Space Radiation and Plasma Environment Monitoring Workshop

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Highly Miniaturised Radiation Monitor (HMRM)

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RAL Space

Science & Technology Facilities Council Technology

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HMRM Final Presentation Overview

- Key Requirements
- HMRM Design overview
- Particle Identification Algorithm
- Data products
- Detailed design overview
  - Mechanical
  - Electrical
- Programme status
- Future work

HMRM Consortium

Consortium Member	Role
STFC - RAL Space	• HMRM Consortium Lead • Overall design and development of HMRM
STFC – Technology Department	• HMRM ASIC Sensor Design and Development
Imperial College London – High Energy Physics	• HMRM Particle radiation simulation • HMRM Particle Identification algorithm development • HMRM testing
ESA ESTEC	• Technical contract management

Consortium strengths:

- Expertise in development of Space instrumentation
- Expertise in instrumentation for High Energy Physics instrumentation
- Knowledge of the space radiation environment

Aims of the HMRM programme

Develop a "chip sized" [1] prototype radiation monitor suitable for application in:

- Coarse radiation housekeeping
- Alert and saving function
- Support to platform and payload systems

Note 1: The clear implication of "chip sized" is that the HMRM is to be smaller, lighter and consume less power than a more conventional radiation monitor…

HMRM Key Requirements

Key Requirements:

Functional Requirements

Requirement
The highly miniaturized radiation monitor (HMRM) shall be an ASIC/APS radiation detector with on-chip sensor elements, read-out electronics, power and communications resources
The HMRM design shall minimize the number of external components needed to operate the device.
Preferred process for the CMOS die shall be a commercial process by a European Foundry
The HMRM design shall minimize the number of pins needed to interface the spacecraft/host PCB
Dosimeter function: The HMRM shall maintain a counter of the accumulated total dose detected

Key Requirements:

Functional Requirements (cont.)

Requirement
Particle Rate Meter function: a rate meter counter shall be maintained. The maximum particle rate shall be 10^7 (#/cm^2/sec) or higher
Particle Species Identification function: capability to classify on chip detected events with respect to particle species (electrons, protons, ions) shall be implemented
The dynamic range shall be such to maximize the discrimination of different particles species for typical satellite orbits within the energy range as indicated in the Statement of Work
The highly miniaturized radiation monitor shall have a temperature monitor on chip. The temperature sensor shall have an accuracy of better than 1°C over the range -40 to +80°C. All calibration parameters to be provided with the detector

Key Requirements :
Functional Requirements (cont.)

Requirement
An in-flight calibration procedure shall be implemented in order to check sensor drift
The HMRM shall include the ability to isolate erroneous sensor elements
The HMRM design shall foresee the possibility of coincidencing operation modes in which several HMRM devices are distributed on different location of the spacecraft

Key Requirements:

Physical and Electrical Requirements

Requirement
The package selected shall allow the possibility to stack more than one detector and to interleave detector chips with passive shielding materials
The power dissipation shall be minimized and be less than 200mW on average
The radiation sensor shall require a minimum of power supply pins. The power supply voltage shall be 5.0 V or lower
HMRM shall be tolerant to ESD on any of its pins with a Human Body Model voltage of at least 300V
The HMRM shall require a minimum of external reference voltages
The mass of HMRM device shall be less than 20 g

Key Requirements:

Environmental Requirements

Requirement
The radiation detector single chip shall have a radiation TID tolerance of at least 100kRad
The radiation detector single chip shall be latch up free
The radiation detector single chip shall have an operating temperature range of -40 to +80°C
The radiation detector single chip shall have a storage temperature range of -60 to +125°C
The sensor shall be capable of meeting the performance requirements under full solar illumination at an orbital radius of 1 AU

Key Requirements:

Quality and Test Requirements

Requirement
Evaluation testing shall be performed compliant to ECSS 9020 [AD-2]
Testing shall be performed to find the 50% failure level of the detector to at least the following conditions: - Mechanical Shock level - Mechanical Vibration level (random and sine) - High and Low Temperature - Radiation total dose
The HMRM shall be free of all non-European export restrictions and shall take all measures needed to ensure this

Key Requirements: Summary and interpretation

Customer needs:

- High quality characterisation of the space radiation environment
    - Dose
    - Electron and proton spectra
    - Wide range of environments
- Low cost
    - Unit cost of Monitor
    - Spacecraft resources (power, mass, TM etc.)
    - Integration
    - Data processing

HMRM Design overview

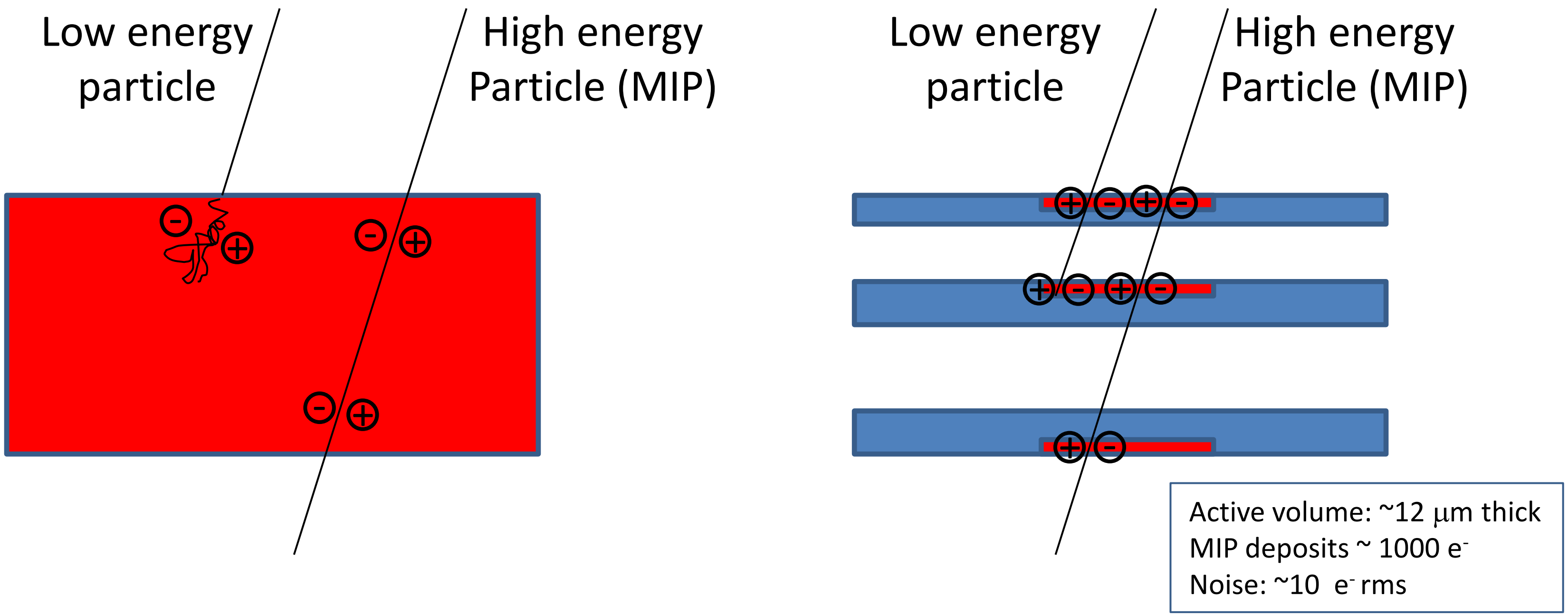
Sensor Tradeoff

- Key tradeoff in the architecture of the sensing element of the HMRM was between a PIN Silicon Diode and Active Pixel Sensors
- APS sensors have several advantages for application in the HMRM

Parameter	Comments
Mass	Integrating the detector function with the signal readout makes APS much more compact
Sensor integration	The sensing element is fully integrated on the monitor chip with APS sensors
Signal quality	Able to achieve ~10 e^- rms noise with saturation of 15 ke^- with APS
Power supply	Bias voltage of CMOS is 3.3 V and no need for “high” voltages to drive the diode into depletion
Flux dynamic range	The APS is able to be electronically shuttered to avoid pileup in high flux environments
Bremsstrahlung susceptibility	The APS detectors have a low cross section for interaction with high energy photons

Sensor Tradeoff

PIN Silicon Diode **Active Pixel Sensor**

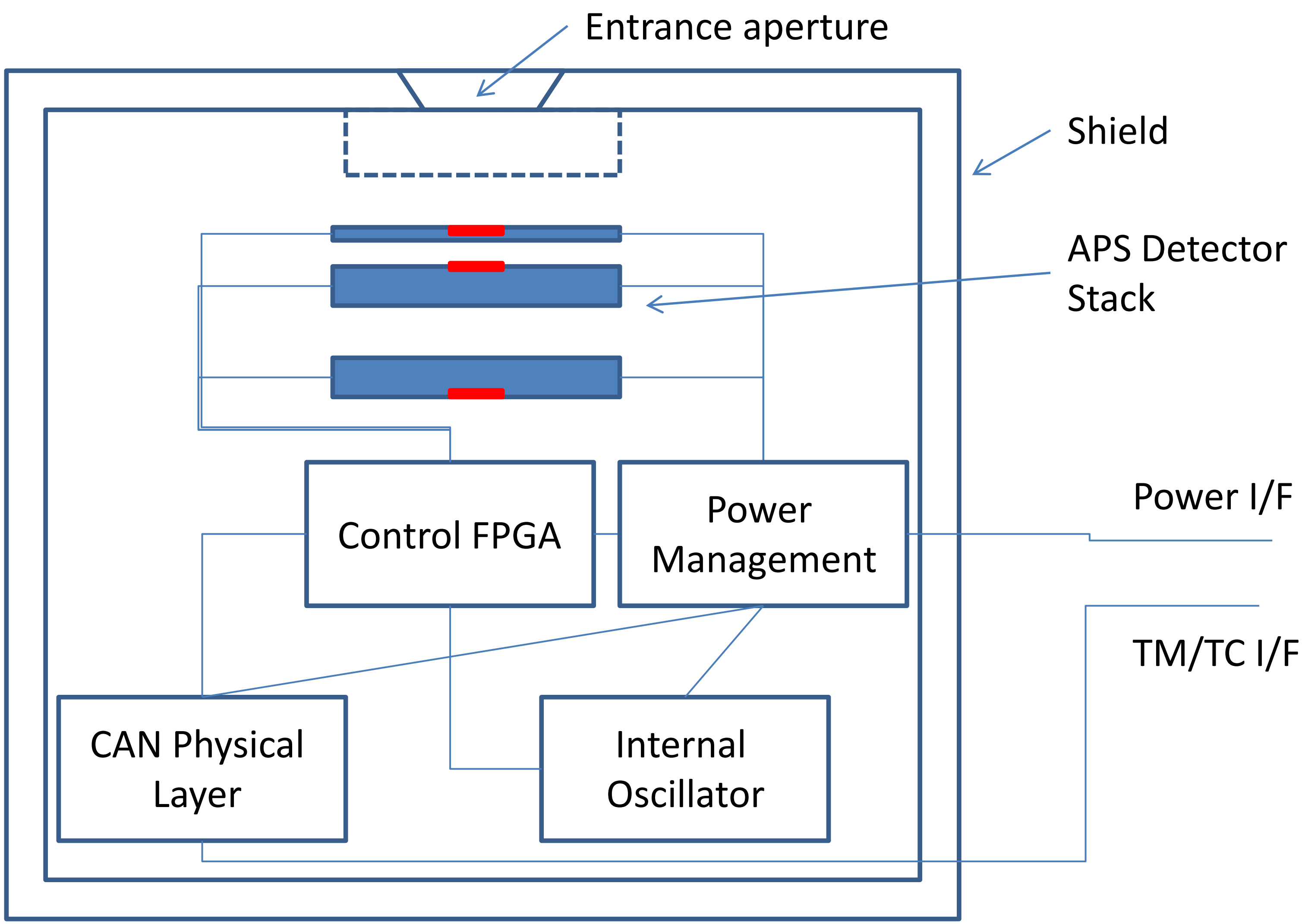


- Ambiguity exists where the energy deposited in the detector by a low energy particle is the same as the energy deposited by a MIP passing through the detector
- Active volume of APS detector: 12 μm with 50-500 μm substrate
- Active volume of Silicon diode: > 50 μm
- With APS sensors; judicious selection of Silicon substrate thickness allows the dE/dx curve to be sampled and uniquely identify the particle species and energy

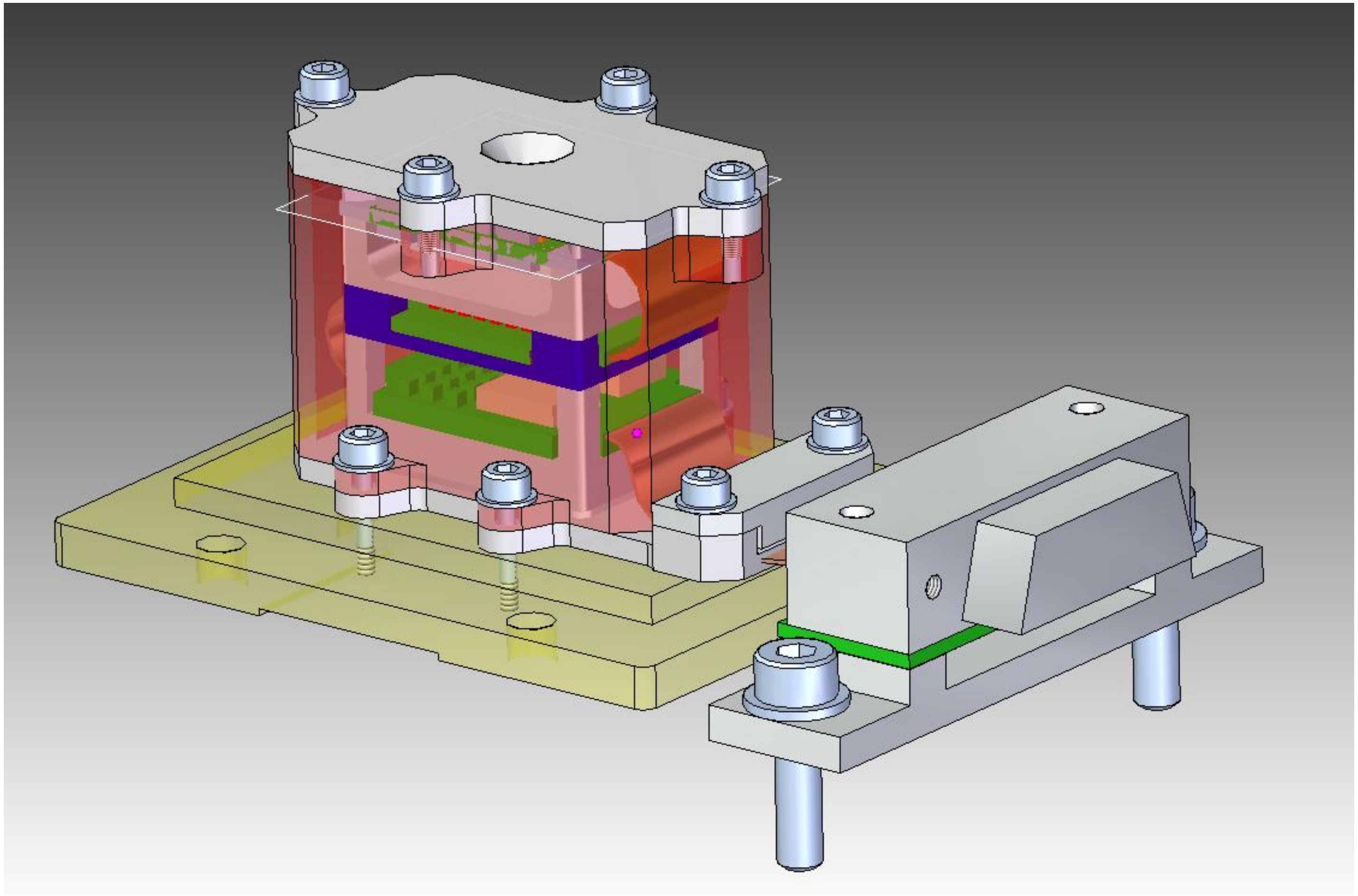
HMRM Design Summary

Characteristic	Specification	
Sensing element	50 x 50 array of 20 µm x 20 µm , 4T APS detectors	
Configuration	Either single chip, or integrated monitor	
Mass	Integrated monitor: 52g (including fasteners and connector) in a stack configuration	Single Chip: 0.8 g
Power	1-2 W (TBC) depending of number of detectors in stack and architecture of power supply	Single Chip: < 200 mW per ASIC
Volume	Integrated monitor: 20x25x30mm - 15 cc	Single chip (unpackaged): 2.54x10x0.6 mm
Radiation measurements	Integrated Monitor: Dose Dose rate Particle radiation spectra: • Electrons: 0.06 – 6 MeV • Protons: 1 – 500 MeV	Single Chip: Dose Dose rate
Maximum flux	10^8 #/cm^2/s	
Aux. measurement	Temperature	
Interface	Integrated Monitor: Data: TM/TC CCSDS CAN Power: 5 V (standard)	Single Chip: Data: CMOS logic I/O Power: 3.3 V + 0.3V references

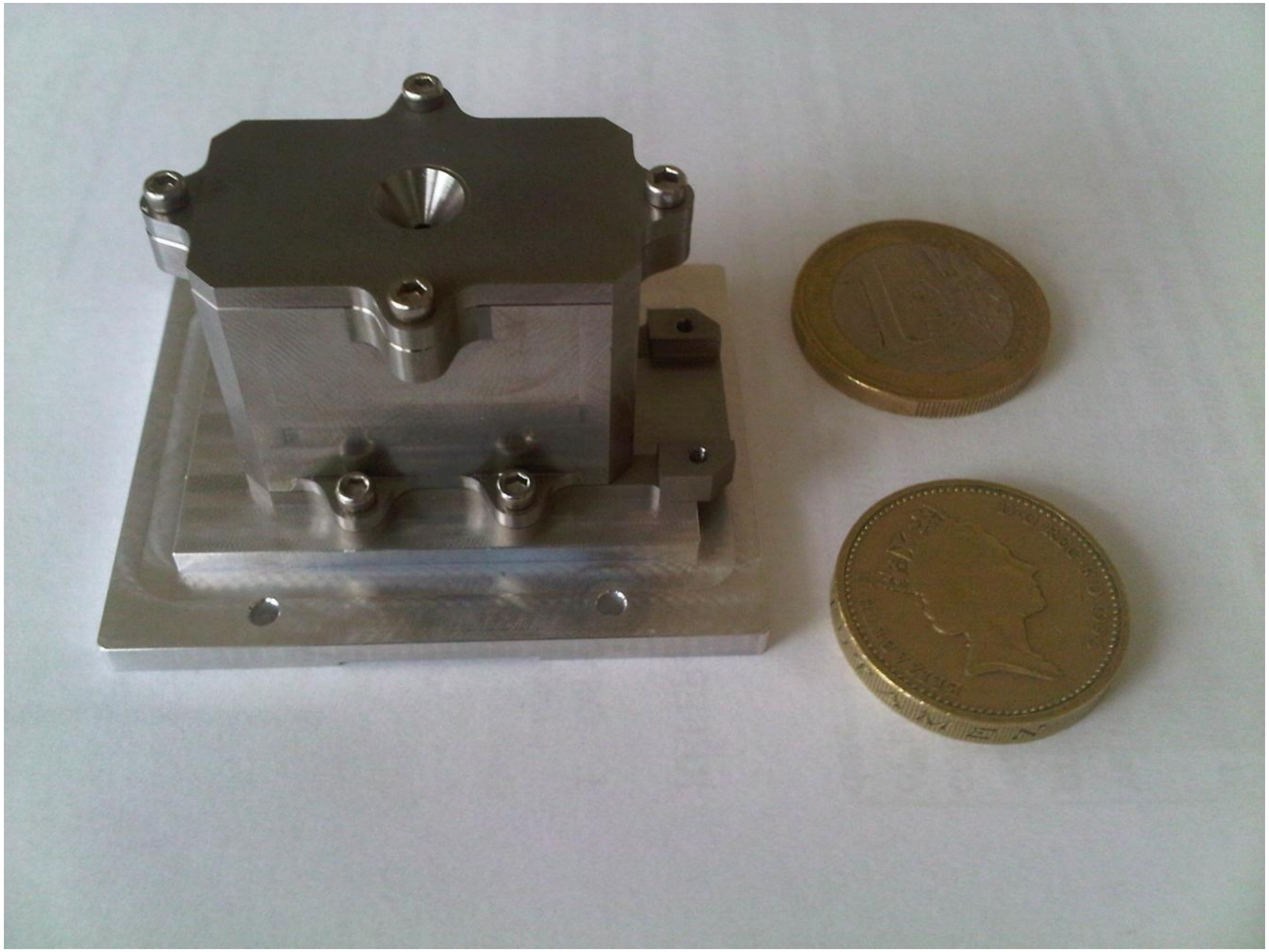
HMRM Block Diagram



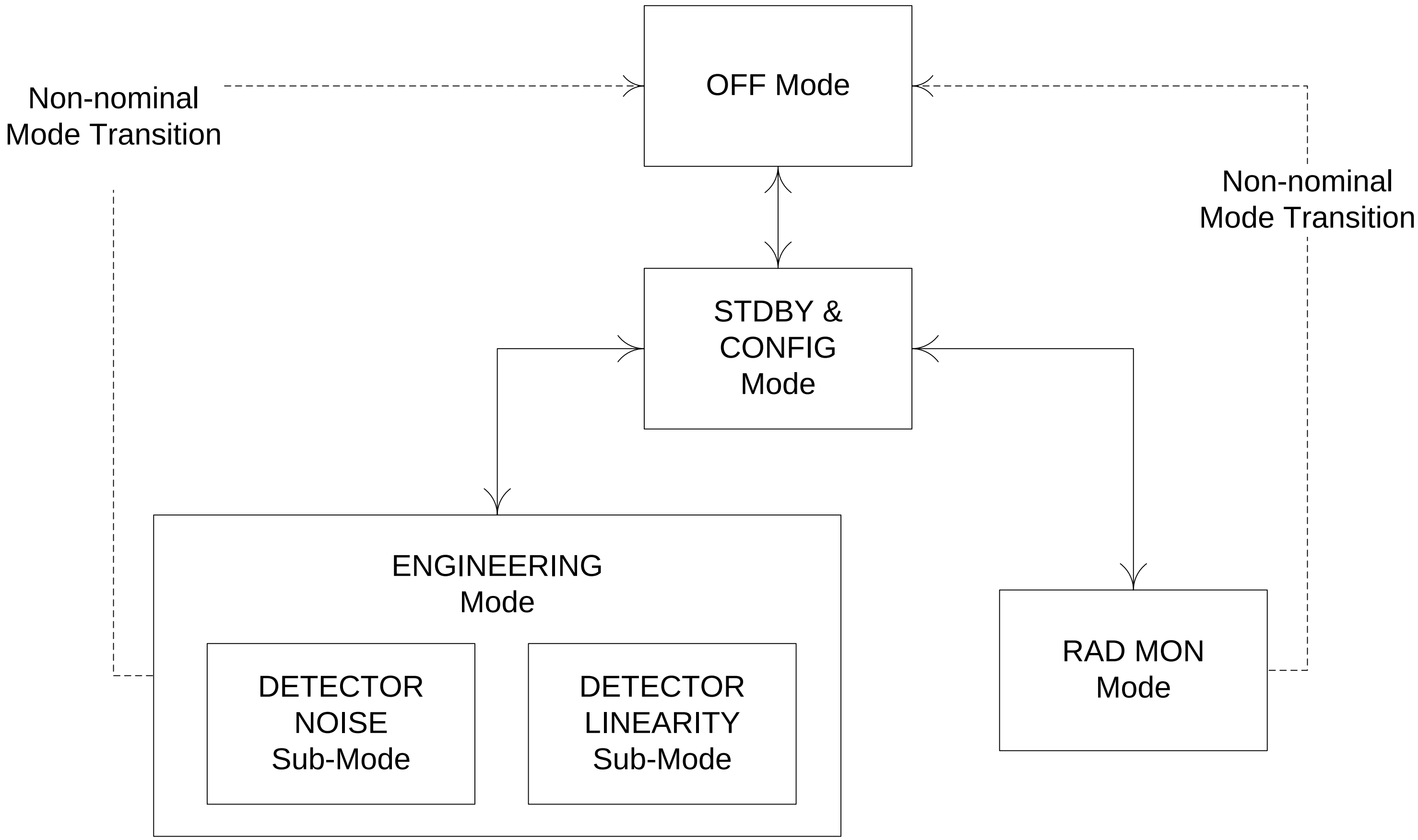
HMRM CAD Model



HMRM Structure



HMRM Mode Transition Diagram



HMRM
Data products

Data Products

- HMRM Generates four types of CCSDS compliant TM frames
  - Engineering
    - Basic radiation HK data
  - “Full Science”
    - Provides data for retrieval of particle spectra
  - Transparent
    - Diagnostic
  - Error frames

Data Products

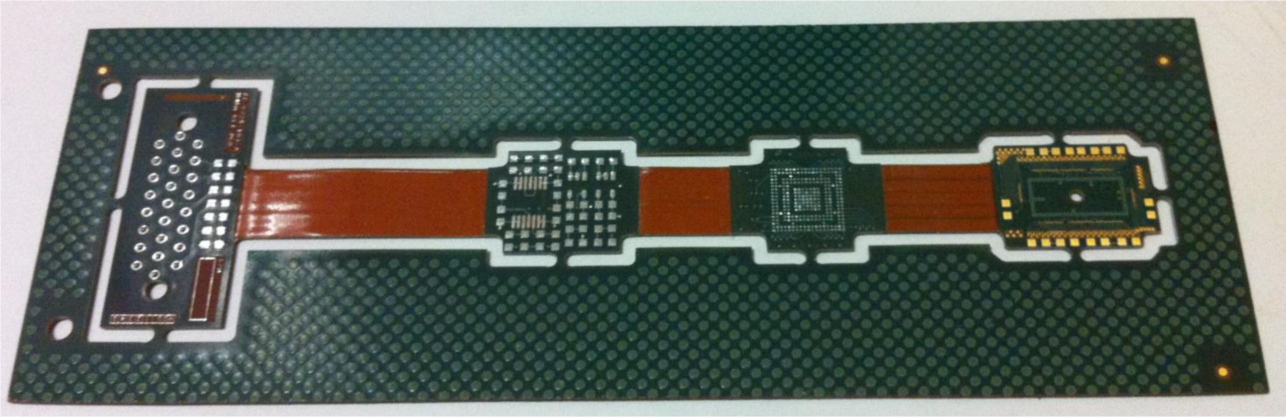
	bits	Full Science	Eng.	CRC Error Event	Transparent
CCSDS Header	48	*Yes*	*Yes*	*Yes*	*Yes*
TM ID	16	*Yes*	*Yes*	*Yes*	*Yes*
Time	42	*Yes*	*Yes*	*Yes*	*Yes*
TC ID for CRC Error Event	16			*Yes*	
Temperatue	9	No	*Yes*		*Yes*
Cumulative Lifetime Doses	64	*Yes*	No		No
Dose Rates	64		*Yes*		
Dose Rate Flags	4		*Yes*		
Mean Particle Rate	26	No	*Yes*		No
Time of Mean Particle Rate Calculation	16	No	*Yes*		No
Q Vector	736	*Yes*	No		No
Front Sensor Alert Flag	1	No	*Yes*		No
tc	25	*Yes*	No		No
Transparent Output of Detectors	30600	No	No		*Yes*
tc2	25		*Yes*		No
ID Dependent Counter "J(3)"	69	No	*Yes*		No
CRC Packing	6			*Yes*	No
Full Science Packing Bits	29	*Yes*	No		No
Engineering Packing Bits	0	No	*Yes*		No
Transparent Packing Bits	5	No	No		*Yes*
Packing Bits	48	*Yes*	*Yes*	*Yes*	*Yes*
CCSDS CRC	16	*Yes*	*Yes*	*Yes*	*Yes*
	bits	1024	384	192	30784
	Num. CAN Frames	16	6	3	481

Data Products

- Engineering and "Full Science" frames are generated at a user configurable rate
- TM bandwidth a function of cadence of measurements only
  - In normal operation average TM rate can be exceedingly low
- Transparent generated at maximum capacity of CAN bus

PCB

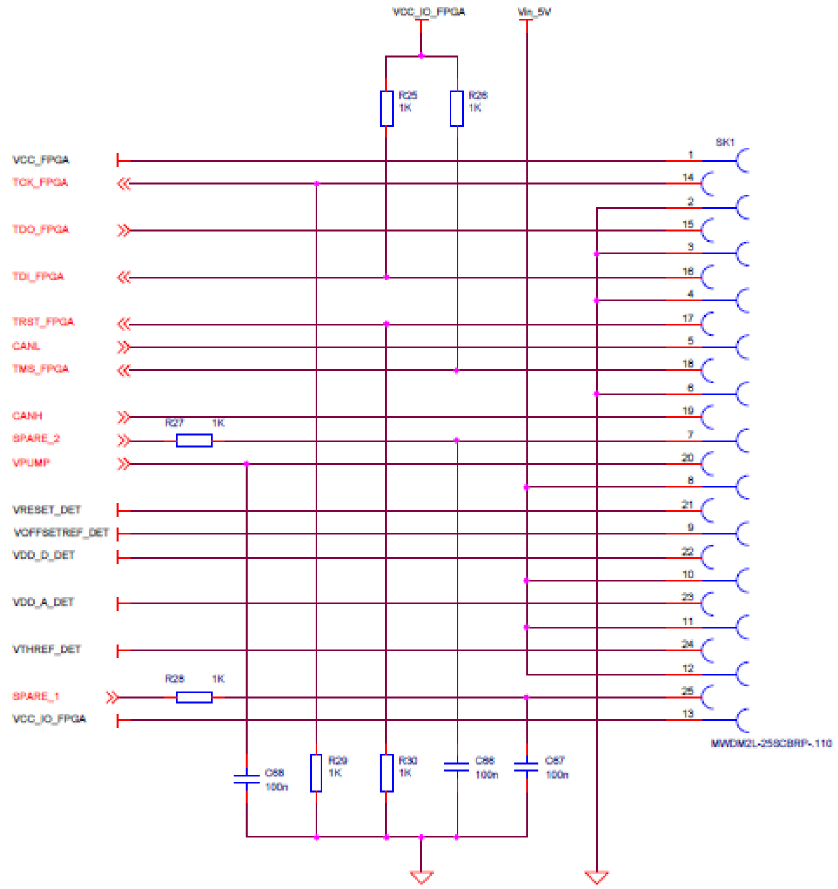
- Flex rigid PCB design
- Four rigid boards
  - Interface connector PCB
  - Interface PCB
  - FPGA PCB
  - Detector PCB



- Very complex design challenge
  - 10 layer PCB
  - 248 through holes
  - 100 buried vias
  - 151 micro-vias
  - HASL finish for soldered components
  - Gold finish for wire bonded ASICs

Interface connector

- 25-way MDM
- Power +5V / return
- CAN I/F lines
- Tell back
- Extra functions for Phase A/B device
  - voltage probes
  - JTAG for FPGA re-programming



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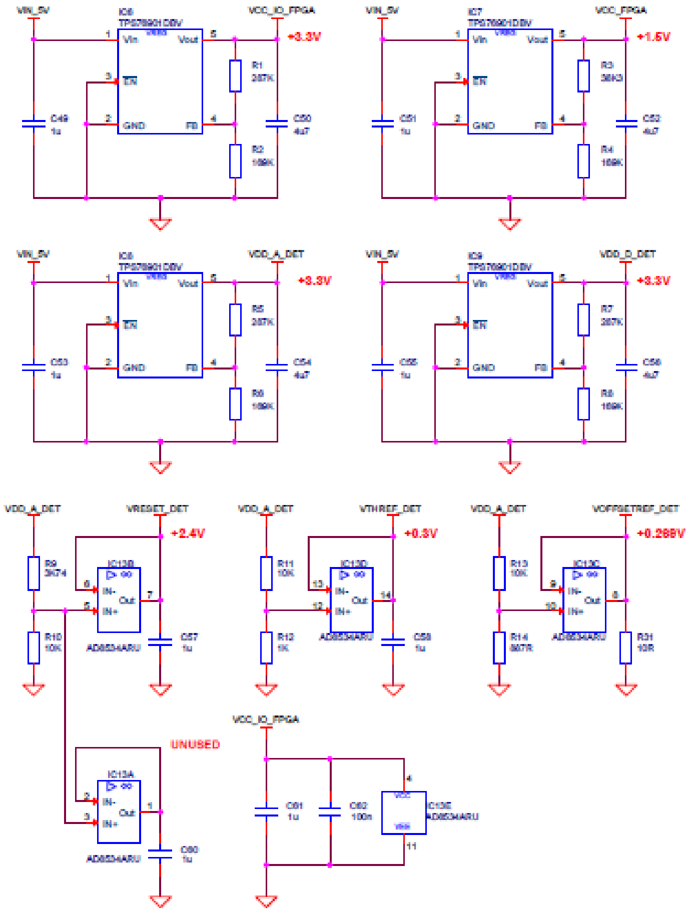
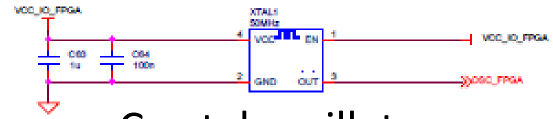
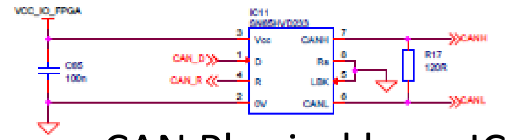
Interface PCB



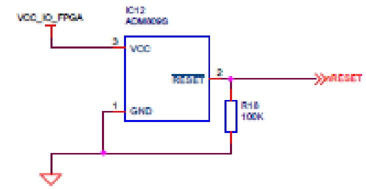
Reference voltages



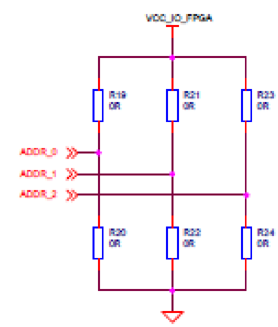
Crystal oscillator



CAN Physical layer IC

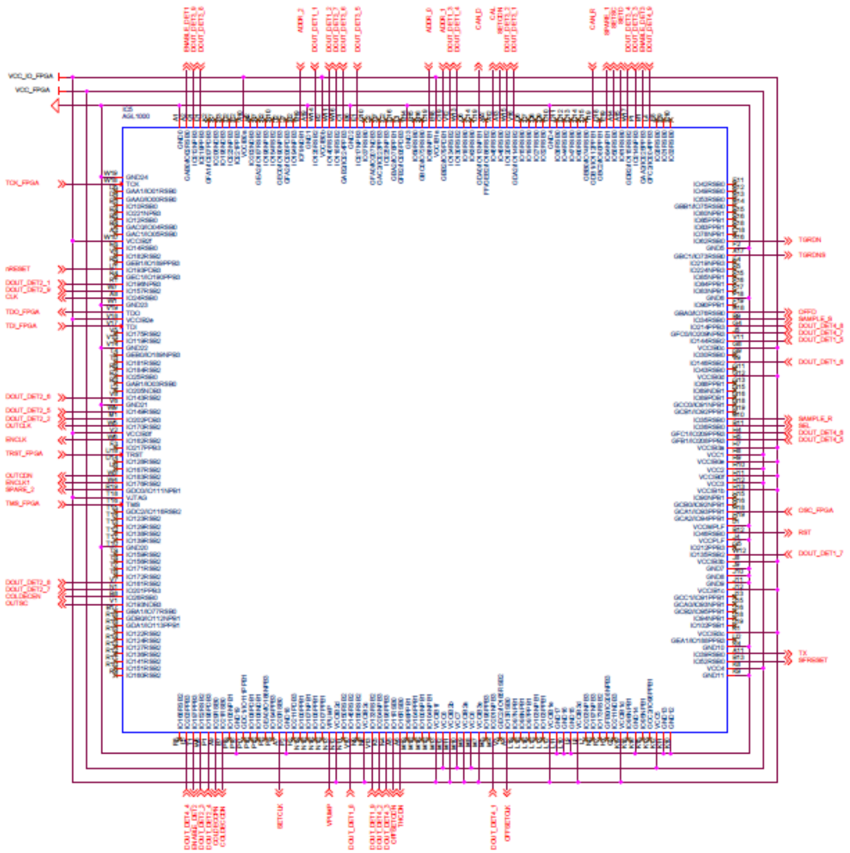


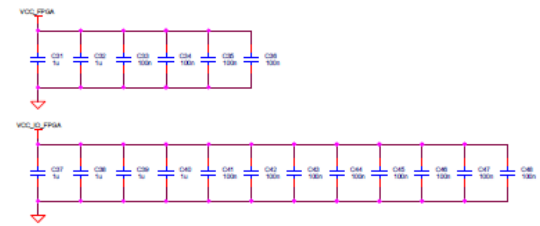
FPGA Power up / reset



Ground point

FPGA Board





- 281 contacts
- 10x10 mm package
- Low proportion of programmable I/Os utilised
- High density micro vias and buried vias required to route signals to flex layers

FPGA Functions

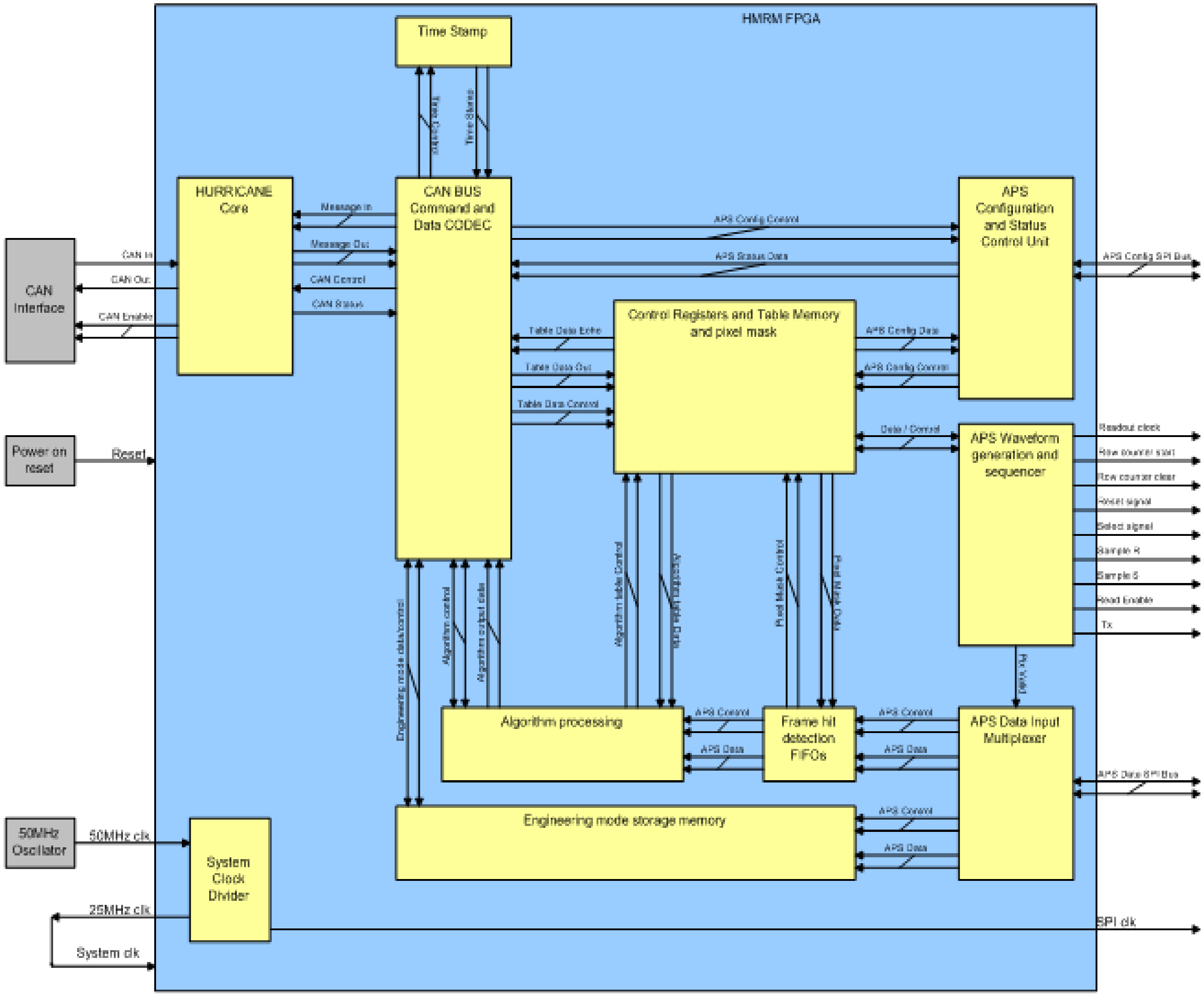
CAN (Controller Area Network) Hurricane Core
Time keeping
Command CODEC
Telemmetry packaging
System clock
Radiation monitoring data processing
APS configuration register programming logic
APS waveform generation
Bad pixel masking function
Engineering mode processing

Device:
Microsemi
AGL 1000V - CSG281

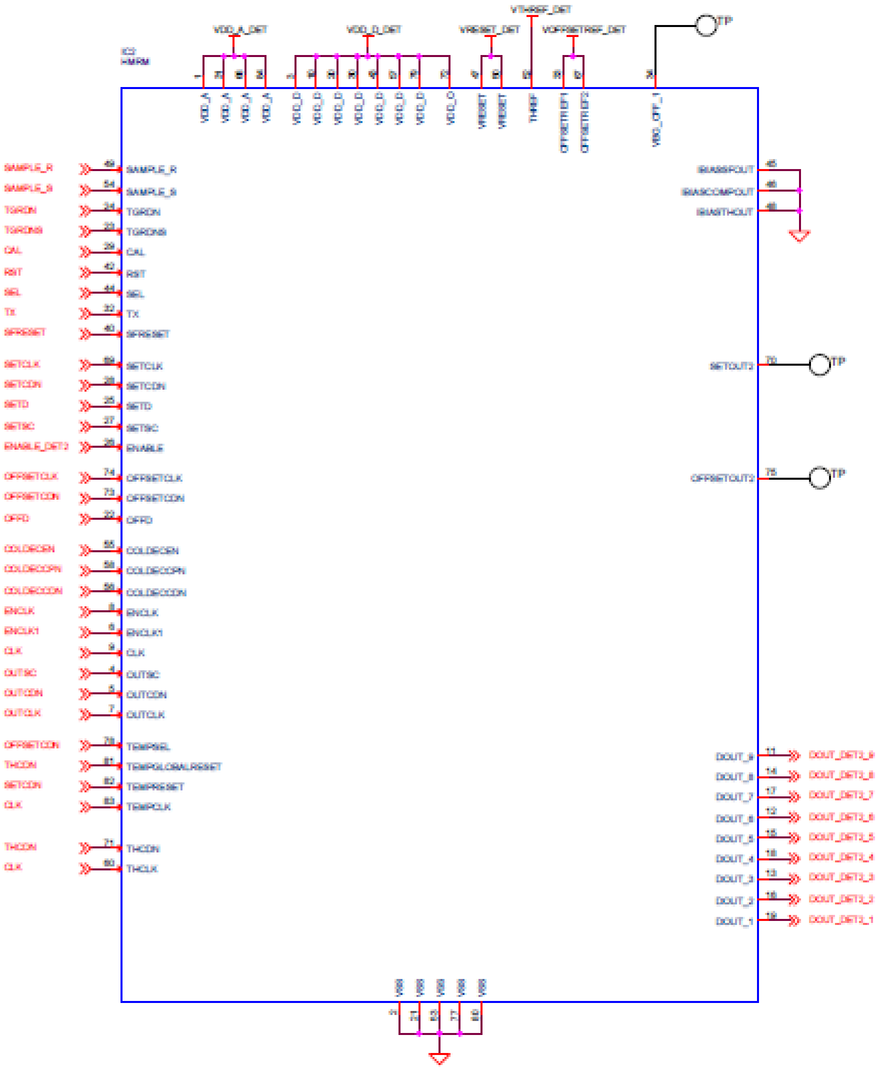
COTS device
Flash programmable
1,000,000 System gates

~80% utilisation

FPGA Architecture

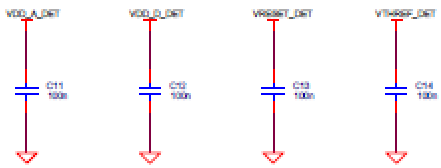


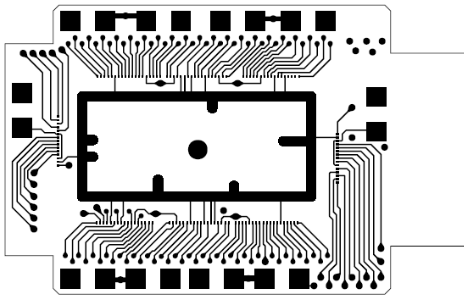
Detector PCB



Mounts the three APS HMRM ASICs in a stack configuration

Sensors are glued to the PCB and co-aligned with respect to reference features



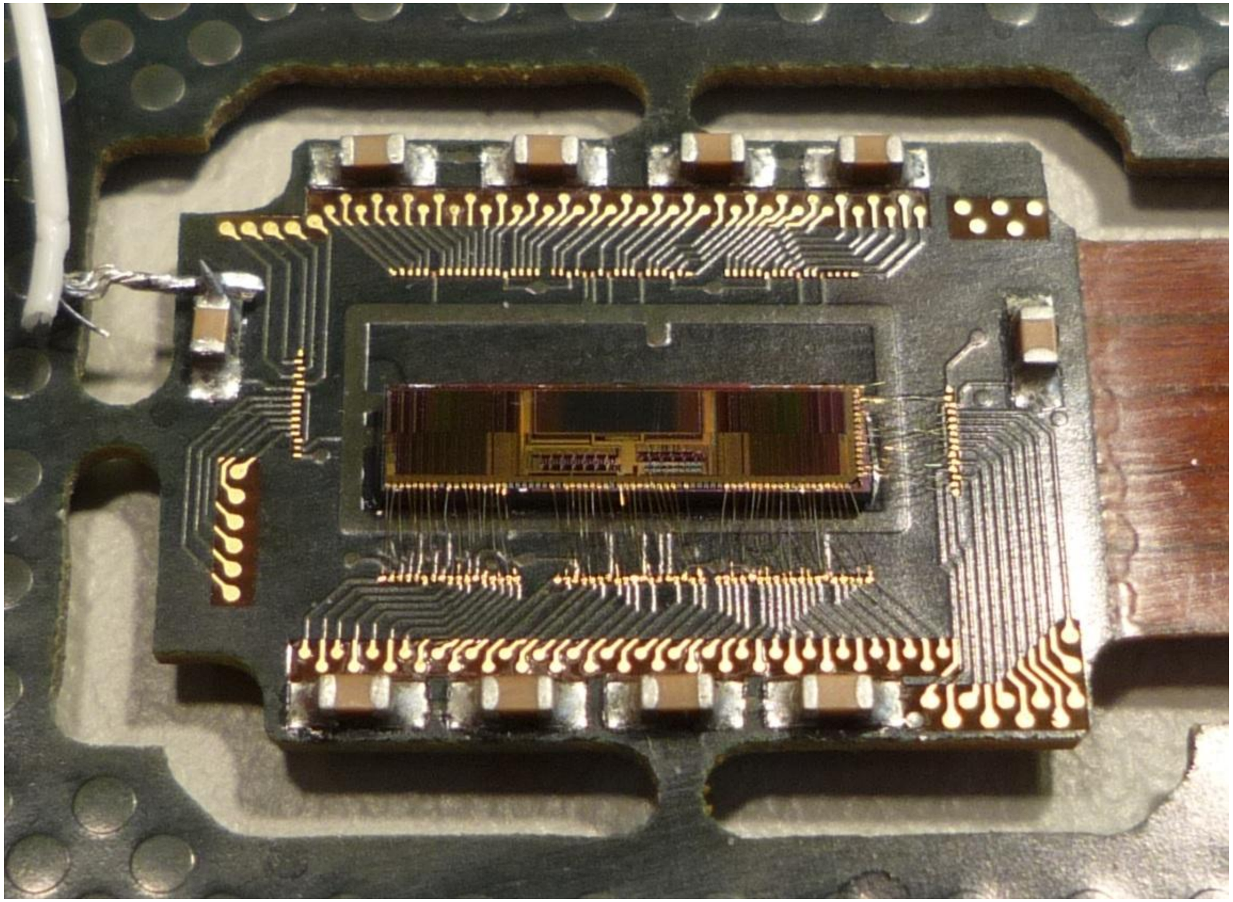


Sensors are wire bonded to PCB (either Gold or Aluminium wire bonds)

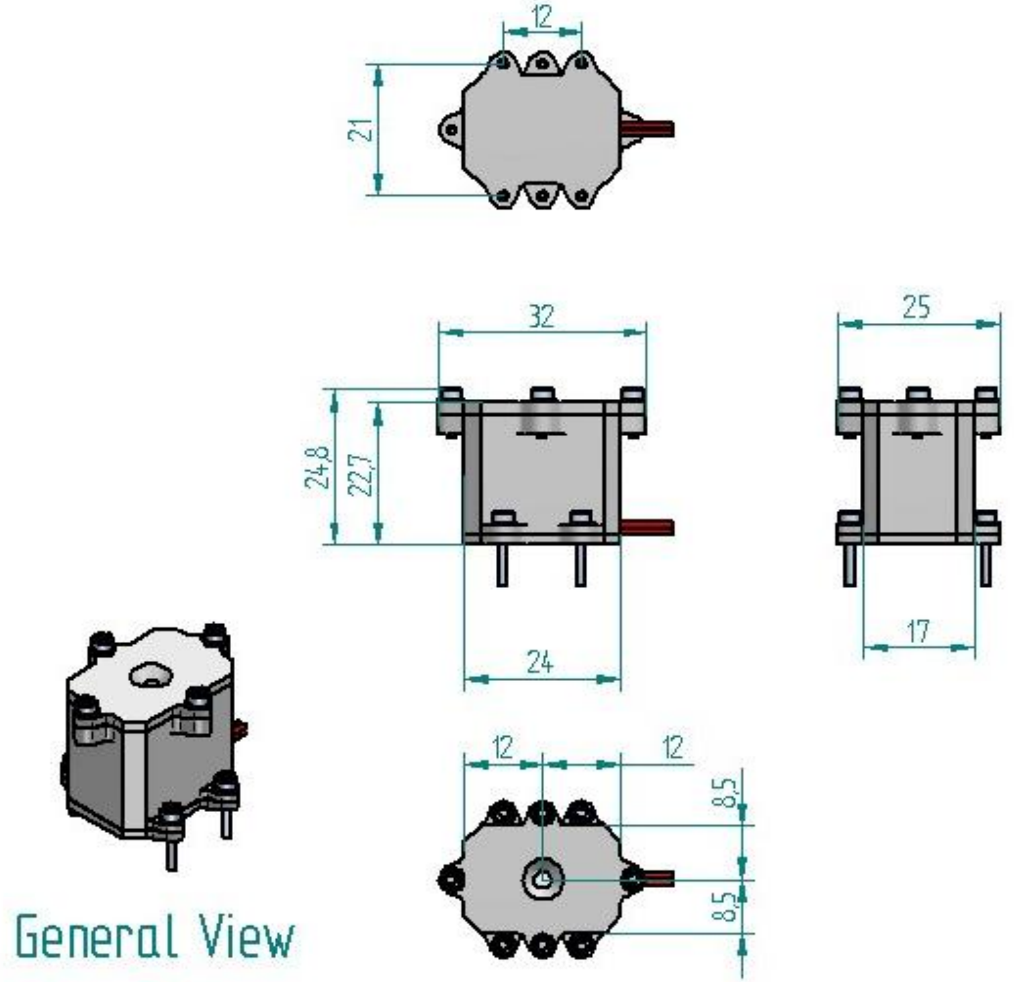
Local decoupling capacitors

Test points included for probing of signals

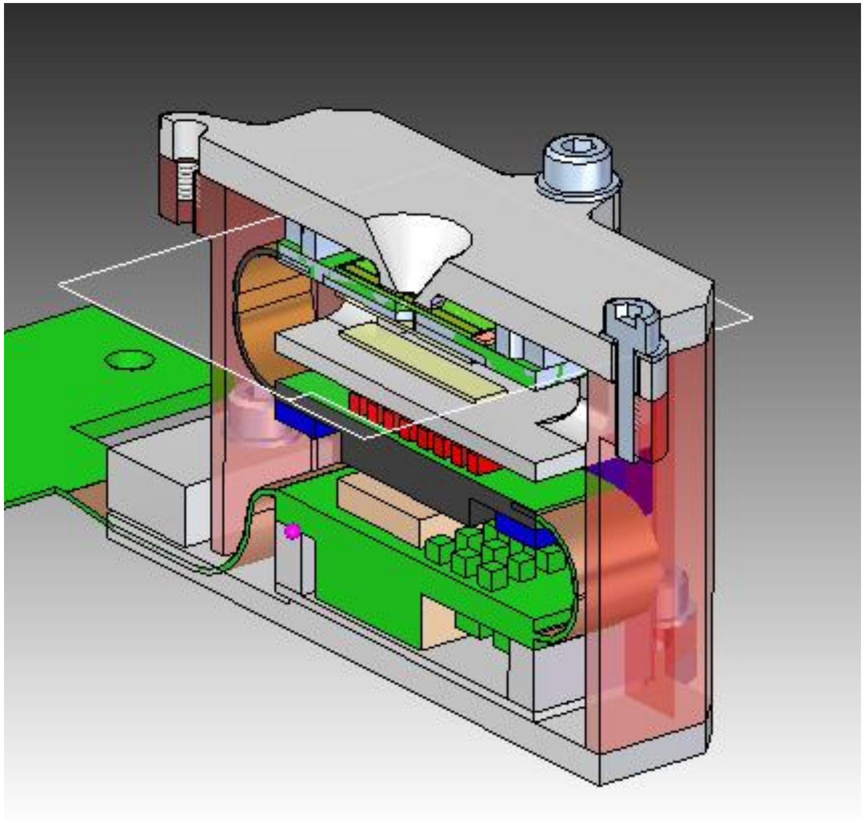
Detector PCB



Mechanical Design



Mechanical Design



Three main mechanical elements of the HMRM Chassis

- Lid
  - Provides the prescribed geometry for detector telescope
  - Mounts the window (for visible blindness)
- Body
  - Main structural housing around electronics and sensing elements
- Base
  - structural interface to spacecraft
  - shields back of HMRM

Fabricated in Titanium

Mass 52g (including fasteners and connector)

HMRM Programme Status

HMRM Programme Status

- Design of Phase A/B monitor complete
- ASIC run #2 to be submitted today!
  - Returned from foundry ~ Sep. 2012
- Wafer level checkout, screening and characterisation
- Assembly into deliverable monitors
- Test and characterisation

HMRM Future Work

Future work

- Complete the hardware technology demonstration aspects of the HMRM programme with the second iteration of the ASIC
  - ASIC functional and performance testing
  - Integration of ASICs into a HMRM monitor
  - HMRM functional, performance and environmental testing
- Commercialisation
  - The Statement of Work explicitly calls for planning for commercialisation of the HMRM
  - The next steps in this regard include:
    - Baselining the differences between the Phase A/B device and a flight qualifiable Phase C/D device
    - Completion of the planning of the development programme to develop the HMRM to this level of maturity

Summary

- The HMRM Phase A/B programme is close to successfully demonstrating the remarkable potential of applying CMOS APS technology to the design of a highly miniaturised spacecraft radiation monitor
- The presenters acknowledges the contribution of ESA to this work in the awarding of AO/1-5978/09/NL/AT to the consortium and the invaluable assistance from ESTEC staff