EUSO-SPB Instrument Definition

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Document History

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created skeleton based on Mini-EUSO Instrumental Definition (LWP)
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added changes from Jim Adams regarding Solar power, batteries and tracker beacon system
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added added changes from Peter Barillion to PDM section

1 Scope

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

2 Documentation

2.1 Applicable Documents

1. EUSO-SPB 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
SPB	Super Pressure Balloon

3 Mission Description

The EUSO-SPB is a stratospheric super-pressure balloon mission aimed at first observation of Ultra-High Energy Cosmic Rays (UHECRs) induced fluorescence from above. The mission is devised with the intention of raising the technology readiness level (TRL) of the future JEM-EUSO mission to observe UHECRs from space [**?**, **?**]. The main component of the instrument – a single-photon detector sensitive in the UV range – will also allow for the possible observation of different phenomena, such Transient Luminous Events. However, the most important side goal of the mission is gathering information about Earth's night time UV emission dependent on the type of terrain below the telescope. Measurement of this glow is especially important to the future JEM-EUSO instrument, which detection rate will depend on the ratio of photons produced by UHECR to background. Therefore EUSO-SPB will play an important role as a precursor to the JEM-EUSO mission.

3.1 *Success criteria

Observation of:

- $>$ 10 air showers
- $>$ 1 air shower with Cherenkov back scatter

3.2 *Mission requirements

Item	Minimum	Comprehensive
Duration	20 nights centered on new moon	100 days
Float Altitude	100,000 ft (30.5 km)	120,000 ft (36.6 km)
Altitude stability	+/- 10,000 ft (3 km)	+/- 5000 ft (1.5 km)
Latitude excursions	-	45s +/- 10
Observation hours	100 hours, at night between astronomical twilight time and no moon.	500
Under Flight (first night)	Highly desirable. We will locate and prepare aircraft	Yes 4 h under balloon while detector operating
Payload Recovery	-	Yes

Figure 1: Mission requirements

4 Instrument Overview

The main characteristics which define the EUSO-SPB 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 EUSO-SPB 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 EUSO-SPB 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 cm^2	$1 \times 10^4\,\mathrm{cm}^2$	$2.2 \times 10^4\,\mathrm{cm}^2$
Resolution	560 m	$5.4 \times 10^3\,\mathrm{m}$	175 m	
FoV/Pixel	0.08°	0.8°	0.23°	0.058°
	$1.4 \times 10^{-3}\,\mathrm{rad}$	0.01 rad	$4 \times 10^{-3}\,\mathrm{rad}$	$1 \times 10^{-3}\,\mathrm{rad}$
FoV/PDM	3.84°	$\pm 19°$	$\pm 5.5°$	$\pm 0.27°$
	$6.7 \times 10^{-2}\,\mathrm{rad}$	± 0.3 rad	$9.6 \times 10^{-2}\,\mathrm{rad}$	$\pm 4.7 \times 10^{-3}\,\mathrm{rad}$
	26.7 km	$2.6 \times 10^2\,\mathrm{km}$		3.8km
N° PDMs	137	1	1	52
N° Pixels	315,648	2,304	2,304	119,808

Table 2: EUSO-SPB main requirements.

Parameter	Value
Dimensions	cm^3
Weight	kg TBC
Power consumption	W TBC
Power Connection	Batteries charged by solar panels
Location	Stratosphere, 40 km above Earth
Operational requirements	Moonless nights, astronomical twilight on 40 km altitude
Main observable	UV light 300 nm to 450 nm
Spot size	
Lenses	three 1 m Fresnel lenses material PMMA
Focal Surface	1 PDM composed of 36 MAPMT, each 64 channels (total 2304 pixels) $17\times17\times23$ cm^3 (Safe:$25\times25\times25$ cm^3)
Temporal resolution	2.5 µs TBC
Direction of observation	Nadir

5 Functional Description

The EUSO-SPB 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

AND Ancillary devices

A functional block diagram of the EUSO-SPB instrument is can be found in Figure 2, showing the interfaces between the various systems. Table 3 lists the EUSO-SPB systems and subsystems 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.

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

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

System	Sub-system	Chapter Ref.	#	Description	Dimensions
TES	TES-MB	Main Body 6.4.1	1	Mechanical structure of the main body of the detector	
OPT	OPT-FL	Front Lens 6.4.3	1	Lens without fitting	1 m diameter (TBD) Round
	OPT-DL	Diffractive Lens 6.4.3	1	Lenses without fitting	1 m diameter (TBD) Round
	OPT-RL	Rear Lens 6.4.3	1	Lenses without fitting	1 m diameter (TBD) Round
	OPT-LFIT	Fitting 6.4.4	2	Connecting lenses to TES-MB	Light tight
PDM	PDM-MEC	Mechanical Structure 6.5.2	1	Focal surface and EC-ASIC support board	
	PDM-EC	Elementary Cell 6.5.3	9	Potted, high voltage included	
	PDM-ECA	EC-ASIC Board 6.5.4	6	EC-ASIC Board (Spaciroc3)	
	PDM-PDM	PDM Board 6.5	1	PDM Board (FPGA)	
PWR	PWR-MEC	Mechanical Structure 6.6.4	1	Power supply mech. structure	
	PWR-PRI	Primary Power Filter **??**	1	Primary DC-DC (inc. filter)	
	PWR-SEC	Secondary Power Filter **??**	1	Secondary DC-DC (inc. filter) 27V ⟶ 12V ± 5V an. 5V dig.	

	PWR-LVPS	Low Voltage Power Supply 6.6.5	1		
	PWR-HVPS	High Voltage Power Supply box 6.6.6	1		
DP	DP-STR	Structure 6.8	1	Mechanical structure	
	DP-CPU	Main processing unit 6.8.1	1	PC104 standard	
	DP-CCB	Cluster Control Board **??**	1	FPGA	
	DP-PDM	PDM Interface **??**	1	Interface to PDM board	
	DP-DST	Data Storage 6.8.5	1	USB, external or few SSD Extractable HD with SATA interf.	Velcro det. side (TBC) USB + Lock
	DP-HK	House-keeping 6.8.6	1		
AND	ADS-PD	Photodiodes **??**	1	Photodiodes	cm
	ADS-CMP	Magnetic Compass**??**	1	Magnetic Compass	
	ADS-IR	Infrared Camera **??**	1	Infrared Camera	
	ADS-SI	SiECA **??**	1	Silicon Photomultiplier Elementary Cell	
	ADS-HL	Health LED **??**	1	Health LED	

6 Instrument Description

6.1 Main Systems

The 7 main systems are as follows:

TES	Telescope
OPT	Optics
PDM	Photo-Detection Module
PWR	Power
DP	Data Processing
AND	Ancillary devices
SIP	

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 EUSO-SPB are developed accordingly based on similar JEM-EUSO methods.

Table 4: The weight of elements of the gondola

Item	**Weight (lbs)**
Detector	925
Batteries (EUSO)	535
Battery stuff	?
Solar Panels (EUSO)	21
Crinoline and cables	?
Ballast	600
SIP	350
Exo-skeleton	600 (?)
Batteries (SIP)	200
Solar Panels (SIP)	28
Crinoline and cables	?
Antennas+boom	150 (?)
EUSO Charging controllers	5.2
Crash pads	50
TOTAL	**3725 (about)**

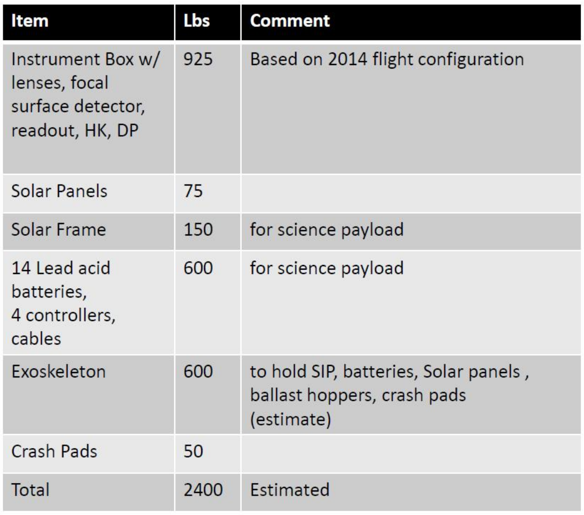
6.2 *Super Pressure Balloon

- 18.8 million cubic feet (considered mid-sized)
    - Flown 3x

  - 150 m diameter at float
  - 26 miles (one marathon) of load tape

- Lift Capacity: 5000 lbs “on the pin”
  - Total mass under balloon equivalent to 5000 lbs (2272.7 kg)

6.3 *Payload



Item	Lbs	Comment
Instrument Box w/ lenses, focal surface detector, readout, HK, DP	925	Based on 2014 flight configuration
Solar Panels	75	
Solar Frame	150	for science payload
14 Lead acid batteries, 4 controllers, cables	600	for science payload
Exoskeleton	600	to hold SIP, batteries, Solar panels , ballast hoppers, crash pads (estimate)
Crash Pads	50	
Total	2400	Estimated

Figure 3: The weight of elements of the payload

6.3.1 *Exoskeleton

6.3.2 *SIP

6.3.3 *Antennas

6.3.4 *Crash pads

6.3.5 *Ballast

6.4 Telescope TES

6.4.1 Main Body

The Telescope Main Body (TES-MB) subsystem is the balloon gondola mechanical structure to which all other systems are attached. The gondola will be hanging from the super pressure balloon.

Figure 4: An example of a balloon gondola

6.4.2 Telescope Optics OPT

A ray-trace simulation of the optical design of EUSO-SPB is shown in Figure 5. The OPT system consists of three sub-systems; three lenses and the surrounding support structure.

Figure 5: Left: Lens design of EUSO-SPB three 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.

6.4.3 Lenses

The optical system of EUSO-SPB is composed of two two-sided Fresnel lenses and one Fresnel-diffractive lens. Each lens is $1\,\mathrm{m}$ in diameter

Figure 6: Specifications of the two-sided Fresnel lenses

Figure 7: The form of the lenses, round with four additional segments at 12, 3, 6 and 9 “o’clock” for integration to the telescope.

6.4.4 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 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 mm. It also has to be light tight to avoid contamination of reflected stray light. The shape of the lenses are depicted in Figure 7. To reduce mass the shape will be round with additional areas at 12,3, 6 and 9 “o’clock” for integration into the telescope.

6.5 Photo-Detection Module PDM

The UV light collected by the telescope is detected by the PDM (fig. 8) composed by 36 Hamamatsu Multi-Anode Photomultiplier Tubes (MAPMT), arranged in nine EC units (3x3 matrix), associated front-end electronics, High Voltage Power Supplies and a FPGA board.

Each one of the nine EC units consists in a 2x2 matrix of MAPMTs followed by a set of boards: one EC-DYNODE which transmits the 14 HVs (cathode, 12 dynodes and grid) to the 4 MAPMTs, four EC-ANODEs which collect the analog signals and pass them on to the readout electronics and one HVPS-EC which produces the 14 HVs. Each MAPMT is equipped with a SCHOTT BG3 filter with anti reflection coating which transmits UV light only in a band between 290 and 430 nm.

The analog signals coming from the EC units are collected by six ASIC boards (called EC-ASIC). Each EC-ASIC board is mainly composed of six (3 on each side) SPACIROC3 ASICs packaged in CQFP160. These 36 microelectronic chips (64 channels), developed in 0.35Âţm SiGe BiCMOS technology, are meant to perform independent photon counting for each one of the 2304 pixels of the PDM and send the digitized data to the next element of the chain: the PDM board.

This board is the corner stone of the PDM. It interfaces with the six EC-ASIC boards, with the control unit part of the HVPS and DP sub-elements (HK, CCB and LVPS-PDM). The logic to communicate with these boards is inside a Xilinx FPGA Virtex 6 which also contains the first level trigger algorithm. The data from the ASICs are kept in buffers and transmitted to the DP system.

The last element of the PDM is the HVPS control unit which provides all the relevant powers and signals to the 9 HVPS-EC. In addition to an interface with the PDM board, it is linked to the HK (commands) and the battery.

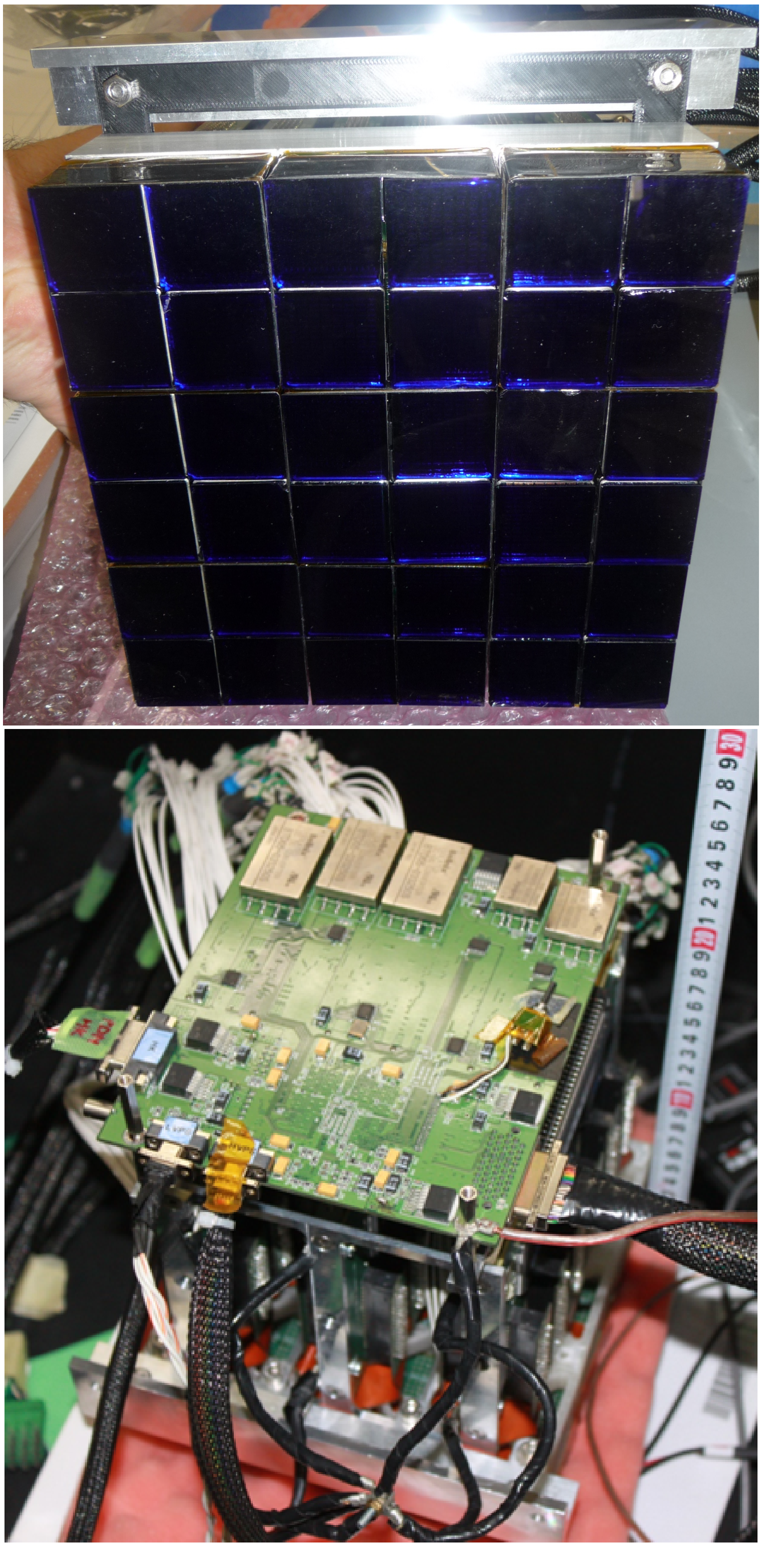


Figure 8: Top: PDM structue with 36 PMTs installed (i.e. 9 ECs). Bottom: The readout electronics of the PDM.

The figure 9 gives a view of the electrical architecture of the PDM with the interfaces between all the sub-elements represented.

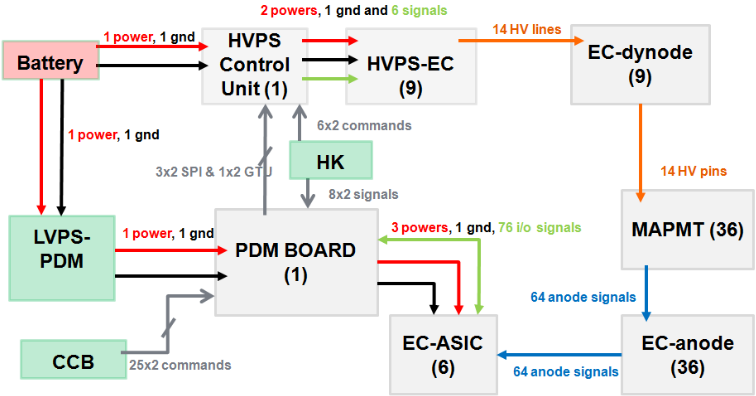


Figure 9: PDM electrical architecture

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

6.5.1 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 10.

6.5.2 Electronics Support Structure

A schematic of the PDM Electronics Support Structure (PDM-ESS) can be viewed in Figure 11. 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 $0.3\ \mathrm{kg}$.

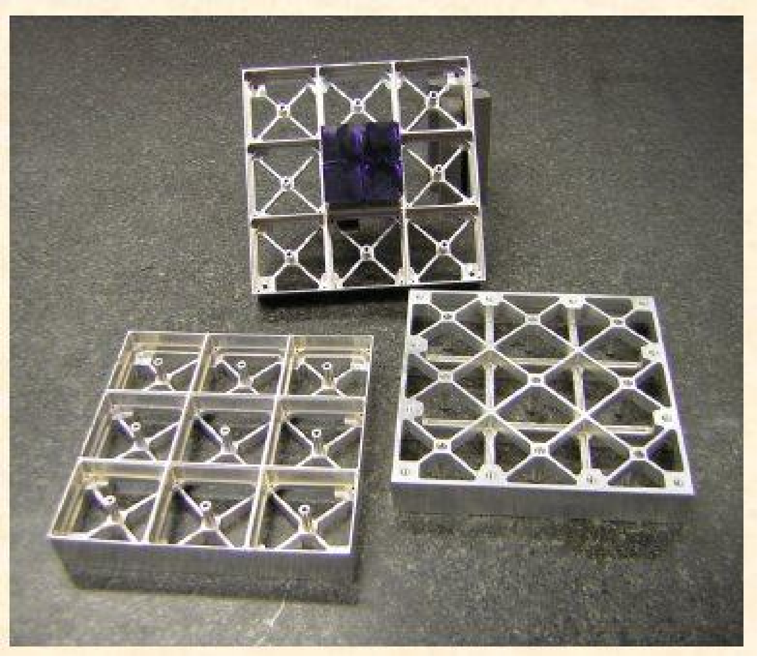


Figure 10: Mechanical support structure of PDM (only one is needed). In top frame an EC (4 PMT) are inserted in the center EC position. Support structure will be in hard plastic.

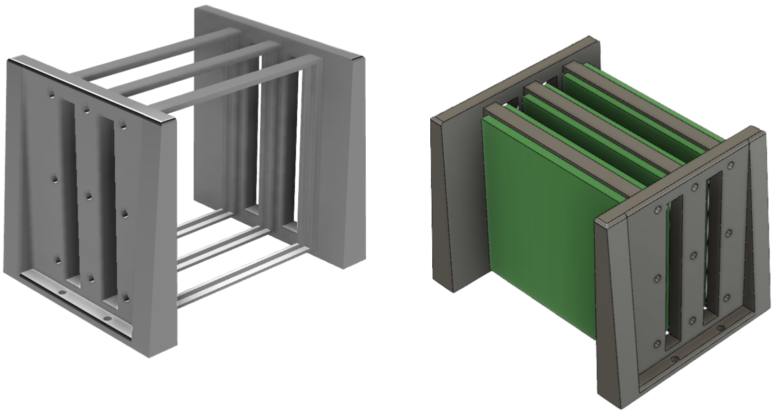


Figure 11: The support structure for the PDM electronics. Overall dimensions: 167mm x 128 mm x 130 mm. The image on the right shows the boards mounted onto the frame.

6.5.3 Elementary Cell Unit (EC-Unit)

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 14.

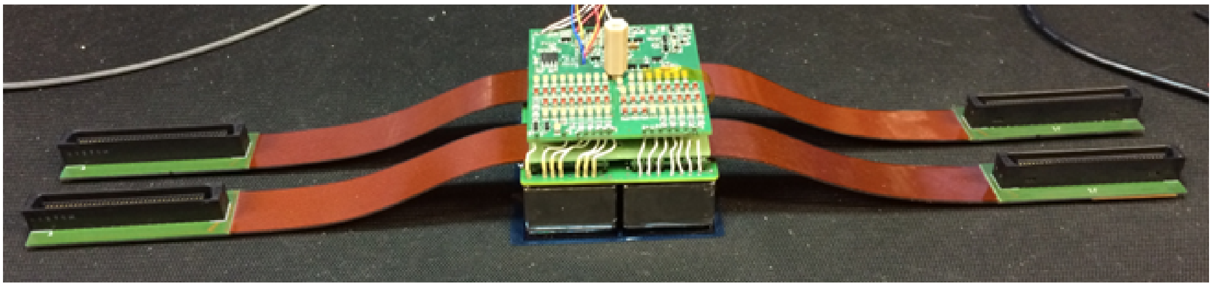


Figure 12: Picture of the EC unit prototype before potting

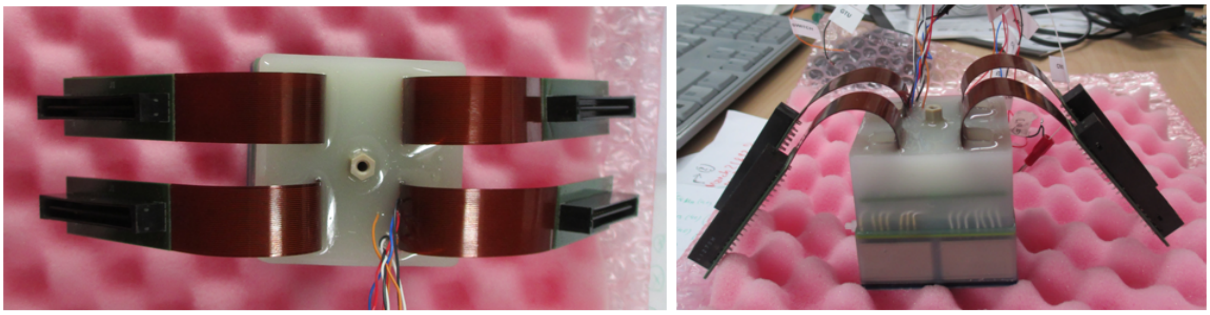


Figure 13: Pictures of the EC unit prototype after potting.

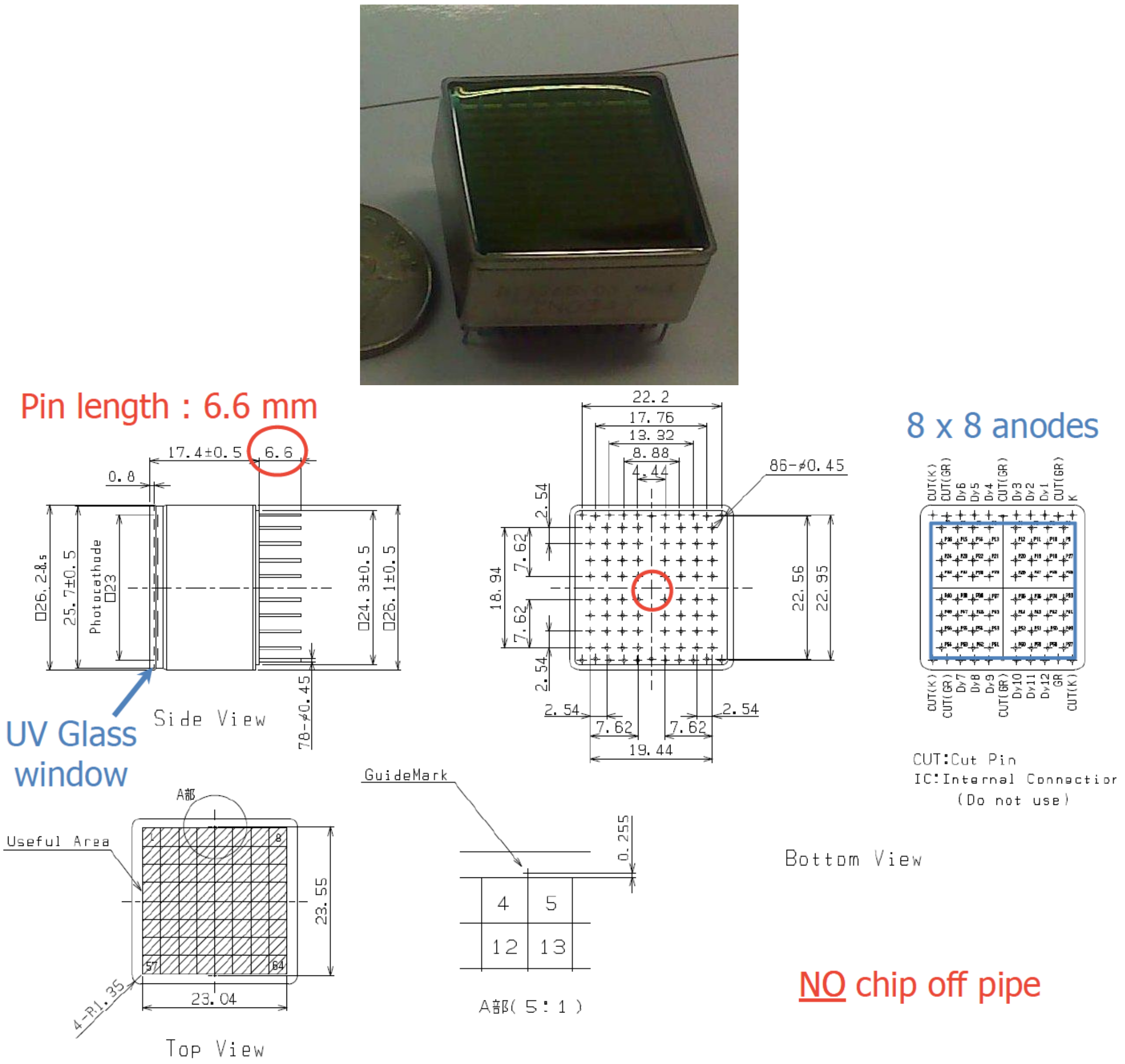


Figure 14: Top: Hamamatsu MAPMT M64 without UV filter. Bottom: Schematic drawing of the MAPMT side/top/internal view.

The EC-dynode (fig. 15) and EC-anode (fig. 16) philosophy is kept with respect to EUSO-BALLOON and EUSO-TA. The boards will just be slightly different.

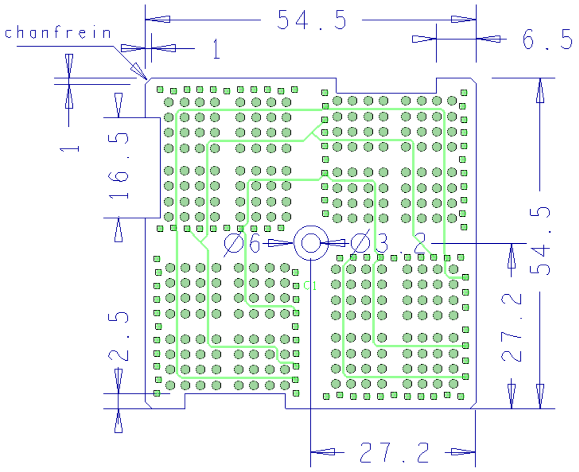


Figure 15: EC-dynode routing drawing with board dimensions.

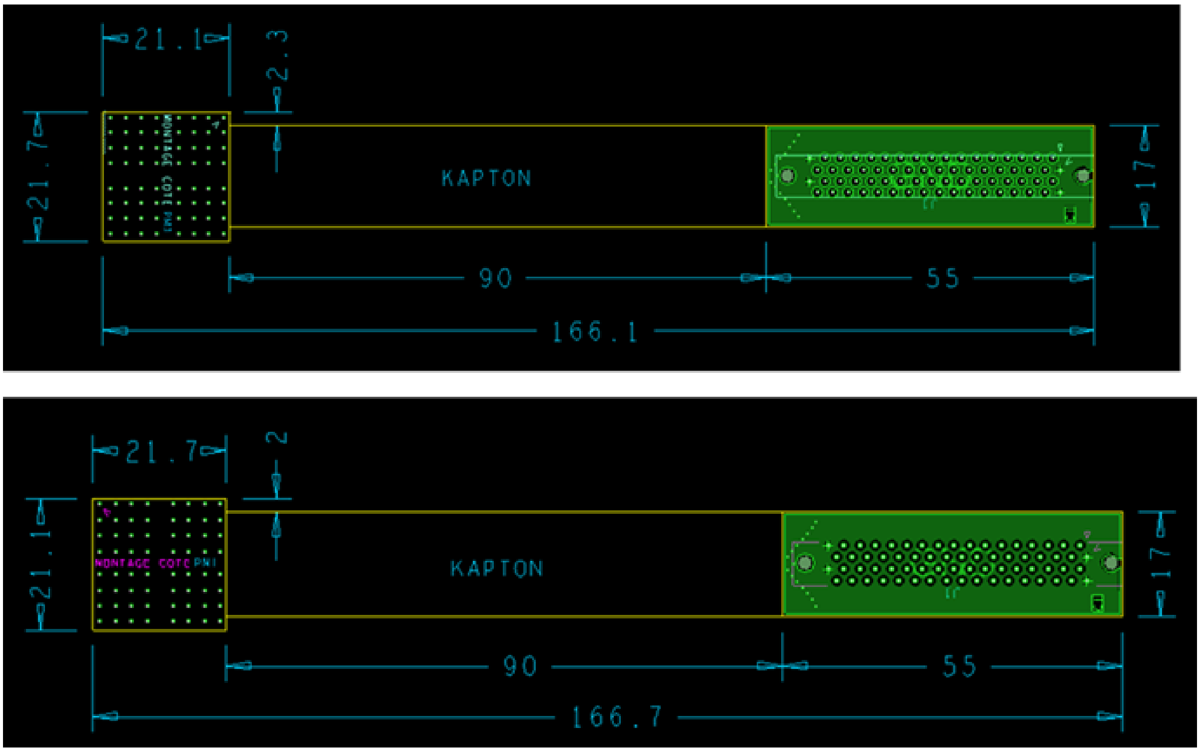


Figure 16: Routing drawing (with board dimensions) of the two types of EC-anode.

6.5.4 EC-ASIC Board

The ASIC boards will be equipped with SPACIROC3 ASICs. The board routing scheme is shown in fig. 17.

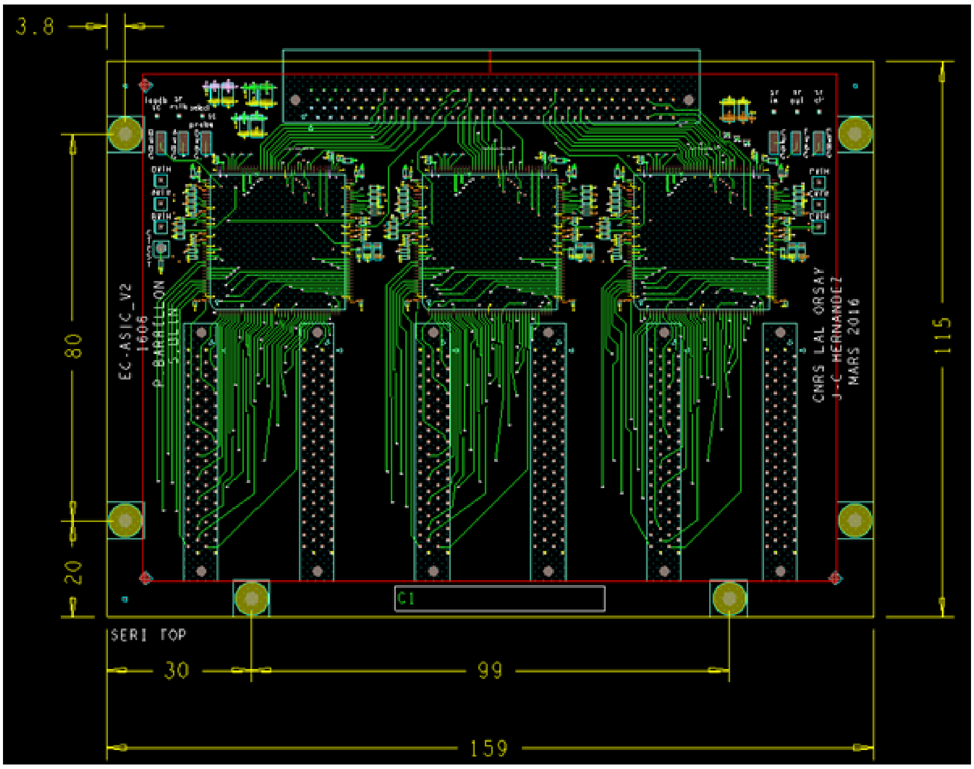


Figure 17: Routing drawing (with board dimensions) of the two types of EC-anode.

The EC-ASIC will be connected to the PDM board through kapton cables (EC-kapton, fig. 18).

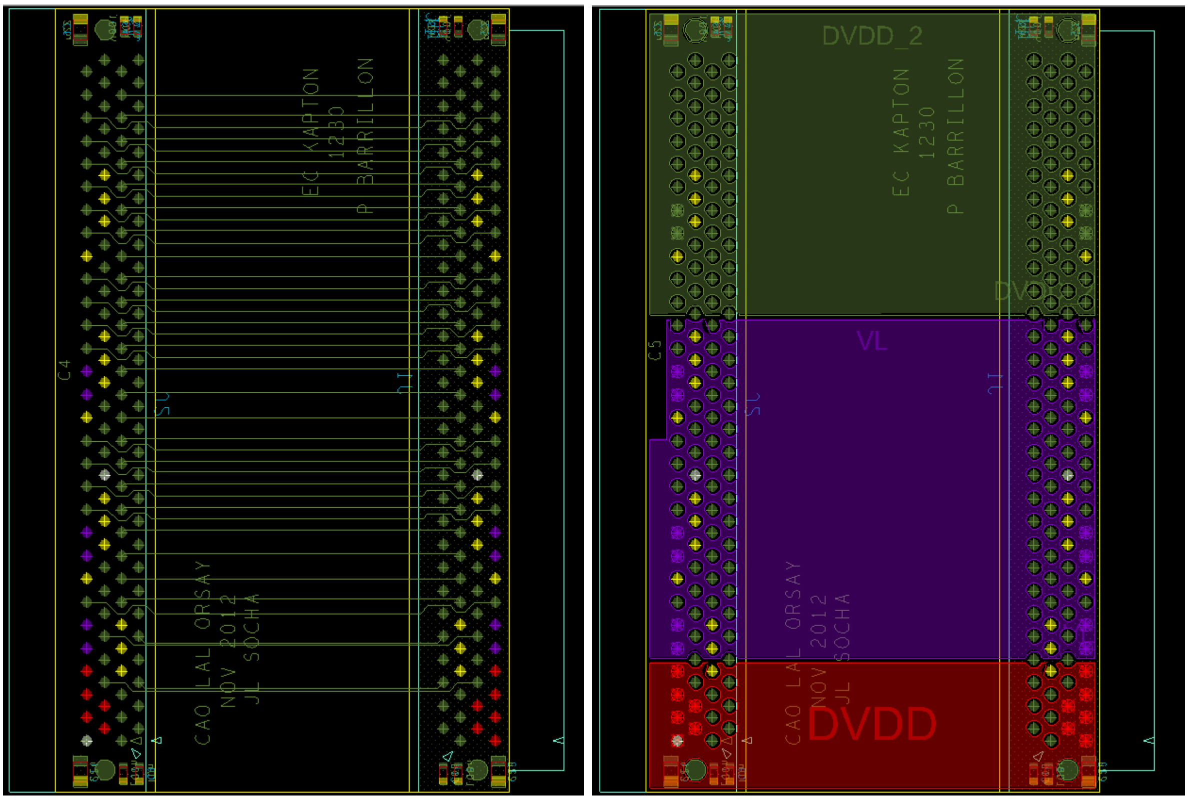


Figure 18: Two routing drawing (with boards dimensions) of the EC-kapton

Inside the EC unit, each MAPMT is labeled 1 to 4 as represented on the figure 19 (left part). Similarly, the ASICs of an EC-ASIC are labeled from a to f (right part of the figure 19).

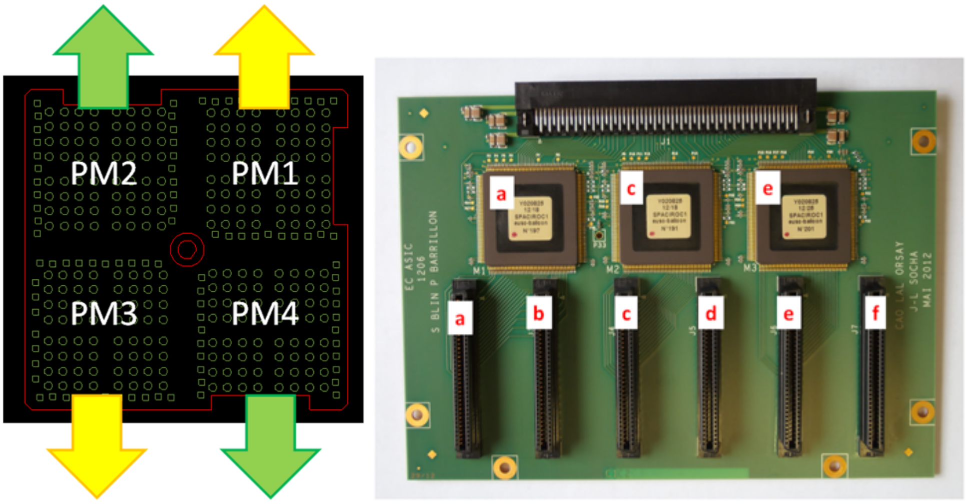


Figure 19: Left: Drawing of the way the 4 MAPMTs are arranged in the EC unit with respect to the EC-dynode. The green and yellow arrows represent the two types of EC-anode and the way they exit. Right: picture of an (old) EC-ASIC board and the way the ASICs are associated to the connectors toward EC units.

Each MAPMT of the PDM will be associated to a single ASIC. The readout of a line of 3 EC units will be performed by a pair of ASIC boards (fig. 20).

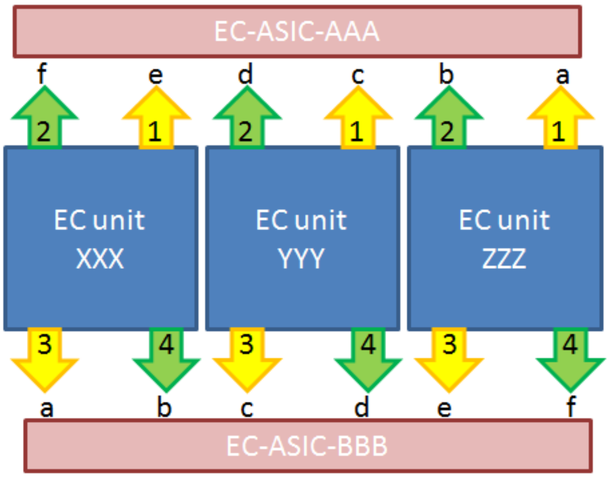


Figure 20: Drawing of the way a line of 3 EC units of the PDM is read out by 2 ASIC boards

The MAPMT and ASIC should be associated like this:

- ASICs a, c and e associated to PMTs 1 and 3
- ASICs b, d and f associated to PMTs 2 and 4

as shown in tab. 5.

Table 5: PMT-ASIC association

PMT	ASIC
XXX-1	AAA-e
XXX-2	AAA-f
XXX-3	BBB-a
XXX-4	BBB-b

6.5.5 *PDM Board

6.6 Power PWR

The main power source of the instrument are batteries charged by solar panels.

6.6.1 *Solar power system design

The design options for the solar power system are coarsely quantized by the available components. The design I present here will probably meet our needs.

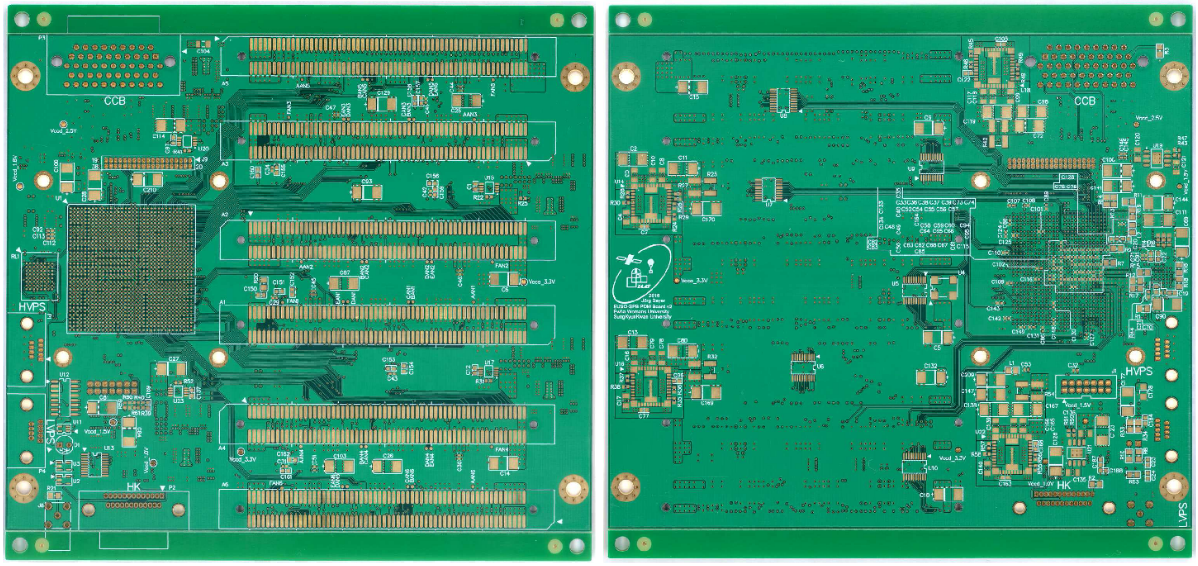


Figure 21: PDM Board: left – front, right – back

Solar panels I propose to use SunCat Solar panels (they are flight proven by CSBF). These panels are physically 27" x 31". They consist of 30 solar cells having a combined area of 0.4730 m^2. This array at 25°, when exposed to solar illumination with a flux of 1000 W/m^2, produces a nominal power of 100 watts. The power conversion efficiency of these solar cells is 0.2114 at 25°.

The efficiency at a temperature different from 25° is given by the formula,

$$\epsilon_T = 0.2114 * (1 - 0.0035(T - 25°C))$$

Using this formula, I calculated tab. 6.

The solar power at balloon altitudes is 1321 W/m^2 at its minimum value (on July 3 every year). This exceeds the reference power at sea level (1000 watts/m^2) by a factor of 1.321. The thermal analysis results of March 21 indicate that the maximum solar cells temperature will be 95°. Based on the solar illumination being 1321 W/m^2 and the conversion efficiency at 95°, power production is expected to be 99.7 watts. I will use this as a minimum value in what follows.

The current output of solar cells depends on the voltage they must produce. The peak power output of a cell occurs at the voltage where the output current begins to decline. This is called the peak power point (PPP). In order to have the voltage at the PPP high enough to charge the battery, we need three of these solar panels in series. When operated at the PPP, these three panels will produce 299.2 watts with the sun is normally incident on them on July 3. Near the launch date, the power will be somewhat higher (310 watts) because the sun will be brighter as the Earth will be nearer the sun. Of course when one side of the gondola is squarely facing the sun (i.e. the panels on the other sides are not illuminated), the power production will be less than this minimum value when the sun does not strike the solar panels at normal incidence.

Assuming that the balloon is floating at 100,000 feet altitude (30.48 km), the sun first strikes the solar panels when the solar elevation is -5.6° (i.e. below the local horizontal) when the sky

Table 6: Solar panels efficiency and power

temp. [°C]	**efficiency**	power [W]
25	0.2114	100.0
30	0.2077	98.3
35	0.204	96.5
40	0.2003	94.7
45	0.1966	93.0
50	0.1929	91.3
55	0.1892	89.5
60	0.1855	87.8
65	0.1818	86.0
70	0.1781	84.3
75	0.1744	82.5
80	0.1707	80.8
85	0.167	79.0
90	0.1633	77.3
95	0.1596	75.5
100	0.1559	73.8

is clear at the horizon. Taking this into account, I have calculated the tilt angle of the solar panels that maximized its power production when one side of the gondola squarely faces the sun throughout the day on the summer solstice. This angle is 12°. For this case these three panels will produce 2901 watt-hours in one day, assuming the solar illumination is 1321 W/m^2 and the solar array temperature is 95° at the summer solstice (shortest day of the year in Wanaka, NZ). I take this to be the worst case.

If the gondola does not rotate just exactly to present one of its sides squarely to the sun all day, the power production will be higher because a second side will be illuminated and will therefore produce power. When a corner of the gondola is facing the sun (so that the panels on two adjacent sides are equally illuminated, the power production is 1.414 larger. Also if the solar array is cooler than 95° or days are longer or the earth is closer to the sun, the power production will be higher.

I will take as the maximum power production the case when the corner of the gondola faces the sun all day, the solar cells are at 85° (average case in the thermal model) and the solar illumination is 1371 watts/m^2 (corresponding to the vernal equinox). In this case, if the sun were normally incident on three solar panels on one side of the gondola, they would produce 324.9 watts. For this case, the energy production is 5503 watt-hours in one day with the solar arrays tilted at 12°. I take this to be the highest daily energy production of the array.

Batteries I am proposing that we use a 24V battery pack consisting of 12V Odyssey PC1200 batteries. These are sealed AGM type batteries that are flight-proven by CSBF. To create a 24 volt pack, we will put pairs of these batteries in series.

The charging controller we are proposing produces a charging current of 15 amps. The longest day will be 12 hours and the most favorable orientation of the gondola is with one corner facing the sun all day. In this case the controller would allow as much as $\sqrt{2}(12)(15) = 254.6$ amp-hours to be added to the battery, however, using the estimate of the maximum energy production above, only 229 amp-hours will be added. Of course, if the solar array were at 25°, the power produced by the solar array would exceed the limits of the charging controller and 254.6 amp-hours could be added to the battery. The capacity of one battery is 40 amp-hours at 25°. According to the Odyssey Application Manual (page 10, figure 5), the capacity of these batteries, at - 20°, is reduced to 60% of the capacity at 25° or 24 amp-hours. At 0° the capacity is 80% or 32 amp-hours. To be sure we can store all the power produced under the most favorable circumstances and at a reasonably low temperature (0°), I propose that we fly 14 batteries, 7 pairs. This will give us a capacity of 224 amp-hours at 0°. This many batteries would weigh 243.6 kg.

Charging Controller I propose that we use Morningstar Model SS-MPPT-15L controllers. We will need four of them, one for each side. These controllers have a base that is 16.9 cm by 6.4 cm and they are 7.3 cm high. They weigh 0.6 kg each for a total weight of 2.4 kg. The controllers are rated at 400 watts and produce a maximum charging current of up to15 amps.

The Odyssey batteries use absorbed glass mat (AGM) valve regulated lead acid (VRLA) technology. Normally this would require that the controllers have an equalization cycle, but Bryan Stilwell does not use equalization. He does use custom settings for the controllers. He sets the absorption voltage to 29.4 volts and the float voltage to 27.2 volts. He also disables equalization. This means that switch 1 should be on and switch 3 should be off on the controllers and the battery jumpers should be removed.

Programming the custom settings requires and adapter. For the Model SS-MPPT-15L MorningStar sells a PC MeterBus AdapterTM (Model: MSC) that converts the MeterBus RJ-11 electrical interface on the controller to an isolated standard RS-232 interface which enables communication between the SunSaver MPPT and a personal computer (PC).

The minimum charge we could get added to the battery pack in one day is about 121 amp-hours. This charge would need to last all day, providing an average power of 121 watts.

Astronomical night begins when the center of the sun reaches 18 degrees below the horizon and ends when the sun is again 18 degrees below the horizon. Because the horizon, as seen from a balloon at 100,000 feet, the horizon is 5.6 degrees below the local horizontal, the solar elevation at the onset and end of astronomical night is -23.6 degrees. At the vernal equinox, astronomical night on the balloon will last 7.4 hours. At the summer solstice it will last 10.5 hours.

Taking that the astronomical night on the summer solstice to be moonless so that the instrument can be operated all night, then the average power demand will (153.9 *10.5 + 105.1*13.5)/24 = 126.5 watts. Note that this does not include an unknown amount of heater power needed to keep the batteries above 0 degrees C. 126.5 watts is only a little more than the minimum power production of 121 watts average for the shortest day. Realistically, the power available on this day will be between 121 and 171 watts.

Nevertheless, I think we will have to manage the power carefully when the days get short, being prepared to shed load on the batteries to keep the essentials like the computer running. If possible, we should be prepared to lose power completely and recover the next day when the batteries get re-charged.

We must certainly monitor the raw battery voltage for the first sign that we are running out of battery power. We will do this by monitoring the remaining stored energy in the battery. To do this we need to monitor the battery pack temperature, the battery pack voltage and the current flowing into and out of the battery. We will have to conduct tests of the battery pack by charging it at various rates up to the highest possible rate (30 amps since two controllers can be charging it at the same time) and discharging it at rates from 3 to 8 amps. Beginning with the battery pack as fully charged as the Morningstar Model SS-MPPT-15L controllers will achieve; we can measure the outflow of energy by monitoring the battery voltage and discharge current. Continuing such measurements until the battery pack is discharged (as far as can be done without damaging the battery pack), we can measure the total stored energy. Similarly, beginning with the battery pack discharged, we can charge it with different currents while monitoring its voltage under charge and measure the energy added to the battery until it is fully charged. Finally the battery pack needs to be charged and discharged while being stored at temperatures ranging from 20° to -20°. With this calibration data set, we can use telemetered measurements of the battery voltage, the inflow current, the outflow current and the battery temperature to estimate the remaining stored energy in the battery during the flight. If these measurements show that the battery pack will not last until dawn, we can terminate "data-taking" mode early to avoid a loss of power to essential parts of the instrument.

We will write a program which uses the battery pack calibration data to track the remaining energy stored in the battery pack and the energy required until dawn according to the plan for data taking. If the battery pack will be exhausted before dawn, the program will intervene to switch from "data-taking" mode to "daytime" mode early. We will try to make this program simple enough to be implemented in the housekeeping onboard. If this is not possible, then we will need a human operator each night to download the current, voltage and temperature data, run the program and, if necessary, upload new times for switching from "data taking" mode to "daytime" mode to avoid exhausting the battery pack before dawn.

Solar Panel Crinoline hangs below the gondola, attached by cables.

Crinoline Dimensions:

- Height 76 cm

- Base: 307.4 cm by 307.4 cm

- Slope of sides: 15 degrees

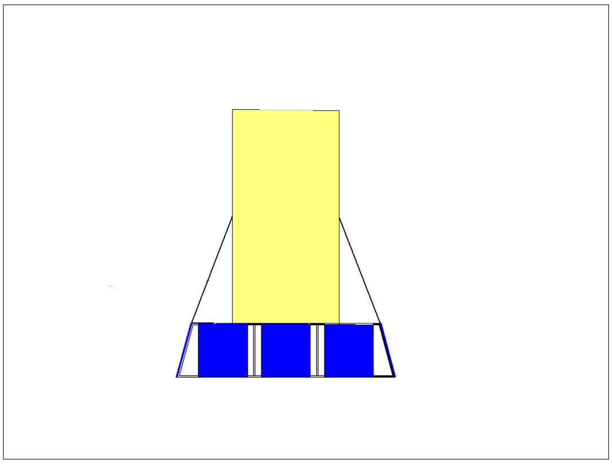


Figure 22: Solar panels mechanics

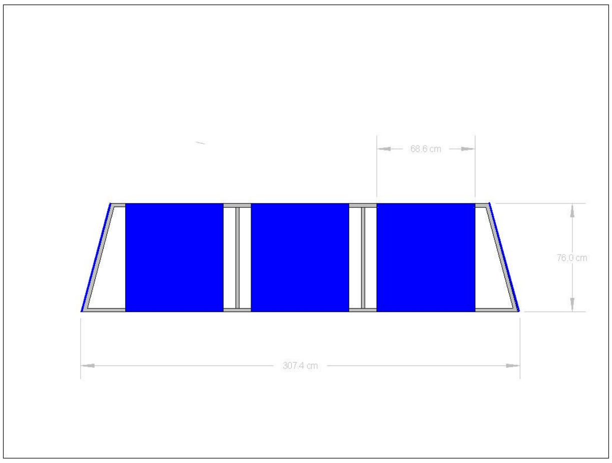


Figure 23: Solar panels frame

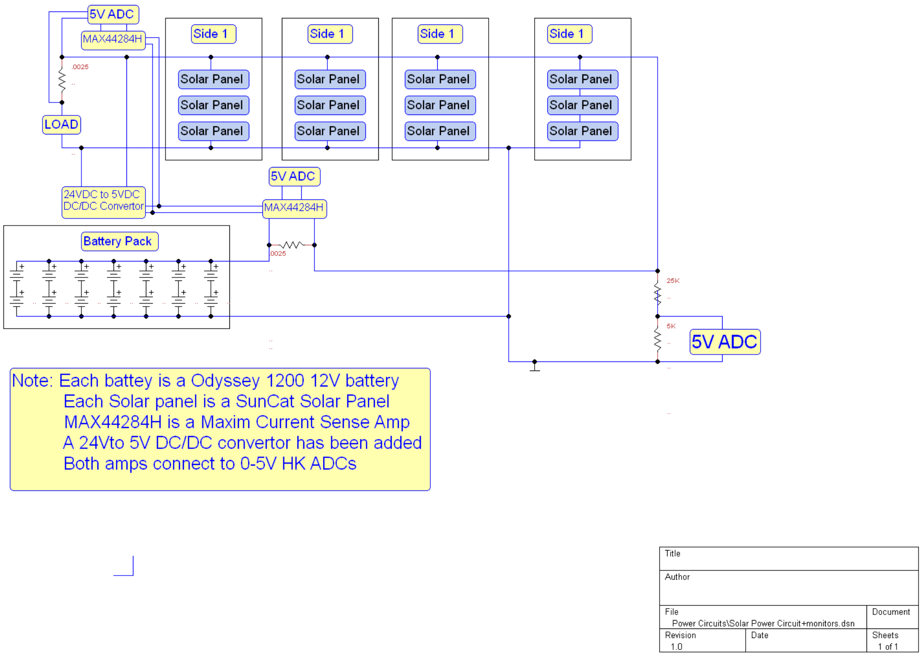


Figure 24: Power system circuit

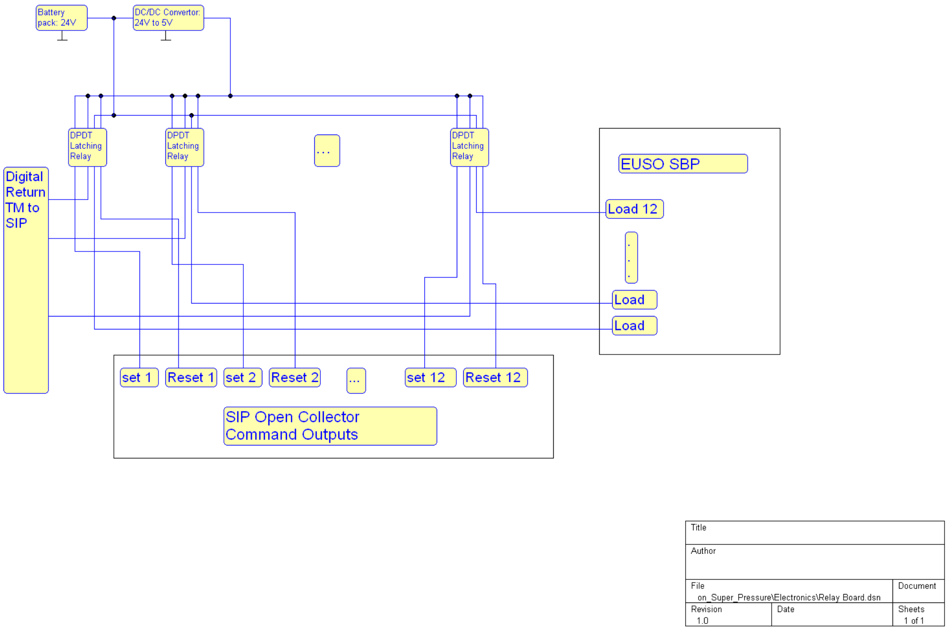


Figure 25: Relay board

Nominal operating modes:

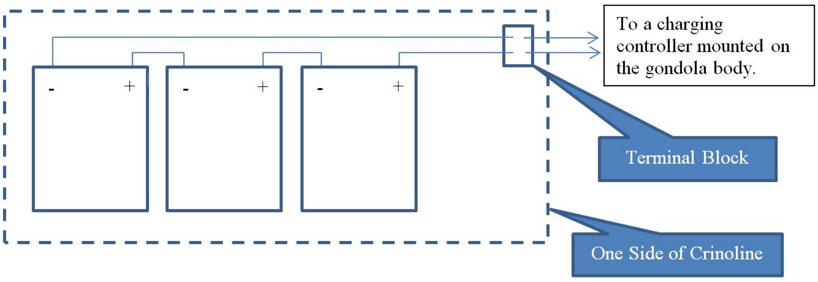


Figure 26: Crinoline wiring scheme

- “Daytime Mode”
  - Housekeeping, CPU, Cooler for IR Cameras
- “Data Taking Mode”
  - Housekeeping, CPU, Cooler for IR Cameras
  - PDM, CCB, CLKB, GPSR, HVPS, Photodiode
  - IR-cameras, Compass, SiPM
  - Health LEDs (as needed)
- “Tracker Beacons”
  - During under-flight and for testing

6.6.2 Wiring layout for solar power system

Here are my ideas for how to lay out the wiring for the solar power system. In the scheme I discuss here, I assume #8 stranded copper cables will be used everywhere.

The crinoline will have three solar panels on each side; each is 27” by 31”. I do not know the details yet of how one makes electrical connections to them so the drawing below is a bit of a guess. In fig.26 I show how one side of the crinoline is wired.

So the three panels are in series and they are wired to a terminal block mounted on the crinoline. This allows the cable leading to the charging controller for this side of the crinoline to be disconnected at the terminal block. The terminal blocks will be mounted at the top and centers of each side on the frame. The wiring circuit on the crinoline will be about 10 feet and will carry up to 15 amps. If we use #8 stranded copper cables, the voltage drop at 15 amps will be 0.09 volts.

The circuit from a side of the crinoline to the charging controller will also be 10 feet (The combined length of the positive and negative leads) so this will contribute another 0.09 volt drop at 15 amps for a total drop of 0.18 volts.

What do you think? Will a 0.18 volt drop be acceptable or should I use heaver wire?

The next part is the wiring within the battery pack. The battery pack will consist of 14 batteries with pairs of batteries in series. We will need to put 7 on each side so one pair will be split. The battery terminals are M6 bolts (1/4 inch). I will use lugs to connect to these, putting

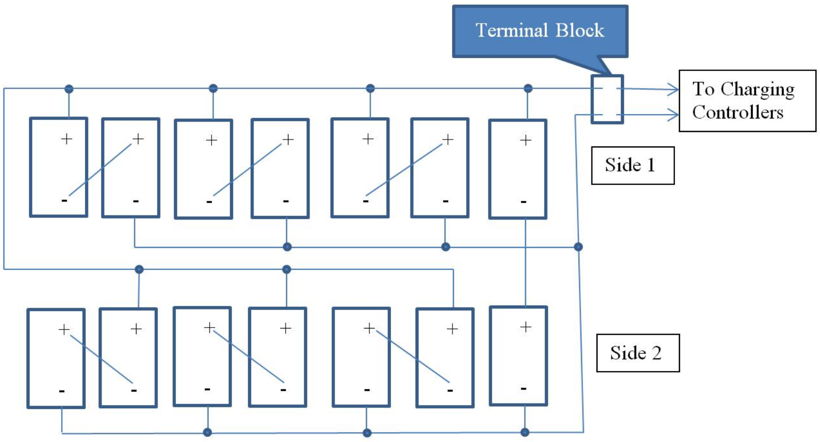


Figure 27: Wiring inside the battery pack

two lugs on some terminals. The terminal block will have two pairs of terminals strapped together. It will also have bolts to hold lugs.

The diagram in fig. 27 shows how I have in mind to wire them. Since only two controllers can be charging the battery at once and since each is limited to 15 amps, the charging current cannot exceed 30 amps. The total circuit through all the batteries will have a length of perhaps 41 feet. The circuit is not carrying the full current over this entire length. The inter-connects between batteries are 18 feet long but carrying only 4.28 amps so the IR drop for this part of the circuit is 0.048 volts. There is another 16 feet running through the battery pack carrying the current for each pair of batteries. On average this part of the circuit is carrying 15 amps so the IR drop should be 0.15 volts. Finally, there is 7 feet carrying 30 amps. The IR drop for this portion of the circuit is 0.12 volts for a total of 0.318 volts.

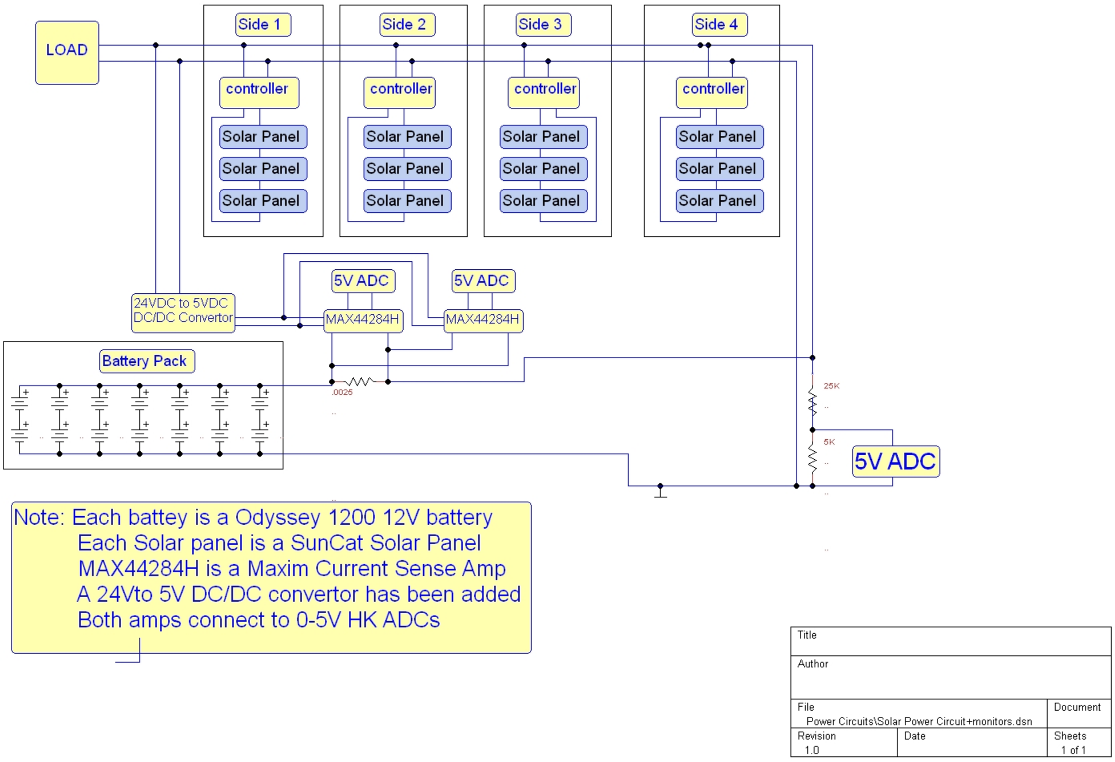
The terminal block on the battery pack is more complicated than I have drawn. It is really two terminal blocks because we need to insert a shunt to measure the current flowing into the battery and out of the battery. This block is really the central tie point for the whole power system. For each polarity of the circuit a cable will come there from the battery pack, each of the four charging controllers and redundant cables will go to the relay board. Finally, we need one more connection for each polarity to connect the voltage divider used to measure the battery voltage. That is a junction of 8 cables on each terminal.

Next are the four cables that run from the battery to each of the four charging controllers. Each charging controller can charge the battery at a rate of up to 15 amps. The length of the circuit that runs from the battery pack to the farthest controller will be 10 feet. The IR drop over this distance using #8 wires will be 0.09 volts.

Finally, there is the cable that runs from the battery to the relay board. It can carry up to 6.4 amps. This circuit will be about 25 feet, so the IR drop is 0.102 volts, assuming one of the redundant cables is not connecting.

Do you think #8 stranded copper cables is large enough or should we go to #6 and reduce the IR drops to 60% of the value I calculated here.

The way I am thinking of wiring it, we can use a single shunt to monitor the current flowing into or out of the battery pack, but I suppose we need an operational amplifier to measure the drop across the shunt. Is there an operational amplifier that swings both ways? When current



Note: Each battey is a Odyssey 1200 12V battery
Each Solar panel is a SunCat Solar Panel
MAX44284H is a Maxim Current Sense Amp
A 24Vto 5V DC/DC convertor has been added
Both amps connect to 0-5V HK ADCs

Figure 28: A schematic drawing of the solar power system

is flowing out of the battery the IR drop across the shunt will be positive but when current is flowing in it will be negative.

6.6.3 Power Distribution and Grounding

6.6.4 Mechanical Structure of the Power Supply

***Battery pack design** I have begun to think of how to design the battery boxes for the battery pack. I suggest having the battery pack in two enclosures on opposite sides of the gondola. Each enclosure will contain 7 batteries. Within the enclosure I would like to have two layers of batteries. The upper layer will have three batteries and a lower layer will have four batteries. I propose to build a two deck aluminum battery box for each side. I will paint the inside of the box with epoxy paint just in case the batteries leak (note: I am using sealed batteries).

I propose to apply two or more G-10 fiber glass blocks to one side of each box. These blocks will extend the full height of the box and be attached to it by screws that run through holes in the wall of the box and screw into threaded holes in the fiberglass blocks. The screws will be flat-head. They will be inserted from inside the battery box into chamfered holes. The blocks will have a width equal to the thickness of the foam insulation. On the outside of the insulation an aluminum structure of some kind will be attached to the blocks also by screws into threaded holes in the blocks. This structure will be designed as a mechanical mounting interface between the battery boxes and the exoskeleton of the gondola. Please suggest a design for this structure.

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

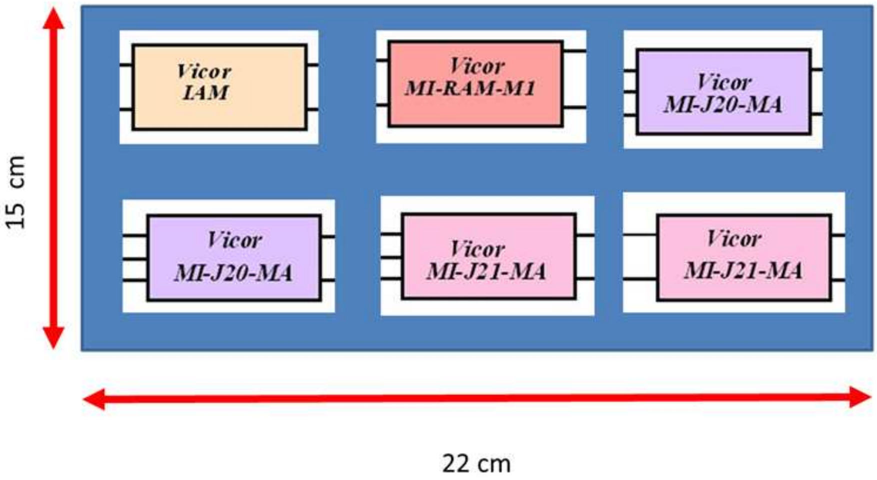


Figure 29: Scheme of the LVPS power distribution: they are allocated on a board 25*15cm

6.6.5 Low Voltage Power Supply

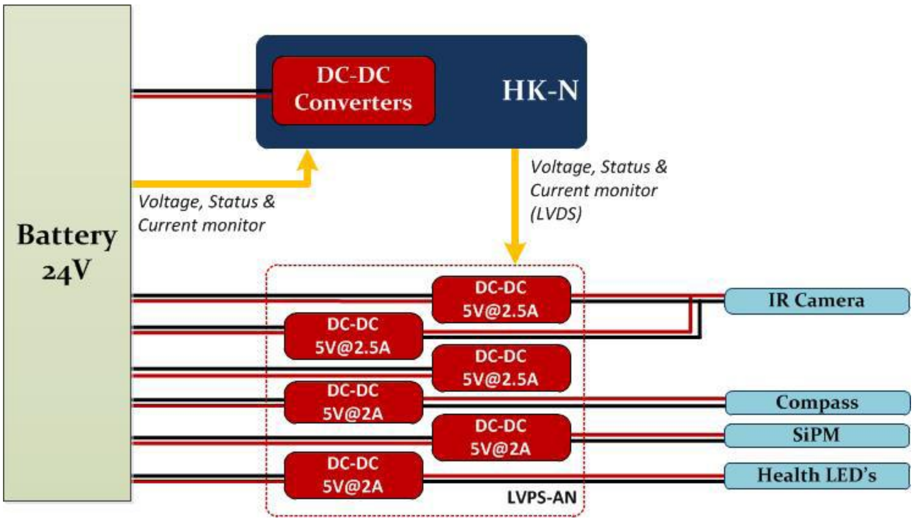


Figure 30: Scheme of the LVPS power distribution.

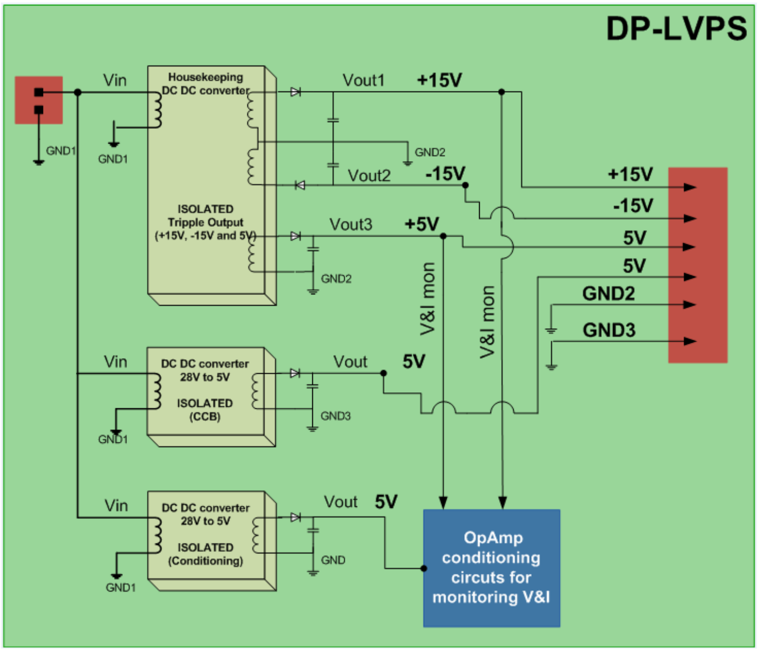


Figure 31: DP-LVPS block diagram

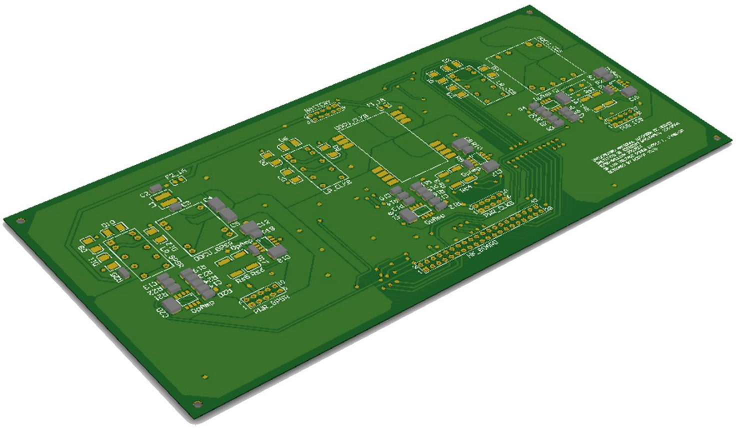


Figure 32: LVPS-DP

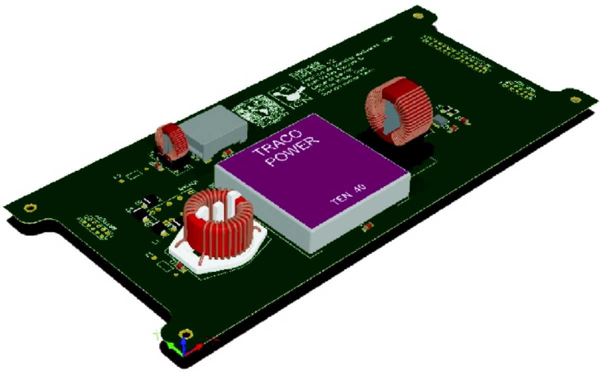


Figure 33: LVPS-PDM

6.6.6 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).

6.6.7 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

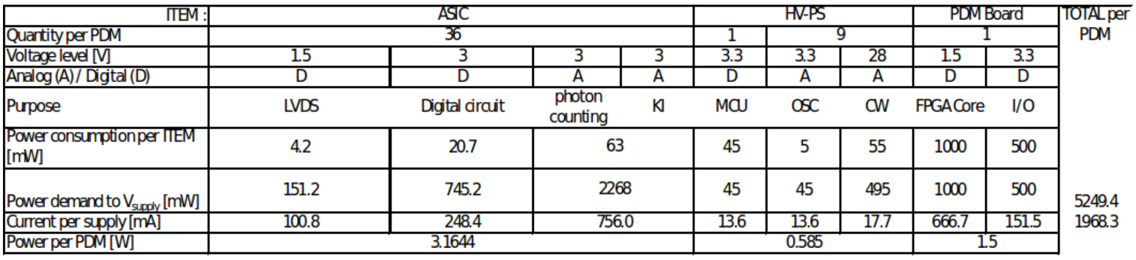
- The LVPS elements must withstand temperature variations in the range 0°C to +50°C during operation.
- The LVPS element must be able to operate at atmospheric pressure.

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.

6.6.8 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 34.



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 34: Power consumption of PDM block, including PDM board

Table 7: Power requirements

		ON				**Cons.**		**PSS eff**	**Voltage**	**PSS**	**All devices**				**New devices**	
Device	**New?**	**Day**	**Night**	**On-Gnd**	**Ascent**	**Pwr [W]**	**Peak pwr [W]**	**Eff.**	**V's**	**PSS**	**Day**	**Night**	**On-Grnd**	**Ascent**	**pwr. Req. Day**	**pwr. Req. Night**
Th cooler	1	1	1	1	1	20	20	100%	24.00	BP	20.00	20.00	20.00	20.00	20.00	20.00
IR Camera	1	1	1	1	0	10	10	85%	5.00	LVPS-AN	11.76	11.76	11.76	0.00	11.76	11.76
Photodiodesx2	1	1	1	1	0	10	10	85%	24.00	BP	11.76	11.76	11.76	0.00	11.76	11.76
Health LEDs	1	0	1	1	0	3	3	85%	5.00	LVPS-AN	0.00	3.53	3.53	0.00	0.00	3.53
SiPM	1	0	1	1	0	6	6	85%	5.00	LVPS-AN	0.00	7.06	7.06	0.00	0.00	7.06
HVPS	1	0	1	1	0	2.5	2.5	85%	24.00	BP	0.00	2.94	2.94	0.00	0.00	2.94
Relay Board	1	1	1	1	1	1	1	85%	24.00	BP	1.18	1.18	1.18	1.18	1.18	1.18
Sci Stack	1	1	1	1	1	0.5	0.5	85%	24.00	BP	0.59	0.59	0.59	0.59	0.59	0.59
Compass	1	1	1	1	1	5	5	85%	5.00	LVPS-AN	5.88	5.88	5.88	5.88	5.88	5.88
PDMB	0	0	1	1	0	10	10	85%		LVPS-PDM	0.00	11.76	11.76	0.00	0.00	0.00
LVPS1-DP	0	1	1	1	1	0	0	100%		BP	0.00	0.00	0.00	0.00	0.00	0.00
CCB	0	0	1	1	0	6	6	85%		LVPS-DP1	0.00	7.06	7.06	0.00	0.00	0.00
CLKB	0	0	1	1	0	4	4	85%		LVPS-DP1	0.00	4.71	4.71	0.00	0.00	0.00
GPSRx2	0	1	1	1	1	3	3	85%		LVPS-DP1	3.53	3.53	3.53	3.53	0.00	0.00
LVPS_PDM	0	1	1	1	1	0	0	100%		BP	0.00	0.00	0.00	0.00	0.00	0.00
PDM-EC-ASIC	0	0	1	1	0	10	10	85%		LVPS-PDM	0.00	11.76	11.76	0.00	0.00	0.00
LVPS2-DP	0	1	1	1	1	0	0	100%		BP	0.00	0.00	0.00	0.00	0.00	0.00
CPU	0	1	1	1	1	12	12	85%		LVPS-DP2	14.12	14.12	14.12	14.12	0.00	0.00
DST	0	1	1	1	1	15	15	85%		LVPS-DP2	17.65	17.65	17.65	17.65	0.00	0.00
LVPS_HK	0	1	1	1	1	0	0	100%		BP	0.00	0.00	0.00	0.00	0.00	0.00
HK-Old	0	1	1	1	1	8	8	85%		LVPS-HK	9.41	9.41	9.41	9.41	0.00	0.00
HK-New	1	1	1	1	1	8	8	100%		BP	8.00	8.00	8.00	8.00	8.00	8.00
HAM Xmitters	1	0	1*	1	1	1.84	5.4	85%	9.00	BP	0.00	0.00	0.00	0.00	0.00	0.00
Science Stack	1	1	1	1	1	1.2	1.5	100%		PB	1.20	1.20	1.20	1.20	1.20	1.20
LVPS-AN	1	1	1	1	1	0	0	85%		BP	0.00	0.00	0.00	0.00	0.00	0.00
								New Val.		**Totals [W]**	**105.08**	**153.91**	**153.91**	**81.55**	**60.38**	**73.91**
								Old Val.		**Totals [W]**	65	116.14				

6.6.9 Thermal Fuse

6.6.10 Switches

6.6.11 *Relay board

The Relay Board (fig. 35)turns on/off all the power to the instrument.It does this using SIP Open Collector Outputs to set/reset latching DPDT relays. One switch in each relay is used to turn/off the power while the other is used to connect/disconnect 5V to the Digital Return TM to the SIP. This allows to remotely confirm the state of each relay. There are 12 relays on the board. Once I know the current drawn by each of the twelve circuits, I can choose the relays.

6.7 Cable and connector

6.8 Data Processing DP

The basic data processing chain of JEM-EUSO is implemented in to the EUSO-SPB experiment.

6.8.1 CPU

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

- RTD/PC104-Express Single Board Computer & Controller
- 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

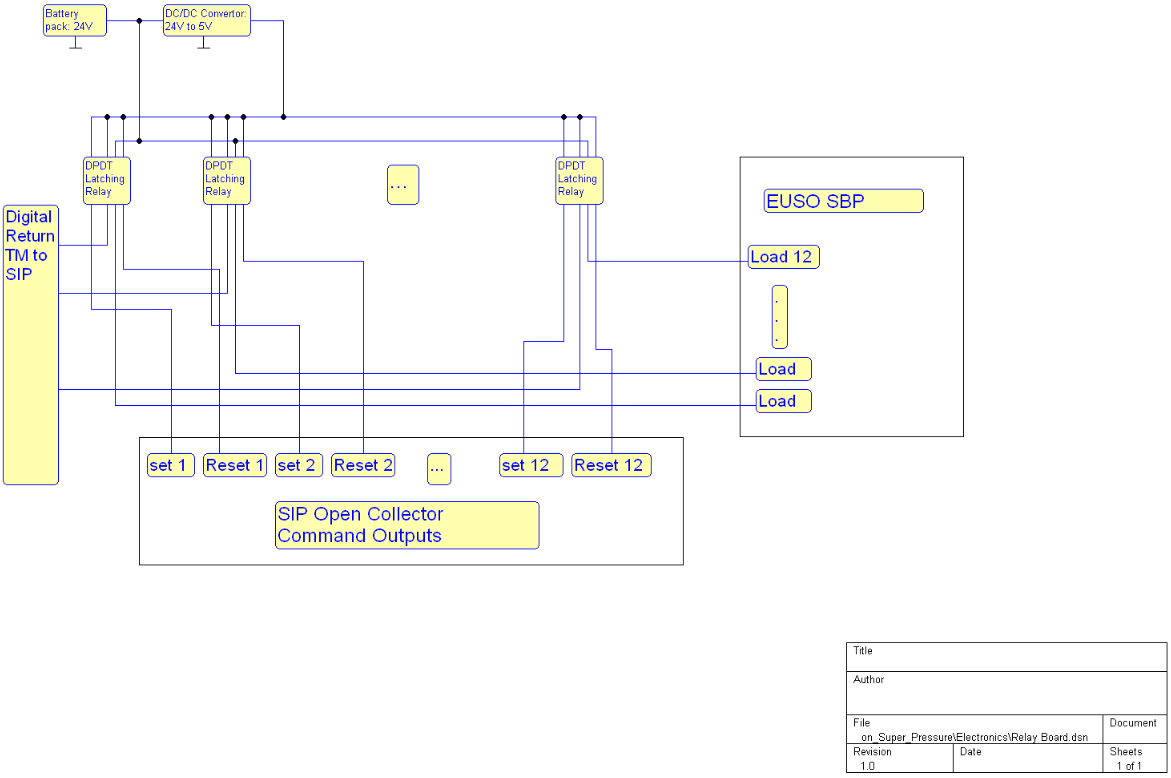


Figure 35: A schematic drawing of the relay board

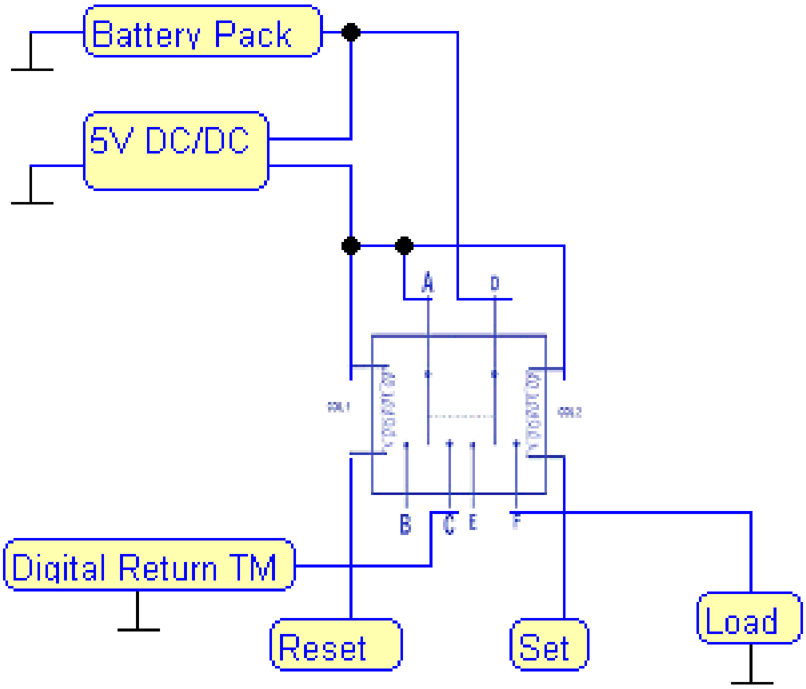


Figure 36: This schematic shows the details of how each latching relay is wired.

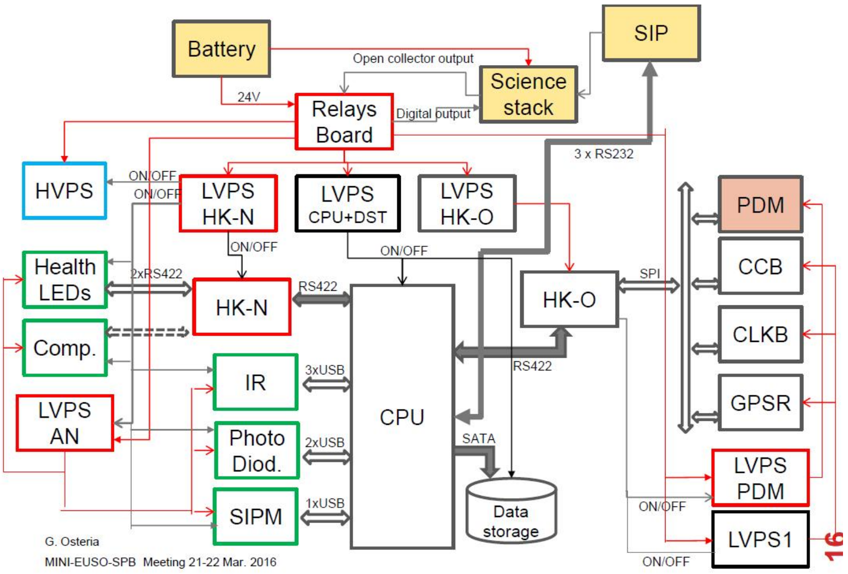


Figure 37: Data Processing block diagram

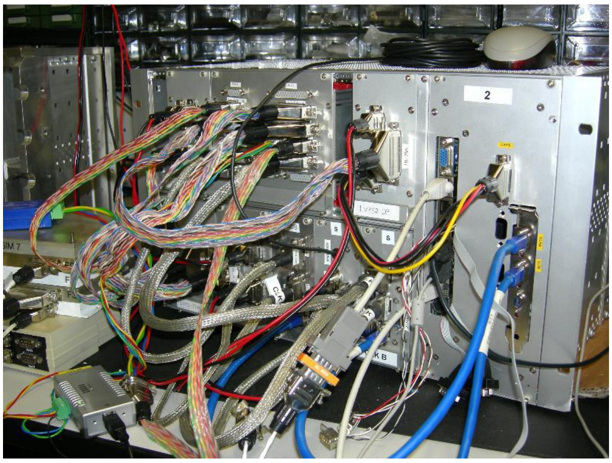


Figure 38: The Data Processing unit during the integration in Napoli, Italy

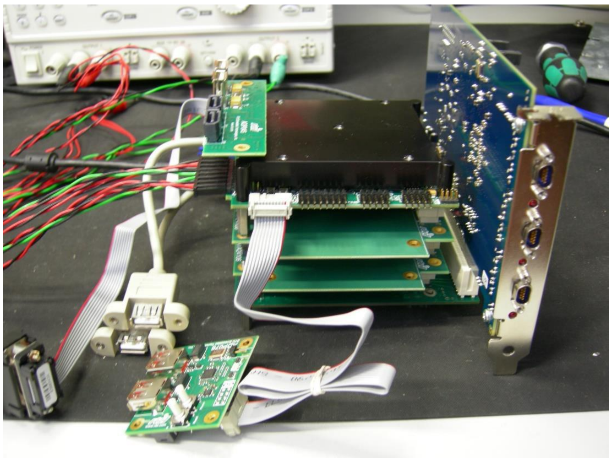


Figure 39: The CPU connected with the SpaceWire board

Figure 40: GPS

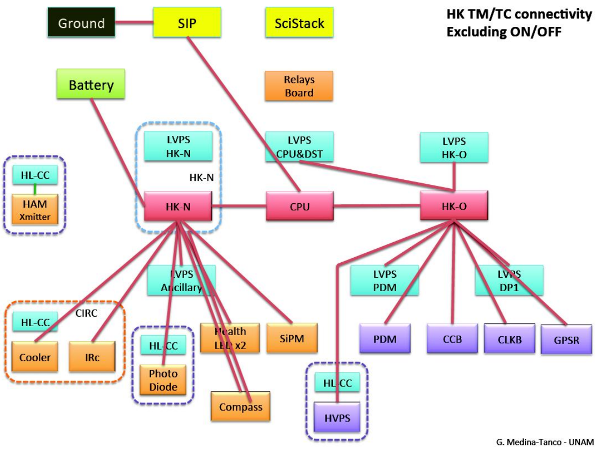


Figure 41: HK connectivity diagram

6.8.2 *CLKB

6.8.3 *GPS

6.8.4 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 PDM board.

PDM board reads the data from all ASICs and performs level 1 (L1) triggering. Packets of 128 GTUs including the trigger are then sent to the CCB for the level 2 (L2) triggering. If the data pass the L2 trigger, it is send to CPU for storage. Event size is therefore 324 kbyte + headers/footers of each event.

Requirements:

6.8.5 Data Storage

6.8.6 Housekeeping

The monitoring system requires ±12V and 5V.

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

THe HK monitors (see Figure 44):

- Voltage and Current of LVPS
- Voltage HVPS (TBC)
- Temperature sensors about 16 sensors (number TBC)
    - 2 lenses
    - Sipm
    - 2 DP

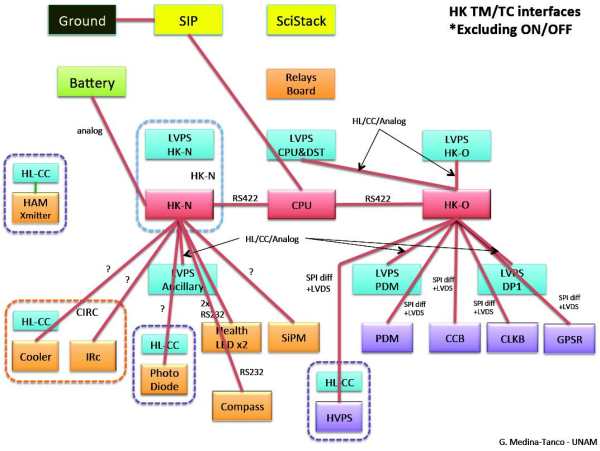


Figure 42: HK interfaces diagram

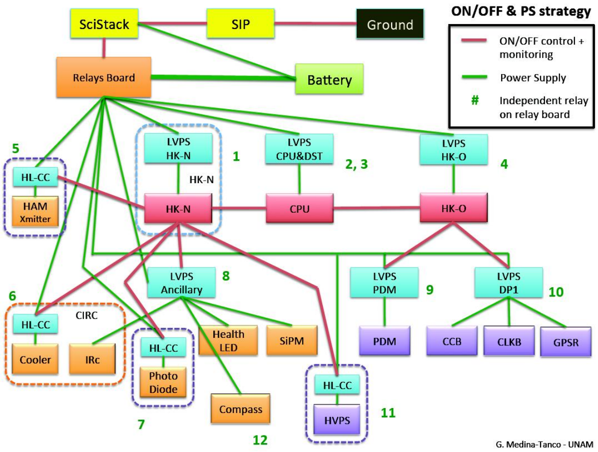


Figure 43: HK on/off strategy diagram

  - 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.

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.

Figure 44: Block Scheme of the turn on sequence.

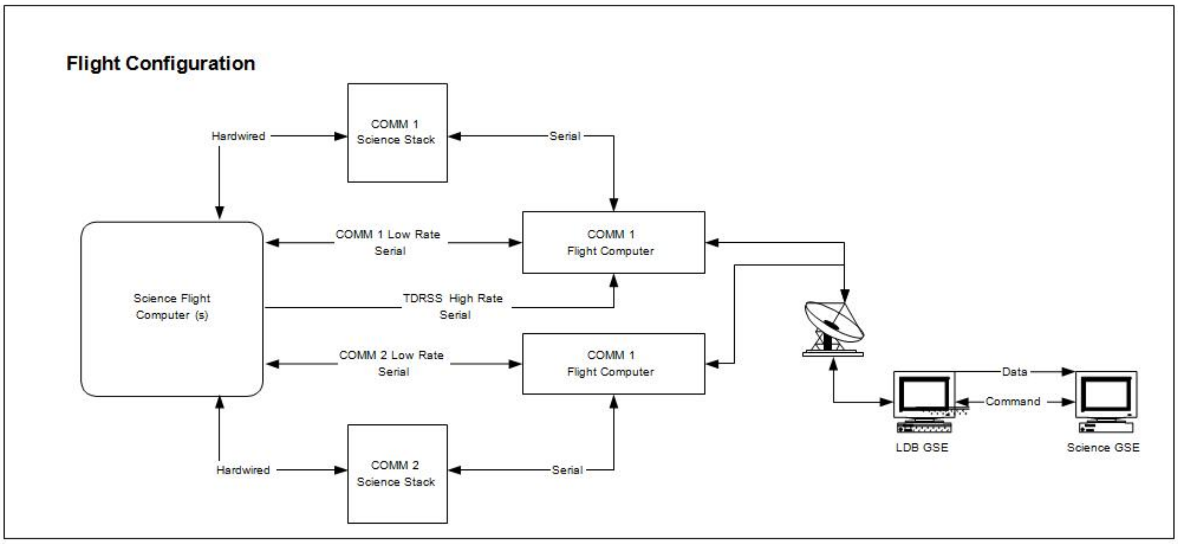


Figure 45: Block Scheme of the turn on sequence.

6.8.7 *Telemetry

Science will be interfaced to the ground control computer via two or three RS232-C ports:

- Downlink (return TM) Port 1 (TDRSS OMNI): 115,200 Baud
- Downlink (return TM) Port (TDRSS HGA): 115,200 Baud
- Command Uplink Port (IRIDIUM): 2400 Baud

A Science Stack option is available which provides:

- 32 analog channels return TM (12 bit resolution)
- 16 digital channels return TM
- 28 Open-Collector Command Outputs (200 ma maximum @ 50 volts @ 100 milli-seconds).
- 4 optional diode clamp command returns to be used if suppression diode is not available on science relay operating on Open Collector Outputs.)
- 1 Timed Open Collector Command Output (200 ma maximum @ 50 volts)
- 5 Volt Reference

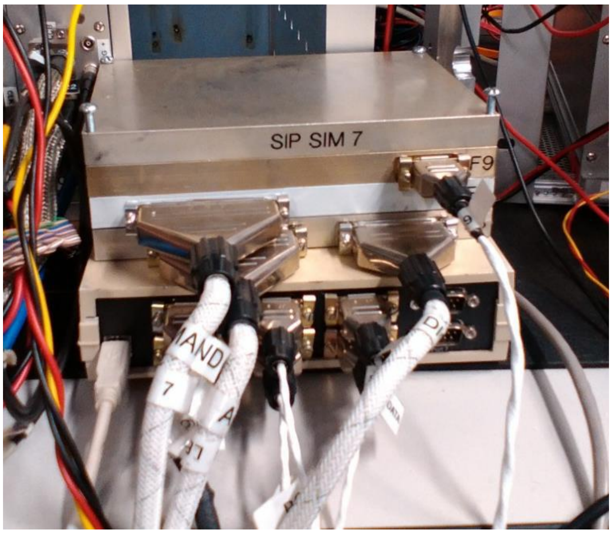


Figure 46: Science stack connected to SIP simulator?

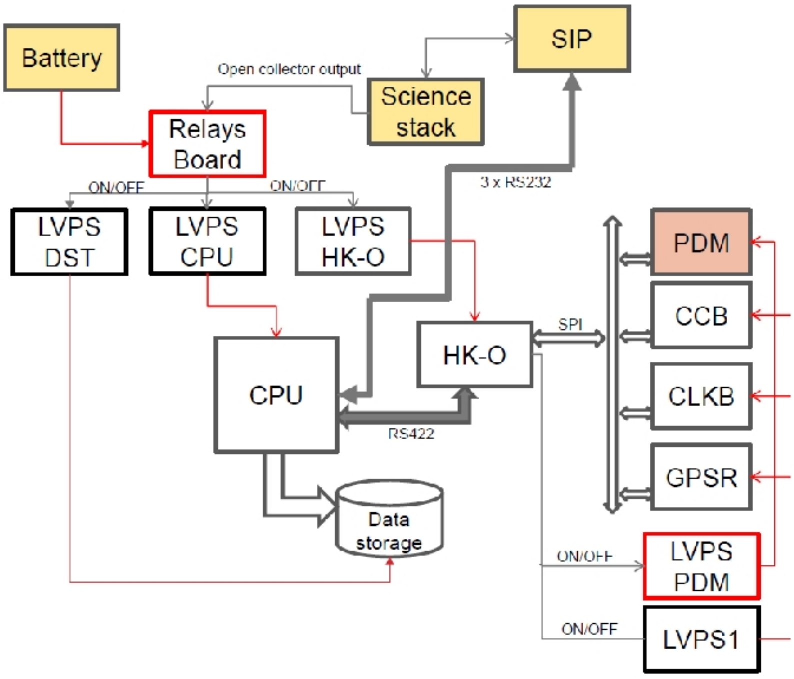


Figure 47: Telemetry interface scheme

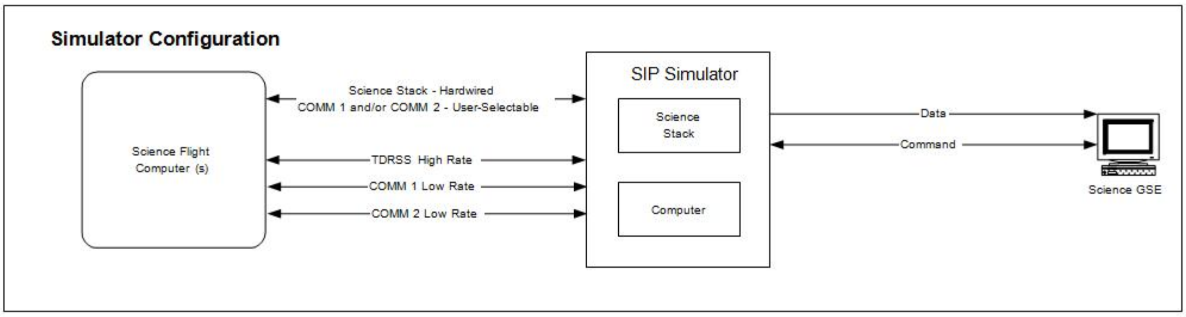


Figure 48: Telemetry interface scheme

Table 8: Ancillary devices power consumption

	5V, 2A	ON/OFF	Other
IR	2	Yes	
Photodiodes	2	Yes	
Health LEDs	1	Yes	
SiPM	1	Yes	
Compass	?	?	

6.8.8 *Ancillary devices interface

The power to the ancillary devices could be provided by the new LVPS_AN LVPS_AN provides 6 outputs (5V, 2A, 2.5A) individually controlled (ON/OFF) by the HK system.

Table 9: Ancillary devices CPU and DP interfaces

	USB (CPU)	Serial RS232	Serial RS422	TRIG II LEV.	TRIG. GPS SYNC	TRIG. other	others
IR	3	-	-	-	-	-	
Photodiodes	-	2	-	-			
Health LEDs	-	-	-	-		2	
SiPM	1	-	-	TBD	TBD	TBD	
Compass	TBD	TBD	-				
SIP	-	3	-				
HK	-	-	2				

Figure 49: 3U unit for hosting HK-N and LVPSs

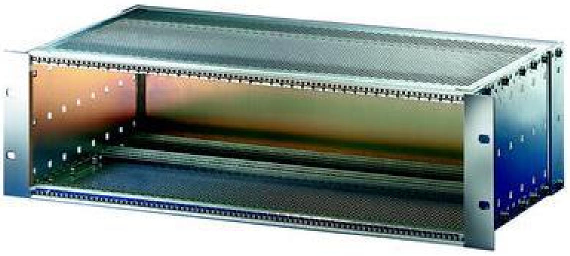


Figure 50: 3U rack for hosting 3U units

Table 10: Photodiode: Power, weight, dimension

	Nova II	PD300UV
Power[W]	3.5	N/A
Current [mA]	260 @ 13.4V	N/A
Weight [kg/lbs]	0.45/1 (no cables)	> 0.05/0.1
Width [cm/in]	11.7/4.6	1.3/0.51
Length [cm/in]	20.8/8.19	12/4.71
Height [cm/in]	4/1.57	2.1/0.83

6.8.9 Daytime Evaluation Unit

6.8.10 *DP Mechanical support

6.9 *Ancillary subsystems

6.9.1 *Photodiodes

- Flying 2 Photodiodes for redundancy
- Cross check with GPS position and time for darkness

Radiometer:

- Ophir: Nova II
- RS232 interface
- No specific driver needed
- ASCII readout
- A lot of experience in Mines

Photodiode:

- Ophir: PD300UV
- Same sensor was used during Timmins flight
- Min. Power: 20pW
- Wavelength: 220-1100nm
- Active area: $1\ \mathrm{cm}^2$

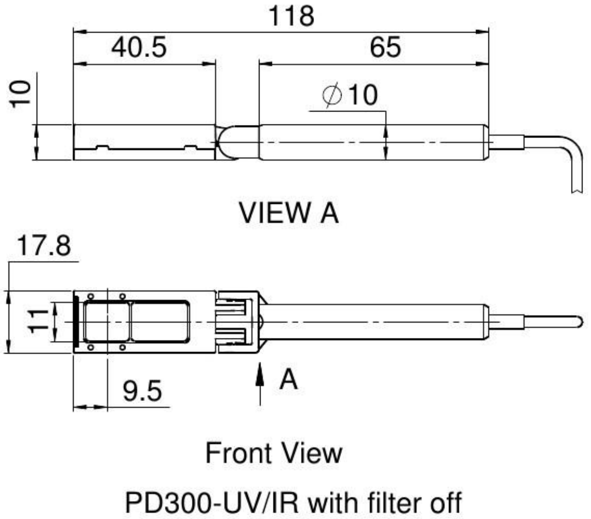


Figure 51: Photodiode

6.9.2 *Magnetic compass

Compass needed for knowledge of azimuth pointing direction of PDM
True North:TNT 4000 Revolution AV Compass

- 3-axis angular rate gyros
- 3-axis accelerometer
- 3-axis magnetometer
- 2-axis liquid eTilt sensor

Properties of compass

- RS232 communication (successfully test with linux machine)
- Available data:
  - Heading, pitch, and roll
  - Temperature, input voltage, and dip angle
  - Magnetometer X, Y, and Z
  - Total, horizontal, and vertical magnetic field strength
  - Raw and conditioned gyro data
- Dimensions (WxLxH): 4.6cm(1.8") x 7.6cm(3.0") x 1.5cm(0.6")
- Weight: 85g (3oz.)

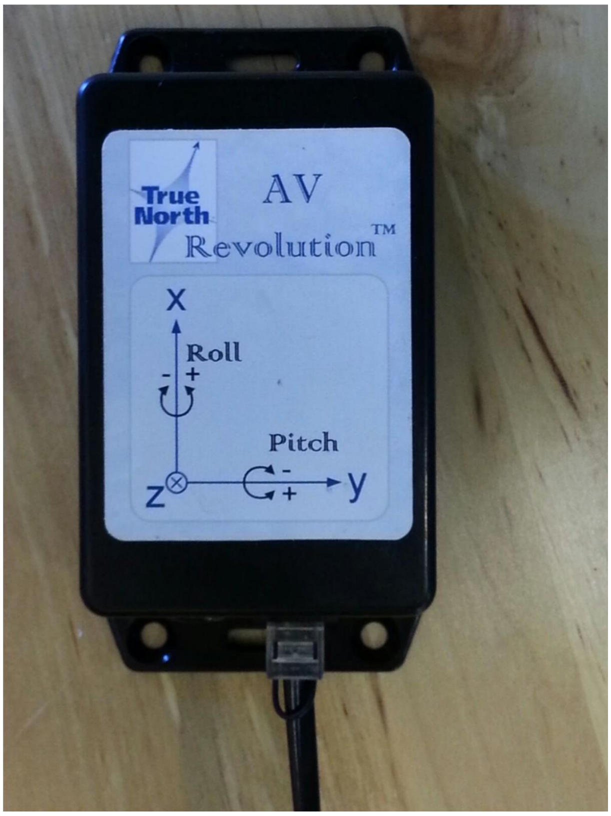


Figure 52: Compass

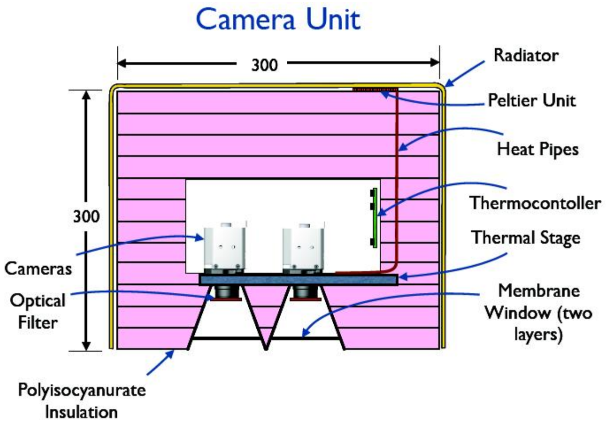


Figure 53: Infrared camera scheme

- Power: 40mA (15mA idle, 5mA standby), 7-45V DC unregulated
- Temperature range: - 40ÂřC âĂŞ 105ÂřC (-20ÂřC with eTilt) for operation
- Shock: 200g

6.9.3 *Infrared camera

Cameras are maintained at +20C continuously but are turned off during the day.

Cameras are maintained at +20C continuously but are turned off during the day.

- Software
  - Cameras are being controlled with a Debian 8 laptop.
  - Thermal controller still using a Windows GUI but we are starting the same process we used with the camera to get it controlled with the Debian system.
- Communication
  - The cameras and the thermal controller each connect to the computer through a USB connection.
- Data
  - The raw pictures are 1.5 MB PPM files. They compress with BZIP2 by a factor of 5 to 1 byte/pixel.
  - The total data is about 90MB/day.
- System Status Register
  - On request the system will report a status register which includes all temperatures, thermal unit battery current, Peltier current, battery and power supply voltages and camera status.

Table 11: IR camera specifications

Size		300 x 300 x 300 mm
Weight		<5 kg
Power Requirement		
	28 V unregulated	20 W maximum, <10 W operating
		Latching relay in camera box controlled by housekeeping
	5 V regulated	7 W total max
		Two circuits one for each camera
		Power shutoff at regulator controlled by housekeeping
Operation Temperature		+20 ± 1 C
Communication		3 x USB 2 for cameras 1 for thermal control
Field of view		32 x 26 degrees
Pixel Format		640 x 512 pixels
Pixel size		17 x 17 micron
Lens		19 mm f/1.25
IR bands		
	Channel 1	9.7 - 11.3 micron
	Channel 2	11.6 - 12.7 micron
Modeled Sensitivity		1.6 K/$\sqrt{Hz}$ for each pixel in each channel
Measured sensitivity		< σ/pixel < 150 mK RMS for 1/32 second exposure with full 9 - 14 μ band. The noise will increase by a factor of 5 when 1 μ wide filters are put in the system.
Absolute Calibration		
		± 2 K from 10 to -40 C target range
		± 4 K below -40 C

- Power
  - Power for each camera is individually controlled by the 5 V regulator output.
  - Power for the thermal control is switched with an internal relay controlled by the housekeeping system.

6.9.4 *Silicone photomultiplier elementary cell

6.9.5 *Health LED

- Health LED system consists of two modules : LED holder and Control Box
- 2 redundant LEDs controlled from HK and 1 LED for ground tests
- LEDs are installed in sockets and can be exchanged

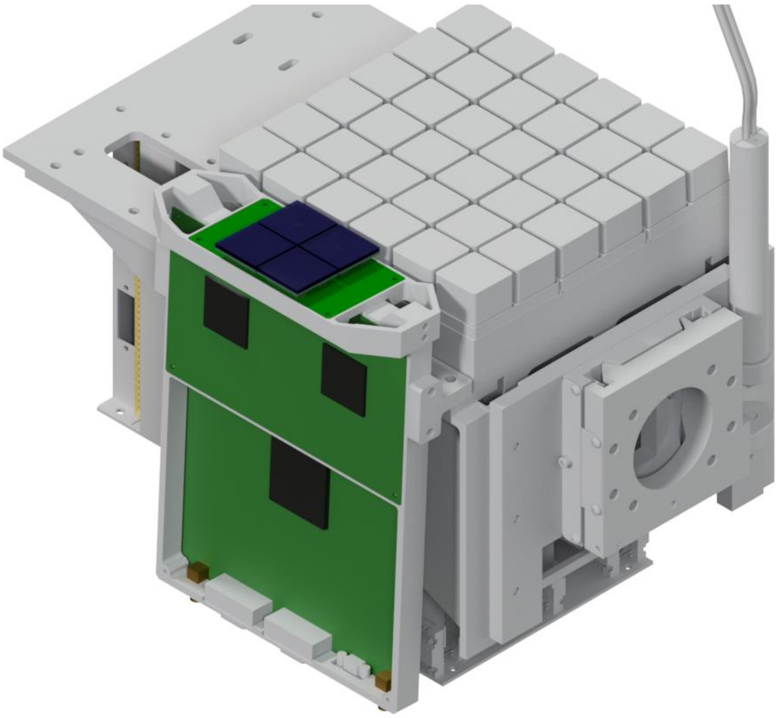


Figure 54: Full assembly of PDM with SiECA attachment. CNC Aluminum frames under production at KIT

Figure 55: SiECA Interface Connections

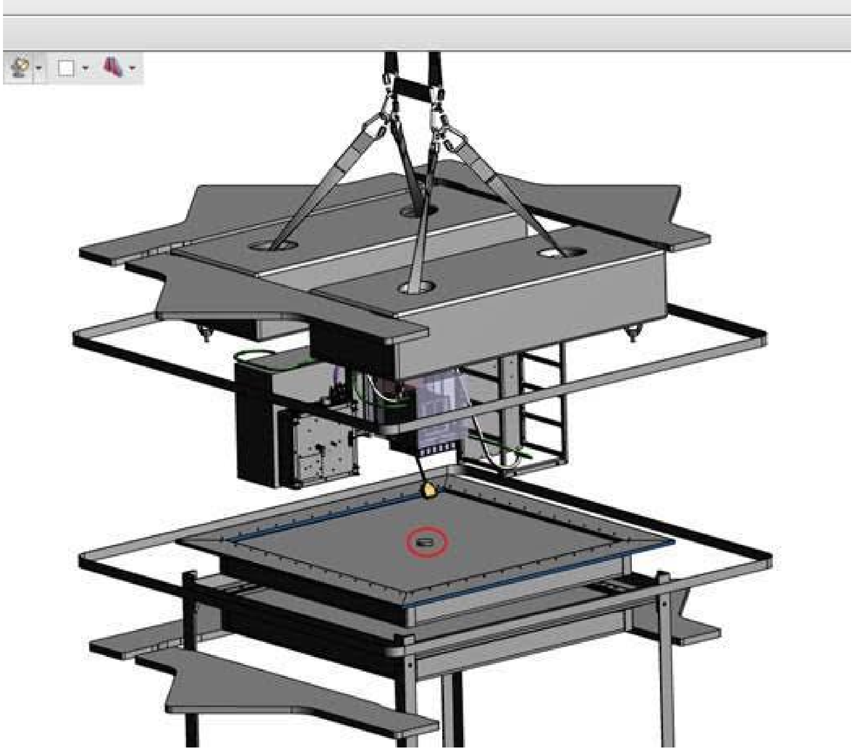


Figure 56: Health LED location and connections

- Set of LEDs: 340nm; 355nm; 365nm; wideband (350 – 390nm)
- Optional neutral density filter and (or) diffuser (opal/ hologr.)
- Pulse width and delay can be adjusted in the Control box (default pulse width : 10us)
- LED intensity is set by 12-bit code received via SPI (LVDS) from HK
- Trigger pulse – from CPU board or external / GPS pps/
- Optional manual adjustment of LED intencity 6

6.9.6 *Tracker beacon system

The system used in Timmins will be used again for the EUSO-SPB flight. It consists of redundant Tracker Beacons on the balloon and a Kenwood software-defined radio on the aircraft. If possible, we would like to have the radio connected to a laptop computer running Google Earth so that the positions of the balloon and the helicopter can be seen on the map.

We will need at least three and preferably five Tracker Beacons, Two will go to New Zealand to be mounted on the balloon and I would like to take a spare. One will go to the aircraft location for pre-flight testing and I would also like a spare with the aircraft.

The redundant beacons on the balloon will need to be located on the antenna boom or some similar place so that they can see the GPS satellites. We will need to mount them on a copper

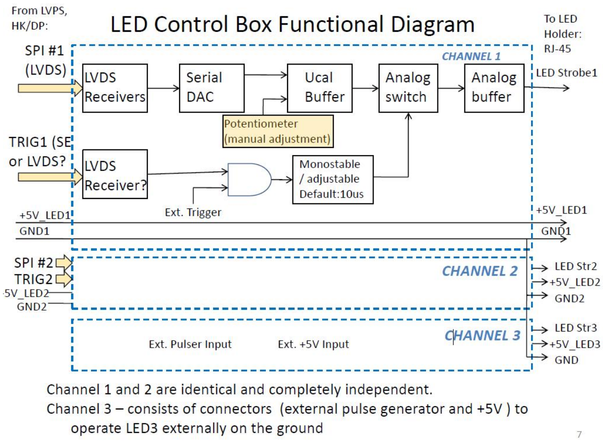


Figure 57: Health LED control box scheme

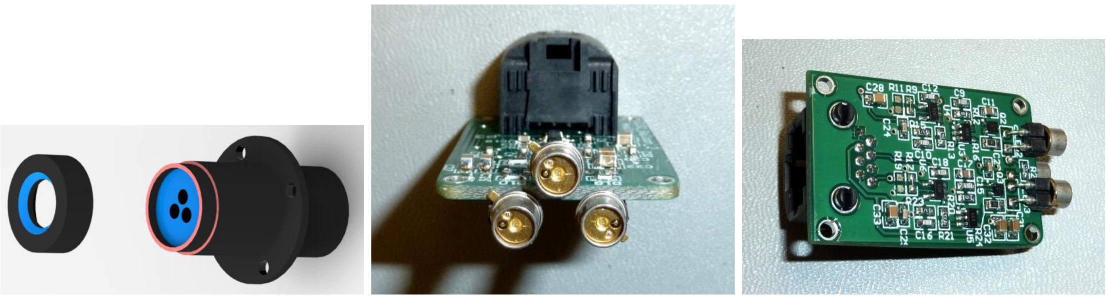


Figure 58: Health LED

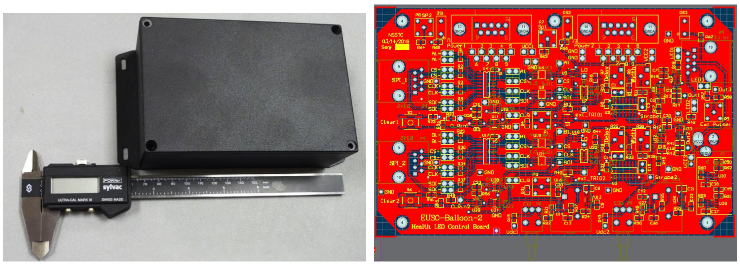
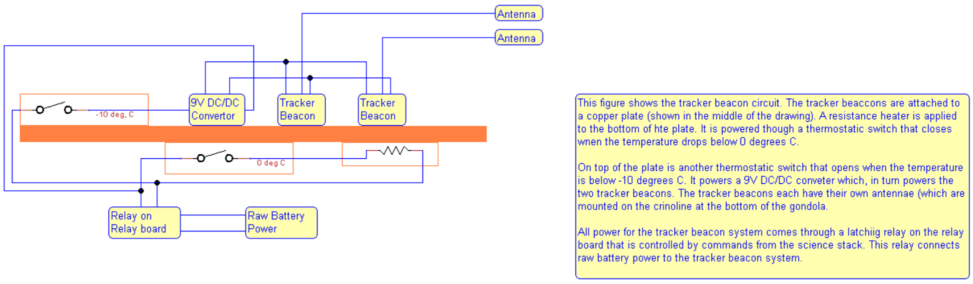


Figure 59: Health LED control box



This figure shows the tracker beacon circuit. The tracker beaccons are attached to a copper plate (shown in the middle of the drawing). A resistance heater is applied to the bottom of hte plate. It is powered though a thermostatic switch that closes wnen the temperature drops below 0 degrees C.

On top of the plate is another thermostatic switch that opens when the temperature is below -10 degrees C. It powers a 9V DC/DC conveter which, in turn powers the two tracker beacons. The tracker beacons each have their own antennae (which are mounted on the crinoline at the bottom of the gondola.

All power for the tracker beacon system comes through a latchiig relay on the relay board that is controlled by commands from the science stack. This relay connects raw battery power to the tracker beacon system.

Figure 60: This schematic shows the circuit for the redundant tracker beacons on the balloon. You can see that one of the relays on the Relay Board turns on/off the tracker beacons. There are two thermal switches. The one set to turn off at 0 degrees C controls the heater. The other at -10 degrees C turns on the beacons when the temperature is above -10 degrees C.

plate to which a MEMCO heater is attached. The heater will be thermostatically controlled to run on at 0 degrees C. There will be additional thermostatic switch set for -10 degrees C which will turn on power to the 9V DC/DC convertor that powers the tracker beacons. These will be used to run on the tracker beacons. Power for the beacons and the heater will be connected to raw battery power through the relay board where there will be a latching relay devoted to turning on/off the tracker beacons. The antennas for the transmitters in the tracker beacons will need to be located at the bottom of the gondola. I propose to put them on the solar power crinoline. It will mean running two coaxial cables from the antenna boom down to the bottom of the crinoline.

We will need to incase the tracker beacons, heater and DC/DC converter in a Styrofoam box to insulate it. The box should probably be painted white. I need to ask the thermal analyst to investigate the design. The operating range for the radio beacons is -10C to +40C.

On the aircraft we need the Kenwood software-defined radio. The one we used was a model THD-72A. We will need three of these. One for testing the beacons in Wanaka and one for the aircraft and one spare for the aircraft. If possible, I would like for Malek to also have a computer connected to the radio and running Google maps so that the position of the balloon and the aircraft can both be plotted on the map.

We will need to test all the radio beacons in Huntsville. I think we should arrange balloon flights through the Space Hardware Club to test the beacons and to familiarize Malek with tracking these balloons using the radio and hopefully the computer.

Two options are being explored for the under flight; New Zealand and Argentina. Where ever it is done, we need to arrange for at least one practice flight so Malek and the pilot can learn to coordinate tracking. I think it will work to put a tracker beacon on a car and have the aircraft track the car. An alternative might be to fly the tracker beacon on a kite. Of course we could send a latex balloon and helium for the aircraft training flights, but that would be logistically complicated. We might try to fly the tracker beacon on a tethered balloon but the wind would probably defeat this plan. We could launch the tracker beacon on the balloon but this would involve recovery of the tracker after the flight, so I think a car is the best plan.

6.10 Functional Block Diagram

6.11 Mass and Power Requirements

The mass requirements for the main parts of the telescope can be found in Table 12. The power consumption of the telescope is estimated to be 60 W.

Table 12: 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 13: 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

6.11.1 Electronics System (ELS), Data Handling

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

7 *Data budget

Ssupposing a trigger rate of: 0,25Hz, we need a compression factor of:

- PDM: 40%
- IrCAM: 30% (always, considering 15 frame/hours/camera, indipendent from the trigger rate)
- SiCa: 20%

8 *Triggering

- Need to select significant events triggered by L1 (2 Hz/PDM) to the level of 0.2 Hz/PDM to be sent via telemetry to ground.
- The other events can be stored on board and collected at the end of the flight, if feasible.
- L2 performs a first check to give priority to the triggered events (readout of the L1 output FIFO) – "First quality criteria"
- CPU trigger runs a similar L1 trigger code during daytime and tries to recover other possible events – "Second quality criteria"
- What is not selected via L2 or CPU stays on board till the end of the flight. May be zipping the data might help reducing the allocated disk space.

8.1 First quality criteria

L2 can perform the FIRST QUALITY check by processing the data contained in the FIFO.

Every GTU of a pre-trigger this FIFO is filled with relevant information (GTU, x & y of the box, counts number) that can be used by L2 to check if the signal is relevant or not.

8.2 Second quality criteria

- Events that do NOT pass the first quality criteria are stored on CPU.
- During day time CPU processes the data using the same L1 trigger logic (1-2 events/s) with lower thresholds.
- Events that pass Second Quality Criteria are downloaded during day time.

9 Interfaces