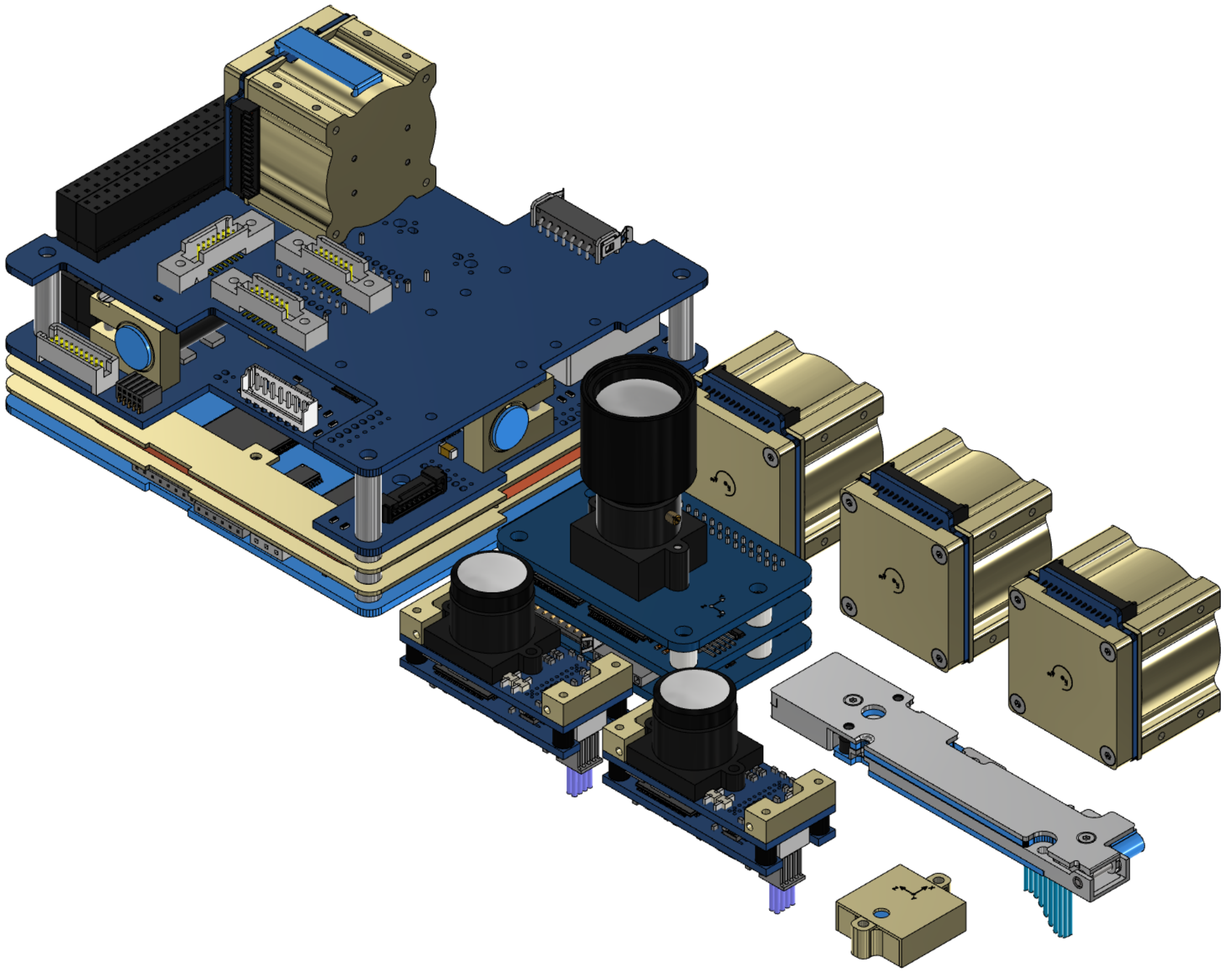
CubeADCS

The complete ADCS solution



Interface Control Document

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List of Acronyms/Abbreviations

ABC	ADCS Body Coordinate
ACP	ADCS Control Program
ADCS	Attitude Determination and Control System
COM	Center Of Mass
CSS	Coarse Sun Sensor
CPU	Central Processing Unit
EDAC	Error Detection and Correction
ESD	Electrostatic Discharge
FS	Full Scale
I^2C	Inter-Integrated Circuit
MCU	Microcontroller Unit
MEMS	Microelectromechanical System
MOI	Moment of Inertia
OBC	Onboard Computer
ORC	Orbit-Referenced Coordinate
PCB	Printed Circuit Board
RTC	Real-Time Clock
SBC	Satellite Body Coordinate
SEL	Single-Event Latch up
SEU	Single-Event Upset
TC	Telecommand
TLM	Telemetry
UART	Universal Asynchronous Receiver/Transmitter

Table of Contents

1 Introduction

CubeADCS provides attitude sensing and control capabilities to nanosatellites. The CubeADCS consist of several CubeSpace sub-systems (CubeProducts) integrated into a compact ADCS solution.

CubeADCS comes pre-programmed with firmware which allows the user to interface to the system via one of multiple communication busses. The firmware allows the user to easily interface, update and extract information from the ADCS system. CubeADCS runs all the required ADCS estimators and controllers while monitoring the health of the sub-systems.

Ground support software is also supplied with each CubeADCS, which allows the user to directly connect to the CubeADCS through a UART serial-to-USB cable using a PC.

This document describes the characteristics of the CubeADCS as well as the mechanical and electrical interfaces. CubeADCS can be configured with different sensors and actuators for different mission requirements. This document covers all CubeADCS configurations and readers can use their discretion in determining which parts are relevant to their various CubeADCS configurations. The version numbers applicable to the products referred to in this document can be found in Section 3.1.

If the reader has doubt over which parts are relevant, please mail us at ***info@cubespace.co.za***.

2 Handling

- ## Anti-static

CubeADCS contains a variety of static sensitive devices. Therefore, the appropriate electrostatic discharge (ESD) protection measures must be implemented. The system must never be handled without proper grounding.

- ## Cleanliness

It is recommended that CubeADCS sub-systems be handled in a clean environment. Therefore, an appropriate laminar flow workbench or a cleanroom of ISO class 8 or better, should be used.

- ## Moisture

The system should be kept free of moisture or liquids, as these could have corrosive effects on the electronics and electronic joints, which may lead to degradation and loss of reliability of the circuits.

- ## Shock

The system must be handled with care. Dropping or bumping a CubeADCS is prohibited.

- ## Camera lens cleanliness

The camera lenses should be kept clean and free of any dirt that may obstruct the images captured by the camera. Dust should be removed with a microfiber cloth. If required, the lens may be cleaned using ethanol and appropriate lens cleaning equipment. Unnecessary cleaning of the glass should be avoided.

- ## Camera lens structural integrity

The camera sensors are aligned to be parallel with the PCBs. This alignment is essential, as misalignment of the cameras influence the performance of the system. Therefore, external forces on the camera modules should be avoided.

- ## Camera lens covers

The optics are fitted with dust caps which should be removed before flight.

- ## Reaction wheels

The aluminum housings of the reaction wheels should NOT be tampered with. Tampering with the housings may damage the wheels. No attempt should be made to loosen or remove the fasteners that secure the housings.

3 Description and Overview

3.1 System components

CubeADCS is fundamentally a modular system which can use a combination of sensors and actuators to achieve the ADCS performance requirements. The sensors used to estimate the attitude of the satellite are magnetometers, coarse Sun sensors, fine Sun sensor(s), nadir sensor(s), and MEMS rate sensor. The actuators used to control the attitude are magnetorquers and reaction wheels. These sub-systems in the CubeSpace context are referred to as CubeProducts.

A CubeADCS system consists of CubeProducts (sub-systems) based on the integrated PC104-standard PCBs and several peripheral CubeProducts, which are to be mounted separately. A basic diagram of the complete CubeADCS solution with all options is displayed in Figure 1.

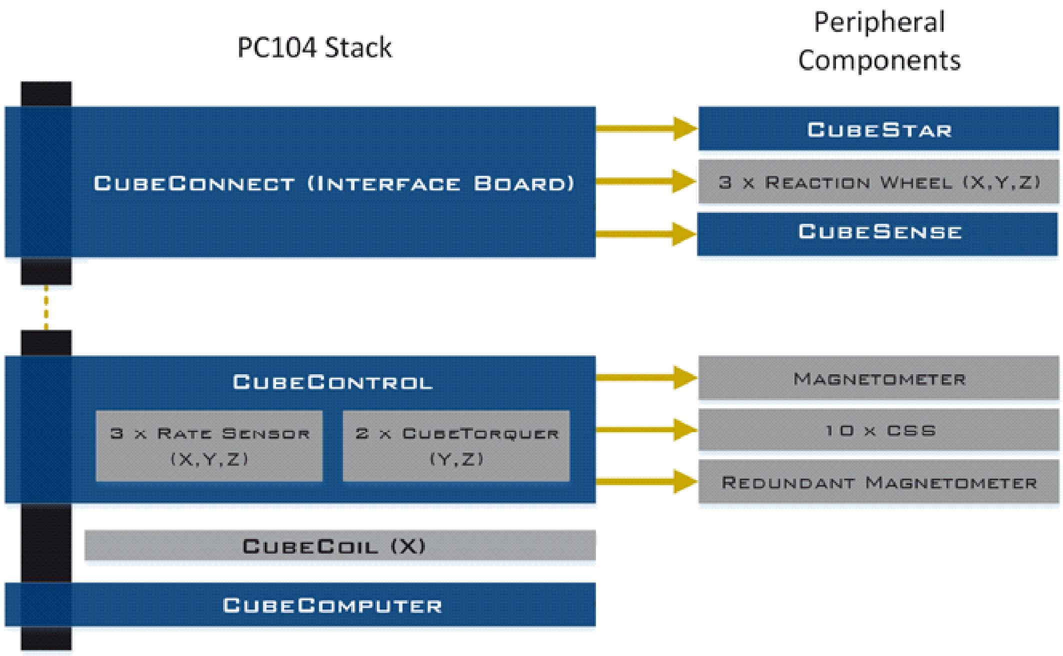
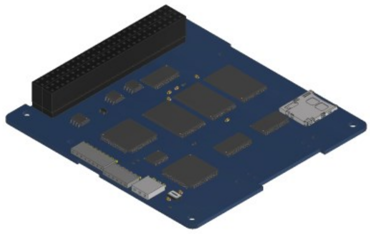
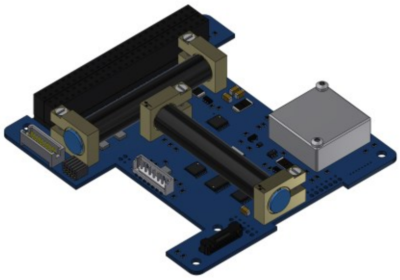
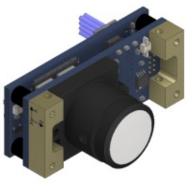
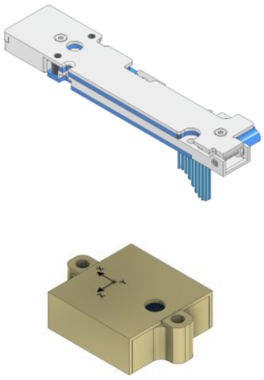
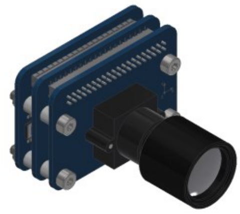
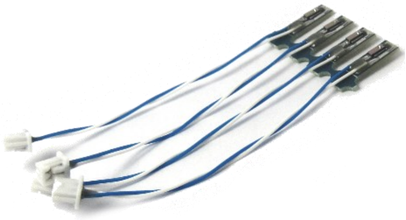
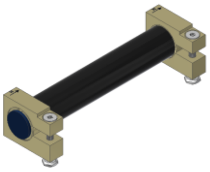
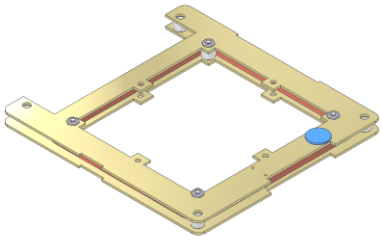
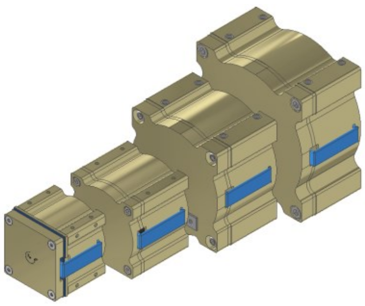


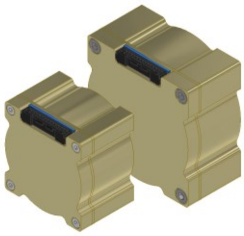
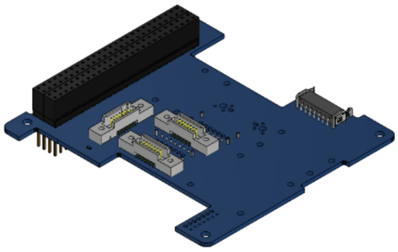
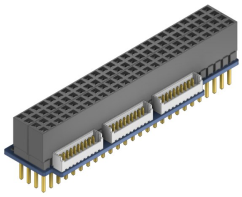
Figure 1 – System diagram of the complete CubeADCS solution

A brief description of the CubeProducts is given in Table 1.

Table 1 – Modules of the CubeADCS solution

CubeProducts	Applicable Version	Description
CubeComputer 	V4.6	CubeComputer is the CubeADCS computing sub-system. Please see Section 7.1 for more information.
CubeControl 	V2.6	CubeControl is an actuator and sensor interface and control module. Please see Section 7.4 for more information.
CubeSense 	V3.1	CubeSense is an integrated Sun or Nadir sensor for attitude sensing. Please see Section 7.2 for more information.
CubeMag Deployable and Redundant 	V4.1 - Deployable V3.2 - Redundant	CubeMag is a 3-axis magnetometer. For more information, please see Section 7.5.

CubeStar 	V4.4	CubeStar is a compact star tracker for nanosatellites. Please see Section 7.9 for more information.
Coarse Sun Sensors 	V1.0	The coarse Sun sensors provide a coarse Sun vector throughout the entire sunlit part of the orbit. For more information, see Section 7.6.
CubeRod 	V1.0	CubeRod is a nanosatellite magnetic torquer that uses a specially treated ferrous core with ultra-low remanence and high linearity. For more information, please see Section 7.3.
CubeCoil 	V1.0	CubeCoil is a nanosatellite magnetic torquer in a low-profile air-coil form that slots into the stack between the PCBs. Please see Section 7.3 for more information.
CubeWheel 	V1.4 – Small V1.5 - Small+ V1.4 - Medium V1.4 – Large	CubeWheel is a compact standalone reaction wheel sub-system for nanosatellites. Please see Section 7.8 for more information.

	V2.2 – CW0057 V2.2 – CW0162	
CubeConnect  	V2.4 - Standard V2.0 - Micro	The CubeConnect board acts as an interface board for the CubeWheels, CubeSense modules and CubeStar module. For more information, please see Section 7.7.

3.2 Software

3.2.1 Bootloader

All CubeComputers delivered by CubeSpace have a bootloader pre-installed.

The bootloader performs several important tasks, such as

- Enabling internal and external watchdogs of the MCU preventing faulty or damaged applications from halting the CPU,
- Allowing reprogramming of application via UART or I2C interface,
- Counting number of reboots and tracks boot attempts,
- Providing status telemetry.

3.2.2 Attitude Control Program (ACP)

The ADCS Control Program (ACP) is the application launched by the bootloader. It controls all functions on the CubeComputer and commands all the other CubeSpace sub-systems within the CubeADCS. It also coordinates the sampling and calibration of sensors, execution of estimators and execution of control commands to the actuators.

3.2.3 ADCS Software Library

The ADCS software library implemented in the ACP has several standard estimation modes:

- MEMS Rate Filter,
- Magnetic Rate Filter,
- TRIAD,
- Full-state EKF,
- MEMS Gyro EKF.

The ADCS software library also has several standard control modes:

- Detumbling (B-Dot),
- High rate detumbling,
- Very high rate detumbling,
- Y-Thompson,
- Sun-spin,
- Target tracking,
- Sun-pointing.

3.2.4 CubeSupport Application

CubeADCS is also supplied with a ground support application called CubeSupport. This software runs on a PC and interfaces directly with the CubeADCS using a Serial-to-USB cable and a dedicated UART header found on the side of the CubeComputer.

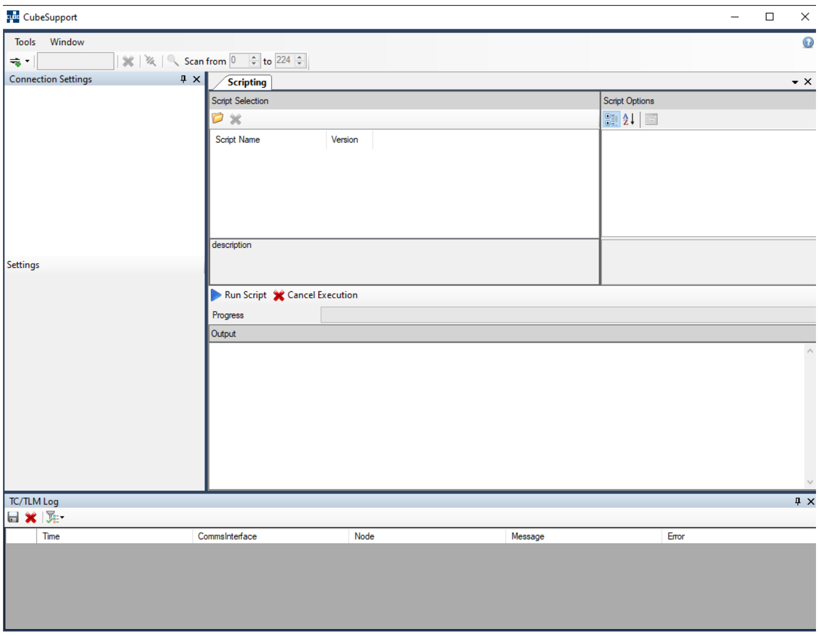


Figure 2 – CubeSupport Application

The CubeSupport application can recognise and connect to the bootloader as well as the ACP. When connected to the bootloader, CubeSupport allows the user to upload new firmware to the external flash on CubeComputer for execution.

CubeSupport also provides the ability periodically log TLM, download images from imager-based sensors and to upload and alter the system configuration and ADCS configuration.

4 Standard CubeADCS solutions

The CubeADCS needs to be configured to meet user ADCS requirements and needs, while the satellite design and size will determine how many sensors are required and what size and number of actuators are required. CubeSpace can assist in determining which CubeADCS configuration will satisfy a specific mission requirement.

This section aims to provide examples of CubeADCS configurations with specific use cases. The specifications from these specific examples are determined from the individual CubeProduct specifications.

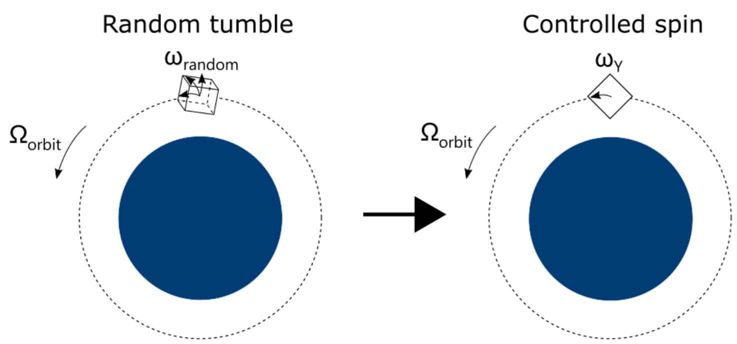
These examples should provide the user with a good idea of which configuration will be required for their mission needs and what the general specification of such a system could be. All dimensions indicated in this document are in mm.

4.1 Magnetic

The pure magnetic ADCS is typically used in 1U satellites but is not limited to them. In these satellites *accurate* pointing is rarely a requirement and space is very limited. This CubeADCS configuration provides a robust and compact solution to get a 1U satellite from its initial random tumble to a controlled slow spin.

Two CubeSense cameras can be added to the base magnetic configuration to allow for more accurate attitude sensing and will allow the ADCS to detumble and perform slow spin-pointing manoeuvres.

The base version has small CubeTorquers mounted on CubeControl and is suitable for up to 3U sized satellites. For larger CubeSats, torquers can be upgraded to Medium or Large sizes for increased control torque.



4.1.1 Drawing

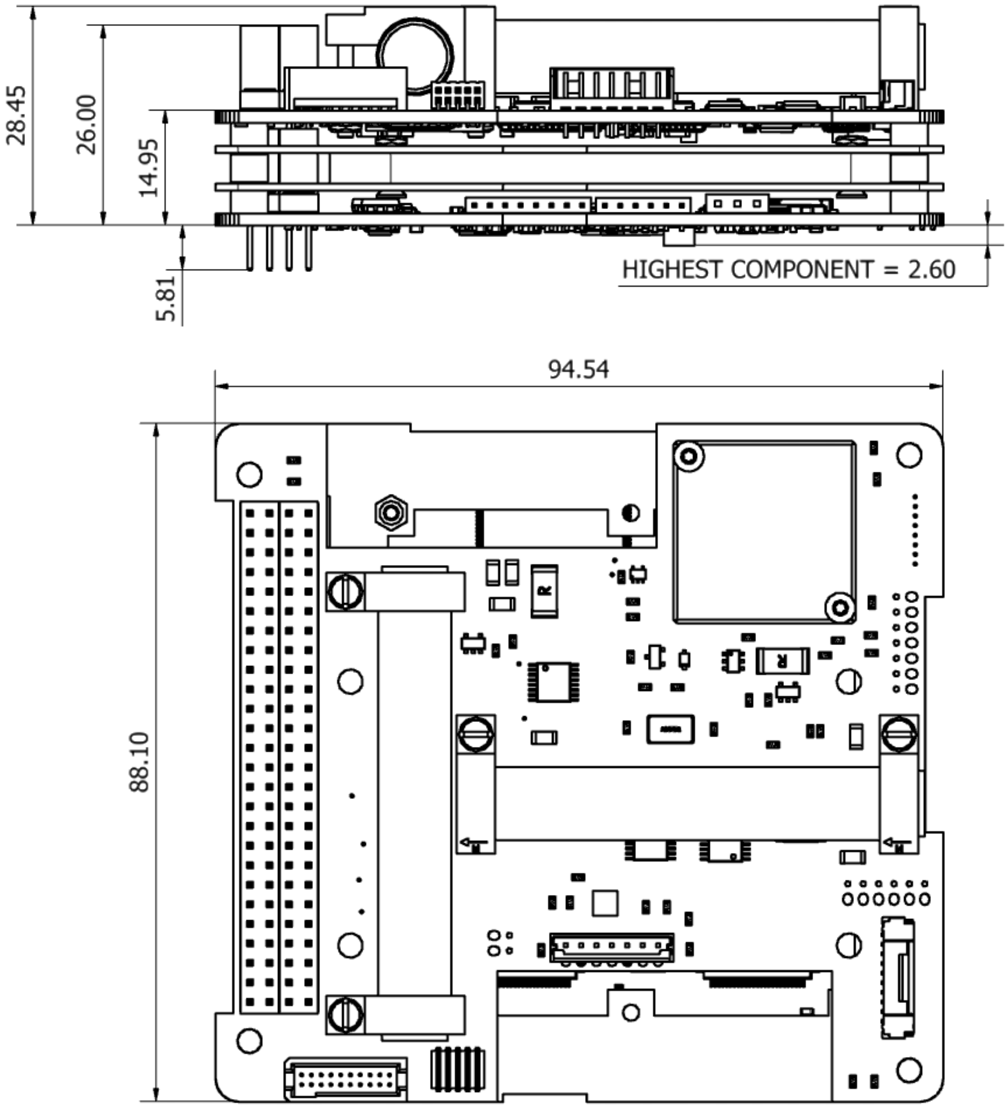


Figure 3 – CubeADCS Magnetic configuration

4.1.2 Specifications

Table 2 – CubeADCS Magnetic specifications

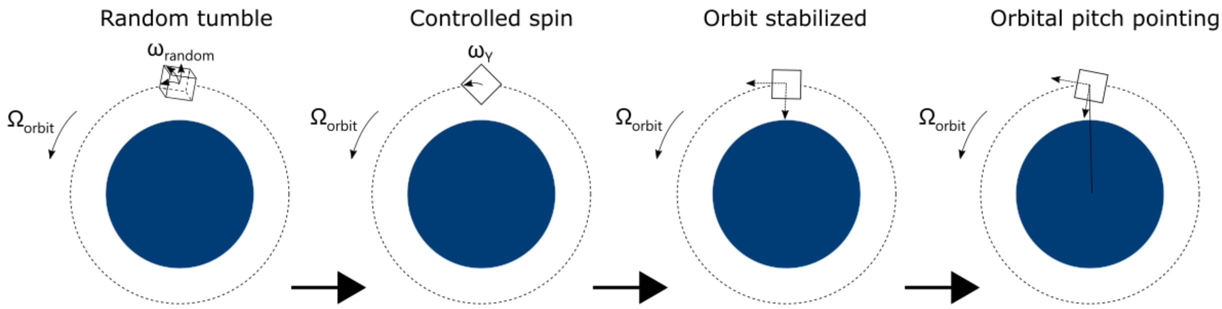
Specification	Value	Notes
Features		
Typical Satellite Size	1U to 3U	
Estimation Modes	MEMS Rate Filter, Magnetic Rate Filter, TRIAD, Full-state EKF, MEMS Gyro EKF	
Control Modes	Detumbling, Y-Thomson, Sun Spin	
CubeProducts included in CubeADCS Magnetic configuration	CubeComputer	
	CubeCoil single	
	CubeControl	
	2 x CubeRod small	
	10 x Coarse Sun Sensors	
	CubeMag Deployable	
Physical*		
Mass	257.5 g	Mass of CubeProducts for CubeADCS Magnetic configuration, including spacers
Stack Dimension	88.10 x 95.11 x 26 mm	
Power		
Power Supply (from EPS)	3.3 V, 5V, Vbat (6.5-16V)	
Power usage	445 mW	Average
	1585 mW	Peak
Environment		
Operating temperature	-10°C to +60°C	
Storage temperature	-25°C to +70°C	
Vibration	8.03 g RMS random	
Radiation	20 kRad	
Optional CubeProducts to change CubeADCS configuration		
Optional	CubeMag Redundant	Could be added to act as redundant sensor to the CubeMag Deployable
	CubeSense(s)	Could be added to provide more accurate attitude sensing
	CubeConnect	
	Larger CubeRods and CubeCoils	Scaled to meet needs of larger satellite designs

* Indicative measurements only. Final dimensions are given by CAD once a CubeADCS is ordered.

4.2 Y-Momentum

For most CubeSat missions, the payload requirement is to be 3-axis stabilized, with the payload pointing nadir or in the flight direction.

The Y-Momentum CubeADCS configuration is used for missions where <1° pointing is not necessarily needed, but a 3-axis stable system is required. Examples of such missions are general Earth observation missions, scientific missions where the payload must be pointed in the velocity direction, and communication missions. This CubeADCS provides the functionality to detumble a satellite into a stable spin and then to absorb the rotation of the satellite into a momentum wheel. This momentum wheel provides good disturbance rejection which makes it possible to further keep the satellite 3-axis stable using magnetic control. The satellite can do pitch maneuvers in the orbital plane by controlling the momentum wheel's speed. This is particularly useful for imaging missions and ground station tracking in communication missions. For any other mission, ground station communications can be improved by performing tracking at least in the pitch direction.



The base version of the Y-Momentum CubeADCS has a single CubeWheel Small reaction wheel and small torquer rods and is suitable for up to a 3U satellite design. For larger satellites the torquers as well as the momentum wheel can be scaled up to suit the Moment of Inertia of the satellite. In such a case, the larger actuators are not mounted on the stack anymore, but rather mounted separately on the satellite structure by the user.

4.2.1 Drawing

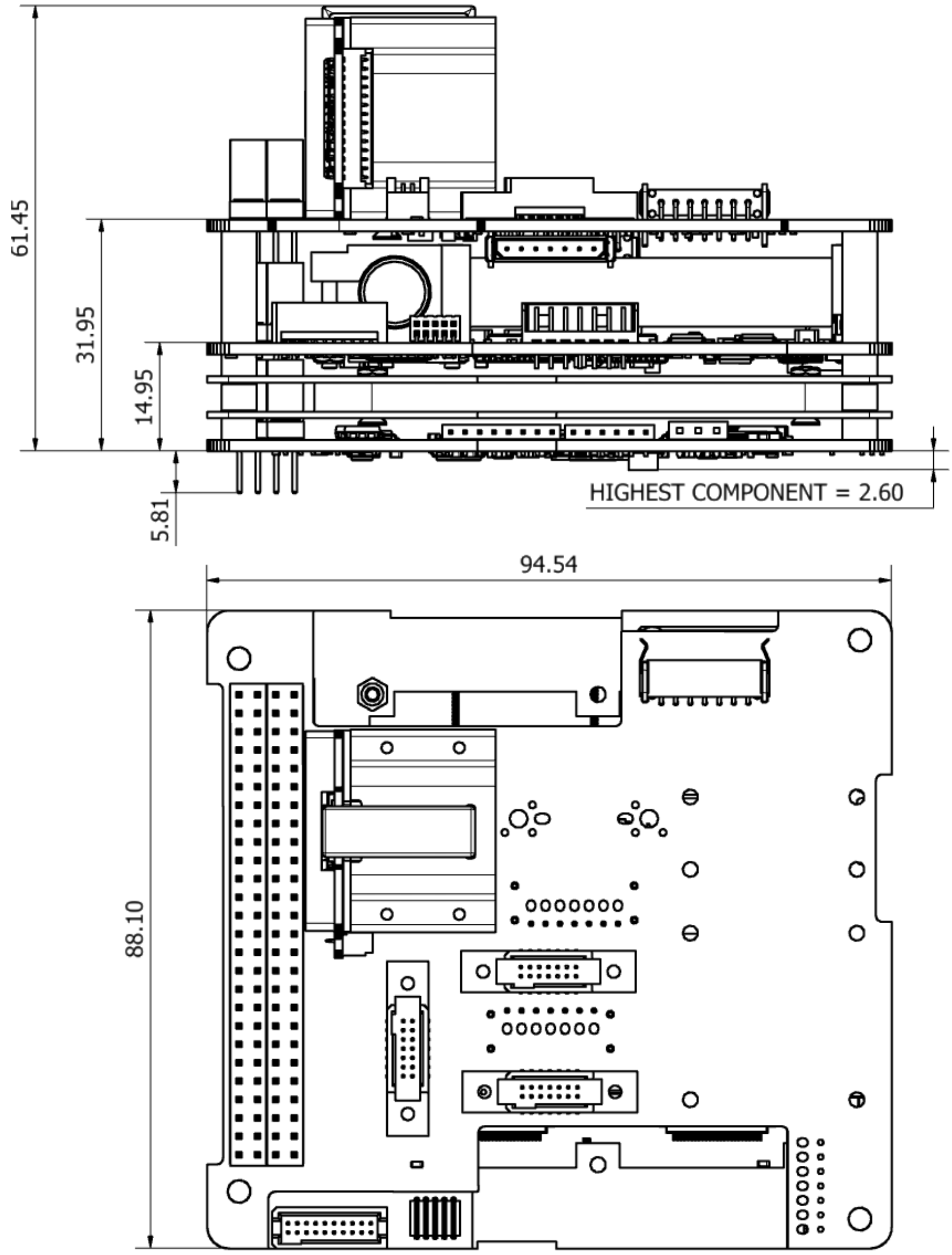


Figure 4: CubeADCS Y-Momentum configuration with mounted small reaction wheel

4.2.2 Specifications

Table 3 – CubeADCS Y-Momentum

Specification	Value	Notes
Features		
Typical satellite size	2U to 16U	
Estimation Modes	MEMS Rate Filter, Magnetic Rate Filter, TRIAD, Full-state EKF, MEMS Gyro EKF	
Control Modes	Detumbling, Y-Thomson, Sun Spin, Nadir Pointing, Pitch Control	
CubeProducts included in CubeADCS Y-Momentum configuration	CubeComputer	
	CubeCoil Single	
	CubeControl	
	2 x CubeRod Small	
	10 x Coarse Sun Sensors	
	CubeMag Deployable	
	CubeConnect	
	CubeWheel Small	
Physical*		
Mass – Standard CubeConnect Selected	395.5 g	Mass of CubeProducts for CubeADCS Y-Momentum configuration, including spacers
Mass – CubeConnect Micro Selected	342 g	Mass of CubeProducts for CubeADCS Y-Momentum configuration, including spacers
Stack Dimension	88.10 x 94.54 x 61.54 mm	CubeWheel Small mounted on Standard CubeConnect
Stack Dimension	88.10 x 94.54 x 43 mm	CubeWheel Small provided loose with CubeConnect Micro
Power		
Power Supply (from EPS)	3.3V, 5V, VBat (6.5V -16V)	
Power consumption	571 mW	Average, Without optional components
	2295 mW	Peak, Without optional components
Environment		
Operating temperature	-10°C to +60°C	
Storage temperature	-25°C to +70°C	
Vibration	8.03 g RMS random	
Radiation	20 kRad	
Optional CubeProducts to change CubeADCS configuration		

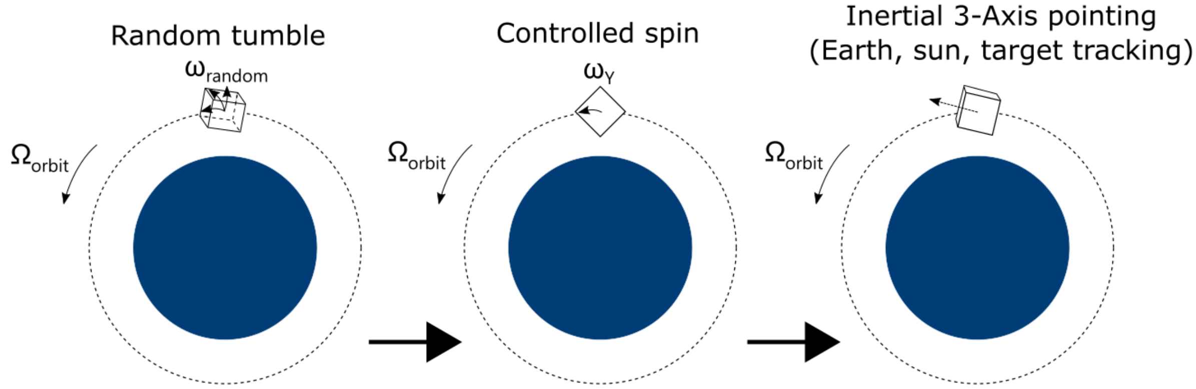
Optional	CubeMag Redundant	Could be added to act as redundant sensor to the CubeMag Deployable
	CubeSense	Could be added to provide more accurate attitude sensing
	Upgrade to CubeWheel Small+, Medium or Large	Scaled to meet needs of larger satellite designs
	Replace the CubeCoil with another CubeRod	Scaled to meet needs of larger satellite designs
	Upgrade CubeCoil form single to a double coil	Scaled to meet needs of larger satellite designs

* Indicative measurements only. Final dimensions are given by CAD once a CubeADCS is ordered.

4.3 3-Axis

CubeSats have evolved to the point where high accuracy inertial pointing has become a requirement in certain missions. In these missions, three reaction wheels are required to provide 3-axis control throughout the entire orbit. Sensors are chosen to provide the level of accuracy required for a specific mission. This system can be upgraded as needed to provide different pointing abilities for different missions. With the latest stand-alone fine sun sensor and nadir sensor, the 3-Axis system is available in a highly compact low-profile solution.

The 3-Axis CubeADCS solution is designed to do inertial pointing with high accuracy. It contains all the controllers that are included in the other CubeADCS solutions but provides the extra functionality of 3-Axis pointing in any direction. The system can function with or without the star tracker, depending on the pointing accuracy that is required. If high accuracy pointing is only required in the sunlit part of the orbit, a star-tracker is not required, as the system can function sufficiently with only the fine Sun and Nadir sensor.



As with the Y-Momentum system, the base version of this CubeADCS contains small torquers and reaction wheels, which are mounted on the CubeADCS. For larger satellites requiring larger actuators, the reaction wheels and torquers are mounted on the satellite structure by the user.

4.3.1 Drawing

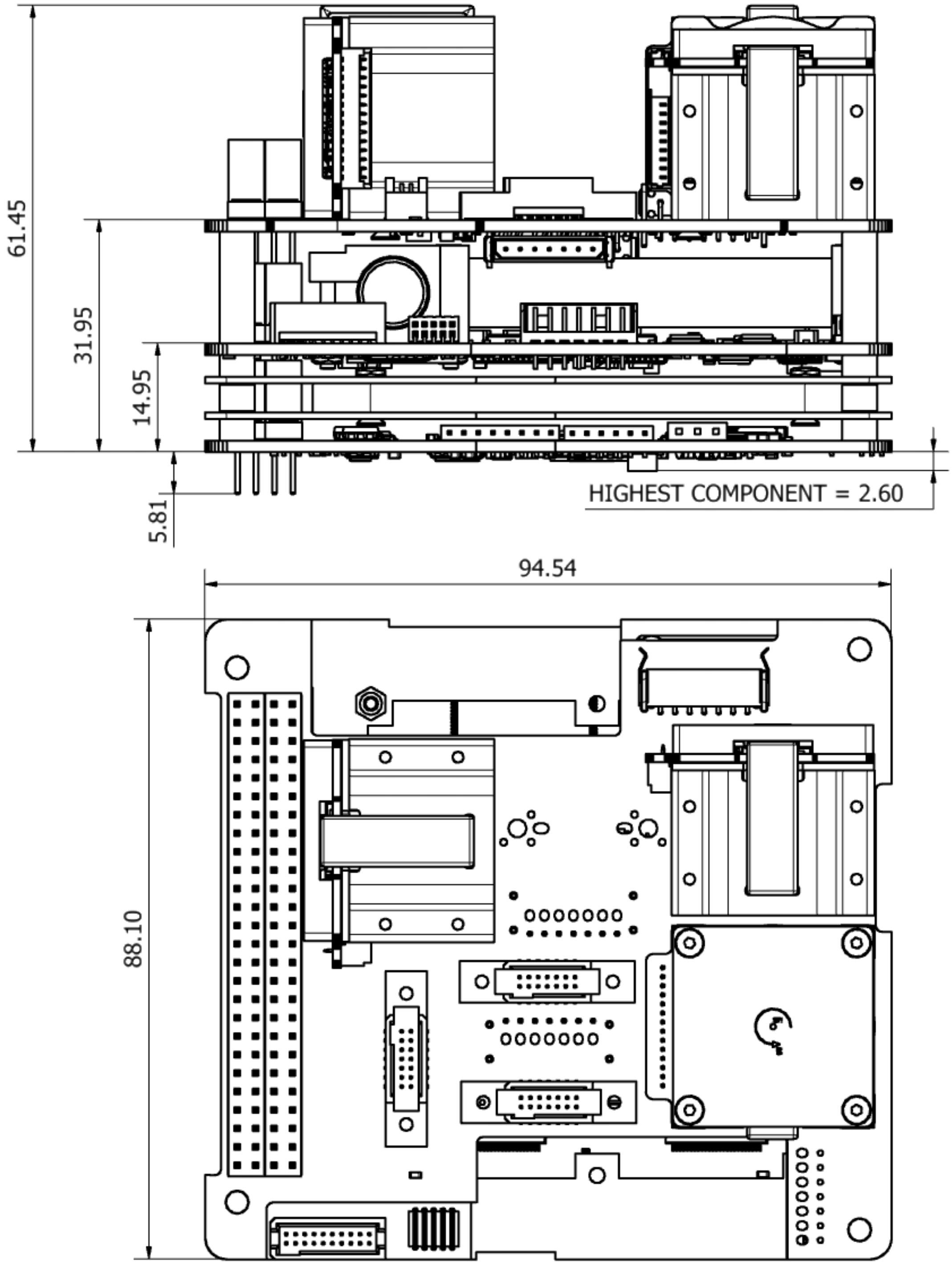


Figure 5 – CubeADCS 3-Axis configuration with mounted small reaction wheels

4.3.2 Specification

Table 4 – CubeADCS 3-Axis specifications

Specification	Value	Notes
Features		
Typical satellite size	2U-3U	For this base example, but can be scaled up to 16U
Estimation Modes	MEMS Rate Filter, Magnetic Rate Filter, TRIAD, Full-state EKF, MEMS Gyro EKF	
Control Modes	Detumbling, Y-Thomson, Nadir Pointing, Inertial Pointing, Sun Pointing, Ground Target Tracking, XYZ Wheel Control	
CubeProducts included in base configuration	CubeComputer	
	CubeCoil Single	
	CubeControl	
	2 x CubeRod Small	
	10 x Coarse Sun Sensors	
	CubeMag Deployable	
	CubeConnect	
	3 x CubeWheel Small	
	CubeSense Sun	
	CubeSense Nadir	
Physical*		
Mass – Standard CubeConnect Selected	555 g	Mass of CubeProducts for CubeADCS 3-Axis configuration, including spacers
Mass – CubeConnect Micro Selected	501.5 g	Mass of CubeProducts for CubeADCS 3-Axis configuration, including spacers
Stack Dimension	88.10 x 94.54 x 61.54 mm	Small CubeWheels mounted on Standard CubeConnect
Stack Dimension	88.10 x 94.54 x 43 mm	CubeWheels provided loose with Micro CubeConnect
Power		
Power Supply (from EPS)	3.3V, 5V, V_{Bat} (6.5V – 16V)	
Power consumption	570 mW	Average, excl. wheels and optional components
	2300 mW	Peak, excl. wheels and optional components
Environment		
Operating temperature	-10°C to +60°C	
Storage temperature	-25°C to +70°C	
Vibration	8.03 g RMS random	

Specification	Value	Notes
Radiation	20 k Rad	
Optional CubeProducts to change CubeADCS configuration		
Optional	CubeMag Redundant	Could be added to act as redundant sensor to the CubeMag Deployable
	Upgrade to CubeWheel Small+, Medium or Large	Small Plus, Medium, or Large
	Replace the CubeCoil with another CubeRod	Scaled to meet needs of larger satellite designs
	Upgrade CubeCoil form single to a double coil	Scaled to meet needs of larger satellite designs
	CubeStar	Added for additional accuracy

* Indicative measurements only. Final dimensions are given by CAD once a CubeADCS is ordered.

5 Electrical Interface

5.1 PC104 interface

The CubeADCS mainly makes use of the standard PC104 header for electrical interfacing. The pin description of the PC104 bus is shown in Figure 6, as used by the CubeADCS. Where the row indicates "*option*", it means that only some of the PC104 pins will be used for that row. These options are configured during manufacturing as specified in the Hardware Configuration document.

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					
External Communication					
	H1	1	CANL	CAN Bus Low	*Option*
	H1	3	CANH	CAN High Low	*Option*
	H1	41	I2C_SDA_SYS	System I2C Data for CubeComputer	*Required*
	H1	43	I2C_SCL_SYS	System I2C Clock for CubeComputer	*Required*
	H1	17, 18, 19, 20	UART_1	Usable Pins for UART_1 (Rx or Tx)	*Option*
	H2	21, 22			
	H1	33, 35, 39, 40	UART_2	Usable Pins for UART_2 (Rx or Tx)	*Option*
External Power					
	H2	29, 30, 32	GND	Ground Connection for All Modules	*Required*
	H2	45, 46	V_Bat	Battery Voltage Bus	*Required*
	H2	25 and 26	5V_Main	Main 5 V Supply	*Option*
	H2	27 and 28	3V3_Main	Main 3.3 V Supply	*Option*
	H1	47, 49, 51	5V_S1/S2/S3	Switched 5 V Supply Options	*Option*
	H1	48, 50, 52	3V3_S1/S2/S3	Switched 3.3 V Supply Options	*Option*
Internal (ADCS Only)					
	H1	2, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16	ENABLE	Usable Pins for Enable Lines for CubeADCS Nodes	*Option*
	H2	15, 17, 18, 19, 20			
	H1	21	I2C_SCL_ADCS	Internal I2C clock line for ADCS modules	*Required*
	H1	23	I2C_SDA_ADCS	Internal I2C data line for ADCS modules	*Required*

Figure 6 – PC104 bus pin description

5.2 Power

5.2.1 Power supply

The ADCS must be supplied with regulated 3.3 V, 5.0 V and the raw battery voltage, $V_{battery}$. Battery voltage must be between 6.5V and 16V.

The 3.3 V and 5.0 V buses must be provided by one of H1-48, 50, 52 or H2-27, 28 (3.3 V) and one of H1-47, 49, 51 or H2-25, 26 (5 V) ***– depending on the selection made by user in the Hardware Configuration Sheet***. The 3.3 V and the 5 V supply must be switched on within 10ms of each other.

The battery bus (pins H2-45 and H2-46) supplies power to the CubeWheels and the magnetometer boom deployment circuitry.

5.2.2 Inrush currents

The CubeADCS and its sub-systems have been optimised to limit the effect of inrush currents. However, the power supply, and the connection from the power supply to the CubeADCS, can still introduce inrush problems if not set-up correctly. Therefore, it is important to ensure:

- Power supply can output at least 12W (1.5A at 8V). During ground testing, 1A at 8V will suffice, as the magnetometer will not be deployed.
- Cables between 3.3 V power supply and CubeADCS are short with sufficient thickness. Ideally <15cm and <24 AWG.

If these conditions are met, inrush should not pose a problem during ground testing or orbit.

5.3 Enable lines

The ADCS has internal power switches for the various individual sub-systems (CubeSense, CubeControl, CubeStar and the CubeWheels), all of which are controlled by CubeComputer. Figure 7 shows an example of the power switching connections. The switch states are available as telemetry (TLM) and can also be toggled using a telecommand (TC).

Please note that the enable lines are connected straight to the CubeComputer's MCU. This means that these pins on the MCU are directly exposed to the PC104 header. If any overvoltage signal inputs are applied to the MCU it will damage and possibly destroy the MCU.

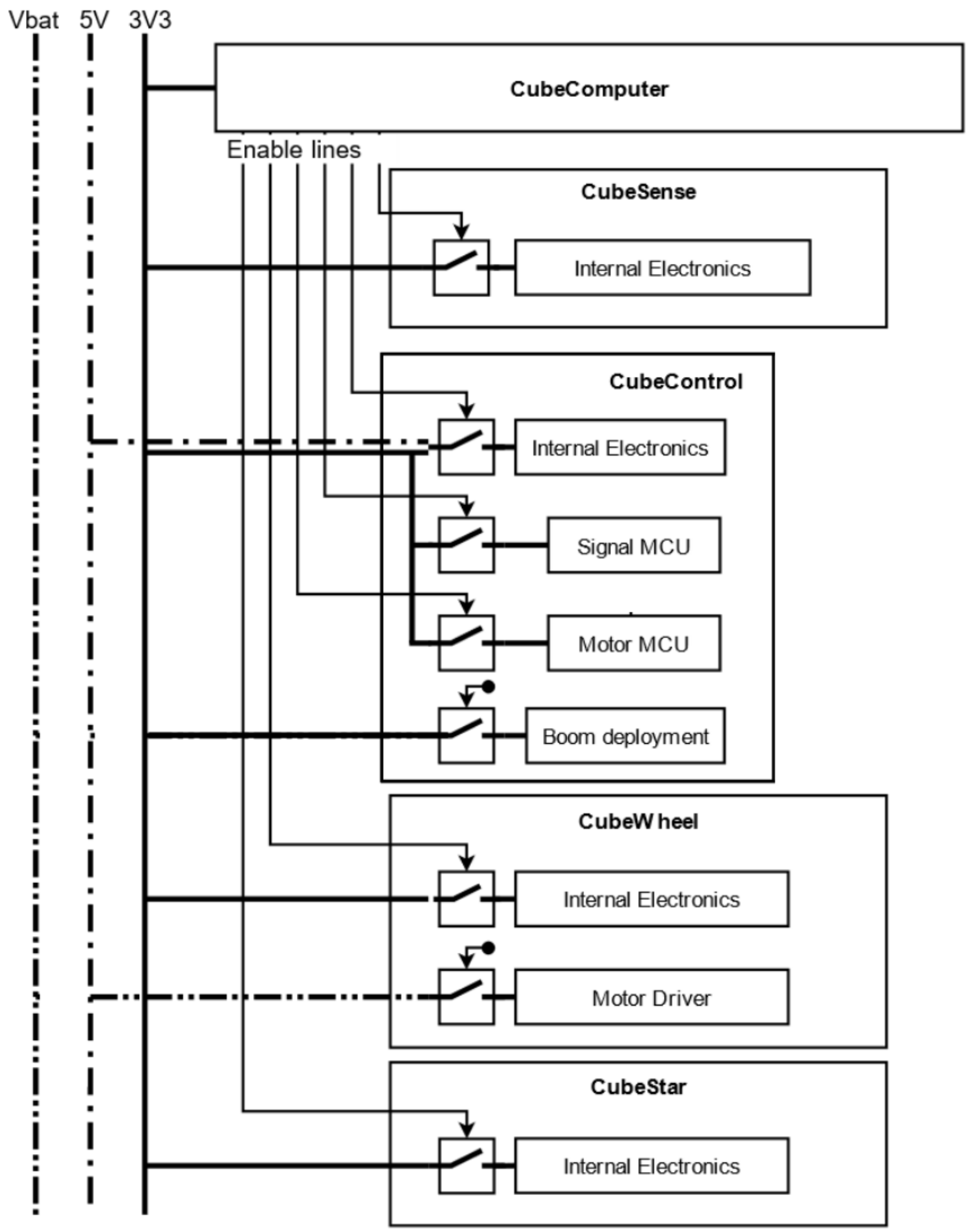


Figure 7 – CubeADCS enable Lines

5.4 Communication

5.4.1 I²C

The CubeADCS system can communicate with other satellite sub-systems using the system I^2C on the PC104 bus (H1-41, 43). CubeComputer will act as a slave on the system I^2C bus, responding to commands and telemetry requests. CubeComputer can be populated with or without pull-up resistors on the system I^2C bus. The system I^2C is permanently connected to H1-41,43, making this the primary communication channel for CubeComputer and the CubeADCS. All I^2C lines on the CubeComputer are buffered using the PCA9512ADP,118 from NXP.

5.4.2 UART

The CubeADCS bundle has two UART channels (on CubeComputer), designated UART 1 and UART 2, which can be used to interface with the CubeADCS. Both channels can be connected to the PC104 header. UART lines on the CubeComputer are buffered using the SN74AVC2T45 from Texas Instruments.

CubeSupport communicates with CubeComputer via UART 1, which is also accessible via a 3-way 2.54 mm pitch square post female header. A UART-to-USB cable is supplied with each CubeADCS system, which enables the user to connect with a PC to the CubeADCS.

5.4.3 CAN

The optional CAN interface on CubeComputer is only available on the main PC104 header (H1-1, 3). The combination of a CAN transceiver and a CAN controller module on CubeComputer allows the CubeADCS to interface at CAN bus voltage levels of 3.3 V or 5 V. A termination resistor between the CANH and CANL lines can be populated and can be configured at order.

6 Mechanical Interface

6.1 Component stack and shape

Most CubeSpace CubeProducts make use of the standard “self-stacking” PC104 CubeSat mechanical interface. The CubeADCS stack includes aluminum spacers to support the inter-PCB spacing. The PC104 header at the top of the stack is the ESQ-126-38-G-D, and the length of the pins at the bottom of the stack is 5.81 mm. Please see Section 4 for examples of our standard CubeADCS configurations and their respective heights. The dimensions of the stacked CubeProducts and mounting locations are displayed in Figure 8.

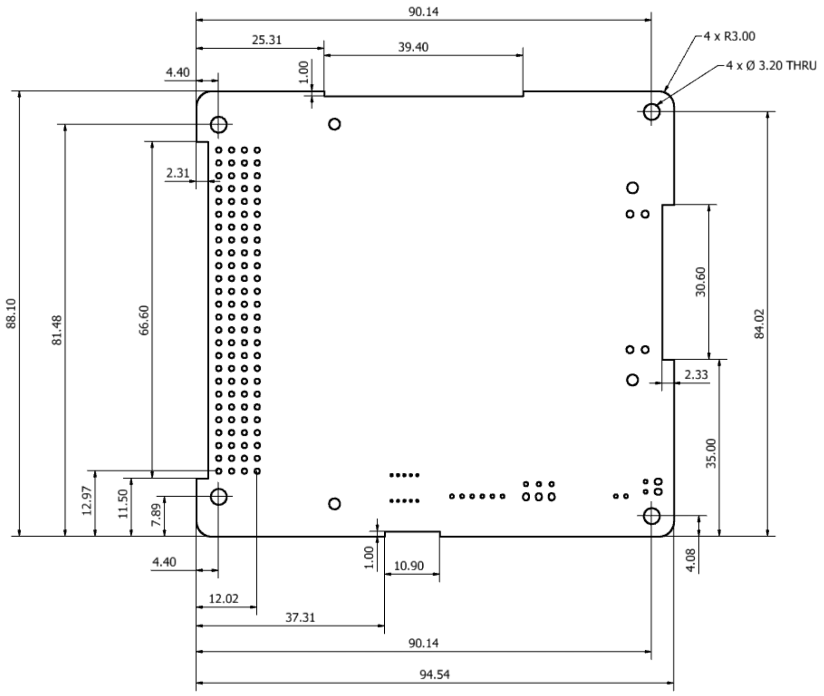


Figure 8 – PC104 board with rounded corners

During shipment the spacers are kept in place by M3, A4 stainless steel bolts and nuts through the mounting holes. When the ADCS is integrated with the rest of the satellite these nuts and bolts will have to be removed, to allow mounting of the system in the satellite. This will cause the spacers to easily fall out of the ADCS. To prevent this, the spacers are epoxied in place to insure they remain in position. Only the bottom part of each spacer will receive epoxy, as shown in Figure 9.

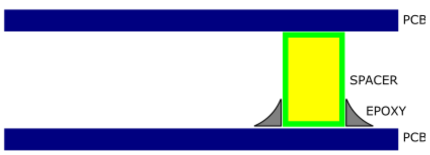


Figure 9 – Epoxy of spacers

7 CubeADCS sub-systems

7.1 CubeComputer

The main computing sub-system in the CubeADCS is the CubeComputer which is effectively a low power ADCS OBC. CubeComputer runs estimator and control algorithms, does logging of TLM and manages communication to the ADCS modules. The CubeComputer features the following functions as standard:

- An integrated RTC and an internal and external watchdog,
- Application code, configurations, and the bootloader is contained in the MCU's internal flash memory,
- A 32 kB EEPROM that contains a backup copy of the configuration,
- A 4 MB external Flash for the reprogramming the bootloader code and application code in-flight, as well as temporary non-volatile storage,
- An FPGA for flow-through EDAC and SEU protection,
- Current monitoring for SEL (latch-up) protection and power cycling ability,
- A MicroSD card for 1 GB of data storage,
- I2C, CAN, UART interfaces to another OBC.

The UART header described in Section 5.4.2 is shown in Figure 10.

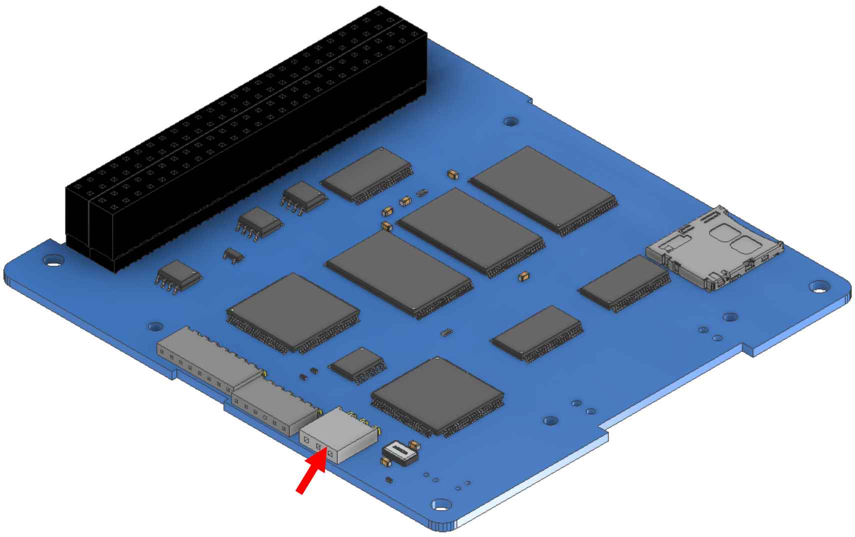


Figure 10 – CubeComputer with UART header location indicated

7.1.1 Specifications

Table 5 – CubeComputer specifications

Specification	Value	Notes
Physical		
Mass	56 g	Mass will vary with configuration
Dimension	89 x 95 x 11.05 mm	Height depends on PC104 header used. This Height is based on ESQ-126-38-G-D which provides a pin length of 5.76 mm measured from the bottom of PCB and header height of 11.05mm
Electrical		
Supply Voltage	3.3 V	Minimum of 3.0V, Nominal 3.3V, Maximum 3.6V
Reset threshold voltage	3.0 V	Minimum of 2.88V, Typical value is 2.93 V and Maximum is 3.0 V
Average power when running ADCS	120mW	
Peak power when running ADCS	200mW	
Environment		
Operating temperature	-40 to 85 °C	Component operation range based on datasheets: -40 to 85°C
Vibration	6.5 g RMS random	
Radiation	TID @ 24 k Rad SEU @ 66 MeV and 200 MeV	High energy particle tests have been conducted to induce SEU and to test protection circuitry and software

7.2 CubeSense

CubeSense is a small camera sub-system. The compact design allows for a more compact CubeADCS and provides the end-user with the freedom to mount the cameras where they have the volume available. The CubeSense can be configured as either Nadir or Sun sensors during manufacturing. The Sun sensor has a filter that allows only intense light emitted from the sun to be detected. Therefore, camera type must be specified when placing an order.

The CubeSense connects to the CubeADCS with a Samtec SFSDT harness that plugs into the back of it. The connector for this cable can be either a straight or right-angle Samtec TFM header. The connector needs to be fixed in place with epoxy after final integration of the satellite to ensure that it does not loosen during launch. This sub-system should be mounted to the satellite side panels with the lens protruding as far as possible to avoid objects being visible in its FOV. The mounting hole layout is shown in Figure 11. The CubeSense comes with M2 threaded mounting brackets attached to the front with a hole depth of 3 mm.

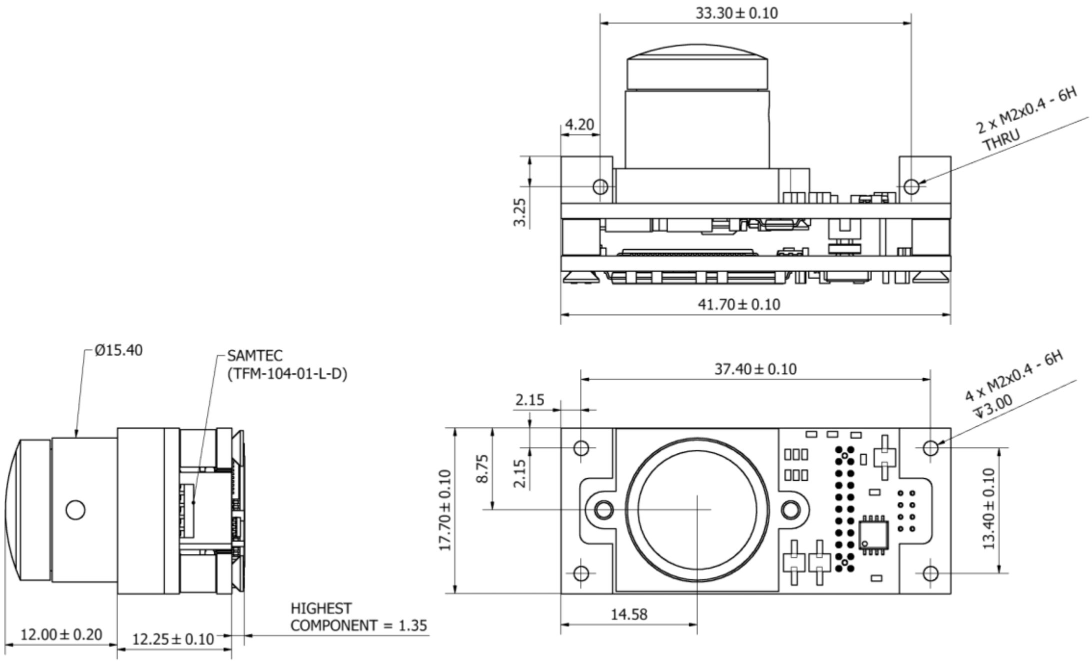


Figure 11 – CubeSense dimensions

7.2.1 Axis definition

The mounting orientation of the CubeSense cameras is specified by a set of three angles **alpha (α), beta (β), and gamma (γ).** These three angles correspond to the angles in a Euler 3-2-1 rotation sequence to rotate the sensor's coordinate frame to the SBC. The sensor coordinate frames for the CubeSense are defined as follows:

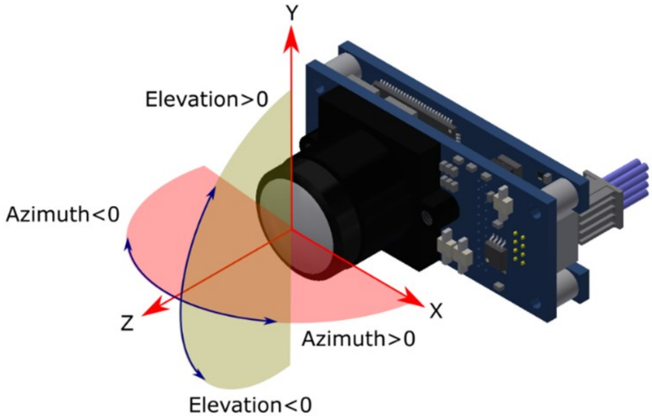


Figure 12 – Coordinate frames of CubeSense

The rotations α, β, and γ are around the sensor's Z, Y and X axes respectively.

7.2.2 Specifications

Table 6 – CubeSense specifications

Specification	CubeSense	Notes
Physical		
Mass	19.7 g	Without harnesses
Dimensions	43 x 17.7 x 27.5 mm	Camera modules
Electrical		
Supply Voltage	3.3 V	
Average Power	100 mW	At 1Hz update rate
Peak Power	200 mW	During image capture
Performance		
Sun sensor Accuracy	<0.22°	Entire FOV, 2σ
Nadir sensor Accuracy	<0.22°	Entire Earth visible in FOV, 2σ
Update Rate	2 Hz	
Sun Sensor FoV	130° vertical/horizontal and 160° diagonal	
Nadir Sensor FoV	170° vertical/horizontal and 180° diagonal	
Image size	1024x1024	Grayscale Images
Environmental		
Operating Temperature	-20°C to 70°C	

7.3 Magnetorquers (CubeRod and CubeCoil)

CubeRod is a nanosatellite magnetic torquer that uses a specially treated ferrous core with ultra-low remanence and high linearity. These rods are driven by the CubeControl. The rods come in three different sizes, depending on the application. Typically, if used, the small CubeRods are mounted on the CubeControl, whereas the medium and large sizes must be mounted separately.

CubeCoil is a low-power nanosatellite magnetic torquer with an air-coil that fits in the stack between the PCBs. It is also driven by CubeControl. In situations where stronger torques are required on the satellite a double winded coil will be used.

7.3.1 Axis definition

The axis of the torquer rods and torquer coil mounted on the CubeADCS aligns with CubeADCS body coordinates, where a standalone torquer (connected to CubeControl) has its positive direction away from the harness connection when a voltage is applied on the pin marked 1 and ground on pin 2. These axis definitions are shown in Figure 13.

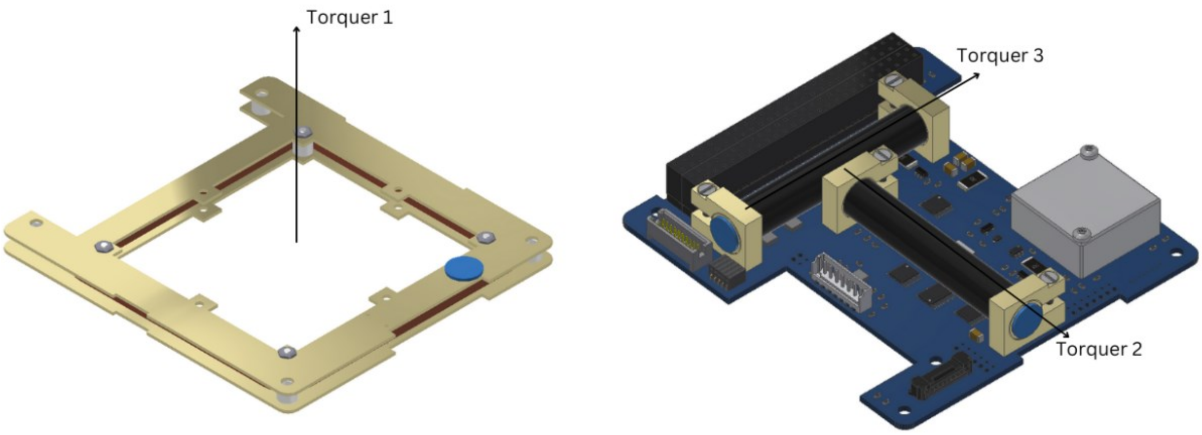


Figure 13 – Magnetorquer axis definition

7.3.2 Specifications

Table 7 – Magnetorquer specifications

Specifications	Small Rod	Medium Rod	Large Rod	Single Coil	Double Coil
Physical					
Mass	28g	36g	72g	46g	74g
Dimensions (mm)	18x14x62	18x14x77	18x14x153	90x96x8	90x96x8
Performance					
Magnetic Moment	0.24 Am^2	0.66 Am^2	1.9 Am^2	0.13 Am^2	0.27 Am^2
Magnetic Gain	2.8 Am^2/A	8.2 Am^2/A	25 Am^2/A	2.1 Am^2/A	2.1 Am^2/A
Linearity (0-5V)	97.5%			NA	NA
Electrical					
Resistance	29-31Ω	63-65 Ω	64-66 Ω	79-81 Ω	35-37 Ω
Max Continuous Current at 25 ℃	150mA				
Environmental					
Operating Temp	-20°C to 70°C				
Vibration	14g RMS				
Outgassing of heat shrink	TML = 0.36%, CVCM = 0.04%				
End Caps	Alodine Aluminium				

7.4 CubeControl

CubeControl is an actuator and sensor interface module. It implements magnetic control actuation by reading up to two magnetometers and driving three magnetorquer rods. It also interfaces with ten coarse sun sensors and a three axis IMU.

7.4.1 Axis definition

The rate sensors align with the X/Y/Z axes of the ADCS Body Coordinates.

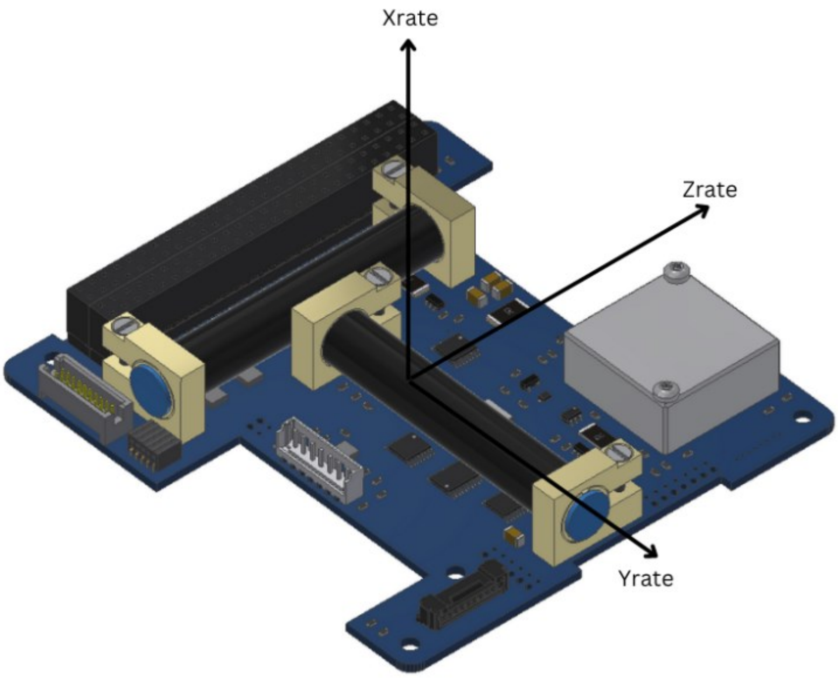


Figure 14 – Rate sensor axis definition

7.4.2 Specifications

The CubeControl and its sub-systems' specifications are shown below in Table 8.

Table 8 – CubeControl specifications

Specification	Value	Notes
Physical		
Dimension (mm)	90 x 96 x 19.5	
Mass		
Total mass	115 g	Including: PCB and 2 magnetorquer rods
PCB and components	47 g	
Magnetorquer rods	56 g	Y-axis and Z-axis rods
Electrical		
Supply Voltage	3.3V & 5V	
Average power	200mW	No Actuators

Specification	Value	Notes
IMU Performance		
Nonlinearity	0.05	% of FS
Update rate	1 Hz	Averaged output
Angular Random Walk	$0.08°/\sqrt{h}$	
Bias instability	1.2°/h	
Environment		
Operating Temp	-10 to 70 °C	
Vibration	8 g RMS random	
Radiation	24k Rad	

7.5 CubeMag

7.5.1 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. The overall dimensions of the CubeMag deployable in its stowed state are shown in Figure 15. The CubeMag connects to the system with a Molex Micro-Lock Plus header, manufacturer part number 5055651001.

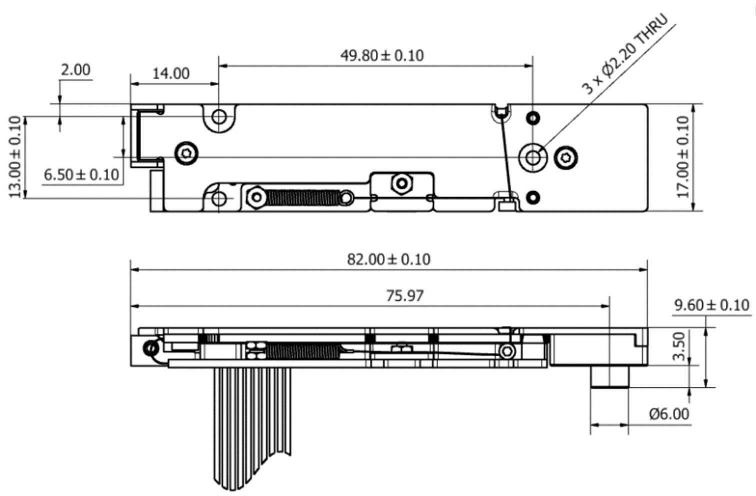


Figure 15: Deployable magnetometer dimensions in the stowed position

Figure 16 displays the dimensions of the deployable magnetometer in the deployed state.

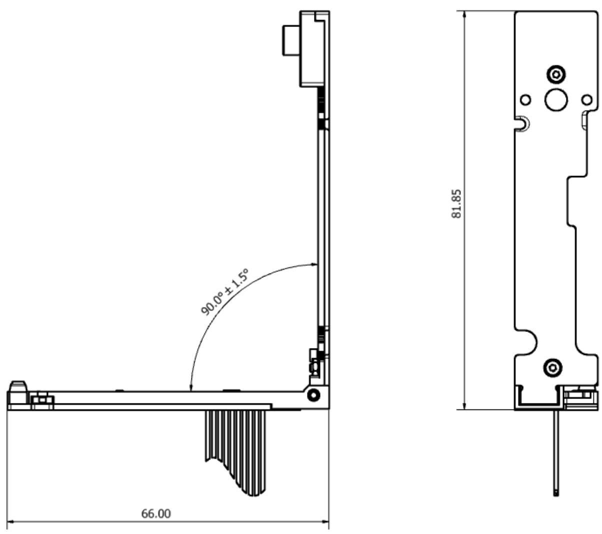


Figure 16: Deployable magnetometer dimensions in the deployed position

The deployable magnetometer is designed to mount to an external surface of the satellite. The magnetometer should not be placed in close proximity to any other part of the satellite that causes significant disturbances.

The hole placement and panel cut-outs required for mounting of the magnetometer is shown in Figure 17. The dashed line shown in Figure 17 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 17 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.

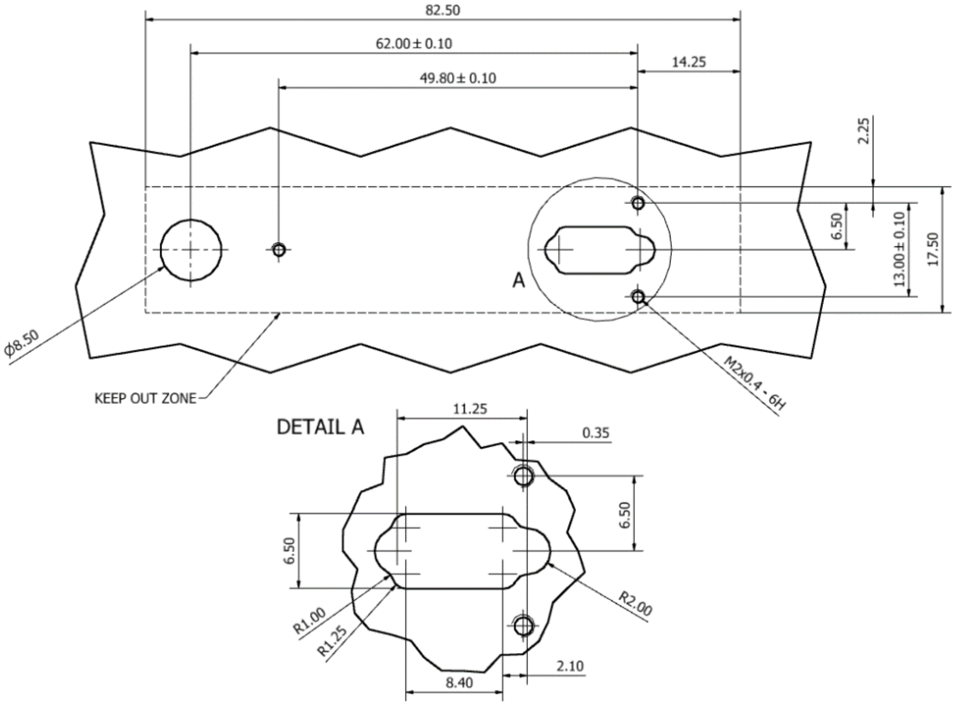


Figure 17: Panel cut-outs required to mount CubeMag Deployable

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 18.

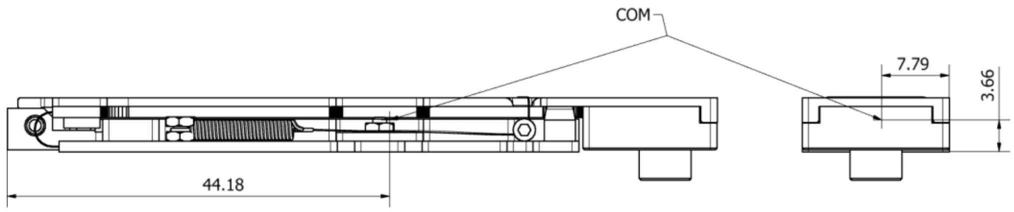


Figure 18: COM position of CubeMag Deployable in stowed state

Figure 19 displays the COM position of the CubeMag deployable (excluding wire harness) in the deployed state.

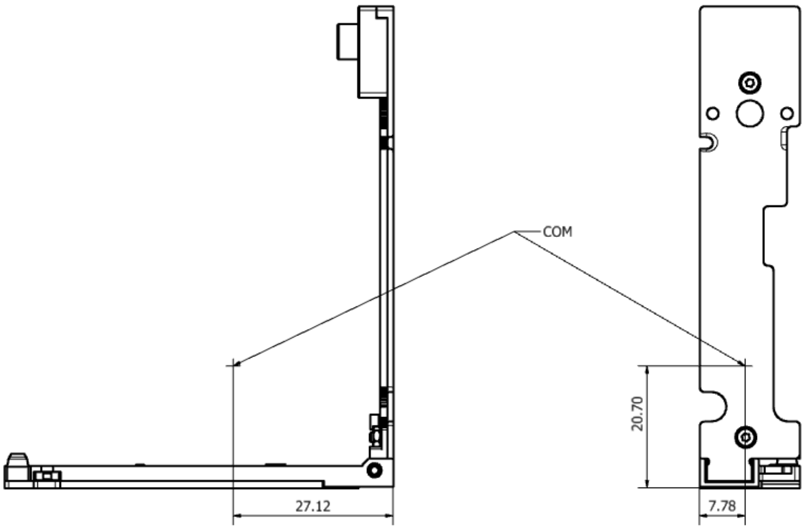


Figure 19: COM position of CubeMag Deployable in deployed state

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 9, the axes reference for the inertias provided is shown in Figure 20.

Table 9: 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 %

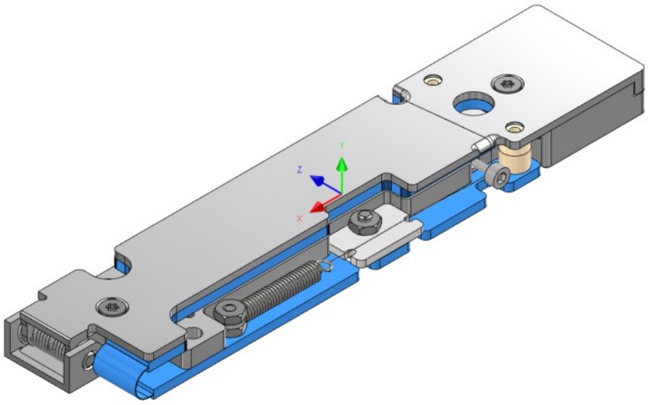


Figure 20: CubeMag Deployable inertial reference frame

The CubeMag Deployable returns the magnetic field as a calibrated measurement[1]. This calibrated measurement reference frame is the same for both the primary and secondary magnetometer, this reference frame is shown in Figure 21. 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.

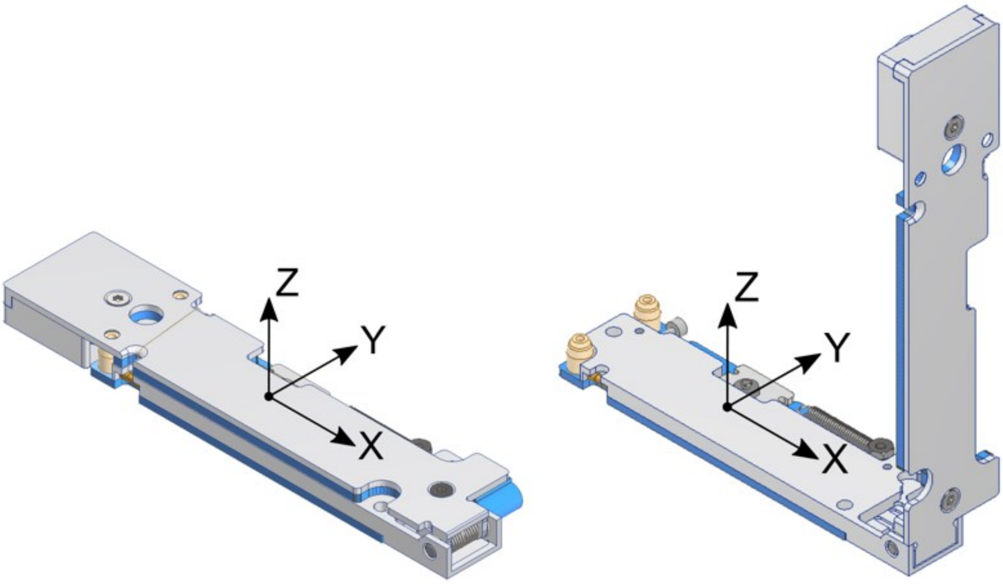


Figure 21: CubeMag Deployable calibrated measurement reference frame

[1] The CubeMag has a TLM for calibrated measurements and a TLM for raw measurements. Only the calibrated measurements TLM follows the reference frame shown in Figure 21.

7.5.2 CubeMag Redundant

The CubeADCS system offers an interface to an optional redundant magnetometer, Figure 23. The magnetometer is housed in the same enclosure as the primary magnetometer, but it is not deployable. The dimensions of the redundant magnetometer are shown below in Figure 22.

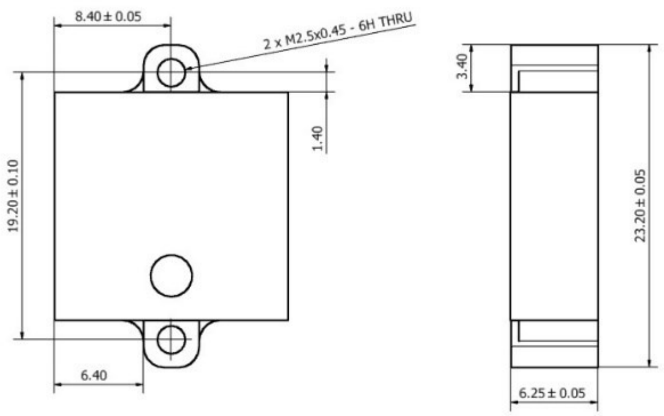


Figure 22 – Redundant magnetometer dimensions.

Figure 23 – Redundant magnetometer

The magnetometer interfaces with the CubeControl module using an Omnetics Nano Circular 6-way in-line connector set. The harness is terminated in a 6-way Molex Micro-Latch female connector. An illustration of the redundant magnetometer connection can be seen in Figure 24.

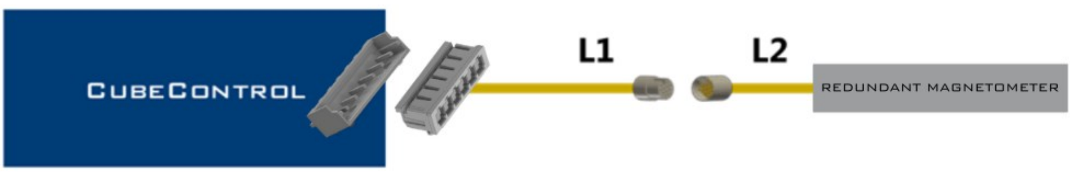


Figure 24: Redundant magnetometer wiring diagram

The length between the CubeControl and the in-line connection can be configured to the user's requirements. The maximum total length of the harness is 350 mm. The in-line Omnetics connector has a diameter of 4.0 mm.

7.5.3 Axis definition

The mounting of the magnetometer is specified by a set of three angles **alpha (α), beta (β), and gamma (γ).** These three angles correspond to the angles in a Euler 3-2-1 rotation sequence to rotate the sensor's coordinate frame to the SBC. The sensor coordinate frames for the various sensors are defined as follows:

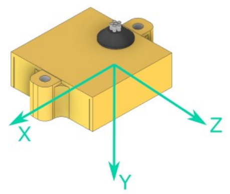


Figure 25 – CubeMag Redundant axis definition

The rotations α, β, and γ are around the sensor's Z, Y and X axes respectively.

7.5.4 Specifications

Table 10 – CubeMag specifications

Specification	CubeMag Deployable	CubeMag Redundant	Notes
Physical			
Mass	15.5 g	3.5 g	
Dimension	82 x 17 x 6.5 mm	23.4 x 16.8 x 8.1 mm	
Operating Temp	-30 to 80 °C	-20 to 85 °C	
Vibration	14.16 g RMS random	8 g RMS random	
Radiation	24k Rad	24k Rad	
Electrical			
Supply Voltage	3.3 V	3.3 V	
Average power	50 mW	35 mW	
Performance			
Measurement noise	< 50 nT	< 50 nT	1σ (per X/Y/Z channel)
Update rate	1 Hz	1 Hz	Averaged output

7.6 Coarse sun sensors

The CubeADCS system can interface with up to ten coarse Sun sensor (CSS) photodiodes, each mounted on a small PCB. The dimensions of each CSS PCB are 3.8 mm x 10.8 mm, and the height is 1.7 mm.

Figure 26 – Single coarse sun sensor PCB and cable

The ten CSSs are each connected to CubeControl by a Molex PicoBlade 2-way in-line connector to ease the satellite integration process. The ten 2-way harnesses are terminated in a single 20-way female connector, of which the male connector is populated on CubeControl. Figure 27 and Figure 28 illustrate the above-mentioned wiring of the CSS components. The PCBs with the CSSs are connected to a short stub that is 50mm long. The in-line harness can be configured to be up to 350mm, with 300mm being the default length.

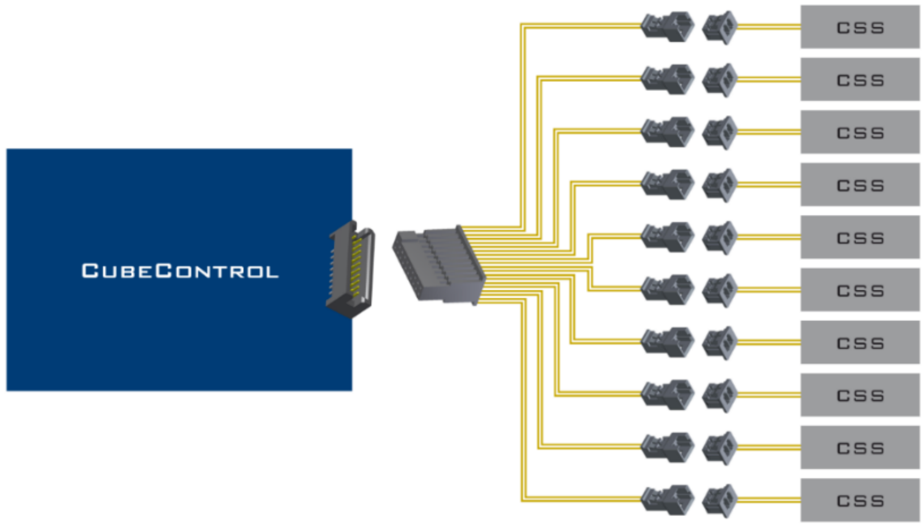


Figure 27 – Coarse sun sensor wiring diagram

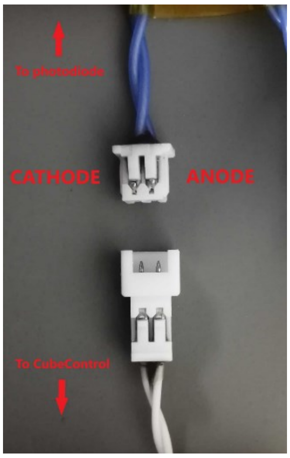


Figure 28 – Coarse sun sensor in-line harness pins

The CSSs do not have mounting holes – they should be attached to the satellite body using epoxy as shown in Figure 29. At least six photodiodes, each on a different facet of the satellite, are required to obtain a coarse Sun vector throughout the entire sunlit part of the orbit. The four additional sensors can be used for redundancy or in cases where sensors are shadowed or obstructed.

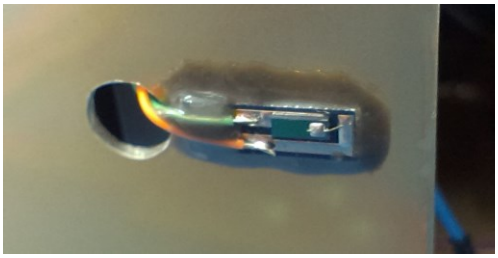


Figure 29 – Coarse sun sensor epoxied to satellite body

7.6.1 Specifications

Table 11 – Coarse sun sensor specifications

Specification	Value	Notes
Physical		
Mass	0.2 g	PCB and 50mm connector stub
Dimension	3.8 x 10.8 x 1.7 mm	
Electrical		
Average power	< 5 mW	All sensors
Performance		
Measurement accuracy	< 10°	1σ
Update rate	1 Hz	
Environmental		
Operating Temp	-40 to 125 °C	
Vibration	8 g RMS random	
Radiation	24k Rad	

7.7 CubeConnect

The CubeConnect board acts as an interface board for several of the loose peripheral sub-systems to connect to the PC104 stack. This board has headers for connecting CubeWheels, CubeStar(s) and the CubeSense modules. The CubeConnect is available in two different versions: A PC104 form-factor board (CubeConnect standard) with cutouts as seen in Figure 30, and the smaller version called CubeConnect Micro as shown in Figure 31.

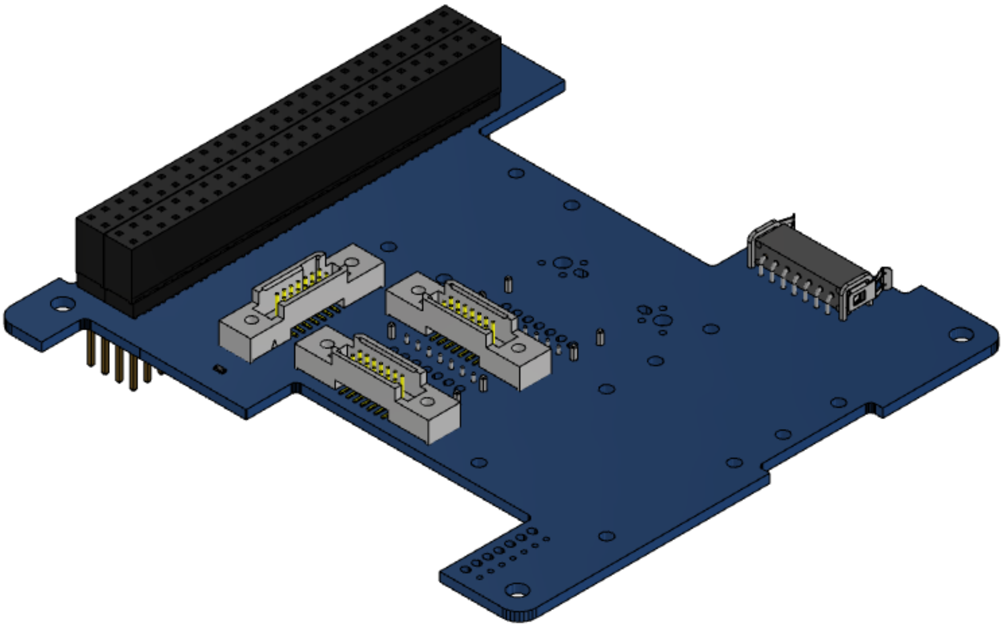


Figure 30: CubeConnect Standard

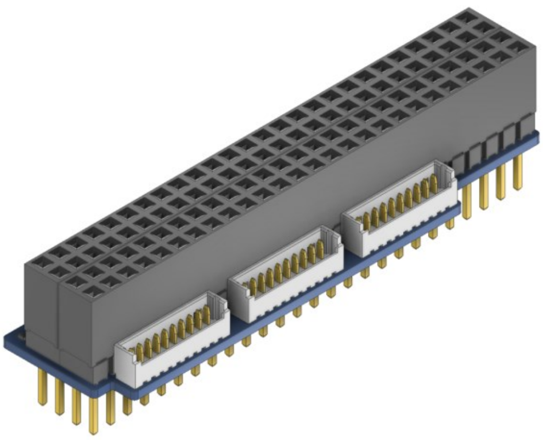


Figure 31: CubeConnect Micro

7.7.1 CubeConnect Standard

The board has 3 Harwin M80 connectors that can be used for either a CubeStar sub-system or a CubeSense sub-system. The board also has 4 Samtec TFM screw down headers that can be used for the wheels. The locations of these headers are shown in Figure 33.

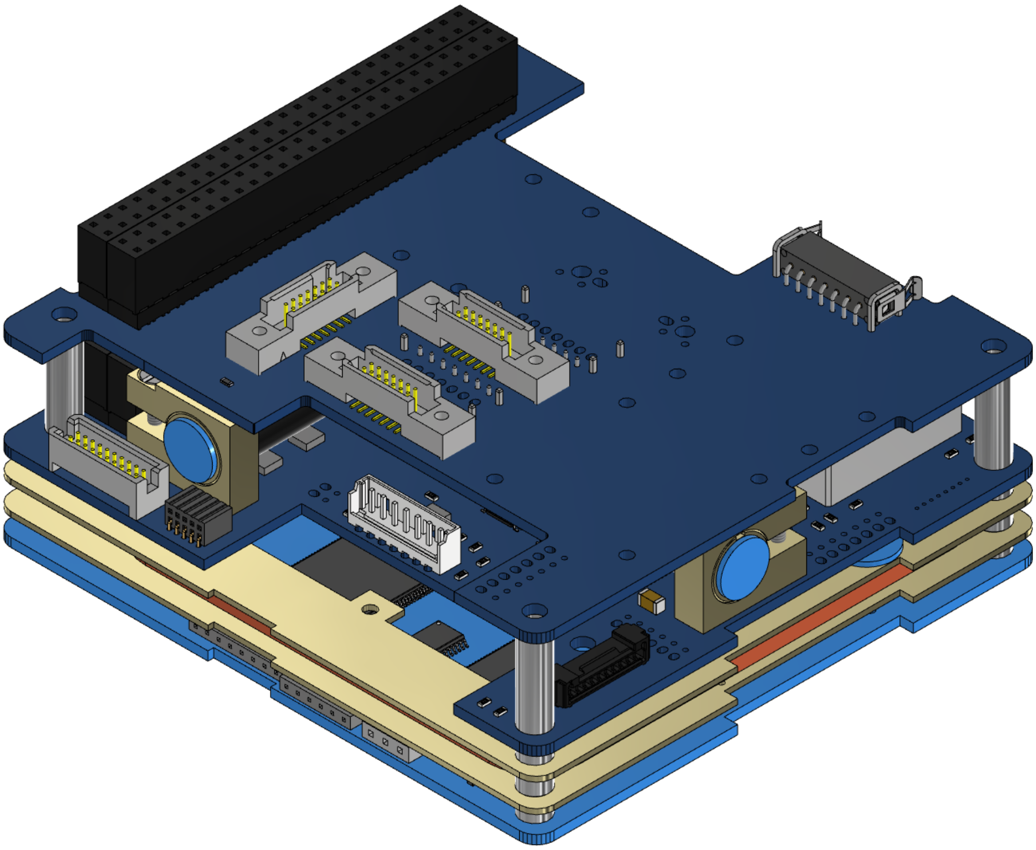


Figure 32: CubeADCS with CubeConnect Standard

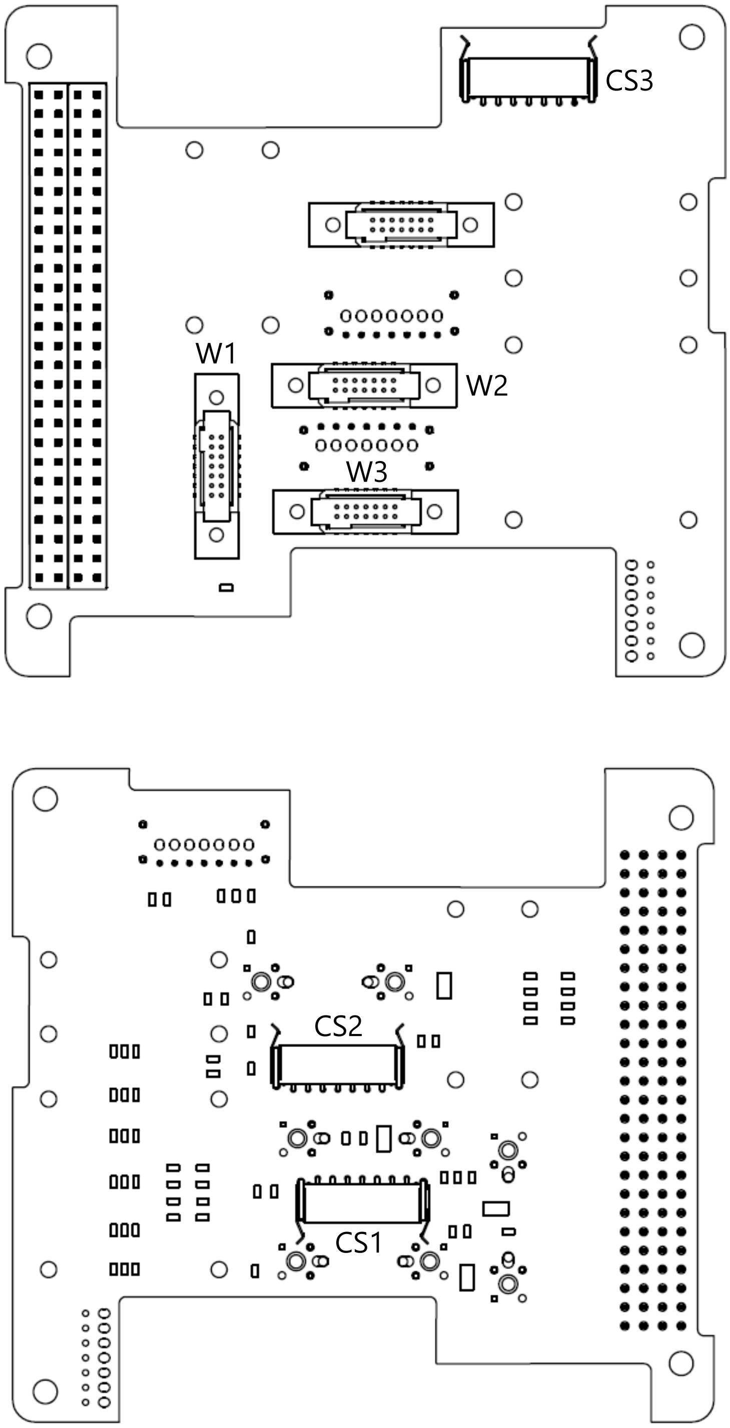


Figure 33 – Standard CubeConnect interface board

For modules that have small wheels, they can be mounted directly on the CubeConnect board as seen in the CubeADCS drawings in Section Standard CubeADCS solutions.

7.7.2 CubeConnect Micro

For bundles with wheels which need to be mounted separately, the CubeConnect Micro can be used which allows for a very compact CubeADCS stack as seen in Figure 34. The locations of the headers are shown in Figure 35. Additional to the PC104 headers the board has Molex vertical PicoBlade connectors. The CubeSense and CubeStar connect to a 5-pin variant, the Cubewheels connect to a 10-pin variant and a 3 pin I2C breakout header is available.

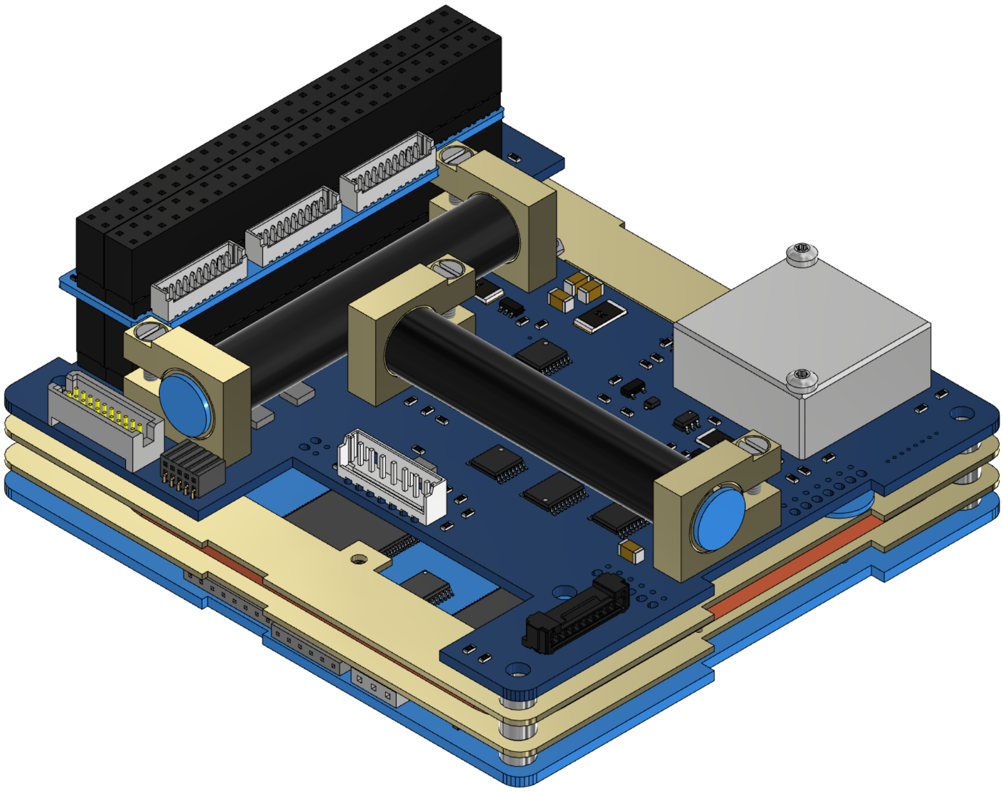


Figure 34 – Micro CubeConnect on ADCS stack

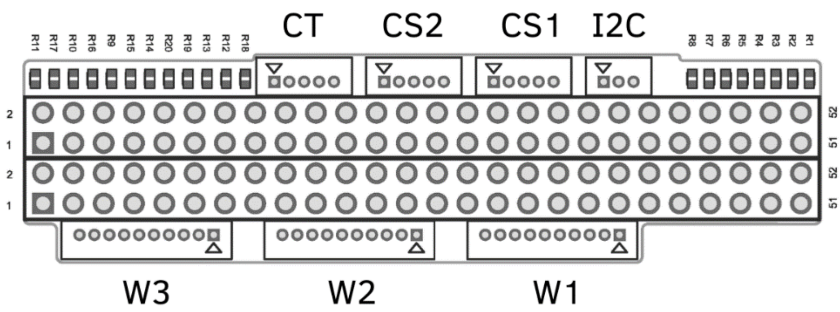


Figure 35 – Micro CubeConnect Interface Board

7.7.3 Specifications

	CubeConnect Standard	CubeConnect Micro
Physical		
Mass	50 g	24.5 g
Dimension	88.10 x 94.54 x 11.05 mm	17.65 x 66.95 x 11.05 mm
Environmental		
Operating Temp	-10 to 60 °C	-10 to 60 °C
Vibration	8.9 g RMS	8.9 g RMS
Radiation	24 kRad	24 kRad

7.8 CubeWheel

The mounting of the three CubeWheel reaction wheels will depend on the size of the CubeWheels.

In the case of small CubeWheels, the wheels can be: (1) mounted on the regular CubeConnect and integrated onto CubeADCS; (2) mounted on the regular CubeConnect and supplied separate from the CubeADCS; or (3) supplied loose with a CubeConnect Micro in the CubeADCS. In this case, the user must mount the wheels to their satellite frame via a bracket.

In the case where any CubeWheel other than the CubeWheel Small is provided as part of the ADCS solution, the only the option is for the user to mount the wheels. The harnesses that connect the CubeADCS to the wheels should have adequate length to cover the required distance with some added slack to avoid strain on the connectors during integration

The disc inside a CubeWheel has been balanced to avoid jitter when the wheel is spinning, but it is still good practise to not mount any CubeWheel on the same mounting surface of sensitive optics.

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 0.3 Nm for the M2 threaded aluminium holes. Ensure that all mounting screws are staked before carrying out vibration tests.

7.8.1 Small CubeWheel

The small CubeWheel has three sets of four M2 mounting holes on three different facets, as illustrated in Figure 36. The outer dimensions of the small CubeWheel are 28 mm x 28 mm x 26.1 mm. Note that an additional 1.5 mm is required on one side of the CubeWheel for internal harnesses.

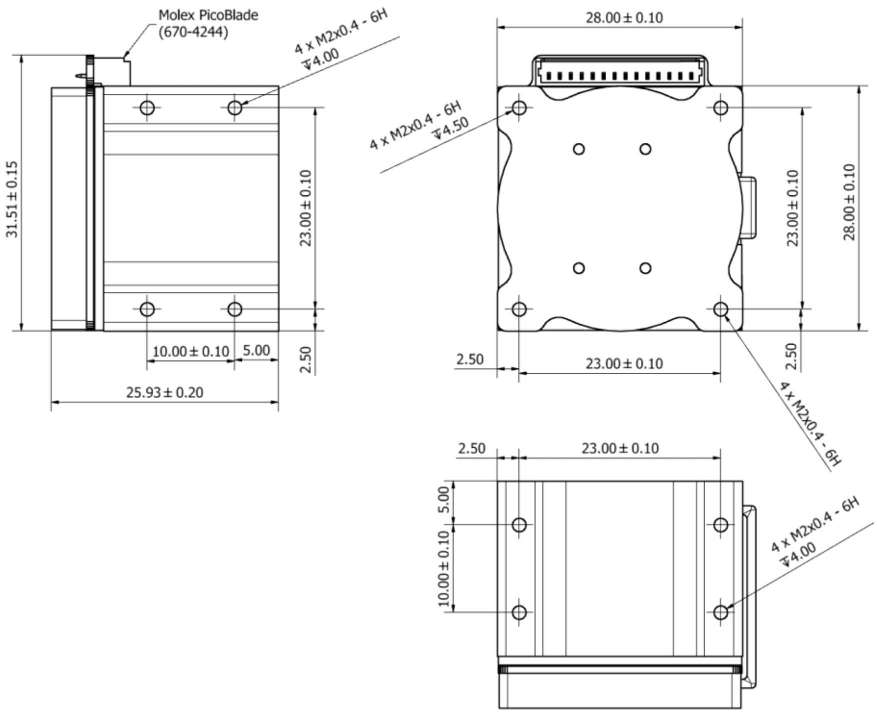


Figure 36 – Small CubeWheel mechanical interface

7.8.2 Small Plus CubeWheel

The Small Plus CubeWheel has three sets of four M2 mounting holes on three different facets, as illustrated in Figure 37. The outer dimensions of the small CubeWheel are 33.4 mm x 33.4 mm x 31 mm. Note that an additional 1.5 mm is required on one side of the CubeWheel for internal harnesses.

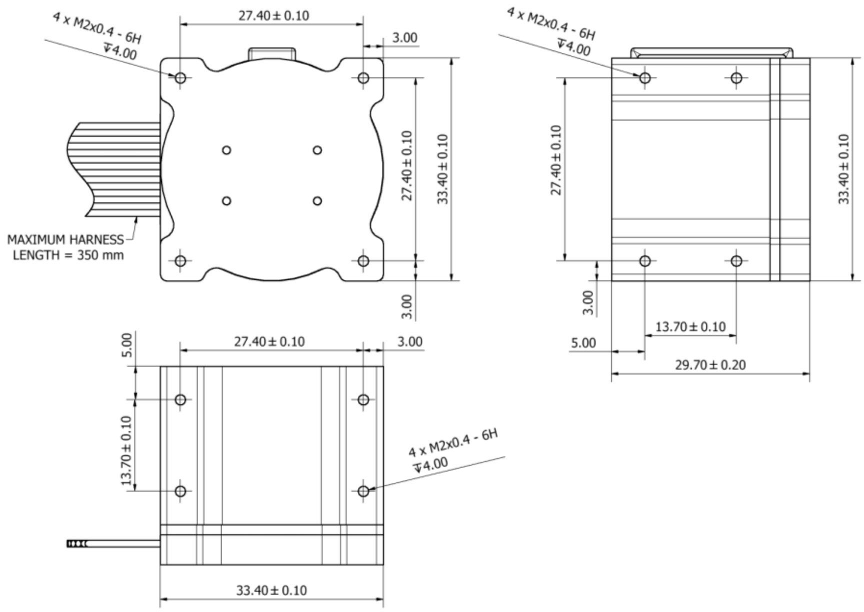


Figure 37 – Small Plus CubeWheel mechanical interface

7.8.3 Medium CubeWheel

The medium CubeWheel has three sets of four M3 mounting holes on three different facets, as illustrated in Figure 38. The outer dimensions of the medium CubeWheel are 46 mm x 46 mm x 31.75 mm. Note that an additional 1.5 mm is required on one side of the CubeWheel for internal harnesses. The M3 mounting holes are fitted with A2 (304) stainless steel helicoils to provide a stronger, more durable thread.

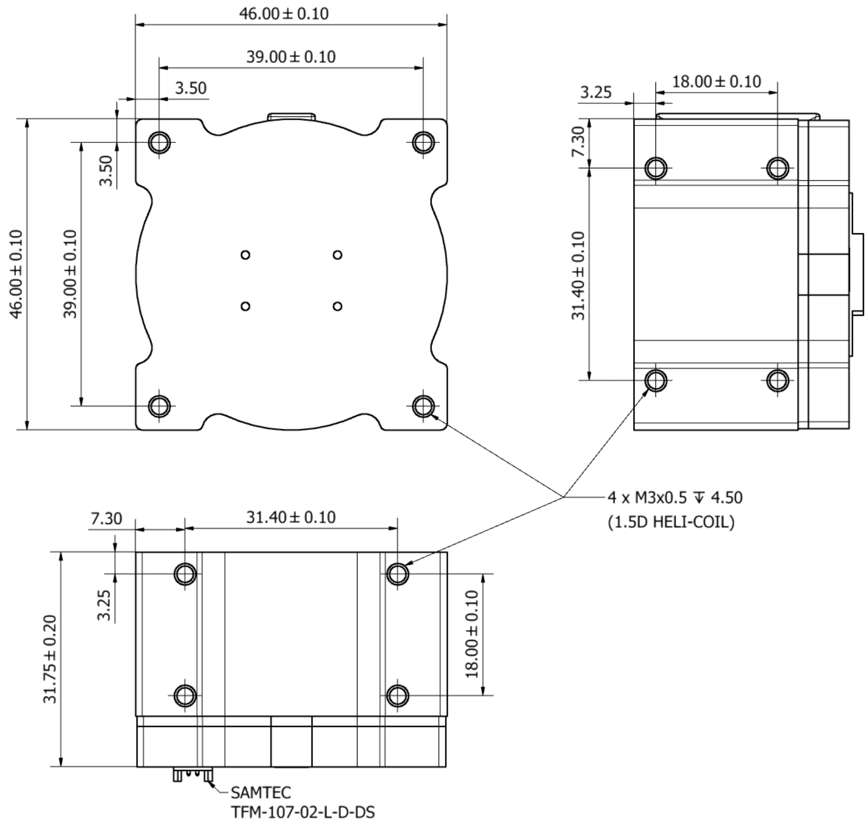


Figure 38 – Medium CubeWheel mechanical interface

7.8.4 Large CubeWheel

The large CubeWheel has three sets of four M3 mounting holes on three different facets, as illustrated in Figure 39. The outer dimensions of the large CubeWheel are 57 mm x 57 mm x 31.5 mm. Note that an additional 1.5 mm is required on one side of the CubeWheel for internal harnesses. The M3 mounting holes are fitted with A2 (304) stainless steel helicoils to provide a stronger, more durable thread.

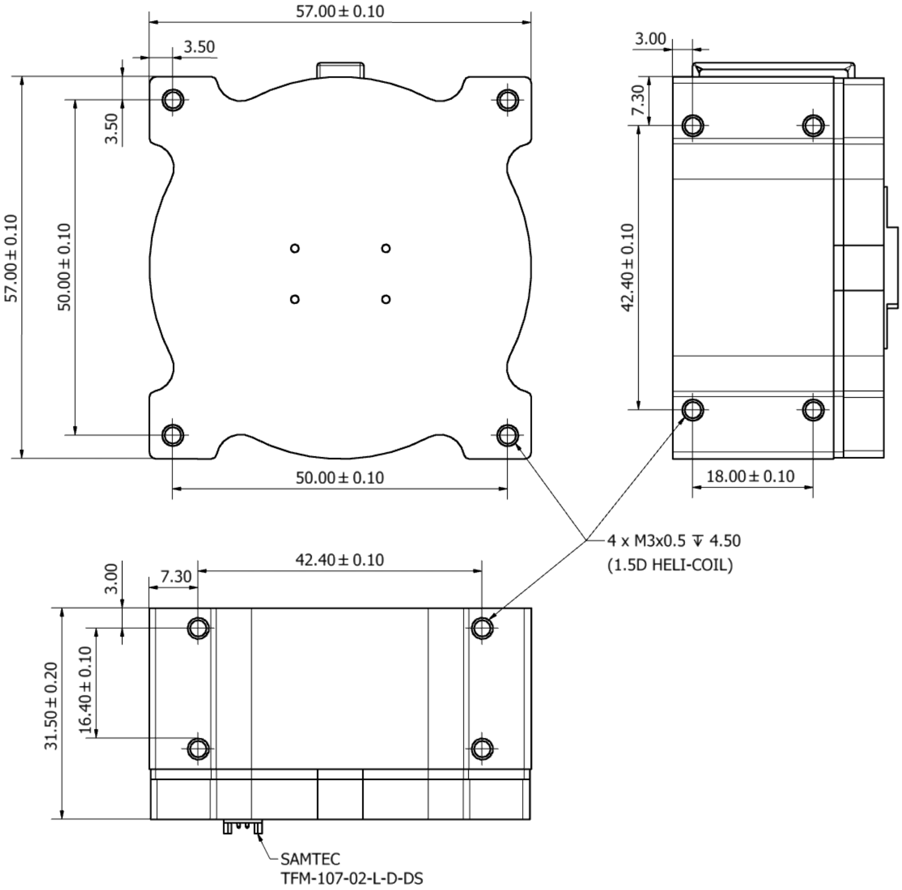


Figure 39 – Large CubeWheel mechanical interface

7.8.5 CW0057 and CW0162

The CW0057 and CW0162 CubeWheels have three sets of four mounting holes on three different facets, as illustrated in Figure 40. The outer dimensions of the respective CubeWheel are specified in Table 12.

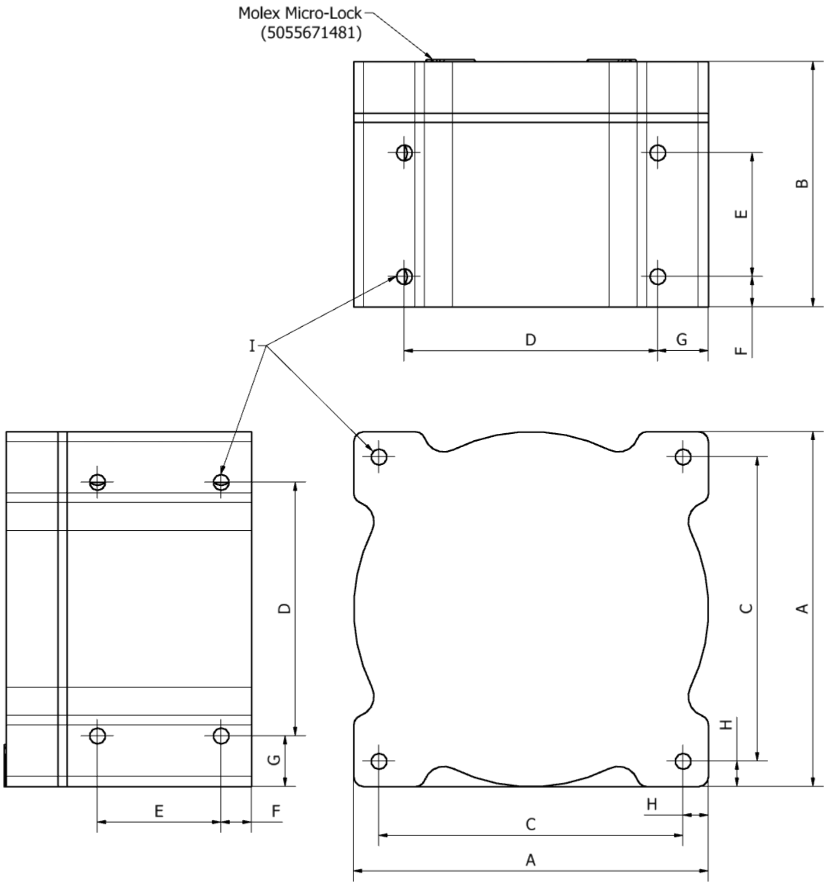


Figure 40 - CW0057 and CW0162 mechanical interface

Table 12: CubeWheel dimensions for each variant

Model	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	G (mm)	H (mm)	I
CW0057	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	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)

7.8.6 Axis definition

The reaction/momentum wheel's positive direction is defined as shown in Figure 41.

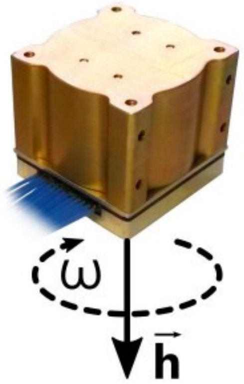


Figure 41 – CubeWheel Small, Small+, Medium and Large polarity

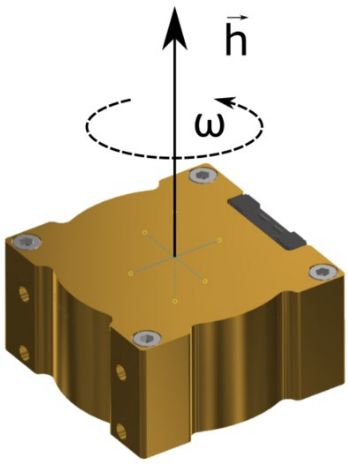


Figure 42: CubeWheel CW0057 and CW0162

If the user mounts the wheels, care must be taken to determine the mounting direction of the wheel according to the definition above.

7.8.7 Specifications

The Generation 1 CubeWheels have a turn-on threshold of 6.5 V, but lower voltages are tolerated without damage to them. The maximum tested bus voltage is 16.0 V. For the wheels to perform optimally, a battery voltage of at least 8V is recommended.

Table 13 – Generation 1 CubeWheel specifications

	Small	Small Plus	Medium	Large	Notes
Physical					
Mass	50 g	95 g	150 g	230 g	Excl harness
Electrical					
Supply Voltage	3V3 & Vbat	3V3 & Vbat	3V3 & Vbat	3V3 & Vbat	
Idle Power	65 mW	65 mW	65 mW	65 mW	@ 0 RPM
Average power	150 mW	190 mW	190 mW	350 mW	@ 2000 RPM
Peak power	0.65 W	2.3 W	2.3 W	4.5 W	@ max torque
Performance					
Maximum momentum	1.7 mNms	3.6 mNms	10.8 mNms	30.0 mNms	
Maximum wheel speed	± 8000 rpm	± 6000 rpm	± 6000 rpm	± 6000 rpm	
Maximum torque	0.23 mNm	1.0 mNm	1.0 mNm	2.3 mNm	
Static Imbalance	<0.003 g·cm	<0.004 g·cm	<0.004 g·cm	<0.006 g·cm	
Dynamic Imbalance	<0.005 g·cm^2	<0.014 g·cm^2	<0.014 g·cm^2	<0.05 g·cm^2	
Environmental					
Operating Temp	-10 to 60 °C	-10 to 60 °C	-10 to 60 °C	-10 to 60 °C	
Vibration	14.16 g RMS	8.9 g RMS	8.9 g RMS	8.9 g RMS	
Radiation	24 kRad	24 kRad	24 kRad	24 kRad	

To achieve the maximum rotation speed (thus momentum), the Generation 2 wheels require 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. The 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.

Table 14 – Generation 2 CubeWheel specifications

	CW0057	CW0162	Notes
Physical			
Mass	101 g	144 g	
Electrical			
Supply Voltage	7.3V to 17.4V	7.3V to 17.4V	Requires 1 3V to achieve 10 000 RPM
Idle Power	106 mW	106 mW	Drawn from 3V3
Steady-state power	458 mW @ 2000 RPM 970 mW @ 6000 RPM	458 mW @ 2000 RPM 970 mW @ 6000 RPM	Measured with 16 V supply
Peak power	11.3 W	16.5 W	Measured with 16 V supply
Performance			
Momentum	5.7 mNms	16.2 mNms	At 6000 rpm
Maximum wheel speed	10 000 RPM	10 000 RPM	Requires 13 V supply
Maximum torque	2 mNm	7 mNm	
Dynamic Imbalance	0.014 g.cm^2	0.014 g.cm^2	
Environmental			
Operating Temp	-20 ºC to 80 ºC	-20 ºC to 80 ºC	
Vibration	14.16 g RMS	14.16 g RMS	
Radiation	24 kRad	24 kRad	

7.9 CubeStar

CubeStar is a miniature star tracker specifically intended for, but not limited to usage in low-power, performance-critical CubeSat missions. The CubeStar mounting holes and the lens holder are connected to ground as a standard configuration.

7.9.1 Interface header

Power and communication lines are connected through the *HARWIN M80-8760722 L-Tek* single inline male interface header.

The position of the CubeStar interface header is shown in Figure 43.

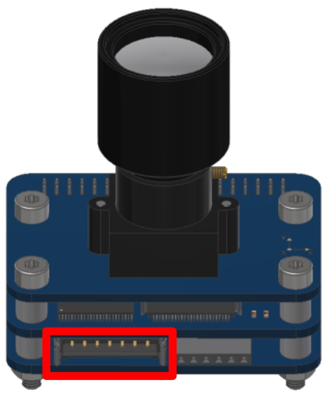


Figure 43 – CubeStar interface header location

Figure 44 shows a drawing of the interface header with pin one, the first pin on the left, indicated with a designator. On CubeStar, pin one of the interface header can be identified as the closest pin to the stand-off post on the edge of the PCB. Pin seven is the pin closest to the center of the PCB.

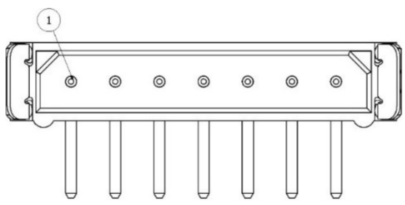


Figure 44 – CubeStar interface header

7.9.2 Physical specifications

The total volume of CubeStar is 50 mm x 35 mm x 54 mm, with a tolerance of ±1mm added on the CubeStar height to account for the calibrated lens position.

The outer dimensions of the CubeStar hardware are shown in Figure 45. Each circuit board in the PCB stack has dimensions of 50 mm x 35 mm x 1.61 mm. In this figure, the total height of CubeStar, measured from the highest component on the bottom of the first PCB to the end of the lens is 56.1 mm.

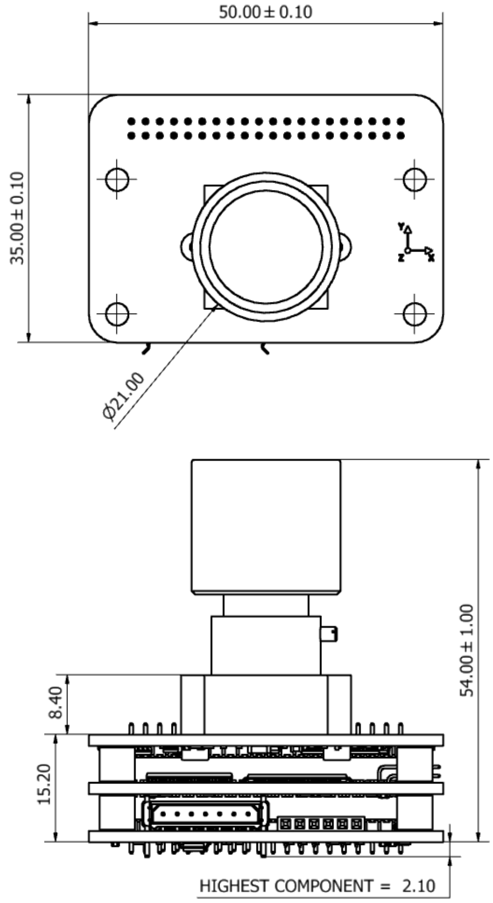


Figure 45 – CubeStar side view with dimensions

It should be noted that the interface header on CubeStar has latches that hold the mating connector in place. These latches protrude over the PCB by 1.61 mm. A front view of the CubeStar hardware, illustrating this latch overhang is shown in Figure 46. The size of the mating connector and wires must be taken into consideration when planning the placement of CubeStar in the satellite.

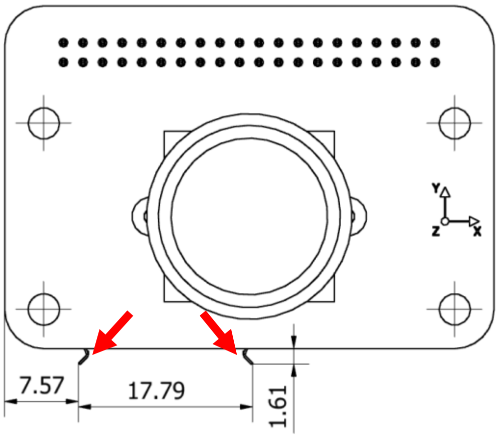


Figure 46 – CubeStar front view with red arrows pointing at connector latch

7.9.3 Field of view

The lens used on CubeStar has a horizontal FoV of 58° and a vertical FoV of 47°. As this lens has a large angle of view, care should be taken to ensure that there are no obstructions in, or near the lens view cone. Internally, the FoV is artificially limited to 42° by using a reduced region of interest of 937 x 937 pixels. An illustration of this FoV reduction technique is given in Figure 47. In this image, the outer rectangle shows the image sensor bounds, the large circle the total unshaded view cone of the lens, and the shaded area the square 42° region of interest.

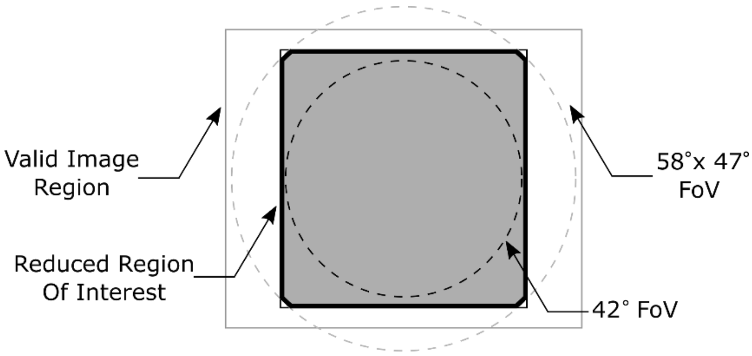


Figure 47 – CubeStar valid image region

The star tracker view-cone is shown in Figure 48. The successful operation of the star tracker cannot be guaranteed if this view-cone is obstructed by deployable satellite structures.

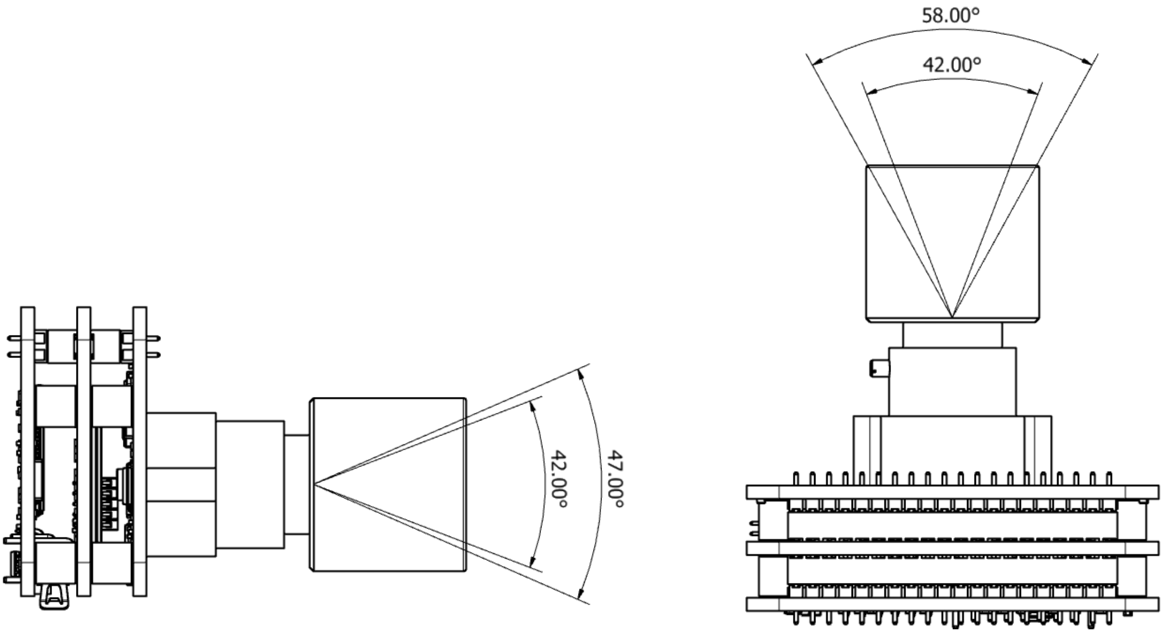


Figure 48 – CubeStar field of view

7.9.4 Mounting considerations

The four mounting holes each have a 3.2 mm diameter to accommodate M3 sized bolts. Figure 49 shows the spacing of the mounting holes. CubeStar is supplied with four A4 grade stainless steel bolts. If required, these bolts can be used to mount CubeStar. It is important to ensure that spacing of at least 3mm is left between the bottom PCB and the rest of the satellite when mounting CubeStar. This spacing is required to prevent electrical shorts.

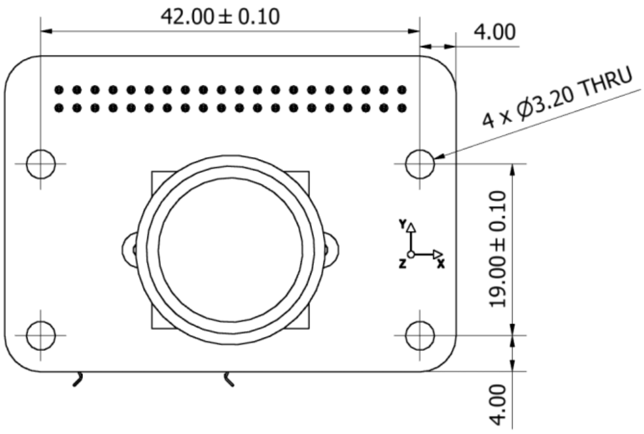


Figure 49 – CubeStar mounting holes

7.9.5 Lens position

The lens is made up of multiple glass elements that can be damaged if not adequately supported. The lens holder and lens position are shown in Figure 50.

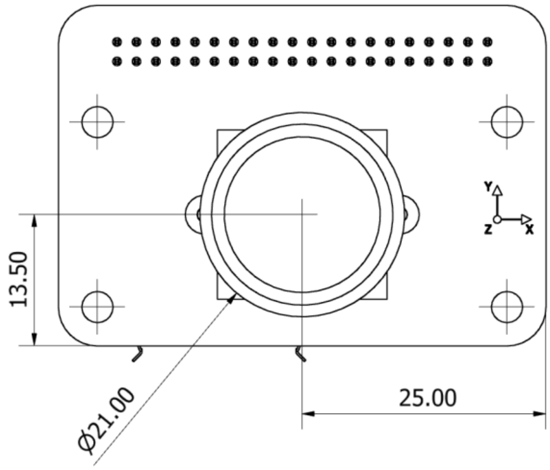


Figure 50 – CubeStar lens position

7.9.6 Mounting restrictions

There are several important factors to consider before choosing a location to mount CubeStar. Although these mounting suggestions are only given as guidelines, they are advised for consideration to ensure optimal star tracker operation.

To ensure optimal performance, no panels, deployable structures, or objects should be mounted in, or close to the star tracker FoV (58° x 47°). It is further crucial that no reflections are cast onto the CubeStar lens as this might degrade the overall star detection performance.

CubeStar should be mounted so that it is pointing away from the Sun, Earth, and Moon during the nominal flight orientation. If these celestial bodies enter the FoV, images will over saturate thereby impeding star detection.

Although active thermal regulation is not required, it is recommended that CubeStar is mounted away from any solar rays. This will prevent performance degradation caused by excessive thermal conditions and possible damage to the image sensor.

CubeStar should be mounted so that there is enough slack on the wire harness. An excess in harness strain can lead to an unsecure connection or damage.

Care should be taken when mounting CubeStar. Ensure that the entire FoV is unobstructed and that there are no objects nearby that could reflect light into the lens. Any light falling on the lens except for the light of the stars will create an invalid image.

7.9.7 Axis definition

Multi-axes sensors include the deployable magnetometer (deployed and undeployed state), redundant magnetometer, fine Sun sensor, fine nadir sensor and star tracker. The mounting of each of these sensors is specified by a set of three angles **alpha (α), beta (β), and gamma (γ).** These three angles correspond to the angles in a Euler 3-2-1 rotation sequence to rotate the sensor's coordinate frame to the SBC. The sensor coordinate frames for CubeStar is defined as follows:

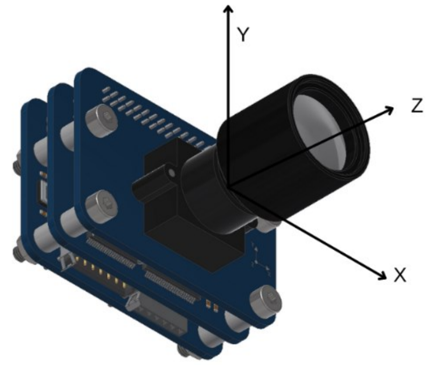


Figure 51 – CubeStar sensor coordinate frame

The rotations α, β, and γ are around the sensor's Z, Y and X axes respectively.

7.9.8 Specifications

Table 15 – CubeStar specifications

Specification	Value	Notes
Physical		
Mass	57 g	Without mounting screws
Dimensions	50 x 35 x 55 mm	The length of ~55mm can vary by ±2mm Excludes baffle
	21 mm	Lens diameter
Electrical		
Operating Voltage	3.3V	
In-rush current peak	156 mA	Maximum inrush peak at power-on.
In-rush current time	1 ms	Maximum time of inrush peaks
Data Interface	I^2C and UART	
Average Power	142 mW	
Peak Power	264 mW	
Performance		
Field of View	58° x 47°	Horizontal (X-axis) X Vertical (Y-axis) (Without baffle)
Star Catalogue Size	410	Subset of the Hipparcos Catalogue
Sensitivity Range	< 3.8	Star Magnitude
Sky cover:	99.71%	
Accuracy	<0.0154°(3σ)	Cross Axis (RA) [<0.0051°(1σ)]

Specification	Value	Notes
	<0.0215°(3σ)	Cross Axis (DE) [<0.0072°(1σ)]
	<0.061°(3σ)	Roll [<0.0203°(1σ)]
Update Rate	1 Hz	
Max Tracking Rate	0.3°/s	
Max Acquisition Time	3 s	
Image Size	1280 x 1030	Approximately 1.3 MB
Environmental		
Vibration	8.03 g	RMS random
Thermal	-10°C to +60°C	
Radiation	TID @ 24 k Rad And 200 MeV	Total dose and High energy particle tests have been conducted to induce SEE

8 Document History

Ver	Author(s)	Pages	Date	Description of change
3.0	MK	ALL	20/03/2017	V3 First draft
3.01	MK	ALL	04/07/2017	Merge 3-Axis & Y-Momentum
3.02	MK	27,28	04/07/2017	Added CAN details
3.03	CJG	All	26/07/2017	General Updates
3.04	MK	All	27/07/2017	Accept/Reject team changes
3.05	MK	24 26	31/10/2017	Fixed incorrect I2C address Changed Table 8 to correct TLM (240)
3.06	CJG	32	02/02/2018	Removed Command 70
3.07	CJG	12	12/02/2018	Added description for the SPI bus
3.08	CCH	All	29/03/2018	General language editing
3.09	CCH	ALL	30/05/2018	Updated language editing
3.10	DGS	13	18/06/2018	Added warning about camera protrusion
3.11	DGS	13	29/10/2018	Specified pin length beneath stack and PC104 type at top
3.12	CJG	11	29/10/2018	Added Backup Power in Description
3.13	LV		20/01/2019	Added Relevant CubeACP version section Updated tables with Commands and Telemetries. See ACP Reference Manual for detail about interface changes.
3.14	CJG	39	24/01/2019	Extended the CubeStar accuracy description
3.15	Various	All	27/09/2019	Large Update.
3.16	GJVV, DGS	9, 22, 54	11/11/2019	Update PC104 table. Added uCN. Verified wheel balance spec
3.17	JG CJG	40 29,30	02/01/2020 16/03/2020	Update stowed magnetometer dimensions. Added explanation and figure for the method of epoxying the spacers.
3.18	CJG	24	26/03/2020	Updated Figure 6 with the correct position of BU_VIN
7.1	JG, GJVV, LH	Several	27/09/2021	New versioning system Added harness to redundant magnetometer axis definition image Added magnetometer spring Added CubeMag Gen 1.1 details Remove ADCS performance (depends on simulation) Added storage temperature range for CubeADCS
7.2	LH MdP	42, Several	28/09/2022	Updated Figure 26 Updated redundant mag to include in-line harness Removed all mention of CubeSense V2 Removed all mention of momentum wheel as part of y-mom solution Replaced y-mom solution with a single rw Updated all relevant images and diagrams Updated all specifications table for each product with latest values
7.3	MdP	Several	10/11/2022	CubeStar updated to V4.4

Ver	Author(s)	Pages	Date	Description of change
7.3	MdP, LH	Several	08/11/2022	Gen 1 Primary CubeMag replaced with Gen 2 Deployable CubeMag CW0057 and CW0162 added to wheel selection CubeControl updated to V2.6 with gen2 compatibility CubeStar v4.2 replaced with v4.4 Relevant ADCS specification tables updated Several drawings updated to conform to the same dimensioning standards