CUBESPACE

CubeADCS Generation 2

Interface Control Document

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1.01	C. Leibbrandt	17/01/2023	Correcting minor errors

Reference Documents

The following documents are referenced in this document.

[1] CS-DEV.PD.CA-01 CubeADCS Standard Product Description Ver.1.00 or more recent.

[2] CS-DEV.GD.TPL-02 ADCS HW config and options Ver.1.00 or more recent

[3] CS-DEV.GD.TPL-01 ADCS Review and Recommendations Ver.1.00 or more recent

[4] CS-DEV.UM.CA-01 CubeADCS Standard User Manual Ver.1.04 or more recent

[5] CS-DEV.ETP.CA-01 Generic Environmental Test Plan Ver.1.03 or more recent

List of Acronyms/Abbreviations

ACP	ADCS Control Program
ADCS	Attitude Determination and Control System
CAN	Controller Area Network
COTS	Commercial Off The Shelf
CSS	Coarse Sun Sensor
CVCM	Collected Volatile Condensable Materials
DUT	Device Under Test
EDAC	Error Detection and Correction
EHS	Earth Horizon Sensor
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FDIR	Fault Detection, Isolation, and Recovery
FM	Flight Model
FSS	Fine Sun Sensor
GID	Global Identification
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GYR	Gyroscope
I2C	Inter-Integrated Circuit
ID	Identification
LTDN	Local Time of Descending Node
LEO	Low Earth Orbit
MCU	Microcontroller Unit
MEMS	Microelectromechanical System
MTM	Magnetometer
MTQ	Magnetorquer
NDA	Non-Disclosure Agreement
OBC	On-board Computer
PCB	Printed Circuit Board
RTC	Real-Time Clock

RWA	Reaction Wheel Assembly
RW	Reaction Wheel
SBC	Satellite Body Coordinate
SOFIA	Software Framework for Integrated ADCS
SPI	Serial Peripheral Interface
SRAM	Static Random-Access Memory
SSP	Sub-Satellite Point
STR	Star Tracker
TC	Telecommand
TCTLM	Telecommand and Telemetry (protocol)
TID	Total Ionizing Dose
TLM	Telemetry
TML	Total Mass Loss
UART	Universal Asynchronous Receiver/Transmitter

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1 Introduction

This document is written with the assumption that the reader is familiar with the concepts and details as described in [1].

The purpose of this document is to provide Interface Control Document (ICD) related information about the standard CubeADCS solution which is described in [1]. Some parts of this ICD may thus not be relevant to a particular CubeADCS solution and / or a particular standard CubeADCS solution might not include all actuator and sensors described in this document.

> Note: Realising that client requirements and -satellite missions may not necessarily be fulfilled by CubeSpace's standard CubeADCS offering as-is (as documented in the above-mentioned standard document or in this standard CubeADCS ICD), custom orders are also catered for. From a documentation point of view, for such custom order situations, CubeSpace provides an additional "Client specific CubeADCS Addendum" document. This addendum document addresses all customization for that client.

This version of ICD applies to the CubeADCS hardware versions as stated in Table 1 below.

Table 1: Document Applicability

CubeProduct	Version	Notes
CubeDoor PC104	M0E1.0	
CubeComputer	M0E5.2	
CubeConnect	M0E4.0	
CubeTorquer	M2.0E1.1	All sizes
CubeWheel	M2.0E2.3	All sizes
CubeMag Deployable	M2.0E4.2	
CubeMag Compact	M2.0E4.3	
CubeSense Sun	M2.0E4.5	
CubeSense Earth	M2.0E1.3	
CubeStar	M2.0E5.3	
CubeNode	M2.0E1.3	

2 Electrical Interface

This section describes the electrical interfaces of the standard CubeADCS. This includes:

1. CubeDoor interfaces,
2. CubeConnect interfaces,
3. Communication interfaces
4. Power interfaces and expected power levels, and
5. Harness details

2.1 CubeDoor interface details

The CubeADCS Core contains the CubeDoor which essentially provides the interface bus between the OBC and the CubeADCS itself. It represents the interface to the satellite / OBC "external" to the CubeADCS solution. For the standard CubeADCS Core offering, the CubeDoor is implemented as / with PC104 headers. (The PC104 headers (CubeDoor) are shown by means of the red arrow in Figure 1.)

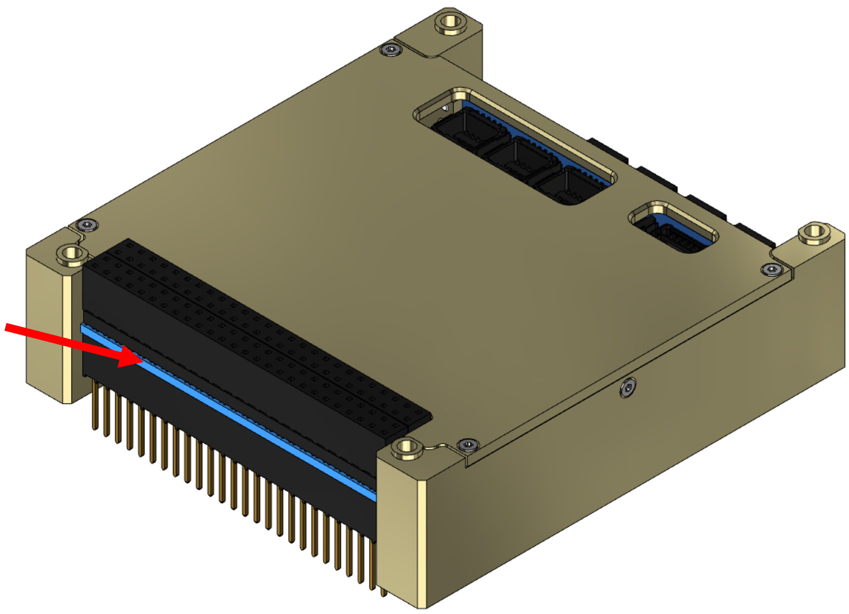

Figure 1: CubeADCS Core with CubeDoor indicated

Two sets of headers are used to allow devices to mate from the bottom and top to the CubeADCS core. The top PC104 header is the Samtec ESQ-126-13-G-D and the bottom PC104 connector is the Samtec SSQ-126-03-G-D. Table 2 shows the pin-out of the PC104 interface to CubeADCS.

Table 2: PC104 pin diagram

H2	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51
H1	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51

PC104 interface pins					
Hdr	**Pin**	**Name**	**Description**	**Range [V]**	**Configuration**
Communication					
H1	1	CAN2L	CubeComputer CAN bus low	-5 to 5	*option*
H1	3	CAN2H	CubeComputer CAN bus high		*option*
H1	2	CAN1L	Nodes CAN bus low	-5 to 5	*option*
H1	4	CAN1H	Nodes CAN bus high		*option*
H1	41	I2C_SDA_SYS	System I2C data	0 to 5.0	*option*
H1	43	I2C_SCL_SYS	System I2C clock	0 to 5.0	*option*
H1	17, 18, 19, 20	UART_1_TX	System UART TX (CubeComputer input)	0 to 5.0	*option*
H2	21, 22	UART_1_RX	System UART RX (CubeComputer output)		
H1	33, 35, 39, 40	UART_2_TX	GNSS UART TX (CubeComputer input)	0 to 5.0	*option*
		UART_2_RX	GNSS UART RX (CubeComputer output)		
H1	9, 11, 13, 15	RS485 / RS422	RS422 TX_P (CubeComputer input)	-5 to 5	*option*
			RS422 TX_N (CubeComputer input)		
			RS422 RX_P (CubeComputer output)		
			RS422 RX_N (CubeComputer output)		
H1	8, 10	PPS (Differential option)	Differential PPS_P	0 to 3.3	*option*
			Differential PPS_N		
H1	14, 16	PPS (CMOS option)	PPS (single-ended)	0 to 5.0	*option*
H2	19, 20	BOOT	Usable Low-level bootloader pins	0 to 5.0 Vlow: < 0.5V Vhi: > 2.6V	*option*
H2	17, 18	ENABLE	Usable pins for ADCS Enable	0 to 18 Vlow: < 0.95V Vhi: > 1.05V	*option*
Power					
H2	29, 30, 32	GND	Ground connection for all modules	0	Always connected
H2	45, 46	V_Bat	Battery voltage bus input	8 to 18	Always connected
H2	25, 26	5V_Main	Main 5 V supply input	5 to 5.25	*option*
H1	47, 49, 51	5V_S	Switched 5 V supply input	5 to 5.25	*option*
H2	27, 28	3V3_Main	Main 3.3 V supply input	3.2 to 3.4	*option*
H1	48, 50, 52	3V3_S	Switched 3.3 V supply input	3.2 to 3.4	*option*
H2	42	Vbackup	Sleep Mode Backup voltage supply input	3.2 to 18	*option*

2.1.1 Custom CubeDoor Design

The external connector interface can be customised[1] based on customer needs if the described standard option will not suffice. The type of connector, the pin-out of the connector, and even the shape of the interface PCB can be customised to fit any satellite bus. Contact CubeSpace for more information. With the custom Interface a user specific addendum document will be provided which will expand on this document to capture the details of such a custom design.

2.2 CubeConnect interface details

CubeConnect is part of the CubeADCS core and serves as the interface PCB to connect the various sensors and actuators. The CubeConnect PCB is shown in Figure 2 and Figure 3. The CubeConnect PCB can be seen on the right-hand side / at the back of the CubeADCS Core in Figure 1 and is clearly shown in Figure 5.

[1] Terms and conditions apply. Please contact CubeSpace for more information.

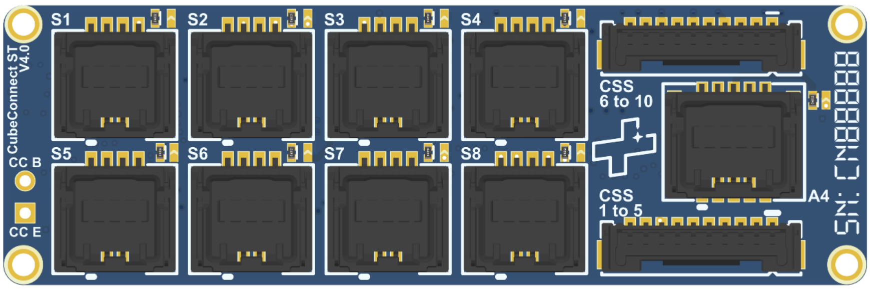

Figure 2: CubeConnect PCB - Top

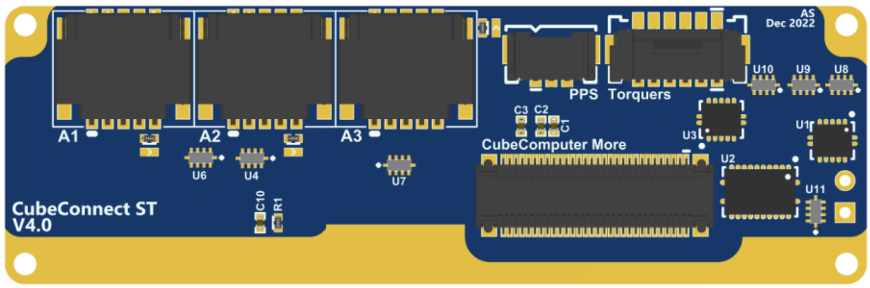

Figure 3: CubeConnect PCB - Bottom

Externally available connections include 8 sensor headers, a single actuator header for a CubeWheel, and 2 headers for coarse sun sensor photodiodes, each capable of interfacing with 5 photodiodes (Coarse Sun Sensors) for a total of 10. The sensor headers on CubeConnect are identical (excluding Course Sun Sensors), sensor harnesses can therefore be connected to any sensor header based on customer needs, and similarly the actuator headers are also identical. An example of a standard sensor configuration is shown in Figure 4.

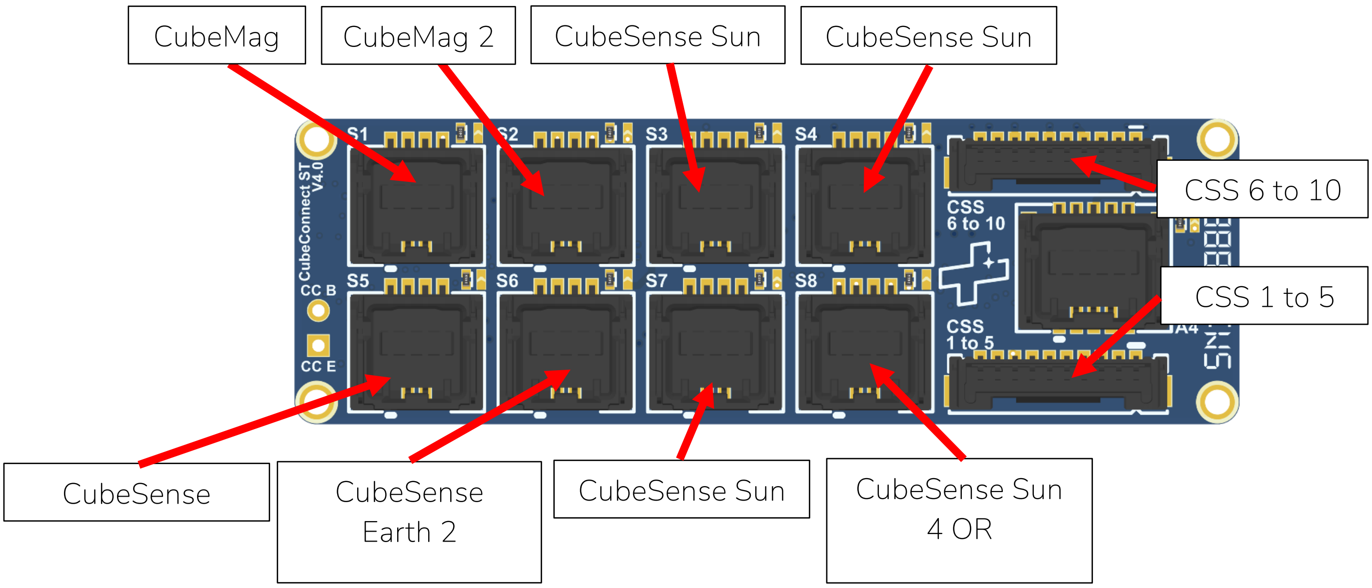

Figure 4: CubeADCS Core CubeConnect External Headers

CubeConnect also contains additional actuator headers that are located internally to the CubeADCS Core, as shown in Figure 5, that are used to connect CubeWheels and CubeTorquers. For the CubeADCS Core Stack for use in 3U satellites (see [1]), these headers are located internally to the CubeADCS Core Stack and will therefore not be visible. For the CubeADCS Core for 6U satellites, these headers are accessible to allow the actuators to be mounted externally from the CubeADCS Core. Figure 5 shows the configuration where all actuators are mounted externally, i.e., somewhere in the satellite but not part of the CubeADCS Core Stack.

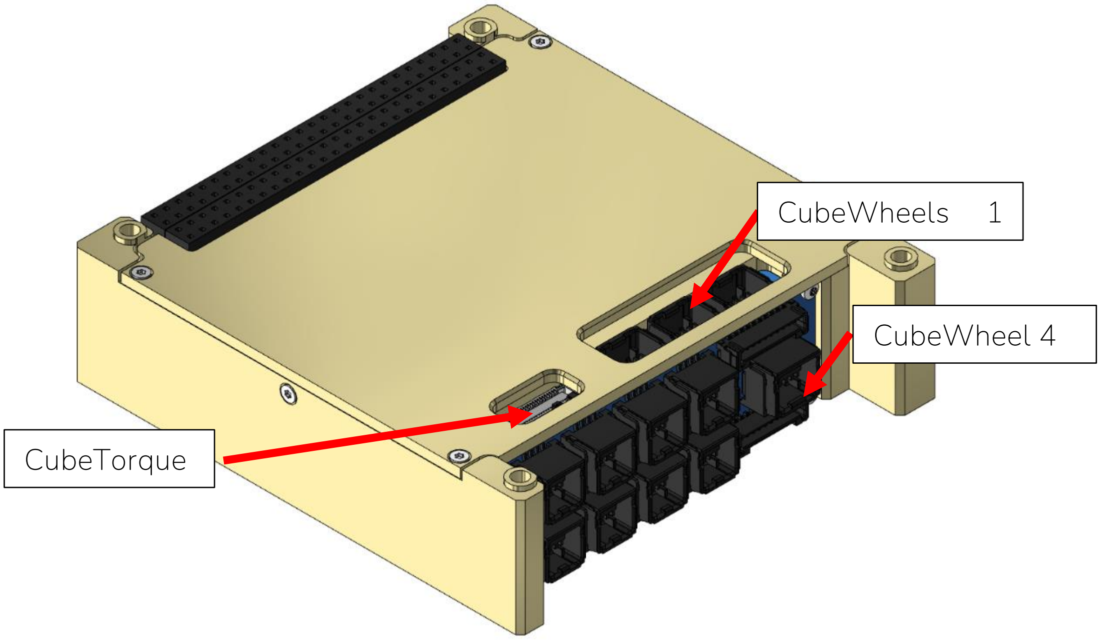

Figure 5: CubeADCS Core: CubeConnect Actuator Headers available to the outside of housing

The sensor- and actuator headers mentioned in this section are described in further detail in the following sub-sections.

2.2.1 Magnetorquer Header

The CubeConnect supports the connection of three CubeTorquers. The CubeTorquers are all connected to a single wire harness which connects to a single header on CubeConnect. This header is located on the bottom of CubeConnect, as shown in Figure 6. The header details are provided in Table 3.

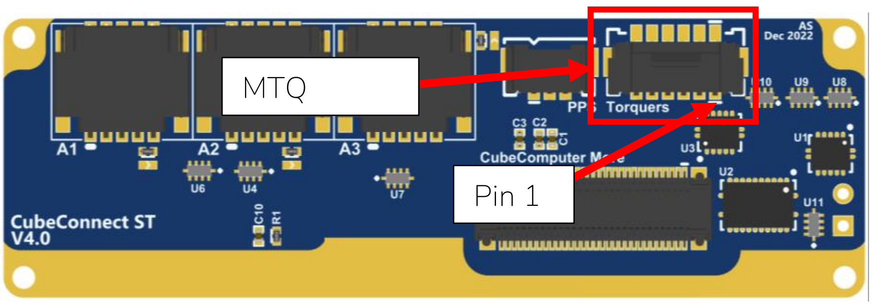

Figure 6: CubeConnect PCB - Magnetorquer Header

Table 3: Magnetorquer header specification

MAGNETORQUER HEADER DETAILS	
Header Type:	Molex Micro-lock plus, single row 5055680671 or 5055670671
Number of pins	6
Number of Headers:	1

MAGNETORQUER HEADER DETAILS	
Mating Housing	[Molex Micro-Lock plus Receptacle Crimp Housing 5055650601](#)
Housing Terminal	[Molex Micro-Lock Female crimp Terminal, Gold , 26-30 AWG, 5054311100](#)

CUBECONNECT MAGNETORQUER HEADER PIN DEFINITIONS				
Pin #	Pin Name	Pin Description	IO Type	Voltage range [V][2]
1	T1+	CubeTorquer 1 pin 1 (V+)	Output, PWM driven H-Bridge	GND-$5V_{regulated}$/$5V_{Supplied}$
2	T1-	CubeTorquer 1 pin 2 (V-)	Output, PWM driven H-Bridge	GND-$5V_{regulated}$/$5V_{Supplied}$
3	T2+	CubeTorquer 2 pin 1 (V+)	Output, PWM driven H-Bridge	GND-$5V_{regulated}$/$5V_{Supplied}$
4	T2-	CubeTorquer 2 pin 2 (V-)	Output, PWM driven H-Bridge	GND-$5V_{regulated}$/$5V_{Supplied}$
5	T3+	CubeTorquer 3 pin 1 (V+)	Output, PWM driven H-Bridge	GND-$5V_{regulated}$/$5V_{Supplied}$
6	T3-	CubeTorquer 3 Pin 2 (V-)	Output, PWM driven H-Bridge	GND-$5V_{regulated}$/$5V_{Supplied}$

2.2.2 *Wheel Headers*

Four CubeWheels can be connected to CubeConnect simultaneously. Three headers are located on the bottom of CubeConnect, and one is located on the top. This is indicated in Figure 7 and Figure 8 . Note that pin 2 is physically located across from pin 1 and not next to pin 1.

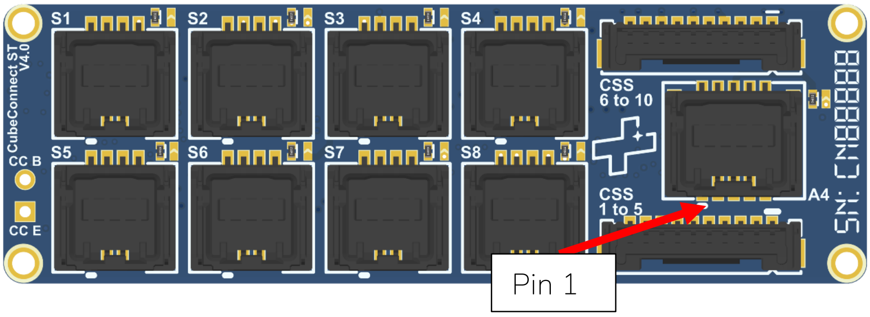

Figure 7: CubeConnect PCB - CubeWheel 4 Header

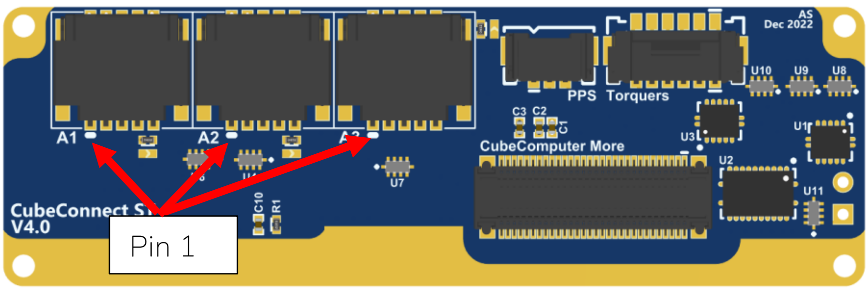

Figure 8: CubeConnect PCB - CubeWheel 1 to 3 Headers

The header details are provided in Table 4 below.

[2] The voltage range depends on the powering option specified in Section 2.4.1. $5V_{regulated}$ is defined as the output voltage of the internal 5V regulator as shown in Figure 14, and controlled to be no more than 5.25V (5.0V typical, TBC). Alternatively, $5V_{Supplied}$ is defined as the externally supplied 5V input as shown in Figure 15, required to be no more than 5.25V as shown in Table 2.

Table 4: Wheel header specifications

WHEEL HEADER DETAILS			
Header Type:	Molex Micro-Lock plus, dual row, 5054331071 or 5054481071		
Number of pins	10		
Number of Headers:	4		
Mating Housing	Molex Micro-Lock plus Receptacle Crimp Housing 5054321001		
Housing Terminal	Molex Micro-Lock Female crimp Terminal, Gold , 26-30 AWG, 5054311100		
CubeConnect Wheel header			
Pin #	Pin Description	IO Type	Voltage Range [V][3]
1	Enable	Output	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
2	GND	Power	GND
3	3V3	Power output	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
4	Boot	Output	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
5	CAN1 H	LVDS	
6	GND (optionally 5V)	Power output	5V$_{regulated}$/5V$_{Supplied}$
7	CAN1 L	LVDS	
8	V$_{Battery}$	Power output	V$_{Battery}$
9	GND	Power	GND
10	GND	Power	GND

2.2.3 Sensor Headers

CubeConnect has eight sensor headers, as shown in Figure 9, that are all located on the top of the PCB. Note that pin 2 is physically located across from pin 1 and not next to pin 1.

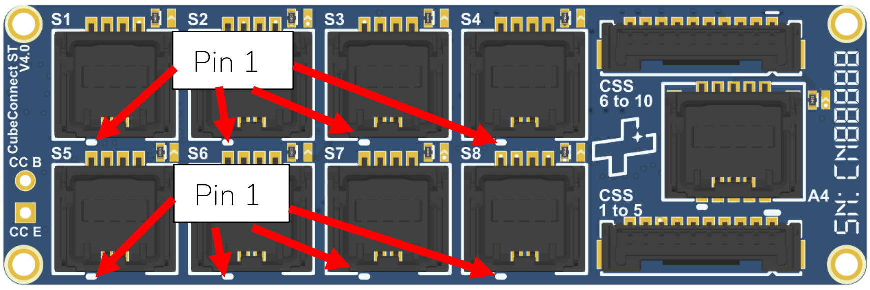

Figure 9 : CubeConnect PCB - Sensor Headers

The header details are provided in Table 5 below.

Table 5: Sensor header specifications

SENSOR HEADER DETAILS	
Header Type:	Molex Micro-Lock plus, dual row, 5054330871
Number of pins	8
Number of Headers:	8

SENSOR HEADER DETAILS			
Mating Housing	[Molex Micro-Lock plus Receptacle Crimp Housing 5054320801]		
Housing Terminal	[Molex Micro-Lock Female crimp Terminal, Gold , 26-30 AWG, 5054311100]		
CubeConnect Sensor Header			
Pin #	Pin Description	IO Type	Voltage Range [V][3]
Pin 1	Enable	Output	GND-$3.3V_{regulated}$/$3.3V_{supplied}$
Pin 2	GND	Power	GND
Pin 3	3V3	Power output	$3.3V_{regulated}$/$3.3V_{supplied}$
Pin 4	Boot	Output	GND-$3.3V_{regulated}$/$3.3V_{supplied}$
Pin 5	CAN1 H	LVDS	
Pin 6	GND (optionally 5V)	Power output	$5V_{regulated}$/$5V_{Supplied}$
Pin 7	CAN1 L	LVDS	
Pin 8	GND	Power	GND

As shown in Table 5**, Pin 6 is connected to ground as standard, however for orders that require a CubeNode, this pin will be connected to 5V.**

2.2.4 Coarse Sun Sensor Header

CubeConnect has two headers to connect the 10 Coarse Sun Sensors (photodiodes) to the CubeADCS core, as shown in Figure 10.

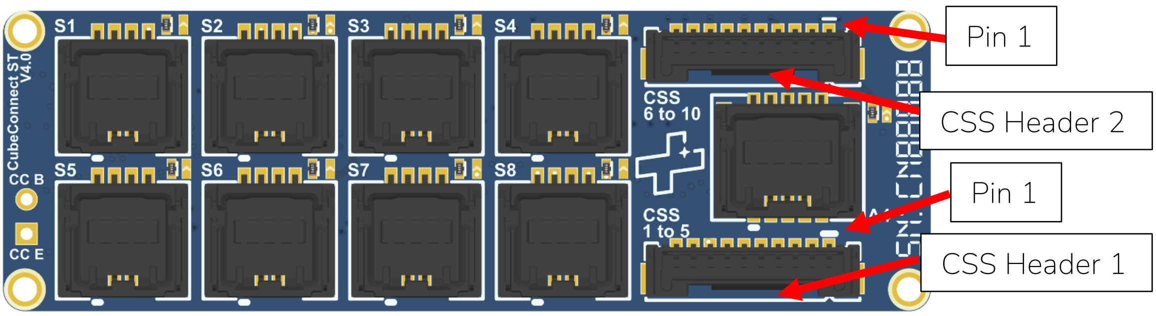

Figure 10: CubeConnect PCB - CSS Headers

Each photodiode has a Cathode and Anode and needs to be connected to the correct corresponding pin. The Anode is grounded, and the Cathode is connected to a sensing circuit. This is shown in Table 6.

Table 6: CSS Header Specifications

CSS HEADER DETAILS	
Header Type:	[Molex Micro-Lock plus, single row, 5055671071]
Number of pins	10

[3]The voltage range depends on the powering option specified in Section 2.4.1. $5V_{regulated}$/$3.3V_{regulated}$ is defined as the output voltage of the internal 5V and 3.3V regulators as shown in Figure 14, and controlled to be no more than 5.25V (5.0V typical, TBC) and 3.4V (3.3V typical, TBC) respectively. Alternatively, $5V_{Supplied}$/$3.3V_{Supplied}$ is defined as the externally supplied 5V and 3.3V input as shown in Figure 15 and Figure 16, required to be no more than 5.25V and 3.4V respectively as shown in Table 2.

CSS HEADER DETAILS					
Number of Headers:			2		
Mating Housing			[Molex Micro-Lock Plus Receptacle Crimp Housing 5055651001]		
Housing Terminal			[Molex Micro-Lock Female crimp Terminal, Gold , 26-30 AWG, 5054311100]		
CSS Header pin definition					
	Pin #	Pin Name	Description	IO Type	Voltage Range
CSS 1 to 5	1	Cat 1	Photodiode 1 Cathode	Input, Opamp -	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
	2	Gnd	Photodiode 1 Anode	GND	GND
	3	Cat 2	Photodiode 2 Cathode	Input, Opamp -	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
	4	Gnd	Photodiode 2 Anode	GND	GND
	5	Cat 3	Photodiode 3 Cathode	Input, Opamp -	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
	6	Gnd	Photodiode 3 Anode	GND	GND
	7	Cat 4	Photodiode 4 Cathode	Input, Opamp -	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
	8	Gnd	Photodiode 4 Anode	GND	GND
	9	Cat 5	Photodiode 5 Cathode	Input, Opamp -	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
	10	Gnd	Photodiode 5 Anode	GND	GND
CSS 6 to 10	1	Cat 6	Photodiode 6 Cathode	Input, Opamp -	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
	2	Gnd	Photodiode 6 Anode	GND	GND
	3	Cat 7	Photodiode 7 Cathode	Input, Opamp -	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
	4	Gnd	Photodiode 7 Anode	GND	GND
	5	Cat 8	Photodiode 8 Cathode	Input, Opamp -	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
	6	Gnd	Photodiode 8 Anode	GND	GND
	7	Cat 9	Photodiode 9 Cathode	Input, Opamp -	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
	8	Gnd	Photodiode 9 Anode	GND	GND
	9	Cat 10	Photodiode 10 Cathode	Input, Opamp -	GND-3.3V$_{regulated}$/3.3V$_{supplied}$
	10	Gnd	Photodiode 10 Anode	GND	GND

2.3 Communication Interfaces

The CubeADCS allows for communication with the OBC over UART, I2C, CAN and/or RS485/RS422. These communication interfaces are implemented at 3.3 V logic levels. Sub-sections below address hardware and signal-level interfacing details (refer to Chapter 5 and relevant sub-sections therein of each communication interface type for configuration and characteristics details).

2.3.1 UART based communication

The UART transmit- (Tx) and receive (Rx) lines are buffered with the SN74LVC2G17MDCKREP IC from Texas Instruments. The CubeComputer MCU Tx is connected to the A-side of the buffer, and the satellite (OBC) bus is connected to the Y-side while the CubeComputer MCU Rx is connected to Y-side and the satellite (OBC) is connected to the A side. This is shown in Figure 11.

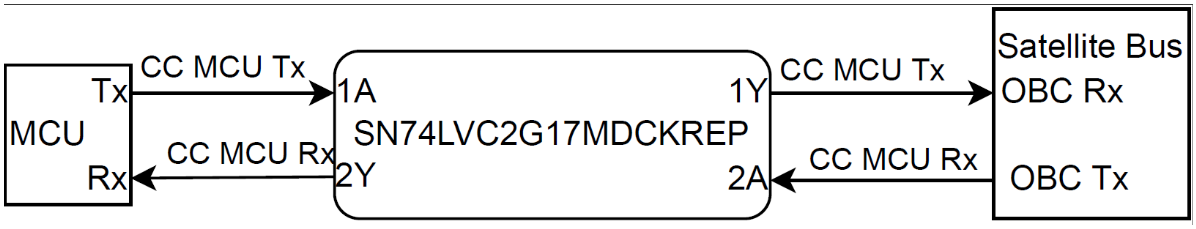

Figure 11: CubeADCS UART Buffer

For more information on the buffer and compatibility, refer to the datasheet on the Texas Instruments web page[4].

2.3.2 I²C based communication

The I²C data and clock lines are buffered with the PCA9512ADP IC from NXP. For more information on buffer compatibility, refer to the datasheet on the NXP web page[5].

There are known compatibility issues with this buffer when the master device is connected incorrectly. It is also important to note that only a limited number of these buffers can be placed in series as each buffer stage introduces a static voltage offset into the signal path. Not adhering to these specifications can influence communication, leading to unreliable data exchanges and unexpected behaviour.

There are no pull-up resistors on the satellite bus side of the I²C bus on the CubeComputer since the CubeADCS acts as a slave to a master device.

2.3.3 CAN based communication

The SN65HVD233-EP[6] CAN Transceiver is used to connect the CubeADCS to the CAN bus. By default, a 1 kOhm termination resistor is placed between CANH and CANL. If the user would like to remove or change this termination resistor it could be specified as an option using [2] for a specific order.

2.3.4 RS485 or RS422 based communication

RS485 (half-duplex, single differential communication channel) or RS422 (full-duplex, dual differential communication channel) can also be selected. These two options are shown in Figure 12 and Figure 13. RS485 mode requires additional overhead for software flow control and is beyond the scope of this document.

The A/B and X/Y data lines are buffered with the SN65HVD33MDREP[7] IC from Texas Instruments. The CubeComputer-side of this buffer is connected to a regular UART channel on the CubeComputer MCU. By default, on the CubeComputer, a 120 Ohm termination resistor is placed between A and B, and another 120 Ohm is placed between Y and Z. If the user would like to remove or change this termination resistor it could be specified as an option using [2] for a specific order.

[4] SN74LVC2G17-EP datasheet

[5] PCA9512ADP datasheet

[6] SN65HVD233 datasheet

[7] SN65HVD33MDREP datasheet

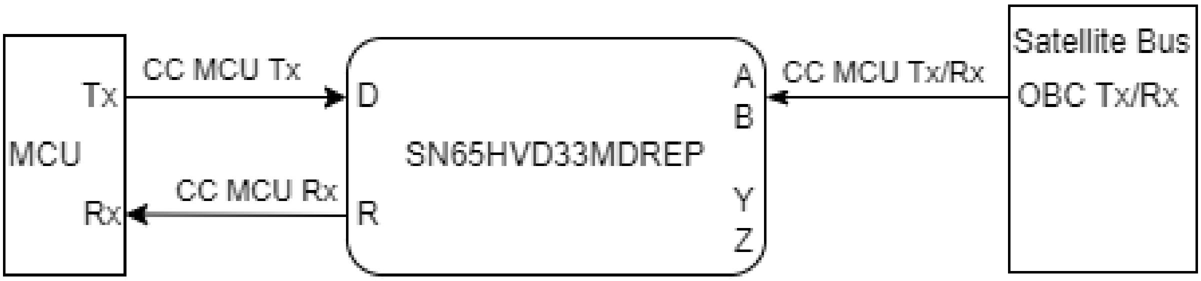

Figure 12: CubeADCS RS485/RS422 buffer in RS485 mode

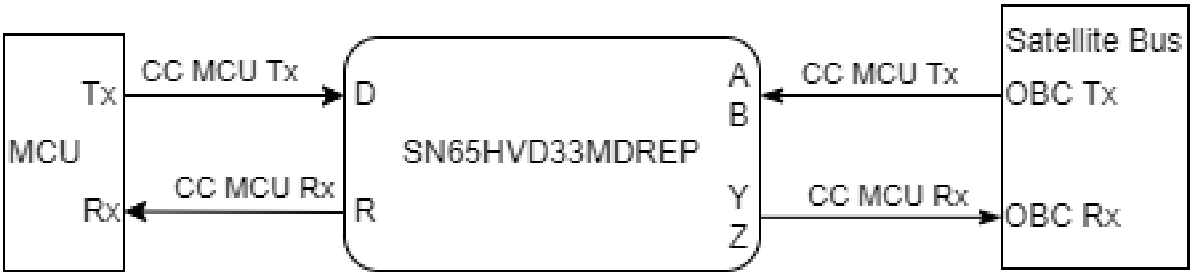

Figure 13: CubeADCS RS485/RS422 buffer in RS422 mode

2.4 Power Interface

2.4.1 Power supply

CubeADCS has three internal power domains: 3.3 V, 5 V, and $V_{Battery}$. These three power domains can either be supplied by the satellite bus as three separate voltage lines for each domain, or they can be regulated by the CubeADCS from a single "unregulated battery voltage" line. The user can indicate their option using [2] for a specific order.

The CubeComputer contained in the CubeADCS Core includes the power regulation circuit. There are three identified use cases or configurations of this circuit.

a. The first option is to only supply satellite- or EPS battery voltage to the CubeADCS. In this case the CubeADCS makes use of switched mode power supplies to regulate its internal 5V and 3V3 power domains (while passing through the battery voltage to the CubeWheel actuators if they are present in the system). This is shown in Figure 14.

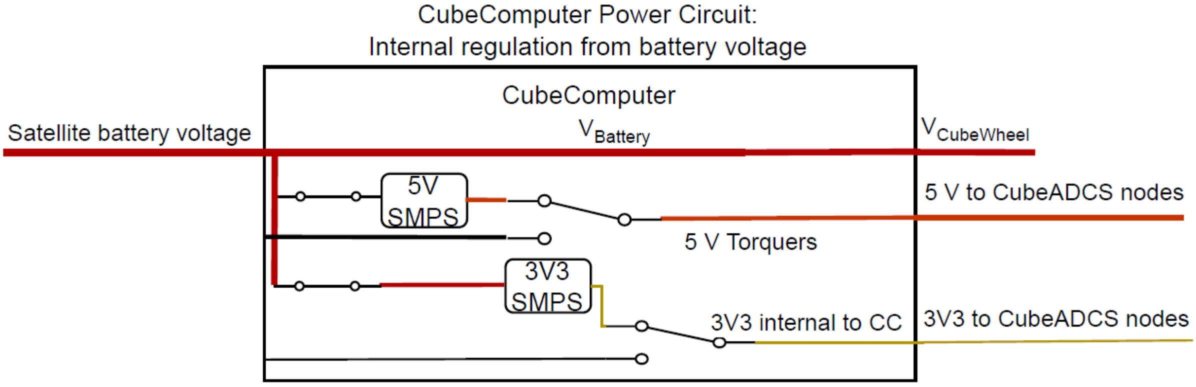

Figure 14: CubeADCS Internal regulation from battery voltage input

b. The second option is to supply all voltage domains with the appropriate regulated voltage from the satellite EPS. This will require more connections than the first option. This option will also disconnect and isolate the switched mode power supply circuit from the CubeADCS. This is shown in Figure 15.

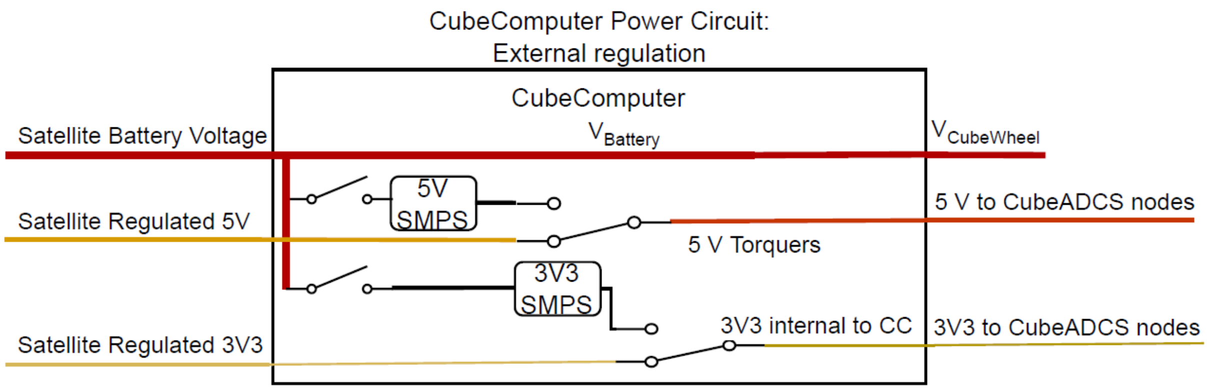

Figure 15: CubeADCS external regulation from EPS input

c. A third option is to supply battery voltage and regulated 3V3 only. This might be an attractive option to the user which can control the 3V3 line from the EPS. This will allow the user to power down the CubeADCS by turning off the 3V3 rail from the EPS. This is shown in Figure 16 below. (Note an Enable line is also available to perform this task, see section 2.4.2 for more details about the optional enable line feature.)

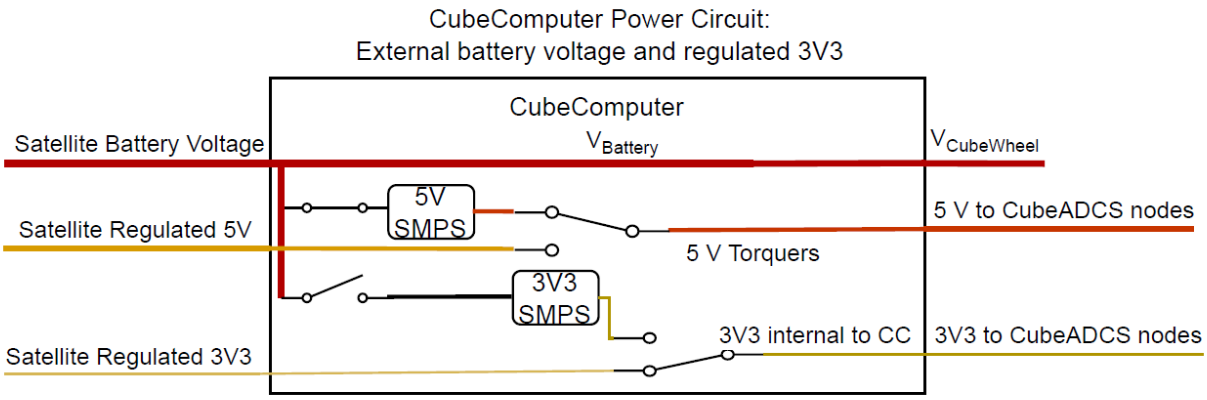

Figure 16: CubeADCS battery voltage and regulated 3V3 input

The user can select how the power supply circuit should be configured in [2].

2.4.2 Power Enable

The CubeADCS has an optional power enable line which can be exposed to the satellite bus. This input can be used to power down regulators and switches on the CubeADCS to power down the complete CubeADCS.

The Enable line is internally pulled high to $V_{Battery}$ with a 10 kOhm resistor. The Enable line is active high, which means that by default the CubeADCS is powered on. If the Enable line is pulled to ground the CubeADCS will be powered down.

2.4.3 Power consumption

The orbit average power consumption of CubeADCS will depend on the sensor and actuator suite used, as well as the manoeuvres performed by the satellite and the satellite's size. The power consumption of the actuators (CubeWheel and CubeTorquer) will greatly depend on the following factors (amongst others):

- Satellite size
- Wheel configuration
- ADCS mode
- Pointing performed during orbit

Most CubeProducts in the CubeADCS will however have an average power consumption on the 3.3 V line independent of the satellite's size or ADCS modes used. This is as the basic digital circuit is designed to be common amongst the CubeProducts, and all are powered from 3.3V. Some CubeProducts and third-party sensors are powered from the 5V rail, e.g. the torquer rods and third party supported devices such as the TY-Space PST3S star tracker.

If the optional regulation on the CubeADCS is used, the power as provided in the following section will be drawn, but the efficiency of the regulation also needs to be considered to determine the power drawn on the satellite bus. The same amount of power will be drawn, but since it will be drawn from the battery voltage bus, the current values will change depending on the actual voltage level of the bus and efficiency of the switch mode power supplies.

The values in this section are therefor indicative only and more accurate power consumption values can only be provided with an ADCS simulation report.

To obtain better estimates for orbital average power a simulation will need to be performed for a specific mission and associated requirements for the mission (e.g. such as typical manoeuvres which needs to be performed by the CubeADCS in a typical orbit.)

2.4.3.1 Power consumption: 3.3V rail

The average and maximum power consumption on the 3.3 V line for each of the CubeProducts is shown in Table 7. The total 3.3 V power consumption will vary based on the combination of sensors and actuators used in the ADCS solution. Note that the current consumption is provided when the onboard regulation is not used.

Table 7: Average power consumption on 3.3 V line (no actuation)

COMPONENT	3.3 V RAIL					NOTES
	Avg Current (mA)	Avg Power (mW)	Max Current (mA)	Max Power (mW)	Inrush (mA – µs)	
CubeComputer	70	231	100	330	120 – 1000	Measured for 5 Hz ADCS loop.
CubeMag Deployable	15	50	70	230	230-100	Excluding deployment current.
CubeMag Compact	15	50	70	230	230-100	
CubeSense Sun	28	93	78	260	260-1000	Measured during 1 Hz detection.

COMPONENT	3.3 V RAIL					NOTES
	Avg Current (mA)	Avg Power (mW)	Max Current (mA)	Max Power (mW)	Inrush (mA – µs)	
CubeSense Earth	61	200	85	280	221-50	Estimated for 1 Hz detection.
CubeStar	50	165	83	274	180-1800	Measured during 1 Hz detection.
CubeWheel	32	105.6	79	260.7	270-0.5	Measured for all modes
CubeNode	22	73	TBD	TBD	24-80	

2.4.3.2 Power Consumption: Magnetorquers (5V rail)

Magnetorquers such as CubeTorquers are active for significant durations during satellite detumbling (often driven at maximum on-time), whereas the magnetic control authority required to desaturate the reaction wheels during normal satellite operations is typically less than 10% on-time. Table 8 shows the peak current consumption and the power consumption scaled with on-time of the various CubeTorquer variants.

Table 8: CubeTorquer power consumption

SATELLITE SIZE	CUBETORQUER VARIANT	MAGNETIC DIPOLE @ 5 V (AM²)	NOMINAL RESISTANCE [Ω]	CURRENT (MA) ON 5 V (*PEAK PER ROD*)	AVG. POWER OVER A 1HZ LOOP[B] (MW) ON 5 V RAIL (*TOTAL FOR 3X CUBETORQUER*)	
					10% on-time	80% on-time[c]
Up to 3U	CR0002	0.2	51.5	98[a]	123	981
	CR0003	0.3	67.5	74[a]		
Up to 6U	CR0004	0.4	40	125[a]	188	1500
Larger than 6U	CR0006	0.6	45	111	167	1334
	CR0008	0.8	44.5	113[a]	168	1349
	CR0010	1.0	37.5	134[a]	200	1600
	CR0012	1.2	36.5	137 [a]	206	1644
	CR0020	2.0	32.5	154 [a]	231	1847

[a] Measured at 20-25°C ambient temperature. Note that resistance (and therefore current) of the torque rods will slightly vary with temperature.

[b] Excluding local DC-DC regulation losses.

[c] Magnetic actuation is limited to 80% of the ADCS loop to allow undisturbed magnetometer measurements to be taken.

2.4.3.3 Power consumption: Reaction wheels (Battery Voltage Rail)

Reaction wheels are responsible for maintaining the satellite's desired attitude by counteracting the in-orbit disturbance torques and by rotating the satellite to achieve the required manoeuvre. The power consumption of reaction wheels is dependent on both the running speed as well as the torque demand.

The current draws at different momentum levels are shown in Figure 17 to Figure 20. The negative side of the graphs indicate the current draw during braking. When the wheel speed crosses the zero value, there is a significant current spike to keep the tracking error as low as possible.

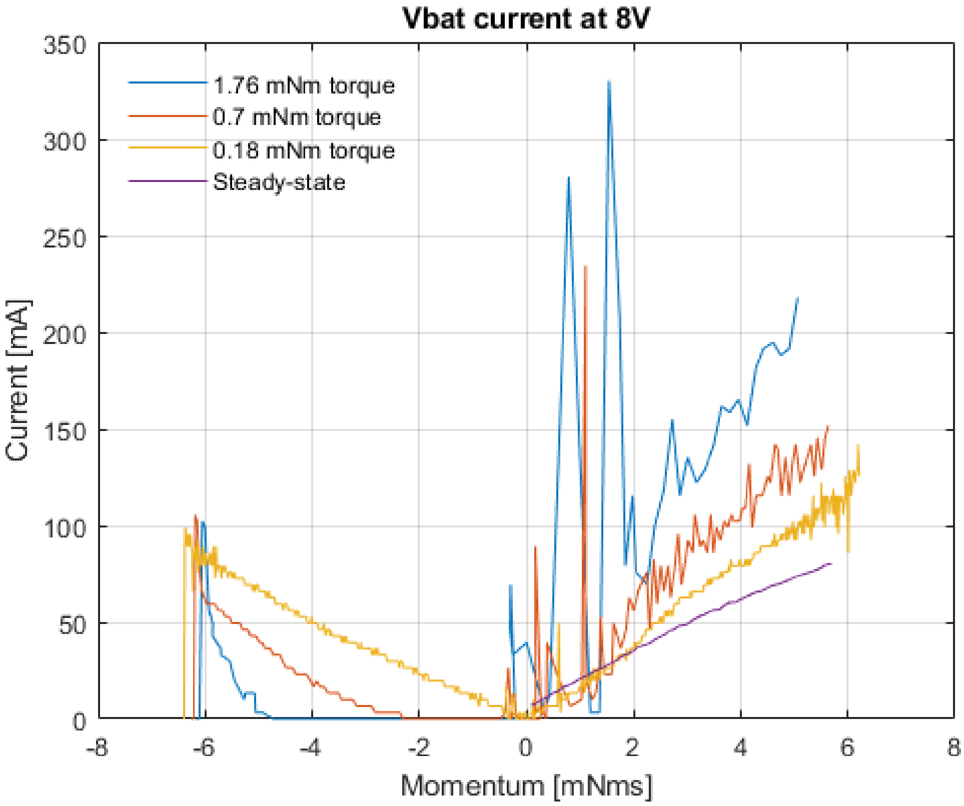

Figure 17: CubeWheel 0057 current draw at 8V supply

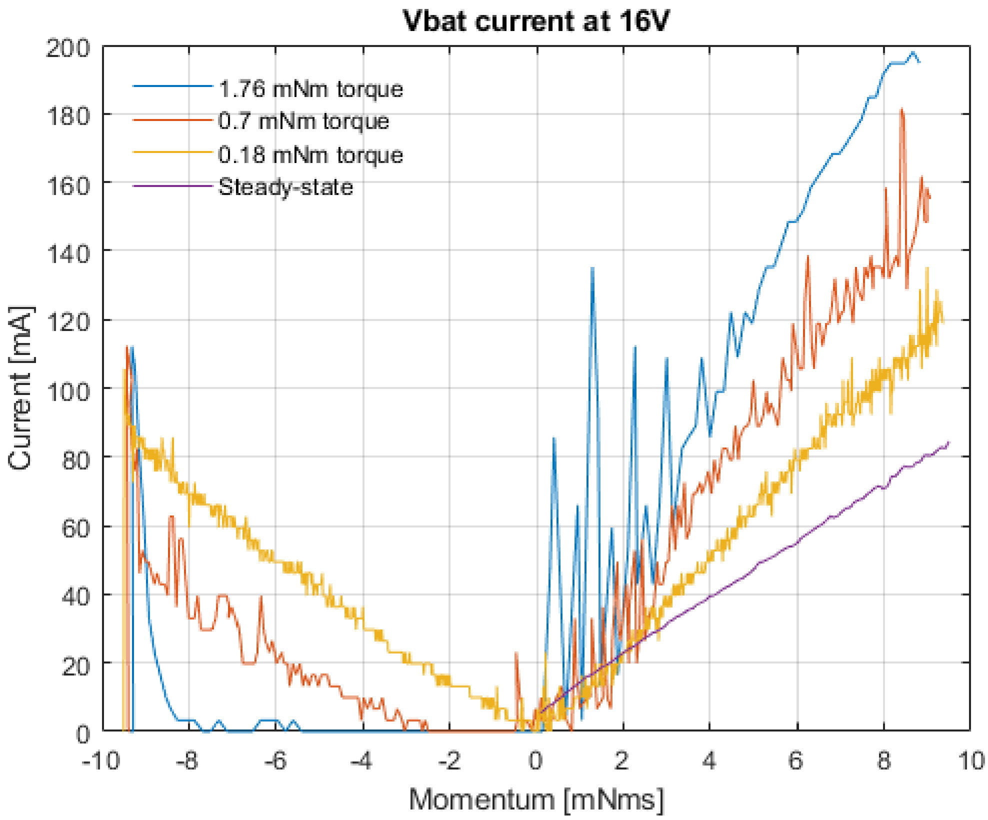

Figure 18: CubeWheel 0057 current draw at 16V supply

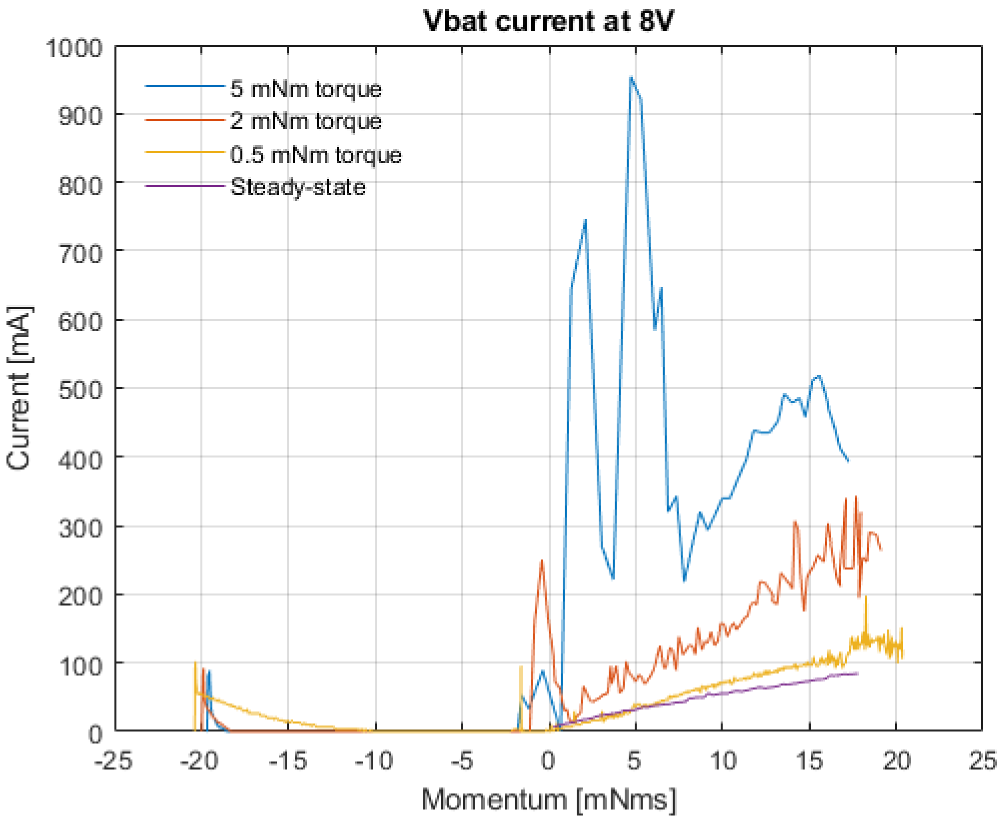

Figure 19: CubeWheel 0162 current draw at 8V supply

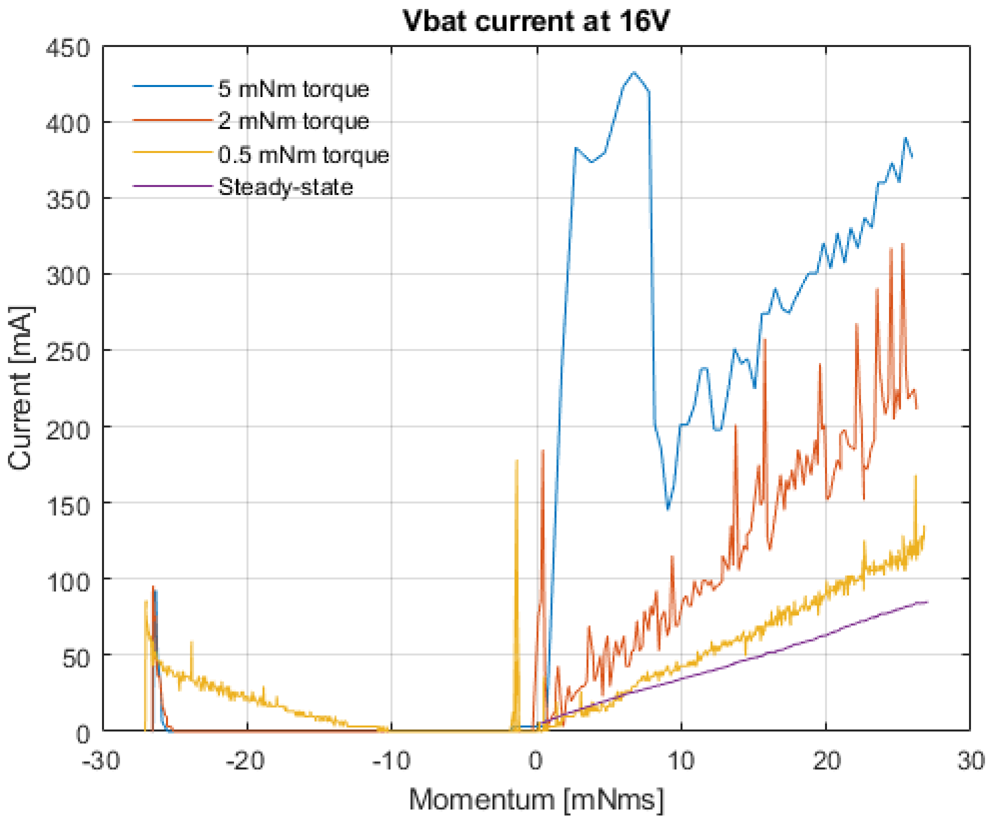

Figure 20: CubeWheel 0162 current draw at 16V supply

Maximum current at the various supply voltages is given in Table 9. The maximum current is drawn in short pulses at 24 kHz which is equal to the frequency of the PWM used in the motor driver.

Table 9: Maximum current draw from battery supply

COMPONENT	MAX CURRENT AT 8V [MA]	MAX CURRENT AT 10V [MA]	MAX CURRENT AT 12V [MA]	MAX CURRENT AT 14V [MA]	MAX CURRENT AT 16V [MA]
CW0057	624	648	656	672	704
CW0162	776	880	952	1010	1030

2.4.4 *Power Protection*

Power Protection is included as deemed necessary. Specifically, if the 3V3 power is supplied externally, as shown Figure 16, the CubeADCS system will automatically switch off if this voltage level falls outside the 2.5V – 4.0V range. It is however expected that the user follows the specifications provided for the CubeADCS system as specified in this document and . Whenever any input or interface is used out of specified ranges, CubeSpace cannot ensure that the CubeADCS will function as intended.

Note that there is no protection against overvoltage on the $V_{Battery}$ bus line. A voltage input above 20V will cause damage.

2.4.4.1 *Switched Mode Power Supply*

The 5V and 3.3V switched mode power supplies can provide regulated power to the system if the client selects this option. The regulator design accepts a battery voltage with a wide input range of 7.5V to 20V.

Note that a max input voltage of 17 volt is specified when CubeWheels are part of the CubeADCS since they are directly provided with this battery input supply.

2.4.4.2 Power Distribution and Control

The CubeADCS power circuit shown in Figure 14 through Figure 21 briefly show the elements that provide protection to the CubeADCS. The CubeComputer controls the enable lines on each CubeADCS node. These enable lines are controlled directly by the MCU on the CubeComputer. If the CubeComputer 3V3 line is turned off all the logic will be turned off and the Enable Lines will be pulled low disabling all CubeADCS nodes. All CubeADCS Gen2 nodes make use of the same input power circuit and thus all have the same protection. This is indicated by the "SW3" component in Figure 21.

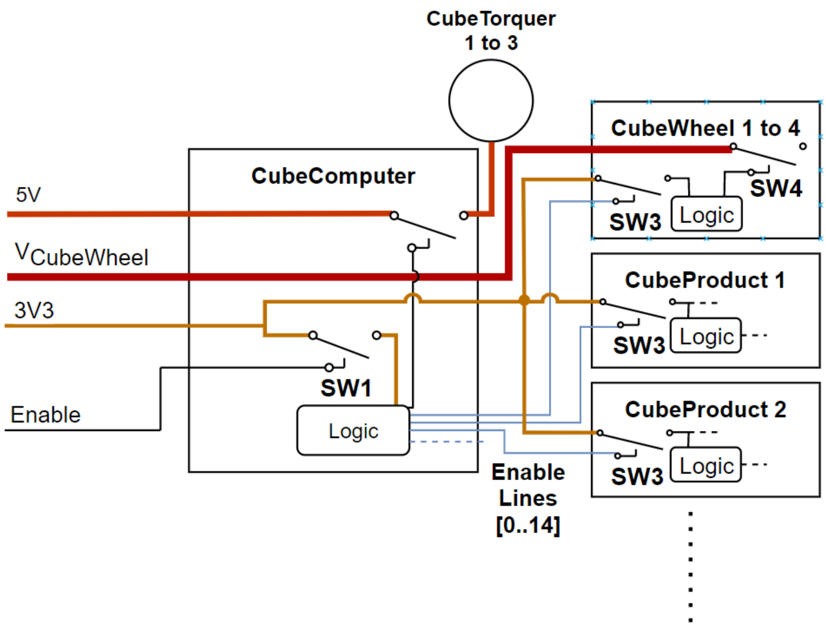

Figure 21: CubeADCS Internal Enable Lines and Switches

2.4.4.3 CubeComputer 3V3 undervoltage protection

The logic on CubeComputer monitors the 3V3 rail voltage level and ensures that it is above a certain voltage threshold level before enabling the various power switches. This protects the 3.3V ICs from under-voltage conditions. This is also required to protect memory and sensitive circuits on the CubeComputer.

2.4.4.4 CubeComputer 3V3 power switch

The switches provide a current limit (3.0 A) and latches off during a fault to protect against hard-latch up events.

Note that SW1 provides overvoltage protection for accidental connection of 5V or battery voltage. However, it does not protect against smaller deviations on the 3V3 rail which may damage sensitive IC's. If the 3.3V supply to this switch is regulated on the CubeComputer as explained in section 2.4.1 this is not a concern since the SMPS will keep the voltage rail stable. However, care should be taken when this voltage is supplied from the satellite bus.

2.4.4.5 CubeProducts 3V3 power switch

"SW3" as shown in Figure 21 is the input power switch for all CubeADCS nodes. It must be enabled by pulling the enable line high for each node. This switch allows nodes to be powered off and isolated from the 3V3 power rail. It also provides a current limit (400mA)[8] feature to protect against hard-latch up events. It also has overvoltage protection set to trigger upwards of 3.9V (depending on thermal conditions).

2.4.5 CubeComputer Backup Power

The CubeComputer can store a bit of backup power to run the RTC during short interruptions in power.

2.4.6 Inrush current

Inrush current is experienced for a short amount of time when the CubeADCS is powered on. The peak current and the amount of time this peak current is drawn are indicated in Table 7.

These larger currents could cause voltage dips on the power rail if there are resistive elements between the load and the source or if the power supply is not able to deliver the required power. To mitigate this compound effect, the CubeADCS implements a staggered power on strategy. With this in place sub-systems will not all be powered on at the same time. This allows the total current draw as experienced by the satellite power supply / EPS to be minimised / staggered over time.

2.5 Harnesses

The CubeADCS connects to external sensors and actuators through wire harnesses. The connection is made between a header on CubeConnect and the interface header on each sensor or actuator. CubeConnect is shown and discussed in section 2.2 and the sensors and actuators are discussed in section 3.2.

The harnesses consist of a housing crimped on to each end as required by CubeConnect and connecting sensor or actuator and a certain harness length. The housings used are Molex Micro-Lock plus as demanded by the mating headers. The wire length between the housings can be specified from a selection of standard lengths. The user can specify the desired length in [2] when the order for the CubeADCS is placed.

The wire used has a PTFE insulation which is low outgassing.

The harness details are described in Table 10 below. In Table 10, Housing 1 and terminal 1 mates with CubeConnect, and Housing 2 and terminal 2 mates with the sensor/actuator.

If a CubeADCS Core stack is to be used, harnessing for three internal CubeWheels and CubeTorquers will be housed within the enclosure. Thus, the only harnesses external to a CubeADCS Core stack will be of an optional 4th CubeWheel, all sensors and Coarse Sun Sensors.

The CubeADCS Core will not house any harnesses within the enclosure, thus all actuators and sensors to be used will require harnesses that are external to the CubeADCS Core.

Table 10: Harness details

HARNESS	QTY	HOUSING 1 MASS (MG)	TERMINAL 1 MASS (MG)	WIRE GAUGE (AWG)	WIRE MASS (KG/KM)	HOUSING 2 MASS (MG)	TERMINAL 2 MASS (MG)	PINS	TOTAL[9] MASS
MTQ	1	138.021	35.434	28	1.4	16	7.04	6	
Wheel	4	261.67	35.434	26	1.96	263.5	35.434	10	
Sensor	8	229.64	35.434	26	1.96	198.8	35.434	8	

[8] The deployable CubeMag current limit is set to 900mA to accommodate the deployment current

[9] Total mass of the harness depends on the harness length. The total mass can thus be self-calculated using the wire mass (in kg/km) for the specified / selected harness lengths

HARNESS	QTY	HOUSING 1 MASS (MG)	TERMINAL 1 MASS (MG)	WIRE GAUGE (AWG)	WIRE MASS (KG/KM)	HOUSING 2 MASS (MG)	TERMINAL 2 MASS (MG)	PINS	TOTAL[9] MASS
CSS	2	198.816	35.434	26	1.96	52.2	9.8	10	

3 Mechanical Interface

This chapter describes the mechanical interface of the CubeADCS. This includes:

1. The outer dimensions of the CubeADCS and all standard CubeProduct sensors and actuators
2. The mounting definition and specifics (hole pattern and if the mounting of the component affects its performance)
3. Mass, Centre of Mass, and Inertia
4. Coordinate System

PLEASE NOTE: The dimensions given in this section are indicative only. The mechanical CAD files received from CubeSpace should be treated as the source of truth.

3.1 Standard CubeADCS configurations

As described in the Product Description (see [1]), three standard CubeADCS configurations are made available.

3.1.1 *Standard CubeADCS Core Stack for satellites up to 3U*

3.1.1.1 *Outer Dimensions*

The dimensions of a standard CubeADCS Core Stack for 3U and smaller satellites is given Figure 22, the tolerance on all dimensions is ±0.15mm unless otherwise specified.

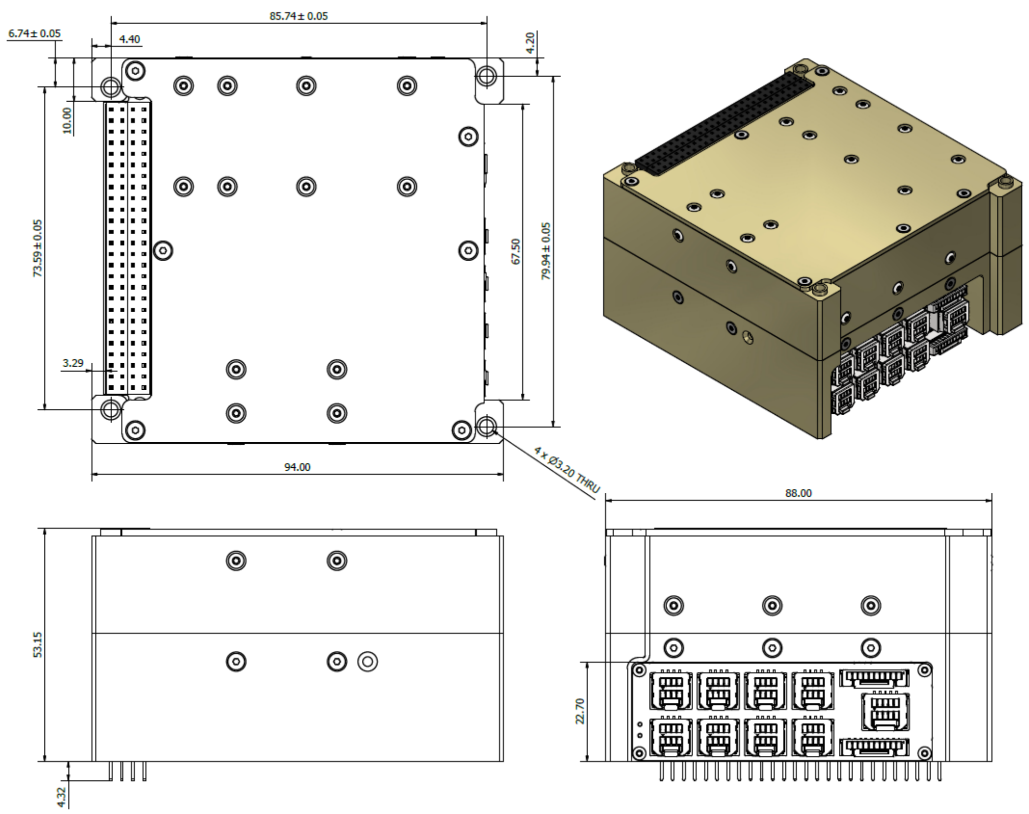

Figure 22: Indicative dimensions of a standard CubeADCS Core Stack for 3U

3.1.1.2 CubeDoor and CubeConnect positions

The CubeDoor and CubeConnect are located opposite one another as shown in Figure 23. The CubeComputer and actuators (CubeWheels and CubeTorquers), are housed/enclosed within the mechanical enclosure made from 6082-T6 aluminium treated with a chromate conversion coating (Alodine).

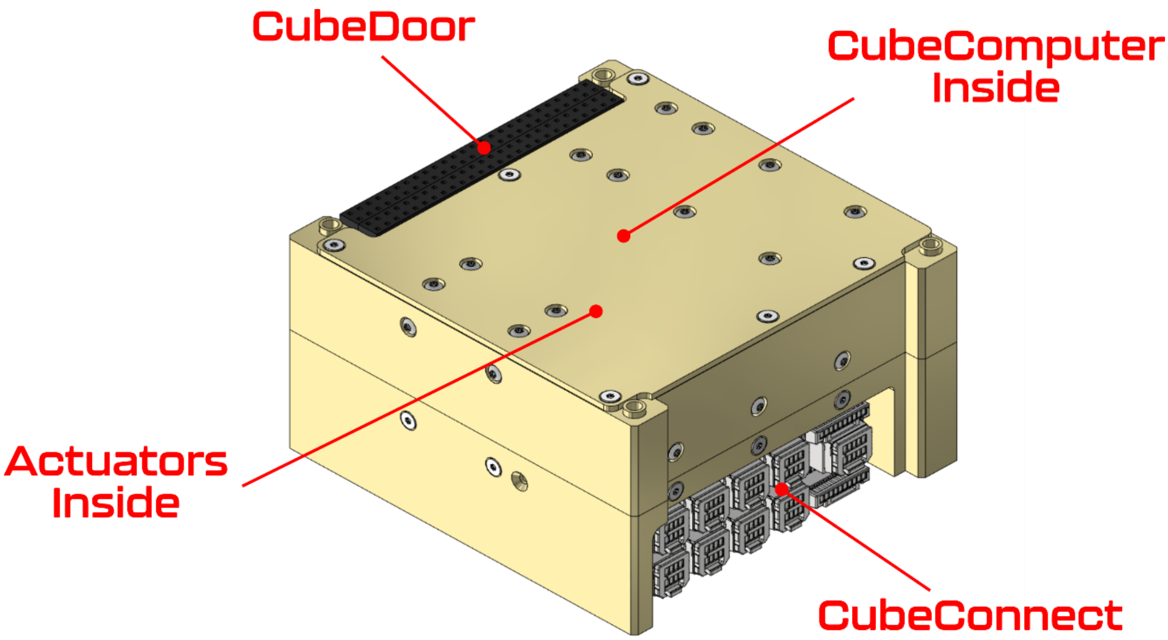

Figure 23: Location of CubeDoor and CubeConnect on a standard CubeADCS Core Stack for 3U

3.1.1.3 Mounting definition

The CubeADCS Core stack for 3U and smaller satellites is reliant on the use of four mounting rails. The stack will slide into the rails through the four ⌀3.20mm mounting holes dimensioned in Figure 22. It is possible to connect the stack to a PC104 header from the top and / or bottom. It will be the client's responsibility to secure the CubeADCS in its final position.

3.1.1.4 Mass, COM and Inertia

The total mass of an integrated CubeADCS stack for 3U is 575 g± 10 %. The COM position of this assembly is shown in Figure 24.

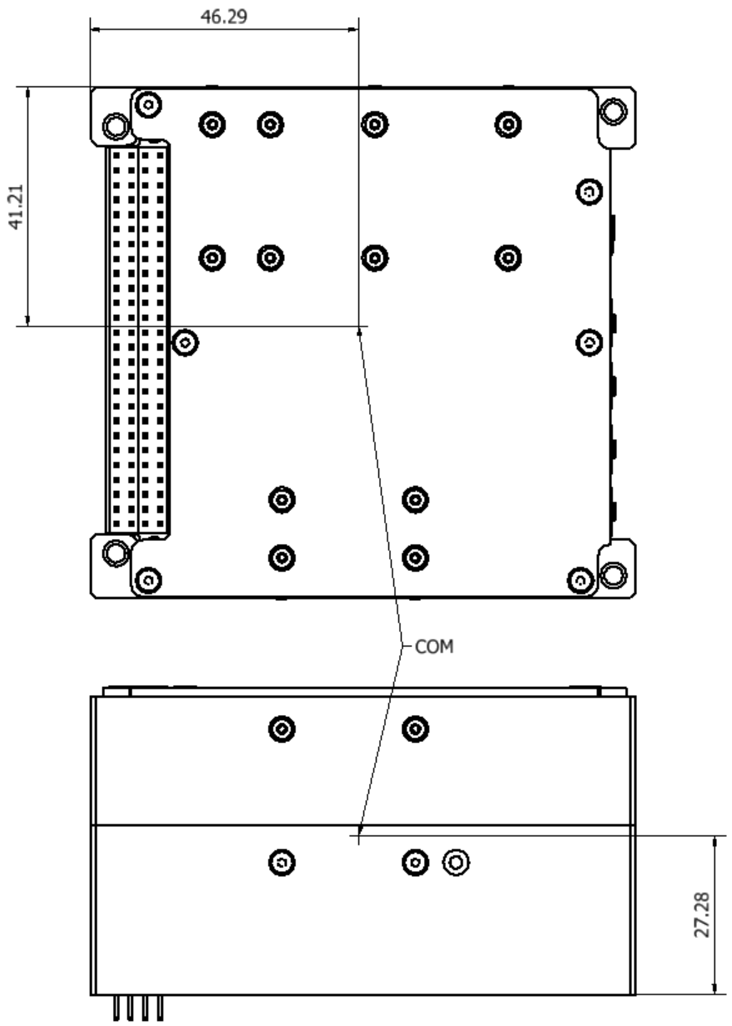

Figure 24: COM position of a standard CubeADCS Core Stack for 3U

The moments of inertia of the integrated CubeADCS Core stack for 3U about its COM are presented in Table 11, the axes reference for the inertias provided is shown in Figure 25.

Table 11: Moments of inertia of Integrated CubeADCS Core Stack for 3U and smaller satellites

AXIS	VALUE
I_{xx} (gmm^2)	510256± 15 %
I_{yy} (gmm^2)	520558 ± 15 %
I_{zz} (gmm^2)	764877 ± 15 %

3.1.1.5 Coordinate System Definition

The coordinate system definition of the CubeADCS Core Stack for 3U is shown in Figure 25.

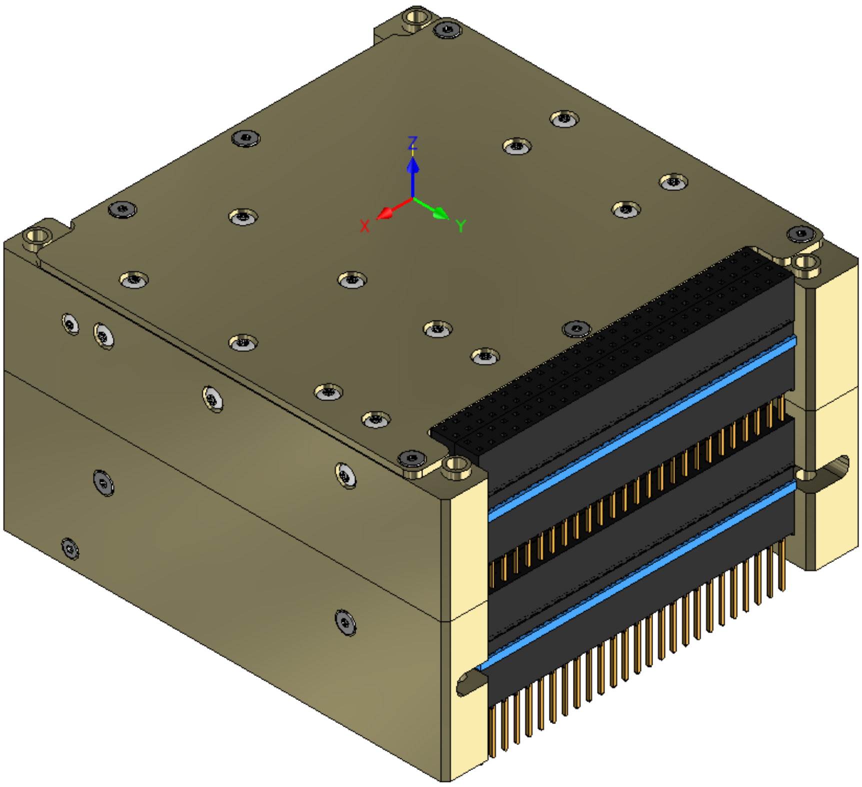

Figure 25: Coordinate system definition for a standard CubeADCS Core Stack for 3U satellites

3.1.2 Standard CubeADCS Core stack for satellite sizes between 3U and 6U

3.1.2.1 Outer Dimensions

The dimensions of a standard CubeADCS Core Stack for typical satellites from 3U-6U in size is given in Figure 26, tolerance on all dimension is ±0.15mm unless otherwise specified.

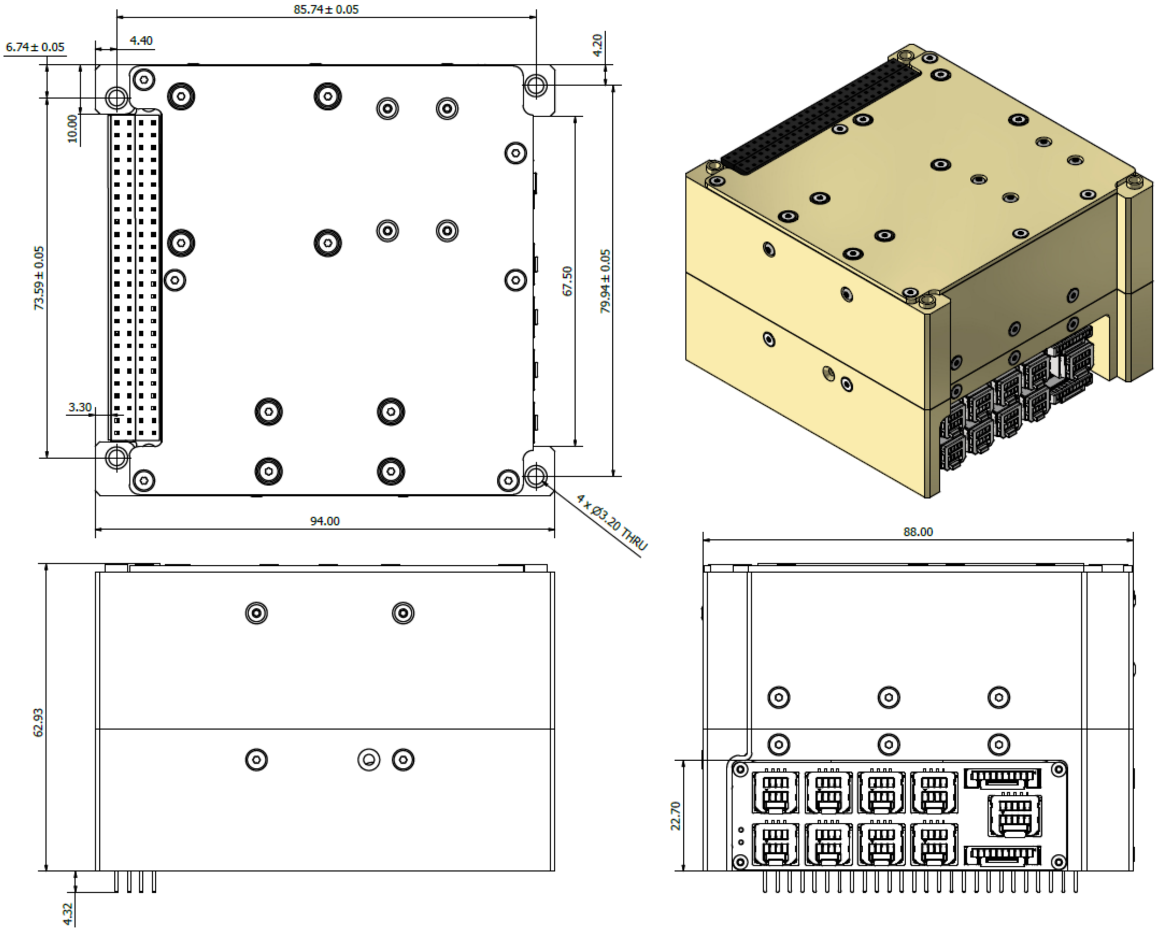

Figure 26: Indicative dimensions of a standard CubeADCS Core Stack for 3U to 6U satellites

3.1.2.2 CubeDoor and CubeConnect positions

The CubeDoor and CubeConnect are located opposite one another as shown in Figure 27. The CubeComputer and actuators (CubeWheels and CubeTorquers), are housed/enclosed within the mechanical enclosure made from 6082-T6 aluminium treated with a chromate conversion coating (Alodine)

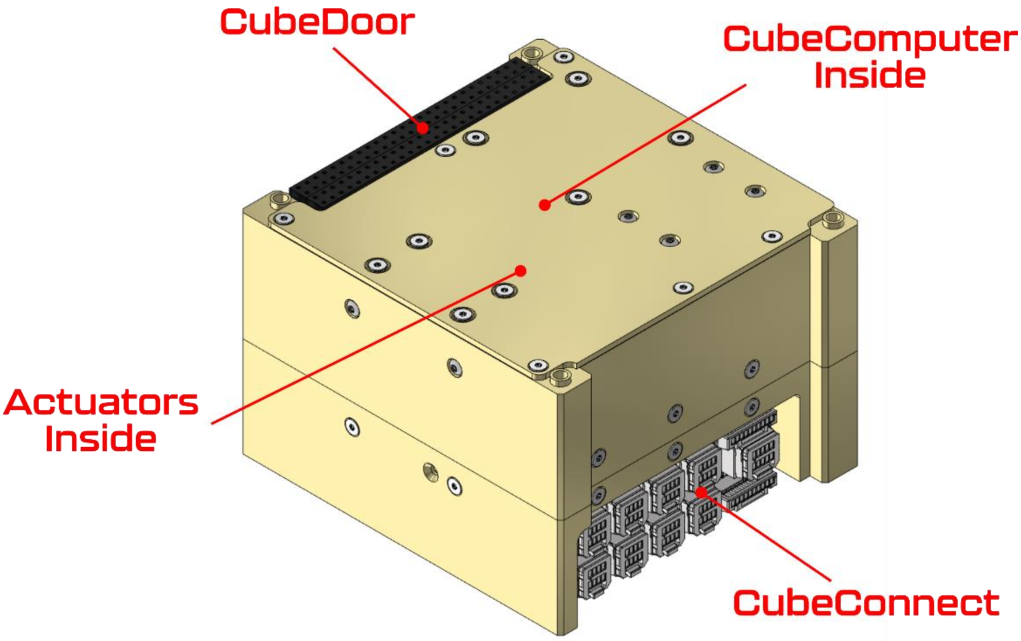

Figure 27: Location of CubeDoor and CubeConnect on an Integrated CubeADCS Stack for3U to 6U satellites

3.1.2.3 Mounting definition

The CubeADCS Core stack for 3U to 6U satellites is reliant on the use of four mounting rails. The stack will slide into the rails through the four ø3.20mm mounting holes dimensioned in Figure 26. It is possible to connect the stack to a PC104 header from the top and / or bottom. It will be the client's responsibility to secure the CubeADCS in its final position.

3.1.2.4 Mass, COM and Inertia

The total mass of an integrated CubeADCS Core stack for 3U to 6U satellites is 743 g ± 10 %. The COM position of this assembly is shown in Figure 28.

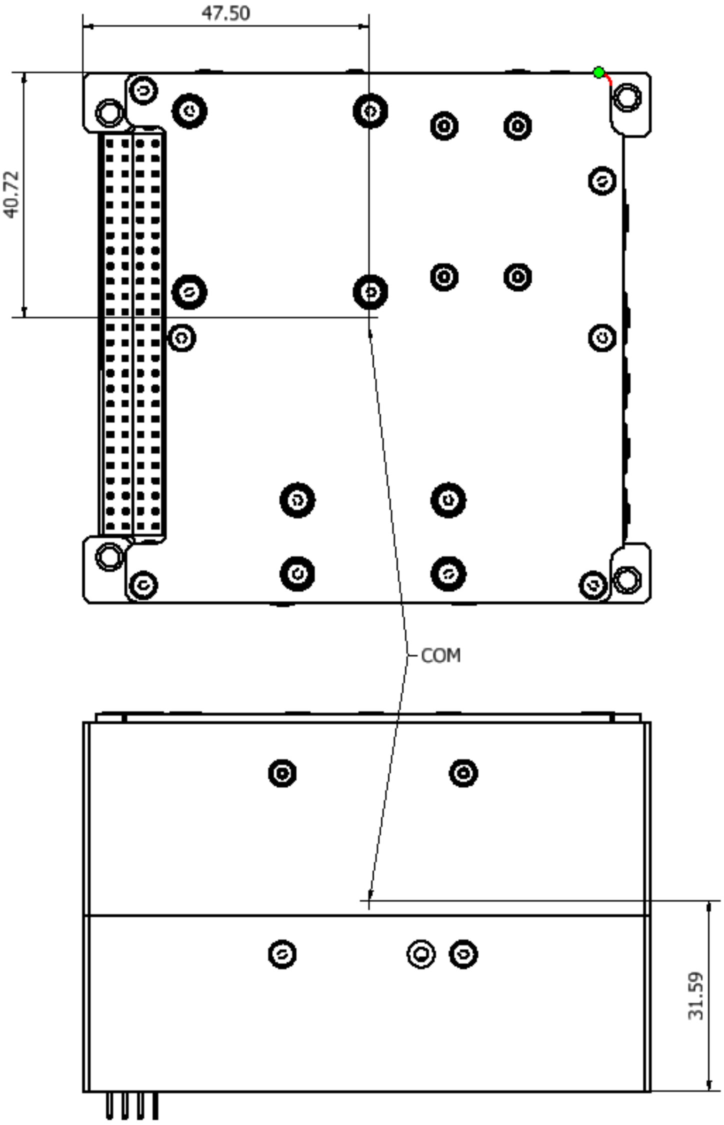

Figure 28: COM position of Integrated CubeADCS Stack for 3U-6U satellites

The moments of inertia of the standard CubeADCS Core Stack for 3U to 6U satellites about its COM are presented in Table 12, the axes reference for the inertias provided is shown in Figure 29.

Table 12: Integrated CubeADCS Stack for 6U moments of inertia

AXIS	VALUE
I_{xx} (gmm^2)	610768 ± 15 %
I_{yy} (gmm^2)	690045 ± 15 %
I_{zz} (gmm^2)	907014 ± 15 %

3.1.2.5 Coordinate System Definition

The coordinate definition of the CubeADCS Core Stack for 3U to 6U satellites is shown in Figure 29.

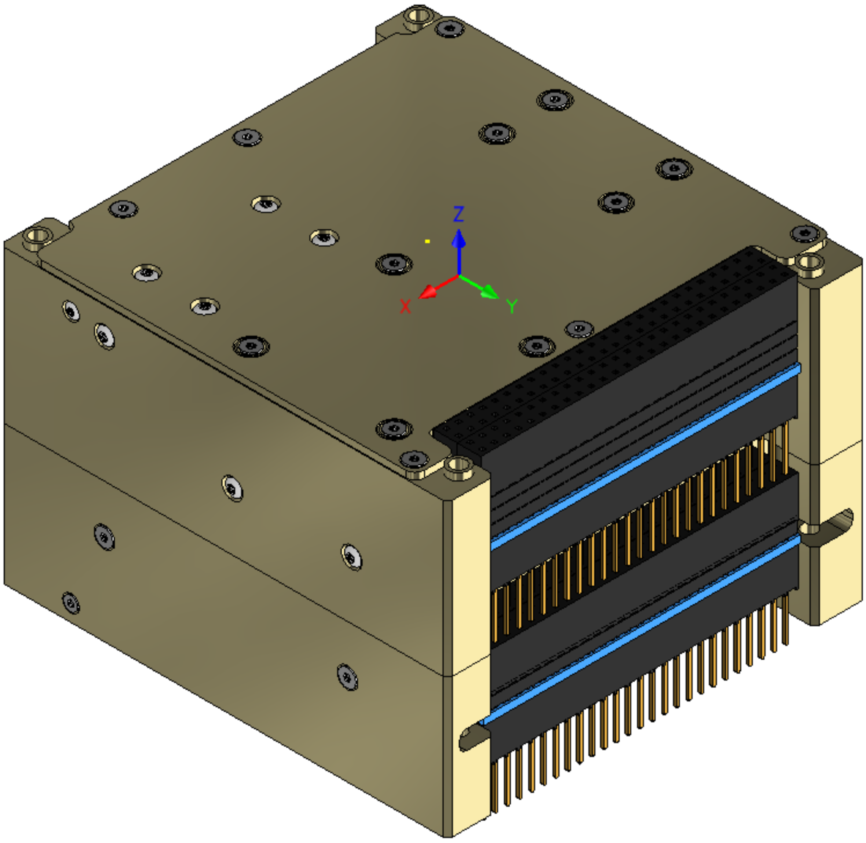

Figure 29: Coordinate system definition for a standard CubeADCS Core Stack for 3U to 6U satellites

3.1.3 Standard CubeADCS Core

3.1.3.1 Outer Dimensions

The dimensions of a standard CubeADCS Core are given in Figure 30, tolerance on all dimension is ± 0.15mm unless otherwise specified.

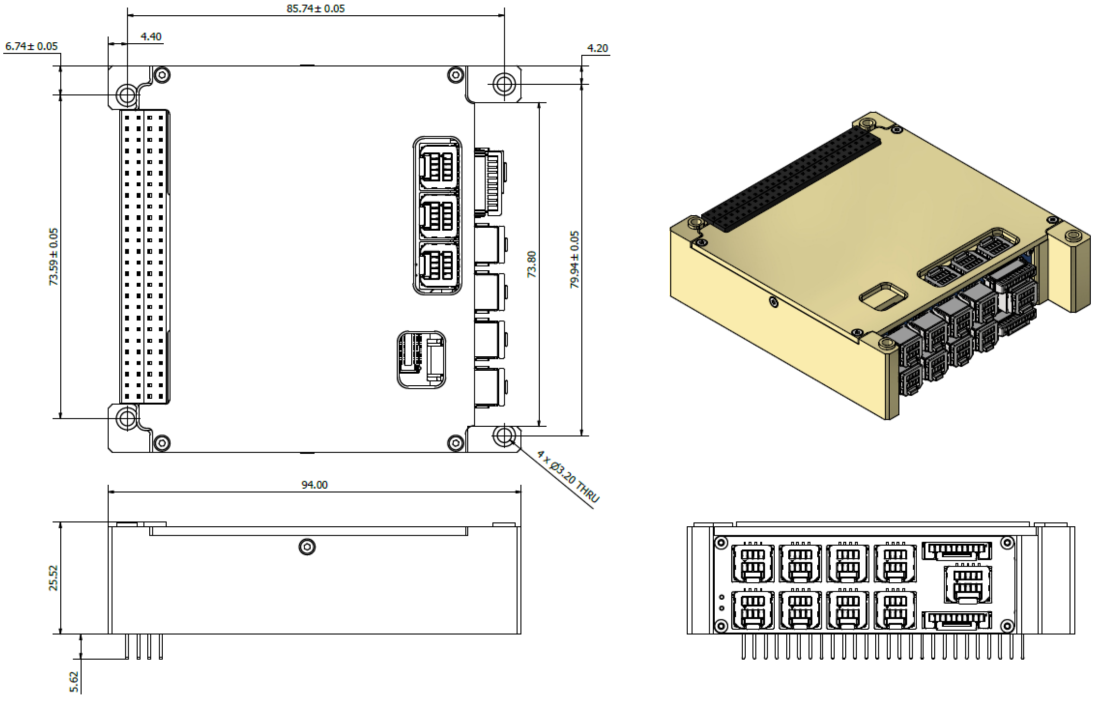

Figure 30: Indicative dimensions of a standard CubeADCS Core

3.1.3.2 CubeDoor and CubeConnect positions

The CubeDoor and CubeConnect are located opposite one another as shown in Figure 31. The CubeComputer is housed/enclosed within a housing made from 6082-T6 aluminium treated with a chromate conversion coating (Alodine).

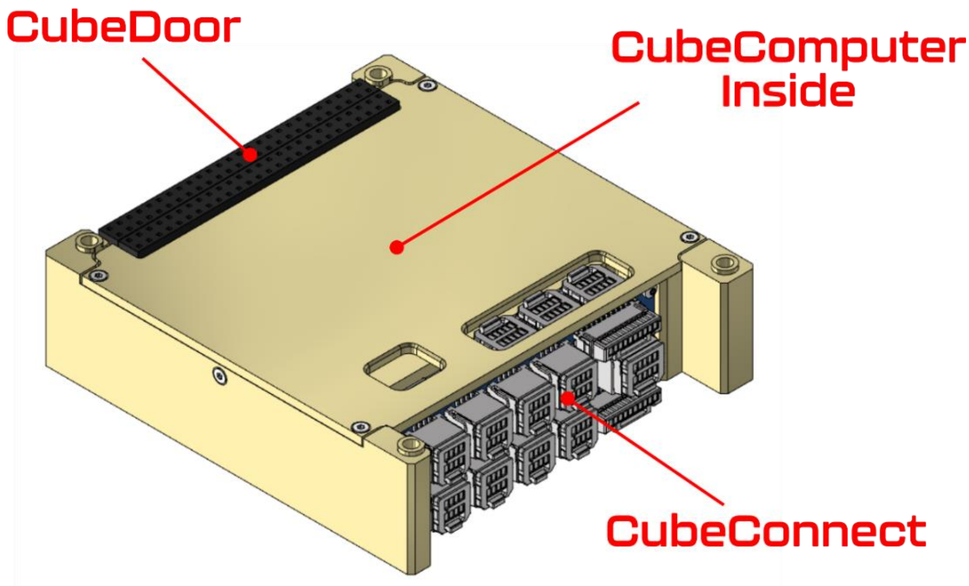

Figure 31: Location of CubeDoor and CubeConnect on a CubeADCS Core

3.1.3.3 Mounting definition

Similar to the standard 3U and 6U assemblies, the CubeADCS Core is reliant on the use of four mounting rails. The stack will slide into the rails through the four ⌀3.20mm mounting holes dimensioned in Figure 30.

It is possible to connect the CubeADCS Core to a PC104 header from the top and / or bottom. It will be the client's responsibility to secure the CubeADCS Core in its final position.

3.1.3.4 Mass, COM and Inertia

The total mass of a standard CubeADCS Core is 214 g ± 10 %. The COM position of this assembly is shown in Figure 32.

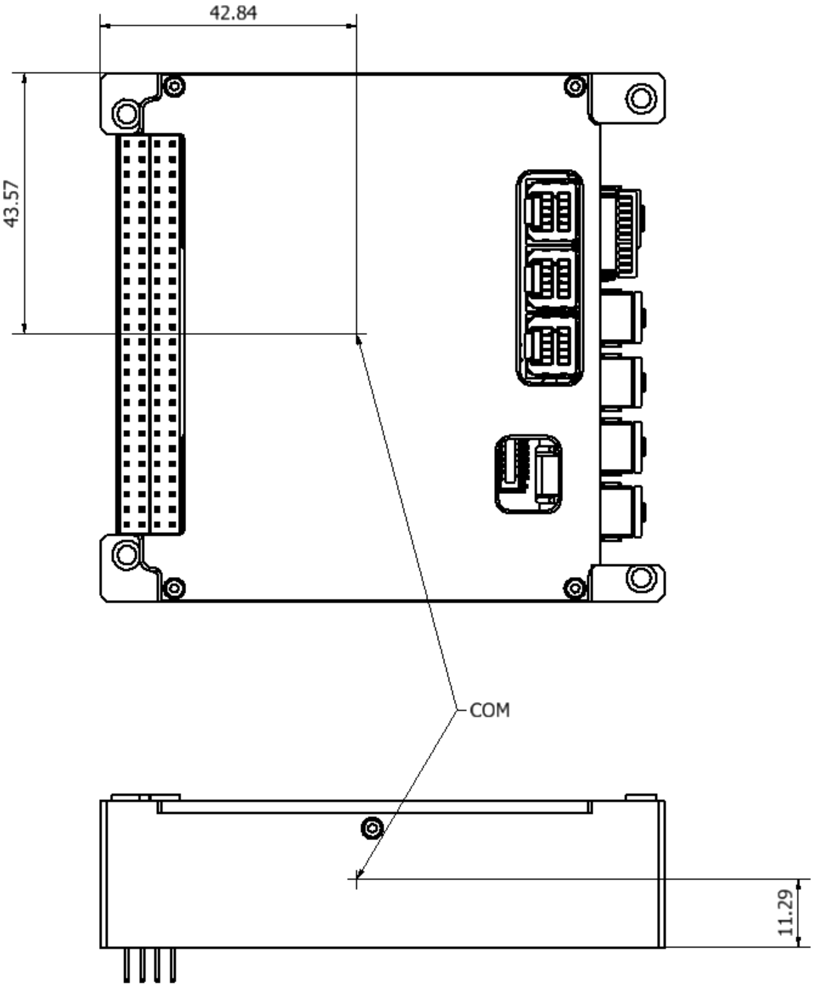

Figure 32: COM position of standard CubeADCS Core

The moments of inertia of the CubeADCS Core about its COM are presented in Table 13, the axes reference for the inertias provided is shown in Figure 33.

Table 13: Standard CubeADCS Core moments of inertia

AXIS	VALUE
I_{xx} (gmm^2)	137980 ± 15 %
I_{yy} (gmm^2)	138660 ± 15 %
I_{zz} (gmm^2)	249794 ± 15 %

3.1.3.5 Coordinate System Definition

The coordinate definition of a the standard CubeADCS Core is shown in Figure 33.

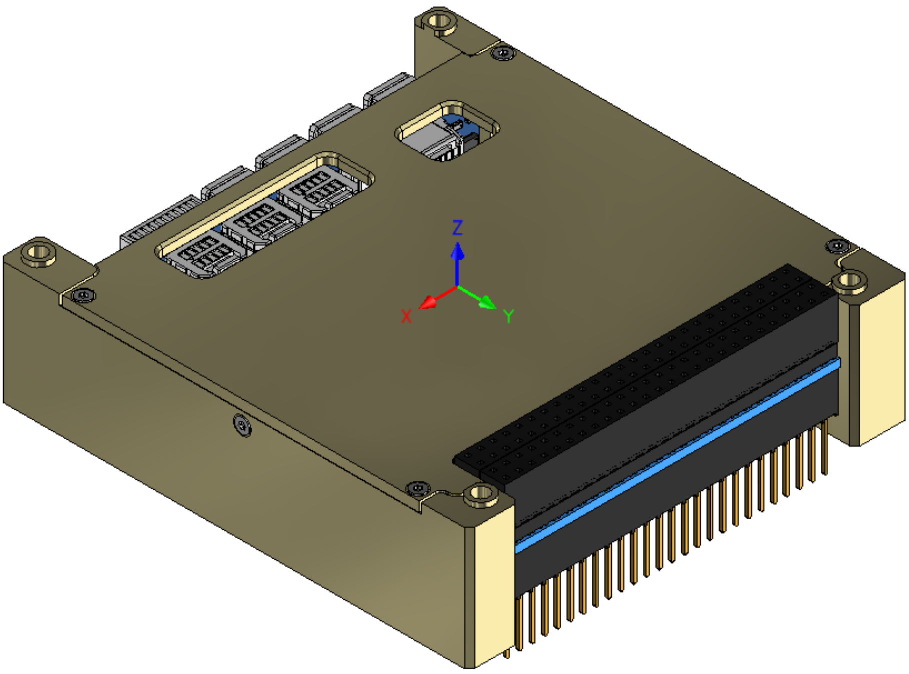

Figure 33: Coordinate system definition for an Integrated CubeADCS Core Stack

3.2 CubeProducts (CubeADCS sub-systems)

3.2.1 CubeMag Deployable

The CubeMag Deployable consists of a base which is mounted on the outside of the satellite, an arm which deploys to 90 degrees when released, and a wire hold-down-and-release mechanism. The CubeMag Deployable has a primary magnetometer in the head of the deployment arm, and a secondary magnetometer on the base. The housing that encloses the magnetometer is manufactured from 6082-T6 aluminium.

3.2.1.1 Outer Dimensions

The overall dimensions of the CubeMag deployable in its stowed state are shown in Figure 34.

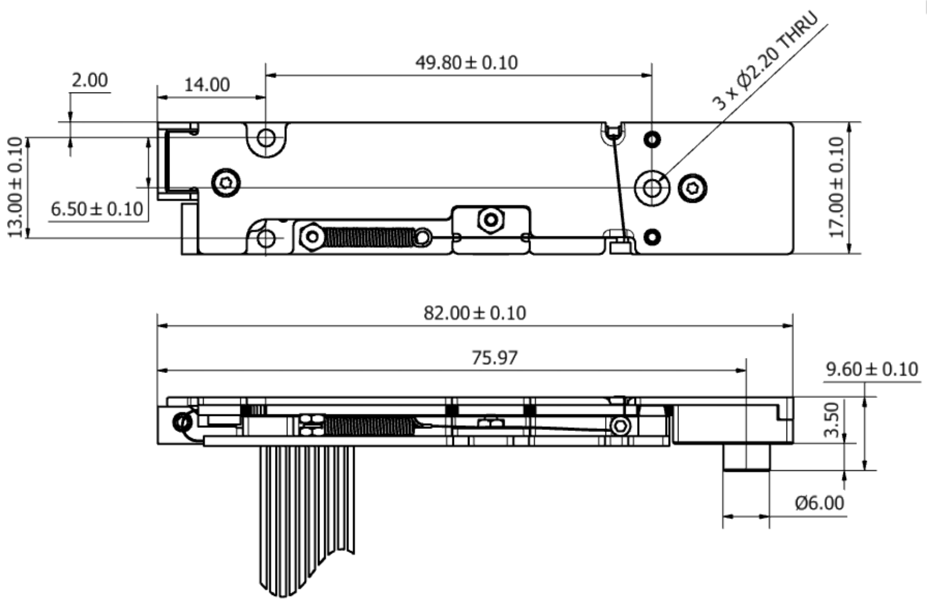

Figure 34: Indicative dimensions of CubeMag Deployable in the stowed state

Figure 35 displays the dimensions of the deployable magnetometer in the deployed state.

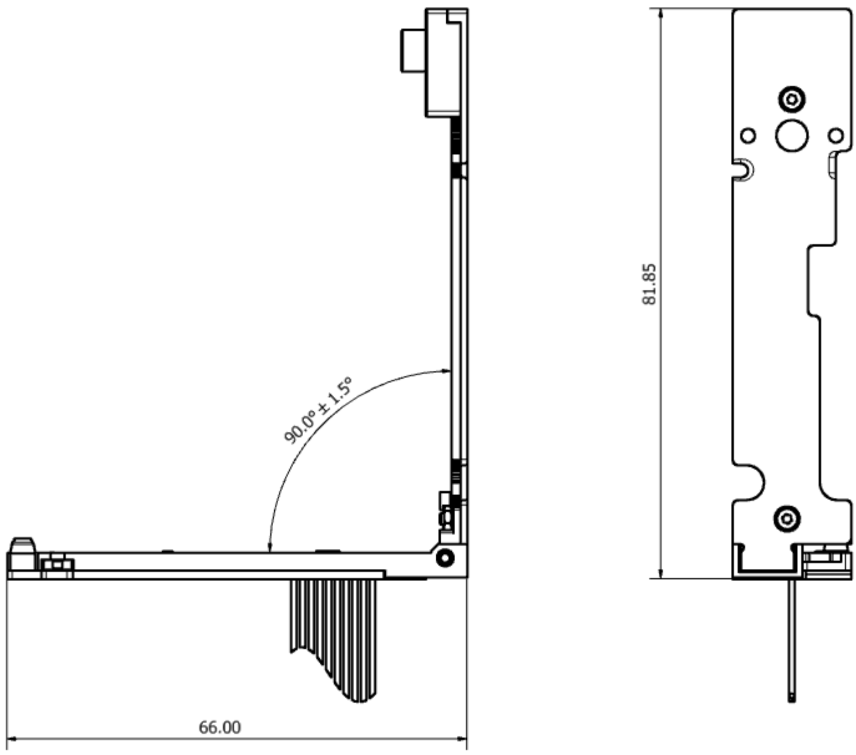

Figure 35: Indicative dimensions of CubeMag Deployable in the deployed state

3.2.1.2 Mounting definition

The deployable magnetometer is designed to mount to an external surface of the satellite. The magnetometer should not be placed in close proximity of any part of the satellite that may cause significant disturbances. See [1] for more details.

The hole placement and panel cut-outs required for mounting of the magnetometer are shown in Figure 36. The dashed line in Figure 36 represents the area the magnetometer will occupy, when in the stowed state, and must not be impinged upon.

Mounting of the deployable magnetometer is performed by way of three (3) non-ferrous M2x0.4mm screws (refer to Figure 36 for screw hole locations) that pass through the magnetometer and thread into the panel onto which the magnetometer is mounted. Alternatively, the screws may pass through both the magnetometer and mounting panel and then secured with nuts on the inside of the panel.

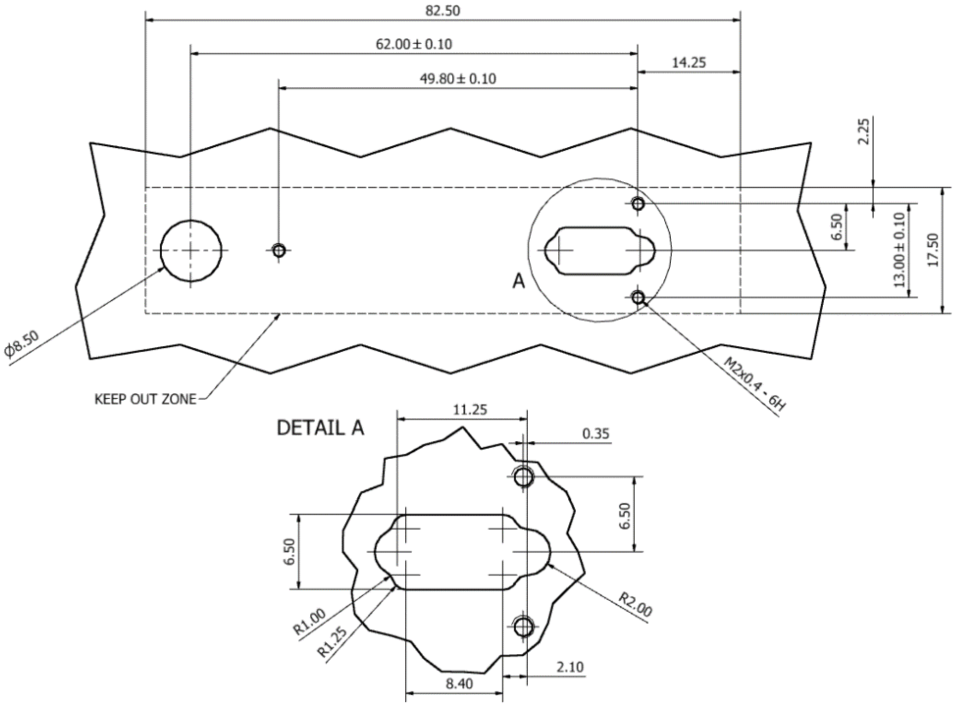

Figure 36: Panel cut-outs required to mount CubeMag Deployable

3.2.1.3 Mass, COM and Inertia

The total mass of the deployable magnetometer including its harness is 15.5 g ± 5 %. The COM position (excluding wire harness) of the deployable magnetometer when in the stowed position is shown in Figure 37.

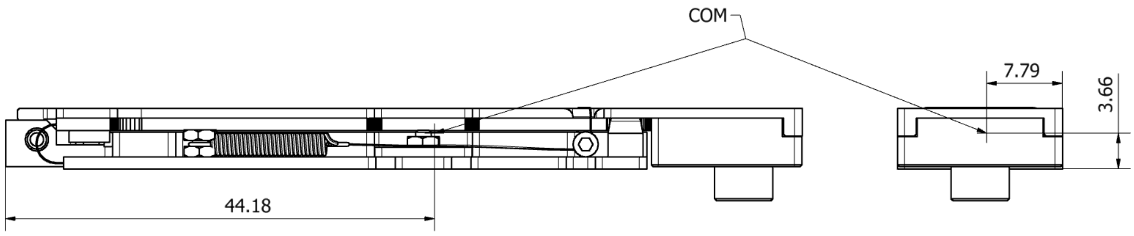

Figure 37: COM position of CubeMag deployable in the stowed state

Figure 38 displays the COM position of the CubeMag deployable (excluding wire harness) in the deployed state.

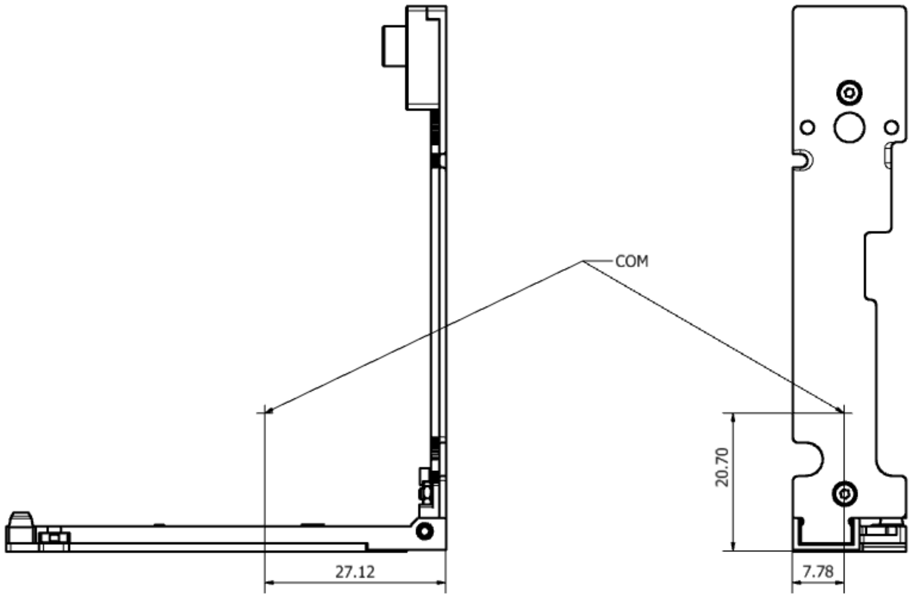

Figure 38: COM position of CubeMag deployable in the deployed state

The moments of inertia of CubeMag deployable in both stowed and deployed states, excluding any wire harness, about their respective COM positions are presented in Table 14, the axes reference for the inertias provided is shown in Figure 39.

Table 14: CubeMag deployable moments of inertia

	STOWED STATE	DEPLOYED STATE
I_{xx} (gmm^2)	316 ± 10 %	12810 ± 10 %
I_{yy} (gmm^2)	8310 ± 10 %	11800 ± 10 %
I_{zz} (gmm^2)	8070 ± 10 %	23880 ± 10 %

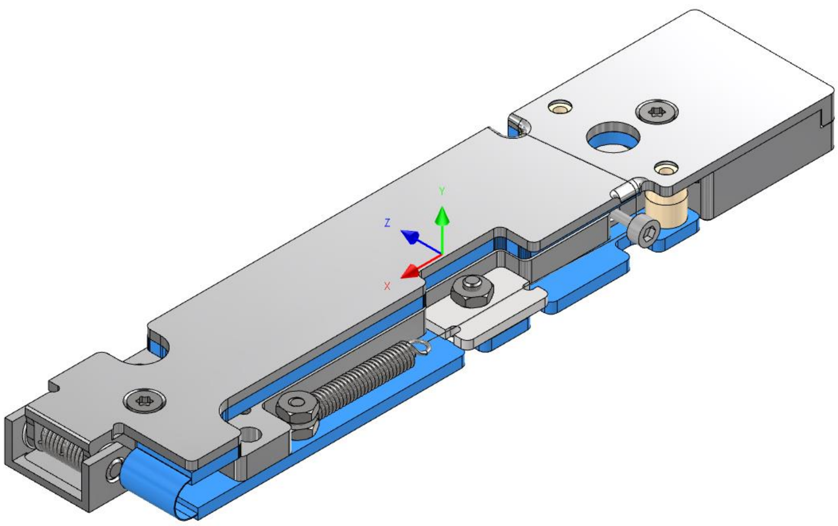

Figure 39: CubeMag deployable inertial reference frame

3.2.1.4 Measurement Coordinate System Definition

The CubeMag Deployable returns the magnetic field as a calibrated measurement[10] via telemetry. This calibrated measurement reference frame is the same for both the primary and secondary magnetometer and is deemed the coordinate system definition of the CubeMag deployable. The reference frame for the primary magnetometer is also the same whether the magnetometer is stowed or deployed. To achieve this, the magnetometer automatically senses whether it is deployed or not and transforms the measurements accordingly.

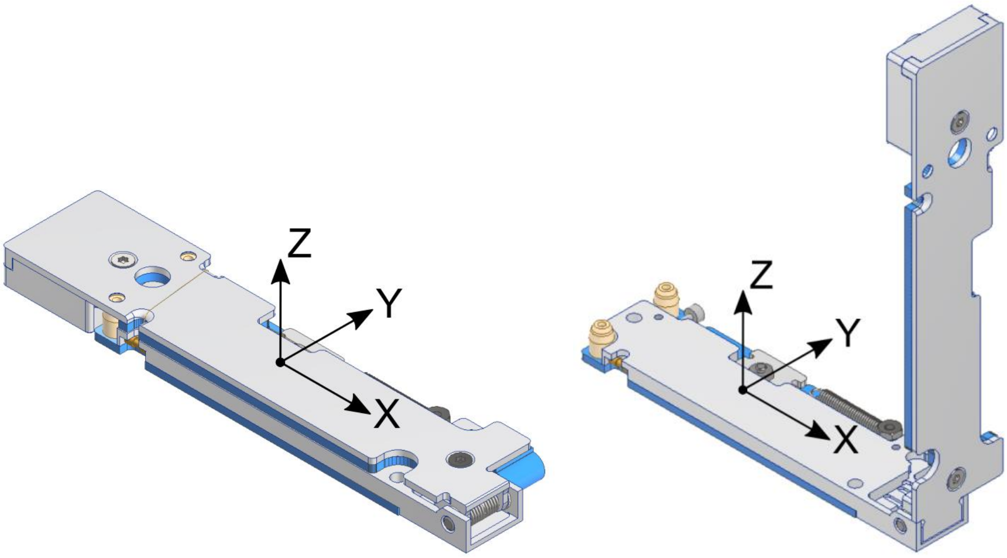

Figure 40: CubeMag deployable coordinate reference frame

3.2.1.5 Electrical Interface

The CubeMag deployable is supplied with a 50mm harness soldered into the CubeMag deployable PCB. The connector on this harness is a 6 pin HARWIN M80-1030698S. A second inline harness is used to connect this harness to the CubeConnect sub-system.

Table 15: CubeMag deployable interface details

CUBEMAG DEPLOYABLE INTERFACE DETAILS				
Header Type:	HARWIN: M80-1030698S			
Number of pins	6			
Mating Housing	HARWIN: M80-8120605			
Housing Terminal	HARWIN: M80-0410005			
CubeMag Deployable Header pin definitions				
Pin #	Pin Name	Pin Description	IO Type	Voltage range [V]
1	Enable	Active high enable	Input	-0.3 to 3.4 $V_{low} < 0.95$

[10] The CubeMag has a Telemetry Message (TLM) for calibrated measurements and a TLM for raw measurements. Only the calibrated measurements TLM follows the reference frame shown in Figure 40.

CUBEMAG DEPLOYABLE INTERFACE DETAILS

				V_{high} > 1.05
2	3V3	Supply voltage for the digital electronics	Power	3.2 to 3.4
3	CAN_P	High level CAN bus line	Differential	-3.4 to 3.4
4	GND	Power ground of electronics	Power	0
5	BOOT	Active High boot line. Leave unconnected if unused.	Input	-0.3 to 3.4 V_{low} < 0.5 V_{high} > 2.6
6	CAN_N	Low level CAN bus line	Differential	-3.4 to 3.4

3.2.2 CubeMag Compact

A CubeADCS bundle can optionally be upgraded with a compact, secondary (redundant) magnetometer. This magnetometer is fully enclosed within an aluminium housing (6082-T6) treated with a chromate conversion coating (Alodine), as shown in Figure 43.

3.2.2.1 Outer Dimensions

The overall dimensions of the CubeMag Compact are shown in Figure 41.

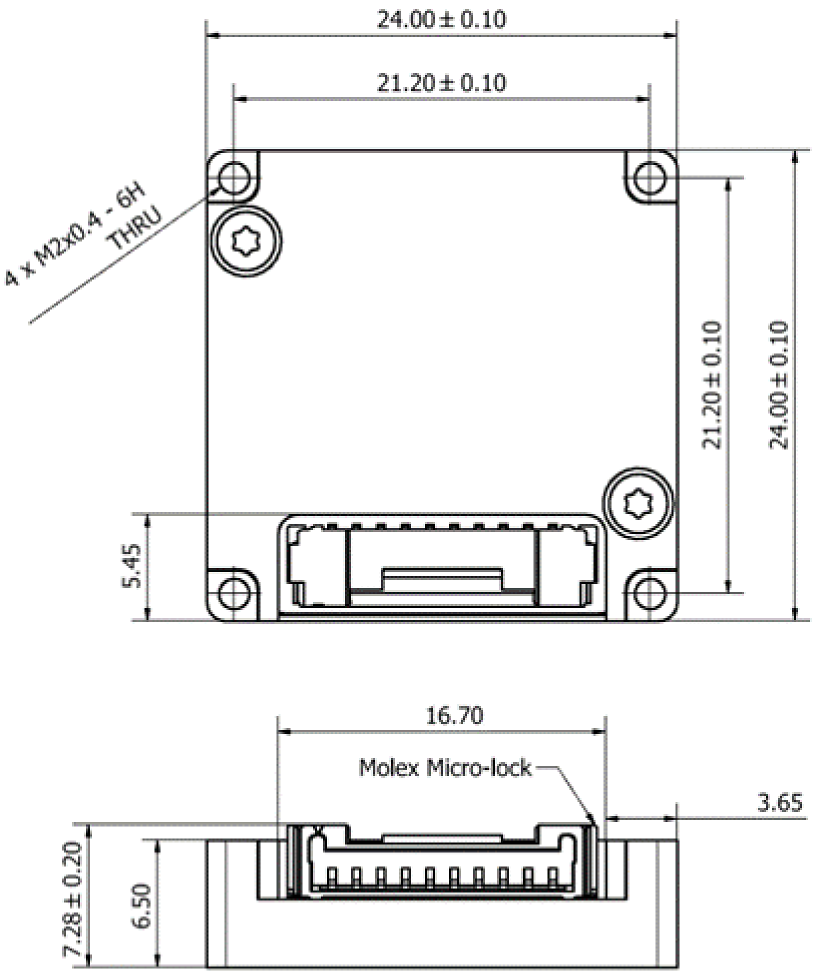

Figure 41: Indicative dimensions of CubeMag Compact

3.2.2.2 Mounting definition

The CubeMag Compact has four (4) M2x0.4mm threaded mounting holes that are used to secure the magnetometer. Non-ferrous screws should be used for securing this CubeProduct. This redundant magnetometer can be mounted with either the top or bottom face against the mounting surface. Regardless of the mounting orientation utilised, sufficient space should be allowed around the Molex connector to ensure easy and reliable connection.

The CubeMag Compact is designed to mount to an external surface of the satellite. The magnetometer should not be placed in close proximity of any other part of the satellite that causes significant disturbances. See [1] for more details.

3.2.2.3 Mass, COM and Inertia

The total mass of the CubeMag Compact is 6.0 g ± 5 %. The COM position of the CubeMag Compact is shown in Figure 42.

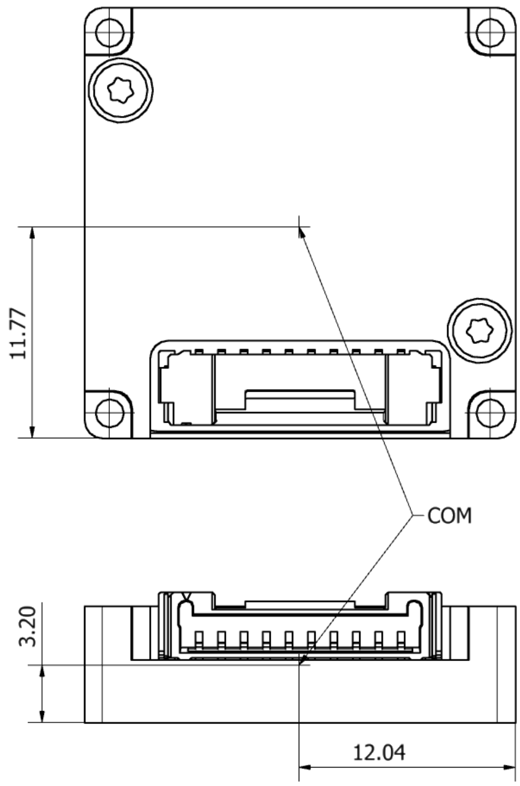

Figure 42: COM position of the CubeMag Compact

The moments of inertia of CubeMag Compact about the COM position are presented in Table 16, the axes reference for the inertias provided is shown in Figure 43.

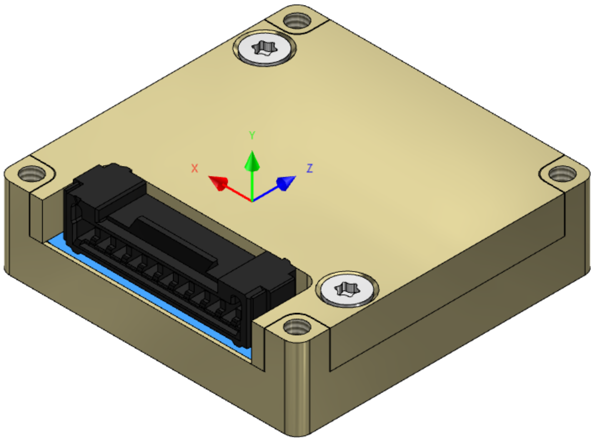

Figure 43: CubeMag Compact Inertial reference frame

Table 16: CubeMag Compact Moments of Inertia (MOI)

AXIS	VALUE
I_{xx} (gmm^2)	134 ± 10 %
I_{yy} (gmm^2)	212 ± 10 %
I_{zz} (gmm^2)	122 ± 10 %

3.2.2.4 Measurement Coordinate System Definition

The coordinate system of the CubeMag Compact is defined and shown in Figure 44. The CubeMag Compact has a TLM for calibrated measurements and a TLM for raw measurements. Only the calibrated measurements TLM follows the reference frame shown in Figure 44.

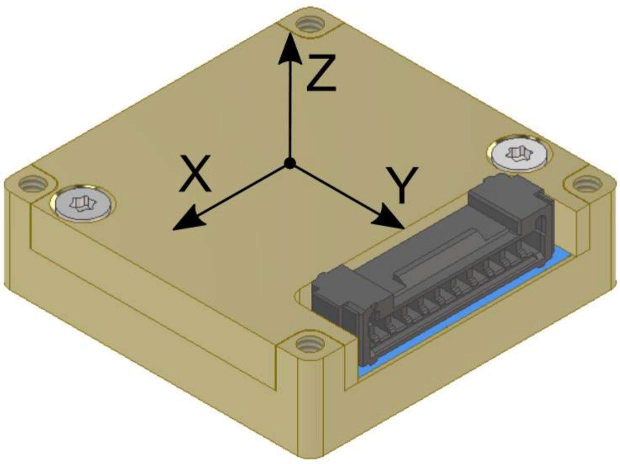

Figure 44: CubeMag Compact coordinate system definition

3.2.2.5 Electrical Interface

A 10 pin Molex 5055671081 right angle header provides the electrical interface to the CubeMag Compact.

Table 17: CubeMag Compact interface details

CUBEMAG COMPACT INTERFACE DETAILS				
Header Type:	Molex 5055671081			
Number of pins	10			
Mating Housing	Molex 5055651001			
Housing Terminal	5037650098			
CubeMag Compact Header pin definitions				
Pin #	Pin Name	Pin Description	IO Type	Voltage range [V]
1	BOOT	Active High boot line. Leave unconnected if unused.	Input	-0.3 to 3.4 V_{low} < 0.5 V_{high} > 2.6
2	GND	Power ground of electronics	Power	0
3	3V3	Supply voltage for the digital electronics	Power	3.2 to 3.4
4	UART_TX (RS485_A)[1]	UART Data Transmit of MCU.	Output	-0.5 to 3.4
5	CAN_P	High level CAN bus line	Differential	-3.4 to 3.4
6	CAN_N	Low level CAN bus line	Differential	-3.4 to 3.4
7	UART_RX (RS485_B)[1]	UART Data Receive of MCU. Pull high if unused.	Input	-0.5 to 3.4
8	GND	Power ground of electronics	Power	0
9	GND	Power ground of electronics	Power	0
10	Enable	Active high enable	Input	-0.3 to 3.4 V_{low} < 0.95 V_{high} > 1.05

[1]CubeMag Compact can be configured for RS485 or UART

3.2.3 CubeSense Sun

The CubeSense Sun sensor is fully enclosed in a housing that also rigidly supports the lens. The aluminium housing is manufactured from aluminium 6082-T6 treated with a chromate conversion coating (Alodine).

3.2.3.1 Outer Dimensions

The overall dimensions of the CubeSense Sun are shown in Figure 45.

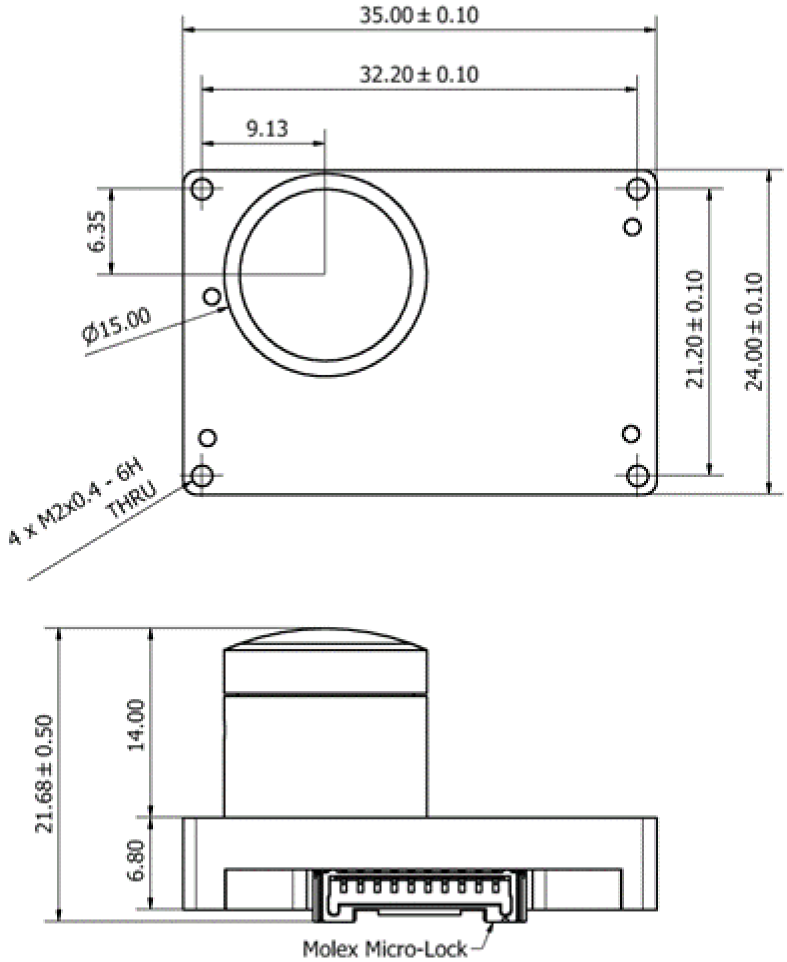

Figure 45: Indicative dimensions of the CubeSense Sun sensor

3.2.3.2 Mounting definition

The CubeSense Sun should be mounted on a satellite's side-panel by way of four (4) M2x0.4mm threaded mounting holes as noted in Figure 45. It is very important to ensure that the camera lens protrudes completely through the side panels of the satellite, as demonstrated in Figure 46.

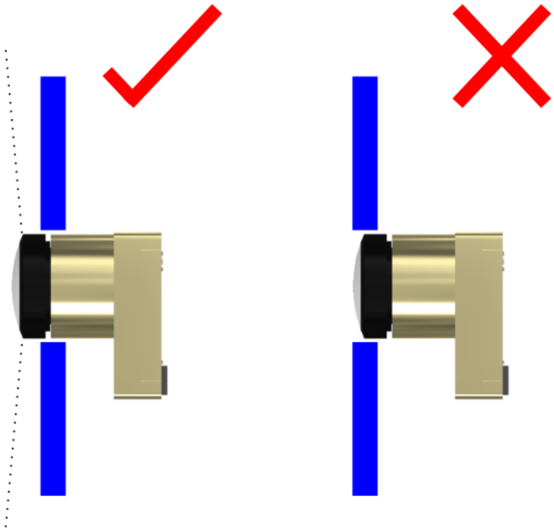

Figure 46: Correct and Incorrect Protruding Distance

If the lens does not protrude fully through the side panel, the sensor will detect reflections from the side panels. Best practice is to have the lens protrude as far as possible from the side panel. The CubeSense lens has a 200-degree FOV of which 180-degrees are evaluated for sun detection as shown inFigure 47.

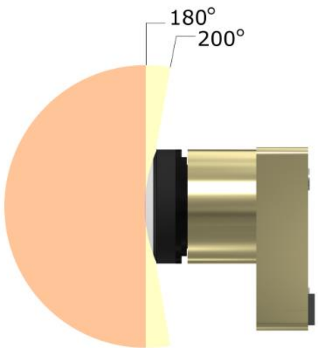

Figure 47: CubeSense FOV

Any reflective panels in the CubeSense FOV should/can be masked in software using the instructions provided in the User Manual [4] The User Manual is typically only supplied to clients once an order has been placed.

3.2.3.3 Mass, COM and Inertia

The CubeSense Sun has a mass of 15.0 g ± 5 %. Figure 48 indicates the COM position.

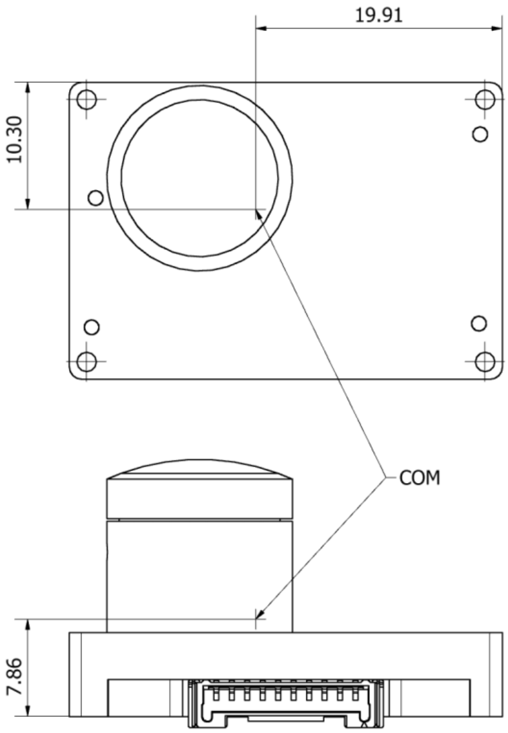

Figure 48: COM position of CubeSense Sun

The moments of inertia of the CubeSense Sun about the COM position are presented in Table 18, the axes reference for the inertias is shown in Figure 49.

Table 18: CubeSense Sun Moments of Inertia (MOI)

AXIS	VALUE
I_{xx} (gmm^2)	909 ± 10 %
I_{yy} (gmm^2)	980 ± 10 %
I_{zz} (gmm^2)	747 ± 10 %

3.2.3.4 Measurement Coordinate System Definition

The vector output used by the CubeSense Sun follows the axis definition shown in Figure 49

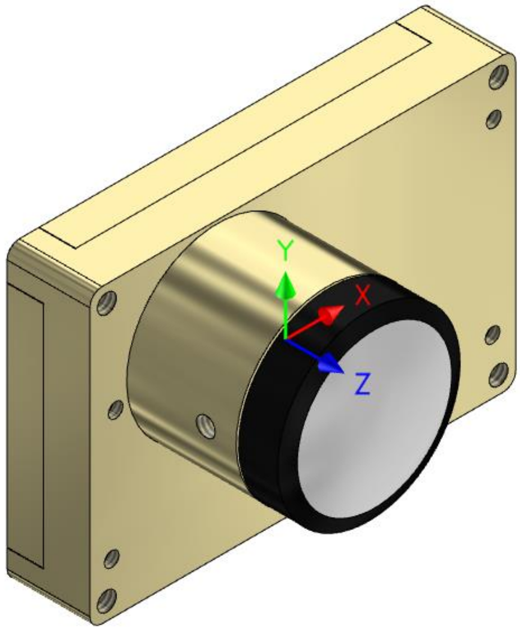

Figure 49: CubeSense Sun coordinate system definition

3.2.3.5 Electrical Interface

Table 19: CubeSense Sun interface details

CUBESENSE SUN INTERFACE DETAILS	
Header Type:	Molex 5055671081
Number of pins	10
Mating Housing	Molex 5055651001
Housing Terminal	5037650098

CUBESENSE SUN HEADER PIN DEFINITION				
Pin #	Pin Name	Pin Description	IO Type	Voltage range [V]
1	BOOT	Active High boot line. Leave unconnected if unused.	Input	-0.3 to 3.4 $V_{low} < 0.5$ $V_{high} > 2.6$
2	GND	Power ground of electronics	Power	0
3	3V3	Supply voltage for the digital electronics	Power	3.2 to 3.4
4	UART_TX (RS485_A)[1]	UART Data Transmit of MCU.	Output	-0.5 to 3.4
5	CAN_P	High level CAN bus line	Differential	-3.4 to 3.4
6	CAN_N	Low level CAN bus line	Differential	-3.4 to 3.4
7	UART_RX (RS485_B)[1]	UART Data Receive of MCU. Pull high if unused.	Input	-0.5 to 3.4
8	GND	Power ground of electronics	Power	0
9	GND	Power ground of electronics	Power	0

CUBESENSE SUN INTERFACE DETAILS				
10	Enable	Active high enable	Input	-0.3 to 3.4 $V_{low} < 0.95$ $V_{high} > 1.05$

[1] CubeSense Sun can be configured for RS485 or UART

3.2.4 CubeSense Earth

The CubeSense Earth sensor is fully enclosed in an aluminium housing manufactured from aluminium 6082-T6 treated with a chromate conversion coating (Alodine). A Molex Micro-lock connector is used to interface with the sensor, as indicated in Figure 50

3.2.4.1 Outer Dimensions

The overall dimensions of the CubeSense Earth are shown in Figure 50

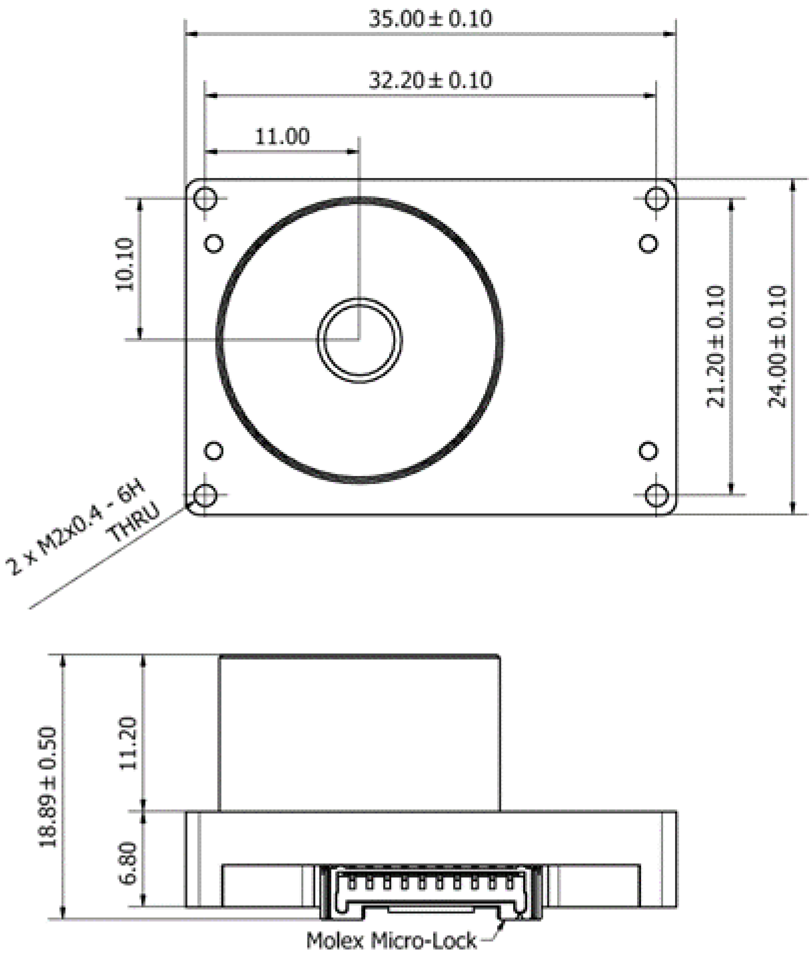

Figure 50: Indicative dimensions of the CubeSense Earth sensor

3.2.4.2 Mounting definition

The CubeSense Earth should ideally be mounted so that the earth horizon will be in the centre of the camera field of view for the satellite's nominal flight orientation. The sensor will then be able to give valid measurements at higher elevation and roll rotations. The detection field of view is 90 degrees horizontal, 80 degrees vertical and 90 degrees diagonal. See Figure 51 for the CubeSense Earth axis definitions. The exclusion field of view, which should be kept clear of obstructions from the satellite, is 90 degrees vertical and 120 degrees horizontal. If this exclusion area cannot be accommodated, contact CubeSpace for arrangement to implement special masking software to mitigate negative effects.

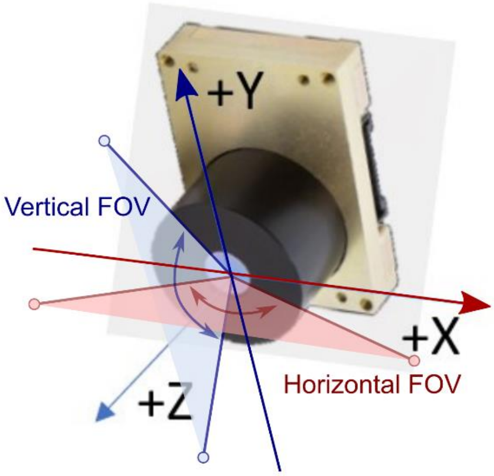

Figure 51: CubeSense Earth Axis definition

3.2.4.3 Mass, COM and Inertia

The CubeSense Earth has a mass of 18.0 g ± 5 %. Figure 52 displays the COM position.

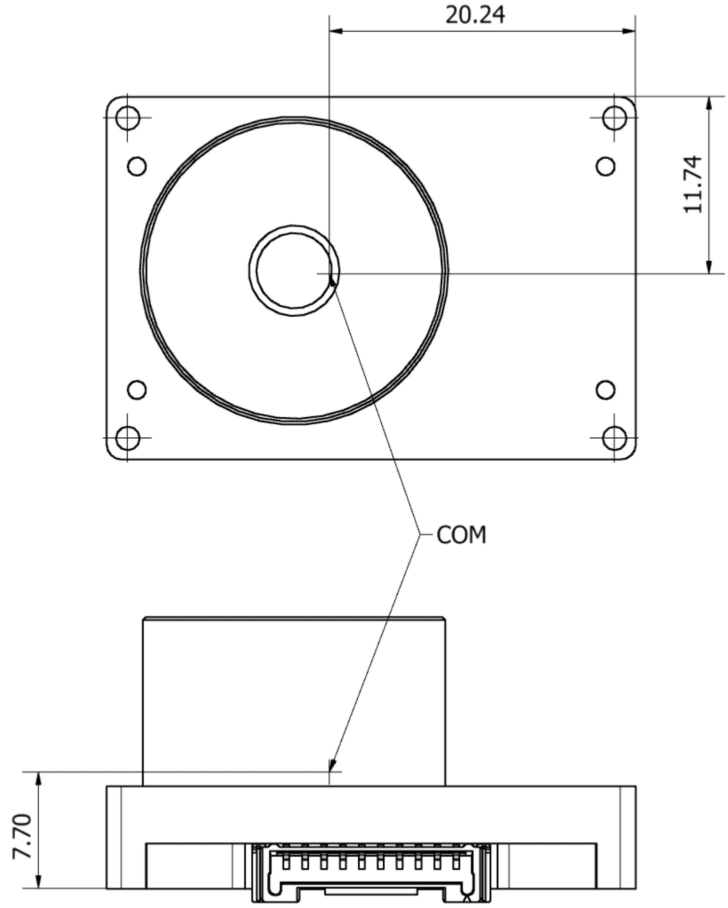

Figure 52: COM position of CubeSense Earth

The moments of inertia of the CubeSense Earth about the COM position are presented in Table 20, the axes reference for the inertias provided is shown in Figure 51.

Table 20: CubeSense Earth Moments of Inertia (MOI)

AXIS	VALUE
I_{xx} (gmm^2)	1081 ± 10 %
I_{yy} (gmm^2)	852 ± 10 %
I_{zz} (gmm^2)	1000 ± 10 %

3.2.4.4 Measurement Coordinate System Definition

Refer to Figure 51 for the coordinate system definition of the CubeSense Earth.

3.2.4.5 Electrical Interface

A 10 pin Molex 5055671081 right angle header provides the electrical interface to the CubeSense Earth.

Table 21: CubeSense Earth Interface details

CUBESENSE EARTH INTERFACE DETAILS	
Header Type:	Molex 5055671081

CUBESENSE EARTH INTERFACE DETAILS	
Number of pins	10
Mating Housing	Molex 5055651001
Housing Terminal	5037650098

CUBESENSE EARTH HEADER PIN DEFINITIONS				
Pin #	Pin Name	Pin Description	IO Type	Voltage range [V]
1	BOOT	Active High boot line. Leave unconnected if unused.	Input	-0.3 to 3.4 V_{low} < 0.5 V_{high} > 2.6
2	GND	Power ground of CubeWheel electronics	Power	0
3	3V3	Supply voltage for the digital electronics	Power	3.2 to 3.4
4	UART_TX (RS485_A)[1]	UART Data Transmit of MCU.	Output	-0.5 to 3.4
5	CAN_P	High level CAN bus line	Differential	-3.4 to 3.4
6	CAN_N	Low level CAN bus line	Differential	-3.4 to 3.4
7	UART_RX (RS485_B)[1]	UART Data Receive of MCU. Pull high if unused.	Input	-0.5 to 3.4
8	GND	Power ground of electronics	Power	0
9	GND	Power ground of CubeWheel electronics	Power	0
10	Enable	Active high enable	Input	-0.3 to 3.4 V_{low} < 0.95 V_{high} > 1.05

[1]CubeSense Earth can be configured for RS485 or UART

3.2.5 CubeStar

The CubeStar star tracker is fully enclosed in an aluminium housing manufactured from AL 6082-T6, treated with a chromate conversion coating (Alodine), that rigidly supports the lens. The enclosure has a section of M24x1.5mm thread for the addition of a baffle to improve the performance of CubeStar. A Molex Micro-lock connector is used to interface with the CubeStar as shown in Figure 53.

3.2.5.1 Outer Dimensions

Figure 53 shows the indicative outer dimensions of CubeStar.

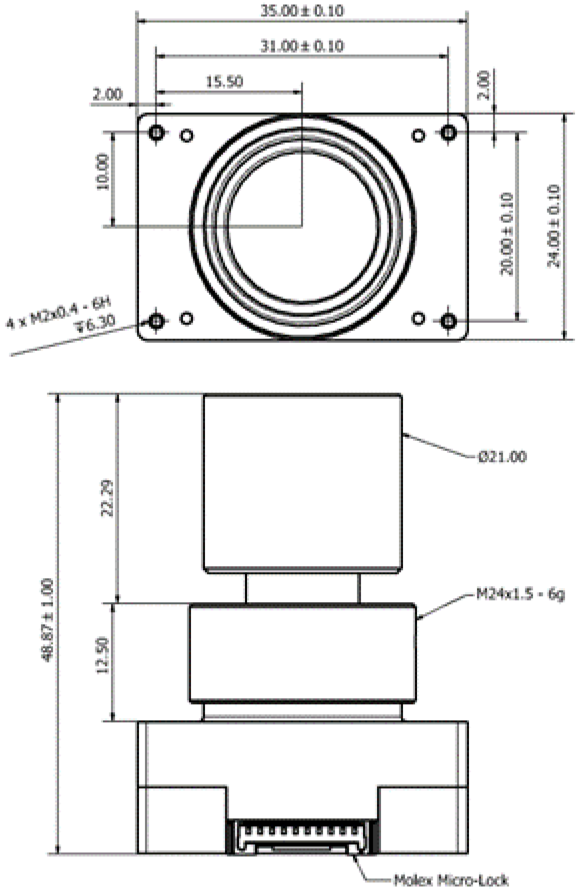

Figure 53: Indicative dimensions of CubeStar

3.2.5.2 Mounting definition

Mounting of the CubeStar is performed through four (4) blind M2x0.4mm threaded holes as shown in Figure 53. The CubeStar can only be secured/mounted via the threaded holes on the face (lens side) of the enclosure as indicated. The lens of the CubeStar does not require additional external support, it is sufficiently supported by the housing.

3.2.5.3 Mass, COM and Inertia

The CubeStar has a mass of 47.0 g ± 5 %. Figure 54 displays the COM position.

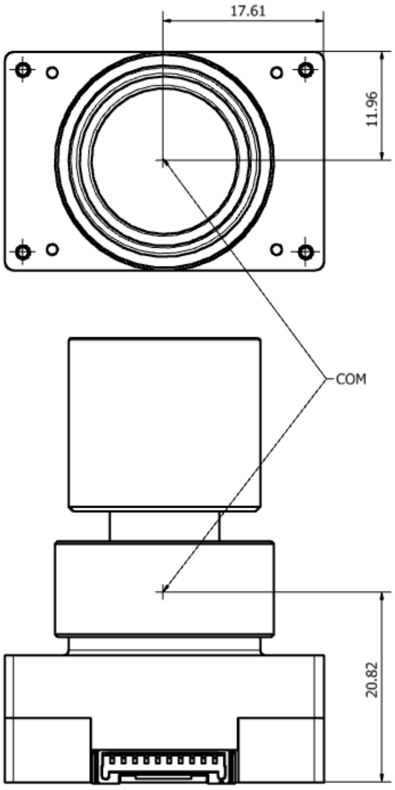

Figure 54: COM position of CubeStar

The moments of inertia of the CubeStar about the COM position are presented in Table 22, the axes reference for the inertias provided is shown in Figure 55.

Table 22: CubeStar Moments of Inertia (MOI)

AXIS	VALUE
I_{xx} (gmm^2)	6710 ± 10 %
I_{yy} (gmm^2)	6548 ± 10 %
I_{zz} (gmm^2)	530 ± 10 %

3.2.5.4 Measurement Coordinate System Definition

The coordinates system definition used by the CubeStar is presented in Figure 55

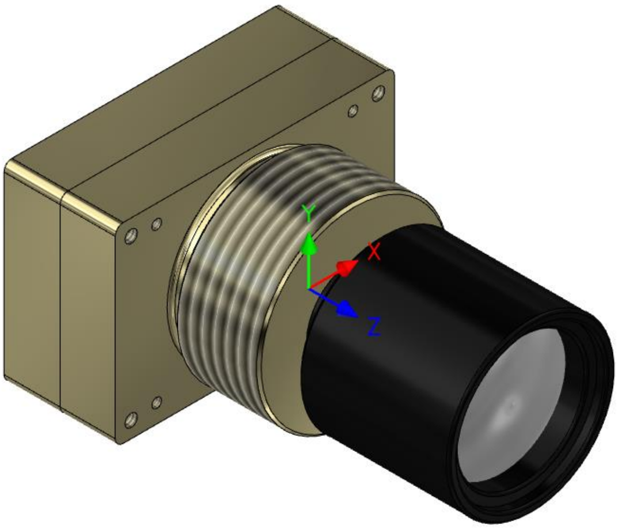

Figure 55: CubeStar Coordinate system definition

3.2.5.5 Electrical Interface

A 10 pin Molex 5055671081 right angle header provides the electrical interface to CubeStar. The details are described in Table 23.

Table 23: CubeStar Electrical Interface

CUBESTAR INTERFACE DETAILS				
Header Type:		Molex Micro-lock Plus, single row 5055671081		
Number of pins		10		
Mating Housing		Molex Micro-Lock Plus Receptacle Crimp Housing 5055651001		
Housing Terminal		Molex Micro-Lock Female crimp Terminal, Gold, 26-30 AWG, 5054311100		
CUBESTAR HEADER PIN DEFINITIONS				
Pin #	Pin Name	Pin Description	IO Type	Voltage range [V]
1	Boot	Active high boot line. Leave unconnected if unused.	Input	-0.3 to 3.4 $V_{low} < 0.5$ $V_{high} > 2.6$
2	GND	Power ground of electronics.	Power	0
3	3V3	Supply voltage for the digital electronics.	Power	3.2 to 3.4
4	UART Tx /RS485 Tx	UART/RS485 Data Transmit of MCU.	Output	-0.5 to 3.4
5	CAN P	High level CAN bus line.	LVDS	-3.4 to 3.4
6	CAN N	Low level CAN bus line.	LVDS	-3.4 to 3.4
7	UART Rx /RS485 Rx	UART/RS485 Data Receive of MCU.	Input	-0.5 to 3.4
8	GND	Power ground of electronics.	Power	0
9	GND	Power ground of electronics.	Power	0
10	Enable	Active high enable.	Input	-0.3 to 3.4

CUBESTAR INTERFACE DETAILS				
				$V_{low} < 0.95$ $V_{high} > 1.05$

3.2.6 CubeNode

The CubeNode is fully enclosed by an aluminium housing manufactured from al 6082-T6 treated with a chromate conversion coating (Alodine). Molex Micro-Lock connectors are used to interface with the sensor, as indicated in Figure 56.

3.2.6.1 Outer Dimensions

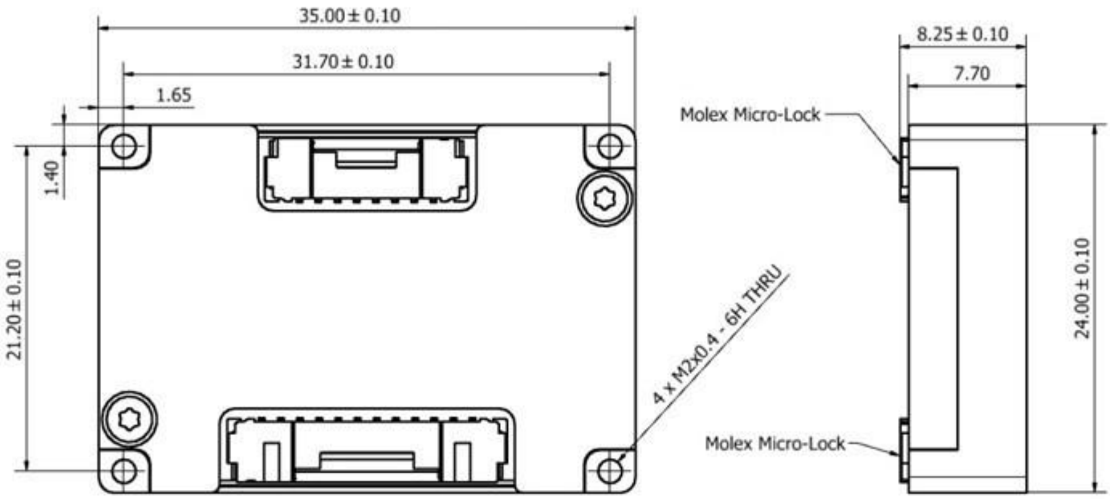

Figure 56: Indicative dimensions of CubeNode

3.2.6.2 Mounting definition

The CubeNode is mounted via four (4) M2x0.4mm screws threaded into the housing, spaced as shown in Figure 56. The threaded holes pass through the full height of the CubeNode allowing for the unit to be mounted on either face perpendicular to the threaded hole axis

3.2.6.3 Mass, COM and Inertia

The total mass of the CubeNode is 9.0 g ± 5 %. The COM position of the CubeNode is shown in Figure 57.

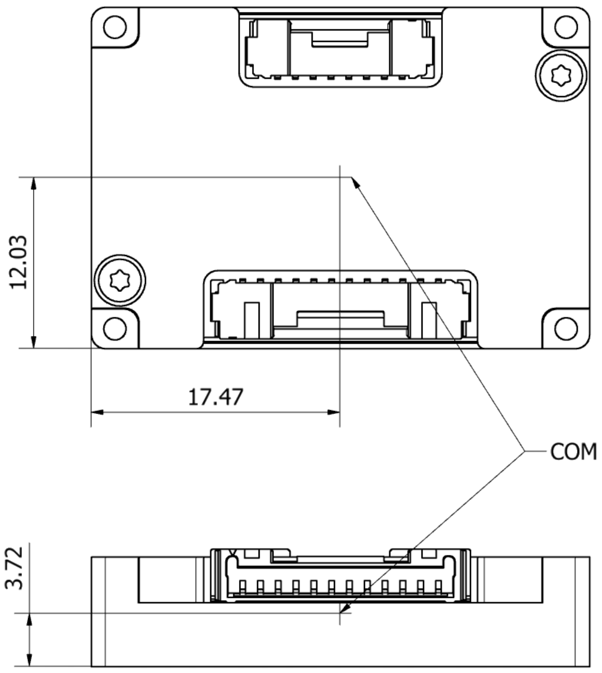

Figure 57: COM position of the CubeNode

The moments of inertia of CubeNode about the COM position are presented in Table 24, the axes reference for the inertias provided is shown in Figure 58.

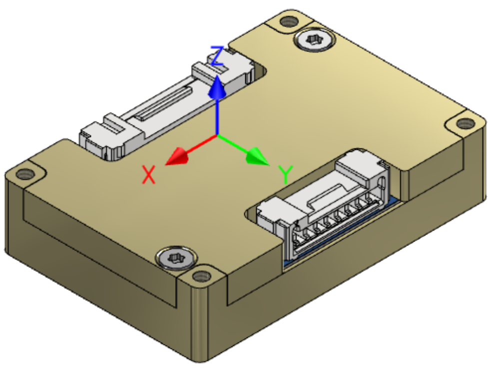

Figure 58: CubeNode Inertial reference frame

Table 24: CubeNode Moments of Inertia

AXIS	VALUE
I_{xx} (gmm^2)	562 ± 10 %
I_{yy} (gmm^2)	1240± 10 %
I_{zz} (gmm^2)	1678± 10 %

3.2.6.4 Measurement Coordinate System Definition

The CubeNode does not implement / utilise a coordinate reference frame per se as it merely serves as an interconnect between the CubeComputer and third-party sensor and actuators. Attitude data (if any) will only be relayed by the CubeNode, and that attitude will be relative to the third-party device, not CubeNode.

3.2.6.5 Electrical Interface

A 12 pin Molex 5055671281 right angle header provides the electrical interface to CubeNode. The details are described in Table 25.

Table 25: CubeNode Interface Details

CUBENODE INTERFACE DETAILS	
Header Type:	Molex Micro-lock Plus, single row 5055671281
Number of pins	12
Mating Housing	Molex Micro-Lock Plus Receptacle Crimp Housing 5055651201
Housing Terminal	Molex Micro-Lock Female crimp Terminal, Gold, 26-30 AWG, 5054311100

CUBENODE HEADER PIN DEFINITIONS				
Pin #	Pin Name	Pin Description	IO Type	Voltage range [V]
1	Boot	Active high boot line. Leave unconnected if unused.	Input	-0.3 to 3.4 $V_{low} < 0.5$ $V_{high} > 2.6$
2	GND	Power ground of electronics	Power	0
3	3V3	Supply voltage for the digital electronics	Power	3.2 to 3.4
4	UART Tx	UART Data Transmit of MCU	Output	-0.5 to 3.4
5	CAN P	High level CAN bus line	LVDS	-3.4 to 3.4
6	CAN N	Low level CAN bus line	LVDS	-3.4 to 3.4
7	UART Rx	UART Data Receive of MCU	Input	-0.5 to 3.4
8	GND	Power ground of electronics	Power	0
9	5V	Supply voltage if required by third party device	Power	4.9 to 5.1
10	Enable	Active high enable	Input	-0.3 to 3.4 $V_{low} < 0.95$ $V_{high} > 1.05$
11	PPS L	Pulse Per Second low	LVDS	0 to 3.3
12	PPS H	Pulse Per Second high	LVDS	0 to 3.3

3.2.7 Coarse Sun Sensors

The Coarse Sun Sensors (CSS) should be mounted on the external surfaces of the satellite panels. It is necessary to ensure that these sensors are not shadowed by other deployable structures. Up to ten Coarse Sun Sensors can be supplied by CubeSpace. Placement of the sensors is at the client’s discretion, typically one sensor must be placed on each of the six external surfaces of the satellite. The four extra photodiodes can be placed on any faces, bearing in mind that shadowing is to be minimised.

Ensure that the photodiodes are kept clear of epoxy or glue

If solar panels already have photodiodes mounted on them, contact the CubeSpace team to discuss the possibility of pairing them with the CubeADCS. CubeSpace makes use of the SLCD-61N8 planar photodiodes from "Silonex inc"/"Advanced Photonix". Any photodiodes with the same specifications should work with the CubeADCS.

3.2.7.1 Outer Dimensions

Indicative dimensions of a Coarse Sun Sensor without a harness are shown in Figure 59

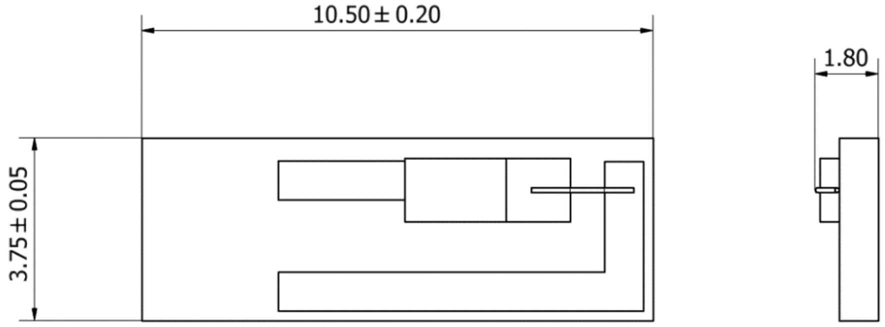

Figure 59: Indicative dimensions of a Coarse Sun Sensor

3.2.7.2 Mounting definition

The CSSs do not have mounting holes – they should be attached to the satellite body using epoxy as shown inFigure 60.

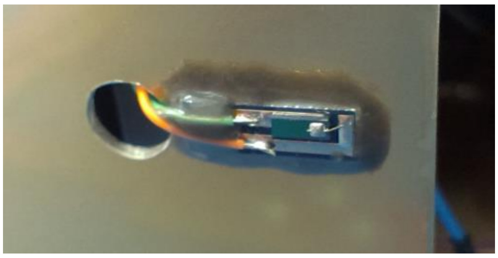

Figure 60: Coarse sun sensor epoxied to satellite body

3.2.7.3 Mass, COM and Inertia

The mass of a CSS is considered negligible.

3.2.7.4 Electrical Interface

The CSS are provided with harnesses which contains in line 2-pin Molex PicoBlade headers. The length of the standard harness is 50 mm.

Figure 61: Single coarse sun sensor PCB and cable

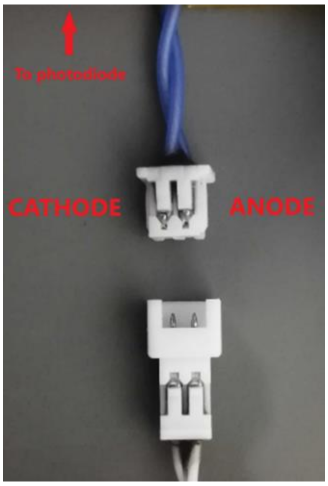

Figure 62: Coarse sun sensor in-line harness pins

Table 26: Coarse Sun Sensor Interface Details

COARSE SUN SENSOR INTERFACE DETAILS				
Header Type:	Molex PicoBlade Receptacle Housing			
Number of pins	2			
Mating Housing	PicoBlade Plug Housing			
Housing Terminal	PicoBlade Male Crimp Terminal			
COARSE SUN SENSOR HEADER PIN DEFINITIONS				
Pin #	Pin Name	Pin Description	IO Type	Voltage range [V]
1	GND	Anode	Input	-0.1 to 0.1
2	Vout	Cathode	Output	-0.1 to 3.4

3.2.8 CubeTorquer

All CubeTorquers have the same basic layout as shown in Figure 63. The torquers are composed of two aluminium mounting brackets, treated with a chromate conversion coating (Alodine), on either end of the magnetic core over which the windings are added. Each torquer is equipped with a 2-pin Molex Pico-Lock connector for interfacing.

3.2.8.1 Outer Dimensions

The physical size and mounting points for the various CubeTorquers are given in Table 27. The dimensions provided in Table 27 are in reference to Figure 63.

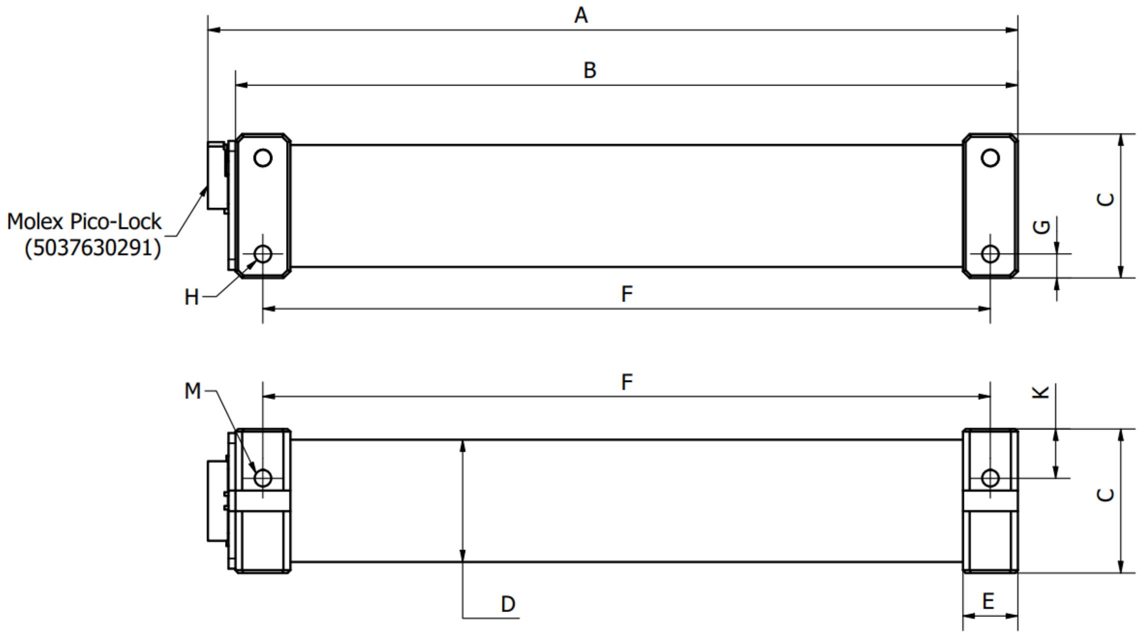

Figure 63: Indicative dimensions of CubeTorquer

Table 27: CubeTorquer dimensions for each variant

<table>
<tr><th>MODEL</th><th>MAGNETIC MOMENT (AM²)</th><th>A (MM)</th><th>B (MM)</th><th>C (MM)</th><th>D (MM)</th><th>E (MM)</th><th>F (MM)</th><th>G (MM)</th><th>H</th><th>K (MM)</th><th>M</th></tr>
<tr><td>CR0002</td><td>0.2</td><td>47.0</td><td>45.0±0.2</td><td rowspan="6">10.5±0.1</td><td>9.3</td><td rowspan="6">4.0</td><td>41.0±0.1</td><td rowspan="8">1.75 ± 0.05</td><td rowspan="8">M1.6 X 0.35 THRU</td><td rowspan="6">3.60±0.05</td><td rowspan="8">M1.6X0.35 3.2 DEEP</td></tr>
<tr><td>CR0003</td><td>0.3</td><td>59.0</td><td>57.0±0.2</td><td>9.3</td><td>53.0±0.1</td></tr>
<tr><td>CR0004</td><td>0.4</td><td>59.0</td><td>57.0±0.2</td><td>9</td><td>53.0±0.1</td></tr>
<tr><td>CR0006</td><td>0.6</td><td>77.0</td><td>75.0±0.2</td><td>9.1</td><td>71.0±0.1</td></tr>
<tr><td>CR0008</td><td>0.8</td><td>92.0</td><td>90±0.2</td><td>8.4</td><td>86.0±0.15</td></tr>
<tr><td>CR0010</td><td>1.0</td><td>92.0</td><td>90±0.2</td><td>8.4</td><td>86.0±0.15</td></tr>
<tr><td>CR0012</td><td>1.2</td><td>122.0</td><td>120.0±0.3</td><td rowspan="2">13.0±0.1</td><td>8.3</td><td rowspan="2">5.0</td><td>115.0±0.2</td><td rowspan="2">4.8±0.05</td></tr>
<tr><td>CR0020</td><td>2.0</td><td>152.0</td><td>150.0±0.3</td><td>8.0</td><td>145.0±0.2</td></tr>
</table>

3.2.8.2 Mounting definition

A CubeTorquer can be mounted on one of three faces using a pair of mounting holes. Two mounting faces that are parallel to one another share a M1.6x0.35 mm tapped hole (see dimension H in Table 27) that pass through the full length of the bracket. The third mounting face that can be used has a M1.6 x 0.35 mm tapped hole (see dimension M in Table 27) of finite depth.

A CubeTorquer should always be mounted to a rigid and flat surface far from any magnetometers or other components overly sensitive to the magnetic field produced by a CubeTorquer.

Magnetic torquer rods must be placed carefully inside the satellite to ensure that neighbouring rods do not cause crosstalk on each other.

Figure 64 indicates some valid and invalid placement options of two rods with respect to one another. Each combination of two rods within the set of 3 rods must adhere to these placement rules.

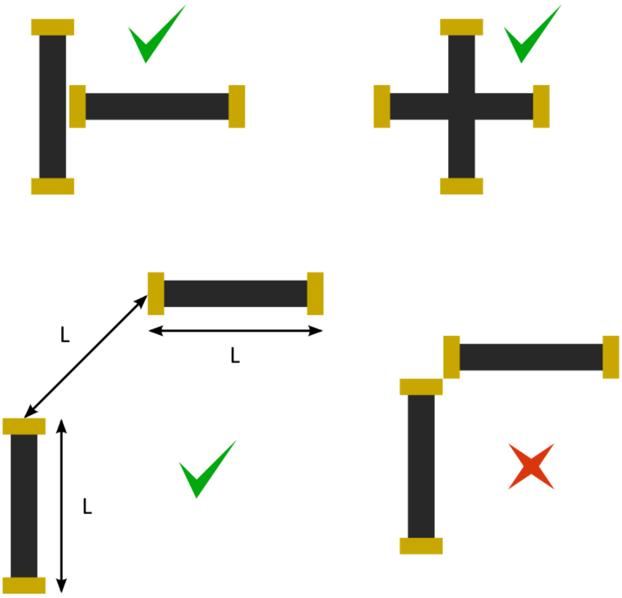

Figure 64: Placement of CubeTorquers with respect to each other

3.2.8.3 Mass, COM and Inertia

The position of the COM and its respective dimensions P, Q and R are shown in Figure 65 with their values detailed in Table 28. The inertial reference frame for all inertia's provided in is the same as the coordinate system definition shown in Figure 66.

Table 28: CubeTorquer mass, COM and inertia for each variant

MODEL	MASS [G]	COM (MM)			INERTIA AROUND COM (GMM^2)		
		P	Q	R	I_{xx}	I_{yy}	I_{zz}
CR0002	16	22.96	5.31	5.26	2889± 10 %	2886± 10 %	170± 10 %
CR0003	24	28.89	5.29	5.26	6659± 10 %	6656± 10 %	246± 10 %
CR0004	23	28.92			6241± 10 %	6239± 10 %	215± 10 %
CR0006	31	37.89	5.28	5.25	14933± 10 %	14930± 10 %	301± 10 %
CR0008	30	45.49	5.28	5.25	21556± 10 %	21553± 10 %	242± 10 %
CR0010	37	45.39			25564± 10 %	25561± 10 %	321± 10 %
CR0012	45	60.43	6.53	6.52	60299± 10 %	60293± 10 %	415± 10 %
CR0020	54	75.45			111583± 10 %	111577± 10 %	462± 10 %

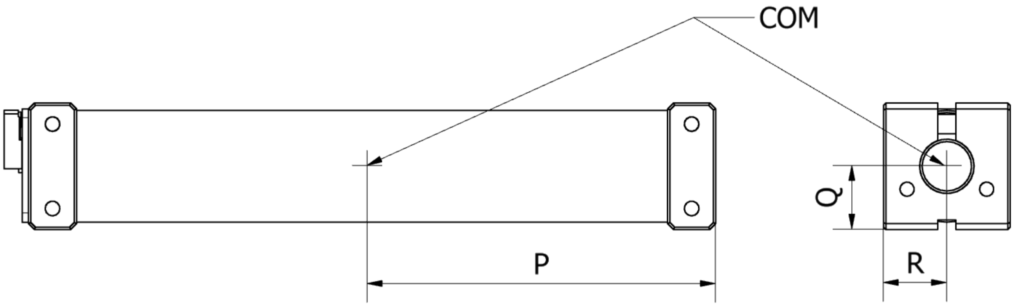

Figure 65: COM position of a CubeTorquer

3.2.8.4 Coordinate System Definition

The coordinates system definition used by the CubeTorquer is presented in Figure 66. This image also displays the magnetic moment direction generated when a positive voltage on Pin V+ relative to Pin V- is applied.

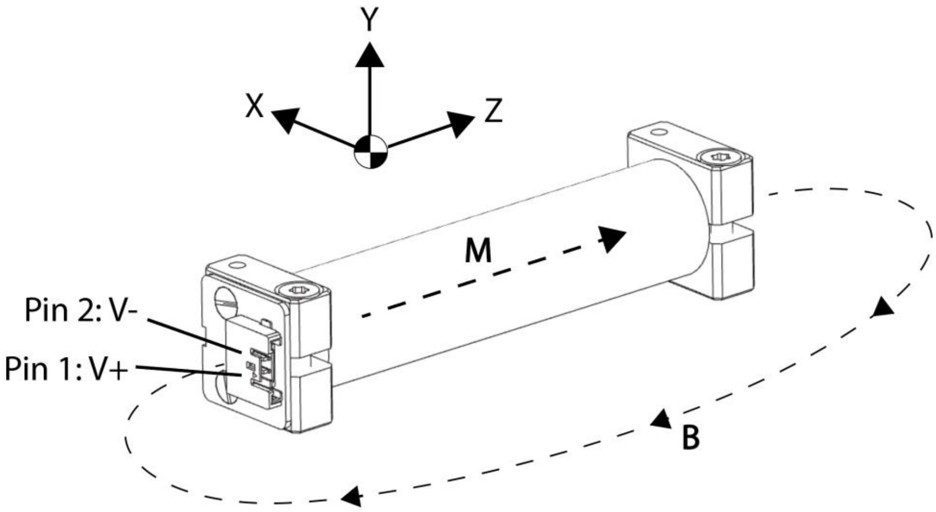

Figure 66: CubeTorquer coordinate system and magnetic polarity definition

3.2.8.5 Electrical Interface

The electrical interface utilised by a CubeTorquer is detailed in Table 29 below.

Table 29: CubeTorquer Electrical interface

MAGNETORQUER HEADER DETAILS				
Header Type:	Molex Pico-Lock, single row, 5037630291			
Number of pins	2			
Number of Headers:	1			
Mating Housing	Molex Pico-lock, 1mm, single row crimp housing			
Housing Terminal	Molex 1mm, Pico-Lock Female crimp Terminal, 28-30 AWG, Gold 5037650098			
CUBECONNECT MAGNETORQUER HEADER PIN DEFINITIONS				
Pin #	Pin Name	Pin Description	IO Type	Voltage range [V]

MAGNETORQUER HEADER DETAILS				
1	T+	CubeTorquer 1 pin 1 (V+)	Output, PWM driven H-Bridge	GND-5V$_{regulated}$/5V$_{Supplied}$
2	T-	CubeTorquer 1 pin 2 (V-)	Output, PWM driven H-Bridge	GND-5V$_{regulated}$/5V$_{Supplied}$

3.2.9 CubeWheel

The CubeWheel reaction wheel comprises a high-performance electric motor driving a balanced flywheel. These components are housed within a robust enclosure made from 6082-T6 aluminium treated with a chromate conversion coating (Alodine).

3.2.9.1 Outer Dimensions

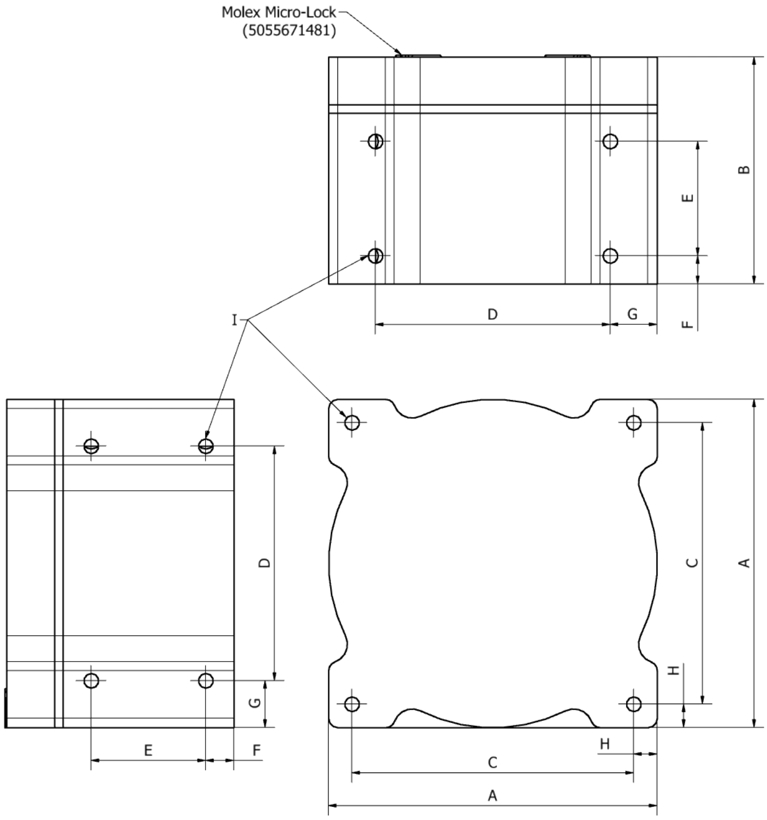

Figure 67: Indicative dimensions of CubeWheel

Table 30: CubeWheel dimensions for each variant

MODEL	MOMENTUM @ 6000 RPM (MNMS)	A (MM)	B (MM)	C (MM)	D (MM)	E (MM)	F (MM)	G (MM)	H (MM)	I
CW0057	5.7	35.0±0.1	24.2±0.2	30.0±0.1	25.0±0.1	12.2±0.1	3.0	3.0	3.0	M2x0.4 4.00 Deep
CW0162	16.2	46.2±0.1	24.2±0.2	39.8±0.1	32.2±0.1	13.2±0.1	2.5	2.5	2.5	M3x0.5 4.5 Deep (Helicoil)

3.2.9.2 Mounting definition

Mounting of wheels should be to a rigid part of the satellite and ideally to more than one side of the wheel. Improper mounting or a flimsy structure can easily result in vibration amplification that can damage the wheel bearings. Fasten the wheels using a torque wrench to achieve 1.2 Nm for the M3 helicoil protected holes and between 0.25 and 0.30 Nm for the M2 threaded aluminium holes. Ensure that all mounting screws are potted before conducting vibration tests.

Each CubeWheel has three orthogonal faces with four mounting holes on each face, refer to Figure 67 for the dimensions of these mounting holes.

3.2.9.3 Mass, COM and Inertia

The mass, COM and Inertia of each respective CubeWheel variant are shown in Table 31. This table also gives the flywheel inertia. The flywheel is free to spin when the motor is not actively controlling the rotation and should therefore not contribute to the total satellite inertia.

The position of the COM and its respective dimensions K, L and M are shown in Figure 68. The inertial reference frame for all inertia's provided in Table 31 is displayed in Figure 69.

Table 31: CubeWheel mass, COM and inertia for each variant

MODEL	MASS (G)	COM (MM)			INERTIA AROUND COM (GMM²)			FLYWHEEL INERTIA (GMM²)
		K	L	M	I_{xx}	I_{yy}	I_{zz}	
CW0057	101	17.37	17.51	9.86	12944 ± 10%	12846 ± 10%	18306 ± 10%	9182
CW0162	144	20.35	23.10	10.92	31926 ± 10%	31817 ± 10%	51640 ± 10%	25666

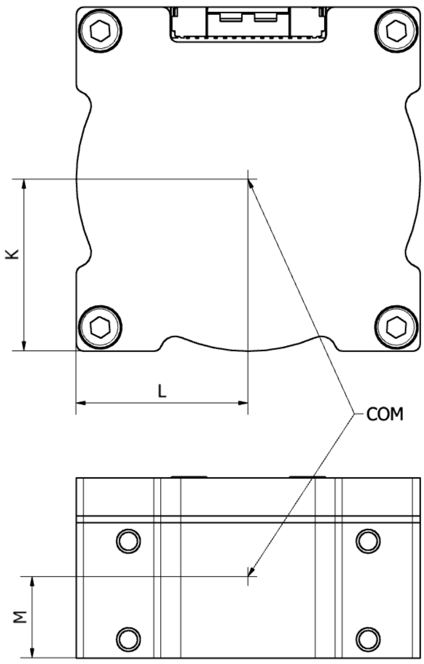

Figure 68: COM position of CubeWheels

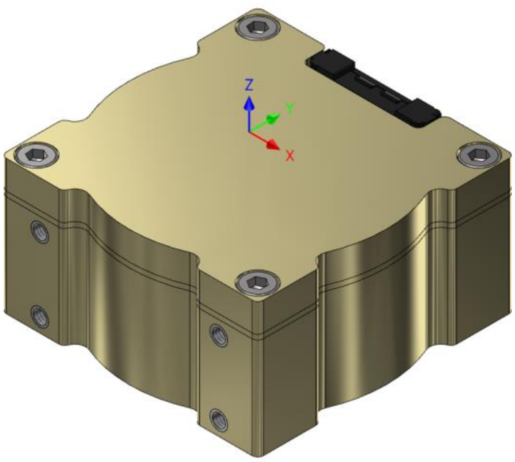

Figure 69: CubeWheel inertial reference frame

3.2.9.4 Coordinate System Definition

A positive rotation (resulting from a positive wheel speed reference command or duty cycle command) can be translated to an angular momentum vector pointing out of the top of CubeWheel as shown in Figure 70.

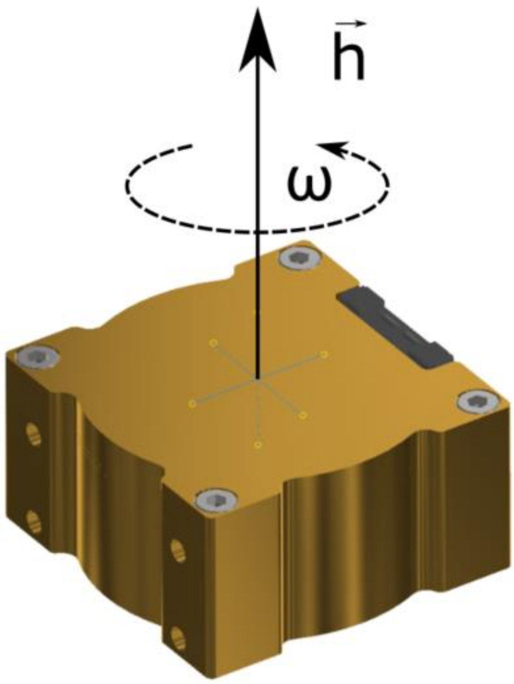

Figure 70: Momentum definition of a CubeWheel

3.2.9.5 CubeWheel Magnetic Dipole

The CubeWheels size variants have static magnetic dipoles shown in Table 32.

Table 32: CubeWheel magnetic dipole

MODEL	MAGNETIC DIPOLE [MAM^2]
CW0057	1.8
CW0162	2.5

These dipoles may cause disturbances on sensitive sensor payloads and therefore should be placed as far apart as possible from such sensors.

3.2.9.6 Power characteristics

To achieve the maximum rotation speed (thus momentum), the wheel requires a battery supply voltage of at least 11 V. The wheel will still operate with lower supply voltages but will have correspondingly lower momentum storage. The voltage range for the supply must be between 6.4 V and 18 V.

A similar restriction is valid for the current vs torque relationship. A wheel requires a minimum of 1.5 A to achieve the 10 mNm specification. Less powerful supplies will have correspondingly lower torque capability from the wheels.

3.2.9.7 Electrical Interface

Table 33: CubeWheel interface details

CubeWheel interface details	
Header Type:	Molex 5055671481
Number of pins	14
Mating Housing	Molex 5055651401

CubeWheel interface details				
Housing Terminal	5037650098			
CubeConnect CubeWheel Header pin definitions				
Pin #	Pin Name	Pin Description	IO Type	Voltage range [V]
1	BOOT	Pull this pin high to enter bootloader.	Input	-0.3 to 3.4 $V_{low} < 0.5$ $V_{high} > 2.6$
2	GND	Power ground of CubeWheel electronics	Power	0
3	3V3	Supply voltage for the digital electronics	Power	3.2 to 3.4
4	UART_TX	UART Data Transmit of CubeWheel MCU. Pull high if unused.	Output	-0.5 to 3.4
5	CAN_H	High level CAN bus line	Differential	-3.4 to 3.4
6	CAN_L	Low level CAN bus line	Differential	-3.4 to 3.4
7	UART_RX	UART Data Receive of CubeWheel MCU. Pull high if unused.	Input	-0.5 to 3.4
8	GND	Power ground of CubeWheel electronics	Power	0
9	GND	Power ground of CubeWheel electronics	Power	0
10	Enable	Pull this pin high to enable CubeWheel	Input	-0.5 to 3.4 $V_{low} < 0.95$ $V_{high} > 1.05$
11	GND	Power ground of CubeWheel electronics	Power	0
12	GND	Power ground of CubeWheel electronics	Power	0
13	VBAT	Supply voltage for motor driver	Power	6.5 to 16.6 [1]
14	VBAT	Supply voltage for motor driver	Power	6.5 to 16.6 [1]

[1] The voltage applied to the motor determines what the maximum steady state speed will be.

3.2.10 CubeWheel Pyramid

The CubeWheel pyramid consists of four reaction wheels mounted in a pyramid configuration. Each reaction wheel in the pyramid configuration is inclined at an angle of 26.57 degrees.

3.2.10.1 Outer Dimensions

The physical size for each CubeWheel Pyramid configuration is provided in Table 34 in reference to Figure 71.

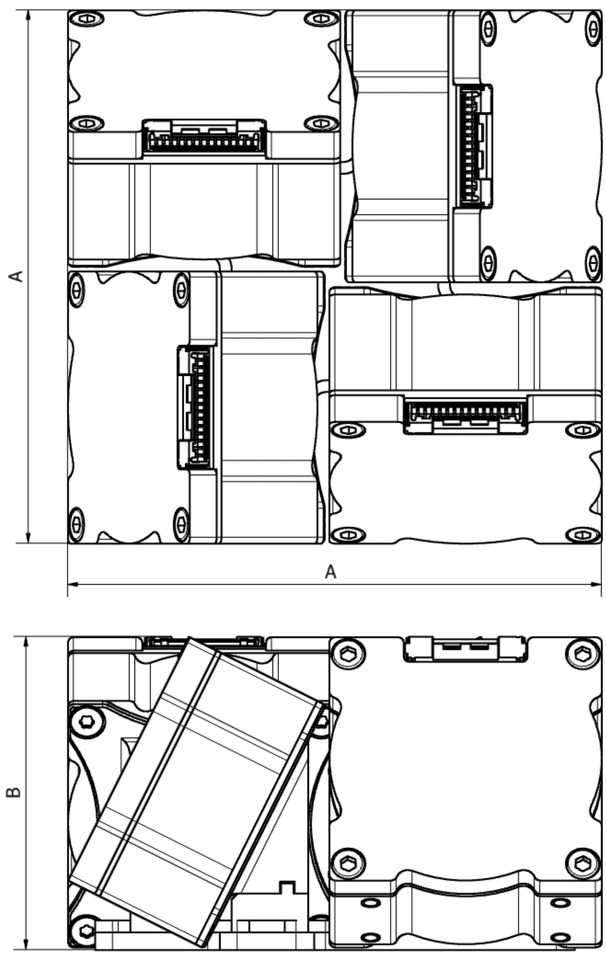

Figure 71: Indicative dimensions of a CubeWheel Pyramid of reaction wheels

Table 34: CubeWheel Pyramid dimensions for each variant

MODEL	REACTION WHEELS	A (MM)	B (MM)
CW0057P	CW0057	73.90±0.5	43.27±0.3
CW0162P	CW0162	90.56±0.5	53.18±0.3

3.2.10.2 Mounting definition

A CubeWheel Pyramid can only be mounted on a single side (base), see Figure 72. The base of the pyramid, as shown in Figure 72 and Table 35, has eight (8) M3 x 0.5mm threaded mounting holes that must all be used to ensure adequate fixation of the pyramid to the structure it is fastened to. Note, all dimensions indicated in Table 35 have a tolerance of ± 0.1 mm unless otherwise specified.

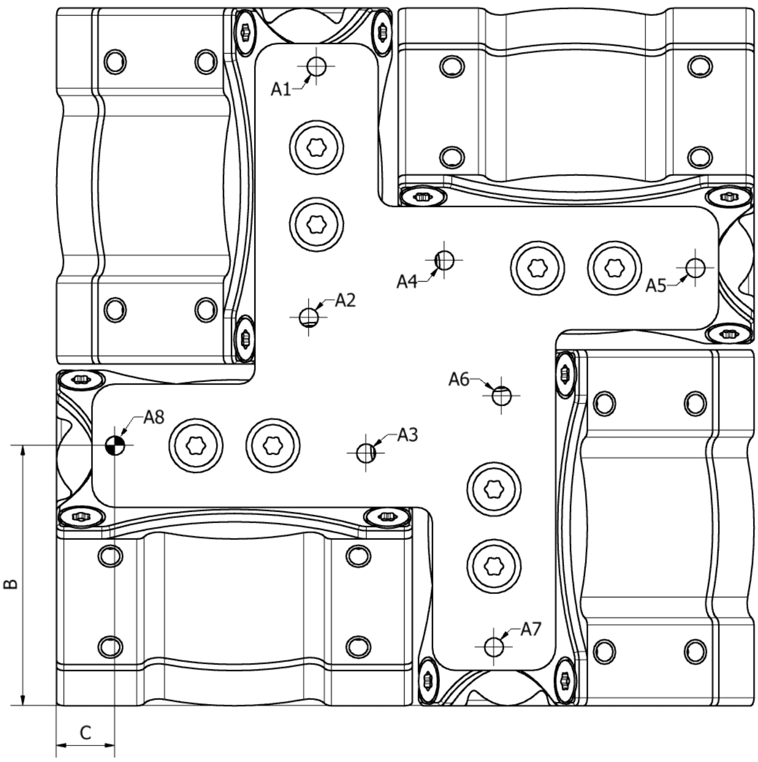

Figure 72: CubeWheel Pyramid Mounting Holes

Table 35:CubeWheel Pyramid mounting hole location values

MODEL	CW0057P		CW0162P	
	X dim (mm)	Y dim (mm)	X dim (mm)	Y dim (mm)
A1	26.16	49.20	26.48	40.42
A2	25.16	16.60	24.98	13.92
A3	32.60	-1.00	26.50	-1.50
A4	42.76	24.40	40.40	15.43
A5	75.36	23.04	66.90	13.93
A6	50.20	6.44	41.92	0.02
A7	49.20	-26.16	40.42	-26.48
A8	0.00	0.00	0.00	0.00
B	29.98		33.76	
C	3.50		7.60	
Hole Type	M3x0.5 4mm Deep		M3x0.5 5mm Deep	

3.2.10.3 Mass, COM and Inertia

The mass, COM and Inertia of each CubeWheel Pyramid variant are shown in Table 36.

The position of the COM and its respective dimensions L and M are shown in Figure 73. The inertial reference frame for all inertia's provided in Table 36 is displayed in Figure 74.

Table 36: CubeWheel Pyramid mass, COM and inertia for each variant

MODEL	MASS (G)	COM (MM)		INERTIA AROUND COM (GMM²)		
		L	M	I_{xx}	I_{yy}	I_{zz}
CW0057P	470	18.68	36.95	224208 ± 10%	224208 ± 10%	360311 ± 10%
CW0162P	704	23.95	45.28	536683 ± 10%	536683 ± 10%	828492 ± 10%

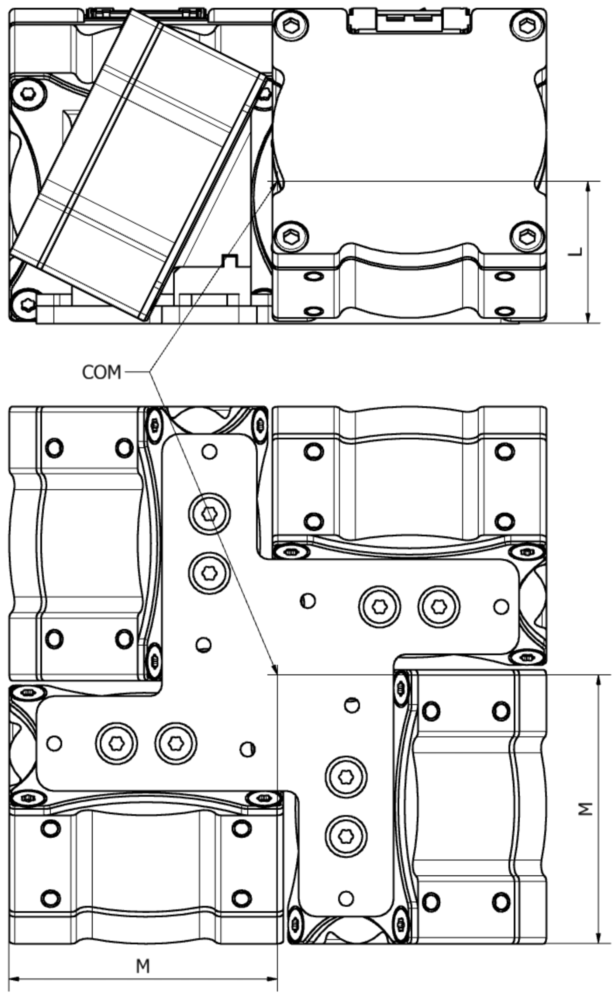

Figure 73: CubeWheel Pyramid COM position

3.2.10.4 Coordinate System Definition

The coordinate system definition used by the CubeWheel pyramid is shown in Figure 74. The individual reaction wheel locations relative to the coordinate system definition is shown by the red numbers (0,1,2,3) on each wheel.

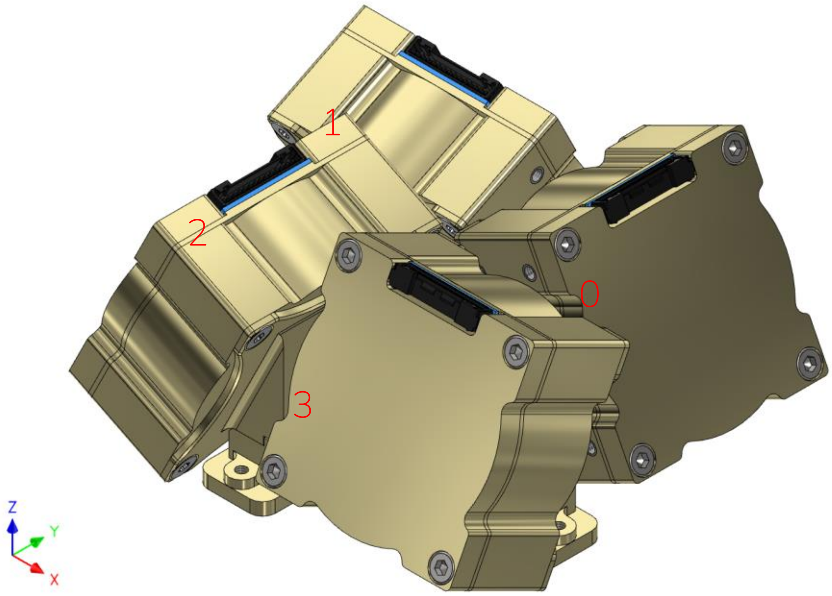

Figure 74: CubeWheel Pyramid coordinate system definition

3.2.10.5 Electrical Interface

The CubeWheel pyramid interface has four individual/separate interfaces, each the same as defined in section 3.2.9.7.

4 Mass Summary

Table 37 details the mass of each CubeProduct making up the CubeADCS solution.

Table 37: Component mass

CUBEPRODUCT (SUB-SYSTEM)	VARIANT/MODEL	MASS (G)[11]	NOTES
CubeADCS + variant	Core Stack for 3U satellites and smaller (see 3.1.1)	575	From CAD Includes: • 1x CR0002 and 2x CR0003 • 3 x CW0017
	Core Stack for 3U – 6U satellites (see 3.1.2)	743	From CAD Includes: • 3 x CR0004 • 3 x CW0057
	Core (see 3.1.3)	214	From CAD Does not include any actuators
CubeMag	Deployable	14	Measured
	Compact	8	Measured
CubeSense Sun	NA	15	Measured
CubeSense Earth	NA	18	Measured
CubeStar	NA	48	Measured
CubeNode	NA	8	Measured
CubeTorquer	CR0002	16	Measured
	CR0003	24	Measured
	CR0004	23	Measured
	CR0006	31	Measured
	CR0008	30	Measured
	CR0010	37	Measured
	CR0012	45	Measured
	CR0020	54	Measured
CubeWheel	CW0057	101	Measured
	CW0162	144	Measured
CubeWheel Pyramid	CW0057P	470	Measured
	CW0162P	704	Measured

[11] This is the mass of the CubeProduct only and does not include any harnessing as these lengths can vary. Allow margin for the harness mass (refer section 2.5).

5 Communication interface(s)

This chapter describes the configuration and characteristics of the following communication interfaces to the CubeADCS.

- CAN
- I2C
- UART
- RS485 / RS422

For hardware and signal-level interfacing information refer to section 2.3.

5.1 CAN Characteristics

The characteristics for the CubeComputer external CAN bus are given in Table 38.

Table 38: CAN bus characteristics for CubeComputer

PARAMETER	VALUE
Supported CAN standard	V2.0B
Supported bitrate(s)	1 Mbit/s
Supported protocol(s)	CubeSpace CAN Protocol, CubeSat Space Protocol (CSP)

5.2 I2C Characteristics

The CubeComputer is always configured as a slave on the I2C bus and cannot initiate communications by itself. It is important to note that the master that communicates with the CubeComputer must support clock stretching. The relevant I2C characteristics for the CubeComputer are given in Table 39.

Table 39: I2C bus characteristics for CubeComputer

PARAMETER	VALUE
Maximum supported bitrate	1 Mbit/s (I2C Fast Mode Plus)
Addressing mode	7-bit configurable slave address
Clock stretching	Yes (master must support clock stretching)
Repeated-start support	Not supported

5.3 UART characteristics

The characteristics of the UART interface are given in Table 40.

Table 40: UART characteristics for CubeComputer

PARAMETER	VALUE
Maximum supported Baud rate	921600 (configurable)
Data bits	8
Parity	None
Stop bits	1

5.4 RS485 / RS422 characteristics

The UART characteristics of the RS485 / RS422 interface are the same as in Table 40. Additional RS485 / RS422 characteristics are given in Table 41

Table 41: RS485 / RS422 characteristics for CubeComputer

PARAMETER	VALUE
Data Enable (DE) polarity	High

6 Timing and synchronization

The CubeADCS has a dedicated timer to increment Unix time.

The Unix time can be set via telecommand or determined from a pre-defined GPS input.

This timer can further be synchronized to a PPS input to an accuracy of 1 ms.

6.1 GPS Interface

The CubeADCS has a dedicated UART and PPS GPS interface available.

7 EMI / EMC

This chapter identifies all oscillators (potential RF emitters) used on all the CubeProducts that make up the CubeADCS. For each oscillator identified its frequency and its frequency stability are indicated.

7.1 Potential RF emitter list

Table 42: Potential Emitters

NO	CUBEPRODUCT	COMPONENT	EMITTER TYPE	FREQUENCY	FREQ. STABILITY
1.	CubeComputer	5V SMPS		200kHz	± 0.07 % / °C
		3V3 SMPS		200kHz	± 0.07 % / °C
		MCU	Crystal	24 MHz	± 50 ppm
		MCU RTC	Crystal	32.768 kHz	± 10 ppm
		MCU PLL and peripherals	PLL	48 MHz	Derived from crystal – should be same
		Comms UART1	UART	921.6 kHz	Derived from crystal – should be same
		Comms LPUART	UART	115.2 kHz	Derived from crystal – should be same
		Comms I2C1	I2C	100 kHz	Derived from crystal – should be same
		FRAM	SPI1	12 MHz	Derived from crystal – should be same
		SRAM	Parallel	3 MHz	Derived from crystal – should be same
		NAND Flash	QSPI	4.8 MHz	Derived from crystal – should be same
		RedIMU	I2C3	100 kHz	Derived from crystal – should be same
		A2D, IMU	SPI3	1.5 MHz	Derived from crystal – should be same
		CAN2	SPI2	6 MHz	Derived from crystal – should be same
		CAN2 Controller	Crystal	20 MHZ	± 50 ppm
2.	CubeWheel	MCU	Crystal	24 MHz	± 50 ppm
		Comms UART	-	921.6 kHz	± 50 ppm
		Comms I2C	-	100 kHz	± 50 ppm
		Comms CAN	-	500 kHz	± 50 ppm
		SPI	-	24 MHz	± 50 ppm
		Motor driver PWM	-	6 kHz	± 50 ppm

NO	CUBEPRODUCT	COMPONENT	EMITTER TYPE	FREQUENCY	FREQ. STABILITY
		Motor Driver oscillator 1	LC	51.5 kHz	± 10 kHz
		Motor Driver oscillator 2	-	103 kHz	± 21 kHz
3.	CubeMag Deployable	MCU	Crystal	24 MHz	± 50 ppm
		Comms UART	UART	0.92MHz	± 50 ppm
		Redundant Mag	I2C	100 kHz	± 50 ppm
		Magnetometer	SPI	370 kHz	± 50 ppm
		Temperature sensor	I2C	100 kHz	± 50 ppm
		Comms CAN	CAN	500 kHz	± 50 ppm
4.	CubeMag Compact	Comms UART	UART	0.92MHz	± 50 ppm
		Comms CAN	I2C	500 kHz	± 50 ppm
		Red Mag	I2C	100 kHz	± 50 ppm
		MCU	Crystal	24 MHz	± 50 ppm
5.	CubeSense Sun	MCU	Crystal	24 MHz	± 50 ppm
		Comms UART	-	921.6 kHz	± 50 ppm
		Internal I2C	-	100 kHz	± 50 ppm
		Comms I2C	-	100 kHz	± 50 ppm
		Comms CAN	-	500 kHz	± 50 ppm
		Camera sensor	Crystal	24.576 MHz	± 20 ppm
6.	CubeSense Earth	Thermal sensor	SPI	2.4 MHz	± 50 ppm
		MCU	Crystal	24 MHz	± 50 ppm
		Comms UART	UART	0.92MHz	± 50 ppm
		Comms CAN	CAN	500 kHz	± 50 ppm
7.	CubeNode	Comms UART	UART	921.6 kHz	± 50 ppm
		Comms CAN	SPI	500 kHz	± 50 ppm
		Comms RS422	RS422	115.2 kHz	± 50 ppm
		MCU	Crystal	24 MHz	± 50 ppm
8.	CubeStar	Image Sensor Crystal	Crystal	20 MHz	± 50 ppm
		Comms UART	UART	921.6 kHz	± 50 ppm
		Comms CAN	SPI	500 kHz	± 50 ppm
		SRAM	FMC	3 MHz	± 50 ppm
		NAND Flash	QSPI	4.8 MHz	± 50 ppm
		MCU	Crystal	24 MHz	± 50 ppm

7.2 Minimising EMI / EMC effects

7.2.1 Grounding

All enclosures and mechanical parts of CubeADCS are connected to the electrical ground through a filter designed to minimise EMI, as illustrated by Figure 75. The enclosures of the CubeADCS core stack and the ADCS nodes can be grounded by the user if desired.

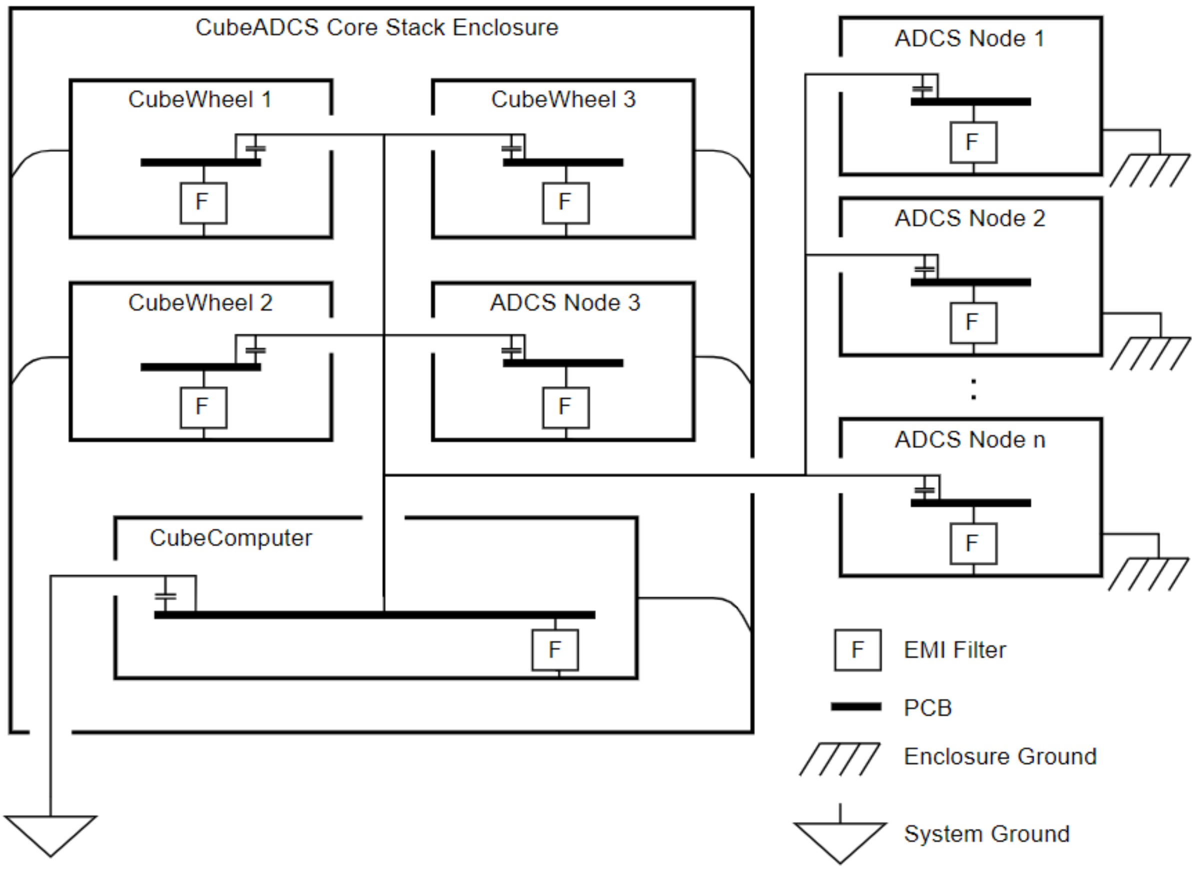

Figure 75: Grounding diagram

The filter design consists of a high value resistor in parallel with a low ESL capacitor. This dissipates high frequency noise to ground and also conducts static buildup off of the enclosure. The commonly used alternative method where the enclosures are directly connected to the ground introduces the risk that shorts may occur during satellite integration.

In some cases a customer might require the enclosures of the various CubeProducts to be completely isolated from the System Ground by removing the EMI filters completely. In such a case it could be specified as an option using [2] for a specific order.

7.2.2 Shielding

Shielding of the CubeProduct electronics is accomplished by the mechanical (Faraday) enclosure. The enclosure makes contact to chassis ground trace on each PCB. This chassis trace is connected to PCB ground through the filter discussed in the previous section.

7.2.3 Harness pairing of conductors and twisting.

The wires of the harnesses provided by CubeSpace for each CubeProduct form twisted pairs, these pairs are summarized in Table 43 below.

Table 43: Twisted Wire Pairs on Harness

PIN 1	PIN 2	COMMENT
3V3	GND	
Enable	GND	On CubeMag deployable Enable and Boot are paired
Boot	GND	On CubeMag deployable Enable and Boot are paired
$V_{Battery}$	GND	Only for CubeWheels
5V	GND	Only for CubeNode
CANH	CANL	If CAN is used
RS485 A	RS485 B	If RS485 is used
UART Rx	GND	If UART is used
UART Tx	GND	If UART is used
PPS H	PPS L	Only for CubeNode
RS485 Y	RS485 Z	Only for CubeNode

Furthermore, the twisted wire pairs are braided/rolled to form the final harness. Figure 76 below shows an image of a final flight harness.

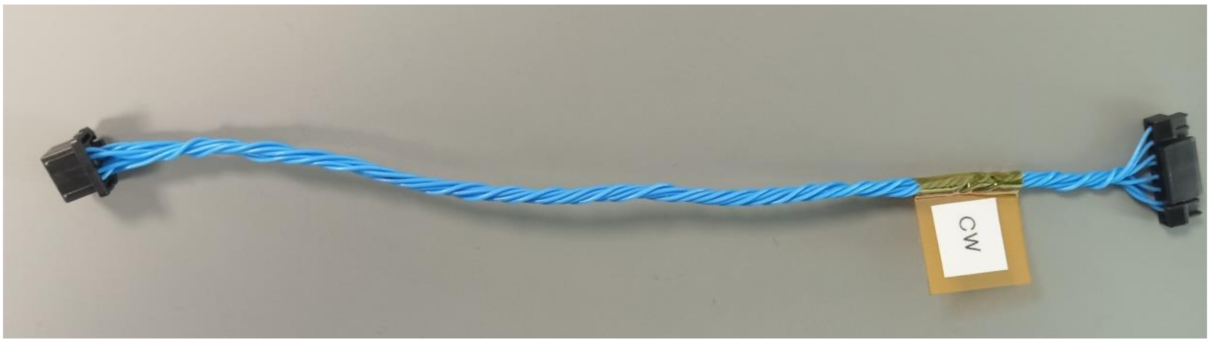

Figure 76: Flight harness example

7.2.4 Filtering and Suppression

The following noise filtering schemes are utilised across all CubeProducts:

a. All pins that are externally exposed through headers are filtered by way of 100pF decoupling to ground as shown in Figure 75.
b. LC filtering on the CubeComputer's external 5V and 3.3V power supply input lines.
c. LC filtering on the CubeComputer's 5V and 3.3V supply lines to the CubeWheels and other external CubeProducts.
d. Common-mode filter on the CubeComputer's CAN communication interfaces (from the OBC, and to the CubeWheels and other external CubeProducts).
e. RC filtering is employed on the CAN, UART, and I2C communication interfaces to minimize spurious frequencies above 1 MHz. The Boot- and Enable lines from the CubeComputer to the CubeWheels and other external CubeProducts employ LC filtering at the CubeConnect-level.

7.2.4.1 Battery Power Rail Filtering

A pre-filter is in place for the satellite battery supply to the CubeADCS. This ensures that noise on this power rail will be minimized before entering the CubeADCS and will also reduce/minimized noise generated by the CubeADCS to be emitted onto the power rail.

8 Environmental Qualification

CubeSpace is currently in progress with a so-called "re-spin" of all generation 2 CubeProducts. The re-spin effort entails minor design improvements across the board to improve lessons learnt during EMI/EMC characterisation sessions, to address minor layout optimisations that were identified and to address failures found on power regulation devices used on the CubeComputer whilst exposed to high TID radiation levels.

CubeSpace will be embarking on a full environmental re-qualification campaign, in parallel to the generation 2 re-spun versions of the CubeProducts as they come of the production line. A completion date of early April 2023 targeted. This chapter will then be updated accordingly documenting the formal qualification status of each CubeProduct.

8.1 Test approach outline

Environmental testing is done according to a "CubeSpace generation 2 Environmental Qualification plan" (See [5] noting that this document is typically only supplied to clients after order placement.)

The mentioned qualification plan contains fairly detailed information and steps to be taken by the typical test engineer when qualifying a CubeProduct, together with the applicable qualification test levels. In addition, derived from [5], detailed Environmental Test Procedure and Results documents were created for each CubeProduct. Each CubeProduct Environmental Test Procedure and Results document further detailed the exact procedure steps to be taken during a particular environmental test as well as the expected results that must be achieved in order to claim a qualification level "PASS" against a test.

The detailed test sequences are outside the scope of this document. Only the applicable qualification test levels are indicated in sub-sections below.

8.2 Thermal (Cold Start and Hot start) qualification testing

A CubeProduct, while not powered, is subjected to a cold start temperature of -35 degC. Once the soak period of minimum 30minutes have passed, the CubeProduct is powered up and its start-up sequence is monitored for correct operation and if successful, a brief health check is done. The CubeProduct is then powered down and temperature raised to +70 degC and the power up sequence and brief heath check is repeated. The CubeProduct is again powered down and brought back to ambient temperature. A complete ATP is then conducted and if all tests pass, the CubeProduct is deemed to have passed its Thermal (Hot and Cold start) qualification test.

8.3 Thermal / Vacuum (TVAC) qualification testing

The components used in all CubeProducts are non-outgassing and are specifically chosen to fall within the CVCM < 0.1%, TML < 1% limits.

For every TVAC cycles (for both hot and cold extremes – see tables below) the CubeProduct is subjected to a full health check test procedure. Once all cycles have been completed the CubeProduct is subjected to a full Acceptance Test Procedure. If the CubeProduct passes all tests, it is deemed to have passed TVAC testing at qualification levels.

Table 44: TVAC Hot cycle qualification levels

TVAC PARAMETER	TEST LEVEL
Chamber Pressure	1e-3 Pa or 1e-5 mBar
Number of Cycles	4

TVAC PARAMETER	TEST LEVEL
Dwell time after thermal stabilisation	1h
Temperature Tolerance	±2 °C
Temperature ramp rate	1 °C/min
Maximum Temperature (Qualification)	+80±2°C

Table 45: TVAC Cold cycle qualification levels

TVAC PARAMETER	TEST LEVEL
Chamber Pressure	1e-3 Pa or 1e-5 mBar
Number of Cycles	4
Dwell time after thermal stabilisation	1h
Temperature Tolerance	±2 °C
Temperature ramp rate	1 °C/min
Minimum Temperature (qualification)	-20±2°C

8.4 Vibration qualification testing

For each of the three axis of a CubeProduct, once a particular vibration type of test is done (see tables below), it is physically inspected for any damage and then subjected to a full health check test procedure. Once all vibration type tests have been completed the CubeProduct is subjected to a full Acceptance Test Procedure. If the CubeProduct passes all tests, it is deemed to have passed Vibration testing at qualification levels.

Table 46: Low level sine resonance search levels

FREQUENCY (HZ)	AMPLITUDE (G) [O-PK]
5	1
2000	1
Sweep rate	2 Oct/min

The success criteria for the resonance search are:

- Less than 5% change in the average frequency of peaks displayed by the accelerometer placed on the DUT.
- Less than 20% in amplitude shift

Table 47: Qualification sine plus quasi-static levels

FREQUENCY (HZ)	AMPLITUDE (G) [O-PK]
5	1
10	2.5
21	2.5
25	15
30	15

FREQUENCY (HZ)	AMPLITUDE (G) [0-PK]
35	3
110	3
125	0.25
Sweep rate	2 Oct/min

Table 48: -3dB random vibration qualification levels

FREQUENCY (HZ)	AMPLITUDE (G^2/HZ)
20	0.0282
50	0.0802
800	0.0802
2000	0.0130
Duration	60 seconds
Grms	10.02

Table 49: Random vibration qualification levels

FREQUENCY (HZ)	AMPLITUDE (G^2/HZ)
20	0.0563
50	0.1600
800	0.1600
2000	0.0260
Duration	120 seconds
Grms	14.16

8.5 Shock qualification testing

For each of the three axis of a CubeProduct, once a particular shock test is done (see table below), it is physically inspected for any damage and then subjected to a full health check test procedure. Once tests in all axes have been completed the CubeProduct is subjected to a full Acceptance Test Procedure. If the CubeProduct passes all tests, it is deemed to have passed Shock testing at qualification levels.

Table 50: Qualification shock test levels

FREQUENCY [HZ]	SHOCK SPECTRUM VALUES [G] - 3DB (LOWER-LEVEL THRESHOLD)	SHOCK SPECTRUM VALUES [G] (NOMINAL QUALIFICATION LEVELS)	SHOCK SPECTRUM VALUES [G] +6DB (UPPER-LEVEL THRESHOLD)
30	2	5	20
1000	750	1500	6000
10000	750	1500	6000

8.6 Radiation

For the CubeSpace generation 2 product line, the minimum successful TID level is defined as 24 kRad at a 95% confidence level. (This is calculated for 3 units tested as: Rating = Mean – 3*STD)

8.7 EMI / EMC

As mentioned in this chapter's introduction only EMI / EMC characterisation sessions have taken place to date. No formal EMI / EMC testing has been done to date.

9 Materials used

A Declared Materials List document is available for all CubeProducts making up the CubeADCS and is available from CubeSpace on request.