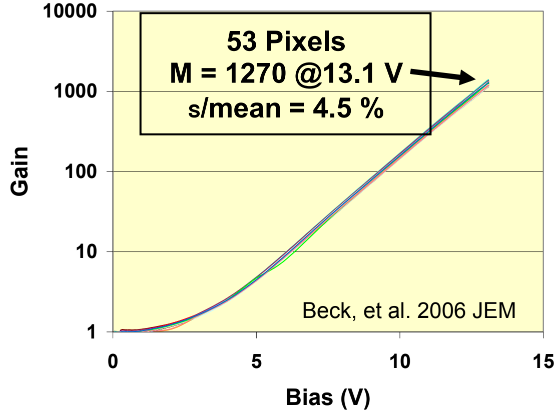
ACS COMPONENTS
- All ACS components hard mount to body around primary payload

SINGLE STAGE LASER
- Output of laser co-bore sighted with IDCA sensor

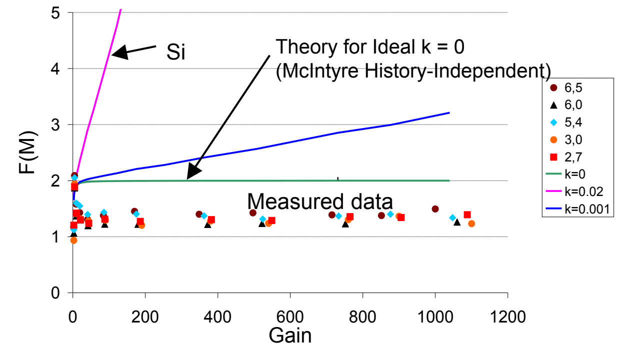
Enabling Technology: Linear Mode HgCdTe e-APD

- High, near noiseless, uniform, avalanche gain
- Gain normalized dark current as low as 100 e/s
- Broad spectral range: UV – MWIR
- High quantum efficiency
- High intrinsic bandwidth (~ 10 GHz)
- Large dynamic range
- Demonstrated photon counting sensitivity
- Continuous operation with no dead time or after-pulsing
  - *Minimum time between events MBE < ~ 10 ns (limited by current ROIC bandwidth)*

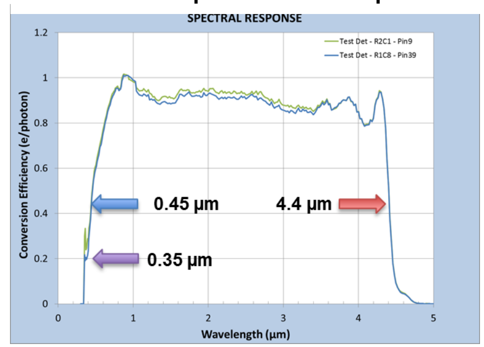
APD Gain vs. Bias



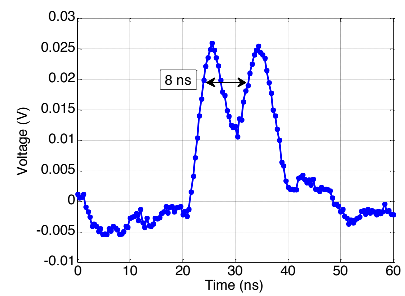
Excess Noise Factor vs. Gain



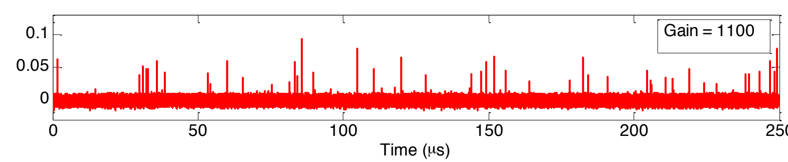
Broad Spectral Response



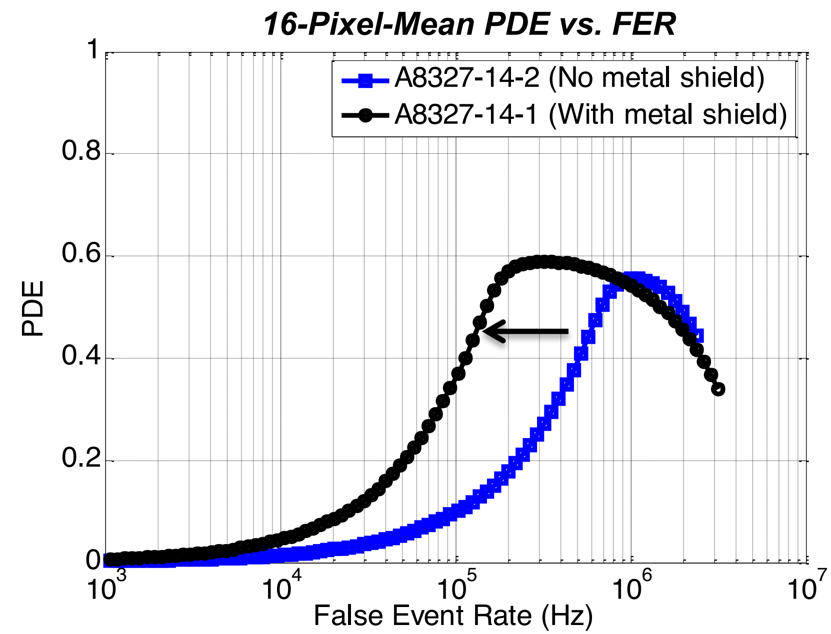
8 ns pulse separation (ROIC BW limited)

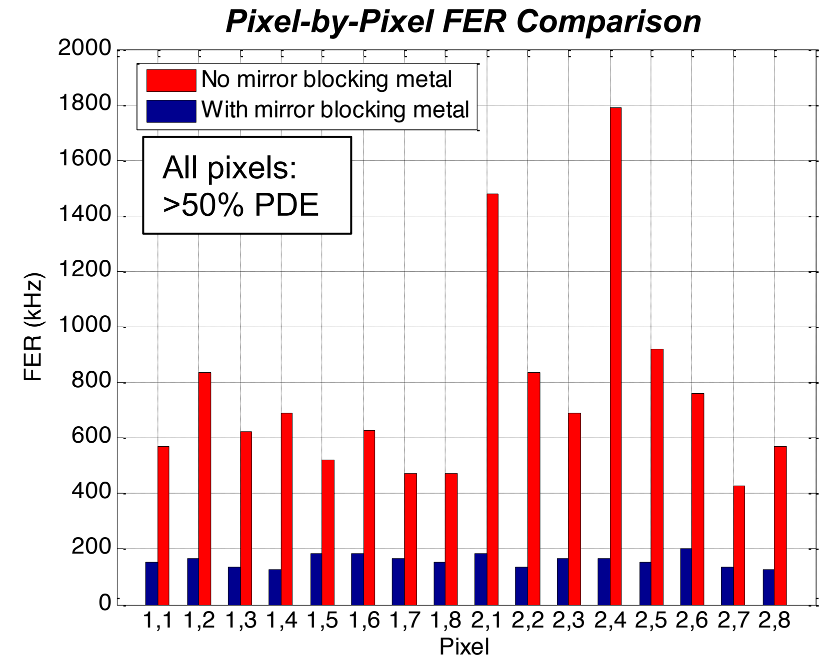


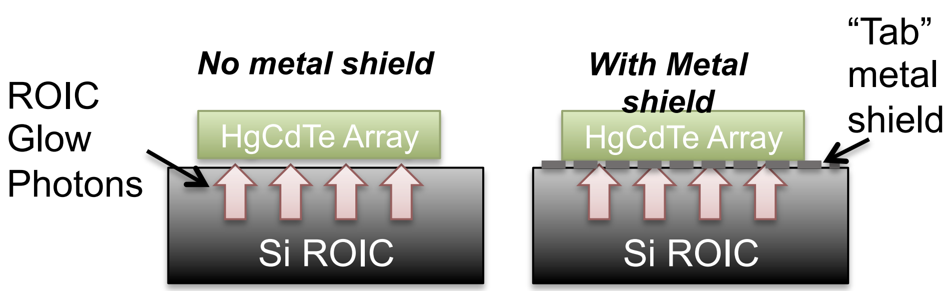
High SNR Single Photon Sensitivity



Blocking Noise from ROIC Glow







FER ≤ 200 kHz for every pixel with blocking metal layer, a 1/5 reduction. Multiple metal layers are expected to decrease FER to diode limit (< 20 kHz).

LMPC HgCdTe e-APD Performance Summary

Parameter	GSFC ACT Program Specification	Oct. 2014 Status	Notes
Size and form factor	2x8 pixel array, 20 µm dia, 64 µm pitch	Demonstrated	Form factor can be changed if funds available for a new ROIC
Photon Detection Efficiency 0.9 to 4.2 µm	> 40% (> 50% goal)	> 50% (> 65% demonstrated)	From optical input to the analog outputs
Dark count rate	< 500 kHz (<100 kHz goal)	< 200 kHz demonstrated	Including detector dark current, ROIC and system noise
Pulse pair separation	≤ 10 ns (< 6 ns goal)	9 ns demonstrated	Stray capacitance limiting bandwidth
Timing jitter	< 1.0 ns rms (< 0.5 ns rms goal)	~1.6 ns rms (< 1 ns rms in 2011 FPA)	Improvement with smaller pitch APDs pixel designs expected.
Excess Noise Factor	< 1.4	Demonstrated	1.2-1.25 Decreased diode junction width
Outputs	Analog and Digital (optional)	Demonstrated	Linear mode multi-photon resolution with analog outputs
Housing	LN2 Dewar (80K) with window, f/1.5 to f/4.9	Demonstrated	May be housed in an existing long lifetime space cryo-cooler
Simultaneity of Specifications	All specifications met at the same time	Demonstrated with exception of jitter	All spec's met, except jitter, at the same time on the same device at the same threshold.

Physical Dimensions of the Cooler and Cold Filter Performance

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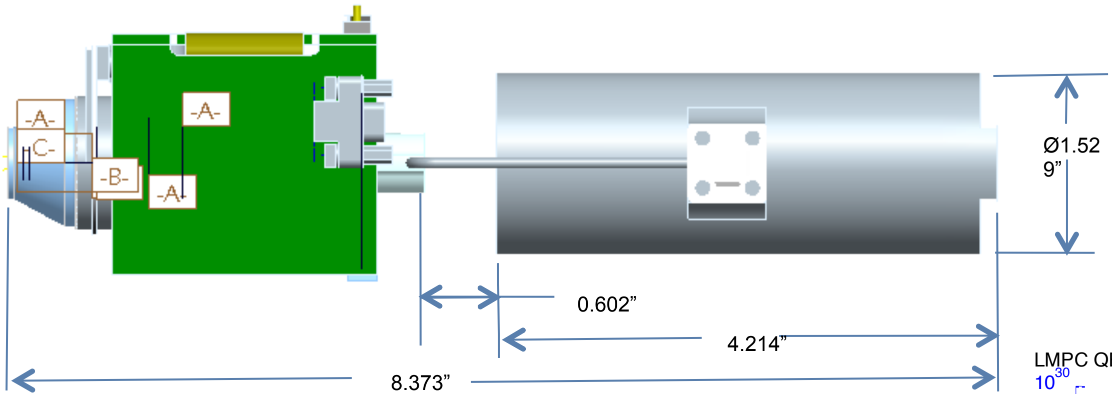
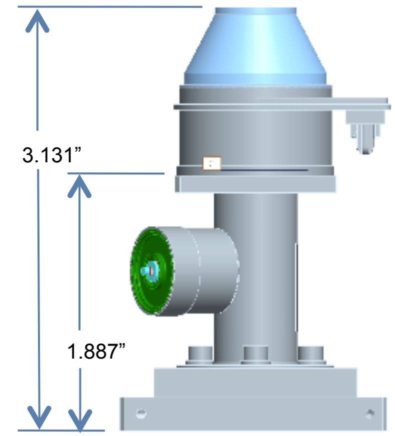
Basic Dimensions of the Integrated Detector Cooler Assembly



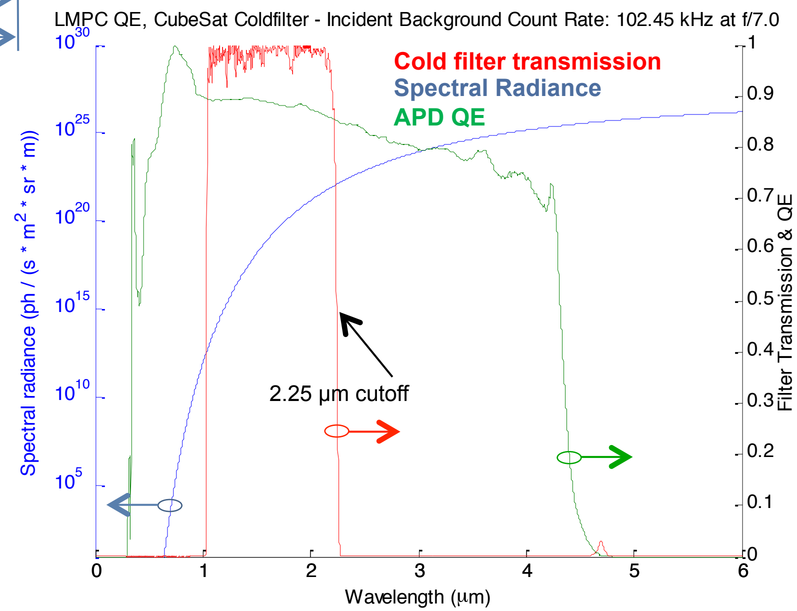


The background count rate was calculated using:

- Materion’s measured cold filter transmission
- QE from previous LMPC APD array

(analysis uses 300 K blackbody temperature, dual stacked cold filters, f/7, and a (64 μm)^2 detector.)

The total expected background count rate is 103 kHz



Stacked filter transmission is very good (>90%) at 1064 nm, 1572 nm, and 2060 nm

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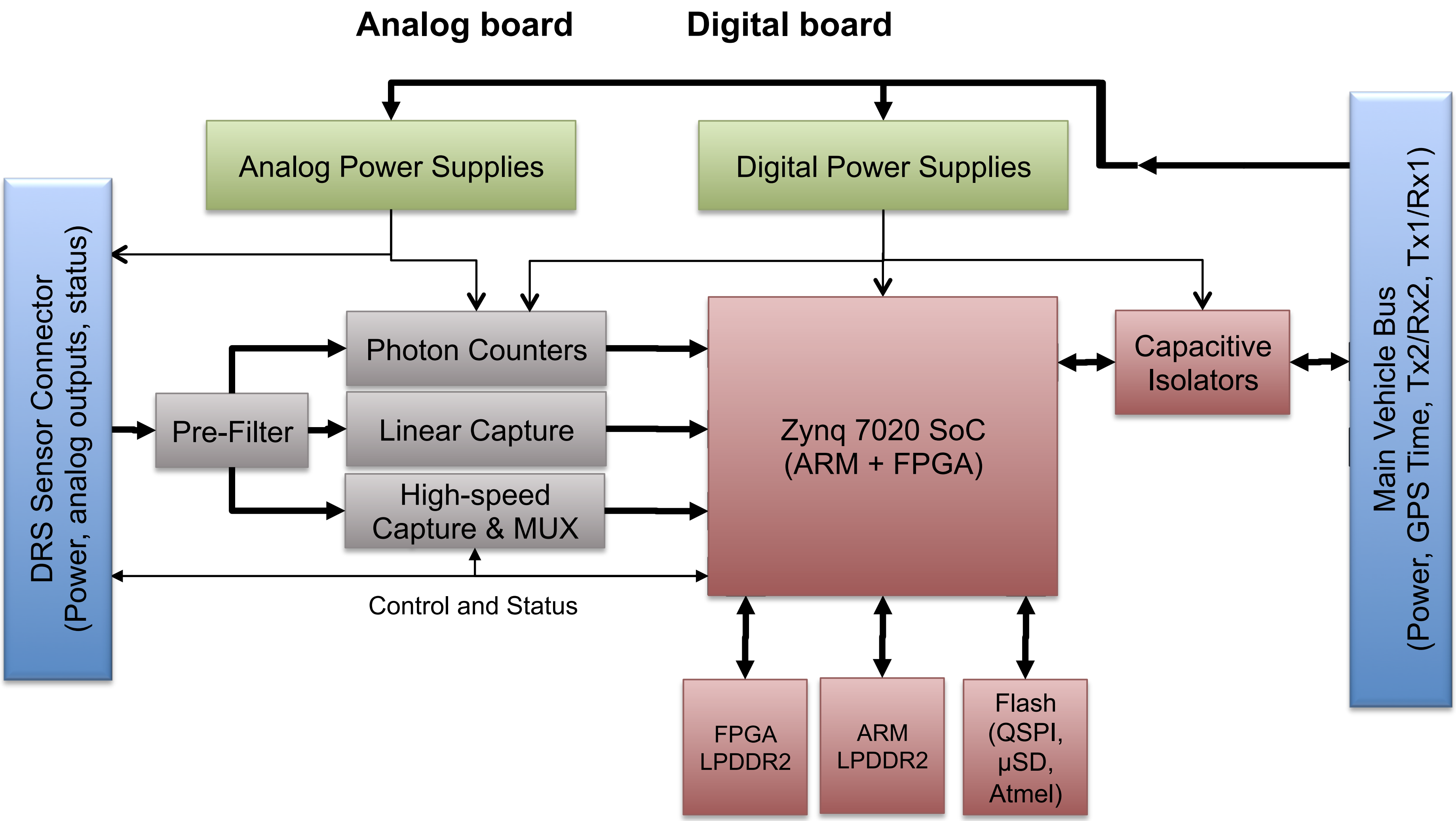
Overall System Block Diagram



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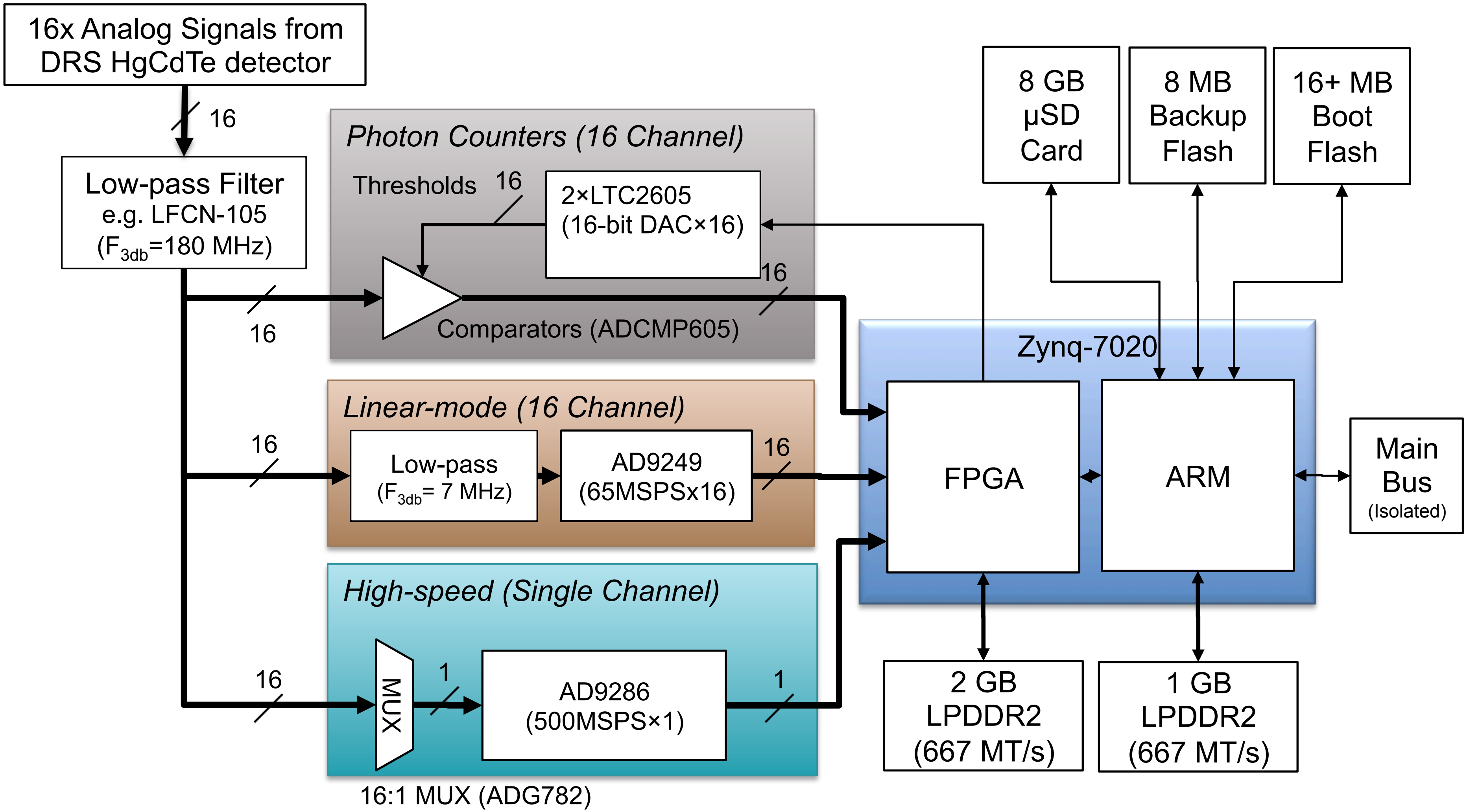
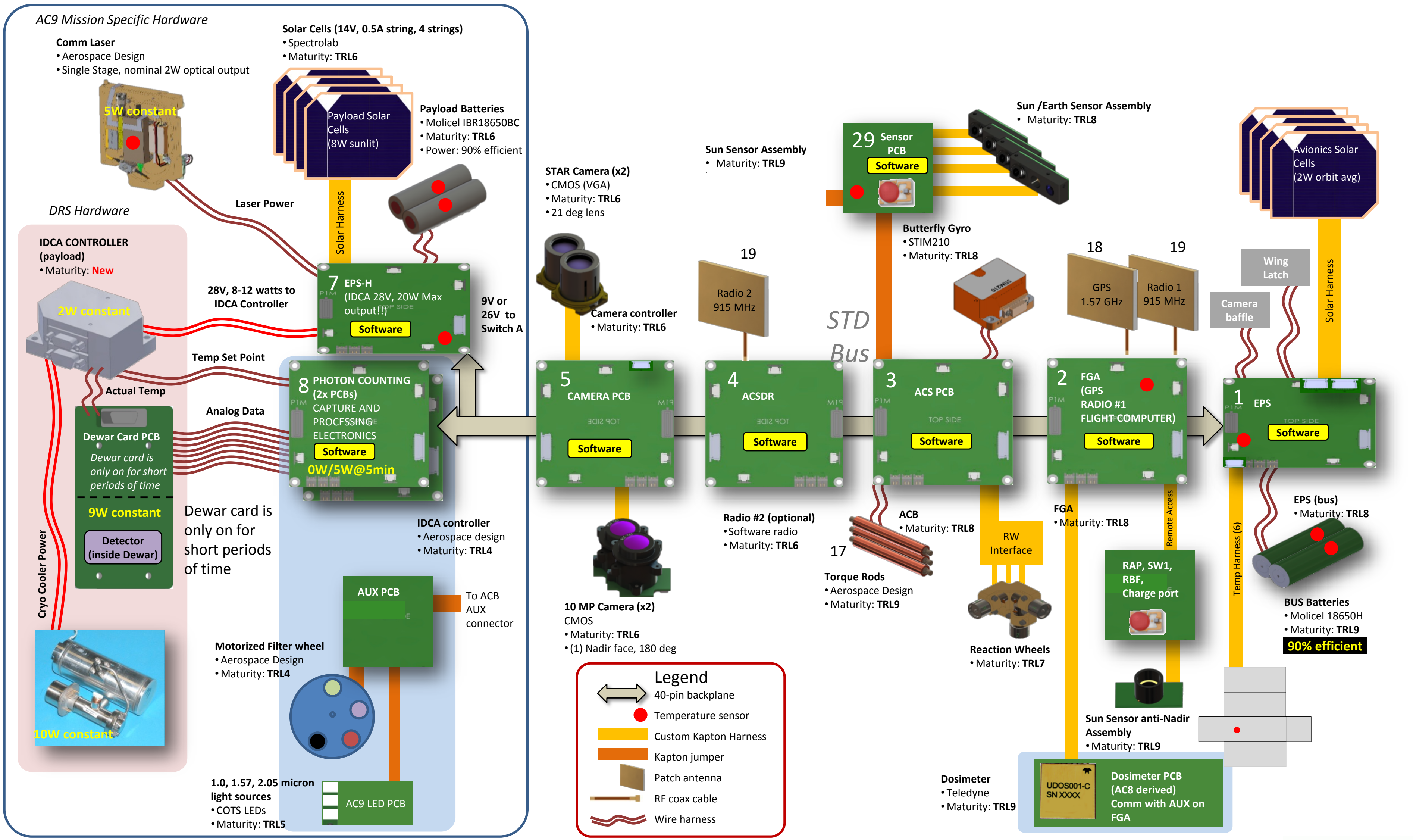
Three Data-Capture Subsystems



Note: I²C/SPI control signals omitted for clarity

System Architecture



AC9 Launch Options

- NASA CSLI Option 1
    - 450 km x 820 km x 99 deg inclined
    - **Aug 2016** delivery to Integrator
    - **Nov 2016** launch
- NASA CSLI Option 2
    - 600 km SSO 10:30 LTDN
    - **April 2016** delivery to Integrator
    - **July 2016** launch

L1 Requirements

No.	Requirement
1	The LMPC shall measure near and short wave IR sources with the 2X8 Mercury Cadmium Telluride (MCT) electron Avalanche Photo Diode (e-APD) focal plane array (FPA) for 1 year to support the component needs for future NASA missions
2	The LMPC shall detect laser light from a ground source
3	The LMPC shall perform a radiometry assessment by scanning the Earth's moon for response calibration
4	The LMPC shall conduct a variable radiometric response experiment by imaging the sunlit Earth and clouds (i.e. no laser source)
5	The vehicle shall conform to CubeSat standards
6	The LMPC shall measure the effects of space radiation on the dark current, APD gain and quantum efficiency of a 2x8 HgCdTe electron Avalanche Photo Diode (e-APD) focal plane array (FPA) in a relevant space environment
No.	**Goal**
1	The LMPC shall be compatible with an optical communications link
2	Measure an atmospheric gas absorption line

Summary

- Demonstrate single photon detection in space compatible with dark current
- Present status:
  - *Despite the relative early stage of the LMPC ACT-10 2 by 8 array, AC9 will have the ability to resolve a 13kcount or greater increase in dark current induced by the radiation exposure*
    - Developments under other programs have significantly reduced systematic background counts due to ROIC glow and pixel jitter to < 1 ns
  - *The ideal coating performance of the Materion cold filters insures relevant performance at the 3 principal earth science lines*
  - *Current performance of AC9 star trackers with potentially 0.01 degree open loop pointing opens relevant optical communication demonstrations*
  - *Impact of cryo-cooler vibration on spacecraft*
    - Linear acceleration RMS = [0.0133 , 0.0141 , 0.0096] g
    - **Angle (jitter) RMS = [0.06 , 0.36 , 0.15] milli-deg (nominal R_gyro)**
    - **Angle (jitter) RMS = [0.06 , 0.51 , 0.77] milli-deg (bounding case R_gyro)**

Even the tight 0.1 degree pointing will not be affected by cryo-cooler vibration