ADCS Interface Control Document

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Version history

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0.1	Draft	13 March 2013	Initial version
1.0	– Draft	8 April 2013	After PDR
1.1	1st release - PDR	1 July 2013	Implemented PDR feedback
2.0	Draft	20 Oct 2013	Updated for CDR
2.1	Draft	11 November 2013	Implemeted CDR changes
2.2	2nd release – CDR	18 November 2013	Updated GPS power switch implementation
3.0	3rd release	18 June 2014	Updated drawing dimenstions (stack height)

Approval for Release

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Vaios Lappas	Manager – SSC		
Herman Steyn	Manager – ESL		
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Table of Contents

Reference documents

[R01]	QB50 System Requirements and Recommendations - Issue 5 – 11 October 2013
[R02]	INMS Requirements Compliancy Table - 20130614
[R03]	FIPEX Requirements Compliancy Table - 20130619
[R04]	MNLP Requirements Compliancy Table - 20130614
[R05]	QB50 ADCS Reference Manual – v1.0 – 28 March 2014

List of acronyms

ACP	Attitude Control Processor
ADCS	Attitude Determination and Control Sub-system
bpp	Bits Per Pixel
CSS	Coarse Sun Sensor
EKF	Extended Kalman Filter
FOV	Field of view
ICD	Interface Control Document
H-wheel	Momentum wheel
OBC	On-board Computer
OBDH	On-board Data Handling
TBC	To Be Confirmed
TBD	To Be Determined
TC	Telecommand
TLE	Two-line Element set
TLM	Telemetry

1 Introduction

The QB50 ADCS will provide attitude sensing and control capabilities to 2U CubeSats in order to meet the QB50 system requirements [R01] and science unit requirements [R02], [R03], [R04]. The QB50 mission will carry a number of 2U CubeSats, each fitted with a Science Unit – a payload that gathers atmospheric data in the lower thermosphere. CubeSats in the QB50 constellation require attitude control in order to

1. Minimize the influence of drag - The orbital life of a satellite will be prolonged if the effect of drag is minimized. This will allow for more atmospheric data to be gathered
2. Ensure science payloads point towards the ram direction

The most stringent attitude requirements on the QB50 mission relate to the INMS Science Unit [R02]. The CubeSats carrying this sensor shall have an attitude control with pointing accuracy of ±10° and pointing knowledge of ±2° from its initial launch altitude down to at least 200km. In addition, CubeSats shall be able to recover from tip-off rates of up to 10 degrees/second within 2 days [R01].

The attitude determination and control sub-system described in this ICD is tailored to meet the QB50 system requirements.

2 Functional description

The QB50 ADCS will make use of a combination of magnetometer, sun and nadir sensor measurements and a MEMS rate sensor to estimate the current attitude. It will use magnetorquers and a single reaction wheel, operating as a momentum wheel, to stabilize and control the attitude of the satellite.

The integrated ADCS functionality is provided by three PC104 sized boards:

CubeControl	The CubeControl board interfaces to most of the sensors and the actuators. The momentum wheel, two of the torquer rods, optional GPS receiver and the sun and nadir sensor cameras are mounted on this board to provide a compact volume. This board will also interface to the external magnetometer and coarse sun sensors (CSS).
CubeSense	CubeSense is a combined sun and nadir sensor. The processing unit is a PC104 sized board and it interfaces to two CMOS cameras – one functioning as a sun sensor and the other functioning as a nadir/horizon sensor. The cameras use wide field-of-view optics (180°) and the sun sensor has a neutral density filter to allow only sunlight onto the detector.
CubeComputer	CubeComputer is a generic CubeSat OBC. In this application it will serve as the attitude control processor.

Figure 1 CubeSense sun and nadir sensor

Figure 2 CubeComputer

Figure 3 CubeControl

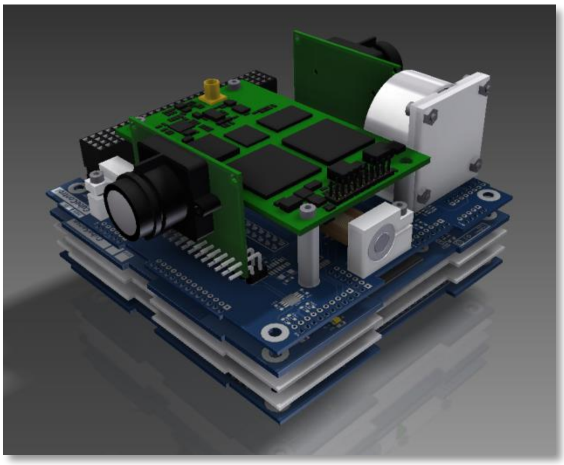


Figure 4 QB50 ADCS component stack

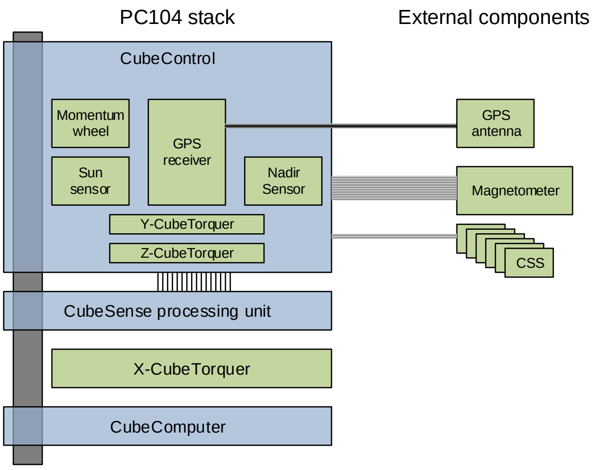


Figure 5 QB50 ADCS block diagram

Although the components can be used individually depending on the specific functionality requirement, this ICD will describe the integrated system and its interfaces.

2.1 Body axes definition and sensor/actuator mounting

The coordinate system definition used by the ADCS is shown below. When the ADCS is controlling the attitude to zero roll, pitch and yaw, the ADCS coordinate system will coincide with the orbit coordinate system.

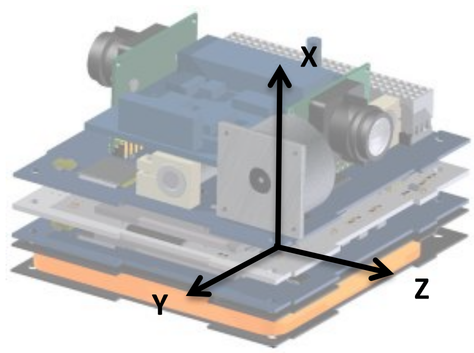


Figure 6 ADCS coordinate system

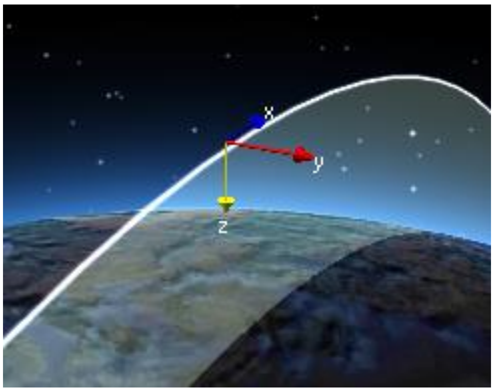


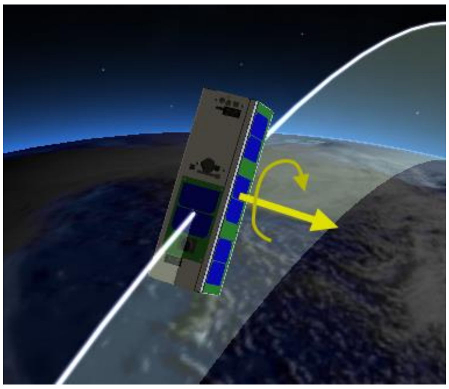
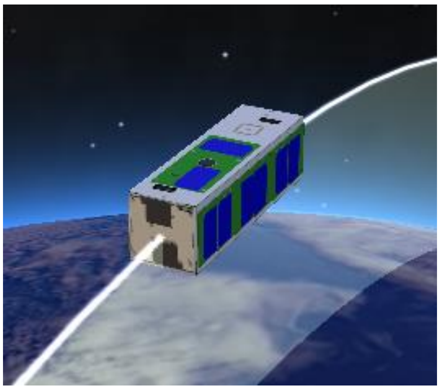
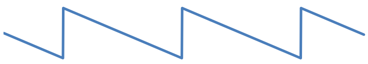
Figure 7 Orbit coordinate system

The sun and nadir sensor mountings are such that in the nominal orientation the nadir sensor will point towards nadir, the sun sensor will point towards zenith and the momentum wheel spin axis will align with the orbit normal.

2.2 Control modes

The QB50 ADCS will have two distinct control modes. The first detumbling mode will serve to recover from any initial tumble condition and place the satellite in a stable and known tumbling motion - a so-called Y-Thomson spin[1]. In this mode the satellite will end-up spinning only about the ADCS Y-axis and the spin axis will align itself with the orbit normal. The second control mode, *Y-momentum mode*, can only be activated once the satellite is in this stable tumbling state. In *Y-momentum mode* the satellite will stop spinning and stabilize to the nominal orientation (zero roll, pitch and yaw angles). In *Y-momentum mode* the pitch angle may be controlled to a specific reference value using a telecommand.

Table 1 QB50 ADCS control modes

Control mode	Detumbling control mode (steady-state)	Y-momentum mode
		
Attitude angles	Roll = yaw = 0 Pitch: 	Roll = yaw = 0 Pitch = θ_{ref}
Angular rates	$\boldsymbol{\omega} = [0 \quad \omega_{y,ref} \quad 0]$	$\boldsymbol{\omega} = [0 \quad 0 \quad 0]$

The *Y-momentum mode* is the nominal mode for QB50 satellites since this mode satisfies the pointing requirements. The *detumbling mode* is an intermediate step towards this nominal mode.

[1] Thomson W.T., Spin Stabilisation of Attitude against Gravity Torque, Journal of Astronautical Science, No.9, pp.31-33, 1962

In order to perform the required control, the ADCS needs to know the current attitude (angles and/or rates). This knowledge is supplied by estimation methods which make use of sensor measurements. Different estimation methods exist with varying sensor dependencies.

The *detumbling* control mode only requires an estimate of the satellite Y-body angular rate. This can be measured directly using the MEMS rate sensor, or it can be estimated using a rate estimator that uses successive magnetometer measurements.

The *Y-momentum mode* requires full attitude knowledge (angles and rates) and in order to estimate this, current position and velocity of the satellite has to be known as well as the current time. This information will be estimated using an SGP4 orbit propagator and requires that up-to-date TLEs and the current time is provided (via telecommand).

The ADCS will always start up in the idle condition – that is with no estimation or control active. The orbit and attitude estimation and control modes can be changed via telecommand. The state diagram below shows the various states and transitions that should occur to transition from idle to stabilized state.

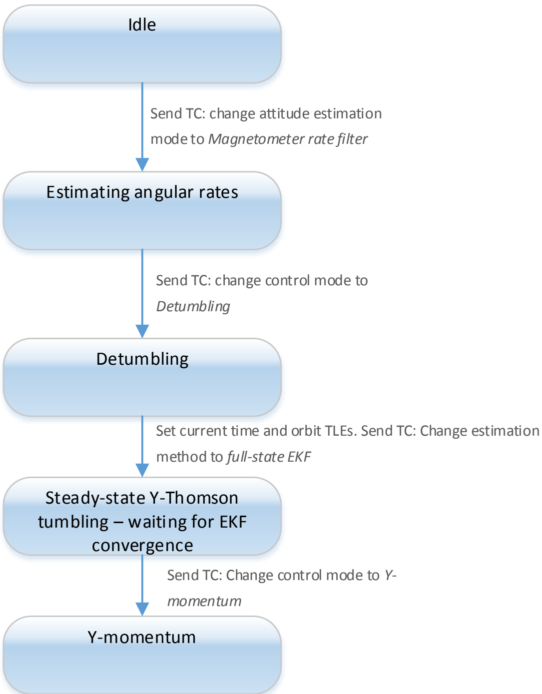


Figure 8 QB50 ADCS state diagram

No.	State	Attitude estimation mode	Control mode
0	Idle	None	None
1	Estimating angular rates	Magnetometer rate filter	None
2	Detumbling	Magnetometer rate filter	Detumbling
4	Y-Thomson Tumbling – waiting for EKF to converge	Full-state EKF	Detumbling
5	Y-momentum	Full-state EKF	Y-momentum

The mode numbers in the following tables apply when sending telecommands to change the current modes.

Table 2 Attitude estimation modes

Mode number	Mode	Notes
0	No attitude estimation	
1	MEMS rate only	
2	Magnetometer rate filter	
4	Full-state EKF	Requires orbit position & velocity estimates from SGP4 propagator
5	TRIAD (magnetometer + Fine sun) and magnetometer rate filter	

Table 3 Control modes

Mode number	Mode	Notes
0	No control	
2	Detumbling	
3	Y-momentum initial	Requires either the full-state EKF or TRIAD estimation mode to be active. (attitude estimation mode >= 4)
4	Y-momentum steady-state	

The difference between control modes 3 & 4 is that in control mode 3, the momentum wheel speed will be ramped up while the satellite still performs a slow Y-tumble. This will continue until the estimated pitch angle is within 20 degrees of the commanded pitch angle. At this point the control will automatically transition to mode 4- the steady state mode in which the pitch angle will be controlled to zero. Commands that engage Y-momentum control mode should always specify a control selection of 3 to allow the automatic transition to occur on the ADCS.

2.3 ADCS control loop

The ADCS control loop executes on the CubeComputer at a rate of 1Hz. Sensors are thus also sampled at this frequency.

2.4 GPS receiver interface

The CubeControl board has the capability to interface to the Novatel OEM615 GPS receiver module with Special Space Firmware. When enabled, it is possible to read the GPS provided position, velocity and time measurements via TLM request to the ADCS. The GPS receiver measurements are not used or required by the ADCS.

3 Electrical interface

The QB50 ADCS will make use of the standard PC104 stacking header for electrical interfacing. The following pins will be used by the ADCS:

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				
	H1	41	SYS I2C_SDA	System I2C Data
	H1	43	SYS_I2C_SCL	System I2C Clock
	H1	47	ADCS +5V	+5V ADCS supply
	H1	48	ADCS +3.3V	+3.3V ADCS supply
	H1	50	GPS +3.3V	GPS 3.3V supply
	H2	27/28	+3V3	connect to 3V3 (either switched on with H1-48 or always on)
	H2	29	GND	Ground connection
	H2	30	GND	Ground connection
	H2	32	GND	Ground connection
	H2	45	V Bat	Battery bus
	H2	46	V Bat	Battery bus

PC104 Reserved pins				
	H1	21	ADCS I2C_SCL	ADCS I2C Clock (used internally)
	H1	23	ADCS I2C_SDA	ADCS I2C Data (used internally)
	H2	20	CubeSense Enable	Enable line to control CubeControl power switch (used internally)

Figure 9 ADCS pin allocation on the PC104 header

3.1 Power

The ADCS should be supplied with 3.3V on pin H1-48, and 5V on pin H1-47. Both supplies must be switched on simultaneously. The ADCS has internal power switches for the different components (CubeSense and CubeControl). The internal power switches are controlled by the CubeComputer depending on the current mode selection. The switch states can be read via telemetry rest and can also be forced on using a telecommand. The ADCS also requires a 3.3V connection on pin H2-27 and H2-28. This supply is only used to power I2C buffers and may be connected to a non-switched (always on) supply. The power draw from this line is minimal.

Current and voltages are measured at various points in the ADCS and can be requested using TLM requests. The ADCS will also use this to switch off components in case of latch-up. The battery bus (pins H2-45 and H2-46) supplies power to the momentum wheel, the magnetometer boom deployment and the GPS receiver patch antenna LNA.

The GPS receiver itself is powered from pin H1-50 (3.3V supply. Only applies if the GPS receiver is included). The GPS does not have to be powered if the ADCS is switched on. The GPS can only be switched on when needed. The ADCS will sense the GPS enabled status and react accordingly by setting up logs and storing telemetry.

3.1.1 Power use

The power use of the ADCS in various operating conditions is listed in the table below.

Condition	Average current (mA)			Total power (mW)
	From 3.3V supply	From 5V supply	From battery bus	
Attitude sensing only (rate estimator)	102	0	0	336

Attitude sensing only (full-state estimator)	102	23	0	450
Detumbling control	102	36	0	516
Y-momentum control (eclipse)	102	10	9	456
Y-momentum control (daylight)	102	48	9	644

The GPS will consume an additional 1W of power from the 3.3V supply when switched on.

3.2 Communication

The QB50 ADCS will communicate using the system I2C interface on the standard PC104 header (pin H1-41 and H1-43 on the standard header). The CubeComputer will act as a slave on the system I2C bus, responding to commands and telemetry requests as detailed in the Reference Manual [R05].

3.2.1 I2C pull-up resistors

The ADCS will have no pull-up resistors on the system I2C bus.

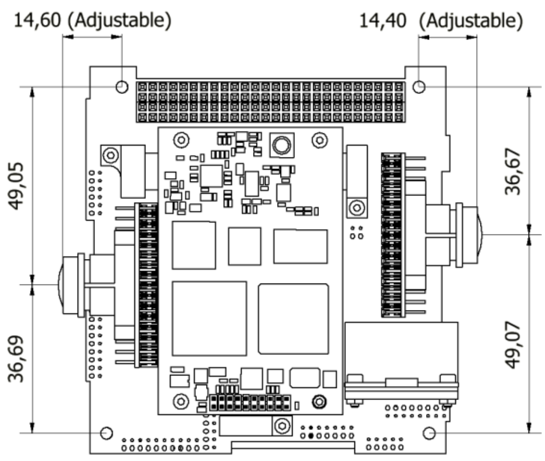
3.3 Logging

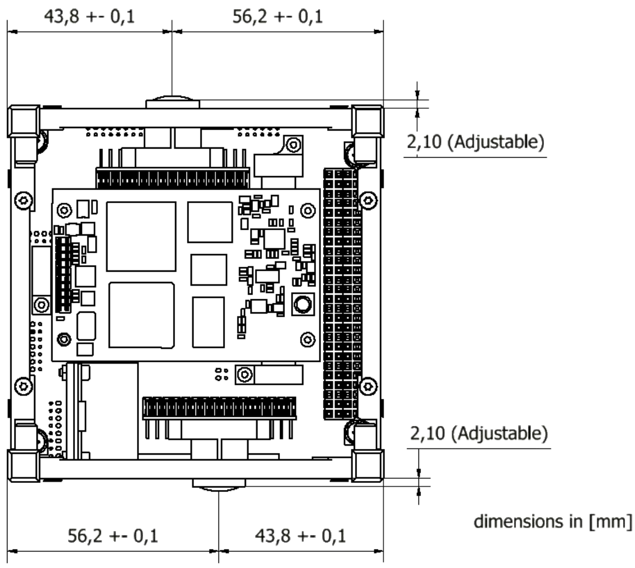
The ADCS has to ability to automatically log data and save it to SD memory card. For detail about the logging, please consult the Reference Manual [R05].

4 Mechanical interface

4.1 PC104 Component stack

The stacked components make use of the standard "self-stacking" CubeSat mechanical interface. The dimensions of the stacked components and mounting locations are shown below.





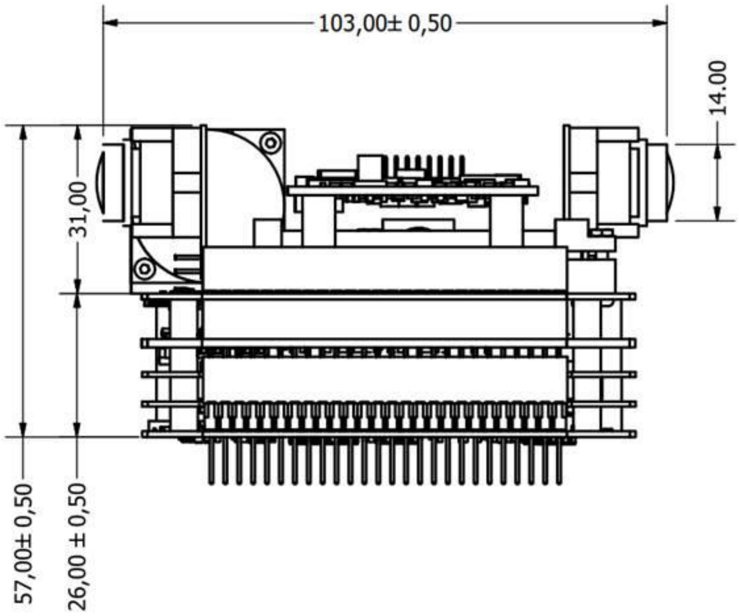


Figure 10 QB50 ADCS PC104 stack dimensions

The ADCS stack will have spacers to support the inter-PCB spacing.

4.2 External magnetometer

The external magnetometer is housed on a small external PCB and encased inside an aluminium housing. The magnetometer housing measures 16 x 17 x 6mm.

The magnetometer housing is supplied with a deployable boom. The boom will give a separation of 8cm from the rest of the spacecraft to limit the effect of electromagnetic interference and result in low noise measurements.

The deployable boom consists of a rod with the magnetometer in a metal enclosure at one end. The other end is connected to a mounting bracket with a spring. The bracket will be mounted on the outside of the satellite structure. The boom will be constrained when stowed and deployment takes place upon a telecommand. The deployable boom and mounting interface is illustrated below:

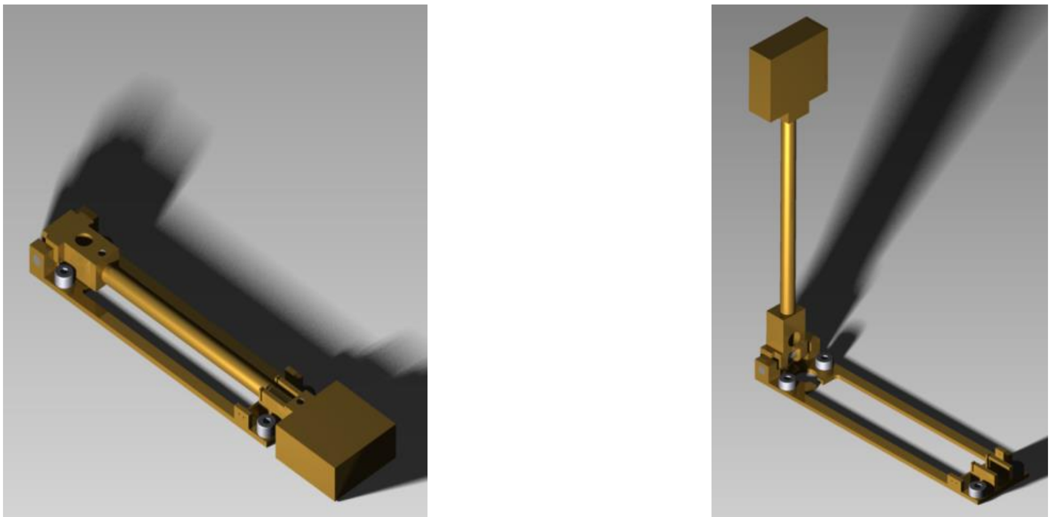


Figure 11 Deployable magnetometer boom stowed (left) and deployed (right)

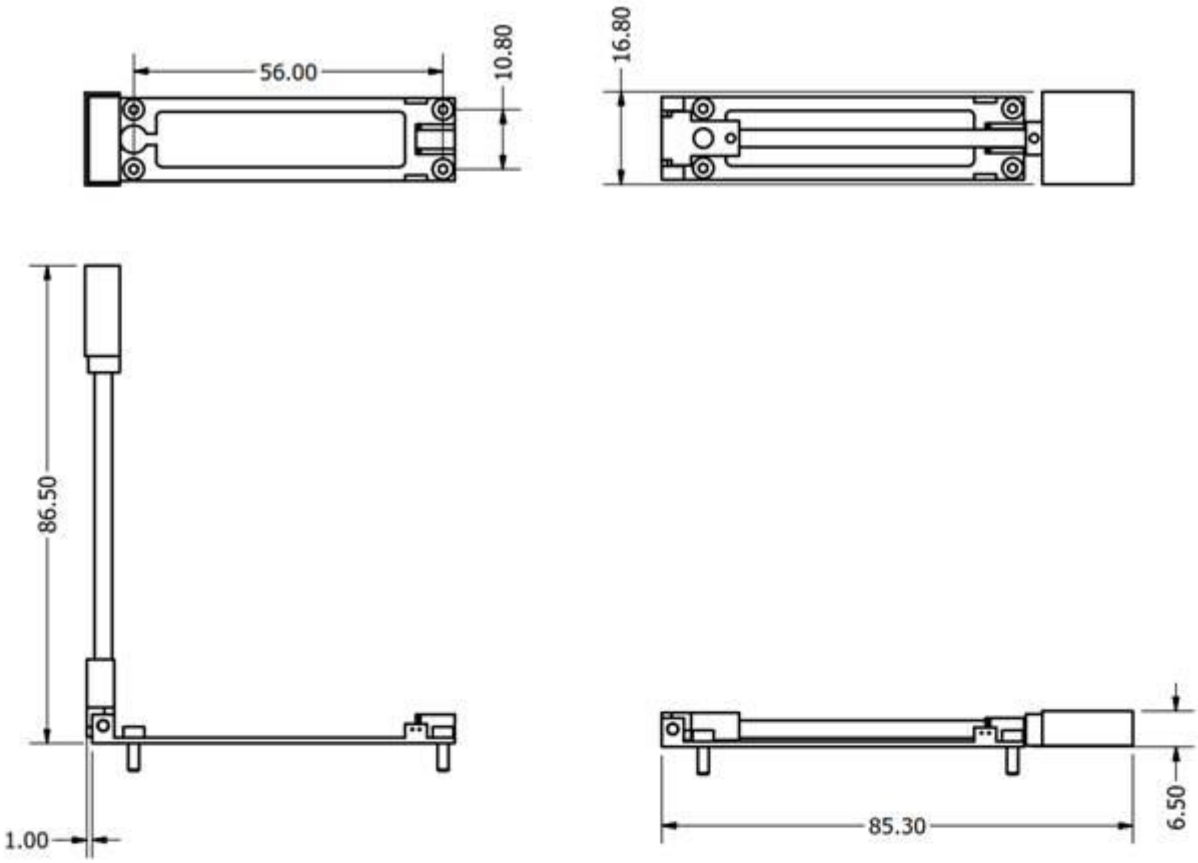


Figure 12 Deployable magnetometer dimensions and mounting locations

Both the magnetometer and the boom deployment actuation will be connected to the CubeControl PCB in the ADCS stack using a harness. The harness between the magnetometer and the CubeControl is broken by a circular 11-way connector with harness length as indicated below.

The connector is an Omnetics nano-circular connector with part number NCP-11-WD-18.0-C for the plug (CubeControl side) and NCS-11-WD-18.0-C for the socket (magnetometer side).

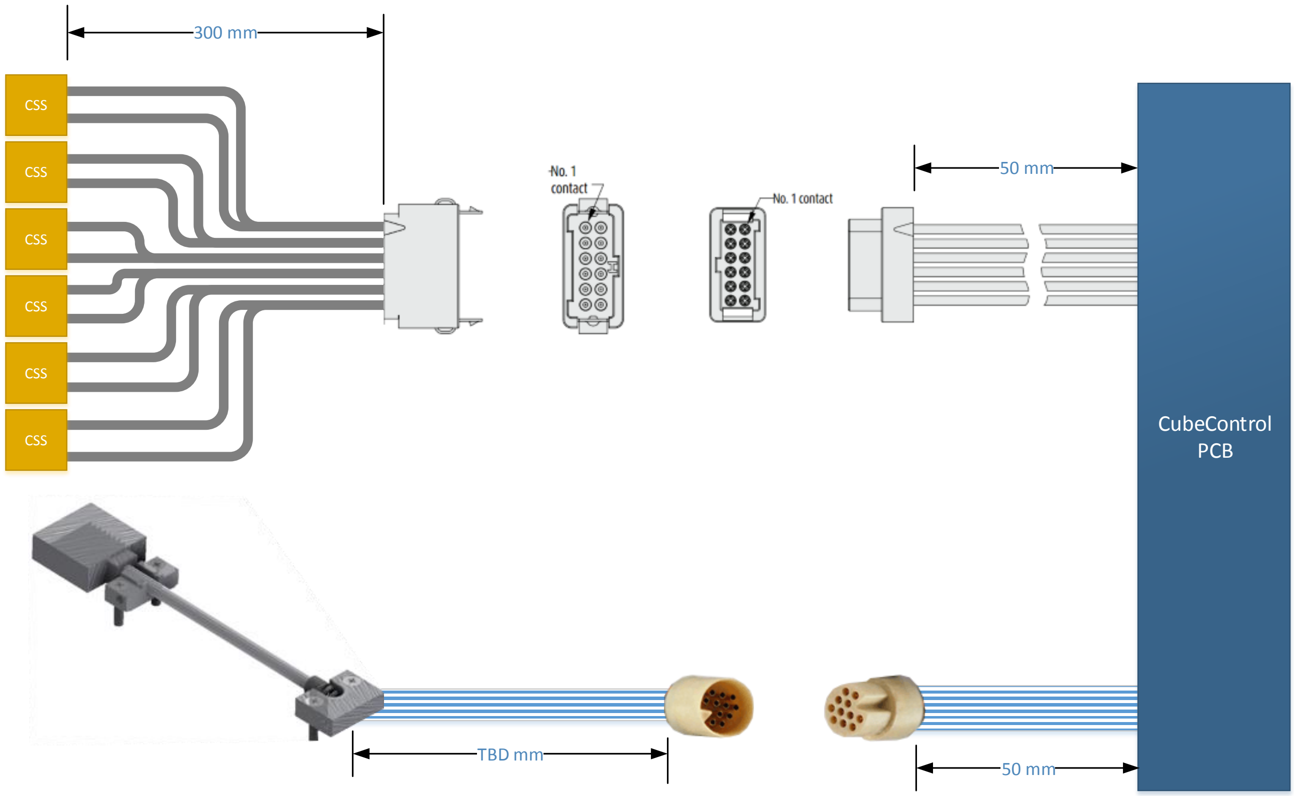


Figure 13 CSS and magnetometer harness lengths

4.3 Coarse Sun Sensors

Each Coarse Sun Sensor (CSS) consists of a photodiode mounted on a small PCB. There are 6 of these CSS in total. The dimensions of each CSS are 4mm x 11mm x 2mm. The CSS do not have mounting holes – they should be staked down to the satellite structure using epoxy. The sensors should be placed on the 6 different facets of the spacecraft.

The CSS are not critical for the operation of the ADCS, and it is expected that it will not be possible to place a CSS on the +X (RAM direction) facet due to the presence of the Science Unit. The ADCS will still be able to estimate sun vectors from the CSS if only 5 are used.

The 6 CSSs will be connected to the CubeControl PCB by wire harness. The wire harness is broken by a single 12-way rectangular connector as in Figure 13. The connector is a latched Harwin Gecko 12-way connector with part number G125-204-12-96-L0 for the socket (CubeControl side) and G125-304-12-96-L4 for the plug (CSS side).

The CSS connector pin assignment is specified in the table below:

Table 4 CSS connector pin assignment

pin	signal	pin	signal	pin	signal	pin	signal
1	CSS1 - cathode	2	CSS1 - anode	3	CSS2 - cathode	4	CSS2 - anode
5	CSS3 - cathode	6	CSS3 - anode	7	CSS4 - cathode	8	CSS4 - anode
9	CSS5 - cathode	10	CSS5 - anode	11	CSS6 - cathode	12	CSS6 - anode

4.4 Mass

The mass of the QB50 ADCS stack and optional and external components are summarized in the table.

Table 5 mass of ADCS components

Component	Mass
PC104 component stack (excluding GPS receiver)	335g
External components	
External magnetometer assembly (including boom)	15g
6x CSS (including harness)	5g

4.5 Inertia moments and Centre-of-mass

The moment of inertia about any satellite body axis for the host satellite on which the QB50 ADCS will be used shall not exceed 0.02 kgm^2.

The host satellite shall have a dominant moment of inertia about the ADCS Y-axis for configurations in which the detumbling mode will be used. The Y moment of inertia (I_{yy}) shall be at least 5% larger than the X and Z inertia moments (I_{xx} and I_{zz}).

The host satellite centre-of-mass and deployable panels should be arranged such that a positive (restoring) aerodynamic torque is generated for all possible angles of attack.

5 Command interface

The ADCS attitude control processor (CubeComputer) acts as an I2C slave node on the system bus with 7-bit addressing. The default 8-bit read and write addresses of the node are:

Table 6 I2C node address

I2C write address	0x24
I2C read address	0x25

For more detail on the communications interface including protocols for telecommands, telemetry and file downloads, please consult the QB50 ADCS Reference Manual [R05].

6 Specifications

Table 7 QB50 ADCS specifications

Specification	Value	Notes
Physical		
Mass	400g	Complete system including GPS receiver and deployable magnetometer boom
Dimensions		
PC104 stack	90 x 96 x 60 mm	

CSS	4 x 11 x 2 mm	
External magnetometer housing	16 x 17 x 6 mm	
Performance		
Attitude update rate	1 Hz	
Attitude measurement accuracy (>200 km)		
Pitch	< 0.5°	1σ
Roll and yaw	< 2.0°	1σ
Pointing accuracy (Y-momentum mode)		
> 300km altitude	< 0.5° [1]	1σ
> 200km altitude	< 2.5° [1]	1σ
Time to reach steady-state Y-Thomson motion from 10°/s initial tip-off rate (at 350km altitude)	< 0.5 days [1]	Maximum time from Monte-carlo simulation of 1000 test cases.
Outgassing		
Total Mass Loss (TML)	< 1.0 %	
Collected Volatile Condensable Material (CVCM)	< 0.1 %	
Vibrations		
Sine sweep	as per [R01]	
Random vibrations	as per [R01]	
Thermal		
Operating temperature range	-10°C to +60°C	
Non-operational temperature range	-10°C to +60°C	

[1] Applies to 2U satellite with no appendages, centre-of-mass location $[0.01, 0.0, 0.0]^T$ m and moment of inertia matrix diag (0.0027, 0.0107, 0.0101) $kg.m^2$

The specifications for the sensors and actuators used in the QB50 ADCS are listed in the following tables.

6.1 Sensor specifications

The sensor specifications below apply when requesting the measurements via the system I2C interface. Individual components may have different update rates when interfacing to them directly.

Table 8 Sensor specifications

Specification	Value	Notes
Sun and nadir sensor		
Sun sensor measurement accuracy **(1σ)**	< 0.5° < 2°	< 40° from bore-sight entire FOV
Nadir sensor measurement accuracy **(1σ)**	0.18°	Entire Earth visible in FOV
Field of view (both cameras)	180°	
Update rate	1 Hz	
Image size	640 x 480 pix	
Image format	8 bpp grayscale	
Coarse sun sensor		
Measurement accuracy	< 10°	1σ
Update rate	1 Hz	
Magnetometer		
Measurement accuracy	< 50 nT	1σ (per X/Y/Z channel)
Update rate	1 Hz	

Rate sensor		
Measurement accuracy	< 0.015 °/s	1σ
Update rate	1 Hz	Averaged output
Angular Random Walk	$0.28°/\sqrt{hr}$	
Bias instability	24 °/hr	

6.2 Actuator specifications

Table 9 Actuator specifications

Specification	Value	Notes
Magnetorquers		
Maximum magnetic dipole	0.2 Am^2	
On-time command resolution	0.2 ms	For a 1Hz control period
Momentum wheel		
Maximum momentum storage	1.7 mNms	
Maximum wheel speed	± 8000 rpm	
Maximum torque	0.15 mNm	
Wheel inertia	2.0 $kg.mm^2$	

7 Handling

The QB50 ADCS shall be handled and integrated in an ISO class 8 or higher cleanroom. ESD protective clothing and wrist- or ankle straps shall be worn when handling the ADCS.

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