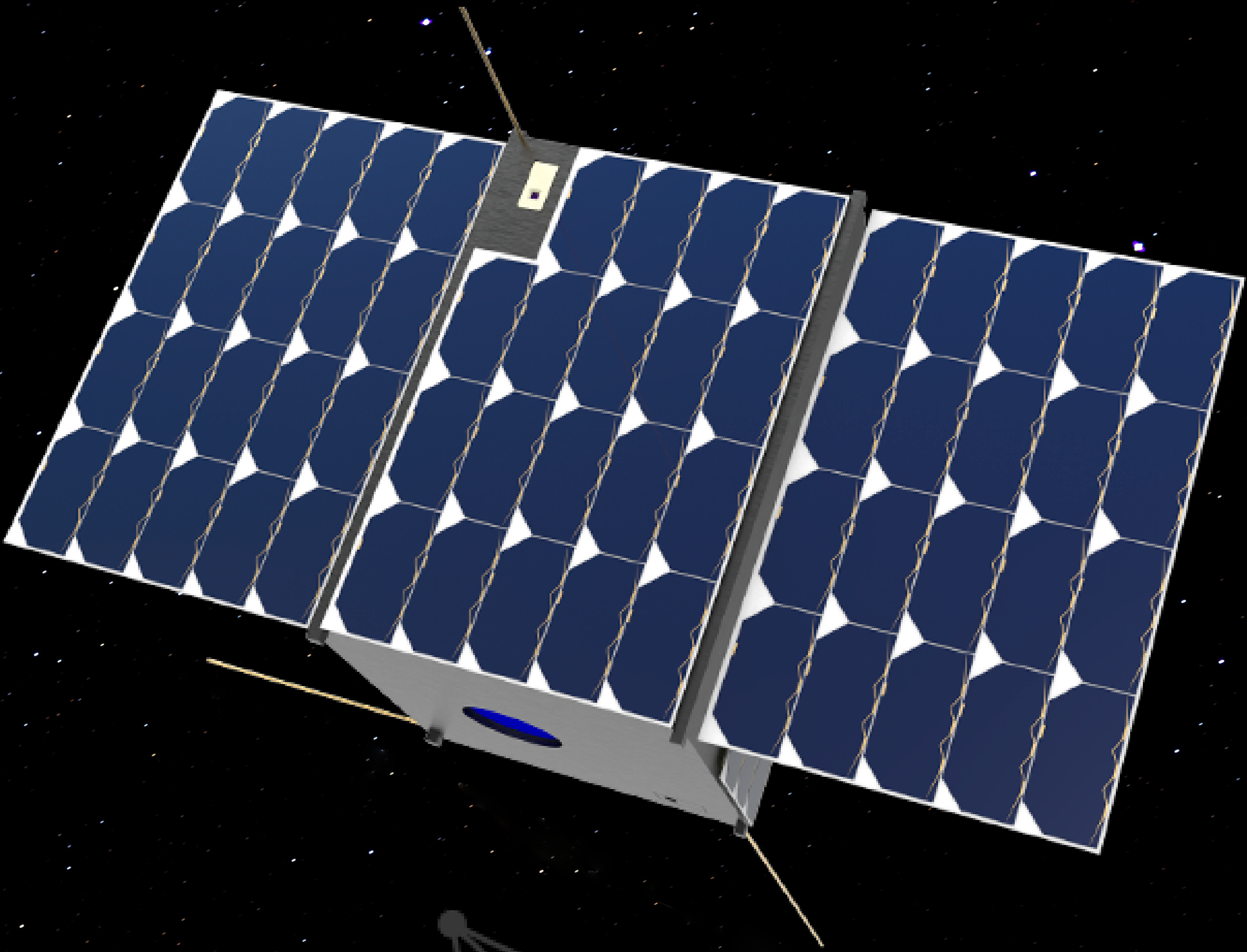
SPACE INVENTOR



Datasheet
12U satellite

BAT-P3

Integrated 8 cell Li-Ion Battery System

For Micro- and Nano-Satellites

Features

- 8 Li-Ion 18650 cells
- 14.4V or 28.8V nominal voltage
- 92 Whr nominal capacity
- Automatic Cell balancing
- Short-circuit protection
- Over- and under-voltage protection
- Always-on ultra-low-power Real Time Clock
- Microcontroller for housekeeping and control
- CAN bus with CSP protocol
- Heater with automatic control
- High-reliability Harwin M80 connectors
- Inhibit connector for insert-before-flight and separation switches:
  - High-side and low-side raw battery
  - High-side and low-side MOSFET with external control lines
- Reliability
  - Radiation total dose tested EEE parts
  - Vibration rated for all launch vehicles
  - Redundant inhibit MOSFETs
- High-quality Enclosure
  - Min. 1.5 mm Al Shielding in all directions
  - PC-104 compatible mounting holes

Description

The BAT-P3 is an 8 cell Lithium-Ion battery system designed for high battery life-time, easy integration, and safety. The battery configuration can either be 4s2p or 8s1p providing 92 Wh in nominal capacity. The BAT-P3 is both flexible enough and sufficiently powerful for most nano- and small-satellite missions.

The automatic balancing circuit maximizes cell lifetime, and the automatic heater keeps the cells operational at low temperatures. Short-circuit and over/under voltage circuits protects the cells from damage. To accommodate different launch vehicle requirements, each module has connectors for both soft and hard inhibits.

The BAT-P3 comes in a rugged and modular 1.5 mm Al enclosure, which both acts as on-orbit radiation mitigation as well as a practical short-circuit protection during satellite assembly.

An always-on ultra-low-power Real Time Clock provides timer-continuity during satellite shutdown.

Functional Description

The BAT-P3 has two seperate protection circuits, one for charging and one for discharging operations.

The Input protection has reverse polarity protection, over current protection and over voltage protection. This protects the battery pack from excessive charge currents and limits the maximum battery voltage to safe operating levels regardless of charge configurations. The input protection breaks the connection between the input port and the battery cells if either the overcurrent or overvoltage limits have been exceeded.

Output protection protects the battery from excessive discharge currents and discharging of the battery to below safe operating level. The output protection breaks the connection between the output port and the battery cells if either the over current or under-voltage limits have been exceeded.

The BAT-P3 is equipped with two hard and two soft inhibits. The hard inhibits carry the full load current of the battery

and must be able to withstand both mean and peak current loads. One inhibit is placed between the battery cells and the output port, the other inhibit is placed between the battery cells and the common GND point. The soft inhibits consist of MOSFETs placed in series with the hard inhibits.

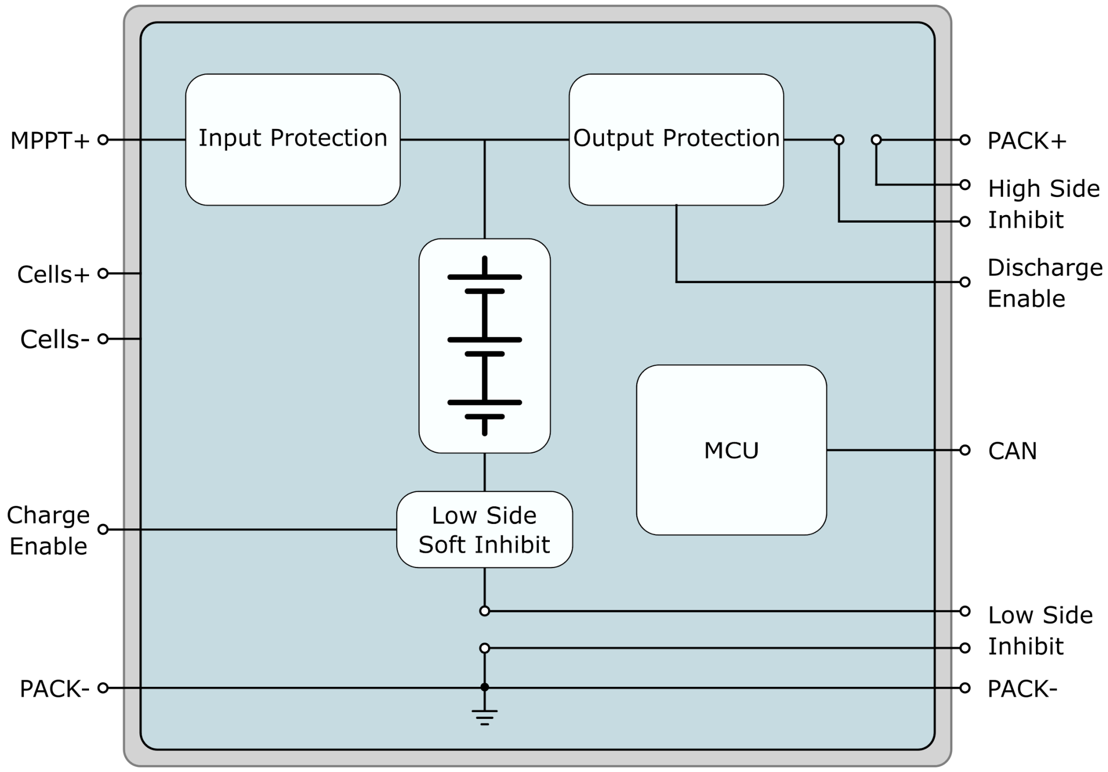
All four inhibits can be controlled individually, in order to charge the battery, the LOW side inhibits must be closed. To be able to discharge, the HIGH side inhibits must be closed. This can be done using kill-switches, a permanent short or controlled by external circuitry.

For full battery functionality all four inhibits must be activated.

Automatic cell balancing and battery heating maintains the battery cells at appropriate voltages and temperature.

Direct access to the battery cells are provided in order to read out the battery voltage without turning the battery ON.

When the battery is active CAN communication can be used to readout telemetry and configure system parameters.



Simplified functional block diagram

Detailed Functional Description

Inhibit Circuit

The BAT-P3 has two types of inhibits allowing compliance to all launch providers, including ISS launches. All inhibits can be used as either insert-before-flight or be routed through separation switches.

Inhibit low/high: These lines are connected in series with the cells and require the battery current to flow through the lines, so therefore the outgoing lines must be shorted to the return lines in order to make the circuit. There is a high-side output inhibit and a low-side inhibit and both must be closed for the battery to be fully enabled. Charging of the battery can be performed with only the low-side inhibit shorted.

These inhibits carry the full current load of the battery, and if any one would fail, in an open state, the battery will be disconnected. Therefore, each inhibit is routed to 3 outgoing pins and 3 returning pins in parallel in order to share the current load and to mitigate the risk of an open circuit failure.

Charge/Discharge Enable: Similarly to the low/high inhibits two MOSFETs are able to open and close the battery circuit. A High-side MOSFET is used to prevent discharging the battery when opened and a Low-side MOSFET prevents charging the battery when opened. Control signal for the MOSFETs are provided in the inhibits connector, and by shorting the control signal pins to the MOSFET gate pins, the circuit is closed.

These inhibits do not carry any current, only the small turn-on gate current for the MOSFETs. Each MOSFET has two control signal pins and two gate pins in parallel, to mitigate the risk of an open circuit failure.

All four inhibits must be closed for the battery to be on. If some switches are not in use, a simple insert before flight connector can be added to permanently close the unused switch input.

Overcurrent and short circuit Protection

The total battery charge- and discharge current is monitored by comparators which can quickly react to an overload or a short circuit and protect the cells and the circuits.

Undervoltage Protection

The cell voltage is monitored by a comparator that will disable battery discharging in under-voltage conditions. When in undervoltage, the microprocessor is also switched off in order to preserve as much power as possible. This means that the heater will also be disabled.

The battery undervoltage should only be used as a second line of defence as it can be harmful to the lifetime of the cells. Especially if the cells are both undervoltage and under temperature.

The recommended method to avoid an undervoltage condition is to gracefully shutdown subsystems as the battery voltage gradually lowers. This is typically performed in the power distribution unit.

Overvoltage Protection

The cell voltage is monitored by a comparator that will disable the battery charging input when the total battery voltage rises above the threshold value. When in overvoltage protection, the battery discharge remains active and all battery functionalities remain in operation.

The overvoltage protection breaks the connection between the battery and the charging circuit, thereby removing the entire load from the charger. This can potentially harm the charging circuit (MPPT), it is therefore advised to limit the charging current when the battery voltage approaches the maximum allowable battery voltage.

Cell configuration

The BAT-P3 supports up to 8 cells in series or two parallel strings of 4 cells in series.

Option	Nominal	Max V	Capacity
8 cells (8s1p)	28.8 V	33.6 V	3200 mAh
8 cells (4s2p)	14.4 V	16.8 V	6400 mAh

Battery voltage and configuration options

Real-Time Clock

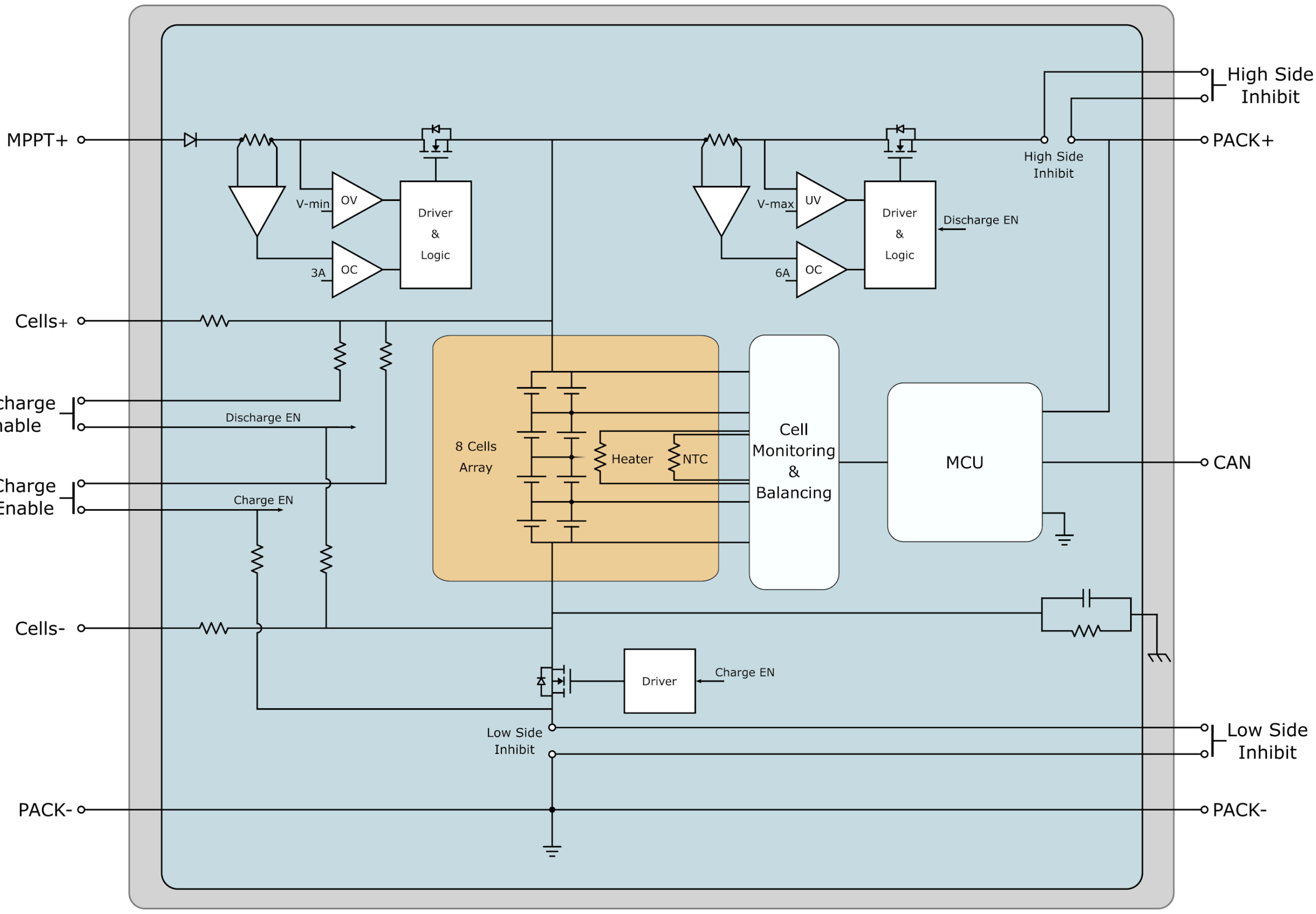
The RTC is powered by the 3.3 V supply for the microprocessor in nominal mode. When the battery is switched off, the RTC is in ultra-low-power mode supplied directly from the battery through a 1 MOhm resistor. The quiescent power in this mode is 2 uA max. Thereby proving a long shelf-life while still maintaining the RTC clock.

Automatic Heater

The batteries perform best over 10 degrees Celsius. It can therefore be necessary to heat the cells in some circumstances. The microprocessor will monitor the temperature and switch the heater on when needed. The desired temperature can be controlled by a software parameter.

CAN Termination

The board features optional 120 Ohm CAN termination mounted to the customers specification.



Detailed Functional System Diagram

Specification

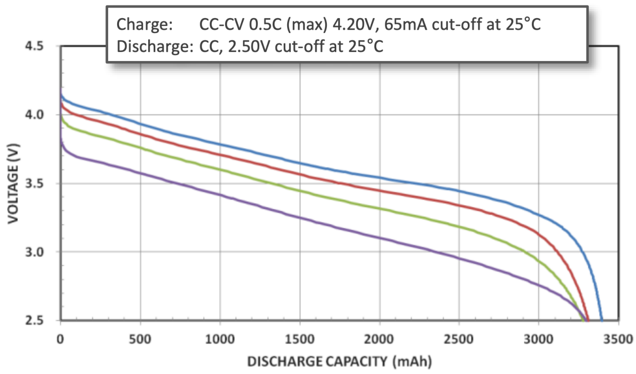
Parameter	Configuration 4s2p	8s1p	Unit
System Ratings			
Nominal Voltage	14.4	28.8	V
Nominal Capacity	6.4	3.2	Ah
Nominal Energy	92	92	Wh
Power output	180	180	W
Peak power output (<500 ms)	300	300	W
Power Consumption			
Quiescent Current			
- Storage, Under-Voltage, Over-Current			
- - Typical[1]	67	84	µA
- - Maximum[2]	78	102	µA
- Nominal and Over-Voltage	2.1	1.0	mA
Efficiency[3]			
- Nominal	98.6	99.6	%
- Over-Voltage Mode	94.0	96.5	%
- Under-Voltage Mode	94.0	96.2	%
Shelftime[4]	652		Days
Battery losses			
Output losses (from cells to connector)			
- Board Resistance	25		mΩ
- Typical hard switch bypass (6 wire loop)	9		mΩ
Charger Input loss (from connector to cells)			
- Board Resistance	31		mΩ
- Low side hard switch bypass (3 wire loop)	6		mΩ

[1] At nominal battery voltage and nominal system idle power consumption
[2] At maximum battery voltage and maximum system idle power consumption
[3] At maximum instantaneous power. The reduced efficiency in over- and under-voltage mode is because the battery is discharged and charged through the low and high-side MOSFET body diodes, respectively.
[4] Shelftime is defined as the typical time it takes to reduce the battery charge by 1000 mAh due to quiescent current. Maximum 25 degree Celsius storage temperature is assumed. Reduction in storage capacity due to battery ageing is not accounted for.

	Configuration		
Parameter	**4s2p**	**8s1p**	**Unit**
Battery Protection			
Under-Voltage Level	12.2	24.4	V
Under-Voltage Hysteresis	1.10	1.10	V
Over-Voltage Level	16.7	33.4	V
Over-Voltage Hysteresis	0.3	0.7	V
Over-Current Threshold	11	5.5	A
Current limit during inrush	22	11	A
Over-Current Trip-Off Time			
- Fast protection	500		ns
- Normal overcurrent	540		ms
Over-Current Retrigger Interval			
- Typical	500		ms
- Minimum	40		ms

Battery Characteristics

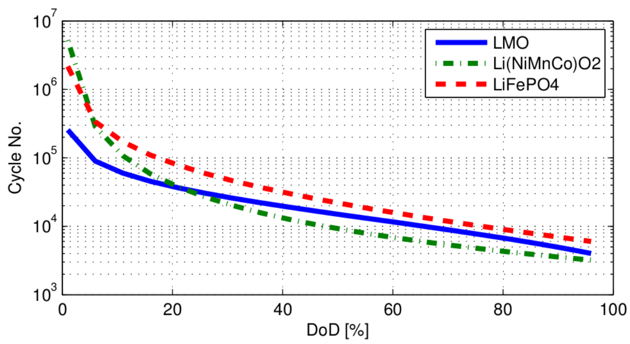
The BAT-P3 uses eight Panasonic NCR18650B cells, that have proven to be very reliable in several space missions. The lifetime of the cells depends on the temperature, the charge and discharge rate and the total discharge depth. At full discharge depth, the cell remains at 90% capacity after 300 cycles at 40 degrees C. The cells will lose about 20-40% of its capacity when operating under 0 degrees C and discharge is not allowed. It is generally recommended to keep the cells above 10 degrees C.



Cell voltage as a function of battery capacity.

Parameter	Condition	Specification
Capacity	Nominal	3200 mAh
Nominal voltage	Average	3.6 V
Max charge voltage		4.2 V
Max charge current		1 C
Max continuous discharge current	-20 - +5 deg. C.	0.5 C
	5 - 45 deg. C.	2 C
	45 - 60 deg. C.	1.5 C
Operating temperature	Charge	0 - 45 deg. C
	Discharge	-20 - 60 deg. C
Storage temperature	1 month	-20 - 60 deg. C
	3 month	-20 - 40 deg. C
	1 year	-20 - 20 deg. C

Battery characteristics



Battery lifetime as a function of depth of discharge (Panasonic NCR18650B is equivalent to the green curve).

Battery lifetime considerations

Analysis of Li-Ion cells have shown how various parameters affected the battery lifetime.

There are three ways the lifetime can be improved for the BAT-P3 system. (For further details see Xu et al.[5])

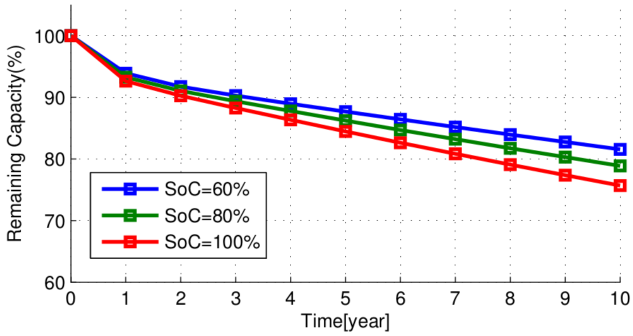
1: Temperature control: Keeping the cells below 35 degrees will keep the capacity above 80% after 5 years. In general the cooler the better. However the cells may not be charged at under 0 degrees C.

2: Reduce End of charge: Reducing the end of charge voltage from 100% SoC to 75% can greatly improve the amount of cycles before reaching end of life at around 80% capacity retention. This setting can be controlled in the battery charger by setting the `mppt_protect` parameter to a lower overall battery voltage.

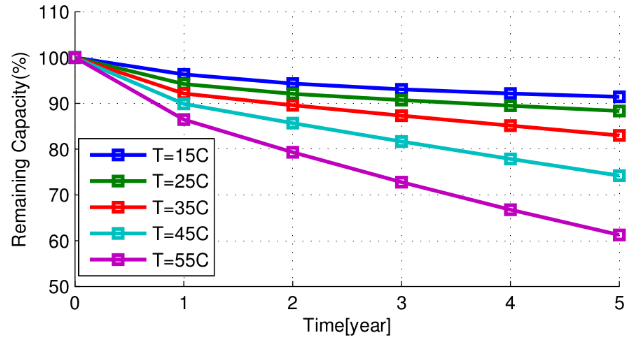
3: Reduce Depth of Discharge: Limiting the DoD to around 20% will increase the lifetime to around 50.000 cycles compared to a 75% DoD which gives only 4000 cycles. The DoD can be controlled with a Space Inventor PCDU-12 by gradually powering off subsystems, for example by entering lower power modes using the `dfl_vprotect` parameter.

Battery Storage

The optimal storage condition is at ~10 degrees C at 50% SoC.



Remaining storage capacity at different SoC levels at 25 degrees C.



Remaining storage capacity at different temperatures at 50% SoC

5 Xu, Bolun & Oudalov, Alexandre & Ulbig, Andreas & Andersson, Göran & Kirschen, D.s. (2016). Modeling of Lithium-Ion Battery Degradation for Cell Life Assessment. IEEE Transactions on Smart Grid. 99. 1-1. 10.1109/TSG.2016.2578950.

Parameters

The persistent configuration variables [conf_*] are stored in the external FRAM chip. The telemetry is updated each second.

Name	Type	Default
Persistent configuration variables		
heater_auto	uint8	1
heater_auto_on_at	int8	10
heater_auto_off_at	int8	15
balance_auto	uint8	1
balance_thr	uint16	50
State variables (on/off)		
heater_on	uint8	0
balance_cell	uint8	0
Telemetry		
tlm_temp	int16	read only
tlm_vcell	uint16[6]	read only
tlm_vin	uint16	read only
tlm_vout	uint16	read only
tlm_iin	uint16	read only
tlm_iout	uint16	read only
Trigger		
powercycle	uint8	0

List of parameters

Heater

The microcontroller continuously monitors the battery temperature and will enable its built-in heaters when the temperature reaches the value set in the `conf_heater_auto_on_at` parameter. The heater will turn off again when the temperature reaches the value set in the `conf_heater_auto_off_at` parameter. The automatic heater can be turned off by setting `conf_heater_auto` to zero.

The `heater_on` state variable shows the current state of the heater at any time. Setting this variable manually will switch the heater on or off.

Cell Balancing

In order to prevent cell imbalance, the microprocessor monitors the individual cell voltage. If the difference between the highest and the lowest cell voltage is greater than 50 mV (default), a bleed-resistor is put in parallel to the battery with the highest voltage. The bleed current is 50 mA.

Telemetry

For testing purposes, telemetry can be collected using a CAN dongle through a test harness. We use and recommend a PCAN IPEH-2022 with galvanic isolation, a Linux PC with socketcan driver and out own **satctl** software.

For more information on how to use **satctl**, request the satctl manual.

Individual cell voltages can be retrieved in the `tlm_vcell[6]` parameter. Automatic cell balancing can be disabled by setting `conf_blance_auto` to zero, and the threshold can be changed by setting `conf_balance_thr`.

The `balance_cell` state variable shows the current state of the balancer at any time. Setting this variable manually will force the balancer on at the given cell number (numbered 1-6). A setting to zero turns bleeding off.

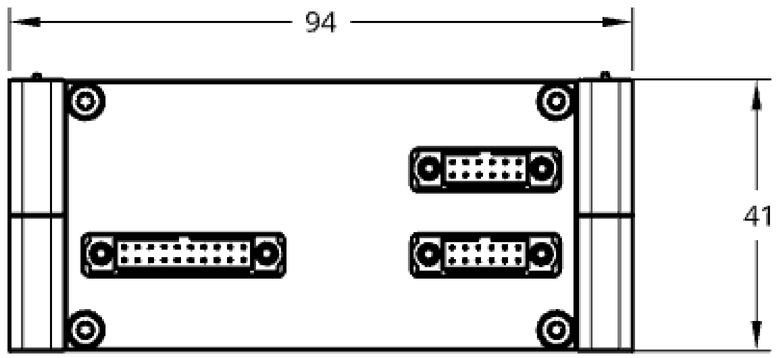
Power Cycle

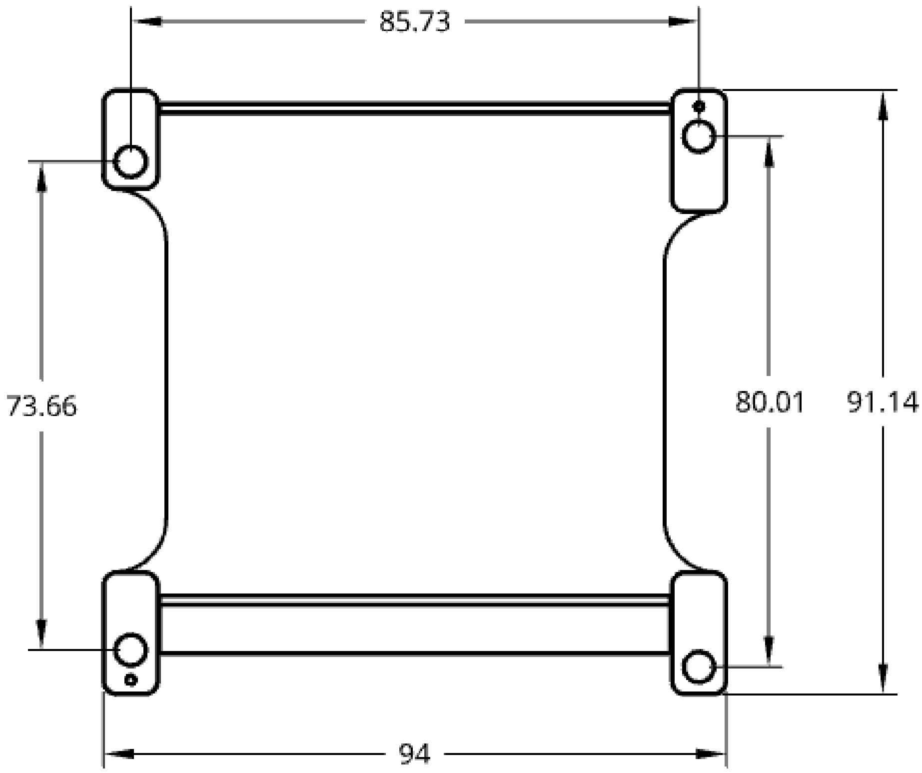
In order to power cycle the battery output the variable `power cycle` should be set to 123. This will trigger the overcurrent protection and turn off the microcontroller and all battery discharging. When the microcontroller is powered off this will clear the power cycle condition, and the system will power up again.

```
/bin/bash
148:1  cells_in_parallel    = 1
147:1  cells_in_series      = 5
 13:1  csp_can_pwrsave      = 0
 11:1  csp_can_speed        = 1000000
 10:1  csp_node             = 1
 12:1  csp_rtable           = ""
171:1  extreset             = 0
  1:1  gndwdt               = 67643
140:1  heater_auto          = 1
142:1  heater_auto_off_at   = 15
141:1  heater_auto_on_at    = 10
160:1  heater_on            = 0
151:1  hw_limit_reg         = 1
137:1  ina_alert_lim        = 0x0
135:1  ina_calib            = 0x0
130:1  ina_conf             = 0x4127
134:1  ina_current          = 0x0
139:1  ina_die_id           = 0x2260
138:1  ina_manuf_id         = 0x5449
136:1  ina_mask_enable      = 0x8
133:1  ina_power            = 0x0
132:1  ina_vbus             = 0x396C
131:1  ina_vshunt           = 0x21
150:1  oc_limit             = 5000
161:1  ov                   = 0
144:1  ov_off_at            = 20500
143:1  ov_on_at             = 21000
170:1  powercycle           = 0
149:1  rsense               = 10.0000
 30:1  temp                 = 2548
 40:1  time_factor          = 1.000000
123:1  tlm_ipack            = -642
124:1  tlm_isys             = 3
120:1  tlm_temp             = 3119
121:1  tlm_vcell            = [3663 3673 3666 3663 3666 80]
122:1  tlm_vpack            = 18348
125:1  tlm_vpack2           = 18375
```

Example telemetry using 'satctl' with CAN-dongle on a PC

Mechanical Drawings



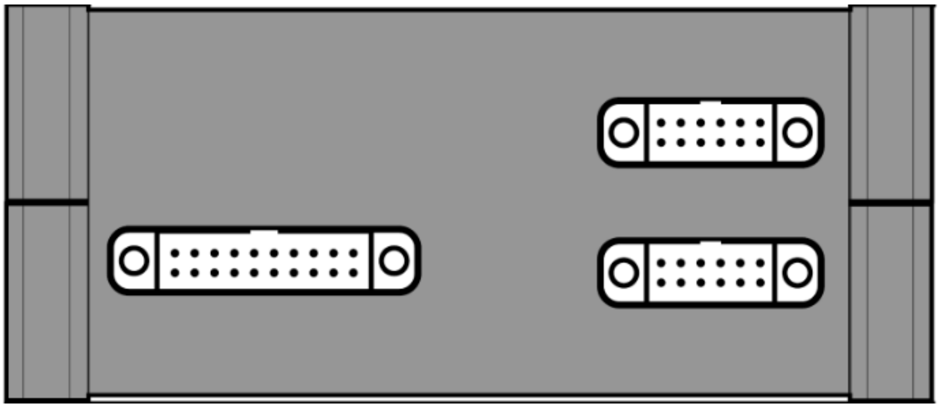


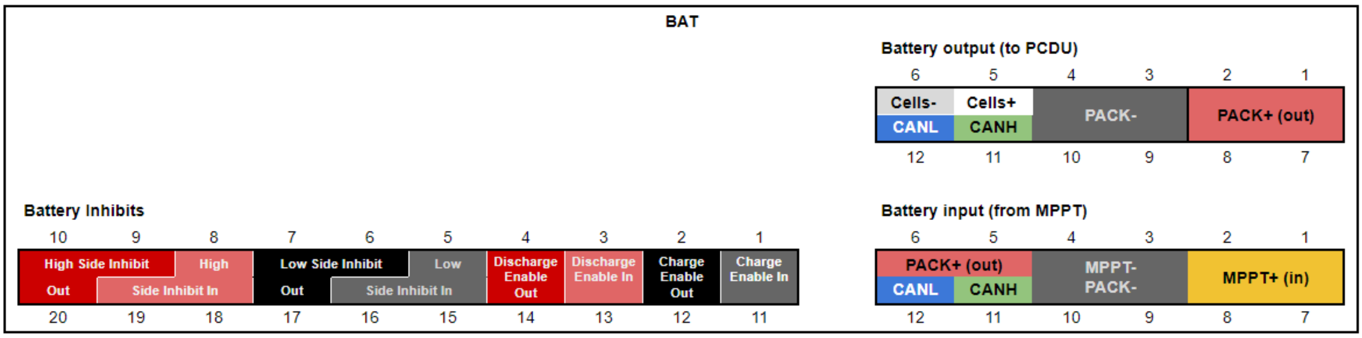
Dimension Drawing

Mass

The weight of the BAT-P3 is 604 gram configured with 8 batteries (50 gram each).

Pin-out





Battery Inhibits

Pin Number	Pin Name	Pin Function
1, 11	Charge Enable In	Enable signal input to turn ON the Low side MOSFET, which enables charging of the battery. Internal pull down, must be driven high to enable.
2, 12	Charge Enable Out	Voltage source which can be used to pull-up Charge enable, by shorting the Charge Enable Out pins to the Charge Enable In pins.
3, 13	Discharge Enable In	Enable signal input to turn ON the High side MOSFET, which enables discharging of the battery. Internal pull down, must be driven high to enable.
4, 14	Discharge Enable Out	Voltage source which can be used to pull-up Charge enable, by shorting the Charge Enable Out pins to the Charge Enable In pins.
5, 15, 16	Low Side Inhibit In	Connection to PACK-, connect to Low Side Inhibit Out to close the circuit between the battery pack and the PACK- power rail.
6, 7, 17	Low Side Inhibit Out	Connection to the battery negative terminal. Connect to Low Side Inhibit In to close the circuit between the battery pack and the PACK- power rail.
8, 18, 19	High Side Inhibit In	Connection to PACK+, connect to High Side Inhibit Out to close the circuit between the battery pack and the PACK+ power rail.
9, 10, 20	High Side Inhibit Out	Connection to the battery positive terminal. Connect to High Side Inhibit In to close the circuit between the battery pack and the PACK+ power rail.

Battery Output

Pin Number	Pin Name	Pin Function
1, 2, 7, 8	PACK+	Protected BAT-P3 power output (V+)
3, 4, 9, 10	PACK-	Protected BAT-P3 power return (GND)
5	Cells+	Positive terminal of the battery pack, protected with a 2.7k series resistor, can be used to monitor battery state of charge when BAT-P3 is turned off.
6	Cells-	Negative terminal of the battery pack, protected with a 2.7k series resistor, can be used to monitor battery state of charge when BAT-P3 is turned off.
11	CAN H	CAN High
12	CAN L	CAN Low

Battery Input

Pin Number	Pin Name	Pin Function
1, 2, 7, 8	MPPT+	Protected BAT-P3 charge input
3, 4, 9, 10	MPPT- / PACK-	Protected BAT-P3 charge and power return (GND)
5, 6	PACK+	Protected BAT-P3 power output (V+)
11	CAN H	CAN High
12	CAN L	CAN Low

MPPT-P3

7 Channel Maximum Power Point Tracker and Battery Charger

For Micro- and Nano-Satellites

Features

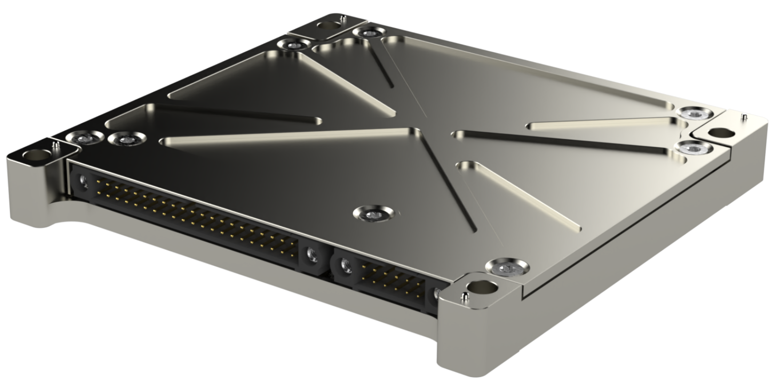
- 4-12 Solar cells per string
- 1-2 solar cell strings per channel (using external combiner diodes)
- 6 PV inputs with variable frequency DC-DC buck converters with maximum power point tracking controller
  - Up to 96% Efficiency
- 1 PV input with boost converter
- 3 Protected battery output (PDU channels) for panel mounted peripherals
  - Up to 2A output
  - Programmable overcurrent and latch-up protection
  - Advanced power metering
- Microcontroller for housekeeping and control
- CAN bus with CSP protocol
- High-reliability Harwin M80 connectors
- Reliability
  - Thermal heat sinking by flush-mounted PCB on 2.5mm Al
  - Radiation total dose tested EEE parts
  - Vibration rated for all launch vehicles
- High-quality Enclosure
  - Min. 1.5 mm Al Shielding in all directions
  - PC-104 compatible mounting holes

Description

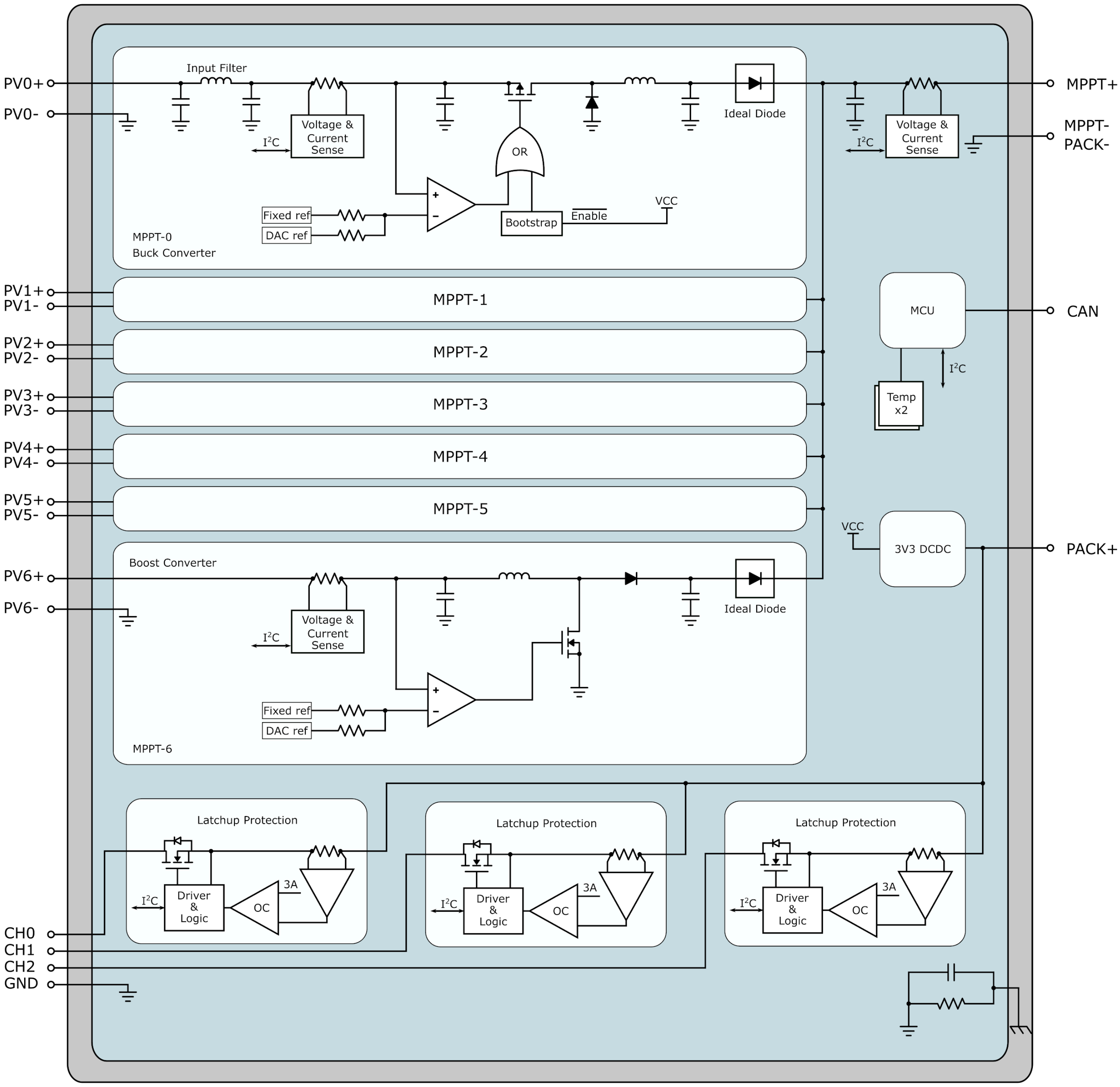
The MPPT-P3 is a six plus one channel maximum power point tracker and battery charger module, designed for durable, simple and robust satellite integration. The system consists of six variable frequency DC-DC buck converters and a single variable frequency boost-converter, that ensure optimal operating voltage for each solar cell array at all temperatures and irradiance levels. After conversion, the channels are combined through ideal diodes to minimize loss, and connected to the battery output.

A configurable end-of-charge setting, will stop charging at a certain voltage level in order to prolong battery life. When components reach end-of-life, a pass-through mechanism will route the solar output directly to the battery bus, whereby functionality is not entirely lost. Likewise, if the on-board MCU is disabled, each MPPT channel has a fixed voltage fallback.

Housekeeping data for all channels are available through CSP telemetry. Appreciating that the solar panels are often combined with external sun and temperature sensors, each solar panel connector are equipped with a protected battery supply and CAN bus interface.



Functional Description



Functional Block Diagram

Overview

The MPPT-P3 consists of six variable frequency DC-DC Buck converters and one variable frequency DC-DC boost converter.

Each buck converter MPPT channel is designed to be a drop-in replacement for conventional power rectifying diodes, but with zero forward voltage drop and power point tracking capabilities. Hence, just as for standard diode rectifiers, each MPPT channel is designed to conduct as long as the photovoltaic voltage is above the battery voltage, and cutoff in all other cases. But contrary to standard diode rectifiers, where the photovoltaic voltage is forced to the battery voltage plus the diode forward voltage, the photovoltaic voltage on each MPPT channel is decoupled from the battery voltage using a Buck converter, which allows the photovoltaic voltage to rise above the battery voltage. This additional degree of freedom is used to adjust the photovoltaic voltage to the optimal power point for the connected solar panel.

A single channel with a boost converter topology makes it possible to populate small surface areas with solar cells with a string voltage lower than the battery voltage. The boost converter functions similarly to the buck converters, decoupling the battery from the photovoltaic voltage. Thereby it can maintain the optimum power point for a photovoltaic voltage lower than the battery voltage.

The optimal power point for each channel is tracked using a perturb-and-observe algorithm which identifies the optimal photovoltaic voltage for any given panel temperature and irradiance levels. Thus, as long as the maximum power point voltage for the connected solar panel is above the battery voltage, the MPPT-P3 will automatically identify the optimal power point. In remaining cases, it will act as an ideal diode

Additionally three Latch-up protected outputs can be used for powering peripherals, such as sensors, thermal knives, or other subsystems.

Detailed Description

The DC-DC converter operation is controlled by an inner and outer loop:

Inner Control Loop: The inner control loop is a free-running multivibrator with a time-constant primarily dependent on the photovoltaic current and conversion rate. When active, the input capacitor is charged at a rate proportional to the photovoltaic current. Charging continues upto the desired photovoltaic voltage plus 50 mV, at which point the comparator trips and triggers the high-side MOSFET. The inductor EMF is allowed to build up until the input capacitor voltage drops below the desired level minus 50 mV. At this point, the high-side is turned off and the capacitor is recharged. In the meantime, the inductor EMF is transferred to the output capacitor and battery. The default photovoltaic voltage of the inner loop is set using a fixed 10 V hardware reference.

Outer Control Loop: The outer control loop controls the photovoltaic input voltage by changing the comparator reference voltage of the inner loop. The specific voltage optimal for the current conditions is determined by observing the input and output power of each channel and perturbing the voltage level, until the optimal power point has been identified. Outer loop tracking is active as long as the on-board microcontroller is running.

Bootstrap logic: Bootstrap logic ensures that the high-side MOSFET is enabled in case the battery provides insufficient power to drive the 3.3V domain, or that the 3.3V regulator has succumb for some reason.

Ideal diode: The ideal diode prevents current flow from the battery to the solar panels. The diode consists of a massively derated N-channel MOSFET and high-side driver circuit.

Temperature sensor: An onboard NTC is used for thermal protection. MPPT-P3 automatically shuts down if the case temperature exceeds the operating limit.

MPPT power requirement: The micro-controller, auxiliary circuits and the gate-driver typically require around 3.5 mA @ >5V in order to operate.

Protected Battery

Temperature sensor: The PCB ground plane temperature is continuously monitored using a NTC resistor, and temperature telemetry readings with an accuracy of ±2 degree Celsius are available through the parameter interface. A thermal fuse is implemented in the MCU, which switches off all MPPT channels if the temperature exceeds the operating limit.

CAN bus termination: The board features *optional* 120 Ohm CAN termination mounted to the customers specification.

Ground-to-chassis coupling: The MPPT-P3 grounding scheme can be configured according to customer specifications. By default, chassis and electrical ground are electrically connected.

Array Configuration

Each MPPT-P3 channel supports solar cell strings containing anywhere from 4 to 12 cells. Solar cell arrays are also supported provided that external power OR-ing (protection diodes) are used.

The maximum number of strings per array (per input channel) is primarily limited by the inductor saturation current, which increases with the photovoltaic current. The available options are listed in Table 1.

PV Input	Cells per String	Strings per Array
PV 0	4 - 12	1 - 2
PV 1	4 - 12	1 - 2
PV 2	4 - 12	1 - 2
PV 3	4 - 12	1 - 2
PV 4	4 - 12	1 - 2
PV 5	4 - 12	1 - 2
PV 6	1 -	1 - 2

Table 1: Allowable solar panel configurations.

At maximum capacity, the MPPT-P3 can provide power point tracking for a total of 144 solar cells. Thus, if fully illuminated simultaneously, the solar panels will produce approximately 173 W of instantaneous power. However, due to electrical limitations, the MPPT-P3 can only deliver 125 W of continuous power (assuming 25 V battery @ 5 A). Naturally, *great care must be exercised not to violate the thermal limitations of the MPPT-P3 when operating with large solar arrays.* See Specification sections for more information about efficiency, solar panels/battery pairing, and thermal limitations.

Specification

Absolute Maximum Ratings

Parameter	Value Min.	Value Typ.	Value Max.	Unit
Operating Limits				
Channel Input Voltage [1]	0	-	36	V
Channel Input Current	0.0004		1.1	A
Channel Output Voltage[2]	0	25	35.9	V
Channel Output Current	-0.024		5	A
Temperature				
- Case	-40		65	℃
- PCB ground plane	-40		75	℃

Electrical Characteristics

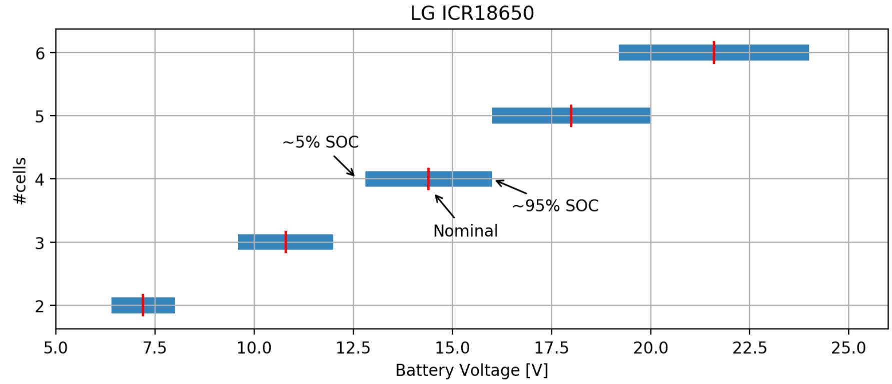
Parameter	Min.	Typ.	Max.	Unit
Threshold Levels				
Inner Loop Set Point[3]		10		V
Outer Loop Control Range	5		36	V
Bootstrap Trip Voltage		2.7		V
Channel Performance				
Efficiency				
- MPPT			94	%
- Tracking Disabled	99			%
Quiescent Current		3.5	4.8	mA
MPPT system power				
- 15 V input		320		mW
On-Resistance		229		mΩ
Reverse Current Leakage		1		μA
Forward Voltage Drop[4]	120			mV
Regulator Responsiveness (outer loop)		1		V/s

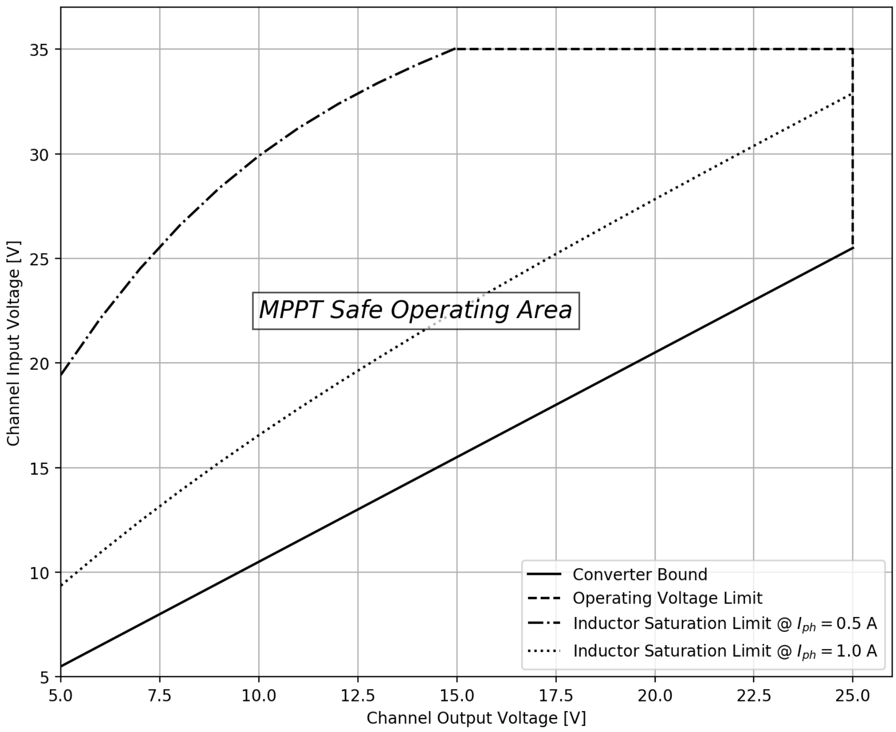
[1] Typical values indicate the maximum photovoltaic voltage, at which the MPPT regulator can operate.
[2] The output voltage is dictated by the battery voltage. Maximum values account for the case where the battery is disconnected, or that the input voltage is 40 V and the bootstrap logic has enabled the high-side P-MOSFET. Batteries with higher voltage (at maximum SOC) than the typical value should not be connected.
[3] This is set low enough that the high-side MOSFET will always be ON when the outer loop is not active.
[4] High-side MOSFET constantly on. Maximum value depends on battery voltage and conversion rate

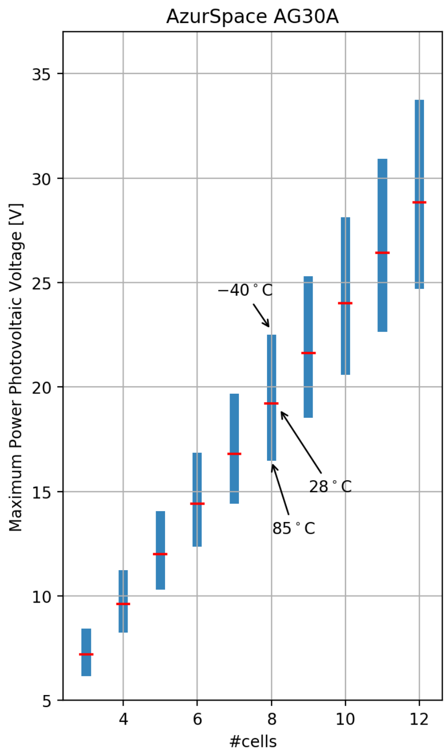
Thermal Characteristics

Parameter	Value Min.	Value Typ.	Value Max.	Unit
Case-to-Ground		TBD		°C/W
Ground-to-Junction			TBD	°C/W

Safe Operating Area







6-Channel MPPT Parameters

The persistent configuration variables are stored in the external FRAM chip. The telemetry is updated each second.

Name	Type	Default	Unit	Description
Persistent configuration variables				
mppt_mode	uint8[6]	0	0-2	0 = hardware controlled, 1 = fixed voltage setting, 2 = automatic tracking
mppt_vfixed	uint16[6]	4580	mV	Voltage to set in mode 1.
mppt_veoc	uint16	8000	mV	Do not charge beyond this voltage
ltc_conf_on	uint8	1	true/false	Startup state (on/off)
ltc_conf_vprotect	uint16	0	mV	Automatic turn off at this battery level
ltc_conf_ilim	uint16	2000	mA	Startup current limit
State variables				
dac_enabled	uint8[6]	0	true/false	Enable dac
dac_value	uint16[6]	n/a	0-4095	Set dac value
Telemetry				
i_in	uint16[6]	read only	mA	Current in
i_out	uint16	read only	mA	Current out
v_in	uint16[6]	read only	mV	Voltage in
v_out	uint16	read only	mV	Voltage out
temp	int16	read only	degrees c	Board temperature

List of MPPT parameters

3-Channel PDU Parameters

The persistent configuration variables [dfl_*] are stored in the external FRAM chip and will be loaded to the working memory variables [ch_*] at system boot. Modifying a working memory variable will take effect immediately. The telemetry is updated each second.

Name	Type	Default	Unit	Description
Persistent configuration variables				
dfl_on	uint8[3]	1	true/false	Startup state (on/off)
dfl_vprotect	uint16[3]	0	mV	Automatic turn off at this battery level
dfl_vprotect_hyst	uint16[3]	250	mV	Hysteresis for vprotect
dfl_ilim	uint16[3]	2000	mA	Startup current limit
dfl_on_in	uint32[3]	0	s	ON timer (countdown)
dfl_off_in	uint32[3]	0	s	OFF timer (countdown)
dfl_enable	uint8[3]	Factory set	true/false	Determines whether a channel is physically present on the board or not. Should never be changed.
Working memory variables				

ch_on	uint8[3]	(see above)	true/false	Set this to switch on/off immediately. The value remains in effect until the PCDU is hard power cycled. A software reboot of the MCU alone will not change the state of the outputs back to the default values.
ch_protect	uint8[3]	read only	true/false	Battery is below channel protection level, if this is showing 1, and the ch_on is also set to 1. The output is turned off, but will go back to on, as soon as the voltage gets high enough.
ch_ilim	uint32[3]	(see above)	mA	Set this to temporarily change current limit. The value remains in effect until the PCDU is hard power cycled. A software reboot of the MCU alone will not change the state of the outputs back to the default values.
Power Channel Telemetry				
tlm_reset	uint8	0	true/false	Set to 1 to reset all telemetry min/max/avg
tlm_energy	uint64[3]	read only	mJ	Energy used
tlm_vmin	uint16[3]	read only	mV	Voltage min
tlm_vmax	uint16[3]	read only	mV	Voltage max
tlm_vcur	uint16[3]	read only	mV	Current voltage
tlm_imax	uint16[3]	read only	mA	Current max
tlm_icur	uint16[3]	read only	mA	Current current
tlm_pmax	uint16[3]	read only	mW	Max power
tlm_pcur	uint16[3]	read only	mW	Current power
tlm_pavg	uint32[3]	read only	mW	Average power
tlm_temp	int16	read only	degrees c	Board temperature
tlm_vbatt	uint16	read only	mV	Battery voltage
fault_oc	uint32	read only	count	Number of seconds the channel has been in output protection (overcurrent)
fault_io	uint32	read only	count	Number of IO faults

MPPT Controller

The MPPT controller has three modes controlled by the mppt_mode parameter:

Mode 0 - Disabled: When the MPPT controller is disabled, the input voltage is controlled by a voltage divider in hardware. The input voltage is typically set to the maximum power point voltage for the string given the maximum expected operating temperature. If the threshold is too high, the MPPT will be disabled at high solar panel temperature, which is unfortunate as temperature, and solar irradiance (and thus power) are strongly correlated.

Mode 1 - Fixed voltage: The fixed voltage setting overrides the hardware setting using a DAC to pull the reference up or down. The voltage is set using the mppt_vfixed register.

Mode 2 - Maximum power point: The input power measurement is feeding into a perturb and observe controller which steps the input voltage up and down converging towards the maximum power point. The control loop runs at 32 Hz and the step size can be adjusted to increase the speed of tracking.

Battery Overcharge Protection

In order to prevent battery overvoltage it is important to set the mppt_protect parameter to protect the battery. When the battery protection monitor sees a voltage higher than the mppt_protect setting, all DAC outputs are overridden to the maximum value, effectively disabling all battery charging.

Protected Battery Supply to Panels

The output switch for the panel supply is controlled by the ltc_conf_on parameter. This is not designed to be switched frequently. Setting this parameter is persistent.

The power limit is set using the ltc_conf_ilim parameter. This should be set to account for the maximum possible current drawn by the panel peripherals.

In order to prevent battery undervoltage, set the ltc_conf_vprotect parameter to switch off the panel peripherals gracefully.

PDU Switch on/off

The ch_on parameter shows the current state at any time and can be set in order to switch on or off. At powerup of the MPPT the dfl_on value will be copied to the ch_on parameter.

Timer function

The two parameters on_in and off_in will be decremented each second until they reach zero. When reaching zero the on timer will set the ch_on parameter to 1 and the off timer will set the ch_on parameter to 0.

Example: Turn on now, and set delayed switch-off
on = 1, dfl_off_in = 600
This is useful to switch off a payload after a ground-station pass.

PDU Overcurrent protection

The ilim parameter sets the overcurrent protection in mA. At boot the dfl_ilim value is written to ch_ilim. If a temporary higher or lower current limit is needed, the ch_ilim parameter can be set after startup of the channel. This is useful if a payload has two different operating modes requiring different amounts of power.

The rapid hard-overcurrent protection protects against short circuits and larger latchup events. The response will be an immediate shut off within 500 ns. There is an automatic retry rate of 4 seconds.

The lowest setting is ~1 A and the highest setting is ~3.5 A in 8 adjustable steps. When setting the parameter, it automatically rounds up to the next possible setting, and the achieved value can be read back in the dfl_ilim parameter.

The fault_oc parameter will be incremented once per second while in hardware overcurrent mode.

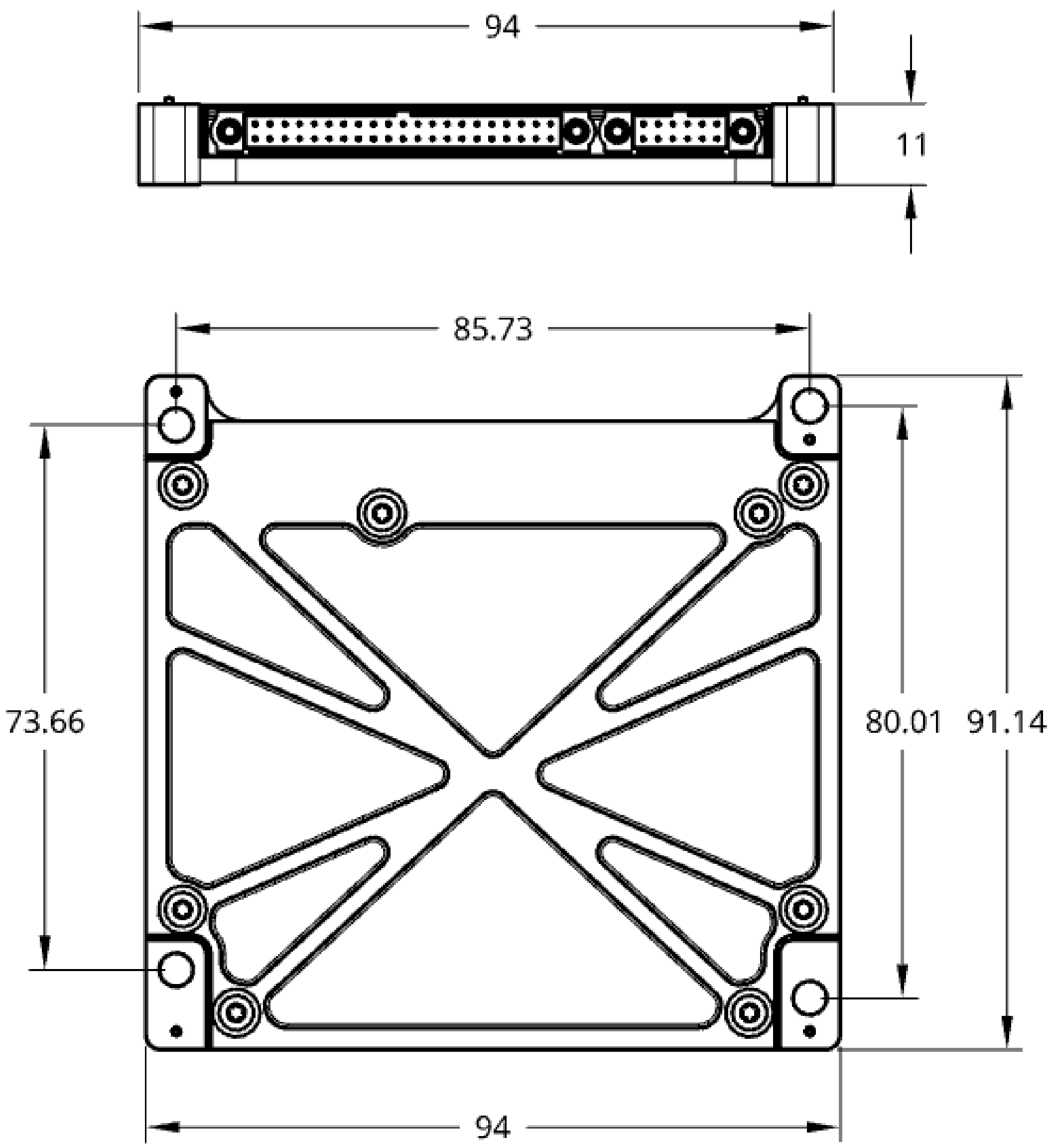
In order to detect smaller overcurrent events of <1 A. The user should setup a monitoring task on an external system to detect small, or gradually changing power levels, which is not in accordance with the subsystem in question.

Battery Discharge Protection

It is vital to the lifetime of the battery to control the depth of discharge. The MPPT-P3 therefore includes a dfl_vprotect parameter that sets the battery voltage limit for each output. This is useful to do progressive shutdown of systems until the satellite is again power positive. The protection affects all channels regardless of their on/off state.

Warning: A failure to enable this feature may result in a battery undervoltage condition that will completely turn off the battery. It is better to go into a low-power mode and keep certain vital subsystems alive.

Mechanical Drawings



Dimension Drawing

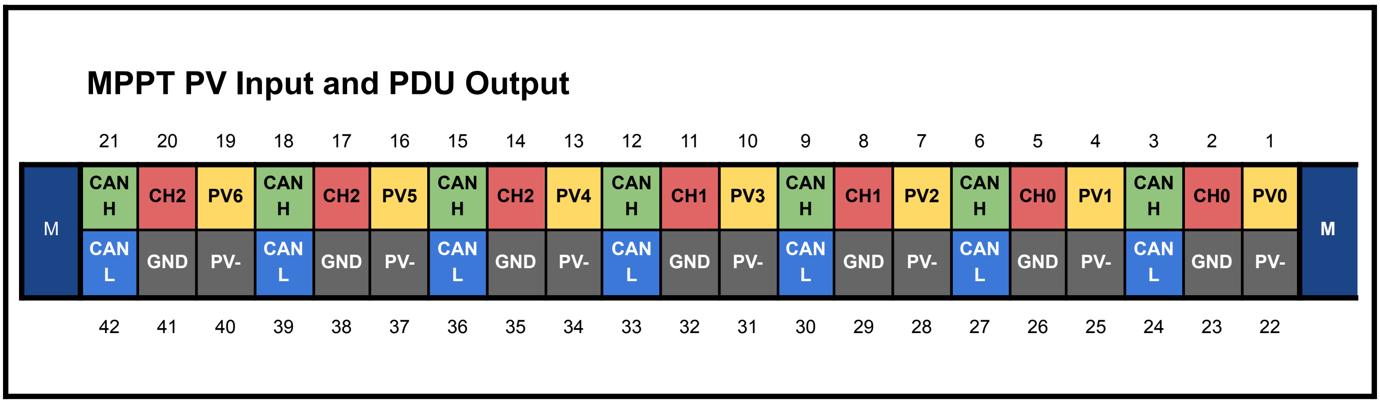
Mass

The weight of the MPPT-P3 is 150 gram.

Pin-out

The pin-out is presented as viewed from the front of the MPPT-P3. All connectors used are Harwin M80 High reliability series. Pin number is presented next to the pin name in the Pin-Out diagrams.

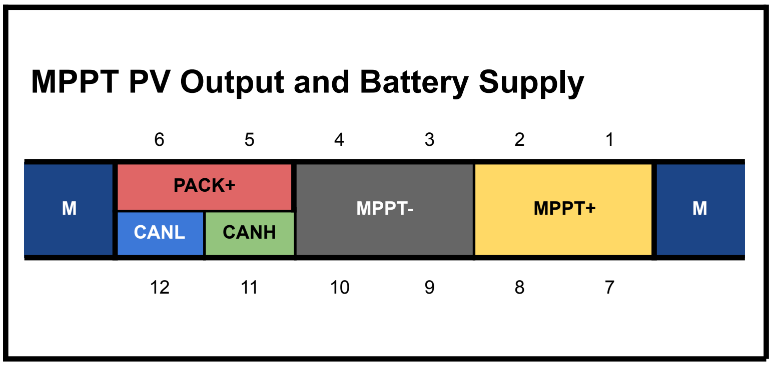
P1 - Solar Panel Input Connector



M80-5424242

Pin #	Pin Name	Functionality
1	PV0	Positive Photovoltaic Input 0. Step-Down converter
4	PV1	Positive Photovoltaic Input 1. Step-Down converter
7	PV2	Positive Photovoltaic Input 2. Step-Down converter
10	PV3	Positive Photovoltaic Input 3. Step-Down converter
13	PV4	Positive Photovoltaic Input 4. Step-Down converter
16	PV5	Positive Photovoltaic Input 5. Step-Down converter
19	PV6	Positive Photovoltaic Input 6. Step-Up converter
2,5	CH0	Latch-up protected battery voltage output Channel 0
8,11	CH1	Latch-up protected battery voltage output Channel 1
14,17,20	CH2	Latch-up protected battery voltage output Channel 2
3,6,9,12,15,18,21	CANH	CANBUS High. 7 CANBUS pairs available, all on the same BUS
24,27,30,33,36,39,42	CANL	CANBUS Low. 7 CANBUS pairs available, all on the same BUS
22,25,28,31,34,37,40	PV-	Negative Photovoltaic Input. All negative PV inputs are connected to a common ground net
23,26,29,32,35,38,41	GND	Ground, power return for all output channels.
-	M	Mechanical Fasteners

P2 - Battery Connector



M80-5421242

Pin #	Pin Name	Functionality
1,2,7,8	MPPT+	Positive PV output from the MPPT
3,4,9,10	MPPT-	GND connection, power return for MPPT+ and PACK+
5,6	PACK+	Positive supply voltage for the MPPT control system and power distribution channels
11	CANH	CANBUS High
12	CANL	CANBUS Low
-	M	Mechanical Fasteners

PCDU-12

12 Channel Power Conditioning and Distribution Unit

For Micro- and Nano-Satellites

Features

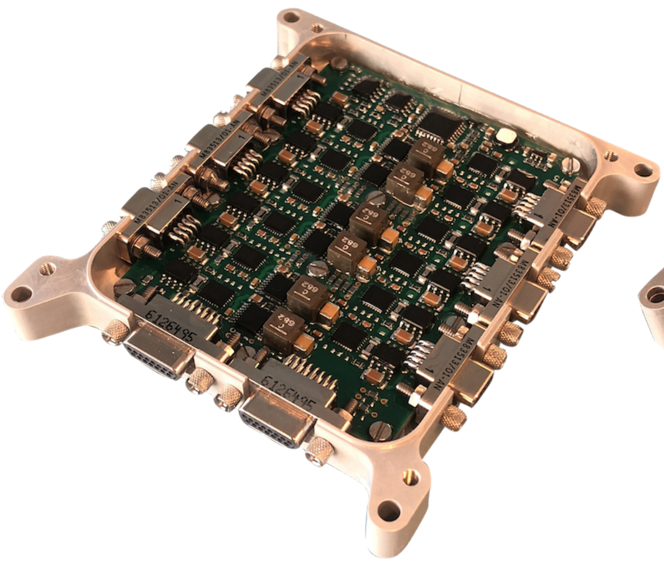
- 6-28 V battery input
- 6 adjustable DC-DC converters 1.8 - 24 V
  - Up to 92% efficiency
- 12 Protected output channels
  - Up to 2A output
  - Programmable overcurrent and latch-up protection
  - Advanced power metering
  - Automatic battery protection modes
  - Programmable on/off timers
  - Each output can be supplied by 3 different sources including unregulated battery
- 6 Power distribution connectors
  - High-reliability Micro-D connectors
  - 2 outputs channels and CAN bus in each connector
- Reliability
  - Thermal heat sinking by flush-mounted PCB on 2.5mm Al
  - Radiation total dose tested EEE parts
  - Vibration rated for all launch vehicles
- High-quality Enclosure
  - Min. 1.5 mm Al Shielding in all directions
  - PC-104 compatible mounting holes

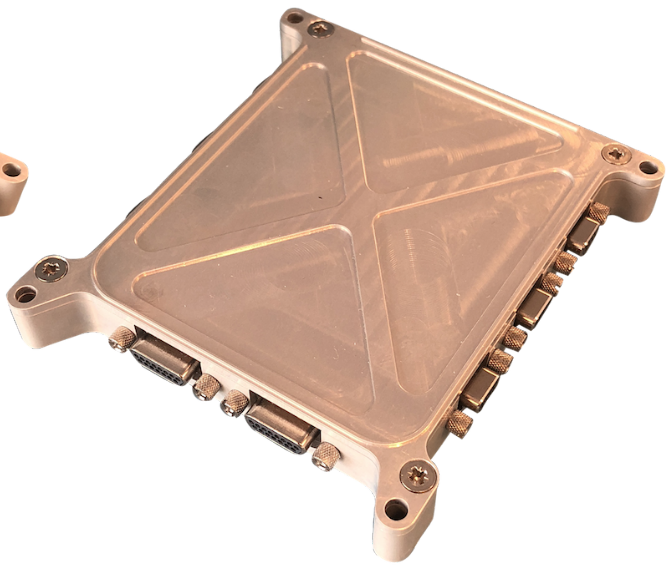
Description

The PCDU-12 is a twelve channel power conditioning and distribution unit in a rugged, compact and modular enclosure. The system features six independent and customizable step-down converters, that can be connected to outputs as required. The PCDU-12 architecture allows designers to allocate one subsystem per connector, whereby many of the EMI issues experienced on shared power busses are eliminated. This makes the PCDU-12 ideal for missions with demanding payloads and sensitive receivers.

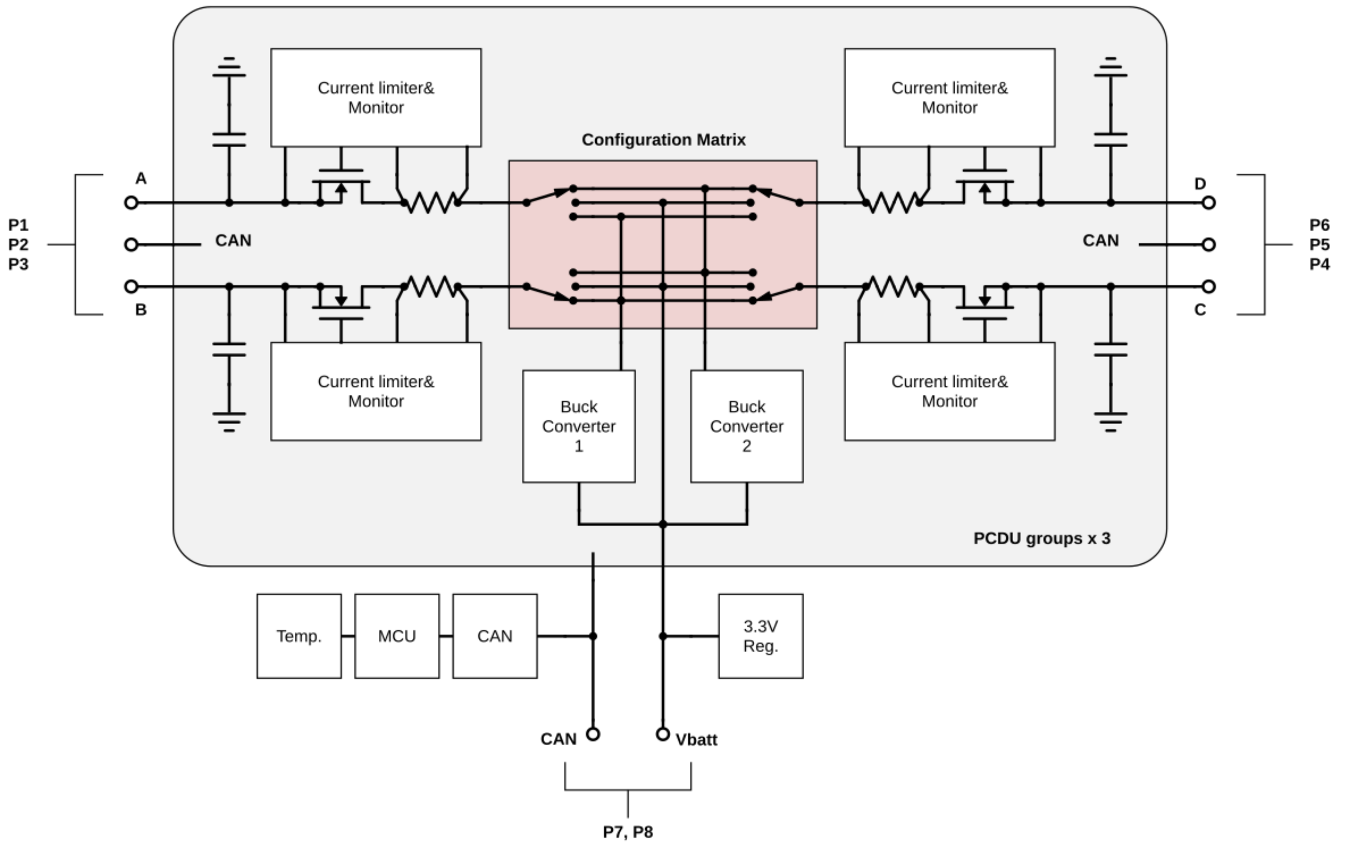
To minimize thermal stresses and mitigate radiation, the PCDU-12 is enclosed in 1.5 mm (min.) Al. The PCB is top-side only and mounted flush with the bottom of the enclosure, which reduces thermal resistance to the satellite body. With a standing height of only 12 mm and PC104 compatible mounting holes, the PCDU-12 easily integrates with existing busses, without occupying excess stack space.

All outputs have independent power monitoring and latch-up protection. Monitoring and configuration is enabled through the CSP protocol and onboard MCU. For convenience all connectors are CAN enabled.





Functional Description



Functional Block Diagram

Synchronous Step-Down Converters

The PCDU-12 features six synchronous DC-DC buck converters divided between three output groups. The converters are capable of delivering up to 3 A non-derated DC load current with exceptional efficiency and thermal performance in a very small solution size. We recommend 33% current derating, meaning that the continuous current per converter should be less than 1 A.

The buck converter employs fixed frequency peak current mode control with Discontinuous Conduction Mode (DCM) and Pulse Frequency Modulation (PFM) mode at light load to achieve high efficiency across the load range. The switching frequency is fixed at 500 kHz.

Protection features include over temperature shutdown, VCC under-voltage lockout (UVLO), cycle-by-cycle current limit, and short-circuit protection with hiccup mode.

Each regulator is configured to the customer's specification according to the following table:

PCDU Group	Buck Converter	Configuration			
		3.3V	5 V	12 V	Custom
1	1		•		
	2	•			
2	1		•		
	2	•			
3	1		•		
	2	•			

Option table 1: Select voltage for each converter. '•' marks default settings. Custom options available upon ordering

Power Distribution

Each output can be driven from one of three options as shown by the following table:

PCDU Group	Output	Configuration		
		Buck 1	Buck 2	Battery
1	A		•	
	B	•		
	C		•	
	D	•		
2	A		•	
	B	•		
	C		•	
	D	•		
3	A		•	
	B	•		
	C		•	
	D	•		

Option table 2: Select supply source for each PCDU output. '•' marks default settings. Custom options available upon ordering

The options are selected using zero-ohm resistors and is mounted according to the customers specification.

Each buck regulator can supply up to four outputs and each output can switch up to 3 A (2 A recommended). It is important not to exceed the regulators maximum current rating.

Protected Output Channels

The PCDU-12 features twelve hot-swap controllers with analog foldback current limiting, reducing the current during inrush.

The controller is well suited to high power applications because the precise monitoring capability and accurate current limiting reduce the extremes in which both loads and power supplies must safely operate.

All outputs have a software adjustable current limit, and features high precision real-time telemetry, Including energy metering, average consumption, min and max values.

CAN Termination

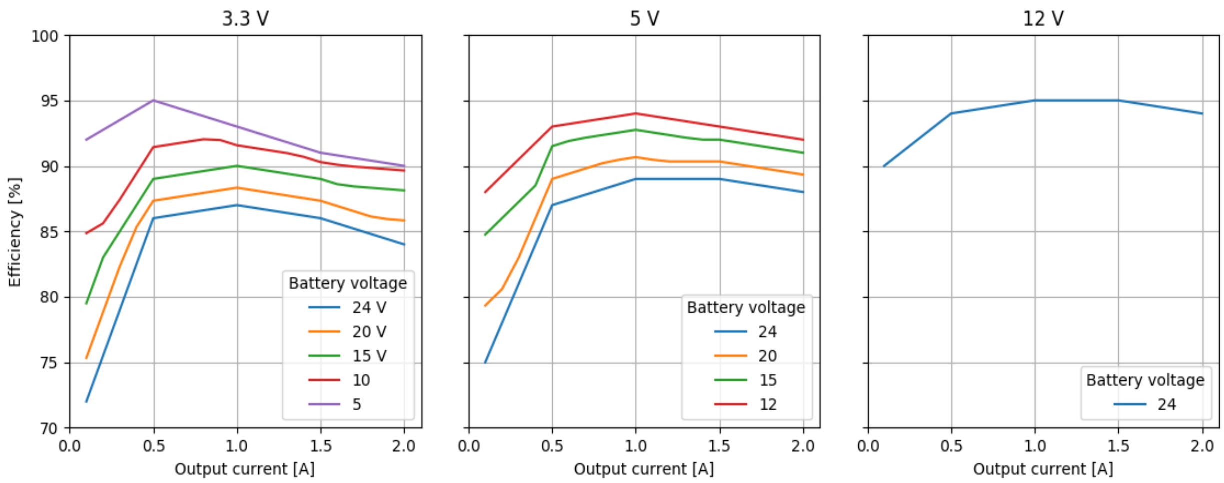
The board features optional 120 Ohm CAN termination mounted to the customers specification.

Option	Yes	No
120 Ohm CAN termination	•	

Option table 3: Select CAN termination. '•' marks default settings.

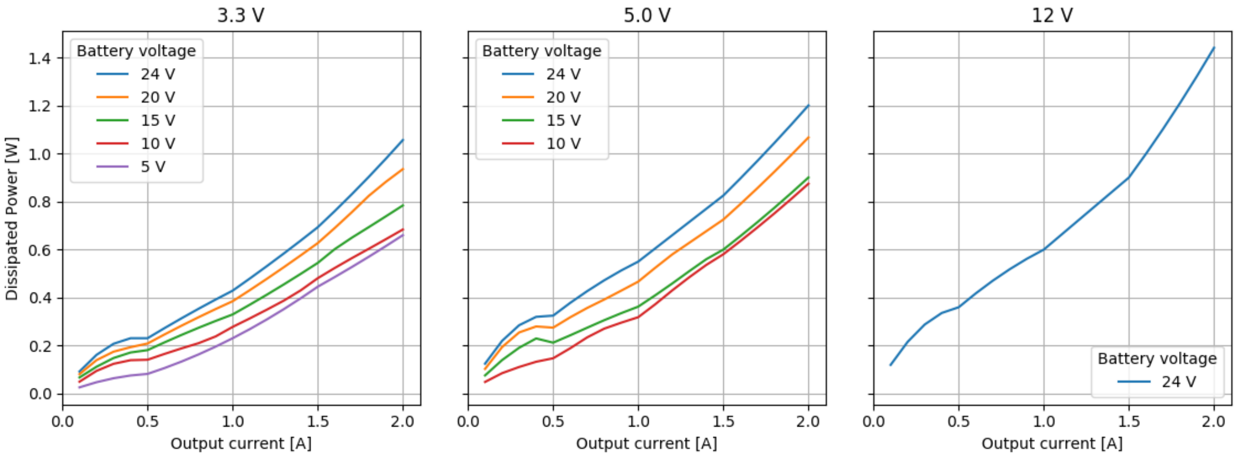
Performance

Converter Efficiency



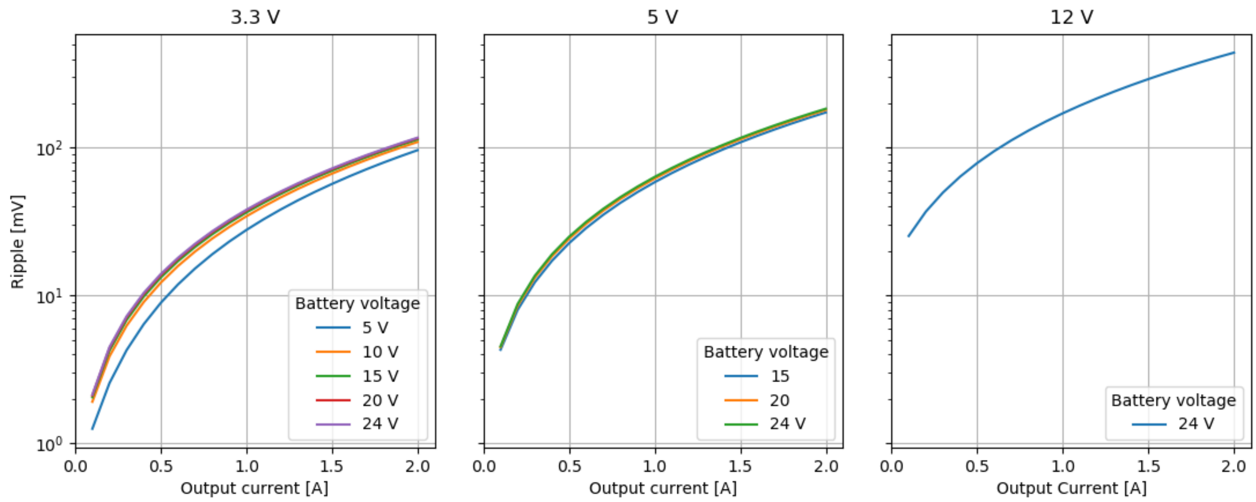
DC-DC converter efficiency relative to output current for different output voltage levels (projected numbers)

Converter Loss



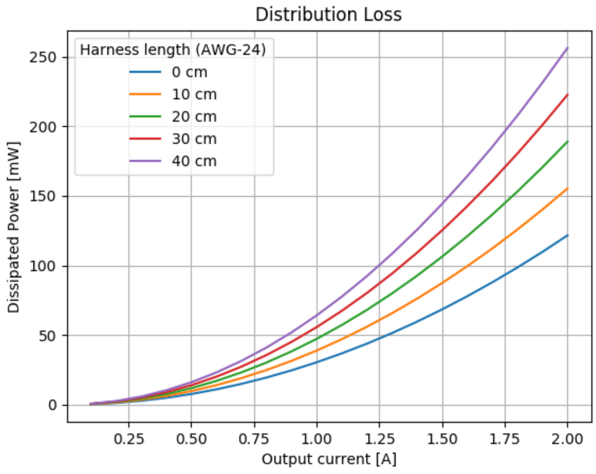
Converter loss relative to output current for different output voltage levels (projected numbers)

Converter Output Ripple



Converter output ripple voltage relative to output current for different output voltage levels

Distribution Loss



Distribution loss for each PCDU output given different harness wire lengths

Parameters

The persistent configuration variables [dfl_*] are stored in the external FRAM chip and will be loaded to the working memory variables [ch_*] at system boot. Modifying a working memory variable will take effect immediately. The telemetry is updated each second.

Name	Type	Default	Unit	Description
Persistent configuration variables				
`dfl_on`	uint8[12]	1	true/false	Startup state (on/off)
`dfl_vprotect`	uint16[12]	0	mV	Automatic turn off at this battery level
`dfl_ilim`	uint16[12]	2000	mA	Startup current limit
`dfl_reboot_on`	uint32[12]	0	s	Startup reboot timer
`dfl_on_in`	uint32[12]	0	s	Startup on timer
`dfl_off_in`	uint32[12]	0	s	Startup off timer
Working memory variables				
`ch_on`	uint8[12]	(see above)	true/false	Set this to switch on/off
`ch_protect`	uint8[12]	read only	true/false	Battery is below channel protection level
`ch_ilim`	uint32[12]	(see above)	mA	Set this to temporarily change current limit
`ch_reboot_in`	uint32[12]	(see above)	s	Set this to reboot a channel delayed
`ch_on_in`	uint32[12]	(see above)	s	Set this to turn on a channel delayed
`ch_off_in`	uint32[12]	(see above)	s	Set this to turn off a channel delayed
Power Channel Telemetry				
`tlm_reset`	uint8	0	true/false	Set to 1 to reset all telemetry min/max/avg
`tlm_energy`	uint64[12]	read only	mJ	Energy used
`tlm_vmin`	uint16[12]	read only	mV	Voltage min
`tlm_vmax`	uint16[12]	read only	mV	Voltage max
`tlm_vcur`	uint16[12]	read only	mV	Current voltage
`tlm_imax`	uint16[12]	read only	mA	Current max
`tlm_icur`	uint16[12]	read only	mA	Current current
`tlm_pmax`	uint16[12]	read only	mW	Max power
`tlm_pcur`	uint16[12]	read only	mW	Current power
`tlm_pavg`	uint32[12]	read only	mW	Average power
`tlm_temp`	int16	read only	degrees c	Board temperature
`tlm_vbatt`	uint16	read only	mV	Battery voltage
`fault_oc`	uint32	read only	count	Number of hard/soft overcurrents

List of parameters

Switch on/off

The ch_on parameter shows the current state at any time and can be set in order to switch on or off. At startup the dfl_on value will be copied to the ch_on parameter.

Timer function

The three parameters reboot_in, on_in and off_in will be decremented each second until they reach zero. When reaching zero the on timer will set the ch_on parameter to 1, the off timer till set the ch_on parameter to 0, and the reboot timer will trigger a reboot of the channel. When a channel is rebooted, the hot-swap controller is reset, the output will be power cycled and the default values will be loaded into the working memory.

Example 1: Delayed switch-on
dfl_on_in = 10, dfl_off_in = 0, dfl_reboot_in = 0
This is useful to prevent switching all channels simultaneously which can cause a transient on the battery in some cases.

Example 2: Turn on now, and set delayed switch-off
on = 1, ch_off_in = 600
This is useful to switch off a payload after a ground-station pass.

Example 3: Turn on once per hour for 10 minutes
dfl_on_in = 1, dfl_off_in = 601, dfl_reboot_in = 3601
This is useful to limit the duty cycle of a payload.

Overcurrent protection

The ilim parameter sets the overcurrent protection in mA. At boot the dfl_ilim value is written to ch_ilim. If a temporary higher or lower current limit is needed, the ch_ilim parameter can be set after startup of the channel. This is useful if a payload has two different operating modes requiring different amount of power.

The output has two different overcurrent failure modes.

1) Hardware or Hard over current
2) Software or Soft over current

A hard overcurrent is triggered by a rapid increase that exceeds the current limit by a factor of three. Such situations could be a short circuit. The response will be an immediate shutoff within 500 ns. This fault will be cleared by the hot-swap controller retrying periodically until the short circuit is cleared.

A soft overcurrent is triggered by a comparator sending an alert signal to the microprocessor. The MCU will respond by initiating a channel reboot, thereby resetting to default values and power cycling the channel.

The fault_oc parameter will be incremented once per soft and hard overcurrent event. When the system is in hard overcurrent, the counter is incremented once per second.

Battery Protection

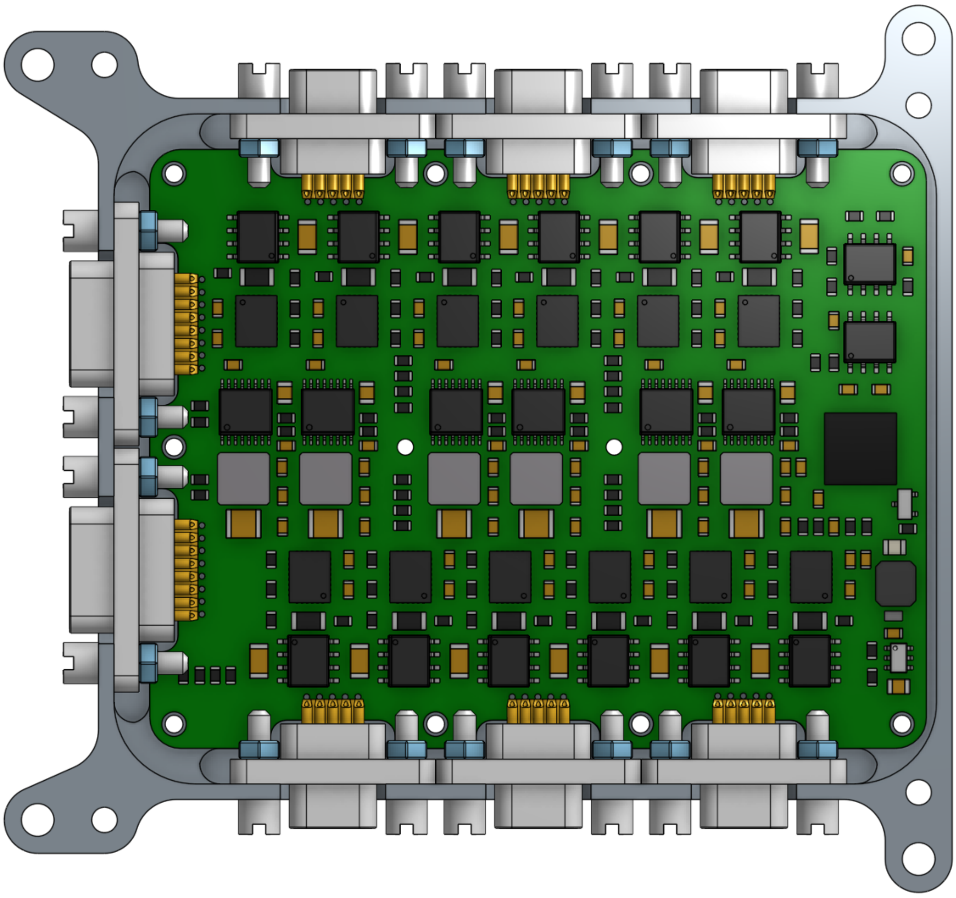
It is vital to the lifetime of the battery to control the depth of discharge. The PCDU-12 therefore includes a dfl_vprotect parameter that sets the battery voltage limit for each output. This is useful to do progressive shutdown of systems until the satellite is again power positive. The protection affects all channels regardless of their on/off state.

Warning: A failure to enable this feature may result in a battery undervoltage condition, that will completely turn off the battery. It is better to go into a low-power mode and keep certain vital subsystems alive.

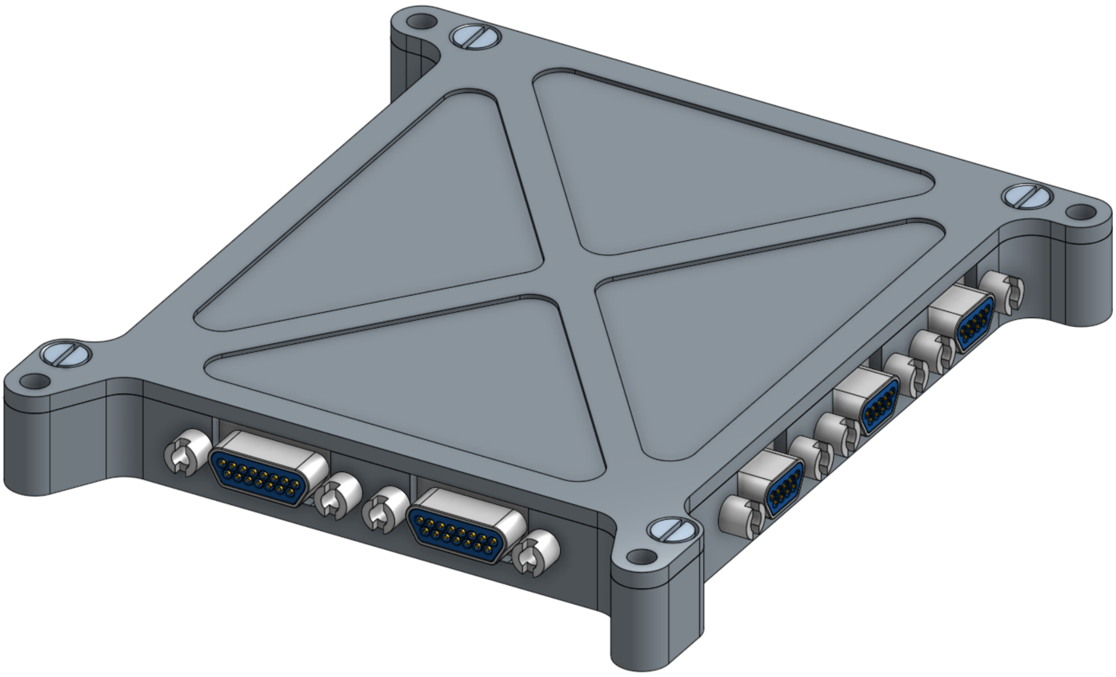
Channel Enumeration

CSP Channel Index	Micro-D		Power Configuration	
	Header	Pin	Group	Output
0	P1	5	1	A
1	P1	1	1	B
2	P2	5	2	A
3	P2	1	2	B
4	P3	5	3	A
5	P3	1	3	B
6	P4	5	3	C
7	P4	1	3	D
8	P5	5	2	C
9	P5	1	2	D
10	P6	5	1	C
11	P6	1	1	D

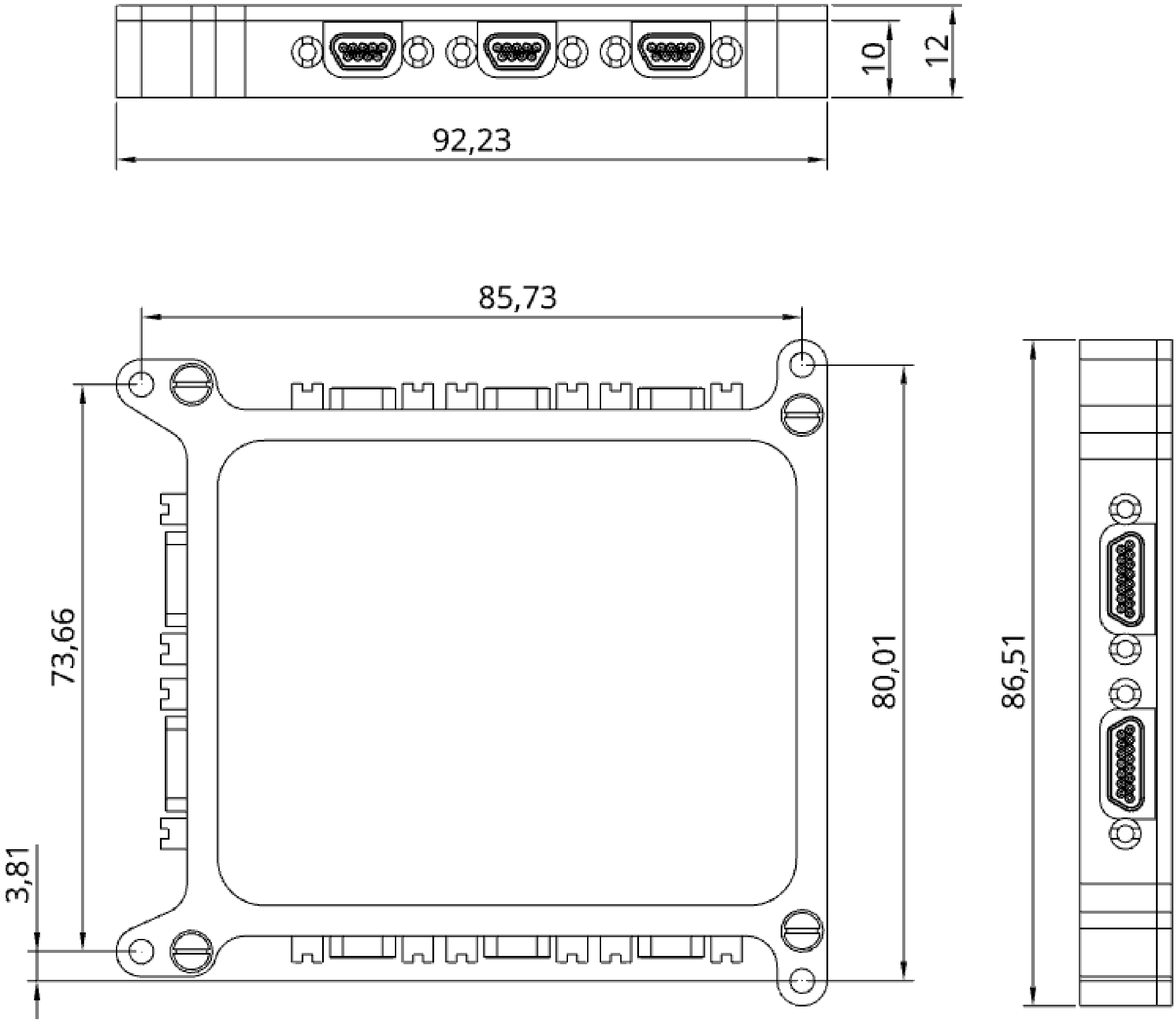
Mechanical Drawings



Top view



Isometric Rendering with 2mm Lid



Dimension Drawing

Mass

The weight of the PCDU-12 is 134 gram.

Pin-out

P1 to P6 are 9-pin Male Micro-D

PIN	Function
1	CH 1
2	CAN Low
3	CAN High
4	CH 0
5	CH 0
6	GND
7	GND
8	GND
9	GND

Header P1

PIN	Function
1	CH 3
2	CAN Low
3	CAN High
4	CH 2
5	CH 2
6	GND
7	GND
8	GND
9	GND

Header P2

PIN	Function
1	CH 5
2	CAN Low
3	CAN High
4	CH 4
5	CH 4
6	GND
7	GND
8	GND
9	GND

Header P3

PIN	Function
1	CH 7
2	CAN Low
3	CAN High
4	CH 6
5	CH 6
6	GND
7	GND
8	GND
9	GND

Header P4

PIN	Function
1	CH 9
2	CAN Low
3	CAN High
4	CH 8
5	CH 8
6	GND
7	GND
8	GND
9	GND

Header P5

PIN	Function
1	CH 11
2	CAN Low
3	CAN High
4	CH 10
5	CH 10
6	GND
7	GND
8	GND
9	GND

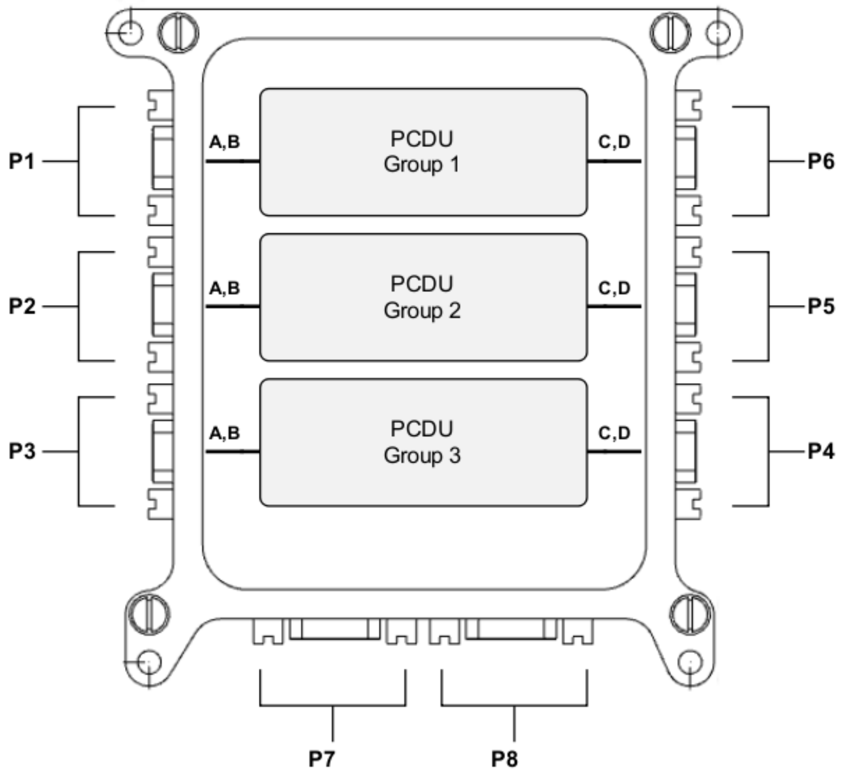
Header P6

P7 to P8 are 15-pin Male Micro-D

PIN	Function
1	CAN High
2	CAN Low
3	Do not connect
4	Do not connect
5-8	Battery
9-10	Do not connect
11-15	GND

Header P7-P8

Connector Location



Micro-D connector enumeration and location

TTC-P3

Dual Hot-Redundant VHF/UHF Satellite TT&C radio

For Micro- and Nano-Satellites

Features

- Full redundancy
  - 2 Half-Duplex VHF/UHF Transceivers
  - 2 Microcontrollers for housekeeping and control
  - 2 Wide range DC/DC regulators for unregulated battery bus
  - Supports hot redundancy. Both receivers active w. packet deduplication
- Modem:
  - Data-rate: 4800 - 38400 kbps nominal. (up to 115.200 available upon request)
  - GMSK, HDLC framing
  - FEC: Convolutional Coding (K=7, r=½) and Reed Solomon (RS-223,255)
  - CCSDS Scrambling
  - 6 dB Eb/No for stable reception
- Wide range VHF/UHF synthesizer
  - Frequency bands: 130-140,140-150, 400-410 and/or 430-440 MHz
  - Temperature compensated high stability oscillator: ± 100 Hz (0.28 ppm)
- Output
  - 30-31.5 dBm output power with dedicated DC-DC Regulator for high efficiency (50% PAE)
- Interface
  - CAN bus with CSP protocol
  - RS-422 with KISS/CSP protocol
  - High-reliability Harwin M80 connectors both signal and RF
- Reliability
  - Thermal heat sinking by flush-mounted PCB on 2.5mm Al
  - Radiation total dose tested EEE parts
  - Vibration rated for all launch vehicles
- High-quality Enclosure
  - Min. 1.5 mm Al Shielding in all directions
  - PC-104 compatible mounting holes

Description

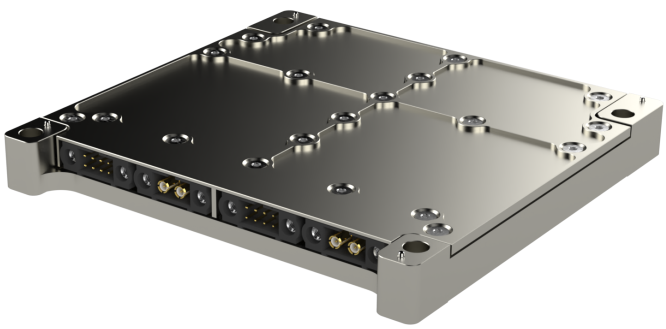
The TTC-P3 is a hot-redundant satellite telemetry, tracking and command (TT&C) radio with two half-duplex VHF/UHF transceivers designed to enable robust and reliable satellite communication.

The TTC-P3 is intended to be used in an antenna diversity scheme, where each channel is connected to orthogonal and cross-polarized antennas. Hereby a good omnidirectional gain pattern can be achieved, which makes signal reception nearly independent of satellite attitude.

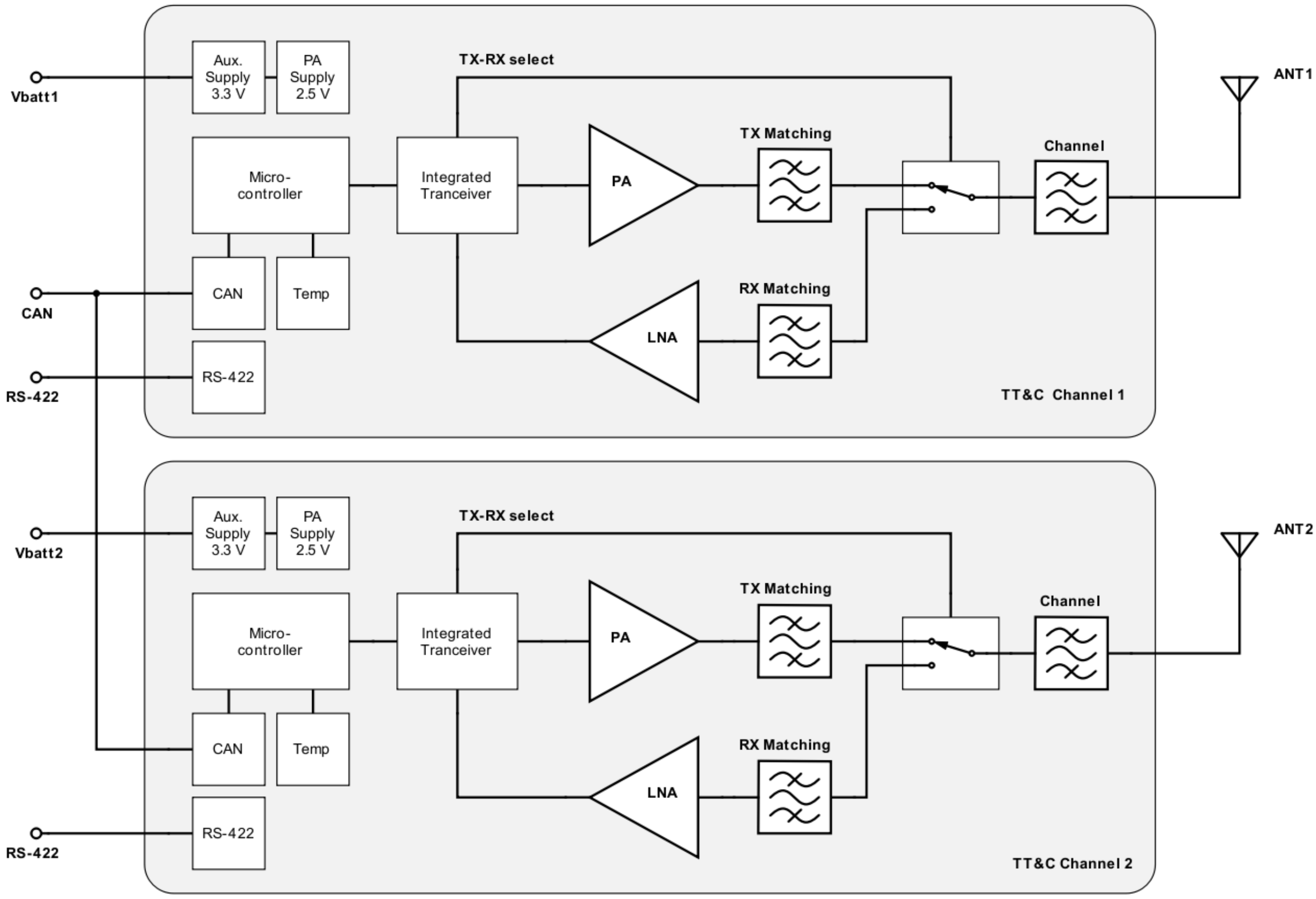
Careful receiver design provides a noise figure below 2 dB, which, combined with concatenated convolutional and Reed-Solomon decoding, ensure excellent sensitivity. Realizing that interference has proved problematic over certain regions, the TTC-P3 also features a 60 dB out-of-band rejection filter.

On the transmission side, the power consumption is minimized using constant envelope GMSK modulation, whereby >50% efficiency is achieved in the PA stage. This makes the TTC-P3 ideal as a low-power backup link.

Fully configurable radio beacons allow basic signal acquisition and coarse tracking of the satellite. User authentication is enabled by default, and (optional) encryption is provided as a part of the CSP protocol.



3 Functional Description



Functional Block Diagram

Half-Duplex

Each radio channel is a half-duplex system. This means that both will be receiving simultaneously. While one radio is transmitting, the other will be deafened by the high TX power of the adjacent system.

The dual radios are intended to be coupled to different antennas with polarization diversity. That is, vertical/horizontal or left-hand/right-hand circular. This diversity ensures an optimal reception in any orientation for the receiving system.

The TTC-P3 has a fast channel turn-around in less than 50 ms. This gives a fast response to commands, and can in most circumstances eliminate the need to have a dedicated uplink channel as in a full-duplex system.

Integrated Transceiver Chip

The TTC-P3 uses a AX5043 integrated transceiver chip. The AX5032 takes care of carrier signal synthesis, modulation, demodulation, and viterbi encoding.

The transceiver supports a wide range of modulation types, frequencies and encodings. For more information about this consult the datasheet of the AX5043.

Several different modes are pre-programmed and supported by default: GMSK 4800, 9600,19200 and 38400.

A flexible configuration memory enables new modes to be uploaded run-time.

Power Amplifier

The PA is a 2 Watt GaAs HBT, designed to be driven in compression, which gives high efficiency of ~50% which is optimal for satellites that are power-limited and makes the TTC ideal as a low-power backup link. The output power is derated to 1 W for improved longevity and VSWR tolerance.

The recommended mode of operation is constant envelope such as FSK/MSK/GMSK.

The PA uses its own power supply directly designed to the specific voltage and transient requirements. The efficiency of this converter depends on the input voltage. The lower the difference in input and output voltage the higher efficiency. At 7-8 V input the efficiency can be expected to be greater than 90% where at 28 V input, it can be as low as 80%.

Low Noise Amplifier

TTC-2: Mini-Circuits PMA-5451+ is a E-PHEMT based Ultra-Low Noise MMIC Amplifier operating from 50 MHz to 6 GHz with a unique combination of low noise and high IP3 making this amplifier ideal for sensitive receiver applications. This design operates on a single 3V supply at only 30mA and is internally matched to 50 Ohms.

TTC-P3: updated to remove external LNA. This saves 200 mW on the satellite, but increases the noise figure from 2 to 5 dB. Uplink power is however cheaper to upgrade, than to increase solar panel area on the satellite.

Channel Filter

A Pi-filter provides last step input and output filtering. This reduces transmission of TX harmonics and can protect the LNA against high power blockers.

Frequency Configuration

Each TTC channel can be configured and matched for either VHF or UHF bands. Please specify either VHF or UHF and the desired frequency range.

Match	Frequency Range	Uplink	Downlink
VHF IARU	130-140 MHz		
VHF ITU	140-150 MHz		
UHF ITU	400-410 MHz		
UHF IARU	430-440 MHz	•	•

Option table 1: Select frequency. '•' marks default settings.

CAN interface

The TTC-P3 is designed to operate as an edge-router in a CSP (Cubesat Space Protocol) network, where the internal CAN bus is meeting the external Radio interface.

Whenever the system is powered it will listen on the CAN-bus analyzing every CSP packet (promiscuous mode). If the destination of the CSP packet is on the outside of the network, the CSP packet will be transmitted over the radio link. Similarly packets received on the Radio link (with a destination on the can bus), will be transmitted on the CAN bus.

Using the CSP protocol has many advantages over a standard point-to-point protocol. For example: Hot redundancy, no single point of error and direct system to system communication.

The board features optional 120 Ohm CAN termination mounted to the customers specification.

Option	Yes	No
120 Ohm CAN termination	•	

Option table 2: Select CAN termination. '•' marks default settings.

RS-422 Interface

The RS-422 / UART interface uses the KISS mac-layer protocol to synchronize variable length CSP packets on the serial interface.

Before transmission over RS-422 the CSP packets are appended a KISS header and CRC32 checksum. The CSP/KISS interface is part of the open source CSP stack.

Data Link Layer

The Data Link layer consists of several blocks inspired by the CCSDS Sync and channel coding. However certain aspects are chosen not to be compatible with the CCSDS recommendation after due cost/benefit analysis.

FEC: Inner code

The first thing applied to the data is a checksum and some forward error correction data. The FEC has both an inner and an outer code. The inner code is a CCSDS compliant Reed-Solomon (223,255) with zero padding for shorter frames.

This coding provides a good countermeasure for burst errors in that it can correct up to 16 byte errors within a 255 byte long frame.

The MTU of the TTC-P3 is limited by this inner code length of 223 bytes.

Scrambling

The next step is a CCSDS compliant Pseudo Randomization. An additive scrambler performs an XOR of the data and a pseudorandom bit-sequence determined by a well-defined polynomial. This will not lead to error multiplication during descrambling as with other multiplicative scramblers.

The purpose of the scrambling is to whiten the signal before transmission, i.e. spread the load of ones and zeros, thereby reducing the occurrence of spectral lines and helping clock recovery at the receiver.

Framing

The TTC-P3 uses a hardware framing chip for high-speed synchronization without the need of CPU intervention. The framing mode is HDLC which is a well known async protocol supporting variable length frames.

HDLC uses a shorter synchronization sequence than the CCSDS recommends. This can lead to falsely identified frames in the presence of noise. However, this is not a problem for the receiver, since; A) The Frame Check sequence (Reed Solomon or HMAC) will discard invalid frames, and; B) The transmitter transmits several HDLC sync markers in sequence in order to clear the receiver state.

The possibility of a bit-error in the HDLC sync flag, is mitigated in part by the transmitting of multiple flags (4x) in combination with the error correction capabilities of Reed Solomon. The RS-code can correct frames with an invalid sync (byte shifted data of up to 8 bytes).

When using the convolutional encoder, the HDLC flags are FEC encoded and become a 16-bit Code Sync Marker (CSM). When sending the CSM, the transmitter ensures enough zero-bit insertions in order to align and clear the encoder. The CSM word is received by a soft-metric correlator in order to increase the detection likelihood for very low Eb/No.

Encoding

The encoding used is NRZ with Bit-stuffing. The data is already pseudo-randomized, however if the exact same random sequence is transmitted, a run-length of 5 or more can occur. In order to prevent transmitting the sync word which contains 6 one's, a zero-bit injection is performed. This is normal behaviour for HDLC.

FEC: Outer code

Finally just before reaching the modulator, the bit stream is run through a convolutional encoder with a memory length K=5 and a rate r=½. This is similar to the CCSDS TM Sync and Coding recommendation. However the hardware encoder used, uses a different polynomial than the CCSDS.

Adding convolutional code provides about 6 dB greater sensitivity at the cost of 3 dB data rate. So it trades some channel bandwidth for sensitivity.

If the link budget closes with a large enough margin, the outer coding can be disabled in order to take full advantage of the bandwidth.

Parameter Overview

Name	Type	Default	Unit	Description
Persistent configuration variables				
conf_rx / conf_tx	uint32	0	-	Set transceiver configuration
rx_freq / tx_freq	uint32	437000000	Hz	Receiver frequency
rx_vit / tx_vit	uint8	0	true/false	Enable viterbi encoding
rx_rs / tx_rs	uint8	1	true/false	Enable reed-solomon encoding
rx_rand / tx_rand	uint8	1	true/false	Enable ccsds randomizer
rx_guard	uint8	50	ms	Guard time after frame received
tx_guard	uint8	100	ms	Guard time after frame transmitted
rx_auth / tx_auth	uint8	0	true/false	Enable HMAC authentication
rx_afcrng	uint16	2000	Hz	Pull-in range of AFC
tx_gauss	uint8	1	true/false	Enable gaussian shaping
tx_max_s	uint16	10	sec	Maximum key-up time (forces a key-down)
tx_inhibit	uint32	0	sec	TX inhibit counts down to zero
tx_updly	uint16	5	ms * 10	Additional key-up time added before preamble starts. Not the time unit is ms * 10
tx_max_temp	int8	60	deg C	Auto switch off TX if exceeded
rssi_offset	int8	0	dB	Adjustment of RSSI meter
rssi_busy_thr	int8	-70	dBm	Listen before talk threshold
rssi_bgnd_ema	float	00.05	-	Exponential Moving Average coefficient for bgnd rssi measurement
rssi_guard	uint16	250	ms	Stops rssi_bgnd measurements after RX or TX
rssi_ignore_thr	int8	-30	dBm	Ignore rssi_bgnd measurements if level is above
primary_node	uint8	0	-	Hot redundant master CSP node (=0 on master)
preamblen	uint8	32	bytes	Preamble Length
dac_level	uint16	3800	-	Gain control for PA (3800 = Max output)
dac_level_safe	uint16	2700	-	Mismatch safe gain setting (typically < 0.5 W)
State variables				
test_mode	uint8	0	-	Special test mode enable
Telemetry				
rssi_bgnd	float	read only	dBm	Background RSSI
rssi	int16	read only	dBm	Last received frame's RSSI
rfoff	int32	read only	Hz	Last received frame's RF Offset
rx_count	uint32	read only	-	Frames received
rx_err	uint32	read only	-	Frames with CRC error
rx_auth_err	uint32	read only	-	Frames with HMAC error
rx_bytes	uint32	read only	-	Total bytes received
tx_count	uint32	read only	-	Frames sent
tx_err	uint32	read only	-	Frames unable to send

tx_bytes	uint32	read only	-	Total bytes sent
ext_temp	float	read only	-	Temperature of NTC sensor close to PA
pwr_fwd	float	read only	-	Forward power (dBm)
pwr_rev	float	read only	-	Reverse power (dBm)
return_loss	float	read only	-	Forward to Reverse ratio
pa_safemode	uint8	read only	-	True if the return_loss gets lower than 3 dB. Clears itself when mismatch condition is removed.
pa_safemode_cnt	uint16	0	-	Increments for each time the transmitter powers on, and the PA enters safe mode

Parameter list (some parameters left out for clarity)

Output power and pa safe mode

The dac_level and dac_level_safe, is a number between 0 and 4095 that defines the gain setting of the power amplifier. The default setting is 3800, which will produce the maximum output power. Setting this value higher than 3800, will not increase power, but can increase harmonics. A value of 2700-2800 will typically yield an output power of 50%. This is temperature dependent and not designed for accurate output power levels.

The dac_level will be used under normal circumstances, but if a return_loss of lower than 3 dB is detected, the PA will use the value defined in dac_level_safe. The return loss is evaluated each 1 ms when the transmitter is keyed up. The total response time is 3 ms. Each time the transmitter is turned off and on again, it will retry the normal output power setting.

The pa_safemode telemetry parameter will show whether or not the protection is active or not. Each time safe mode is triggered the pa_safemode_cnt parameter will be incremented.

The instantaneous power can be read through the pwr_fwd and pwr_rev parameters. This value is updated each 1 ms. The return_loss is the difference between the forward and reverse power.

RSSI system

The two telemetry parameters, rssi and rssi_bgnd contain the received signal strength in dBm, measured at frame reception and background levels respectively.

There are a few settings which contain the behaviour of the measuring system. The rssi_offset contains a fixed value that is added (or subtracted if negative sign) from the measurement. This value is calibrated to within 1 dB during checkout. The linearity of the RSSI is not guaranteed over the entire range. In the lower end it will be influenced by the noise floor, and in the very high end by compression and AGC performance. The typical performance is within a few dB's.

The rssi_busy_thr is used for listen before talk arbitration and should generally be disabled for when establishing initial satellite contact. The feature can be disabled by setting the threshold very high. For example -70 dBm.

The background measurement is affected by two parameters. The rssi_bgnd_ema is a moving average weight used for a 1st. order IIR lowpass filter of the measured RSSI level. Setting to 1 completely disables the filter. Setting to 0 puts infinite filtering on, and it will freeze the current background rssi level. The sampling frequency when the transmitter is idle is 100 Hz. The rssi_guard parameter defines the amount of time to wait in ms, after transmission of a frame, before background measurements should be active.

Finally, the rssi telemetry parameter will be updated with the power detected for the last valid packet, given that it is not above rssi_ignore_thr. This limit ensures that only the faint signals of a remote transmitter are logged, not the ones from onboard or nearby transmitters, which is particularly useful when using hot redundancy.

Arbitration methods

The TTC-P3 uses LBT (listen before talk) arbitration. There are generally three time sections in which a collision can occur.

1) **TX updelay:** The transmitter starts by powering on the PA and then awaits for RX/TX relays to switch over, before applying power. This delay is only needed if external high power equipment is used, as for example with the 200 W GND-2 transceiver. During the TX updelay, there is no transmission, so it is not possible to guard against collision. However, for ongoing communication, the two parameters rx/tx guard will ensure no collisions.

2) **Preamble period:** The first bits transmitted are the preamble pattern. This is used for clock synchronization of the receiver and power ramp up of the PA. During this period, the receiver has not seen any sync word, and the only method to see that somebody is transmitting is on the RSSI indicator. The rssi_busy_thr parameter should be tuned to be just about 10-15 dB higher than the noise floor. Something that must happen in orbit, since the background noise is not known in advance.
3) **After the sync word:** When the receiver has detected a sync word, and the framer is active. The channel is considered busy.

Test Modes

The TCC-2 has three modes controlled by the test_mode parameter:

Mode 0 - Disabled: Normal operation

Mode 1 - TX Carrier: The TX will be powered on without any modulation. The TX will be switched off after tx_max seconds.

Mode 2 - TX Pattern: A bit-pattern of 01010101 is transmitted. This is useful for bit-error rate testing. The TX will be switched off after tx_max seconds.

Mode 3 - RX Raw: Receive all bits directly into the RX FIFO. This is only used for bit-error rate testing and should not be enabled in a mission.

After a test has ended, the test_mode parameter must be manually reset to zero

Hot Redundancy

In order for hot redundancy to work, one of the TTC's must be selected as the primary_node. The master should have this = 0, and the slave should point to the master's CSP address.

Background Noise Measurement

When the RX or TX have been inactive for rssi_guard ms, the background noise will be measured 100 times per second. The measurement will update the rssi_bgnd parameter using an EMA weight of rssi_bgnd_ema. If the measured rssi is above rssi_ignore_thr, the sample is discarded in order to prevent detecting when the neighbour radio is transmitting.

Transceiver Configurations

Select a transceiver mode

Mode	Description
0	(G)FSK 4800, HDLC, h=0.667
1	(G)FSK 9600, HDLC, h=0.667
2	(G)FSK 19200, HDLC, h=0.667
3	(G)FSK 38400, HDLC, h=0.667

Preset transceiver configurations: h is the modulation index.

Checkout Procedure

Upon reception of the TTC-P3 system it is recommended to perform an incoming checkout. This procedure is a short version of the full checkout performed before packaging and shipping.

Required Equipment

The following equipment is required to perform the test.

- Power Supply with current measurement
- Spectrum Analyzer
- Signal Generator with FSK modulator

Test: Power usage

1. Apply a 50 Ohm load to the RF port system
2. Connect power supply and CAN or RS-422
3. Measure the idle / Rx current consumption
4. Set ‘test_mode’ to 1 and measure the Tx current consumption
5. Set ‘test_mode’ back to 0 and disconnect system

Test: TX spectrum

1. Connect Spectrum Analyzer to RF port
2. Connect power supply and CAN or RS-422
3. Set ‘test_mode’ to 1 and verify a clean carrier and the TX power level is satisfying
4. Set ‘test_mode’ to 2 and verify sidelobes are within acceptable range, also verify 2nd and 3rd harmonic output power are below limits.
5. Set ‘test_mode’ back to 0 and disconnect system

Test: RX Sensitivity

This test is the most demanding, since not all signal generators are capable of generating the required FSK modulated signal. It is possible to get a signal generator with a built-in modulator, or use a vector signal generator with I/Q inputs together with an external function generator.

Either way the required output of the generator is:

1. RF Carrier with adjustable power down to -125 dBm
2. ‘10101010’ bit-pattern modulated with a bit-rate of 4800 baud.
3. FSK Deviation set to +/- 1200 Hz

The test procedure is as follows:

1. Connect Signal Generator to RF port
2. Connect power supply and CAN or RS-422
3. Switch on the RF Carrier at -100 dBm
4. Read the ‘rssi_bgnd’ variable a couple of times (this variable is low-pass filtered, so a little time is required for it to settle) it should show -100 dBm +/- 3 dB
5. Switch on the FSK modulated signal
6. Set ‘test_mode’ to 3
7. Read the ‘test_ber’ and ‘test_count’ variables a couple of times. The test_count variable simply counts the number of received bits. This should reach a significant number before reading out the BER variable. In order to restart the counter and the reset, the BER average, set `test_reset` to 1.
8. Adjust the RF Carrier gradually downwards towards -125 dBm, setting `test_reset` to 1 for each step and take note of the BER at each value.
9. Verify that the measured BER levels correspond to the value provided in the system checkout document provided with the TTC-P3. (Note: due to the FEC the BER can be as high as 0.1 whilst still receiving a valid frame, however this is stochastic, and depending on the placing of the bit errors the frame could be rejected)

In orbit health check

Current

The RX current should match the current from before launch. We expect this will be exactly the same.

The TX current should match the same from before launch. The TX current varies with antenna matching. So it should be possible to detect bad antenna deployment from the TX current. However, this can also be detected by the missing downlink signal strength.

Temperatures

The board temp should follow the satellite mean temperature quite closely.

The PA temp should match the board temperature normally, and rise to 11.2 K/W * 1.8 W = approximately 20 degrees over the board temperature. Both temperatures are subject to lag due to thermal mass, and its only rarely that the PA is powered on for long periods so a steady state will be reached. So it is safe to assume that the nominal temperature is within 0 and 30 degrees from the board temp.

Boot Counter

The boot counter should be equal to the last value before launch + 1. To this you should add any number of days you have been without contact to the system (reset the ground watchdog). If this number is any bigger you can have power issues on the satellite.

Signal Strength

The RSSI Background parameter is expected to be higher than it was on ground due to the larger area of man-made noise sources visible from the satellite.

The RSSI of the received packets is expected to be in the area around -100 to -85 dBm. This depends on many other factors in the link budget, so that a quite large range is given. In reality each received packet should be logged and compared to antenna position, spacecraft orientation for a full link budget analysis.

Frequency Offset

The frequency offset should be within 2 kHz. This is adjusted for by closing the loop with the ground station doppler correction software. The absolute accuracy of the TCXO is very good and the temperature variation very low. So we don’t expect a high offset. However the precision and timing of the TLE can vary several minutes from expected satellite arrival to actual arrival. This means that any doppler compensation that relies on the accurate time of arrival, is bound to be off and fail.

A known method to circumvent this problem is to manually control the pass. Deactivate doppler compensation, and set the ground station to the expected frequency at time of arrival, and point at the expected azimuth and continuously send a ping request. When the first response arrives, you know the time of arrival, and can adjust the ground station doppler compensation accordingly. A time offset to the prediction algorithm is enough. We expect the TOA to be off by +/- 2 minutes.

Once new TLE’s arrive, the time compensation is no longer needed because the NORAD TLEs will gain accuracy after a few days.

The frequency offset over time of a pass is a very interesting parameter to plot, so the doppler compensation algorithm can be followed.

Antenna Delivered Power

The pwr_fwd and pwr_rev should stay at the same levels as during checkout with the antennas before launch. Generally the return loss should not be larger than 6 dB. And safe mode will kick in at 3 dB. Safe mode can only protect against certain mismatch such as an open connector, and cannot protect the TTC against a shorted antenna. It is therefore crucial that you do not transmit before the antenna has been deployed. If the pa_safemode_cnt parameter is > 0, this should raise a serious warning as something is wrong with the antenna.

TX Inhibit

It is very important that the TX inhibit is set during the launch process and until the antenna has been deployed. TX inhibit can be checked before the launch, and once deployed you must wait this amount of time until you can expect data from the satellite. The satellite can still receive commands while in TX inhibit mode.

Counters and packet loss

You can check the number of received packets rx_count, versus the number of packets with CRC error rx_err, and the tx_count of the ground station to see what your packet error rate is. This should be plotted against the current elevation angle and signal strength to give and understanding of overall link budget.

Satellite orientation (antenna pointing)

If the satellite only has one active TX antenna, which means that at some angles the signal strength will be lower than others. The ground operator should try to work with this in the first passes. So that means to expect periods without signal, even when the satellite is in range of the ground station. This has an effect on file transfer, retransmissions and the software capabilities to recover from packet losses. Luckily most commands are single packets where retransmission is simple.

Once ADCS has been comissionsed, a default attitude can be chosen where the antenna has good pointing properties.

Electrical and Thermal Characteristics

Power Supply	Min.	Typ.	Max.	Unit
Positive Supply Voltage	6		32	V
Current consumption: RX	190	230		mW
Current consumption: TX		3		W
CAN interface				
CAN High	-2	1.7 - 3.3	7	V
CAN Low	-2	0.5 - 1.7	7	V
CAN Speed (software configurable)	100.000	1.000.000	1.000.000	Hz
RS-422 interface				
TX-	-3.3	0		V
TX+		0	3.3	V
RX-	-3.3	0		V
RX+		0	3.3	V
Baud-Rate (software configurable)		1.000.000	1.000.000	Baud
Thermal Properties				
Operational temperature range (aluminium enclosure)	-40		60	Deg C.
PA case to aluminium enclosure, thermal resistance		11.2		K/W
PA junction to PA case, thermal resistance		26		K/W
NTC sensor to aluminium enclosure, thermal resistance[1]		3.72		K/W
Typical dissipated power during TX (at 31 dBm output)	1.5	1.8	2	W
PA junction temperature (over operational range)	27		127	Deg C.
PA absolute maximum junction temperature			150	Deg C.

RF Characteristics

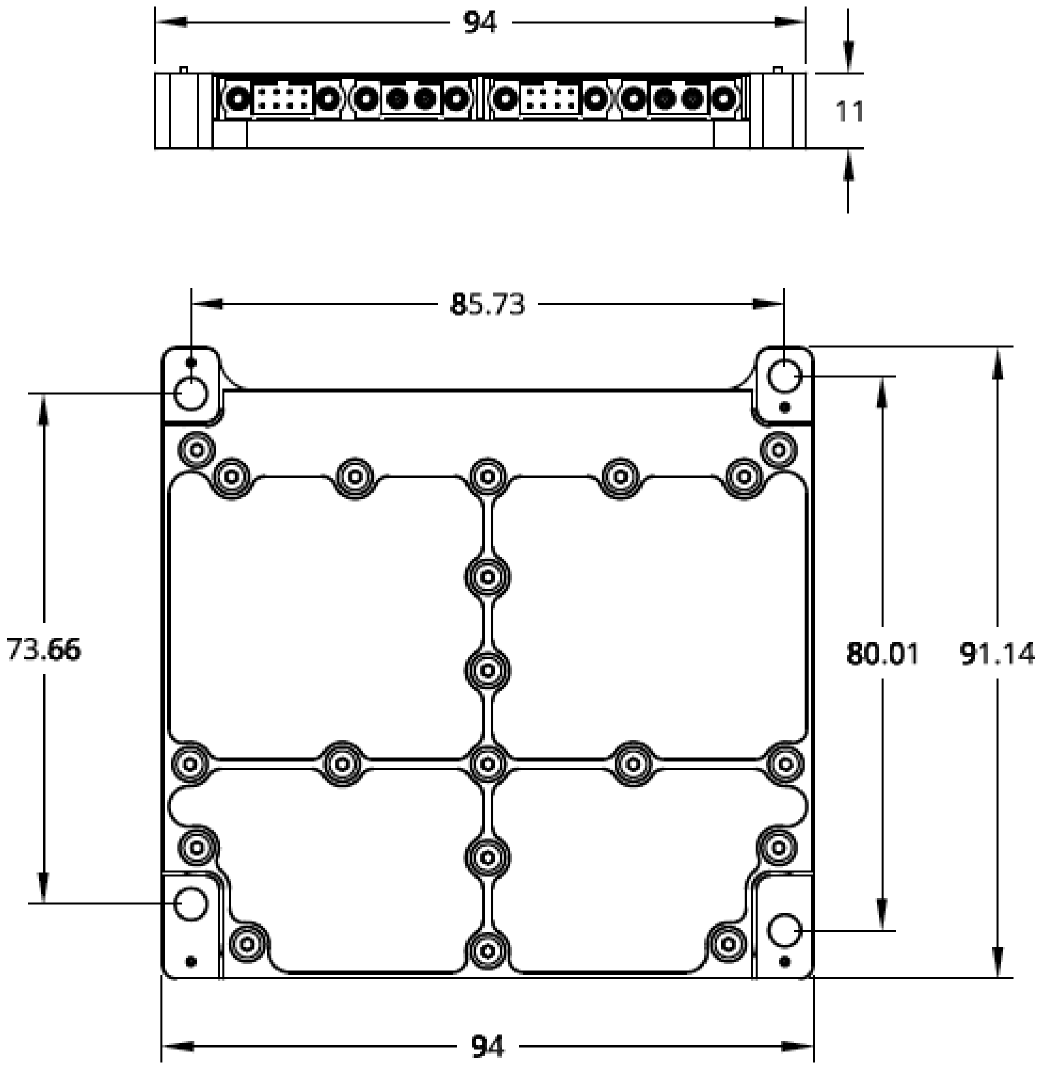
Frequency Synthesiser				
Frequency Range (Amateur band)	430	-	440	MHz
Frequency Range (Earth observation band)	400.2	-	403	MHz
Frequency Step Controllable		1		Hz
Frequency Calibration @ 25 deg C	-1		1	ppm
Frequency Stability (over temperature range)	-280		280	ppb
Long Term Stability (1 year @ 25 deg C)	-1		1	ppm
Aging (per life, 20 years)	-3		3	ppm

[1] NTC temperature relative to the aluminum enclosure, based on power dissipated in the PA in TX mode. In RX mode, NTC temperature = aluminum enclosure temperature.

Aging (per day)	-40		40	ppb
Receiver				
Baud / Symbol Rate[2]	4800	9600	38400	Baud
AFC pull-in range		5	15	%
Adjacent channel suppression (25 kHz)		45		dB
Out of band rejection +/- 10 MHz		78		dB
Absolute maximum input power		+10		dBm
Data–rate Error Tolerance	-10		10	%
Sensitivity with FEC				
• 4800 baud		-122		dBm
• 9600 baud		-119		dBm
• 19200 baud		-116		dBm
RSSI measurement accuracy	-3	1	3	dB
Transmitter				
Output power at connector 50 Ohm	1.3	1.5	1.6	W
Baud / Symbol Rate	4800	9600	38400	Hz
Adjacent channel power[3]		-50		dBc
2rd harmonic		-47		dBc
3rd harmonic		-59		dBc
Other spurs (+/- oscillator frequency 20 MHz)		-60		dBc
Phase Noise at 1 MHz offset		-120		dBc/ Hz

[2] Using hardware viterbi encoding with rate r=½, reduces the bit-rate by ½ times the symbol rate
[3] Adjacent channel power GFSK BT = 0.5, 500 Hz deviation, 1.2 kbps, 25 kHz channel spacing, 10 kHz channel BW

Mechanical Drawings



Dimension Drawing

Mass

The weight of the TTC-P3 is 143 gram.

Pin-out

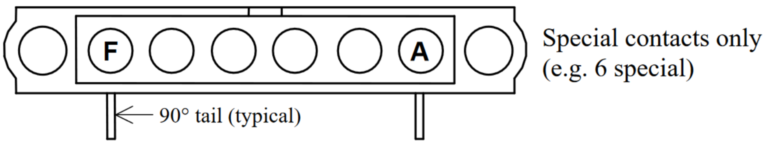
Power and control

Connector type PCB: M80-5430805 (male)
Pin 1 position: Top right corner, when looking into the male connector. Pinout according to Harwin C00531
(note: the image displays a larger pin-count connector)

4	3	2	1
RS-422 RX+	RS-422 TX+	CAN H	BAT
RS-422 RX-	RS-422 TX-	CAN L	GND
8	7	6	5

RF Connector

Harwin M80 coax (2 pin) RF bus
Pinout according to Harwin C00531



Note: Image depicts larger header.

B	A
RF TX/RX or RX(optional)	RF TX (optional)

Changelog

1.3 More clear pinout

2.0 Update on layout and font

ADCS-P3

Versatile ADCS Computer with Sensor and Actuator control

For Micro- and Nano-Satellites

Features

- 1x ARM® Cortex-M7 Main Processing Units
  - Powerful DSP instructions
  - Double precision hardware FPU
  - Upto 300 MHz operating frequency
  - Real-time OS incl. hardware drivers, filesystem and IDE
  - Real-time clock, watch-dogs, etc.
- Integrated sensors
  - 6 Degree of freedom IMU sensor
  - 3 axis magnetometer
- High-reliability Harwin M83 connector with
  - 2 x RS422/485 UART
  - 2 x CAN
- Onboard power conditioning with 5V - 28V input
- Driver circuit for torque rods
  - Current-mode resonant switching converters
  - > 80% efficiency
  - Bidirectional current measurement on all rod output
- 12 Protected output power channels
  - 6 x regulated power lines (3.3V) or unregulated battery supply
  - 6 x unregulated battery supply
  - 12 x CAN
- Reliability
  - Radiation total dose tested EEE parts
  - Vibration rated for all launch vehicles
  - 5 years design lifetime

Description

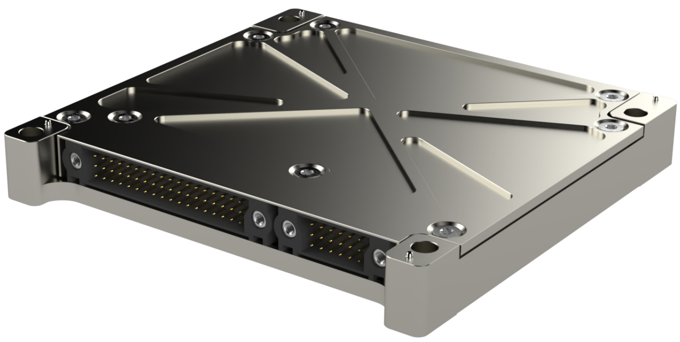
The ADCS-P3 is an interface and control computer for the attitude determination and control systems for advanced nano and microsatellite missions using a distributed sensor and actuator architecture.

The processing core is based on the Space Inventor OBC-P3 platform using the ARM Cortex-M7 computing platform executing the control algorithms. The interfaces to the computer are based on CAN bus and RS422 or RS485 UART.

The ADCS-P3 is designed to operate with external attitude sensors connected via CAN bus or UART such as sun sensors, star trackers, GPS and others and using external actuators for control. However an IMU with 6 degrees of freedom and 3 axis magnetometer are integrated in the unit.

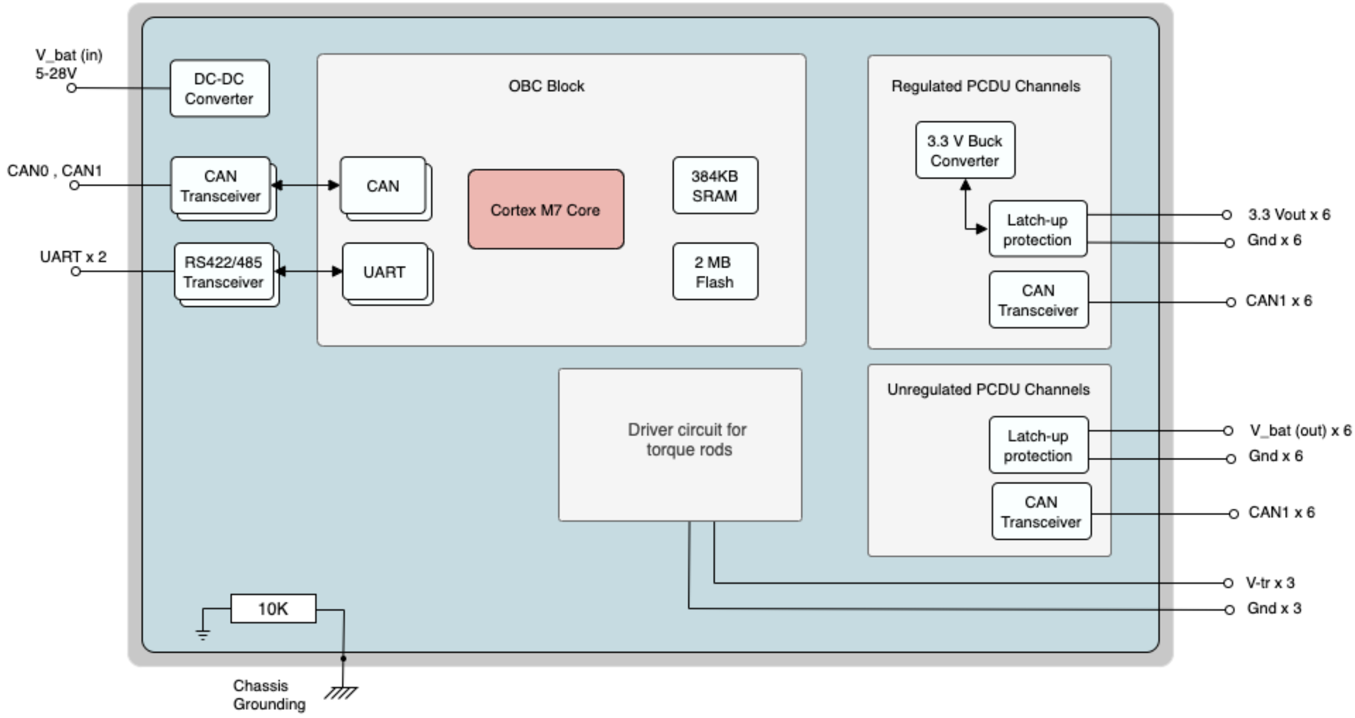
The ADCS-P3 includes 3 magnetorquer drivers which use buck converters to give very precise control over the generated dipole moment even at very low current in the torque rods.

The ADCS-P3 includes power distribution with latch-up protected outputs for 12 devices. The channels are divided into 6 channels with regulated voltage or unregulated and another 6 unregulated power channels, and each channel has dedicated power and CAN pins for easy harness connections to external sensors and actuators.



Functional Description

A functional block diagram of the ADCS-P3 is illustrated below with 6 regulated 3.3V power channels and 6 unregulated power channels.



Another configuration of the ADCS-P3 is with a total of 12 unregulated channels and no regulated power channels. This is used for a typical setup using Space Inventors ADCS sensors and actuators, where all systems are working with unregulated power channels for fine sunsensors (FSS-1), GPS module (GPS 2.5), momentum wheels (WHL-X) and star tracker (STAR-T3). This approach gives the satellite designer maximum design flexibility, since it will be possible to have long cables between the ADCS-P3 unit and the individual sensors.

The driver circuits for the torque rods use three buck converters combined with H-bridges to provide an accurate, filtered bi-directional DC voltage to each rod. This gives super "quiet" torquers that will not radiate a lot of EMI and create radio interference in the satellite as opposed to driving them with pure, unfiltered PWM. The output current will typically be from 10-300 mA in 4 to 8 ohm coils and is controlled by the microcontroller.

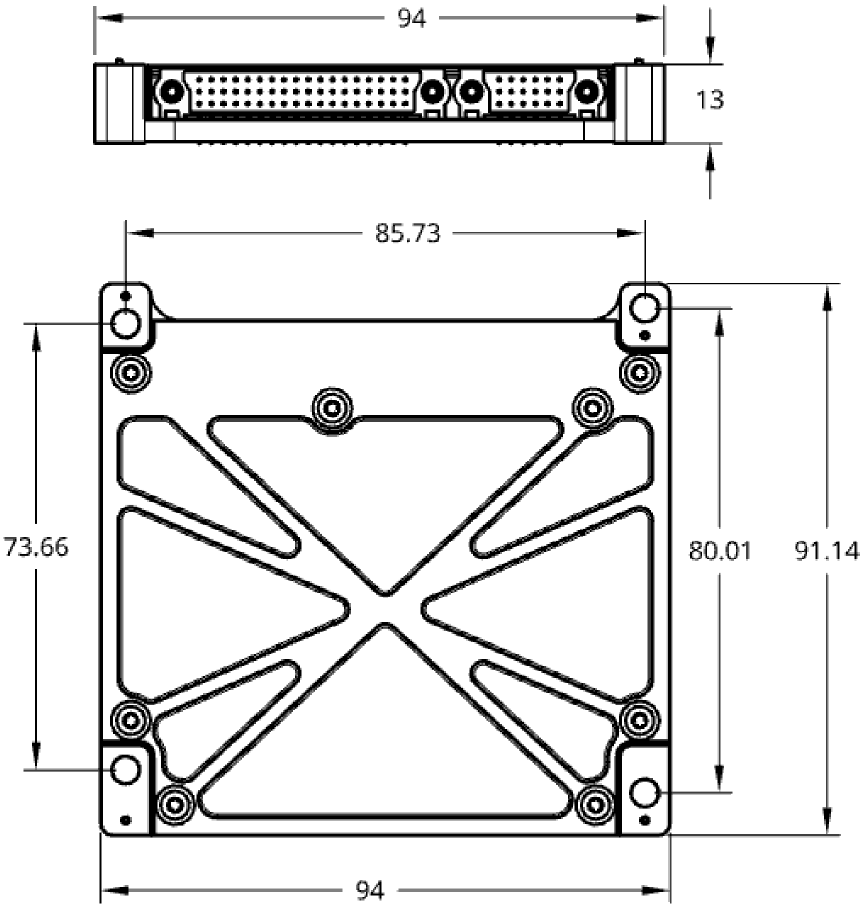
The system has two physical CAN buses - one intended to interface to the satellite bus (CAN0) plus a dedicated CAN bus for the ADCS-Sensors and actuators (CAN1). If the satellite is using a fully redundant bus scheme, the sensor and actuator bus, CAN1, can also be connected to a secondary external OBC such as an OBC-P3 or indeed to a secondary CAN satellite-level bus.

Software

The ADCS-P3 comes with FreeRTOS and drivers for the different interfaces on the board. Furthermore it also comes with CSP and lib param installed allowing easy system integration. With the OS, drivers and network protocol system it will be very straightforward for the programmer to write their own applications.

Space Inventor can also provide an ADCS software package that includes extended Kalman filtering and the following control modes: Ground tracking, inertial pointing, detumbling, momentum dumping. The ADCS algorithms can be tailored for the specific mission as well.

Mechanical Drawings



Dimension Drawing

Mass

The weight of the ADCS-P3 is estimated to be TBD gram.

Pin-out

The Harwin M83 connector with 54 pins is used for distributing power to the different sensors or actuators. The second Harwin M83 connector with 18 pin contains the interface to the satellite bus via CAN and RS485 or RS422 UART.5

Harwin M83 (54 pin)

18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
GND	V_BAT	CANH	CANL	GND	V_BAT	CANH	CANL	GND	V_REG	CANH	CANL	GND	V_REG	CANH	CANL	TR-1b	TR-1a
GND	V_BAT	CANH	CANL	GND	V_BAT	CANH	CANL	GND	V_REG	CANH	CANL	GND	V_REG	CANH	CANL	TR-2b	TR-2a
GND	V_BAT	CANH	CANL	GND	V_BAT	CANH	CANL	GND	V_REG	CANH	CANL	GND	V_REG	CANH	CANL	TR-3b	TR-3a
54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37

Harwin M83 (18 pin)

6	5	4	3	2	1
V_BAT		CAN0 H	CAN0 L	CAN1 H	CAN1 L
GND		RS0 TX+	RS0 RX+	RS1 TX+	RS1 RX+
DNC	DNC	RS0 TX-	RS0 RX-	RS1 TX-	RS1 RX-
18	17	16	15	14	13

WHL-50

50mm high performance reaction wheel

For Micro- and Nano-Satellites

Features

- Performance
  - Max nominal RPM: 10.000
  - Momentum of 42 mNms @ 10.000 RPM
  - Max Torque > 5 mNm
  - Control: Momentum, torque, speed or motor voltage
  - Automatic motor flux reduction (FOC)
- Physical
  - 50 x 50 x 25 mm
  - Mass: 165 gram
  - Rotor inertia: 40 x 10^{-6} kg mm^2
- Interface
  - CAN
  - 6-pin Gecko connector from Harwin
- Power
  - 12-16V unregulated DC
- Temperature Range
  - Operating temperature range -40°C to 60°C
- Reliability
  - Long life brushless motor design
  - Radiation total dose tested EEE parts
  - Vibration rated for all launch vehicles
  - 5 years design lifetime

Description

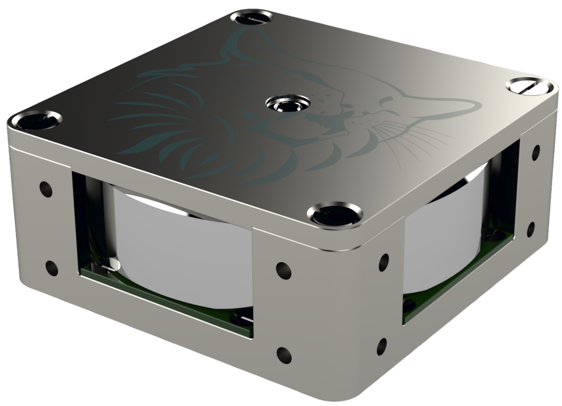
Fully integrated reaction wheel unit for high performance satellite attitude control for Micro and Nano-satellite missions with mission lifetime up to 5 years (minimum).

The REWL-50 wheel is an integrated 3-phase outrunner Permanent magnet synchronous motor (PMSM) with 8 rare-earth magnet poles in the rotor and 6 teeth in the stator. Material for the body is Al-7075-T6, rotor is made of ferritic stainless steel while the magnets are Neodymium.

The rotor is axially suspended between two hybrid ceramic high precision bearings chosen for long life and low friction in vacuum conditions. The wheel is commutated by its own internal microcontroller, which runs the control loop to control speed and acceleration upon commands from the ADCS computer.

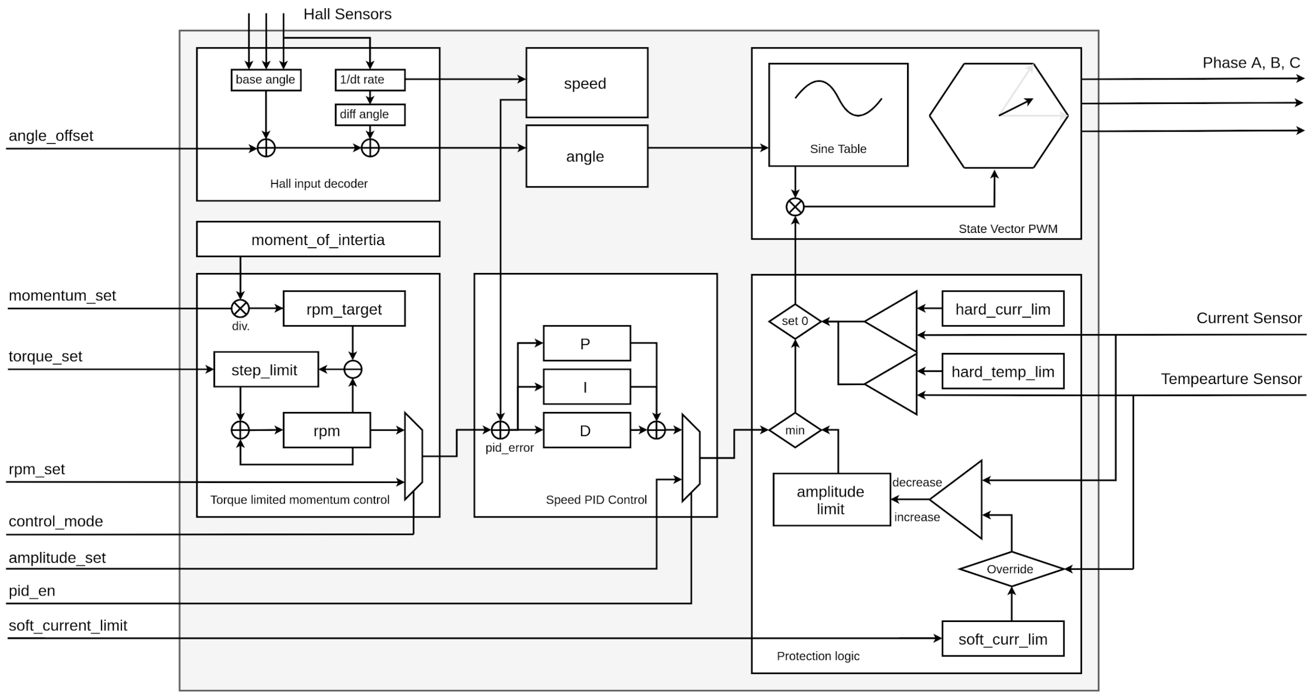
Each wheel has a CAN bus interface with CSP making them accessible to the satellite communication bus. The wheels are fitted with basic telemetry sensors: Temperature, current, speed.

Our recommendation for complete 3 axis control is to use the REWL-450 momentum wheel assembly, which uses four powerful REWL-50 reaction wheels that are integrated into the classic tetrahedron configuration for the benefit of both redundancy and elimination of zero crossing the wheel speeds.



REWL-50 Reaction Wheel

Functional Block Diagram



REWL-50 Functional Block Diagram

Functional description

The REWL-50 uses hall-sensor based sinusoidal SVPWM commutation with PID speed control, and a torque controller as input for the PID. The inner loop runs at up to 30 kHz with PWM clock of 60 kHz. The outer speed control loop runs at 100 Hz.

Angular Momentum Control

When control_mode is set to 1, the momentum controller is enabled. This controls the rpm_set output variable, depending on the momentum_set and torque_set input parameters.

The angular momentum is set using the Si unit [mnMs]. The controller uses the rotors moment of inertia to translate the desired input value to an rpm_target parameter. The target is then compared to the current rpm, to determine the difference or the desired change in rpms.

If the torque_set parameter is set to zero (or a very high value) the desired rpm_step will be applied immediately, effectively giving the maximum torque. If the torque_set is not zero, this is translated to a maximum acceleration or rpm/sec and the rpm output variable will be increased at this rate, effectively applying a torque limit.

If control_mode is set to 0, the output variable rpm_set, is not modified and can be controlled directly from an external controller.

PID Speed Control

When the pid_en parameter is 1, the speed controller will adjust its amplitude output variable in order to try and match the speed sensor input to the desired rpm_set variable.

When pid_en is set to 0, the amplitude output parameter will not be touched, and can be controlled directly from an external controller.

The parameters, kp, ki and kd, have been set to good default values, but can be adjusted to the user needs.

Protection Logic

The desired amplitude signal can be either set to zero, or softly decreased based on the protection modes.

The hard overcurrent limit and hard temperature limits are set by factory, and will immediately result in the amplitude being set to zero.

A soft_current_limit parameter can be set by the user in order to limit the current used. This can be used as a simple torque controller, as current and torque are related, but is is not as precise as using the actual torque controller. It should mainly be used as a failsafe, or secondary limit.

The soft current limit will be overridden by the temperature sensor so the maximum available torque falls with higher temperature.

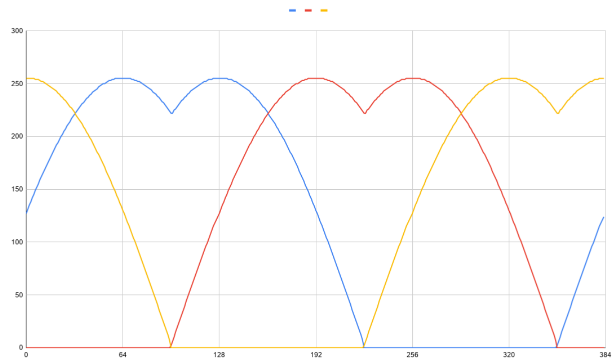
The soft limiter uses an asymmetric limiter, so each time the current is over the soft limit, the amplitude is decreased very rapidly, and then it is slowly increased again. This gives a quick reaction time, but a sawtooth torque ripple while in current limitation.

State Vector PWM

The output amplitude,or control voltage, is fed to the SVPWM module as a duty cycle. The wheel rotor angle, which estimated with a resolution of 0.94 degrees, is used in conjunction with a third harmonic injected SVPWM or THIPWM waveform to decide the three phase output signals. The amplitude or duty cycle is multiplied with the output signals to reduce the speed.

The PWM module runs with a switching speed of up to 60 kHz, and the angle estimator and waveform update performed at half the PWM output frequency.

Double sided, Centre Aligned Synchronous PWM is used for all three phases, in order to reduce switching harmonics. Furthermore Zero Sequence Vector Modulation with bottom clamping is used to reduce switching losses[1]



Third Harmonic Sine, with bottom clamping

Speed Estimation

When the wheel is running, the rising and falling edge of the hall sensors provides timing information that can be used to calculate the speed.

A 48 MHz 24-bit hardware timer is used to accurately time the period between the two falling edges of a Hall sensor. There are 8 magnets in the rotor, which gives 8 slightly different period times, due to their physical alignment and magnetic field variances. The last 8 period counters are stored in the period[8] register in a circular insertion mode. The mean of these 8 are calculated and stored in the period_mean8 register. Using the full rotation cycle mean gives a very high precision and low noise speed estimate.

The lower the speed, the more rarely the estimate is updated. The estimator works down to a speed of 21 RPM, but at this low speed the update rate is lower than the control loop and the wheel cannot run stable in closed loop speed control.

Angle Estimation

The three Hall sensors provide a base angle for the wheel, but the accuracy of this is only 60 degrees and is only accurately known at the point where the hall sensors change state. In order to increase the accuracy, the angle is updated based on linear interpolation using the speed estimate. That means the angle estimate is very accurate at steady state, and either lagging or leading slightly when the wheel is accelerating.

The angle estimator is considering the direction of the wheel and a fixed factory calibrated angle_hyst parameter is used to subtract half the hysteresis angle caused by the hall sensors. The result is accurate angle estimation in both directions.

[1] https://microchipdeveloper.com/mct5001:visualizing-zsm-alternatives

Angle offset

The angle offset parameter is used to allow the controller to work with any hall to stator offset angle. Basically any output angle can be made from any hall sensor input angle. This allows a great deal of freedom in production and design of PCB and hall sensor placement. The accuracy of the offset also allows for fine adjusting to obtain the best possible torque and efficiency.

Angle Advance

The advance angle is used to negate the effects of back EMF on the output waveform. With traditional Field oriented Control theory, this is handled by sampling the phase current, and calculating the in-phase and quadrature currents using the Clark and Park transformations.[2] The best performance is obtained when the stator flux current is zero. At low speed the back EMF is negligible and the current lags the voltage by a precise 90 degrees. At higher speeds the back EMF combines and produces a further lag of the current relative to the voltage. This produces an undesirable in-phase current which is a waste of energy.

At each RPM setting, there will be a different angle offset required to obtain the highest efficiency. A factory checkout measures the effect of the back EMF, and adjusts the angle_gain parameter in order to obtain optimal efficiency across all speeds.

This provides the benefits of Field Oriented Control, without having heavy mathematical transformations in the loop, speeding up the control loop considerably.

The wheel is capable of measuring the current at each speed step, and automatically tuning for the best efficiency. Setting test_en = 2 starts and automatic adjustment of the angle_offset. This is already performed on all wheels during checkout.

[2] https://en.wikipedia.org/wiki/Vector_control_(motor)

Exposed Parameters

The following table shows all the exposed parameters of the reaction wheel. Each parameter contains a mask value, this is used as a filter for different types of parameters, e.g. to filter for configuration or telemetry parameters. These flags can be conjoined such that a parameter could be filtered as both a configuration and a telemetry parameter.

Some parameters are used to represent some physical value, and the unit of the value are also denoted in the parameter system.

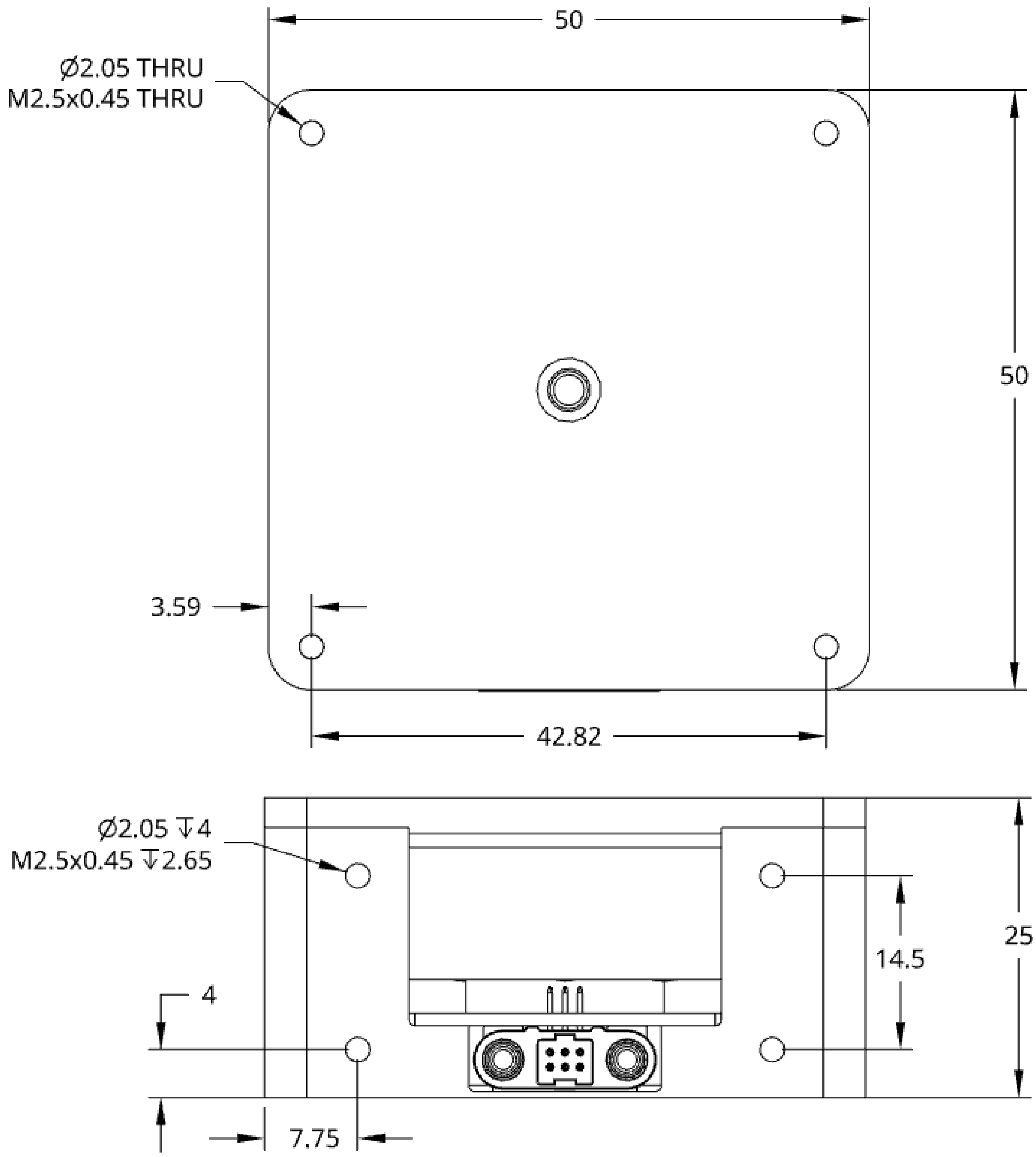
For more information about the parameter system, please see spaceinventor/libparam

Name	**Mask**	**Unit**	**Description**
temp	0x0009	1/100 deg C	CPU temperature.
csp_node	0x0080		CSP node (address).
csp_rtable	0x0080		CSP routing table.
csp_debug	0x0200		Enable/Disable CSP debugging information.
gndwdt	0x0140	s	Watchdog, if not poked the reaction wheel will reset and load it's backup configuration.
boot_err	0x0060		Used to signal if a error occured during the boot sequence.
boot_cnt	0x0040		Accumulated number of reboots.
boot_cur	0x0040		Current boot image.
boot_img0	0x00c0		Indicates where boot image 0 begins.
boot_img1	0x00c0		Indicates where boot image 1 begins.
time_factor	0x0080		Calibration value related to oscillator uncertainties.
stdbuf_out	0x0008		Captures stdout to a ringbuffer. This ring buffer can be read from the ground station emulating stdio.
stdbuf_in	0x0008		stdin ring buffer. Works in the same way as the above.
period_mean8	0x0008		Mean rotation period over all the the 8 hall sensors.
period	0x0008		Rotation period as seen from each of the hall sensors.
freq_ema	0x0004		Filter constant used in a low pass filter of the hall sensors.
adc_ch11	0x0200		Raw value from ADC ch11.
adc_ch9	0x0200		Raw value from ADC ch9.
temp_brd	0x0008	deg C	Temperature of the board.
current	0x0008	mA	Internal current measurement.
hall_cnt	0x0200		Hall sensor counter.
hall_dir	0x0200		Direction as seen from the hall sensor.

hall_nibble	0x0200		Intermediate value. Used to determine hall_dir.
angle_gain	0x0200		Intermediate value. Used in the Angle Advance algorithm.
angle_hyst	0x0200		Tuning parameter for angle estimation.
sine	0x0200		Output to each coil when using the sinusoidal waveform.
diff_angle	0x0200		See the Angle Offset section.
angle_advance	0x0008		See the section on Angle Advance.
angle	0x0200		Estimated angle of the rotor.
pid_en	0x0004		Enable/Disable PID controller.
kd	0x000c		Gain for the PID.
ki	0x000c		Gain for the PID.
kp	0x000c		Gain for the PID.
rpm	0x000c		Estimated RPM.
rpm_err_sum	0x000c		Integrated error.
rpm_err	0x000c		Apparent error.
rpm_set	0x000c		Reference RPM. Can either be set manually, or used as part of the momentum control (this value is updated automatically).
ramp_en	0x0004		Enable/Disable rate limited RMP. Limited based on torque_set, and the final rpm based on momentum_set.
torque_set	0x000c	mNm	Reference torque..
momentum_set	0x000c	mNms	Reference momentum.
moment_of_inertia	0x0004	gm^2	Inertia of the swing mass.
pwm_period	0x0204		PWM duty cycle period.
pwm_isr_inter	0x0200		PWM interrupt service routine interval.
pwm_isr_ticks	0x0200		Measure of the CPU time spend in the PWM interrupt service routine.
amplitude_max_step	0x0004		Maximum step size in amplitude per update.
amplitude	0x000c		Amplitude of the PWM output.
cooldown	0x0200		Seconds to wait when hitting a hard protection.
test_en	0x0004		See Angle Advance.
curlim_soft	0x0004	mA	Soft current limit. The RW will slowly reduce the torque while in this limit.
curlim_hard	0x0004	mA	Hard current limit. The RW will stop torquing, and free float for a period.
templim_hard	0x0004	1/100 deg C	Hard temperature limit. The RW will stop torquing, and free float for a period.

auto_resume	0x0004		Resume operations on reboot.
rpm_target	0x000c		If ramp_en is set to 1, this value is updated based in the torque profile.
rpm_per_sec	0x000c		If ramp_en is set to 1, this value is updated based in the torque profile.
angle_offset	0x0004		See Angle offset.
waveform	0x0200		Select between a sine wave of square function as input for the electromagnets .
odometer	0x0008	krev	Accumulated number of revolutions of the reaction wheel.

Mechanical Drawings



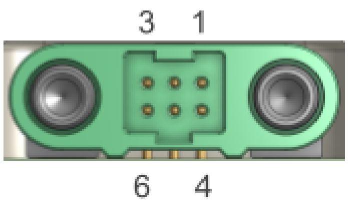
Mass

The mass of the REWL-50 is 165 gram.

Pinout

The pinout of the Harwin Gecko G125-MH10605M4P male socket is as shown below for both options, where the socket is viewed from the wire side looking into the module. Note that the connector is upside down in the dimension drawing on the previous page as well as all other illustrations of the wheel.

Pin no.	Function - CAN option
1	Supply voltage (power input)
2	
3	CANH
4	GND (power return)
5	
6	CANL



WHL-200

70 mm high performance reaction wheel

For Micro- and Nano-Satellites

Features

- Performance
  - Max nominal RPM: 12.000
  - Momentum of 200 mNms @12.000 RPM
  - Max Torque > 25 mNm
  - Control: Momentum / Speed, Torque or Motor voltage / Duty Cycle.
  - Automatic motor flux reduction (FOC)
- Physical
  - 70 x 70 x 45 mm
  - Mass: 423 gram
  - Rotor inertia: 147.1 x 10^{-6} kg mm^2
- Interface
  - CAN
  - 12-pin Gecko connector from Harwin
- Power
  - 6.5-33.6 V unregulated DC
- Temperature Range
  - Operating temperature range -40°C to 60°C
- Reliability
  - Long life brushless motor design
  - Radiation total dose tested EEE parts
  - Vibration rated for all launch vehicles
  - 5 years design lifetime

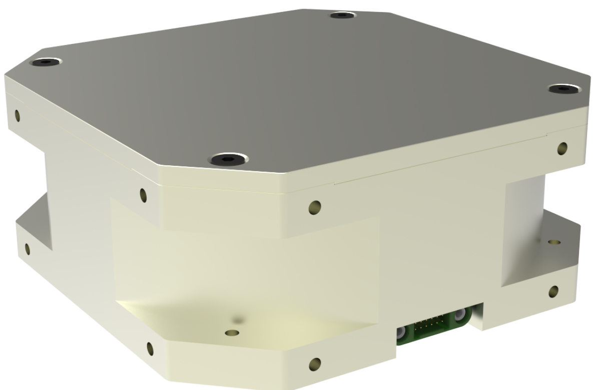
Description

Fully integrated reaction wheel unit for high performance satellite attitude control for Micro and Nano-satellite missions with mission lifetime up to 5 years (minimum).

The WHL-200 wheel is an integrated 3-phase outrunner permanent magnet synchronous motor (PMSM) with fully integrated motor control electronics and software. Material for the body is Al-7075-T6, and the rotor is made of ferritic stainless steel while the magnets are Neodymium. The rotor is axially suspended between two hybrid ceramic high precision bearings chosen for long life and low friction in vacuum conditions. The wheel is commutated by its own internal microcontroller, which runs the control loop to control speed and acceleration upon commands from the ADCS computer.

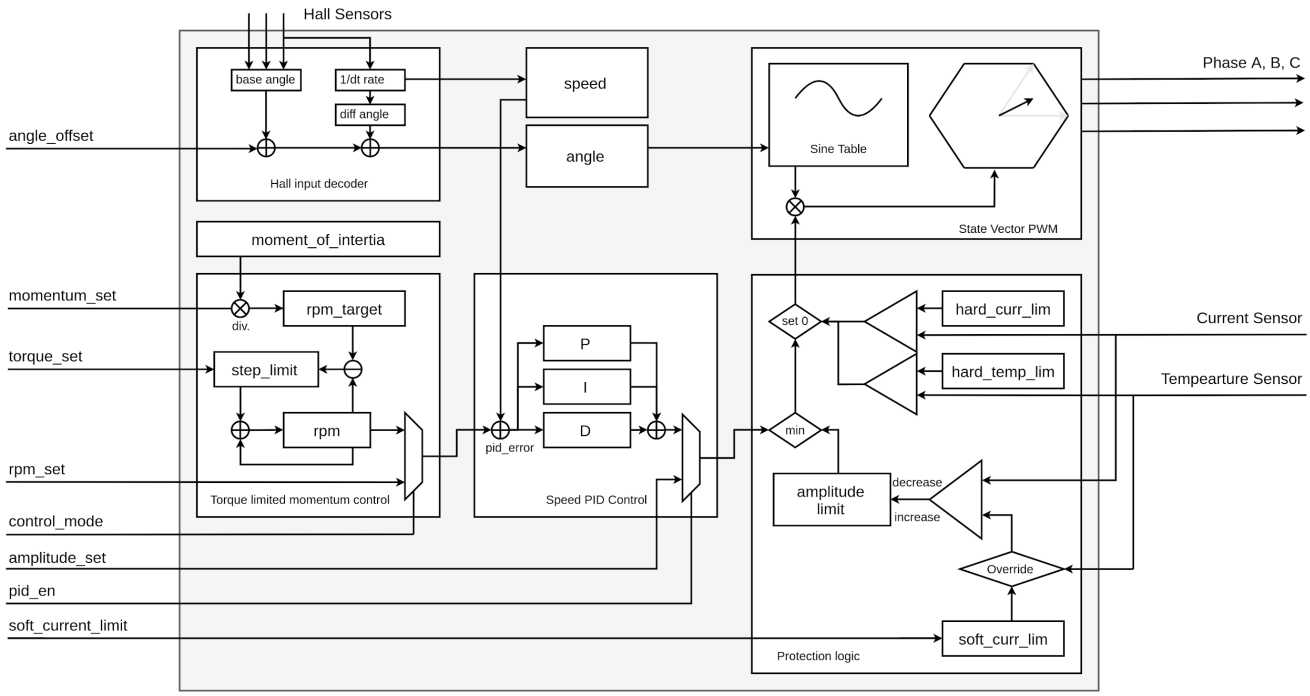
The wheel has a CAN bus interface with CSP making it accessible to the satellite communication bus. The wheel is fitted with basic telemetry sensors: temperature, current, and speed.

Our recommendation for complete 3 axis control is to use a momentum wheel assembly, which uses four powerful WHL-200 reaction wheels that are integrated into the classic tetrahedron or pyramid configuration for the benefit of both redundancy and elimination of zero crossing the wheel speeds.



WHL-200 Reaction Wheel

Functional Block Diagram



WHL-200 Functional Block Diagram

Functional description

The WHL-200 uses hall-sensor based sinusoidal SVPWM commutation with PID speed control, and a torque controller as input for the PID. The inner loop runs at up to 30 kHz with PWM clock of 60 kHz. The outer speed control loop runs at 100 Hz.

Angular Momentum Control

When control_mode is set to 1, the momentum controller is enabled. This controls the rpm_set output variable, depending on the momentum_set and torque_set input parameters.

The angular momentum is set using the Si unit [mNms]. The controller uses the rotor's moment of inertia to translate the desired input value to an rpm_target parameter. The target is then compared to the current rpm, to determine the difference or the desired change in rpms.

If the torque_set parameter is set to zero (or a very high value) the desired rpm_step will be applied immediately, effectively giving the maximum torque. If the torque_set is not zero, this is translated to a maximum acceleration or rpm/sec and the rpm output variable will be increased at this rate, effectively applying a torque limit.

If control_mode is set to 0, the output variable rpm_set, is not modified and can be controlled directly from an external controller.

PID Speed Control

When the pid_en parameter is 1, the speed controller will adjust its amplitude output variable in order to try and match the speed sensor input to the desired rpm_set variable.

When pid_en is set to 0, the amplitude output parameter will not be touched, and can be controlled directly from an external controller.

The parameters, kp, ki and kd, have been set to good default values, but can be adjusted to the user's needs.

Protection Logic

The desired amplitude signal can be either set to zero, or softly decreased based on the protection modes.

The hard overcurrent limit and hard temperature limits are set by factory, and will immediately result in the amplitude being set to zero.

A soft_current_limit parameter can be set by the user in order to limit the current used. This can be used as a simple torque controller, as current and torque are related, but it is not as precise as using the actual torque controller. It should mainly be used as a failsafe, or secondary limit.

The soft current limit will be overridden by the temperature sensor so the maximum available torque falls with higher temperature.

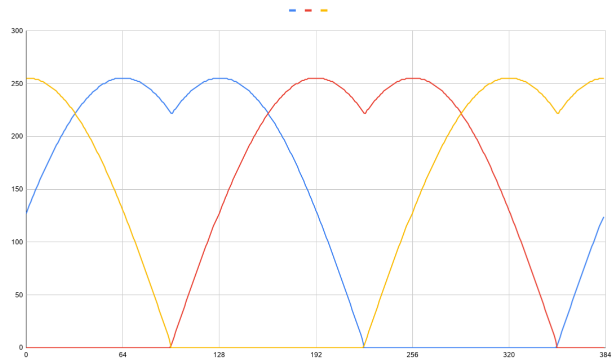
The soft limiter uses an asymmetric limiter, so each time the current is over the soft limit, the amplitude is decreased very rapidly, and then it is slowly increased again. This gives a quick reaction time, but a sawtooth torque ripple while in current limitation.

Space Vector PWM

The output amplitude, or control voltage, is fed to the SVPWM module as a duty cycle. The wheel rotor angle, which, estimated with a resolution of 0.94 degrees, is used in conjunction with a third harmonic injected SVPWM or THIPWM waveform to decide the three phase output signals. The amplitude or duty cycle is multiplied with the output signals to reduce the speed.

The PWM module runs with a switching frequency of up to 60 kHz, and the angle estimator and waveform update are performed at half the PWM output frequency.

Double sided, Centre Aligned Synchronous PWM is used for all three phases, in order to reduce switching harmonics. Furthermore Zero Sequence Vector Modulation with bottom clamping is used to reduce switching losses[1]



Third Harmonic Sine, with bottom clamping

Speed Estimation

When the wheel is running, the rising and falling edge of the hall sensors provides timing information that can be used to calculate the speed.

A 48 MHz 24-bit hardware timer is used to accurately time the period between the two falling edges of a Hall sensor. There are 8 magnets in the rotor, which gives 8 slightly different period times, due to their physical alignment and magnetic field variances. The last 8 period counters are stored in the period[8] register in a circular insertion mode. The mean of these 8 are calculated and stored in the period_mean8 register. Using the full rotation cycle mean gives a very high precision and low noise speed estimate.

The lower the speed, the more rarely the estimate is updated. The estimator works down to a speed of 21 RPM, but at this low speed the update rate is lower than the control loop and the wheel cannot run stable in closed loop speed control.

Angle Estimation

The three Hall sensors provide a base angle for the wheel, but the accuracy of this is only 60 degrees and is only accurately known at the point where the hall sensors change state. In order to increase the accuracy, the angle is updated based on linear interpolation using the speed estimate. That means the angle estimate is very accurate at steady state, and either lagging or leading slightly when the wheel is accelerating.

The angle estimator is considering the direction of the wheel and a fixed factory calibrated angle_hyst parameter is used to subtract half the hysteresis angle caused by the hall sensors. The result is accurate angle estimation in both directions.

1 https://microchipdeveloper.com/mct5001:visualizing-zsm-alternatives

Angle offset

The angle offset parameter is used to allow the controller to work with any hall to stator offset angle. Basically any output angle can be made from any hall sensor input angle. This allows a great deal of freedom in production and design of PCB and hall sensor placement. The accuracy of the offset also allows for fine adjusting to obtain the best possible torque and efficiency.

Angle Advance

The advance angle is used to negate the effects of back EMF on the output waveform. With traditional Field oriented Control theory, this is handled by sampling the phase current, and calculating the in-phase and quadrature currents using the Clark and Park transformations.[2] The best performance is obtained when the stator flux current is zero. At low speed the back EMF is negligible and the current lags the voltage by a precise 90 degrees. At higher speeds the back EMF combines and produces a further lag of the current relative to the voltage. This produces an undesirable in-phase current which is a waste of energy.

At each RPM setting, there will be a different angle offset required to obtain the highest efficiency. A factory checkout measures the effect of the back EMF, and adjusts the angle_gain parameter in order to obtain optimal efficiency across all speeds.

This provides the benefits of Field Oriented Control, without having heavy mathematical transformations in the loop, speeding up the control loop considerably.

The wheel is capable of measuring the current at each speed step, and automatically tuning for the best efficiency. Setting test_en = 2 starts and automatic adjustment of the angle_offset. This is already performed on all wheels during checkout.

[2] https://en.wikipedia.org/wiki/Vector_control_(motor)

Exposed Parameters

The following table shows all the exposed parameters of the reaction wheel. Each parameter contains a mask value, this is used as a filter for different types of parameters, e.g. to filter for configuration or telemetry parameters. These flags can be conjoined such that a parameter could be filtered as both a configuration and a telemetry parameter.

Some parameters are used to represent some physical value, and the unit of the value is also denoted in the parameter system.

For more information about the parameter system, please see spaceinventor/libparam

Name	Mask	Unit	Description
temp	0x0009	1/100 deg C	CPU temperature.
csp_node	0x0080		CSP node (address).
csp_rtable	0x0080		CSP routing table.
csp_debug	0x0200		Enable/Disable CSP debugging information.
gndwdt	0x0140	s	Watchdog, if not poked, the reaction wheel will reset and load it's backup configuration.
boot_err	0x0060		Used to signal if an error occurred during the boot sequence.
boot_cnt	0x0040		Accumulated number of reboots.
boot_cur	0x0040		Current boot image.
boot_img0	0x00c0		Indicates where boot image 0 begins.
boot_img1	0x00c0		Indicates where boot image 1 begins.
time_factor	0x0080		Calibration value related to oscillator uncertainties.
stdbuf_out	0x0008		Captures stdout to a ringbuffer. This ring buffer can be read from the ground station emulating stdio.
stdbuf_in	0x0008		stdin ring buffer. Works in the same way as the above.
period_mean8	0x0008		Mean rotation period over all the 8 hall sensors.
period	0x0008		Rotation period as seen from each of the hall sensors.
freq_ema	0x0004		Filter constant used in a low pass filter of the hall sensors.
adc_ch11	0x0200		Raw value from ADC ch11.
adc_ch9	0x0200		Raw value from ADC ch9.
temp_brd	0x0008	deg C	Temperature of the board.
current	0x0008	mA	Internal current measurement.
hall_cnt	0x0200		Hall sensor counter.
hall_dir	0x0200		Direction as seen from the hall sensor.
hall_nibble	0x0200		Intermediate value. Used to determine hall_dir.

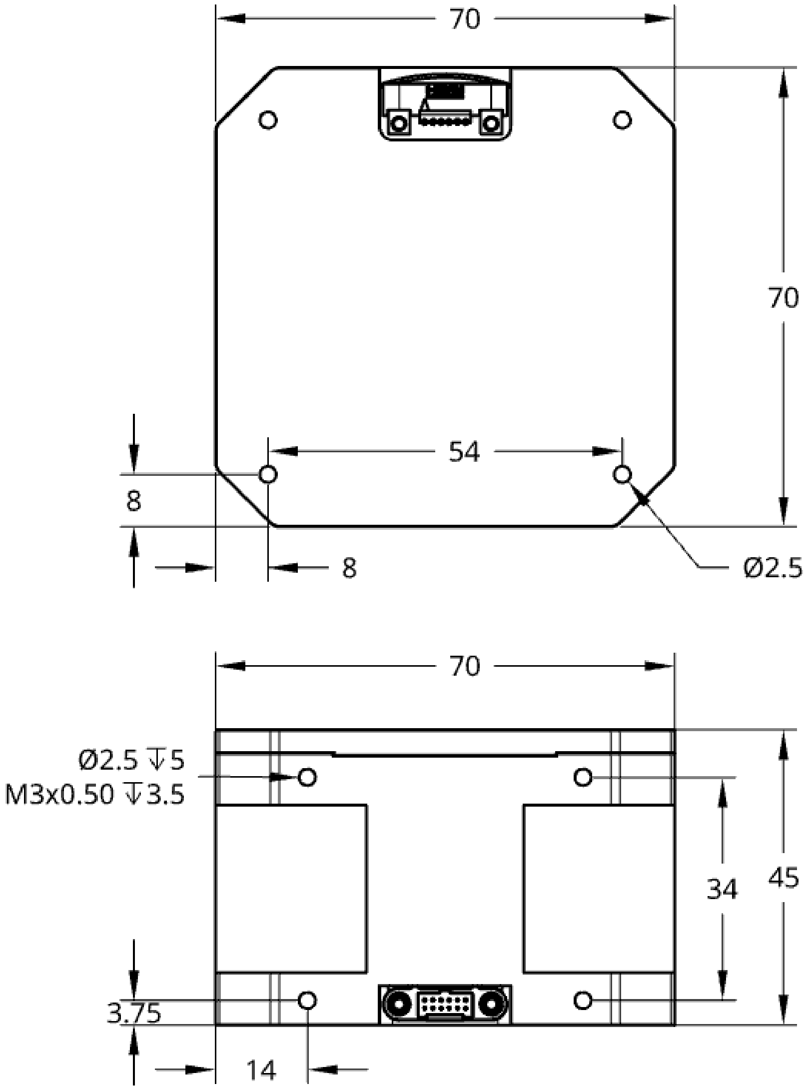
angle_gain	0x0200		Intermediate value. Used in the Angle Advance algorithm.
angle_hyst	0x0200		Tuning parameter for angle estimation.
sine	0x0200		Output to each coil when using the sinusoidal waveform.
diff_angle	0x0200		See the Angle Offset section.
angle_advance	0x0008		See the section on Angle Advance.
angle	0x0200		Estimated angle of the rotor.
pid_en	0x0004		Enable/Disable PID controller.
kd	0x000c		Derivative gain for the PID.
ki	0x000c		Integral gain for the PID.
kp	0x000c		Proportional gain for the PID.
rpm	0x000c		Estimated RPM.
rpm_err_sum	0x000c		Integrated error.
rpm_err	0x000c		Apparent error.
rpm_set	0x000c		Reference RPM. Can either be set manually, or used as part of the momentum control (this value is updated automatically).
ramp_en	0x0004		Enable/Disable rate limited RMP. Limited based on torque_set, and the final rpm based on momentum_set.
torque_set	0x000c	mNm	Reference torque.
momentum_set	0x000c	mNms	Reference momentum.
moment_of_inertia	0x0004	gm^2	Inertia of the swing mass.
pwm_period	0x0204		PWM duty cycle period.
pwm_isr_inter	0x0200		PWM interrupt service routine interval.
pwm_isr_ticks	0x0200		Measure of the CPU time spent in the PWM interrupt service routine.
amplitude_max_step	0x0004		Maximum step size in amplitude per update.
amplitude	0x000c		Amplitude of the PWM output.
cooldown	0x0200		Seconds to wait when hitting a hard protection.
test_en	0x0004		See Angle Advance.
curlim_soft	0x0004	mA	Soft current limit. The RW will slowly reduce the torque while in this limit.
curlim_hard	0x0004	mA	Hard current limit. The RW will stop torquing, and free float for a period.
templim_hard	0x0004	1/100 deg C	Hard temperature limit. The RW will stop torquing, and free float for a period.
auto_resume	0x0004		Resume operations on reboot.

rpm_target	0x000c		If ramp_en is set to 1, this value is updated based on the torque profile.
rpm_per_sec	0x000c		If ramp_en is set to 1, this value is updated based on the torque profile.
angle_offset	0x0004		See Angle offset.
waveform	0x0200		Select between a sine wave of square function as input for the electromagnets .
odometer	0x0008	krev	Accumulated number of revolutions of the reaction wheel.

Electrical Characteristics

Power Supply	**Min.**	**Typ.**	**Max.**	**Unit**
Positive Supply Voltage	6		33.6	V
Current consumption CPU		75		mW
Current consumption motor @ 20 mNm (steady state)		TBD		W
Current consumption motor @ 20 mNm + 1 mNm		TBD		W
Current consumption motor @ 20 mNm + 2 mNm		TBD		W
CAN interface				
CAN High	-2	1.7 - 3.3	7	V
CAN Low	-2	0.5 - 1.7	7	V
CAN Speed	1.000.000	1.000.000	1.000.000	Hz

Mechanical Drawings



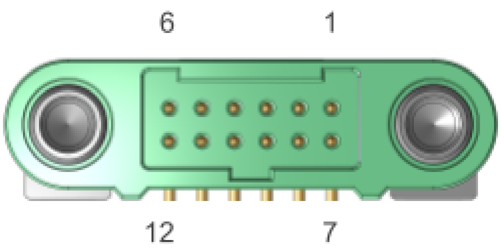
Mass

The mass of the WHL-200 is 423 gram.

Pinout

The pinout of the Harwin Gecko G125-MH11205M4P male socket is as shown below, where the socket is viewed from the wire side looking into the module. Note that the connector is upside down in the dimension drawing on the previous page as well as all other illustrations of the wheel.

Pin no.	Function - CAN option
1-2	Supply voltage (power input)
3	CANH
4	CANL
7-8	GND (power return)
9	RS-422 Rx-
10	RS-422 Rx+
11	RS-422 Tx-
12	RS-422 Tx+



STAR-T3

Accurate Star-tracker unit

For Micro- and Nano-Satellites

Features

- Accuracy (1 sigma)
  - Pitch/yaw <2 arcsec
  - Roll < 12 arcsec
- Timing
  - Update rate: 5 Hz
  - Time to first fix: 5-10 sec
- Slew-rate :
  - Up to 0.3 deg/s (full performance)
  - Up to 1.5 deg/s (reduced performance)
- Physical
  - 60 x 60 x 100 mm including baffle
  - 37.5 deg (half cone) Sun exclusion angle
  - 350 gr mass
- Interface
  - CAN or RS422
  - High reliability Harwin M80 connector
- Power
  - Power consumption - 2 Watt
  - 5V regulated or 7-28V unregulated input
- Temperature
  - Operating with full performance: -40 °C to +30 °C
  - Operating with reduced performance: +30 °C to +50 °C
  - Survival range : -40 °C to +70 °C
- Reliability
  - Radiation total dose tested EEE parts
  - Vibration rated for all launch vehicles
  - 5 years design lifetime

Description

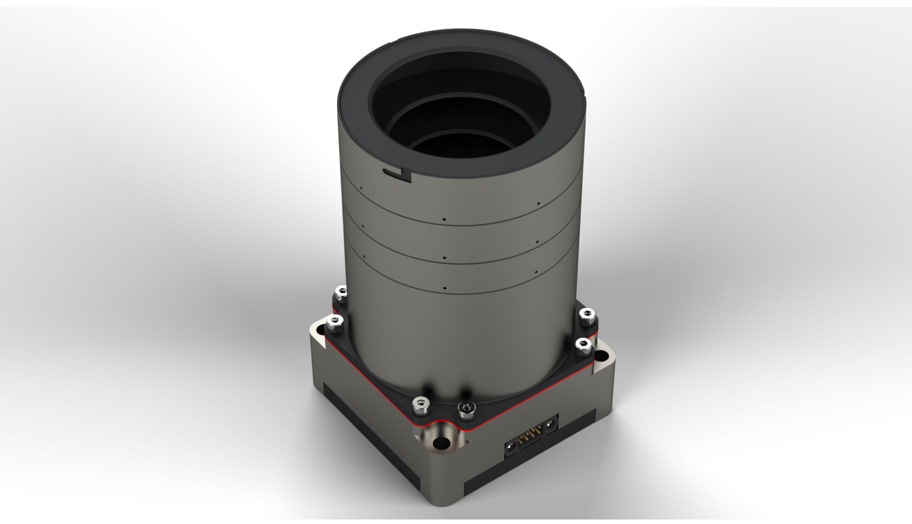
Compact autonomous star-tracker unit providing high accuracy determination based on advanced star-tracking algorithms for Micro and Nano-satellite missions with mission lifetime up to 5 years (minimum).

The star-tracker is jointly developed by Terma A/S and Space Inventor ApS based on a scaled-down version of the Terma's T1 star-tracker with a smaller optical system and computer processing unit based on high reliable COTS components.

The compact optics of the camera provides a 20° circular field of view and - although compact - provides enough signal to track across the entire celestial vault. The standard baffle provides a Sun exclusion half-angle as low as to 37.5°.

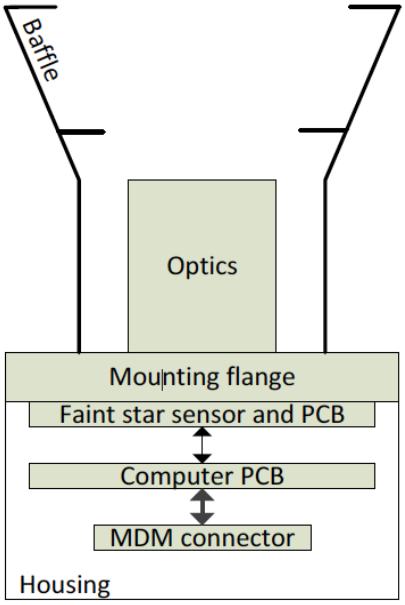
The optical head is based on a CMOS Active Pixel Sensor with a suite of integrated on-chip functionality supporting a complete new class of miniaturized high-performance star trackers. Terma has taken the miniaturization challenge as far as possible, without compromising the accuracy required from a state-of-the-art star tracker. The new Optical Head has been designed with very few components, for high reliability and low recurrent cost.

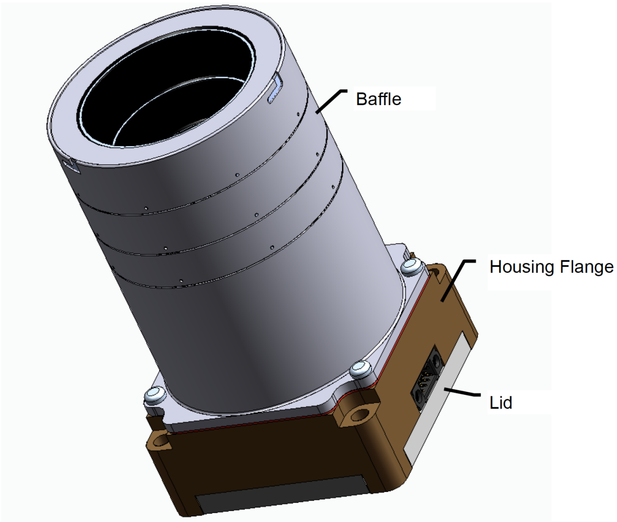
The processing unit houses the star catalogue and the software algorithms for initial attitude determination and continuing attitude update. Also, the unit provides power to the camera.



High Level Block Diagram

A high level block diagram of the T3 star tracker and mechanical outline is presented below:



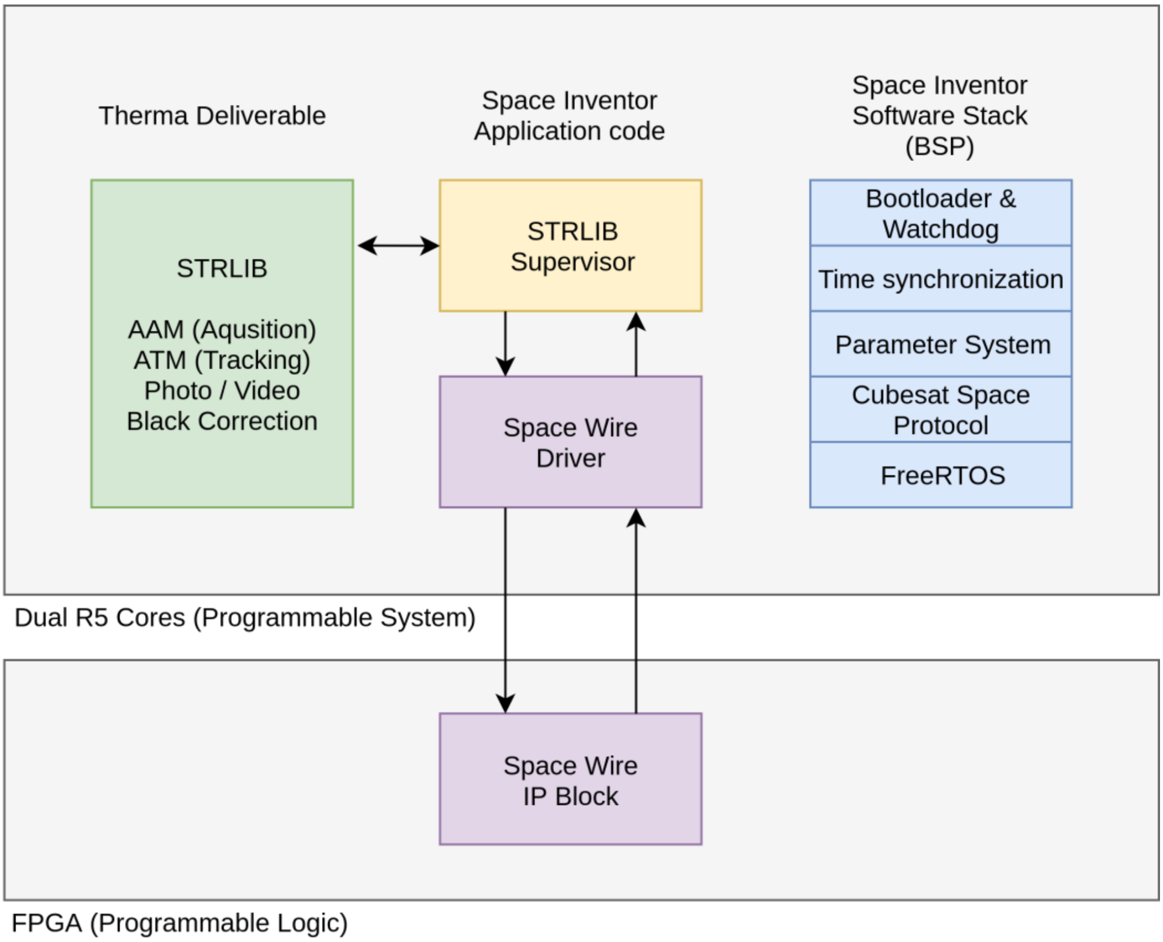


The main elements comprise:

1. Compact single stage straylight baffle
2. Fast compact straylight optimized optics
3. Mechanical mounting flange and housing
4. Sensor (Faintstar) PCB including proximity electronics and CTE matching optics and mounting flange
5. Computer PCB with interface to Spacecraft (power and communication) and sensor PCB (SpaceWire and +5 V voltage supply)
6. Electrical interface connector - 8 pin Harwin M80

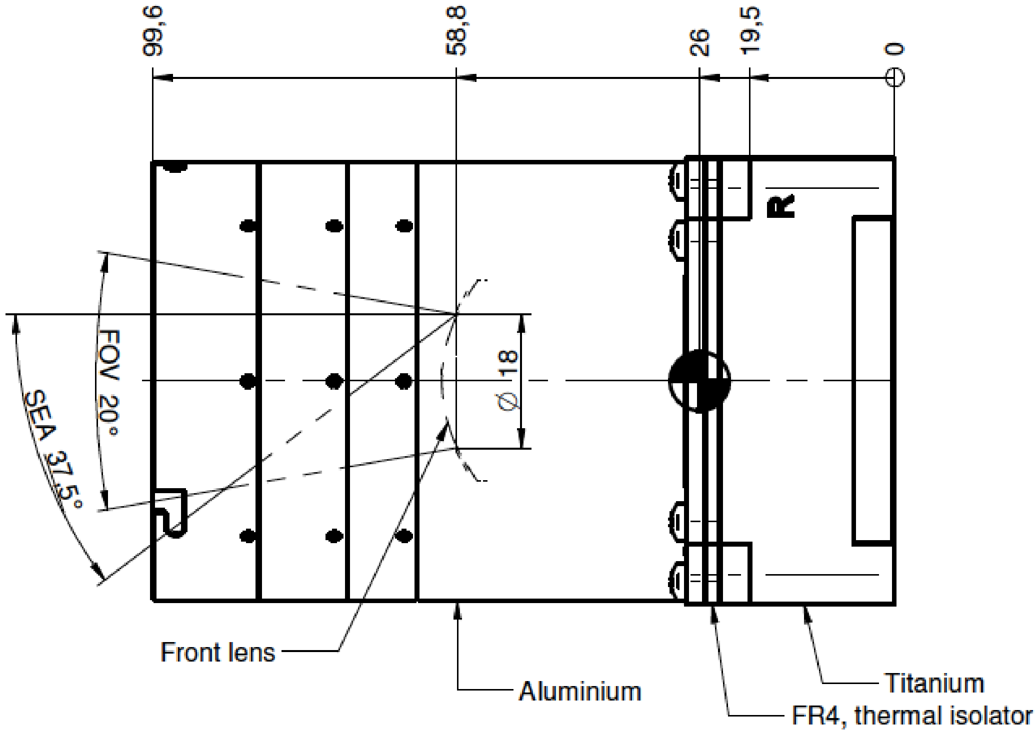
Computer Unit Software

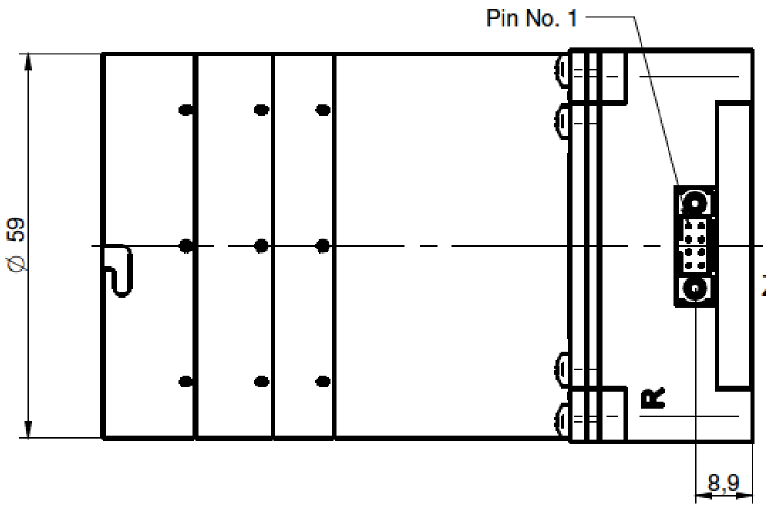
The star tracker on-board software consists of a star tracker supervisor and the Terma generic STRlib library as depicted in the following figure. The SpaceWire driver SW as well as FPGA IP core are integral parts of the Computer Board. The TC/TM interface is based on the existing Cubesat Space Protocol. The STRlib is developed by Terma and integrated as an integral part of the Application Software Code by Space Inventor.

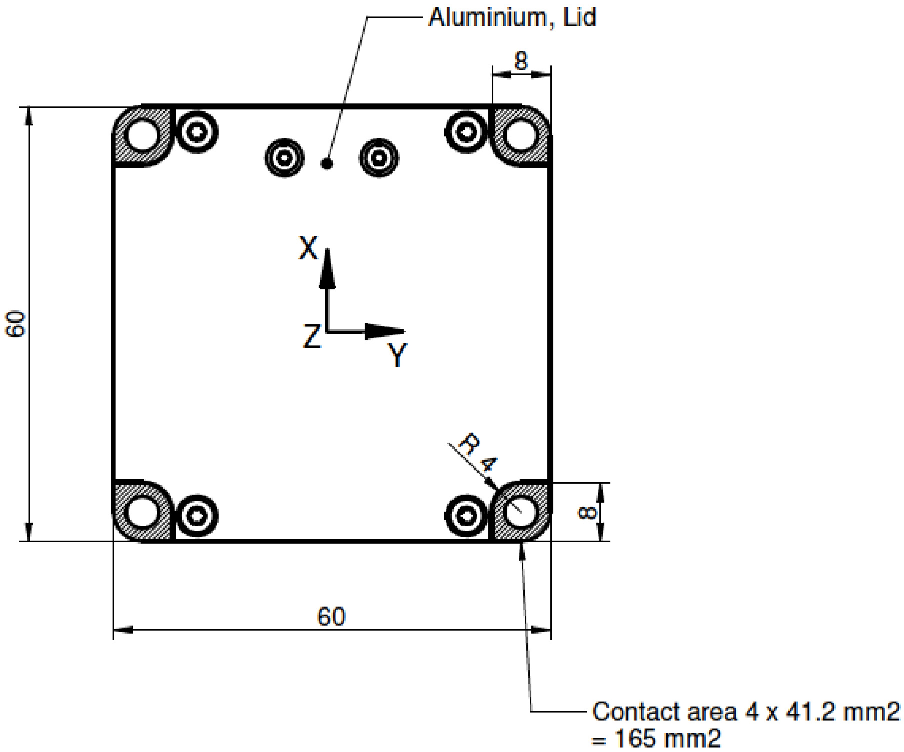


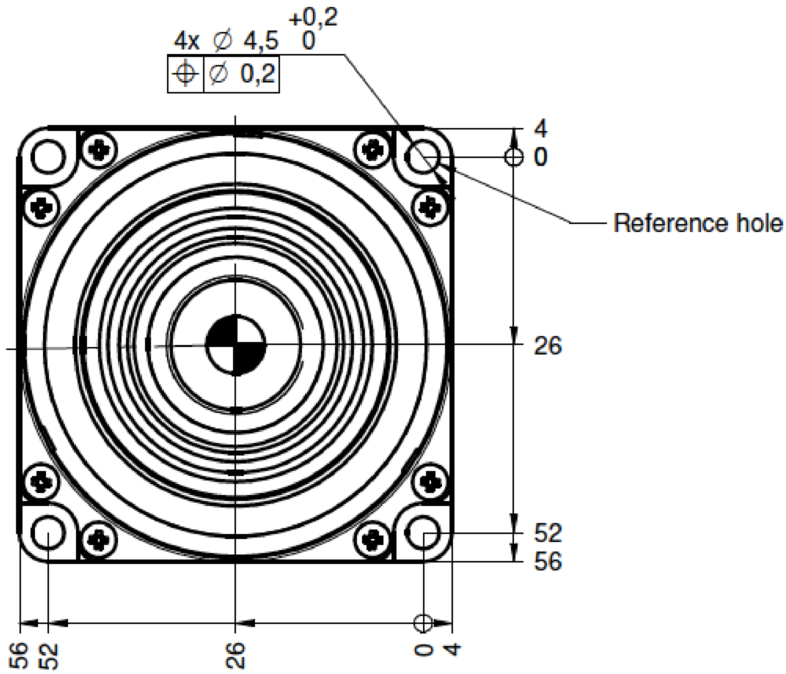
The star-tracker software is based on libraries and software concepts with several years of flight heritage. Furthermore, software can in a safe manner be uploaded to the star-tracker during operation.

Mechanical Drawings









Mass

The total weight of the STAR-T3 is 350 gram

Configuration

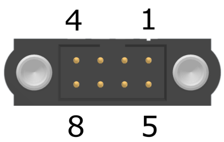
The T3 can be ordered with either CAN interface or RS-422. In both cases, the PPS input signal is RS-422. Both options come in a 5V or a 7-28V supply version:

Option #	CAN	RS422	PPS RS-422	Voltage
01	•		•	5V
02	•		•	7-28V
03		•	•	5V
04		•	•	7-28V

Option table 1: Select data interface and supply voltage for STAR-T3

Pin-out

The pinout of the 8 pin Harwin M80-54308 male socket is as shown below, where the socket is viewed from the wire side looking into the module:



CAN option pin-out	
Pin no.	Function
1	Supply voltage (power input)
2	CANH
3	
4	PPS IN+
5	GND (power return)
6	CANL
7	
8	PPS IN-

RS-422 option pin-out	
Pin no.	Function
1	Supply voltage (power input)
2	RS-422 IN+
3	RS-422 OUT+
4	PPS IN+
5	GND (power return)
6	RS-422 IN-
7	RS-422 OUT-
8	PPS IN-

Electrical Characteristics

Power Supply

Parameter	5V version	7-28V version
Supply voltage range	4.5-5.5V	7 - 33 V
Power consumption	2W	2W
Inrush current	TBD	TBD

CAN Interface

If the T3 is configured to have CAN, the following electrical specifications apply:

Parameter	Value
Data rate standard	1 Mbps
Common mode voltage range	-7 to 12 V
Driver output voltage:	Max 3.3 V
Input differential voltage range	-6 to 6 V
HBM ESD capability	+/- 12 kV
Crosswire protection and overvoltage protection	±36 V
Common-mode transient protection	±100 V.

RS422 Interface

If the T3 is configured to have RS422, the following electrical specifications apply:

Parameter	Value
Data rate standard	921600 baud (slower other speeds available)
Nodes on bus	1
Bus HBM ESD protection	+/- 30 kV
Input voltage range any bus pin	-7 to 12 V
Differential input voltage range	-12 to 12V
Output voltage into 100R	Min. 2.0V
Character layer	8n1 (8 data bit, no parity, 1 stop bit)

PPS Interface

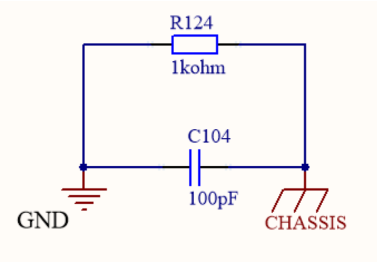
If the T3 is configured to have PPS input, the following electrical specifications apply. It is based on the same differential characteristics as the RS422 interface.

Parameter	Value
Pulse frequency	1 Hz
HBM ESD protection	+/- 30 kV

Grounding scheme

The GND pin of the connector is the common ground for all electrical interfaces and power. It is also the common ground for all electronics inside the module.

The aluminium chassis of the T3 is coupled to GND inside the module through the following circuit. The value of the resistor and the value of the capacitor can be customised when ordering the module.



Optical Ground Support Equipment

Two high fidelity optical simulators have been developed for the star-tracker series from Terma A/S including for the STAR-T3.

The Static OGSE provides easy last minute check-out capabilities with no need for loading special software, as the projected star scene inside the OGSE is of high fidelity both with respect to star positions and star magnitudes.

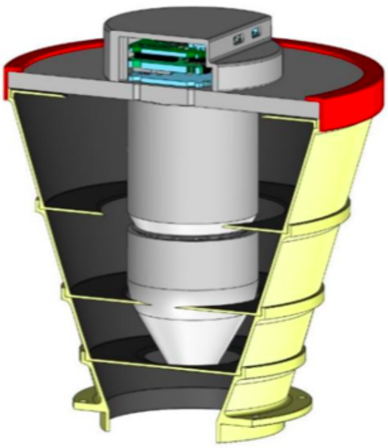


Figure - Static OGSE and Baffle mount principle

A dynamic OGSE can be delivered with a very similar design as the static OGSE for dynamic close loop testing. Terma has developed this miniaturized dynamic OGSE based on high-resolution OLED VR Display. The star scene generation software is running on a Raspberry Pi connected via Bluetooth to a PC with a user friendly interface. The dynamic OGSE can easily be adopted to fit any baffle providing repeatable and stable mounting, required for closed loop testing.

Figure - Dynamic OGSE

FSS-1-G2

1 deg accuracy Fine Sun Sensor with integrated gyro and magnetometer.

For Micro- and Nano-Satellites

Features

FINE SUN SENSOR:

- 2-axis sun direction sensor based on quad photo diode array
- 1 degree precision
- 55 degree half-cone FoV

MAGNETOMETER:

- Integrated 3-axis magnetometer
- 0.25mG per LSB resolution
- 0.4mG total RMS noise
- Magnetic field direction accuracy 1°

GYRO:

- Integrated 2-axis Gyro
- Ultralow noise: 0.004°/s/√Hz

INTERFACE:

- 5-28V unregulated power input
- Data interface: CAN bus with CSP2.0

DIMENSIONS:

- 40x20x10 mm

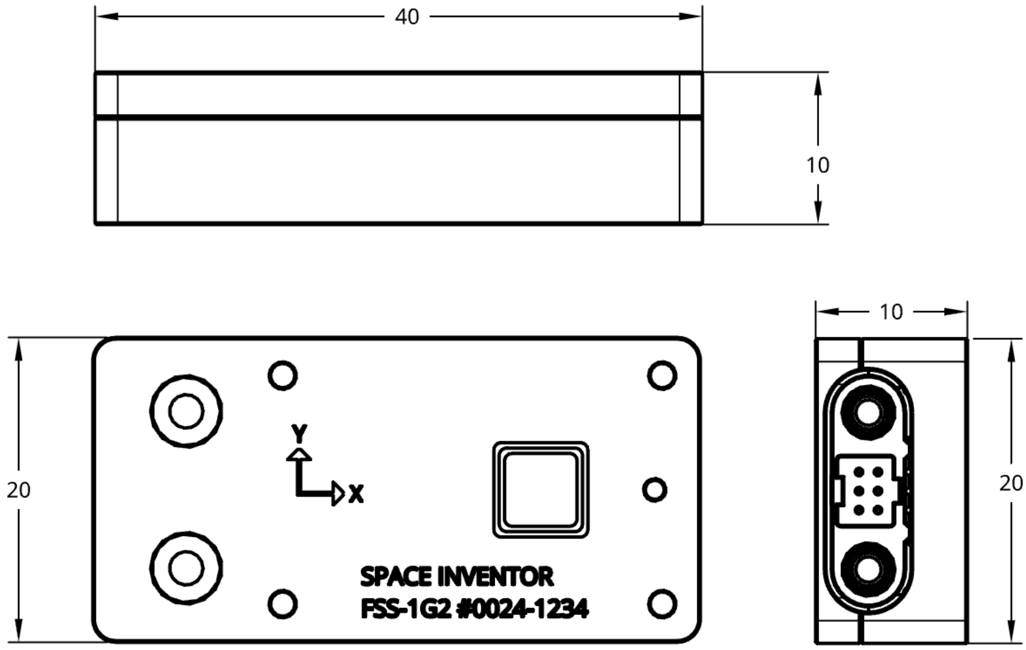
Description

Small factor 2 axis stand-alone fine sun sensor with integrated gyro and magnetometer. It has two different estimates modes; table based (from ground calibration) or polynomial fit (on-orbit or ground calibration). The sensor provides an estimate of the sun vector and multiple measurements can be combined to increase the precision of the sun vector estimate, e.g. using a Fraser-Potter fixed-interval smoother or a Kalman Filter.

Everything except the photodiodes is shielded in an aluminum casing to protect it from the harsh environment of space. The CAN interface together with Space Inventor's parameter system provides an easy to setup and user interface for the sun sensor. The sun vector along with calibration parameters, raw values and intermediate calculations are exposed by the parameter system.

FSS-1-G2 - Fine Sun-sensor with integrated gyro and magnetometer

Mechanical Drawings

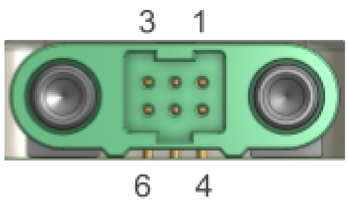


Dimensions Drawing

Pinout

The pinout of the Harwin Gecko G125-MH10605M4P male socket is as shown below.

Pin no.	Function - CAN option
1	Supply voltage (power input)
2	
3	CANH
4	GND (power return)
5	
6	CANL



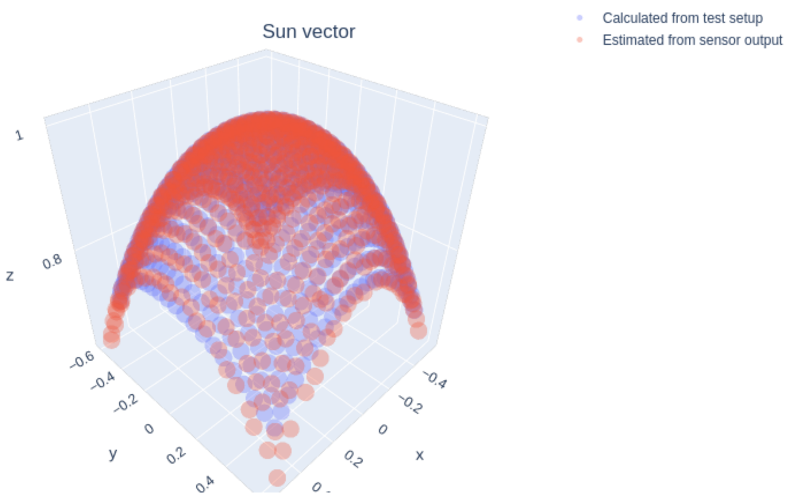
Mass

10 grams

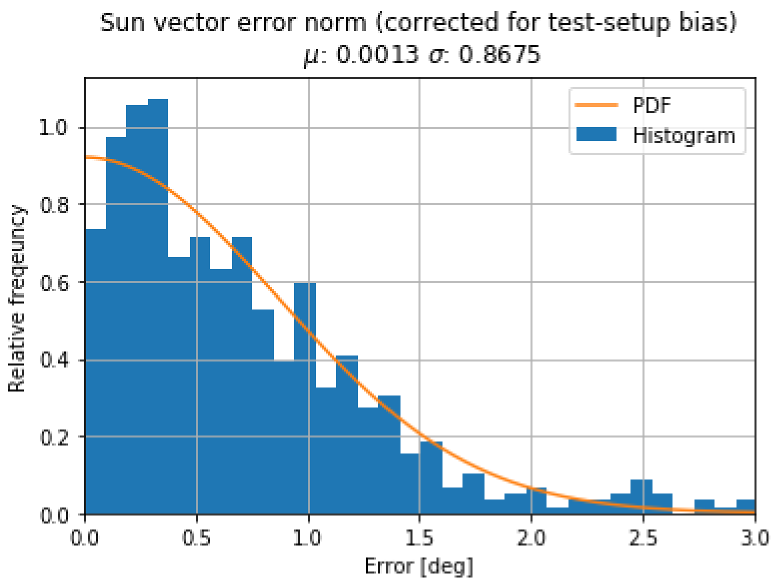
Performance and Coordinate System

The Fine Sun Sensor outputs the sun vector in the coordinate system shown on the unit - see the picture in the mechanical drawings section. The diodes A, B, C and D are mapped to the parameter system, and are named *adc_ch6*, *adc_ch7*, *adc_ch5* and *adc_ch4*.

Based on the value from the diodes, the sun spot on the diodes is calculated, and the sun vector is estimated. The below figure shows an example of the expected sun vector (calculated from the test setup), and the estimated sun vector on the FSS.



The Sun Sensor has a knowledge accuracy of 1 deg, 1σ. Each sun sensor is calibrated in our test setup to ensure performance. Below is an example of the performance of a Fine Sun Sensor post calibration. The estimated sun vector is available in the parameter *ffs_v*. Support for mapping the estimated sun vector into another frame is also provided. This can be done by setting the matrix, *fss_R*, which is used as a rotation matrix, and the rotated vector is mapped into the parameter system as *fss_Rv*.



Parameter Table

The following parameters are found on the FSS.

Name	Unit	Description
temp	1/100 deg C	Board temperature.
csp_node		CSP adresse.
csp_can_speed		CAN bus speed.
csp_rtable		CSP routing table.
csp_debug		Enable/Disable debug flags.
gndwdt	s	Watchdog, if not poked, the reaction wheel will reset and load it's backup configuration.
boot_err		Used to signal if an error occurred during the boot sequence.
boot_vnt		Number of times the system has booted
boot_cur		Current image.
boot_img0		Location of image 0.
boot_img1		Location of image 1.
time_factor		Calibration value related to oscillator uncertainties.
stdbuf_in		STDIO has been mapped to two ring buffers. One for input, and one for output
stdbuf_out		
adc_ch4		Analog input 4, connected to diode D
adc_ch5		Analog input 4, connected to diode C
adc_ch6		Analog input 4, connected to diode A
adc_ch7		Analog input 4, connected to diode B
alpha_a		Calibration value
alpha_b		Calibration value
beta_a		Calibration value
beta_b		Calibration value
fss_R		Rotation matrix from FSS frame to another frame
fss_freq	Hz	Update frequency of the FSS. Maximum of 10 Hz
fss_h	mm	Physical property of the FSS
fss_s	mm	Physical property of the FSS
fss_th		Threshold value. If the total intensity is below, discard the measurement
fss_v		Estimated sun vector as [x, y, z]
fss_Rv		Sun vector rotated by fss_R
fss_x	mm	Estimated sun spot (x-coordinate)
fss_y	mm	Estimated sun spot (y-coordinate)

OBC-P3

Versatile Onboard Computing Platform

For Micro- and Nano-Satellites

Features

- Two fully independent onboard computer modules in a shared enclosure.
- 2x ARM® Cortex-M7 Main Processing Units
  - Powerful DSP instructions
  - Double precision hardware FPU
  - Upto 300 MHz operating frequency
  - Real-time OS incl. hardware drivers, filesystem and IDE
  - Real-time clock, watch-dogs, etc.
- Memory for each on-board computer
  - 384 kB SRAM
  - 64 GB eMMC mass storage
  - 32 kB FRAM application memory
  - 2 MB on-chip flash memory
- High-reliability Harwin M80 connector for each on-board computer
  - 2 x RS422 UART
  - 2 x CAN
  - 2 x I2C
  - 7 x GPIO
  - 1 x USB
  - 3 x ADC channels
- Onboard power conditioning with 5 - 28 V input
- Reliability
  - Radiation total dose tested EEE parts
  - Vibration rated for all launch vehicles
- High-Quality Enclosure
  - Min. 1.5 mm Al shielding in all directions
  - PC-104 compatible mounting holes

Description

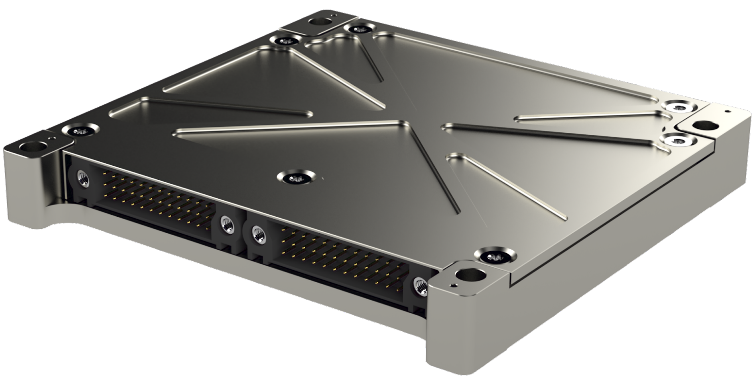
The OBC-P3 is an onboard computing platform consisting of two independent ARM Cortex-M7 modules, each with separate power supply, interfacing, and storage. The dual architecture makes the OBC-P3 a suitable choice for hot/cold redundancy solutions often desired for mission critical subsystems, such as T&C, GNC, or management of valuable payloads. Each on-board computer has a large memory storage of 64GB for user data.

The application of the OBC-P3 is further enhanced by the powerful DSP functionality provided with the Cortex-M7 architecture, which makes it possible to port heavy floating-point processing such as ADCS or RvD algorithms without severe performance penalties and error-prone quantization.

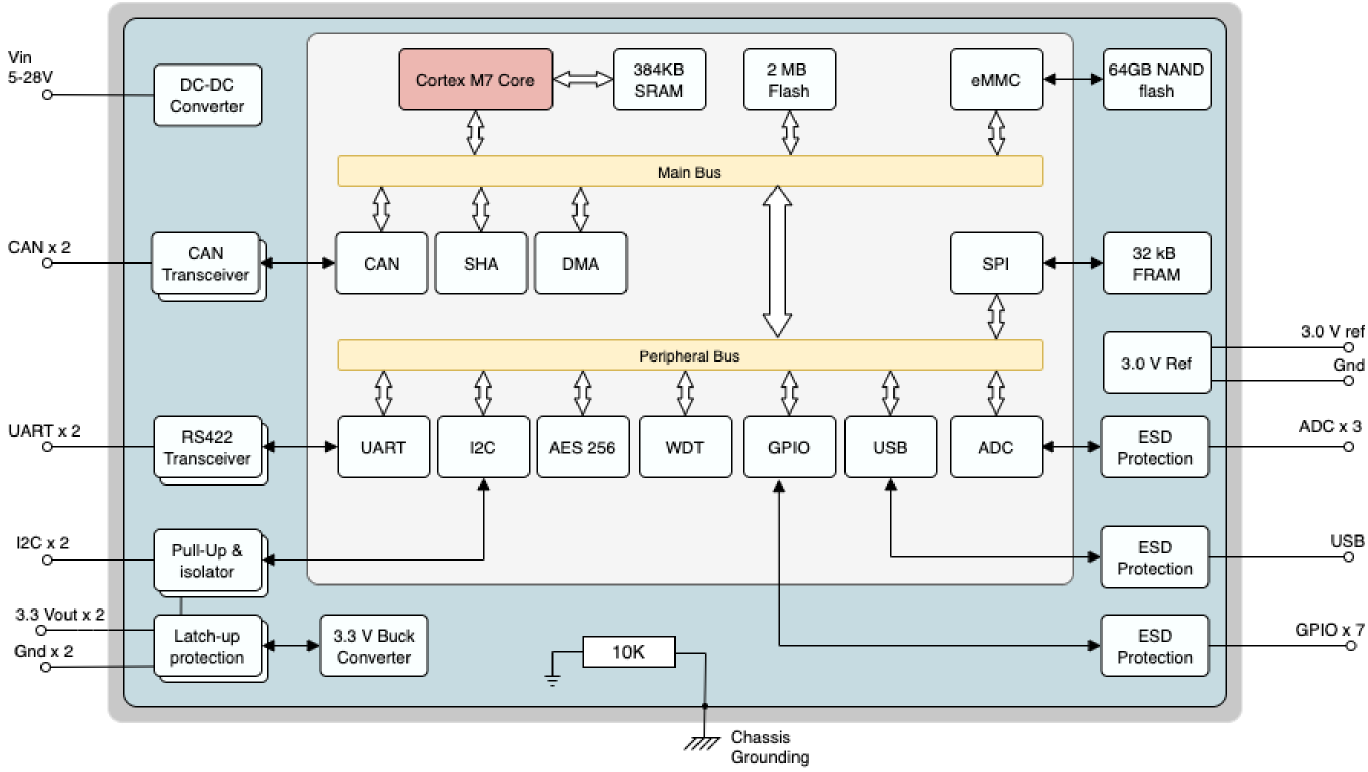
If redundancy is not required, the OBC-P3 provides an advantageous platform for combining different subsystem functionality, such as ADCS and T&C, in a compact form-factor.

By default, the OBC-P3 is configured either as an on-board data handling unit with telemetry collection functionality, or as an OS-only installation for designers to write their own application.

To mitigate integration and radiation risks, the OBC-P3 uses high-quality Harwin connectors and is protected by an 1.5 mm Al enclosure.



Functional Description



Functional Block Diagram of one of the OBC-P3 computers. Only selected features of the SAME70N21 processor are shown

Overview

Both of the OBC-P3 computers are based on the Microchip SAM E70 ARM® Cortex®-M7 microcontroller combined with external non-volatile memory for general storage and configuration, as well as separate communication transceivers and power conditioning unit.

The OBC-P3 is designed to support both point-to-point, point-to-multipoint, and multi-drop network topologies, making it suitable for centralized as well as distributed OBC architectures.

Finally, due to a wide array of hardware accelerators and functions embedded in the SAM E70, the OBC-P3 provides a very capable platform for signal processing or implementation of advanced security features.

By default, the OBC-P3 is provided with two software options: Either a bare-bone real-time OS (FreeRTOS) including hardware drivers and filesystem, or a telemetry collection application based on the base-bone software as well as a CSP stack for telemetry collection over CAN.

Hardware Description

Core: The Armv7-M core of the SAM E70 is a modified Harvard architecture with separate 64kB ECC-enabled data and instruction caches. DSP extensions provide single-cycle MAC execution and SIMD instructions. Likewise, division and single/double precision floating-point arithmetics are hardware accelerated. The maximum operating frequency is 300 MHz, although Space Inventor recommends using a lower frequency to account for timing shifts caused by ionising radiation and ageing.

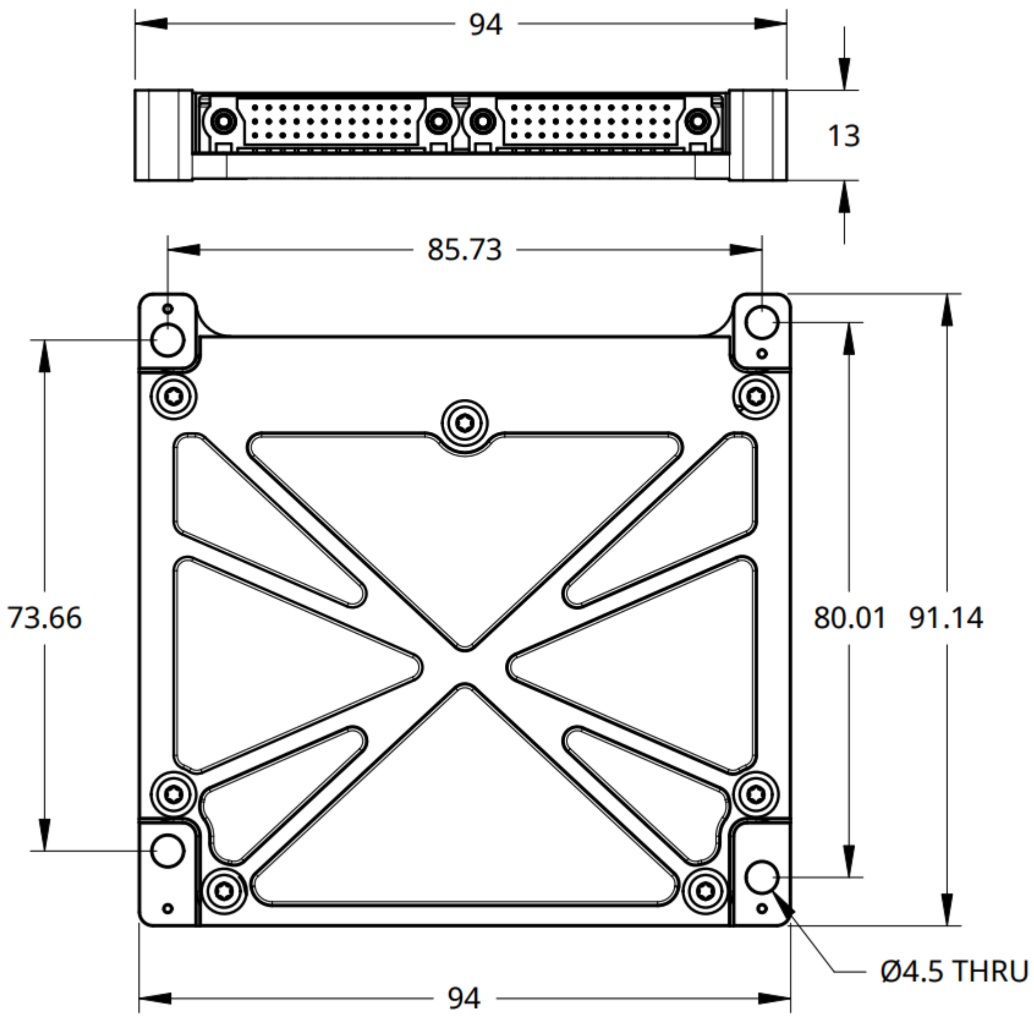
Memory: The microcontroller has 384 kB of SRAM memory tightly-coupled to the core. For permanent storage, 2MB of internal Flash memory is available, as well as 64 GB of external eMMC Flash memory. Finally, 32 kB FRAM memory is available for storage of critical information such as crypto keys and system parameters.

Interfaces and Protocols: The OBC-P3 features two CAN transceivers with embedded hardware controllers for multidrop/distributed networking. The dual CAN controllers allow the OBC-P3 to be used, for instance, in redundant CAN networks, or to serve as a hub between different CAN subnets. For point-to-point and point-to-multipoint communication, two UARTs with RS422 are available. Finally, in acknowledgement of the historical use hereof, two TWI channels are available. For new applications, Space Inventor generally discourage the use of TWI due to proven reliability issues. If required, ensure proper grounding and minimize lead lengths.

Additional interfaces are support for USB plus 3 analogue inputs connected to the internal ADC.

Cryptography: Encryption and decryption of sensitive data is possible using the embedded AES core. Likewise a true random number generator (TRNG) is available for key generation. The OBC-P3 also includes hardware accelerated SHA validation, which is practical in many security applications and protocols.

Mechanical Drawings



Dimension Drawing

Mass

The weight of the OBC-P3 is 120 gram.

Pin-out

P1 and P2 (Power and control)

Connector type PCB: M83-LML3M7N36 (male)
Pin 1 position: Top right corner, when looking into the male connector

12	11	10	9	8	7	6	5	4	3	2	1
GPIO0	GPIO1	GPIO2	GPIO3	GPIO4	GPIO5	GPIO6	SGND	V_{REF} OUT	AIN0	AIN1	AIN2
CAN0 H	CAN1 H	RS0 TX+	RS0 RX+	RS1 TX+	RS1 RX+	I2C1 VCC	I2C1 SCL	I2C0 VCC	I2C0 SCL	USB+	BAT
CAN0 L	CAN1 L	RS0 TX-	RS0 RX-	RS1 TX-	RS1 RX-	I2C1 GND	I2C1 SDA	I2C0 GND	I2C0 SDA	USB-	GND
36	35	34	33	32	31	30	29	28	27	26	25

GPIO: *These signals are connected directly (no isolation) to the MCU. They must be referenced to the DGND pin.*
Analog: *These signals are connected directly (no isolation) to the MCU. They must be referenced between VREF OUT and SGND.*
V_{REF}: *This output can supply maximum 1 mA, referenced to SGND.*
I2C: *SCL and SDA are bidirectional isolated input and outputs with a built in pull-up to I2C VCC of 10k. The signals are referenced to the isolated I2C GND. Optional: The OBC can supply power (600 mA shared) to the I2C device using the I2C VCC/GND outputs.*

Z7000-P3

Versatile Payload and Onboard Computing Platform

For Micro- and Nano-Satellites

Features

- Dual ARM® Cortex-A9 Main Processing Units
  - Double precision hardware FPU
  - Up to 667 MHz operating frequency
  - Real-time OS incl. hardware drivers
  - Real-time clock, watch-dogs, etc.
- Memory
  - 256KB on-chip memory
  - 512 MB ECC or 1GB RAM
  - Up to 64GB mass storage
- Logic
  - 125K Programmable Logic Cells
- Interface
  - Harwin M83 (36 pin) #1
    - 2 x CAN
    - 6 x LVDS pairs
    - 1 x Ethernet
    - 1 x SPI
    - 1x RS232 TTL UART
    - Power
  - Harwin M83 (36 pin)#2
    - 10 x LVDS pairs
    - 1 x RS422 UART
    - 4 x ADC channels
    - 1 x I2C
- Power consumption: <1.5 W idle. Up to 20 W depending on FPGA load.
- Power supply: 25 W, with either onboard power conditioning 6.5 - 33.6 V input, or 5 V.
- Reliability
  - Radiation total dose tested EEE parts
  - Vibration rated according to NASA GEVS covering much commercial launches available
- High-Quality Enclosure
  - Min. 1.5 mm Al shielding in all directions
  - PC-104 compatible mounting holes

Description

The Z7000-P3 is a powerful system on a chip FPGA based payload computer with a dual-core ARM Cortex-A9 MPCore™ and FPGA logic with 125K programmable cells. The Z7000-P3 is a suitable choice as a payload computer with requirements for high data-rates and processing capabilities.

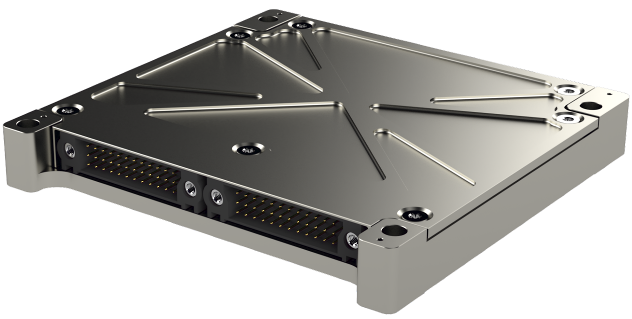
The Z7000-P3 offers a broad range of interfaces including LVDS/SpaceWire and up to 1Gb Ethernet. Furthermore traditional OBC interfaces such as CAN, UART, I2C etc are supported. For standard control interface for commanding and telemetry, Space Inventor recommends using the CAN bus.

For storage of payload generated data a mass memory system is included with a capacity up to 64GB.

The processing platform consists of a dual-core ARM Cortex-A9 processing unit which is assisted with a NEON™ media-processing engine and a single and double precision Vector Floating Point Unit (VFPU). The supported operating system is FreeRTOS but Linux can also be implemented. The control software will enable the application to be reprogrammable in a secure environment with a fallback system in case of failure. This also includes reprogramming of the logical blocks in the FPGA.

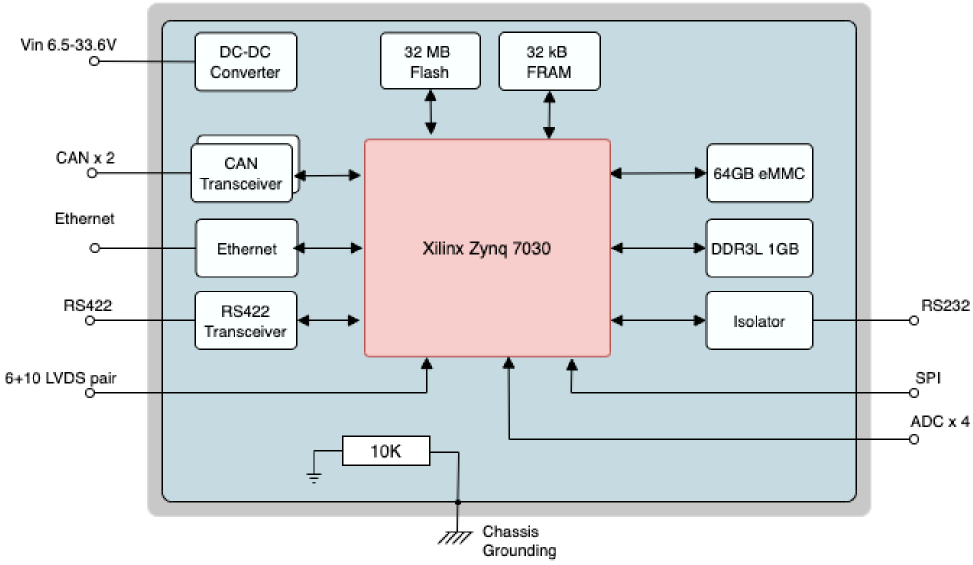
The Kintex®-7 FPGA logic has 125K programmable logic cells and contains support for look-up tables, flip flops, DSP blocks, IO blocks etc.

To mitigate integration and radiation risks, the Z7000-P3 uses high-quality Harwin connectors and is protected by an 1.5 mm Al enclosure.



Functional Description

The block diagram of the Z7000-P3 is shown below:



The core of the Z7000-P3 is the Xilinx Zynq 7030 SoC. The functional block diagram for this unit is illustrated below.

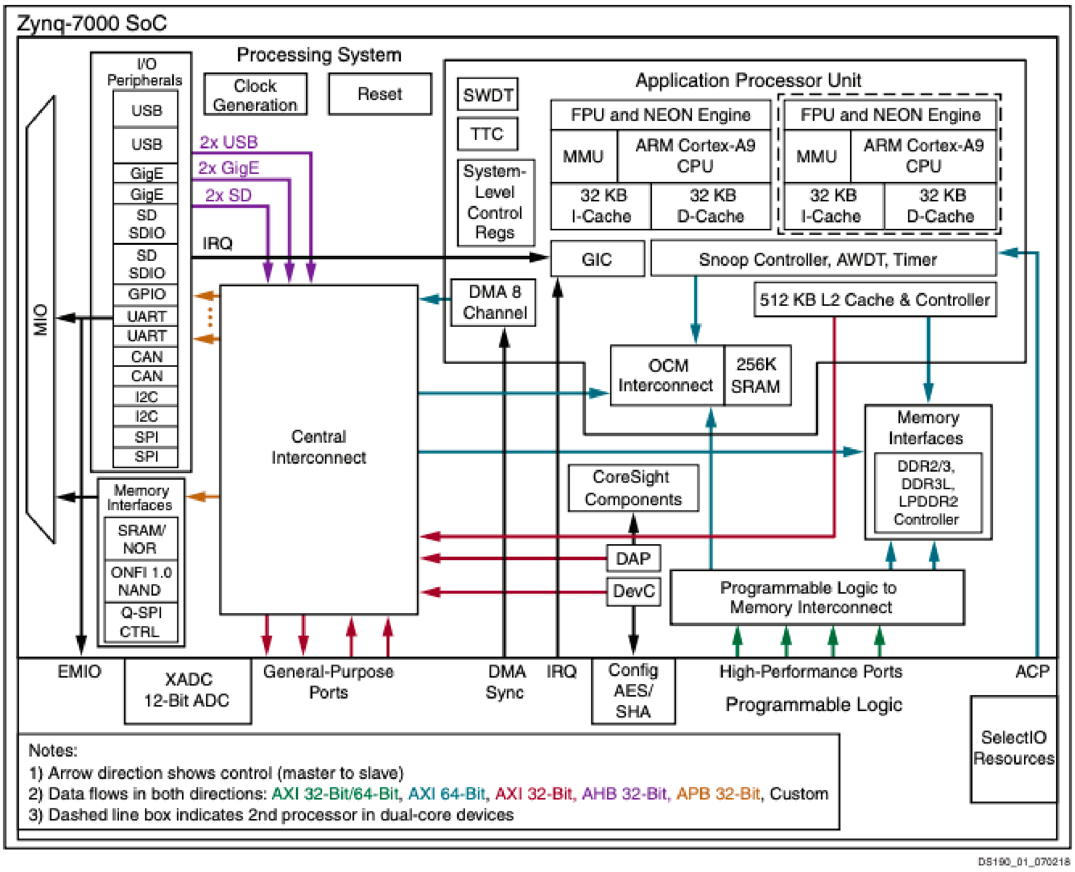
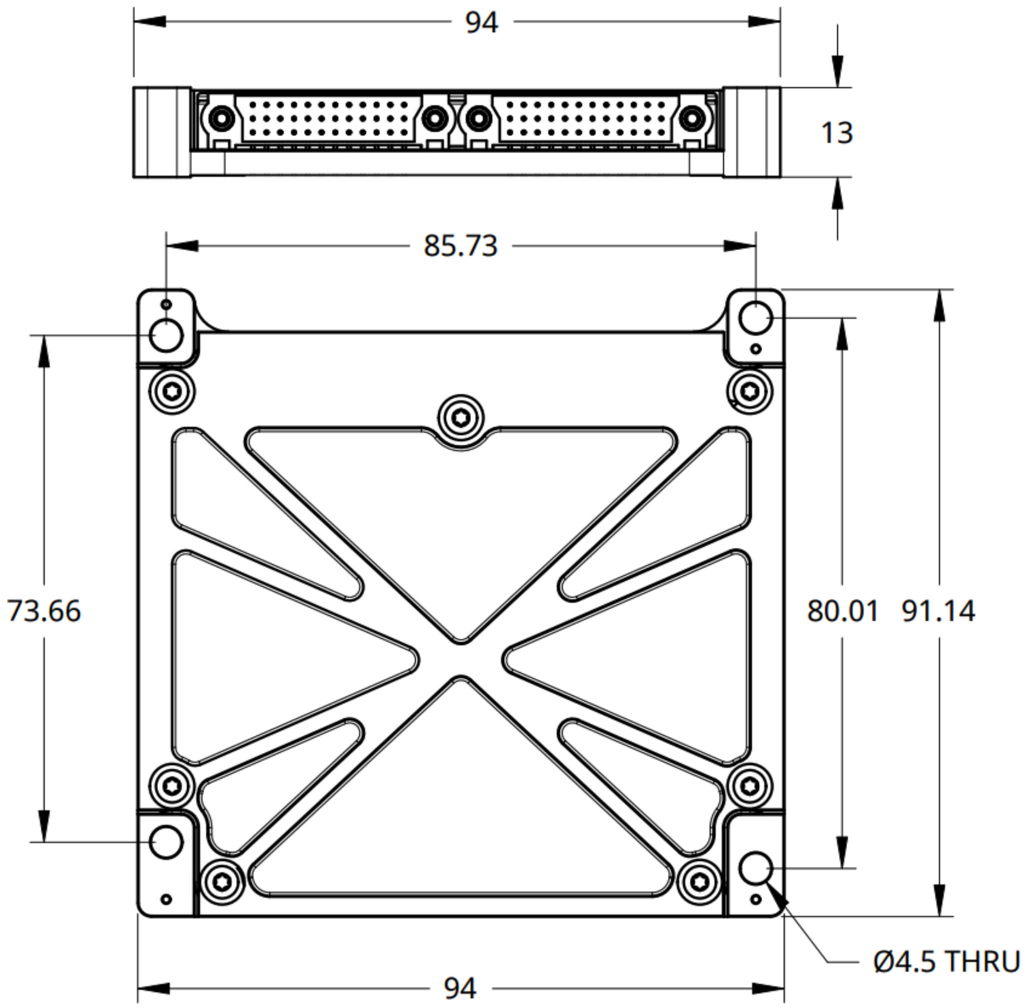


Illustration of the functional blocks of the Zynq-7000 architecture

Mechanical Drawings



Dimension Drawing

Mass

The weight of the Z7000-P3 is 155 gram.

Configuration

The Z7000-P3 comes equipped with 512MB of DDR3L ECC memory, but can optionally be fitted with 1GB.

The two power inputs in the external connectors can be configured to have separate power inputs for the Z7000-P3 and the board-to-board connector for add-on boards. In this case, Vin1 powers the Z7000-P3 and Vin2 powers the add-on board.

Pin-out

The Z7000-P3 has two Harwin M83 connectors with 36 pins.

Connector type PCB: M83-LML3M7N36 (male)
Mating connector: Harwin M83-LFC1F2N36-0000-000

Pin 1 position: Top right corner, when looking into the male connector

Connector #1

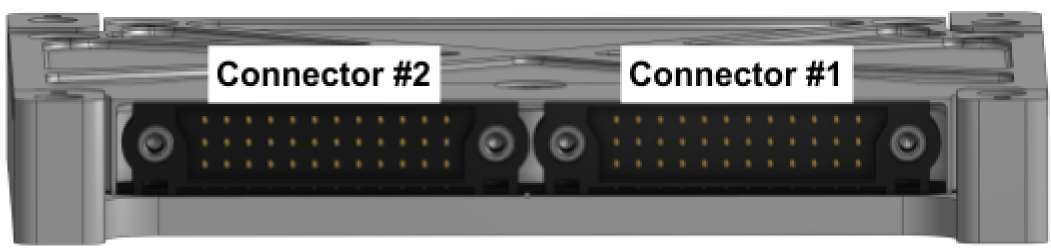
- 2 x CAN
- 6 x LVDS pairs
- 1 x Ethernet
- 1 x SPI
- 1 x RS232 TTL UART
- Power 6.5V - 33.6 V unregulated

12	11	10	9	8	7	6	5	4	3	2	1
LVDS 5-P	**LVDS 4-P**	**LVDS 3-P**	**LVDS 2-P**	**LVDS 1-P**	**LVDS 0-P**	**Vin2**	**Vin1**	**CAN H0**	**CAN L0**	**CAN H1**	**CAN L1**
LVDS 5-N	**LVDS 4-N**	**LVDS 3-N**	**LVDS 2-N**	**LVDS 1-N**	**LVDS 0-N**	**GND**	**GND**	**ETH A-P**	**ETH B-N**	**ETH C-P**	**ETH D-N**
SPI SS	**SPI CLK**	**SPI MISO**	**SPI MOSI**	**232 TX**	**232 RX**	**GND**	**GND**	**ETH A-N**	**ETH B-P**	**ETH C-N**	**ETH D-P**
36	35	34	33	32	31	30	29	28	27	26	25

Connector #2

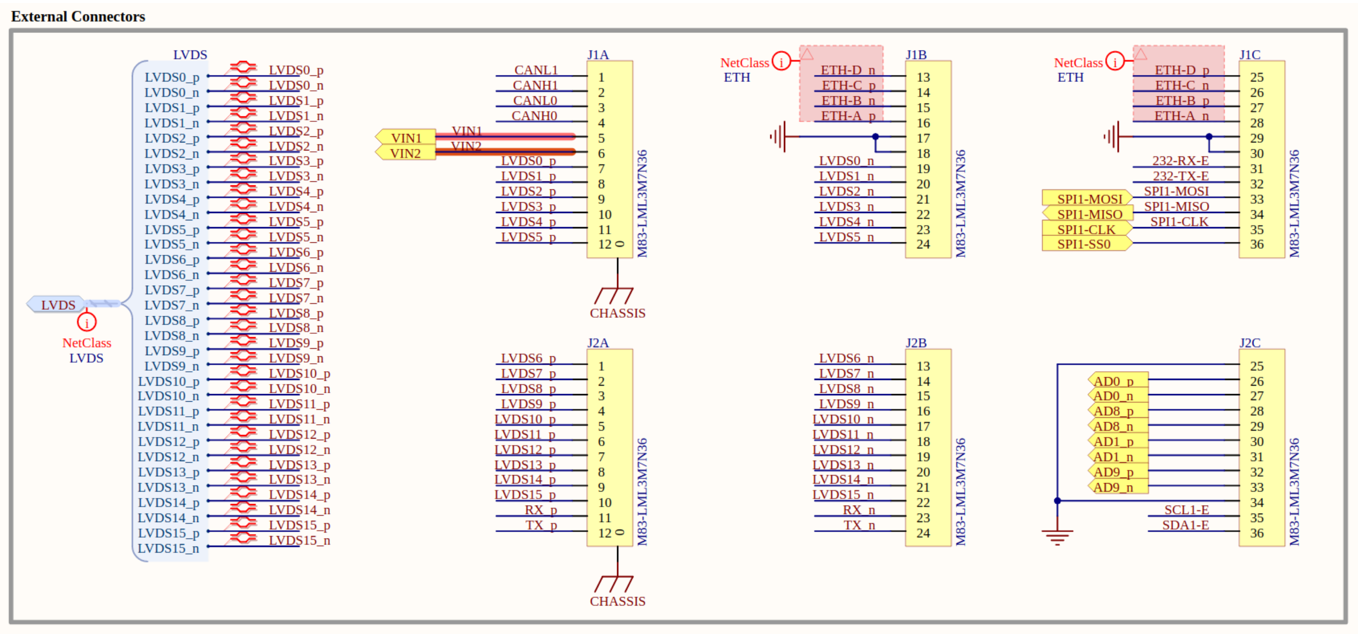
- 10 x LVDS pairs
- 1 x RS422 UART
- 4 x ADC pair (signal and reference)
- 1 x I2C

12	11	10	9	8	7	6	5	4	3	2	1
422 TX-P	**422 RX-P**	**LVDS 15-P**	**LVDS 14-P**	**LVDS 13-P**	**LVDS 12-P**	**LVDS 11-P**	**LVDS 10-P**	**LVDS 9-P**	**LVDS 8-P**	**LVDS 7-P**	**LVDS 6-P**
422 TX-N	**422 RX-N**	**LVDS 15-N**	**LVDS 14-N**	**LVDS 13-N**	**LVDS 12-N**	**LVDS 11-N**	**LVDS 10-N**	**LVDS 9-N**	**LVDS 8-N**	**LVDS 7-N**	**LVDS 6-N**
I2C SDA1	**I2C SCL1**	**GND**	**AD9-P**	**AD9-N**	**AD1-N**	**AD1-P**	**AD8-N**	**AD8-P**	**AD0-N**	**AD0-P**	**GND**
36	35	34	33	32	31	30	29	28	27	26	25

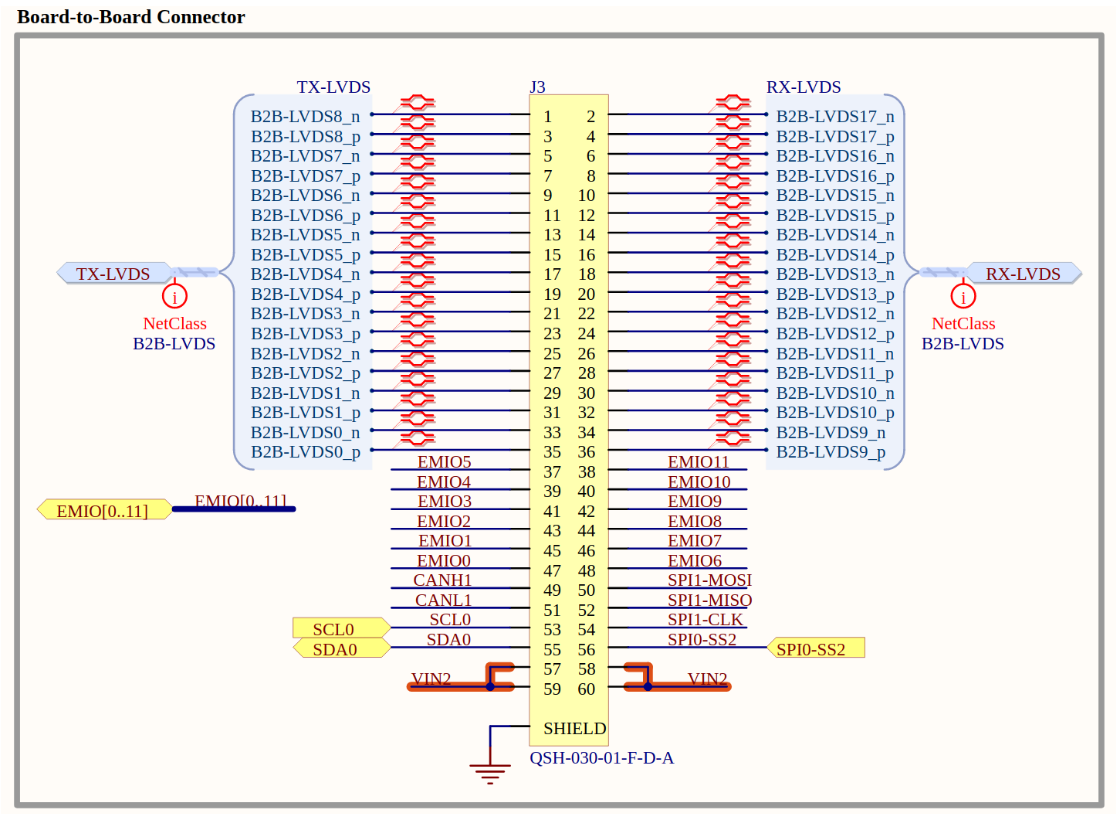


Schematics

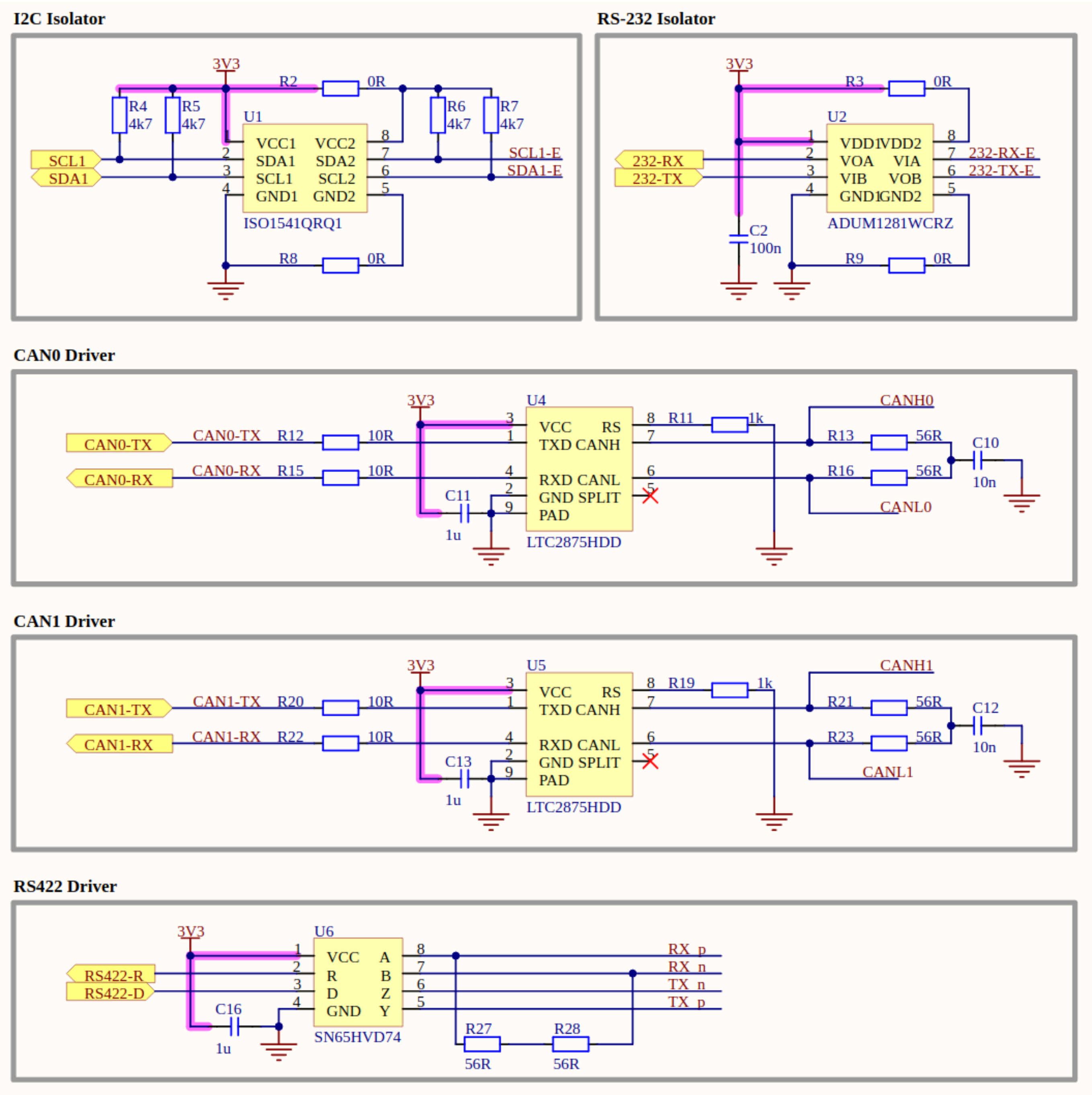
The two main headers J1 and J2 are seen in the following schematic.



The internal board to board connector, designed for addon modules are displayed in the following figure

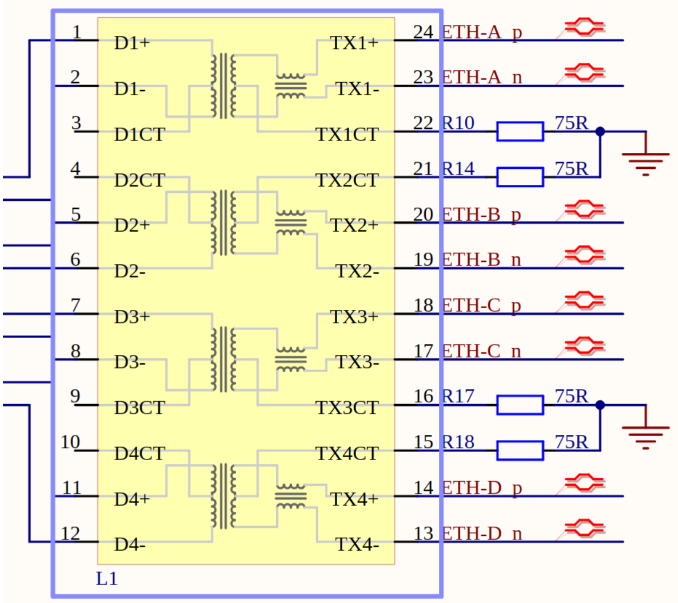


A series of isolators protect the processor and drives external busses



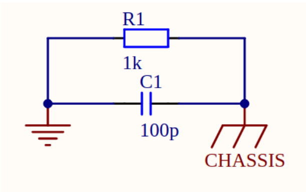
The CAN terminations and RS422 terminations, and I2C pullups are optional components.

The Ethernet port is magnetically isolated

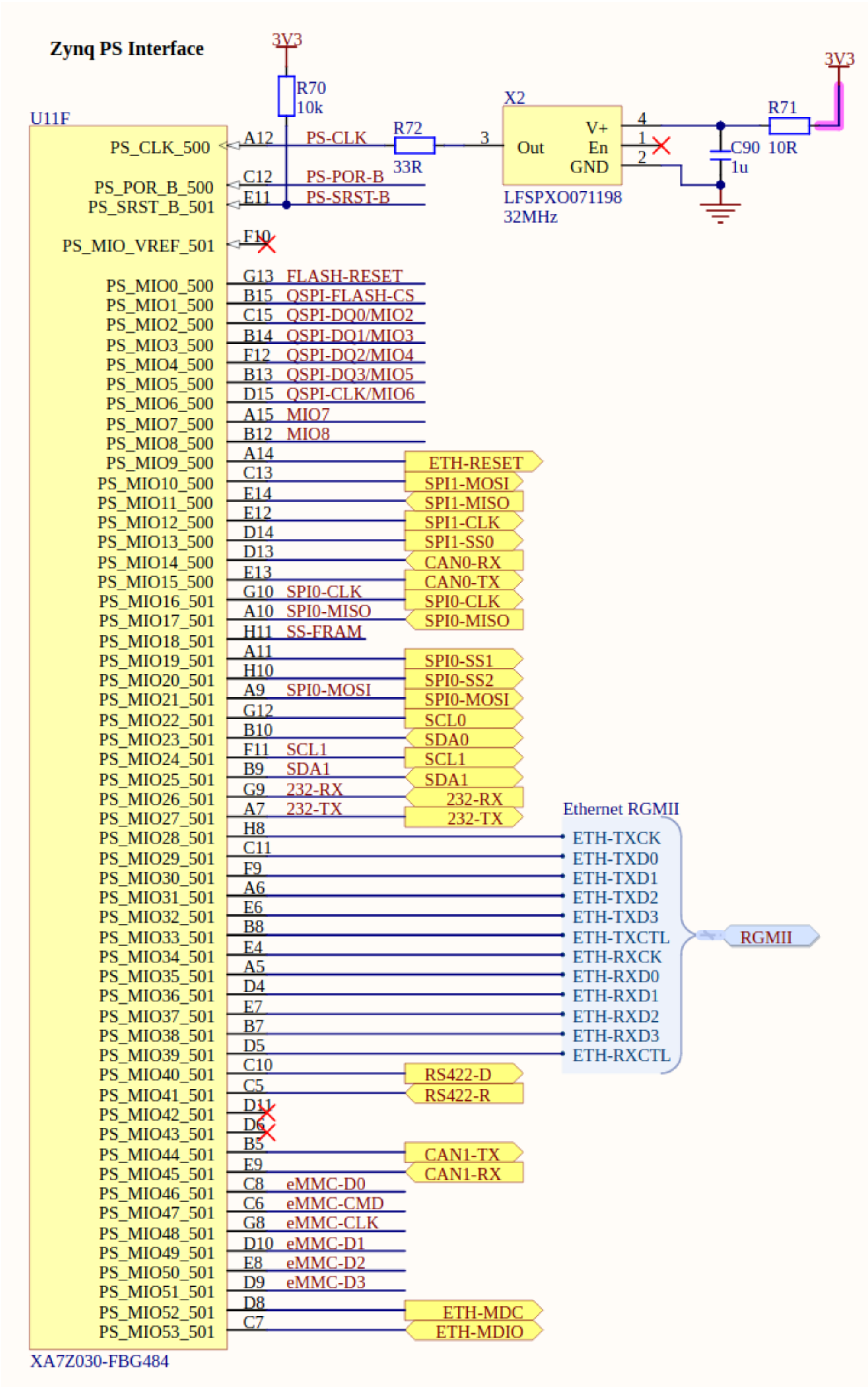


Grounding scheme

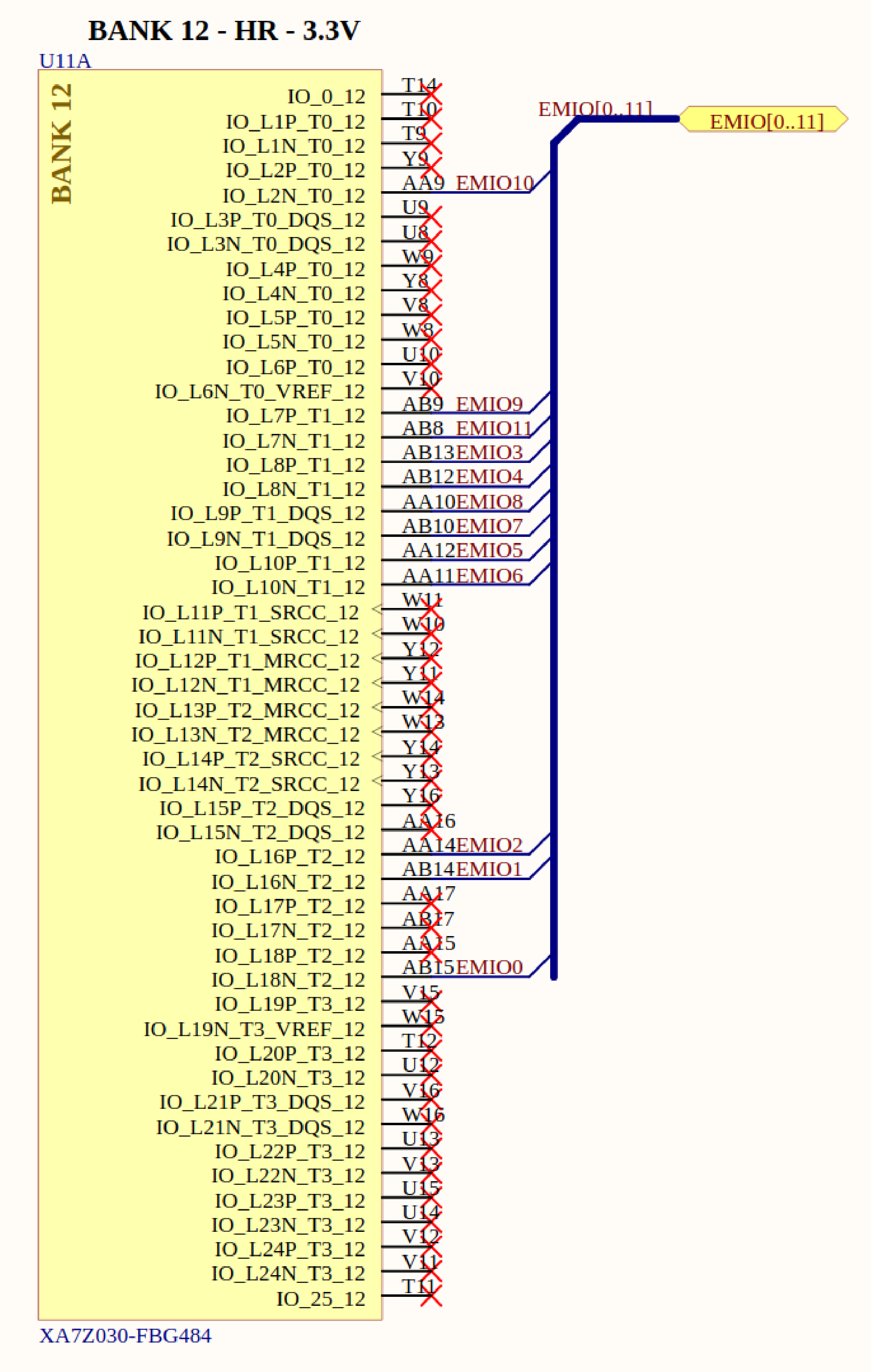
The Chassis is bonded to the PCB ground with a 1k and a 100p capacitor.



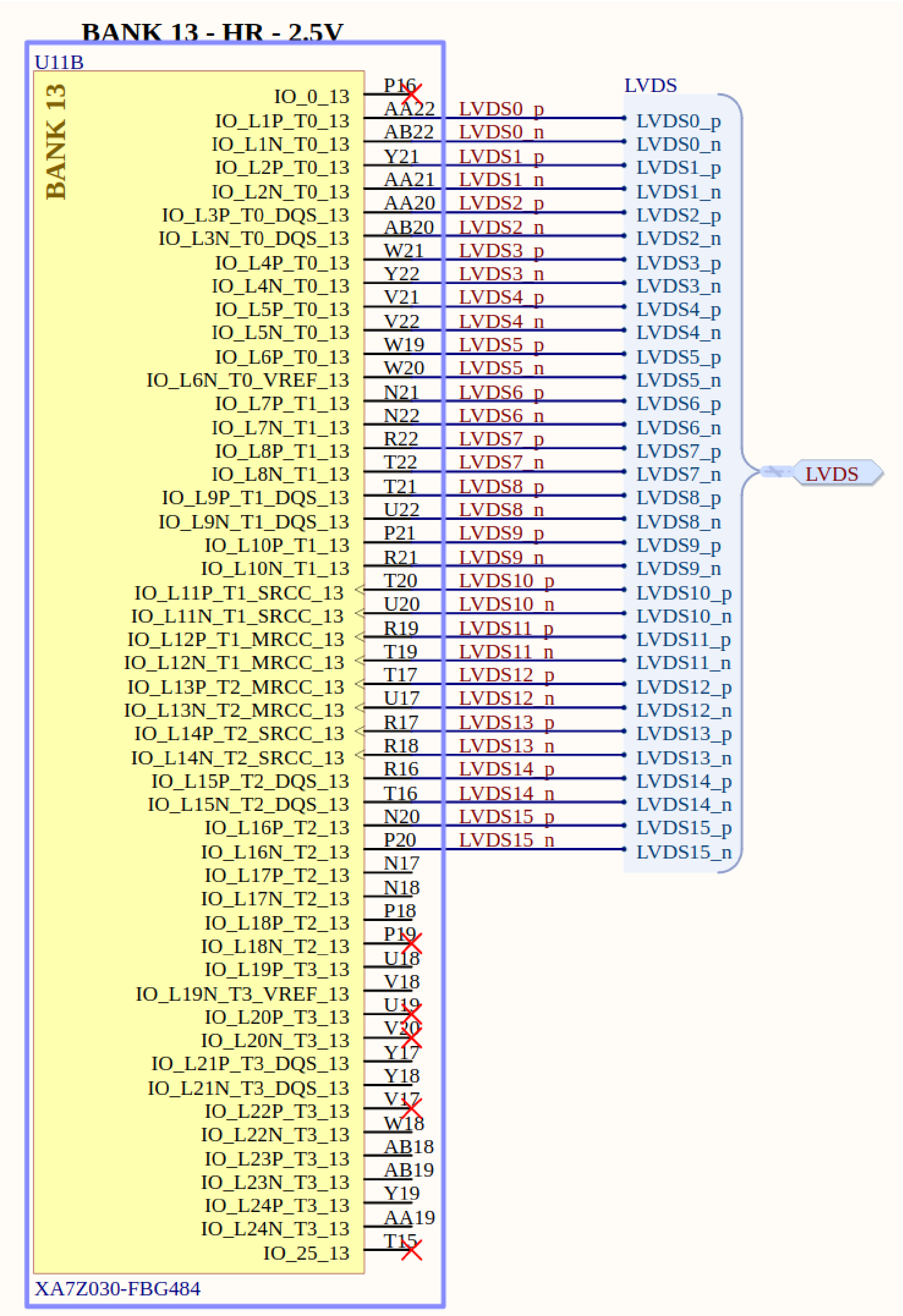
The PS Bank 500 and 501 is mapped to the peripherals like this:



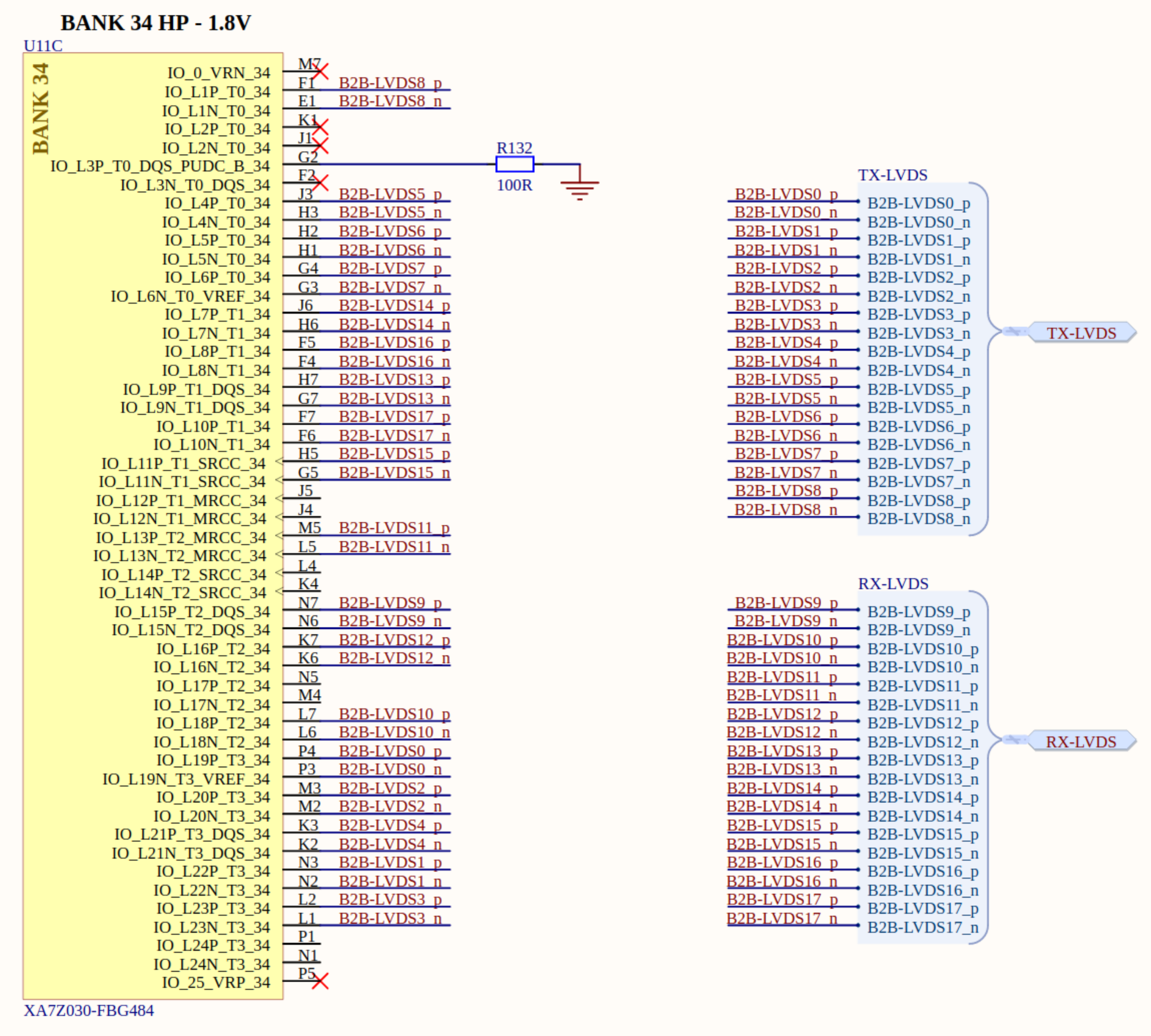
Bank 12


BANK 12 - HR - 3.3V
U11A
BANK 12
IO_0_12 T14
IO_L1P_T0_12 T10
IO_L1N_T0_12 T9
IO_L2P_T0_12 Y9
IO_L2N_T0_12 AA9 EMIO10
IO_L3P_T0_DQS_12 U9
IO_L3N_T0_DQS_12 U8
IO_L4P_T0_12 W9
IO_L4N_T0_12 Y8
IO_L5P_T0_12 V8
IO_L5N_T0_12 W8
IO_L6P_T0_12 U10
IO_L6N_T0_VREF_12 V10
IO_L7P_T1_12 AB9 EMIO9
IO_L7N_T1_12 AB8 EMIO11
IO_L8P_T1_12 AB13 EMIO3
IO_L8N_T1_12 AB12 EMIO4
IO_L9P_T1_DQS_12 AA10 EMIO8
IO_L9N_T1_DQS_12 AB10 EMIO7
IO_L10P_T1_12 AA12 EMIO5
IO_L10N_T1_12 AA11 EMIO6
IO_L11P_T1_SRCC_12 W11
IO_L11N_T1_SRCC_12 W10
IO_L12P_T1_MRCC_12 Y12
IO_L12N_T1_MRCC_12 Y11
IO_L13P_T2_MRCC_12 W14
IO_L13N_T2_MRCC_12 W13
IO_L14P_T2_SRCC_12 Y14
IO_L14N_T2_SRCC_12 Y13
IO_L15P_T2_DQS_12 Y16
IO_L15N_T2_DQS_12 AA16
IO_L16P_T2_12 AA14 EMIO2
IO_L16N_T2_12 AB14 EMIO1
IO_L17P_T2_12 AA17
IO_L17N_T2_12 AB17
IO_L18P_T2_12 AA15
IO_L18N_T2_12 AB15 EMIO0
IO_L19P_T3_12 V15
IO_L19N_T3_VREF_12 W15
IO_L20P_T3_12 T12
IO_L20N_T3_12 U12
IO_L21P_T3_DQS_12 V16
IO_L21N_T3_DQS_12 W16
IO_L22P_T3_12 U13
IO_L22N_T3_12 V13
IO_L23P_T3_12 U15
IO_L23N_T3_12 U14
IO_L24P_T3_12 V12
IO_L24N_T3_12 V11
IO_25_12 T11
EMIO[0..11]
EMIO[0..11]
XA7Z030-FBG484

Bank 13


BANK 13 - HR - 2.5V
U11B
BANK 13
LVDS
IO_0_13 P16
IO_L1P_T0_13 AA22 LVDS0_p LVDS0_p
IO_L1N_T0_13 AB22 LVDS0_n LVDS0_n
IO_L2P_T0_13 Y21 LVDS1_p LVDS1_p
IO_L2N_T0_13 AA21 LVDS1_n LVDS1_n
IO_L3P_T0_DQS_13 AA20 LVDS2_p LVDS2_p
IO_L3N_T0_DQS_13 AB20 LVDS2_n LVDS2_n
IO_L4P_T0_13 W21 LVDS3_p LVDS3_p
IO_L4N_T0_13 Y22 LVDS3_n LVDS3_n
IO_L5P_T0_13 V21 LVDS4_p LVDS4_p
IO_L5N_T0_13 V22 LVDS4_n LVDS4_n
IO_L6P_T0_13 W19 LVDS5_p LVDS5_p
IO_L6N_T0_VREF_13 W20 LVDS5_n LVDS5_n
IO_L7P_T1_13 N21 LVDS6_p LVDS6_p
IO_L7N_T1_13 N22 LVDS6_n LVDS6_n
IO_L8P_T1_13 R22 LVDS7_p LVDS7_p
IO_L8N_T1_13 T22 LVDS7_n LVDS7_n
IO_L9P_T1_DQS_13 T21 LVDS8_p LVDS8_p
IO_L9N_T1_DQS_13 U22 LVDS8_n LVDS8_n
IO_L10P_T1_13 P21 LVDS9_p LVDS9_p
IO_L10N_T1_13 R21 LVDS9_n LVDS9_n
IO_L11P_T1_SRCC_13 T20 LVDS10_p LVDS10_p
IO_L11N_T1_SRCC_13 U20 LVDS10_n LVDS10_n
IO_L12P_T1_MRCC_13 R19 LVDS11_p LVDS11_p
IO_L12N_T1_MRCC_13 T19 LVDS11_n LVDS11_n
IO_L13P_T2_MRCC_13 T17 LVDS12_p LVDS12_p
IO_L13N_T2_MRCC_13 U17 LVDS12_n LVDS12_n
IO_L14P_T2_SRCC_13 R17 LVDS13_p LVDS13_p
IO_L14N_T2_SRCC_13 R18 LVDS13_n LVDS13_n
IO_L15P_T2_DQS_13 R16 LVDS14_p LVDS14_p
IO_L15N_T2_DQS_13 T16 LVDS14_n LVDS14_n
IO_L16P_T2_13 N20 LVDS15_p LVDS15_p
IO_L16N_T2_13 P20 LVDS15_n LVDS15_n
IO_L17P_T2_13 N17
IO_L17N_T2_13 N18
IO_L18P_T2_13 P18
IO_L18N_T2_13 P19
IO_L19P_T3_13 U18
IO_L19N_T3_VREF_13 V18
IO_L20P_T3_13 U19
IO_L20N_T3_13 V20
IO_L21P_T3_DQS_13 Y17
IO_L21N_T3_DQS_13 Y18
IO_L22P_T3_13 V17
IO_L22N_T3_13 W18
IO_L23P_T3_13 AB18
IO_L23N_T3_13 AB19
IO_L24P_T3_13 Y19
IO_L24N_T3_13 AA19
IO_25_13 T15
LVDS
XA7Z030-FBG484

Bank 34


BANK 34 HP - 1.8V
U11C
BANK 34
XA7Z030-FBG484
R132
100R
TX-LVDS
RX-LVDS

Analog input bank