Mini-EUSO Instrument Definition

Version: 1.6

April 11, 2016

Drafted by	**F. Capel, O. Larsson, M. Casolino**	
Agreed by	**M. Casolino**	
Approved by		

Contents

List of Figures

List of Tables

Document History

2015-12-14
corrected to 37 cm. MC

2015-08-21
Converted into LaTeX format. Based on version 2.0 (Draft) of Mini-EUSO Instrumentation Definitions document from 22 July 2014
By O. Larsson

1 Scope

The scope of this document is to provide a technical description of the Mini-EUSO instrument, and the definition of requirements relevant to its performance, design and acceptance.

2 Documentation

2.1 Applicable Documents

1. Mini-EUSO Mission Description

2.2 Reference Documents

2.3 Glossary

ADC	Analogue to Digital Converter
ASIC	Application Specific Integrated Circuit
CCB	Cluster Control Board
CPU	Central Processing Unit
EC	Elementary Cell
EUSO	Extreme Universe Space Observatory
FPGA	Field-Programmable Gate Array
FS	Focal Surface
FoV	Field of View
HD	Hard Drive
HK	House Keeping
HV	High Voltage
JEM	Japanese Experimental Module
LV	Low Voltage
LVDS	Low Voltage Differential Signalling
MAPMT	Multi-Anode Photo Multiplier
PDM	Photo Detection Module
PMT	Photo Multiplier tube
PS	Power Supply
PSF	Point Spread Function
SiPM	Silicon Photo Multiplier
SSD	Solid State Disk
TRL	Technological Readiness Level
UHECR	Ultra High Energy Cosmic Ray

3 Mission Description

The Mini-EUSO telescope is designed to perform observations of the UV light emission from Earth [1]. The mission is devised with the intention of raising the technology readiness level (TRL) of the future JEM-EUSO mission to observe ultra high energy cosmic rays (UHECRs) from space [2, 3]. The Mini-EUSO measurements will be performed from within the International Space Station (ISS) through a UV transparent window in the Russian Zvezda Service Module. Through UV Earth observation, Mini-EUSO presents the opportunity to study a diverse range of scientific phenomena including atmospheric physics, strange quark matter, bioluminescence and UHECRs. Furthermore, Mini-EUSO is the first step in a roadmap of potential space debris removal via laser ablation [4]. The future JEM-EUSO instrument will only be able to detect cosmic rays with energies down to a well-defined minimum value. This is because the flux of UV photons generated by the cosmic ray's interaction with the atmosphere must be greater than that of the flux of UV photons reflected from the Earth during night observation. For this reason, it is critical to study this UV background as seen from the ISS using Mini-EUSO as a pathfinder before proceeding with the main JEM-EUSO mission.

The Mini-EUSO instrument comprises a compact telescope with a large field of view ($\pm 19°$), based on an optical system employing two Fresnel lenses for increased light collection. The UV light is focused onto an array of photo-multiplier tubes (PMTs) and the resulting signal is converted to digital, processed and stored via the electronics subsystems on-board. An overview of the instrument design and functionality can be found in section 4 with a more complete description given later in section 7.

The instrument is to be designed and built by the members of the JEM-EUSO collaboration. The telescope components such as photo-detectors, electronics and optics are all based upon the state of the art technologies originally developed for the JEM-EUSO mission.

JEM-EUSO is a large imaging telescope that will be placed on the ISS with the primary objective of observing highly energetic cosmic rays with energies exceeding 10^{20} eV. These cosmic rays create air showers upon interaction in the Earth's troposphere, ultimately resulting in the production of a UV light signature. JEM-EUSO aims to detect and measure the UV light from these cosmic ray events from its vantage point approximately 400 km above the Earth's surface. In this way, the Earth's atmosphere is utilised as a giant detector and a much larger surface area can be observed than with ground-based technologies. Through such observations of air showers, one can deduce the energy and angle of incidence of an incoming cosmic ray particle. At the high energies considered here (10^{20} eV), the trajectories of such particles will be mostly unaffected by the galactic magnetic field thus enabling the extrapolation of the track back into space. This could provide novel information on the origin of these high energy phenomena. The JEM-EUSO mission will also involve the study of complementary science objectives in the fields of fundamental high energy physics and astrophysics.

In order to reach the TRL required for the JEM-EUSO project, a pathfinder program was developed. This currently includes the Mini-EUSO instrument, but also the EUSO-Balloon and the ground-based EUSO-TA instruments, all designed to demonstrate and develop the key technologies for JEM-EUSO.

4 Instrument Overview

The Mini-EUSO instrument to be installed on the ISS can be divided into three main sub-parts: the optics, the photon collection and the data processing.

The optics consists of two Fresnel type lenses, each $25\,\mathrm{cm}$ in diameter. Fresnel lens design means that the construction of a large aperture lens with a short focal length is possible with a much smaller mass and volume budget, making the concept well-suited to space application. The optical system focusses the incoming light onto the focal surface for effective collection.

The photon collection is realised through an array of 6×6 multi-anode photomultiplier tubes (MAPMTs), each with 64 pixels, resulting in a readout of 2304 channels. Signals are pre-amplified and converted to digital before being passed to the data processing unit.

Multiple trigger levels are used to filter out noise and identify events of interest. Relevant data is then stored at regular time intervals depending upon the complexity of the trigger. Data transfer to Earth takes place physically via the delivery of a hard drive and there is no telecommunication with the ISS systems or directly to ground from the instrument.

In addition to these 3 main systems the instrument also features both an BW and visible light camera to provide complementary information on the observation conditions. A selective filter is also placed in front of the lens allow through only the UV wavelengths of interest. The instrument has a mechanical interface with the UV transparent window on the Zvezda module featuring an iris to provide protection from light exposure during the daytime, which also covers the IR and visible cameras for simplicity. This system could be controlled via a simple light sensor placed outside of the iris, permitting automated detection of night time conditions and thus automated switching on and off of the instrument without need for astronaut interaction (TBD). A conceptual design and layout of the detector is shown in Figure 1.

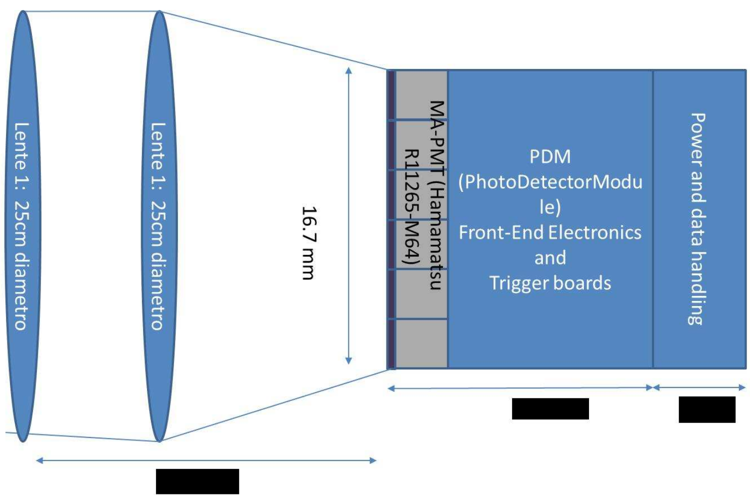


Figure 1: Mini-EUSO block scheme: Optical system with two Fresnel Lenses ($25\,\mathrm{cm}$ diameter) focuses the UV light on to a focal surface consisting of a single photo detection module (PDM), containing 36 multi-anode PMTs, all in all 2304 pixels

The main characteristics which define the Mini-EUSO experiment are:

- The area of the light collection surface (lens size).

- The Pixel FoV (angular radius of the pixel).
- The Instrument FoV (two half angular views).

Given these, it is possible to calculate or estimate the following important quantities by simulation:

- The surface corresponding to the projection of the instrument FoV.
- The photon background per pixel.
- The signal to noise ratio.

The Mini-EUSO parameters are displayed in Table 1 where the values are shown alongside those for the JEM-EUSO and the EUSO-Balloon instruments for easy reference and comparison. Additional information on the Mini-EUSO instrument is also summarised in Table 2.

Table 1: Defining parameters of the JEM-EUSO, Mini-EUSO and EUSO-Balloon instruments.

	JEM-EUSO	**Mini-EUSO**	**EUSO-Balloon**	**K-EUSO**
Lens Shape	Circular	Circular	Square	Circular
Lens Area	$4.5 \times 10^4\,\mathrm{cm}^2$	$490\,\mathrm{cm}^2$	$1 \times 10^4\,\mathrm{cm}^2$	$2.2 \times 10^4\,\mathrm{cm}^2$
Resolution	$560\,\mathrm{m}$	$5.4 \times 10^3\,\mathrm{m}$	$175\,\mathrm{m}$	
FoV/Pixel	0.08°	0.8°	0.23°	0.058°
	$1.4 \times 10^{-3}\,\mathrm{rad}$	$0.01\,\mathrm{rad}$	$4 \times 10^{-3}\,\mathrm{rad}$	$1 \times 10^{-3}\,\mathrm{rad}$
FoV/PDM	3.84°	$\pm 19^\circ$	$\pm 5.5^\circ$	$\pm 0.27^\circ$
	$6.7 \times 10^{-2}\,\mathrm{rad}$	$\pm 0.3\,\mathrm{rad}$	$9.6 \times 10^{-2}\,\mathrm{rad}$	$\pm 4.7 \times 10^{-3}\,\mathrm{rad}$
	$26.7\,\mathrm{km}$	$2.6 \times 10^2\,\mathrm{km}$		3.8km
N$^\circ$ PDMs	137	1	1	52
N$^\circ$ Pixels	315,648	2,304	2,304	119,808

Table 2: Mini-EUSO main requirements.

Parameter	Value
Dimensions	37×37×62cm^3
Weight	30 kg TBC
Power consumption	60 W TBC
Power Connection	ISS (27 V)
Location	UV transparent window of Russian Service Module
Operational requirements	Work only in ISS local night
Main observable	UV light 300 nm to 450 nm
Spot size	3.6 mm to 3.8 mm RMS TBC
Lenses	two 25 cm Fresnel lenses material PMMA
Focal Surface	1 PDM composed of 36 MAPMT, each 64 channels (total 2304 pixels)
	17×17×23 cm^3 (Safe:25×25×25 cm^3)
Temporal resolution	2.5 µs and above (averages in 10 ms, 100 ms and 1 s)
Direction of observation	Nadir

5 Functional Description

The Mini-EUSO instrument system consists of 7 systems and the respective sub-systems. These are summarised in the list below along with their respective abbreviations.

TES Telescope

PDM Photo-Detection Module

PWR Power

DP Data Processing

ADS Additional Data Acquisition System

HAR Harness

A functional block diagram of the Mini-EUSO instrument is can be found in Figure 2, showing the interfaces between the various systems. Table 3 lists the Mini-EUSO systems and sub-systems along with a short description and dimensions for easy reference. Here, a sub-system is defined as a unit which has its own casing or box. This means that each sub-system is to be integrated and tested separately, including spaceflight qualification testing. Some additional information about the Mini-EUSO interfaces is given in the list below.

Connection to the ISS

- Power connection (+27V main + spare)
- No data link with ISS or ground station, data is sent to Earth via the physical transfer of a hard drive (HD)

- Potential for some interface between data and astronauts, mainly for limited data analysis and control of power source for rebooting the system if necessary
- Position information comes from NORAD/SGP4 and data packets of the ISS (downlinked separately)

Time synchronisation

- Internal high precision clock, synchronised before launch and corrected offline
- In addition, time synchronisation of the detector using ground based high energy lasers will be explored

UV acceptance filter

- Single filter on each PMT, will improve the signal to noise ratio by enabling increased photon collection

Mechanical connections

- Tripod and Velcro

Autonomous operation

- Process of switching on and off the Mini-EUSO instrument could be be automated via the use of a simple UV sensor placed outside of the instrument's iris
- Suitable detector could be similar to that of the Tatiana-2 UV detector, consisting of one PMT and simple electronics
- This concept is still under investigation, but can easily be implemented in the final stages of the project design

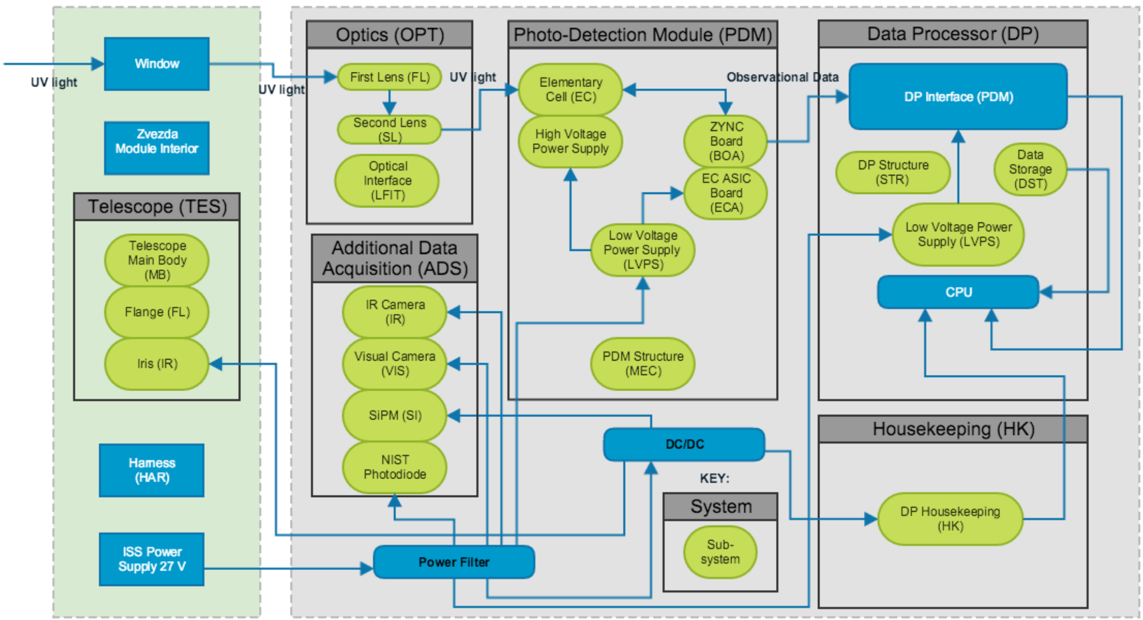


Figure 2: Functional block diagram of the Mini-EUSO instrument.

Table 3: List of systems and sub-systems for Mini-EUSO

System	Sub-system	Chapter Ref.	#	Description	Dimensions
TES	TES-MB	Main Body 7.2.1	1	Mechanical structure of the main body of the detector	37×37×58(TBC) cm
	TES-FL	Flange 7.2.2	1	Mechanical interface to ISS	50 cm TBC
	TES-IR	Iris 7.2.3	1	Protective mechanism to avoid saturation of focal surface	25 cm diameter TBC
OPT	OPT-FL	1^{st} Lens 7.2.5	1	Lens without fitting	25 cm diameter (TBD) Round
	OPT-SL	2^{nd} Lens 7.2.5	1	Lenses without fitting	25 cm diameter (TBD) Round
	OPT-LFIT	Fitting 7.2.6	2	Connecting lenses to TES-MB	Light tight
PDM	PDM-MEC	Mechanical Structure 7.3.2	1	Focal surface and EC-ASIC support board	
	PDM-EC	Elementary Cell 7.3.3	9	Potted, high voltage included	
	PDM-ECA	EC-ASIC Board 7.3.4	6	EC-ASIC Board (Spaciroc3)	
	PDM-DP	Zinq Board 7.3	1	Zinq Board (FPGA)	
PWR	PWR-MEC	Mechanical Structure 7.4.2	1	Power supply mech. structure	
	PWR-PRI	Primary Power Filter 7.4.3	1	Primary DC-DC (inc. filter)	
	PWR-SEC	Secondary Power Filter 7.4.3	1	Secondary DC-DC (inc. filter) 27V $\longrightarrow$ 12V $\pm$ 5V an. 5V dig.	

	PWR-LVPS	Low Voltage Power Supply 7.4.5	1		
	PWR-HVPS	High Voltage Power Supply box 7.4.6	1		
DP	DP-STR	Structure 7.6	1	Mechanical structure	
	DP-CPU	Main processing unit 7.6.1	1	PC104 standard	
	DP-PDM	PDM Interface 7.6.5	1	Interface to PDM board	
	DP-DST	Data Storage 7.6.3	1	USB, external or few SSD Extractable HD with SATA interf.	Velcro det. side (TBC) USB + Lock
	DP-HK	House-keeping 7.6.4	1		
ADS	ADS-BW	Black-White Camera 7.7.1	1	Black-WHite camera	$5\times5\times10$ cm
	ADS-VIS	Visible Range Camera 7.7.2	1	Visible camera	Same as For ADS-BW
	ADS-SI	SiPM sensor 7.7.3	1	SiPM	Dim. 5.5 ÃŮ 5.5 ÃŮ 3 cm
HAR		Harness 7.8	1	Power supply and GND cables	

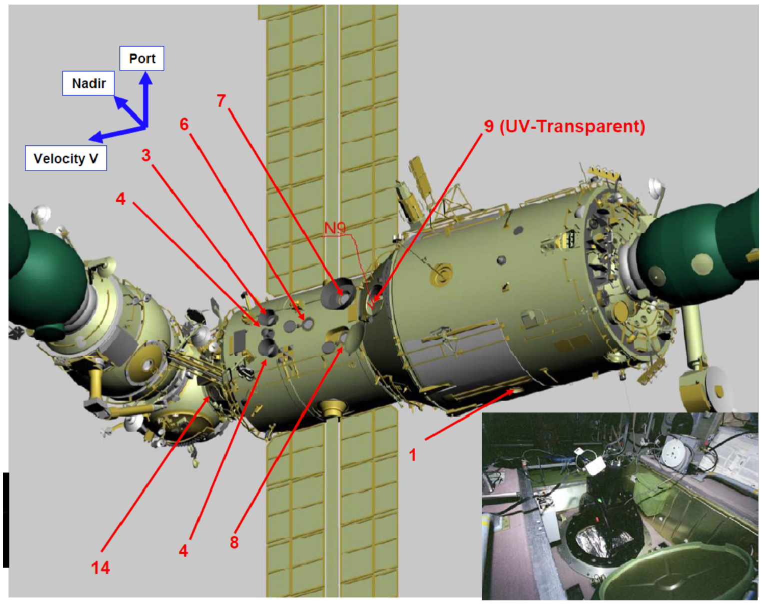


Figure 3: Russian service module seen from below. Port 9 is the one to be used.

6 Accommodation on the ISS

On the ISS the Mini-EUSO telescope will be located inside of the Russian Service Module Zvezda. As a result the operational environment will be room temperature (nominal range $18.3\,°\mathrm{C}$ to $26.7\,°\mathrm{C}$ at a sea level air pressure (nominal range $97.9\,\mathrm{kPa}$ to $102.7\,\mathrm{kPa}$).

6.1 Russian Service Module

The Russian Service Module Zvesda is equipped with a UV-transparent window facing in the nadir direction. Window number 9 in Figure 3 is the the window in question.

The transparency of the window in the UV range (300 to 400 nm) is above 80 $\%$ and close to constant over the spectral range, this can be seen in Figure 4. Mini-EUSO will be bolted to the rim of the window by a docking flange. This flange will fix the telescope in position and create a light-tight seal between the window and the telescope. In Figure 5 the relaxation experiment can be seen, bolted to the UV transparent window in the same manner as planed for Mini-EUSO.

6.2 Mechanical Structure and Interface

The dimensions of the whole detector are $37{\times}37{\times}62\ \mathrm{cm}^3$. An additional mechanical interface to the window will allow positioning. The detector system will need to be in darkness (black cloth?). Detector Block (TES-MB) to be attached to ISS via a flange (TES-FL) . Figure 6 gives an overview of the ME instrument, showing the main dimensions and positioning of the subsystems.

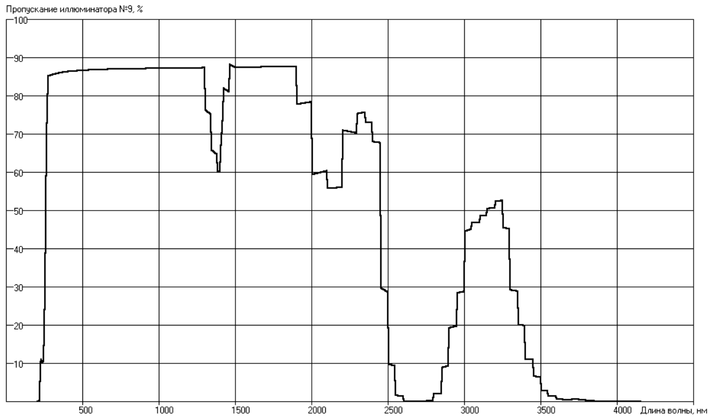


Figure 4: Window transparency as function of Wavelength $200\,\mathrm{nm}$ to $4500\,\mathrm{nm}$.

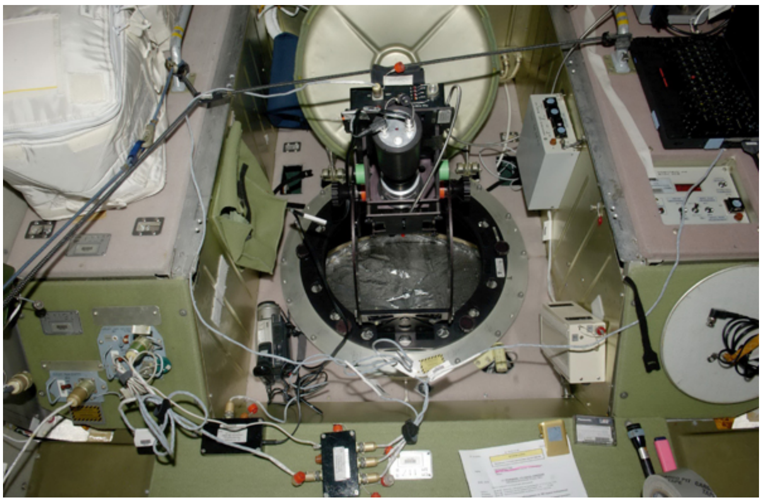


Figure 5: Setup of a previous experiment at the UV-transparent window.

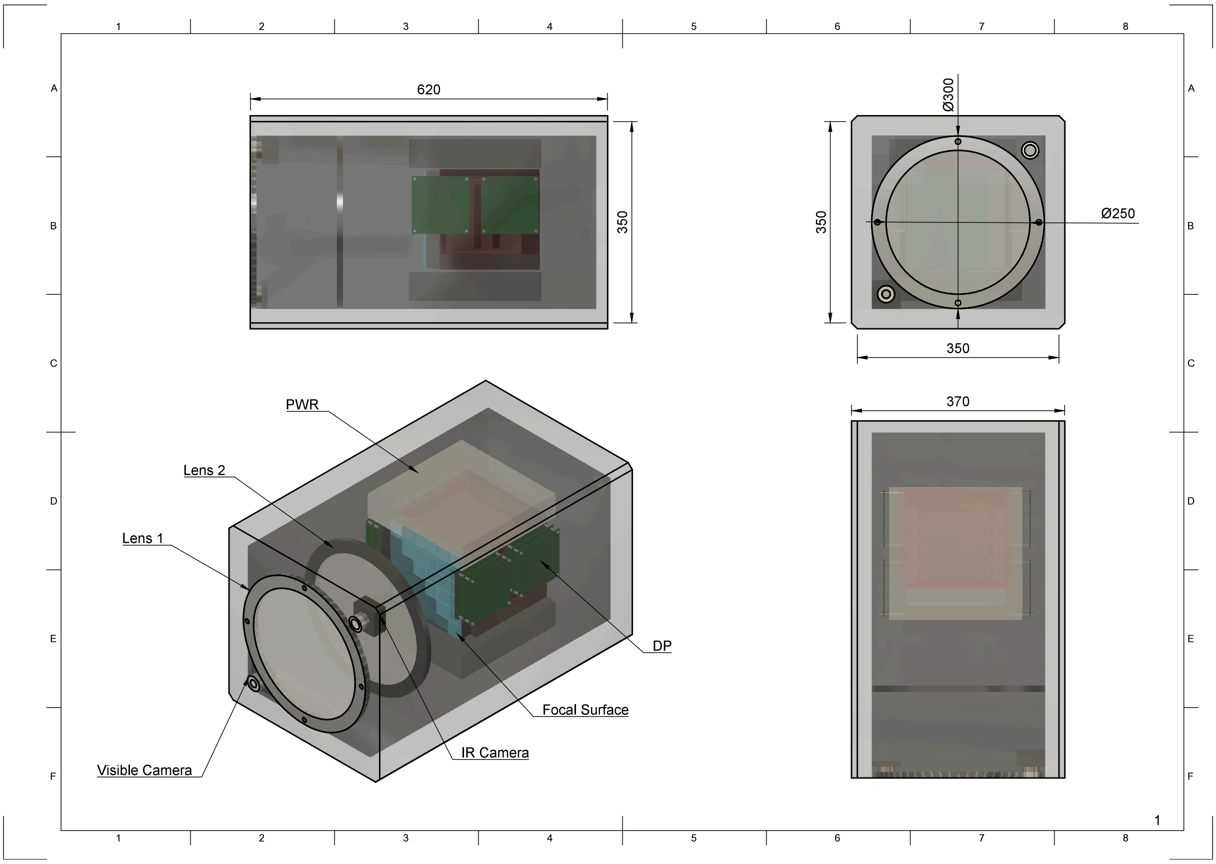


Figure 6: Orthographic projection of the Mini-EUSO conceptual design. The main dimensions and some visible subsystems are highlighted.

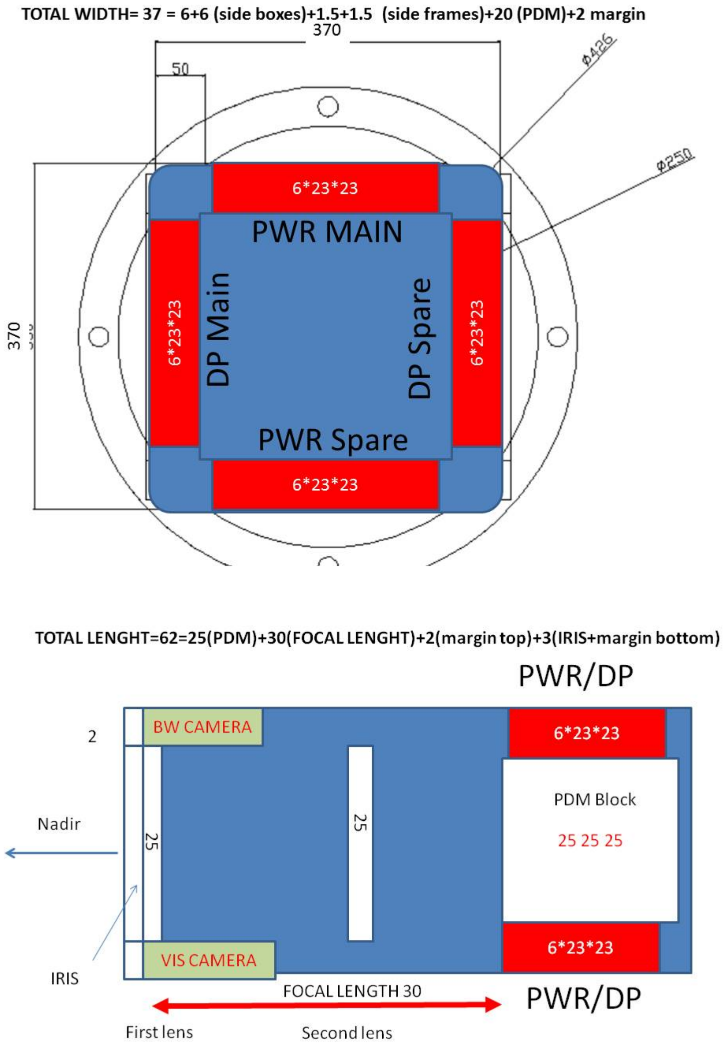


Figure 7: Top: Drawing of BW and VIS camera placements, bottom view. Centre: Placement of PWR and DP systems, bottom view. Bottom: Drawing of BW and VIS camera placements, side view.

7 Instrument Description

7.1 Main Systems

The Mini-EUSO instrument is made up of several systems and subsystems. There are 7 main systems and each system is in turn constitutes one or more subsystems. The different systems and respective subsystems are specified in detail in sections 7.2 through 7.8 and were summarised previously in Table 3. The 7 main systems are as follows:

TES	Telescope
OPT	Optics
PDM	Photo-Detection Module
PWR	Power
DP	Data Processing
ADS	Additional Data acquisition System
HAR	Harness

The functional block diagram is presented in Figure 2. The UV light signal is focused onto the PDM for detection. The PDM selects candidate events via the use of trigger algoritms and forwards this candidate data to the DP. Since the data interface of the PDM is well defined for the JEM-EUSO instrument, the other systems and sub-systems of Mini-EUSO are developed accordingly based on similar JEM-EUSO methods.

The PDM is attached to the telescope (TES) with an alignment accuracy of better than 0.1° (TBC). Therefore, the relevant PDM hardware can be delivered and integrated during the final stages of instrument assembly. If the alignment between TES and PDM is achieved and is reliable, the two sub-systems can also be shipped separately.

7.2 Telescope TES

The Telescope system consists of three sub-systems: the main body, the iris and the flange. A 3D graphical representation of the main body in relation to the rest of the Mini-EUSO instrument can be found in Figures 6 and 8. However the flange and iris are separate to the main instrument and so are not pictured there.

7.2.1 Main Body

The Telescope Main Body (TES-MB) subsystem is the mechanical structure to which all other systems are attached. The volume constrain is $37 \times 37 \times 62\ \mathrm{cm}^3$.

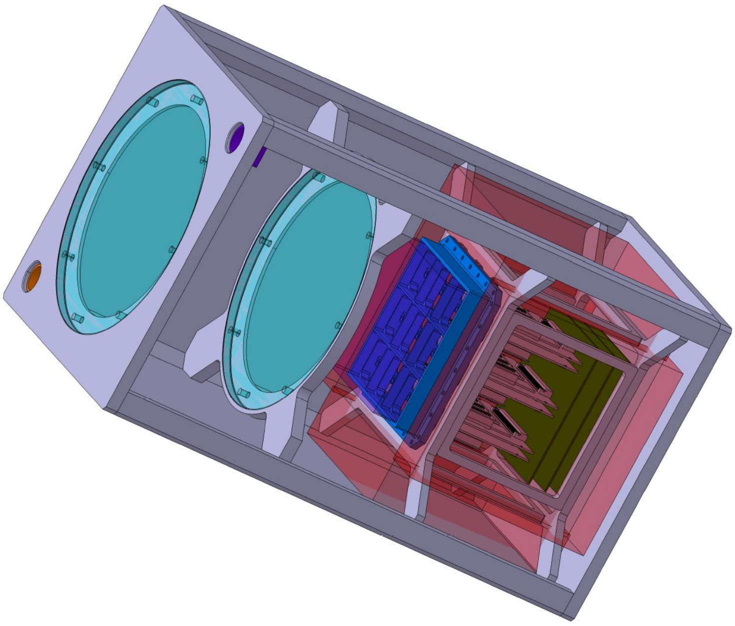


Figure 8: A three dimensional representation of the Mini-EUSO instrument main body including the BW (top right) and VIS (bottom left) cameras.

7.2.2 Flange

The Telescope Flange (TES-FL) is the mechanical interface between the Mini-EUSO telescope and the ISS. The diameter of flange is 50 cm (TBC). The mass of the flange will not have to be included in the Mini-EUSO mass limit of 30 kg.

7.2.3 Iris

To protect the light sensitive MAPMTs during ISS local day time an iris will be mounted in the detector. The iris will be operated by light-sensitive diodes, the Daytime Evaluation Unit (see 7.6.6) as seen in Figure 9. Redundancy can be applied to the light-sensitive diodes in case of failure. Further investigation is currently required into the exact placement of such an external detector. One of the Mini-EUSO project goals is to study the possibility of space debris (of size 1 to 10 cm) detection during the twilight period (ie. when debris is lit by the sun, but the Earth's surface is in darkness). Such a period should occur every 90 minutes for a duration of around 5 minutes. Care must be taken to ensure that any external diode observes the correct field of view that is relevant to the PDM, and that the instrument is also switched on and ready for data collection during twilight without risking any damage to the PMTs. The response of the HVPS could also play a role in the automated switching on and off of the PDM.

7.2.4 Telescope Optics OPT

A ray-trace simulation of the optical design of Mini-EUSO is shown in Figure 10. The OPT system consists of three sub-systems; two lenses and the surrounding support structure.

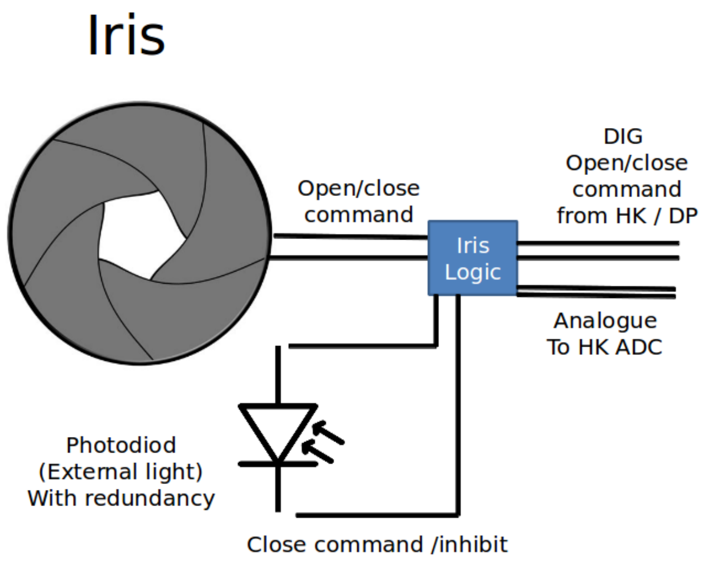


Figure 9: Basic iris operation and control scheme.

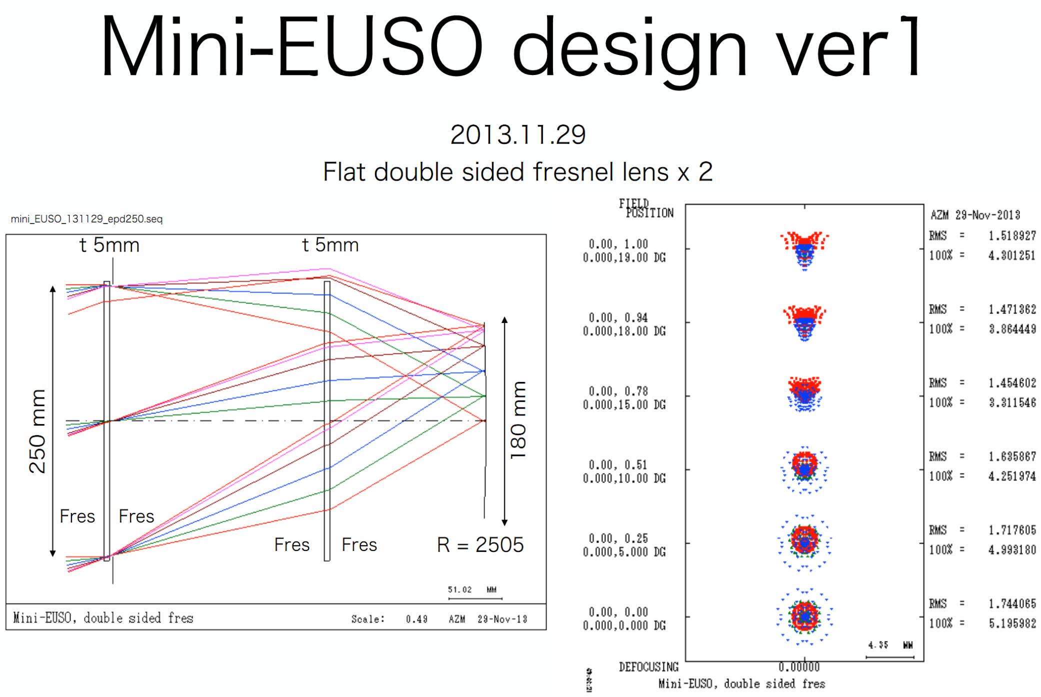


Figure 10: Left: Lens design of Mini-EUSO two lenses configuration. Scheme of the optical system (code-V simulation) of Micro-UVT. UV radiation enters from the left and the focal surface is shown towards the right side. Right: The point spread function (PSF) of the system.

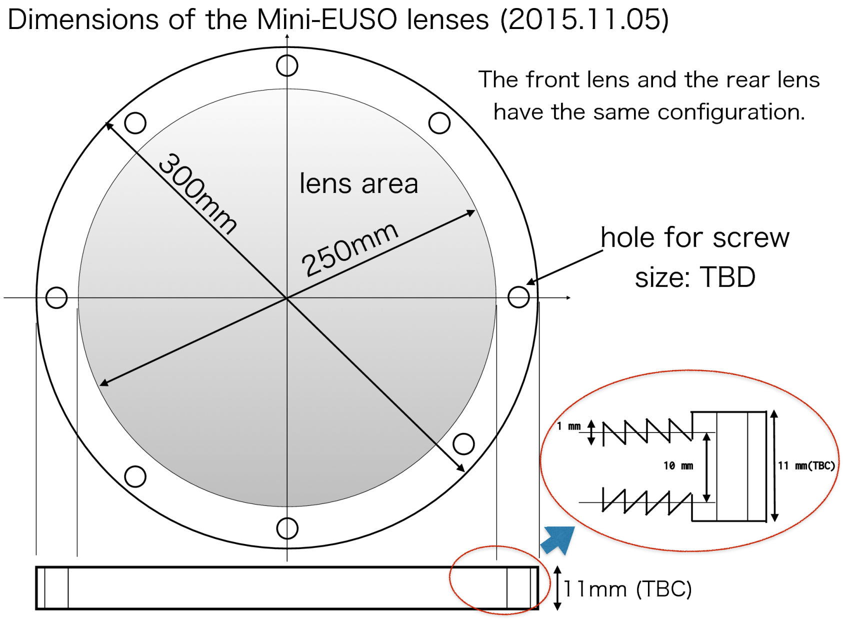


Figure 11: Specifications of the two-sided Fresnel lenses

7.2.5 Lenses

The optical system of Mini-EUSO is composed of two two-sided Fresnel lenses (the first lens, OPT-FL, and the second Lens, OPT-SL). Each lens is $25\,\mathrm{cm}$ in diameter, $11\ \mathrm{mm}$ thick (TBC) and weighing $3\ \mathrm{kg}$. The focal length will be $1474\ \mathrm{mm}$ (TBC) and the UV light will therefore be concentrated onto the focal surface of the detector. There is a $2\ \mathrm{mm}$ hole in the center of the lenses (for manufacturing purposes). Technical drawing of the lens is presented in Figure 11.

7.2.6 Lens Fitting

The lens fitting (OPT-LFIT) integrates the lenses to the TES-MB. The lenses have to be kept in position with a square $30\ \mathrm{cm}$ aluminium frame with hole in the center. Thermal expansion/contraction coefficient have to be provided to plan mechanics accordingly. The precision of the OPT-LFIT has to ensure a fitting tolerance of the lenses of $<1\ \mathrm{mm}$. It also has to be light tight to avoid contamination of reflected stray light. The shape of the lenses are depicted in Figure 12. To reduce mass the shape will be round with additional areas at 12,3, 6 and 9 “o'clock” for integration into the telescope.

7.3 Photo-Detection Module PDM

The top image in Figure 13 depicts a full PDM with 36 MAPMTs and the bottom image depicts the electronic readout board at the back of the PDM. The MAPMTs are grouped in units of 4 (2×2) and such a unit is referred to as an Elementary Cell (EC). The size of the whole PDM is $17\times17\times23\ \mathrm{cm}^3$ (Safe: $25\times25\times25\ \mathrm{cm}^3$).

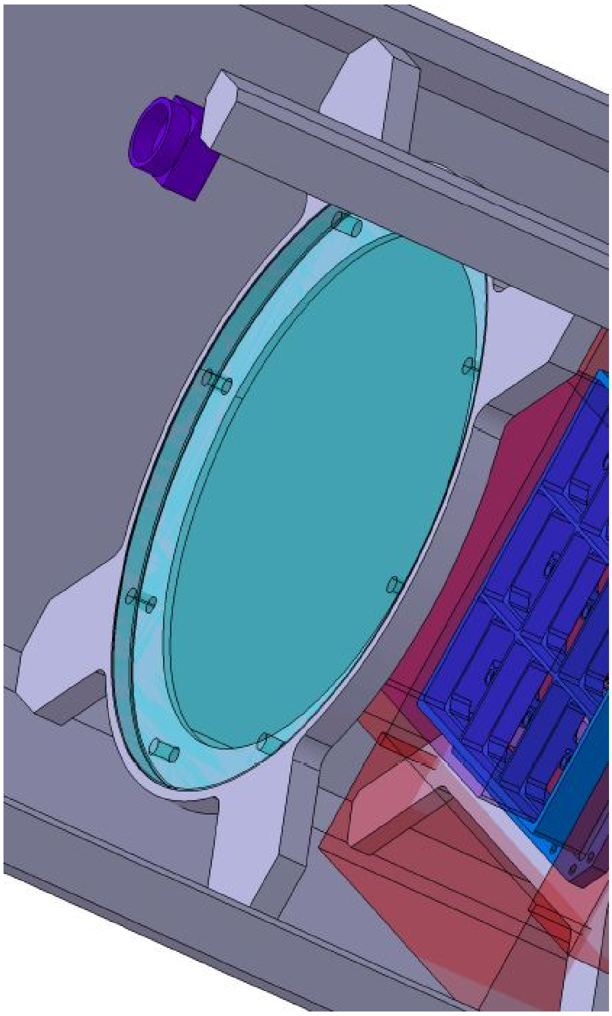
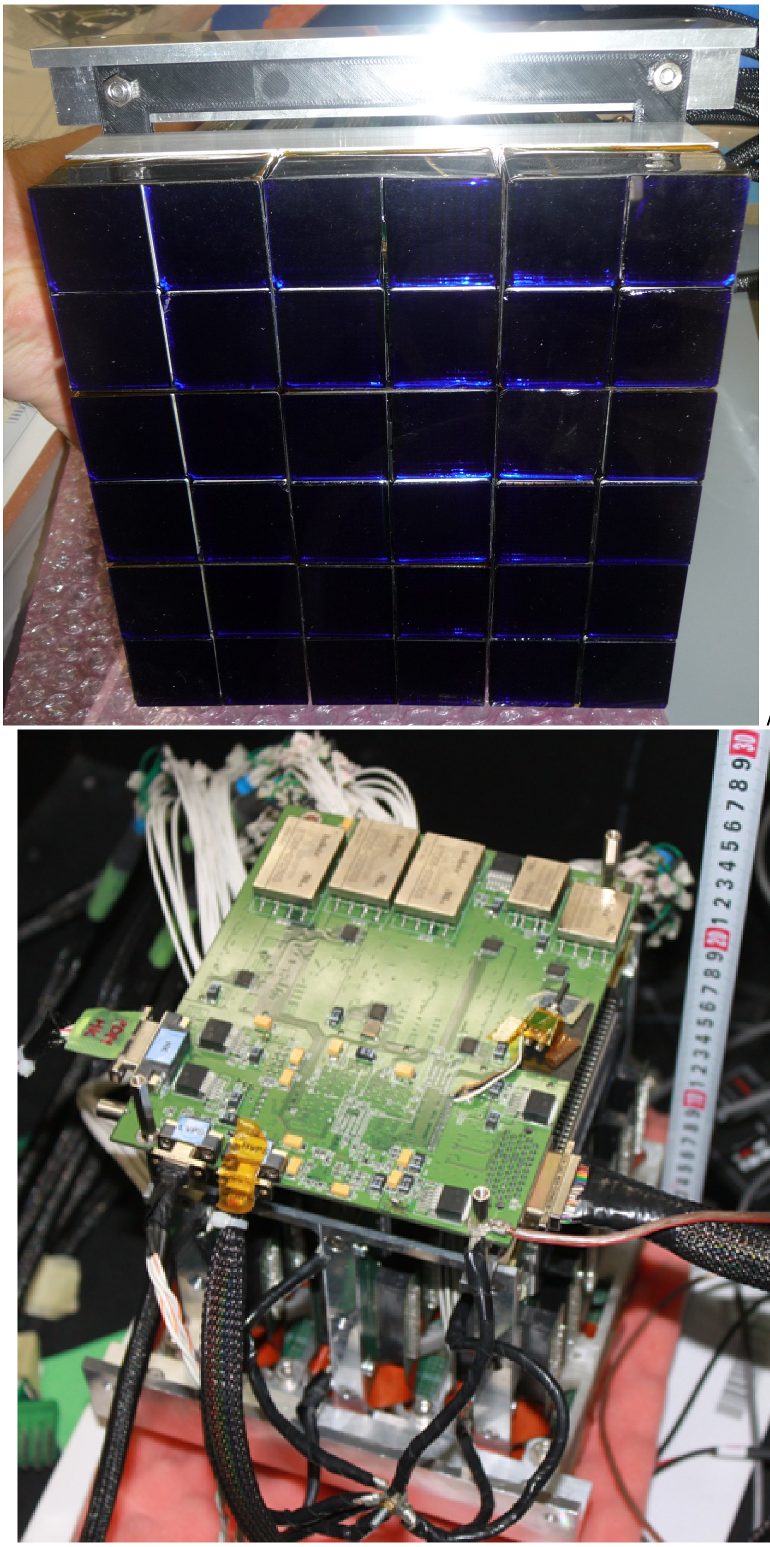


Figure 12: The form of the lenses, round with four additional segments at 12, 3, 6 and 9 "o'clock" for integration to the telescope.



//

Figure 13: Top: PDM structue with 36 PMTs installed (i.e. 9 ECs). Bottom: The readout electronics of the PDM.

The PDM support structure is divided in two parts, the MAPMT support structure and the

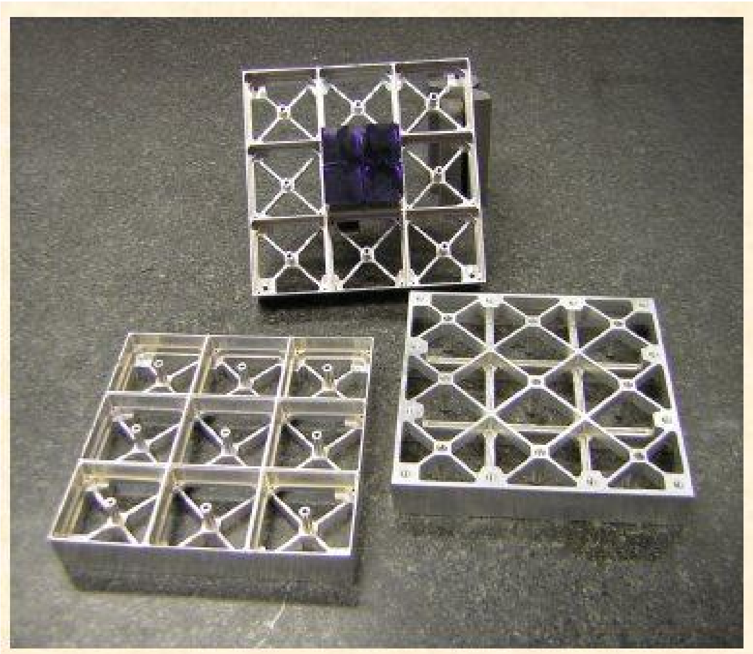


Figure 14: Mechanical support structure of PDM (only one is needed). In top frame an EC (4 PMT) are inserted in the center EC position. Support structure will be in hard plastic.

electronics support structure.

7.3.1 MAPMT Support Structure

The mechanical support structure of the PDM (PDM-SUP) will have the dimensions of $167 \times 167 \times 28.7(z)\ \mathrm{mm}^3$ and it will be produced in hard plastic thereby having a mass of only $0.33\ \mathrm{kg}$ and avoiding potential short circuiting. The top surface of the frame, where the MAPMTs will be attached, is not spherical, but flat. The design of the PDM support structure can be observed in Figure 14.

7.3.2 Electronics Support Structure

A schematic of the PDM Electronics Support Structure (PDM-ESS) can be viewed in Figure 15. It will house the electronics for the readout and first level data processing. The PDM-ESS will be constructed out of hard plastic with the dimensions of $167 \times 128 \times 130\ \mathrm{mm}^3$. The mass of the structure is estimated to be $0.3\ \mathrm{kg}$.

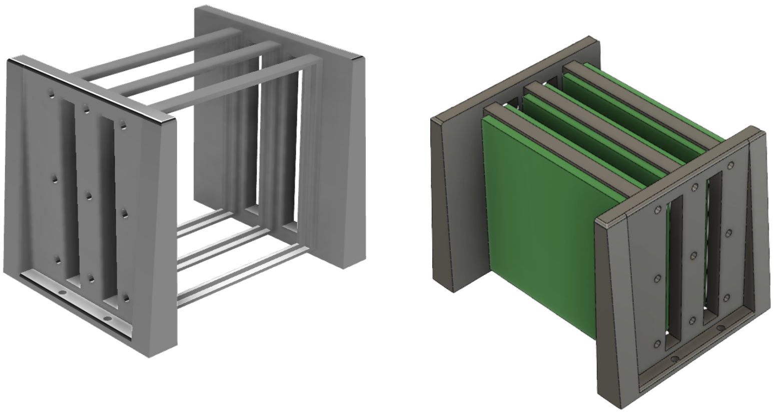


Figure 15: The support structure for the PDM electronics. Overall dimensions: 167mm x 128 mm x 130 mm. The image on the right shows the boards mounted onto the frame.

7.3.3 Elementary Cell

1 Elementary Cell (EC) consists of 4 MAPMTs (Multi-Anode Photo-Multiplier Tubes). The ECs are arranged in a 6×6 grid, and each MAPMT has 8×8 pixels for a total of 256 channels per EC (4×64). A single MAPMT without the UV filter (top) and a schematic representation (bottom) are depicted in Figure 16.

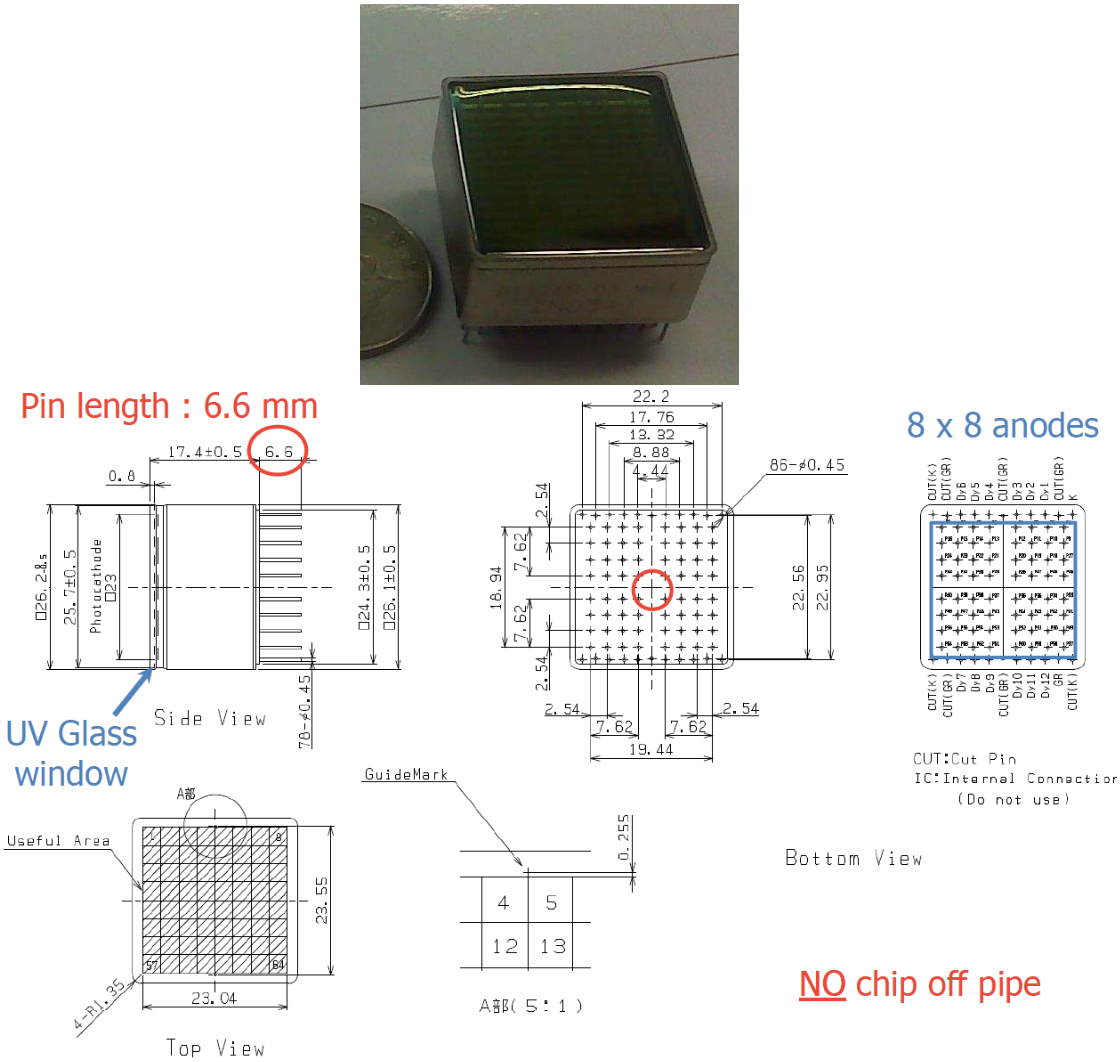


Figure 16: Top: Hamamatsu MAPMT M64 without UV filter. Bottom: Schematic drawing of the MAPMT side/top/internal view.

7.3.4 EC-ASIC Board

Sub Assembly Specifications: The EC-ASIC board can be seen in Figure 17.

7.4 Power PWR

The main power source of the instrument is the standard on-board +27 V. The power budget of the Instrument is 60 W. In order to limit the inrush current and reduce EMC noise a voltage filter is installed. Inside the instrument the +27 V is be converted to different voltage levels using standard DC/DC converters. The Power system is summarised in Figure fig. 18 and **????**.

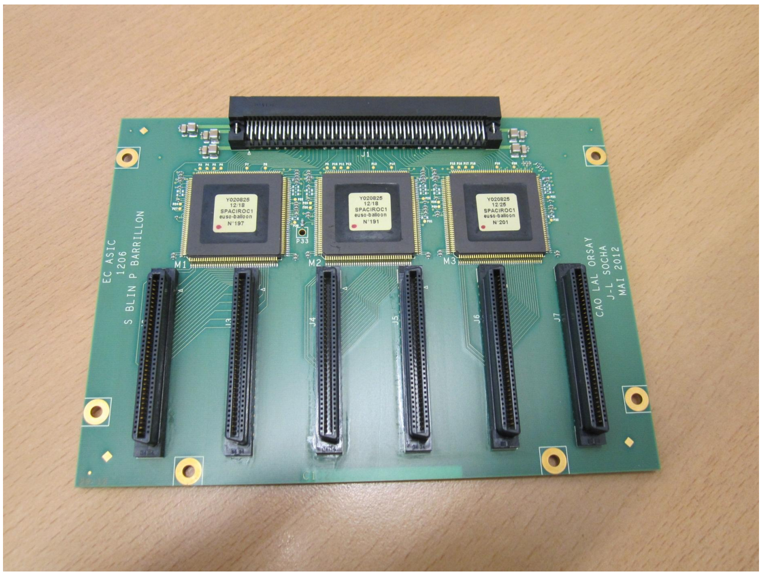


Figure 17: EC-ASIC Board

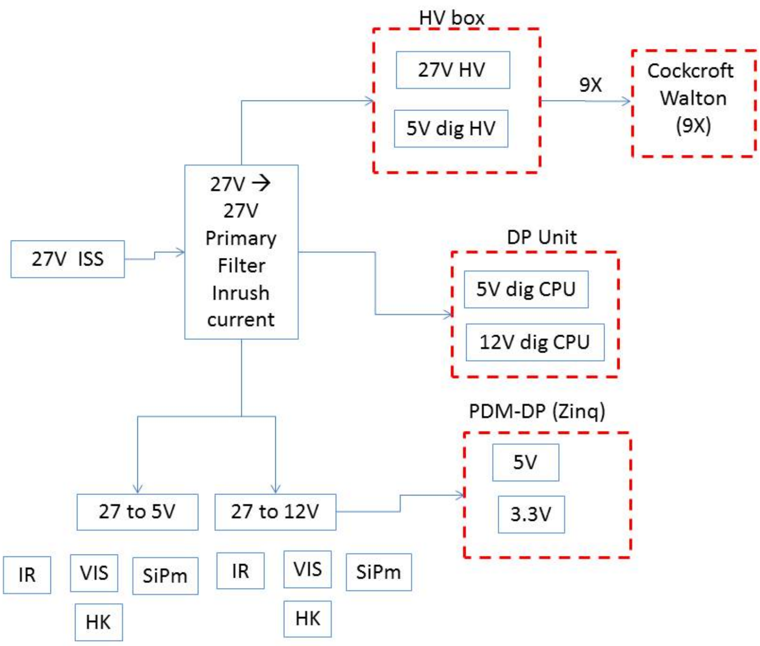


Figure 18: Block diagram of the Power system (update top pic with bottom data).

7.4.1 Power Distribution and Grounding

Mini-EUSO instrument has a 27V power supply from the ISS. The primary power lines shall be isolated, i.e. the return lines shall be isolated from the secondary return which is the ground line of the secondary power distribution system. The primary power distribution is shown in

Figure **??**. The primary return lines shall be twisted with hot lines.

7.4.2 Mechanical Structure of the Power Supply

The mechanical structure housing the power supply and DC/DC converters is a baseplate of 15*25 cm which houses the six modules.

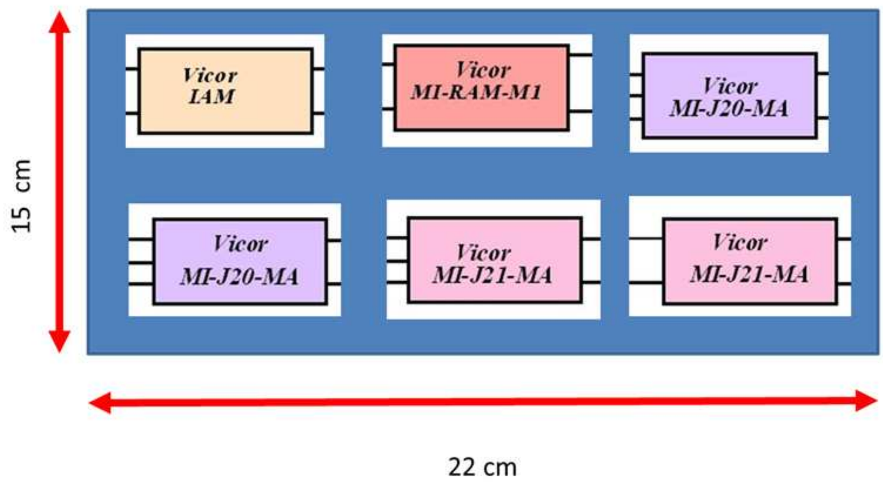


Figure 19: Scheme of the LVPS power distribution: they are allocated on a board 25*15cm

7.4.3 ISS Voltage Filter

In order to protect against inrush current a pre-charge circuit, VICOR IAM (input attenuator module) isbe installed in order not to exceed the power consumption budget of the instrument during power-on operations.

7.4.4 DC to DC Converter

From the main ISS voltage of +27 V the following voltage levels are produced:

- 27 V for the High Voltage
- 5 V for the High Voltage
- 5 V for the CPU
- 12 V for the PDM-DP (Zinq board)
- 12 V for the BW Camera
- 12 V for the CPU Camera
- 12 V for the Visible Camera

PDM board receives data from the 36 ASICs each 2.5µs. It stores the data in a 128 GTU buffer and performs trigger readout. Can also perform pedestal and background measurement. Averages can also be calculated by PDM to measure noise on different time scales.

7.4.5 Low Voltage Power Supply

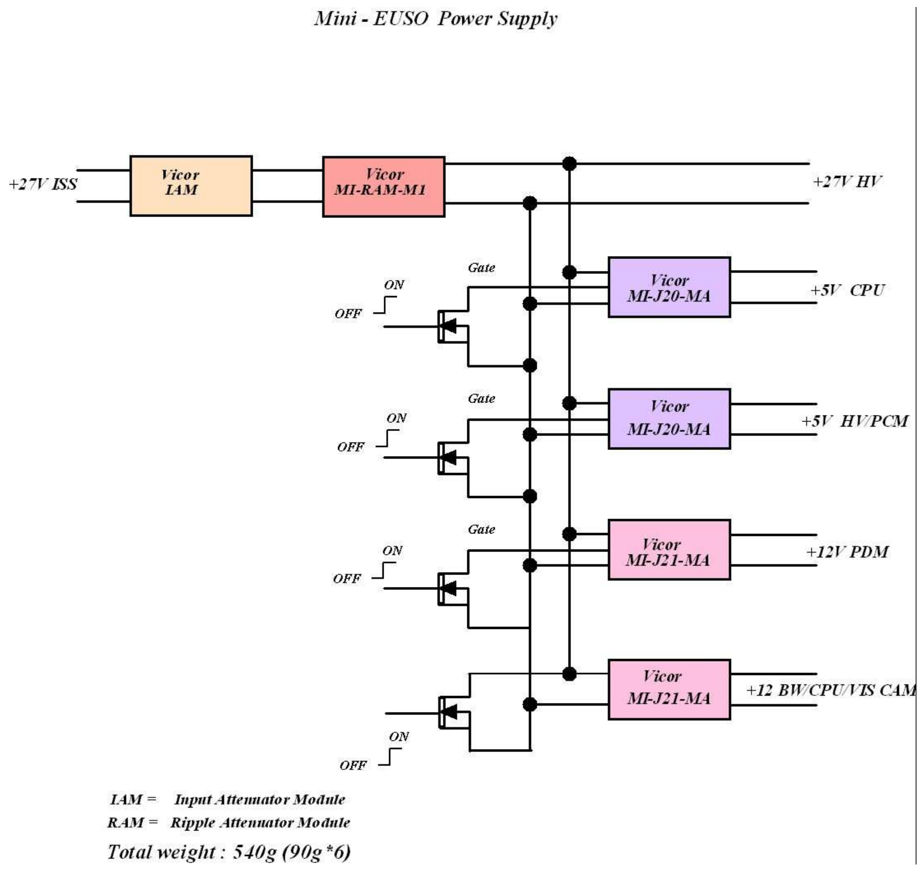


Figure 20: Scheme of the LVPS power distribution.

7.4.6 High Voltage Power Supply

High Voltage power supply distributes the power (4 connectors. 27 V input, 27 V output, 5 V output) from the LVPS and the HK to the Cockcroft Walton (9 connectors).

7.4.7 LVPS Requirements (TBC)

Functional requirements

- The LVPS module shall provide isolation interface between the 28 V bus and the payload subsystems.
- The isolation stage will comprise isolated DC-DC converters with efficiencies equal to or higher than 80%.

- Propagation failures inside of LVPS modules must be controlled. If any failure event occurs, it cannot propagate to either the primary or secondary sides of the isolation stage.
- The LVPS module must include remote on/off functionality, in order to be controlled.
- The DC-DC Converter must provide output over-current protection function.
- The maximum PCB dimensions must conform to 6 by 23 by 23 cm

Environmental requirements

- The LVPS elements must withstand temperature variations in the range 0°C to +50°C during operation.
- The LVPS element must be able to operate at atmospheric pressure.

Communication requirements

- Tele-command (TC) must be used for turning on/off remotely LVPS module.
- Status on/off by contact closure (CC) signal must be provided from LVPS module.
- Telemetry (TM) data, about voltage and current (V & I) levels, must be generated and transmitted from the LVPS module to the HK subsystem.

7.4.8 Power Consumption

Current power consumption is <15 W (5.2 W in PDM block + PDM board, 5 W CCB, 2 W storage system, + margin and DC/DC efficiency), see Figure 21.

ITEM :	ASIC				HV-PS			PDM Board		TOTAL per PDM
Quantity per PDM	36				1	9		1		
Voltage level [V]	1.5	3	3	3	3.3	3.3	28	1.5	3.3	
Analog (A) / Digital (D)	D	D	A	A	D	A	A	D	D	
Purpose	LVDS	Digital circuit	photon counting	KI	MCU	OSC	CW	FPGA Core	I/O	
Power consumption per ITEM [mW]	4.2	20.7	63		45	5	55	1000	500	
Power demand to V_{supply} [mW]	151.2	745.2	2268		45	45	495	1000	500	5249.4
Current per supply [mA]	100.8	248.4	756.0		13.6	13.6	17.7	666.7	151.5	1968.3
Power per PDM [W]	3.1644				0.585			1.5		

Figure 21: Power consumption of PDM block, including PDM board

7.4.9 Fuse

Fuse voltage 27V Fuse amperage 3A (TBC) (70W/27V)

Figure 22: Top: Picture of the thermal fuse. Bottom: Specifications of the thermal fuse.

7.4.10 Switches

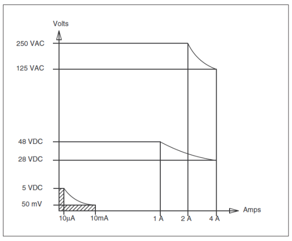
According to the electrical power connection, the switch selection should be based on the next conditions, which are the next

- Temperature operation range: 10 °C / 30 °C.
- Operating Voltage: 28 V
- Watts Required: 30 W
- Current = 3 A

Model: M3950/16 and M83731/24.
Company: Apem

ELECTRICAL SPECIFICATIONS

- Max. current/voltage rating with resistive load : 2A 250VAC - 4A 125VAC - 4A 28VDC
- Minimum load : 10mA 50mV, 10µA 5VDC
  When used above 300mA 28VDC, the gold plating is removed on contact areas and is considered only as a protection against oxidation during storage.
- Initial contact resistance : 10 mΩ max.
- Insulation resistance : 1.000 MΩ min. at 500VDC
- Dielectric strength :
  1.000 Vrms 50 Hz min. between terminals
  2.000 Vrms 50 Hz min. between poles
  2.000 Vrms 50 Hz min. between terminals and frame
- Contact bounce : 2 ms max.
- Electrical life :
  - At 2A 250VAC - 4A 28VDC :
  20.000 cycles (10.000 for functions 5, 4-1R, 4-2R)
  - At low level (50mV 10mA) :
  150.000 cycles (switches with 2 maintained positions)
  100.000 cycles (switches with 3 maintained positions)
  50.000 cycles (momentary functions 7, 8, 4-1R, 4-2R, 5)



GENERAL SPECIFICATIONS

- Torque : 1,50 Nm (1.10 Ft.lb) max. applied to nut
- Panel thickness : 8 mm (.314) max. - 3 mm (.118) min.
- Shock test : 50g - 11ms (IEC 68-2-27)
- Vibrations : 10-500 Hz - 10g (IEC68-2-6)
- Operating temperature : -40°C to +85°C
- Humidity test : 56 days, 93 % R.H., 40°C (IEC 68-2-3)
- Salt spray test : 96 hours (IEC 68-2-11)

Figure 23: Spec. on the Switch

7.5 Cable and connector

10 pin connector as in picture: 4 pins +27V 4 pins -GND 2chassis. Grounding cable is separate.

Figure 24: Power connector

7.6 Data Processing DP

The basic data processing chain of JEM-EUSO is implemented in to the Mini-EUSO experiment. The design of the PDM is identical to teh EUSO-Balloon long duration balloon flight. The PDM requires a dedicated data transfer interface and a PC-104 form factor is employed to interface to PDM. The one PDM data processing is implemented in FPGA and other auxiliary functions are implemented in the residual part of the FPGA. The support functions such as power supply, HK monitoring functions, etc. are also implemented according to the requirements of the Mini-EUSO system.

7.6.1 CPU

The Data Processing block (DP) consists of the following:

- RTD/PC104-Express Single Board Computer & Controller

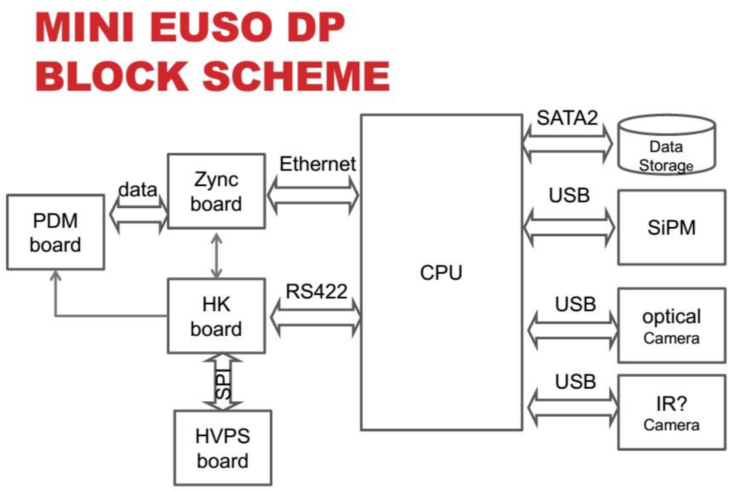


Figure 25: Scheme of the connections of the DP

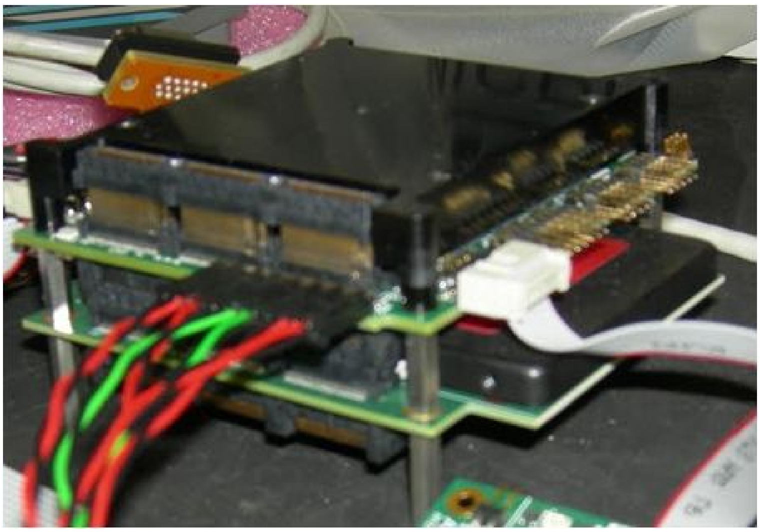


Figure 26: Removable Hard Disk below the DP

Figure 27: The CPU with the heat sink to be linked to the wall of minieuso

- Processor: AMD Fusion G-Series FT1 Single Core 615 MHz
- Memory: 2 GB DDR3 SDRAM
  (Surface mounted for maximum reliability)
- Mass Memory:
  - Serial ATA (SATA) 32GB Surface-Mounted SATA Flash
  - Three additional SATA2 ports (two on the top bus connector, one on the bottom)
- OS: Linux
- Power consumption: $\leq$7.5 W.
- PCIe/104 User Programmable FPGA Modules
- Boards: CPU, HK, HDD, FPGA, Power

7.6.2 Data Handling Structure

ASIC Single photon counting data are read from ASIC board (one each PMT, for a total of 64 channels for each Spaciroc 3 ASIC from the Omega group) every 2.5 µs = 1 GTU (Gate Time Unit). All data is taken in photon counting mode and is sent to the Zinq board.

Zinq board reads the data and performs trigger algorithm on 128 GTU frames and storage on TBC frames. If the data pass the trigger (can be simple background readout according to parameters, data are sent to the DP for storage. Event size is therefore 324 kbyte + headers/footers of each event. Full transmission is not possible, since it requires 0.96 Gbyte/second or 3.5 Tbyte/hour

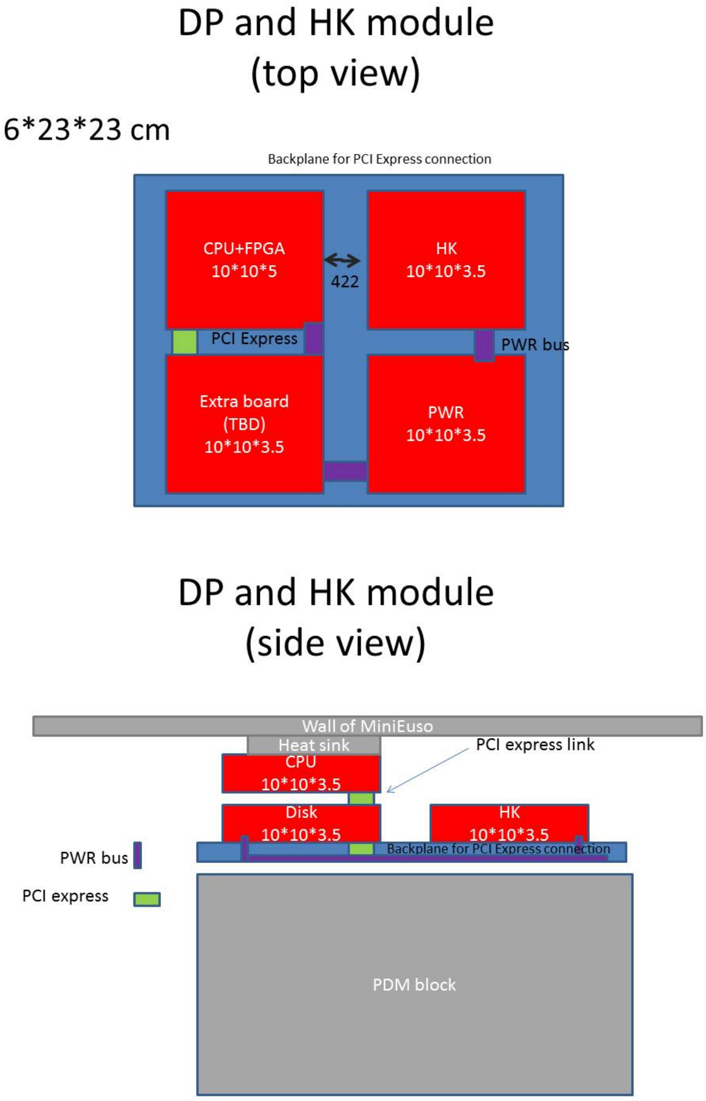


Figure 28: Layout of the DP block elements

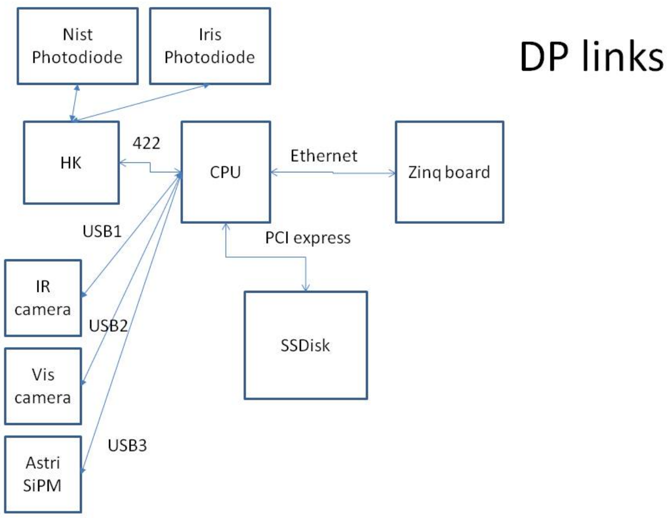


Figure 29: Layout of the DP data links.

We will plan several acquisition modes to measure various kind of background, test various signals (physics, internally and externally generated). This will be subject of a separate document.

Requirements:

- Storing the selected data on a 1 Tbyte (TBC) RAID-01/RAID-10 (TBD) system composed of 4 Solid State Disks (SSD) each with a capacity of 512 Mbyte (TBC)
- Control the HK board, record and sent HK data
- Passing the configuration data from CPU to Zinq

7.6.3 Data Storage

The Data will be stored on external Solid State Disks (SSDs) which will connect to the DP via USB connector. The disks will be coupled with the telescope through Velcro. These SSDs will be transported to and from the ISS through resupply missions.

7.6.4 Housekeeping

The monitoring system requires $\pm$12V and 5V.

The HK intefaces to DP via 422 detector (see figure 29)

THe HK monitors (see Figure 32):

- Voltage and Current of LVPS
- Voltage HVPS (TBC)
- Temperature sensors about 16 sensors (number TBC)

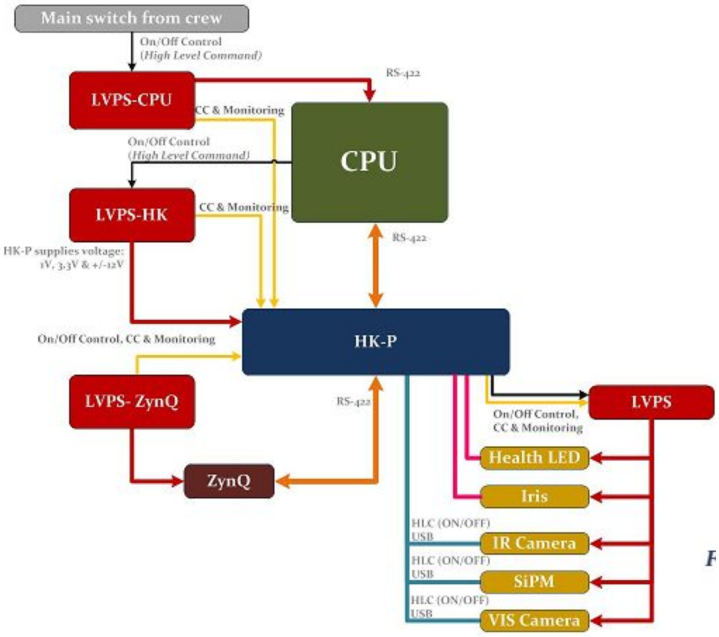


Figure 30: Block Scheme of the HK connections.

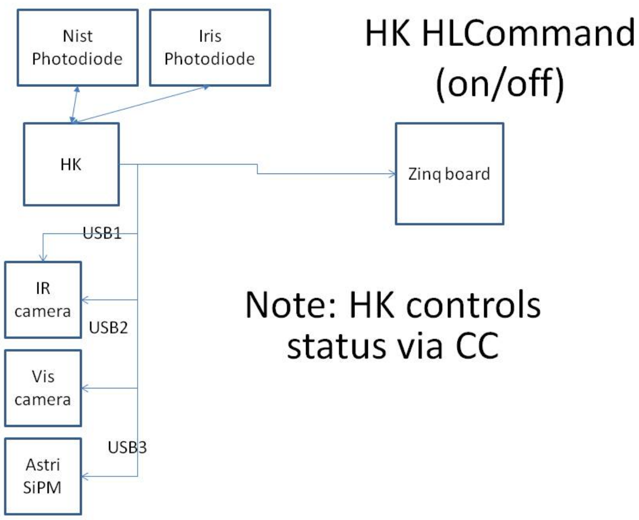


Figure 31: Layout of the HK command links.

- 2 lenses
- Sipm
- 2 DP
- 2 Zinq board
- 2 LVPS
- FS
- 2 flange
- TBC

- Contact Closure for about 16 points (number TBC)
  - Zinq Board
  - VIS cam USB
  - BW cam USB
  - Nist Photodiode
  - Astri SiPM LVPS
  - Astri SiPM USB
  - Iris open/close
  - TBC

THe HK should control with HLC:

- Zinq board (TBC)
- VIS camera
- BW camera
- Nist photodiode
- Iris open/close
- Astri SiPM LVPS
- Astri SiPM USB

Functional Requirements (to be updated) The HK board distributes tele-commands and collects telemetry from several sub-systems of the instrument in slow control mode, i.e., within time scales of the order of 1 to few seconds. The HK has interfaces with the following sub-systems: LVPS, Zinq, HVPS, CPU. The HK has On/Off and status monitoring capability (HL-CMD/CC) of LVPS boards, it is responsible for monitoring voltages and currents at the PDM/DP LVPS, has a serial bus to convey telemetry (TM) and tele-commands (TC) through the CPU interface, and/or to other sub-systems if required. The HK manages the following communication protocols: SPI, RS232, RS422, HL-CMD, CC, Open drain output.

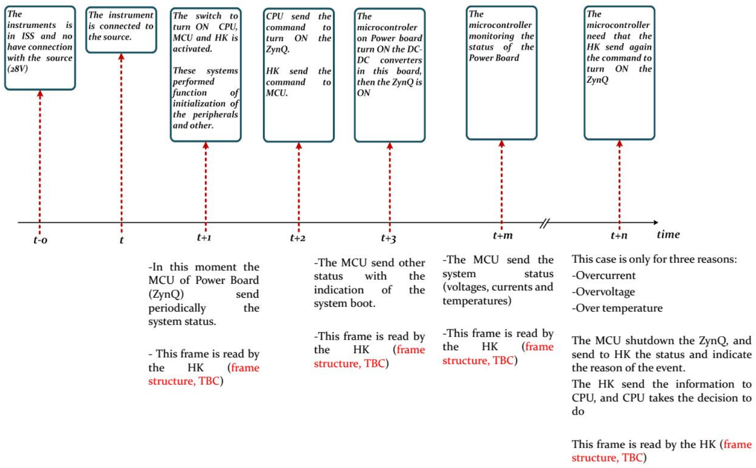


Figure 32: Block Scheme of the turn on sequence.

The HK is implemented around an off-the-shelf microprocessor board (Arduino Mega 2560), combined with 5 custom-made protocol interface boards to pre-process the various signals. The HKDP performs On/Off and status monitoring of all the LVPS boards and, through them, of their associated subsystems, as well as monitoring of temperature, current and voltage, distribution of TC and reception of TM, and the generation of alarms for tasks that do not require response on time scales below 1 sec. Alarms and reset signals generated by other susbsystems are also handled by HK under CPU instructions. The HK functions in two modes: cyclic and on-demand from the CPU.

7.6.5 Iris Operations

The DP will monitor the operation of the protective iris (see 7.2.3). The opening and closing of the iris will be based on the light conditions observed by light-sensitive diodes on the front of the telescope (see 7.6.6). The basic scheme of the iris control system can be seen in Figure 9. The operation of the iris is automated and only monitored by the DP. If malfunction of the control system occurs the DP has override power. TBC

7.6.6 Daytime Evaluation Unit

The Daytime Evaluation Unit (DEU) is a photo sensor located on the front of the telescope, located such that it is constantly exposed to the surface of the earth, independently of iris operations. The DEU will monitor the light levels and the DP will operate the iris based on the data from the DEU. This includes both opening of the iris when light levels are low enough as well as closing it when local dawn at ISS is approaching.

7.7 Additional Data Acquisition System ADS

The Additional Data Acquisition System (ADS) consists of two additional digital cameras mounted on the rim of the front end of the telescope. The two cameras, one being sensitive in the infra-read spectrum and the other in the visible range, will be mounted inside the iris thereby having the same operational time as the main telescope. Data from the cameras will help in the measurements of the emissions of the Earth and the study of transient phenomena. Additional science objectives specific to the VIS range will be described in the various documents.

- Power BW: <4 W (from Tokyo presentation)
- Power vis: TBD<4 W
- Voltage BW: 12 V, provided by shared DC-DC converters
- Voltage Vis: provided by shared DC-DC converters
- Data and command Link: USB via CPU
- Operating system: Linux (Flavour TBD)
- Power on/off will be commanded by CPU to the HK board.
- Data budget: TBC, determined by HDD size.
- Optimal Acquisition rate: 1 frame every 25 s to allow overlapping of the FoV.

The acquisition for BW and VIS cameras will take place with two separate jobs, running in parallel to the main acquisition of Mini-EUSO. Execution of the specific program will be controlled by a program manager which handles all processes.

Commands to the VIS and BW cameras are sent as setup parameters in a configuration text file. The default file is loaded prior to launch. In case of specific changes the configuration file can be uploaded to the ISS and then loaded via SD card to Mini-EUSO. Time of implementation will be of the order of days, according to crew availability. Data will be physically sent to the ground every 6 months (TBC) with the rest of the UV data.

7.7.1 Black White Camera

The BW Camera (ADS-BW) will operate in parallel with the main telescope providing black white data. It will operate durign the night in conjuction with the other detectros.

Figure 34: View of the VIS-Camera.

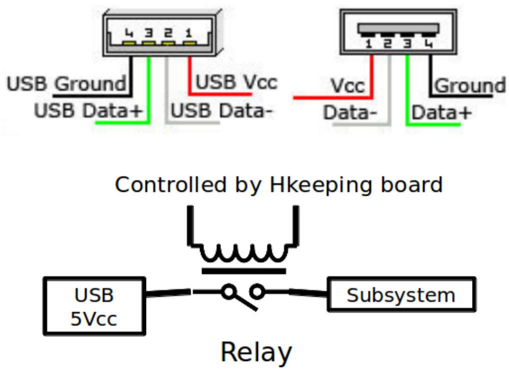


Figure 33: Basic scheme of cameras and SiPM relay control.

7.7.2 Visible Camera

The second ADS camera (ADS-VIS) will be sensitive in the visual range ($390\,\mathrm{nm}$ to $700\,\mathrm{nm}$). The specifications of the ADS-VIS are the same as for the ADS-BW.

EO-2013C

Model Number EO-2013C

Pixels (H x V) 1600 x 1200

Dimensions (mm) 34 x 32 x 27.4

7.7.3 ASTRI SIPM

Box of detector should be couple mechanically to Mini-EUSOchassis to improve thermal stabilization.

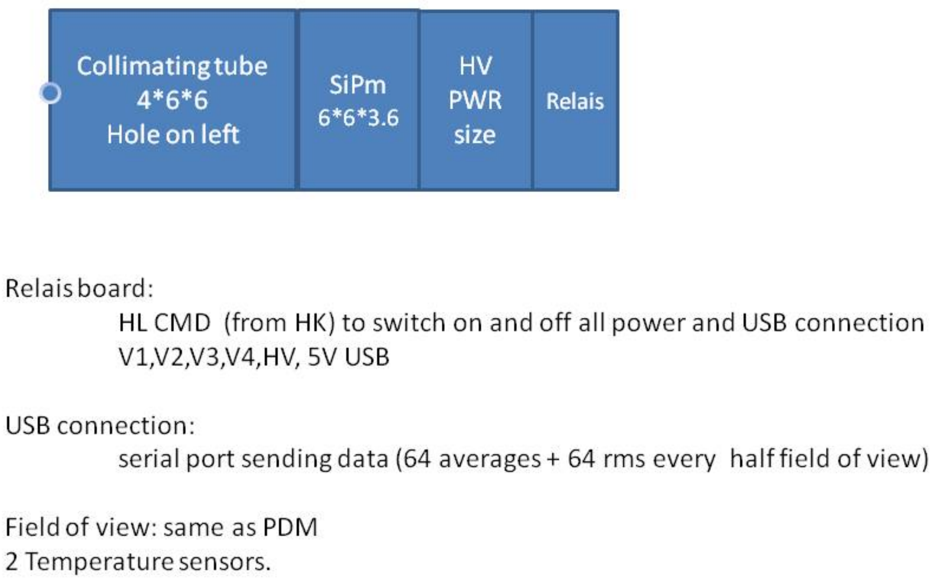


Figure 35: ASTRI SIPM mechanical block scheme

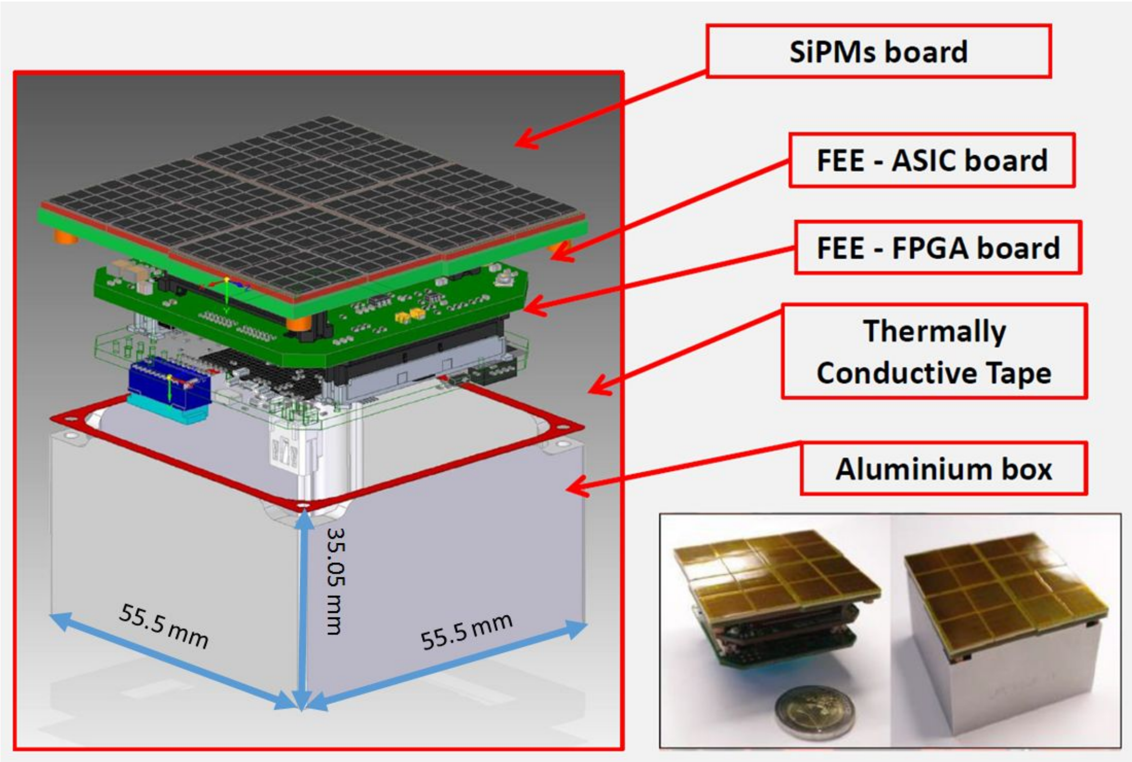


Figure 36: ASTRI SIPM drawing

- dimensions: 5.5×5.5×3 cm (3 on z axis) + 4 cm optics on z for a total of 7 cm on z
- weight Aluminum container = 75 g electronics =70 g total weight less 150 g.
- Optics TBC, either small lens or collimator with pinhole
- power 3 W TBC
- 64 channels
- USB output
- Measures background with variance method
- Requires: thermal stabilization, therefore good thermal coupling and cooling (Peltier) TBC.

Power supply for ASTRI (provided by ASTRI PWR box). Powers indicated are maximum. Nominal consumption is half.

- V1: + 3.6V DC $\leq$ V+ 1 FEE PS $\leq$ +5.0V DC, Vnominale = +3.6Vdc; PV1 = 2W max
- V2: + 5.6V DC $\leq$ V+ 2 FEE PS $\leq$ +5.9V DC, Vnominale = +5.6Vdc; PV2 = 1W max
- V3: - 5.0V DC $\leq$ V- 3 FEE PS $\leq$ -2.7V DC, Vnominale = -3.3Vdc; PV3 = 1W max

- V4: + 6.0V DC $\leq$ V+ 4 FPGA PS $\leq$ +12.0V DC, Vnominale = +7.0Vdc; PV4 = 3W max
- HV SiPM 55 V +- 3 V. max 9mA.

7.8 Harness HAR

Micro-D Connectors and Cables with screws have to be used. No connector without screws can be used due to vibration.

See $http://www.glenair.com/micro_d/$ or $http://fr.farnell.com/webapp/wcs/stores/servlet/Sea$ $25\&st = micro + d + plug\&catalogId = 15001\&categoryId = 700000047501\&langId = -2\&storeId = 10160$

Note that there are version for PCB, pigtail (with cables already soldered) and connector saver.

Figure 37: Two examples of microD connectors. Top: Glennair, Bottom: Cannon. Note that there are several versions, some already prepared with cables.

7.8.1 LED of power panel

- CPU on

- PDM-DP on
- PWR 27
- PWR 12
- PWR 5
- Disk on
- Disk full (TBD)

7.8.2 External Connectors

- PWR MAIN
- PWR SPARE
- GND
- PDM-DP JTAG (AUX Connector)
- PDM-DP 2nd Ethernet (AUX Connector TBD)
- PDM-DP Uart connector (AUX Connector)
- DP VGA (AUX Connector)
- DP Keyboard and mouse (AUX Connector)

AUX connector will not be used in space. All connectors should be in an excased region to protect them from being hit

7.8.3 Slots and removable objects

- Hard Disk
- SD card
- Fuse

7.8.4 Wiring Between Components

The wire harness are categorized as follows.

1. Primary Power Harness
2. HL Command Harness
3. Data Harness
4. HK Sensing Harness

As the baseline, the signal line between components shall be differential media such as LVDS (Low Voltage Differential Signalling), RS-422, differential analogue, etc. Primary Power Harness shall not share the connector with the harness of other category. HL Command Harness will be wired by shielded twisted pair. HK Sensing harness is wiring passive sensor wiring such as thermistor, platinum sensor which may be bundled with signal harness.

7.9 Functional Block Diagram

7.10 Mass and Power Requirements

The mass requirements for the main parts of the telescope can be found in Table 4. The power consumption of the telescope is estimated to be 60 W.

Table 4: Mini-EUSO mass requirements

Item	Number	Weight [kg]	Total [kg]
Lenses	2	3	6 TBC
Lens Frame	1	TBD	
	1	TBD	TBD
PDB Box	1	0.7 (only mech.)	
Electronics	TBD		

Table 5: Mini-EUSO power requirements

Item	Voltage	Power Nominal (W)	Power Peak (W)
PDM unit (with Zinq)	12V	15TBC	TBC
DP	12V	10 TBC	TBC
Vis Cam	5V	4 TBC	TBC
BW Cam	5V	4 TBC	TBC
SiPm	12TBC	6TBC	8 W
HVPS distributor	27V	< 2.5 W	
HK	12V	4 TBC	TBC
Total	n.a.	45.5 TBC	TBC

7.10.1 Electronics System (ELS), Data Handling

The data handling scheme has been adopted from the data handling of the JEM-EUSO telescope.

8 Interfaces

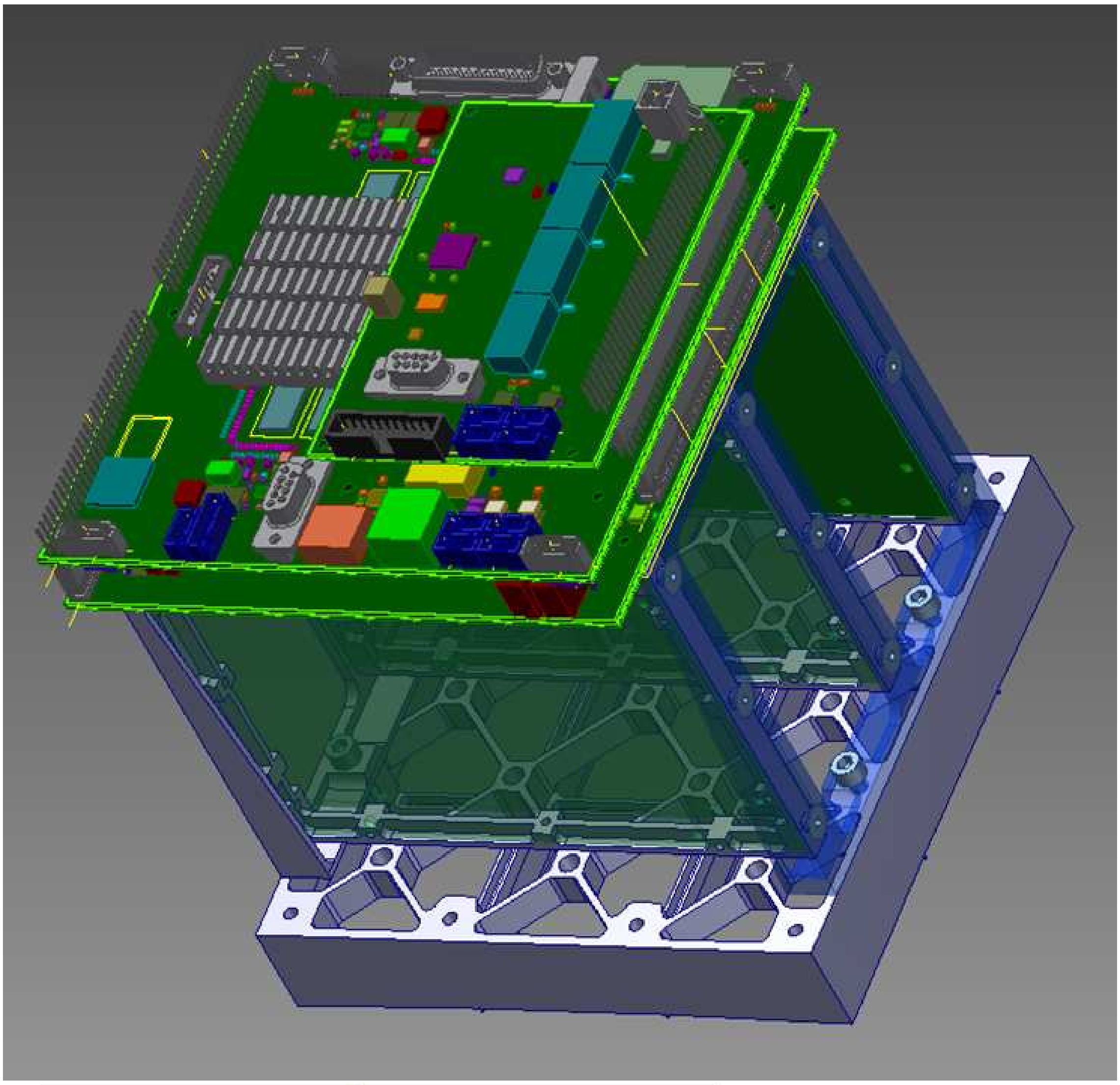
Connectors to the PDM, Clock Board, CPU and Power will be micro-SubD while analogue HK sensors might be individually connected via Lemo or other simple connectors.

The various interfaces (still TBD) are:

- Ethernet connection between Zinq and DP

- Analogue sensors to HK

8.1 Zinq board



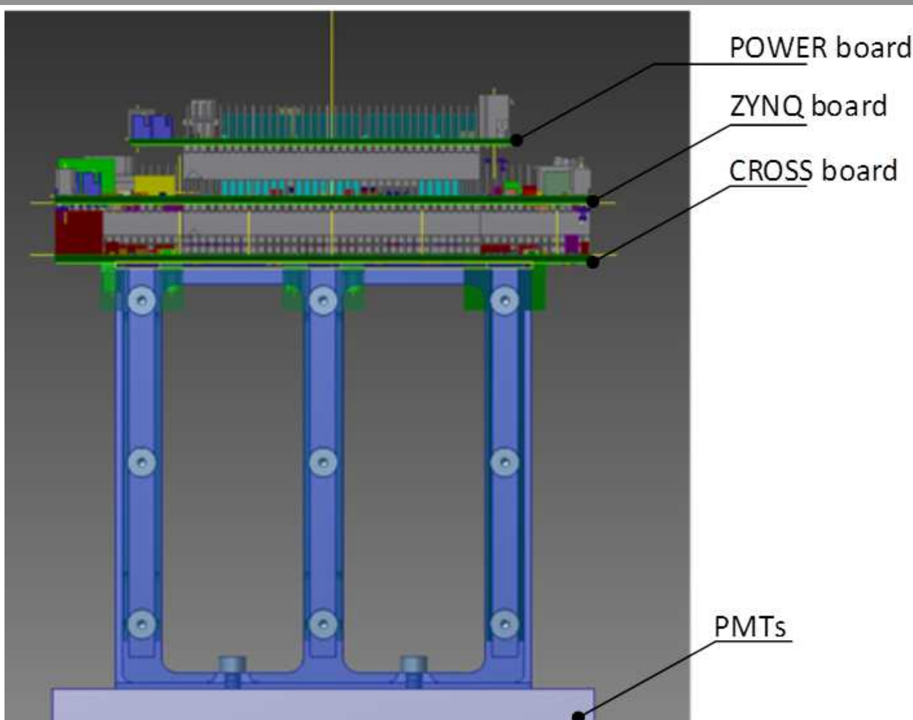


Figure 39: Zinq board (prototype) picture

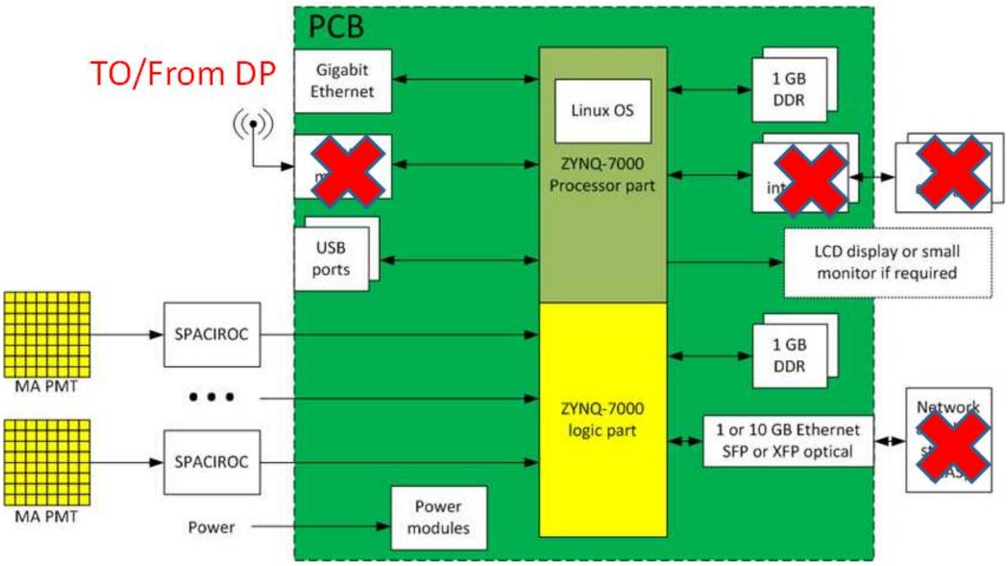


Figure 40: Block scheme of interfaces of zinq

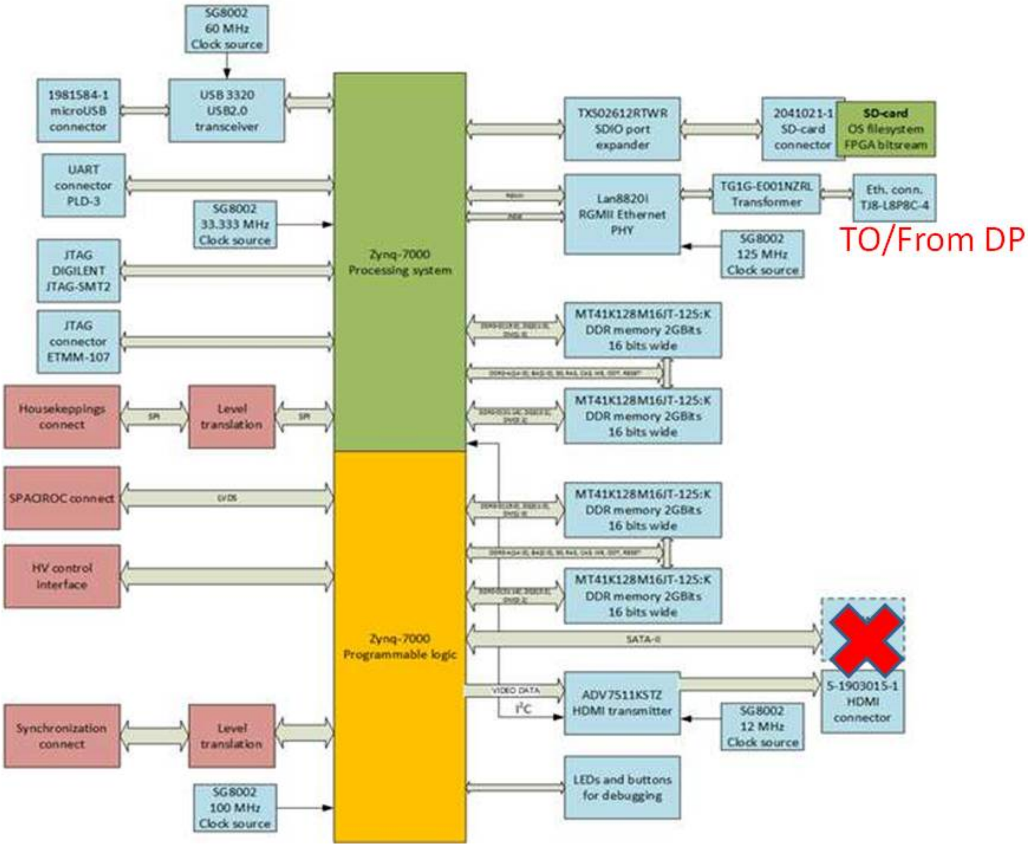


Figure 41: Internal Block scheme of Zinq boards. Note that Eth connT18-l8p8c-4 goes to DP. And SATA is absent.

References

[1] Marco Ricci, Marco Casolino, and Pavel Klimov. Mini-EUSO: a pathfinder for JEM-EUSO to measure Earth's UV background from the ISS. In *ICRC 2015*.

[2] T Ebisuzaki, Y Uehara, H Ohmori, K Kawai, Y Kawasaki, M Sato, Y Takizawa, ME Bertaina, F Kajino, T Sawabe, et al. The JEM-EUSO project: Observing extremely high energy cosmic rays and neutrinos from the International Space Station. *Nuclear Physics B-Proceedings Supplements*, 175:237–240, 2008.

[3] Yoshiyuki Takahashi, JEM-EUSO Collaboration, et al. The JEM-EUSO Mission. *New Journal of Physics*, 11(6):065009, 2009.

[4] Toshikazu Ebisuzaki, Mark N Quinn, Satoshi Wada, Lech Wiktor Piotrowski, Yoshiyuki Takizawa, Marco Casolino, Mario E Bertaina, Philippe Gorodetzky, Etienne Parizot, Toshiki Tajima, et al. Demonstration designs for the remediation of space debris from the International Space Station. *Acta Astronautica*, 112:102–113, 2015.