6th QB50 Workshop

QB50 ADCS
Design and interface specification

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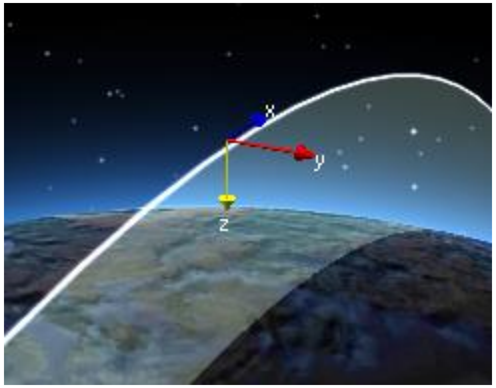
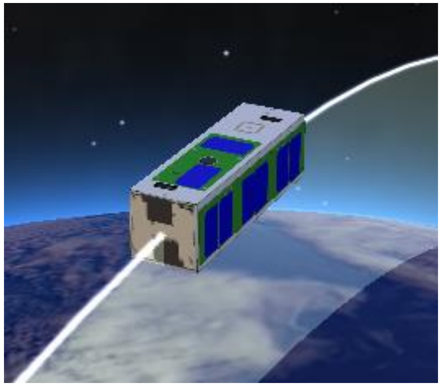
ADCS Requirements

Requirements

- Attitude control is required on QB50 CubeSats because:
  - 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
  - Ensure science payloads point towards the ram direction

- ADCS performance requirements:
  - pointing accuracy of ±10° and
  - pointing knowledge of ±2° (down to 200km altitude).
  - recover from tip-off rates of up to 10 degrees/second within 2 days





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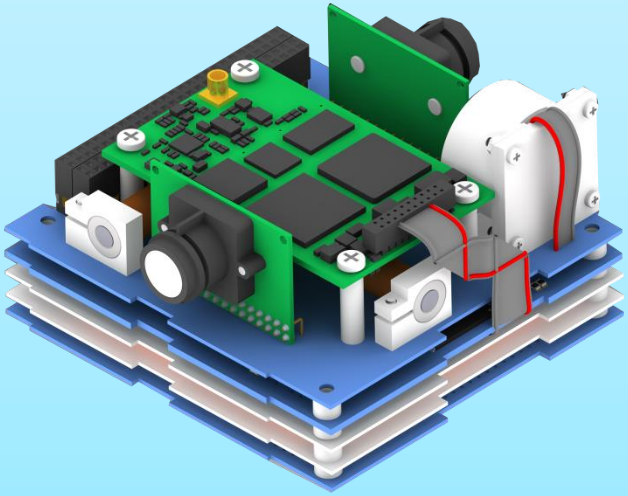
ADCS design and interface specification

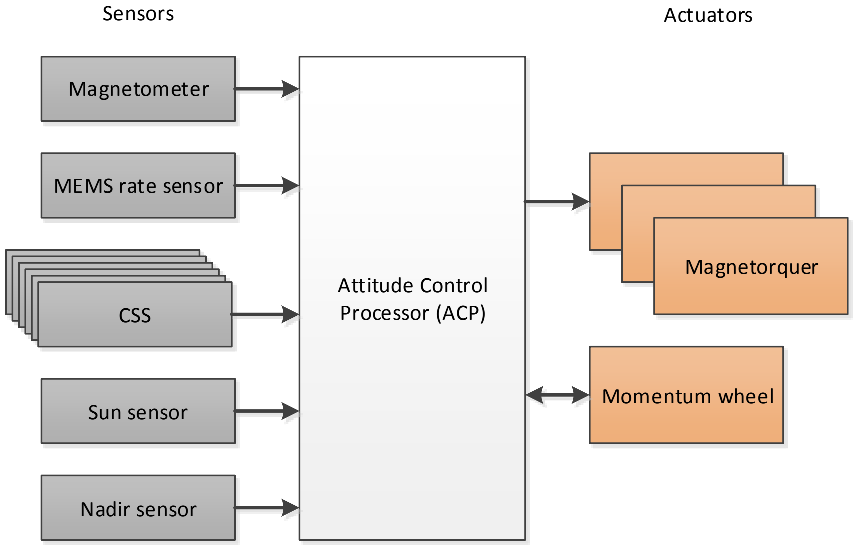
ADCS Design



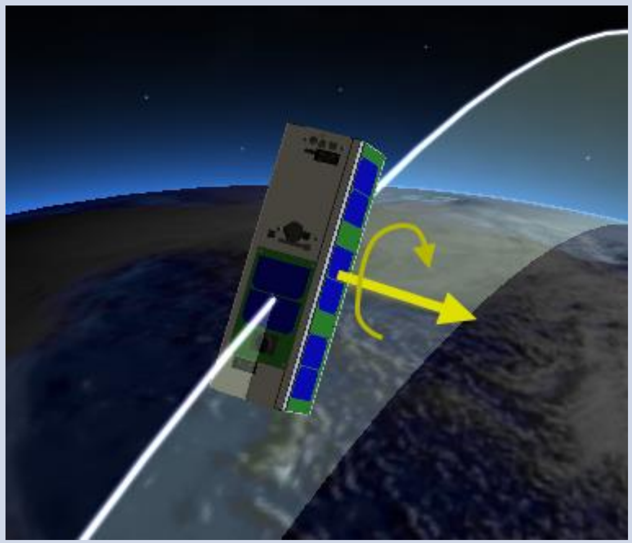
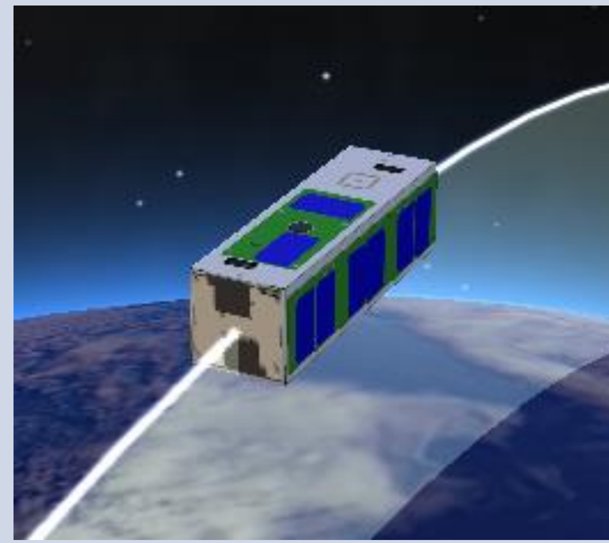
Design

ADCS concept

- Three axis stabilized with controllable pitch angle
  - Magnetic control using three axis magnetorquers
  - Y-axis aligned momentum wheel
- low cost miniaturized sensors to meet the mass and volume restrictions of CubeSats
  - Magnetometer
  - Y-axis MEMS rate sensor
  - Coarse sun sensing using up to 6 photodiodes
  - Optical fine sun sensor
  - Optical nadir sensor



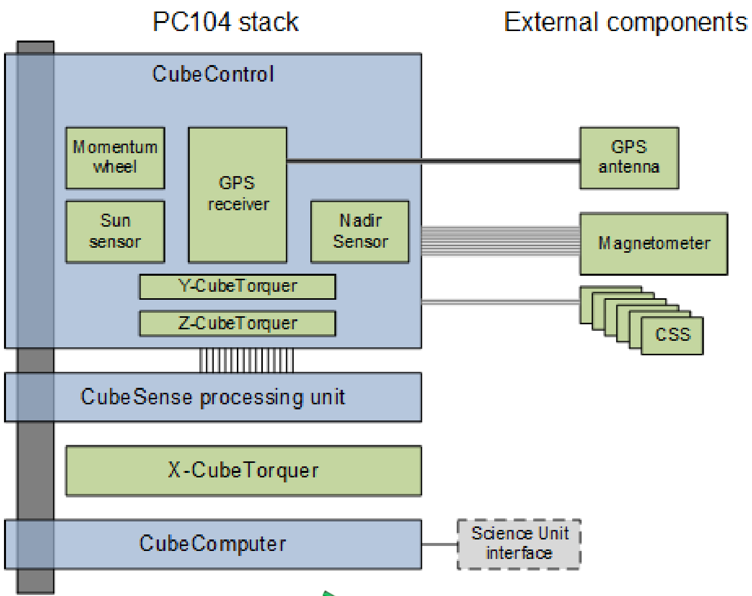
Control modes

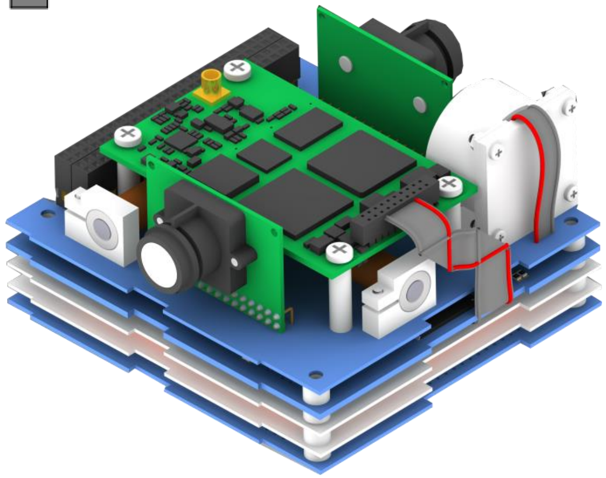
Control mode	Detumbling control mode (steady-state)	Y-momentum mode
		
Attitude angles	Roll = yaw = 0 Pitch: 	Roll = yaw = 0 Pitch = θ_{ref}
Angular rates	$\boldsymbol{\omega} = [0 \quad \omega_{y,ref} \quad 0]$	$\boldsymbol{\omega} = [0 \quad 0 \quad 0]$

Design

Hardware design

- 3x PC104 boards
  - CubeComputer
  - CubeSense processing board
  - CubeControl
- Peripheral components
  - Fully integrated ADCS has momentum wheel, sun- and nadir cameras, GPS receiver and magnetorquers contained in stack
  - External GPS antenna, magnetometer and coarse sun sensor photodiodes

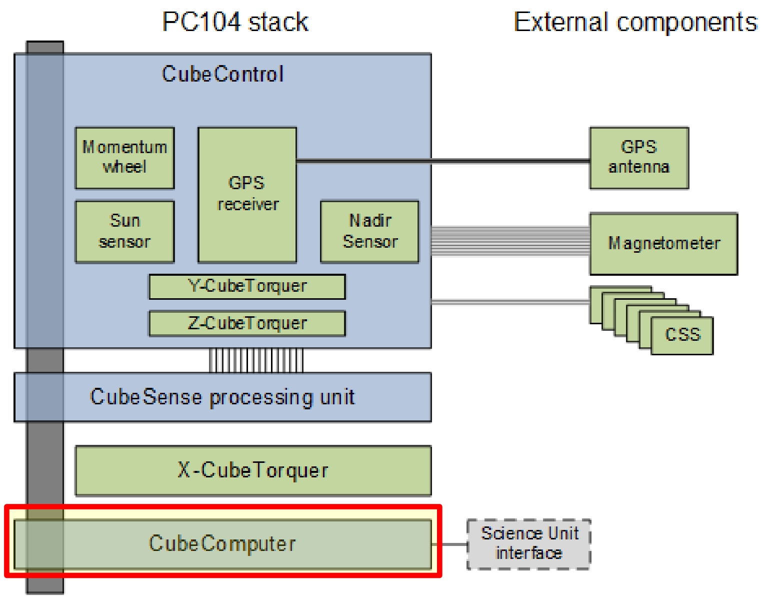




Design

Hardware design - CubeComputer

- In this application serves as dedicated attitude control processor
- 32-bit ARM Cortex-M3 MCU
- EDAC protected SRAM for SEU and SEL
- Bootloader for in-flight reprogrammability
- Optional interface to Science Unit (for full OBC functionality)



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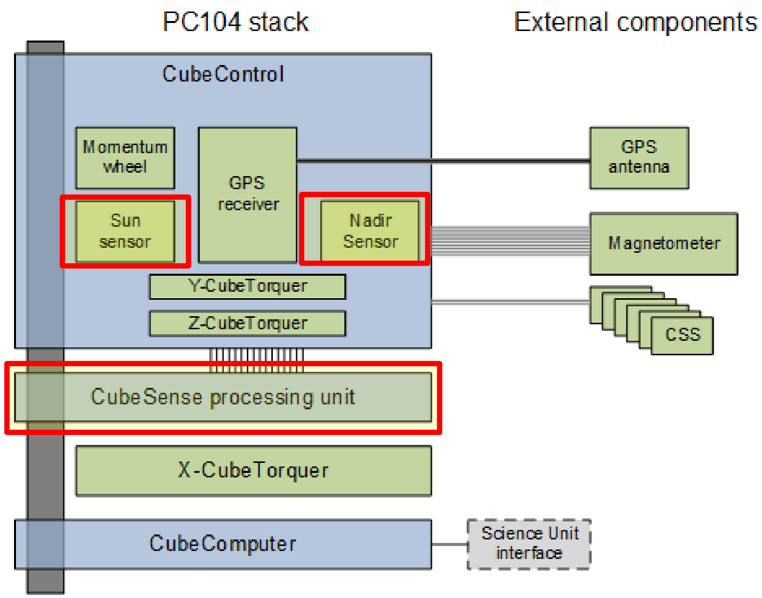
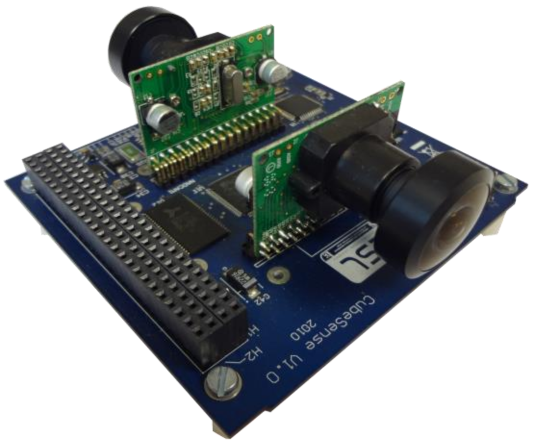


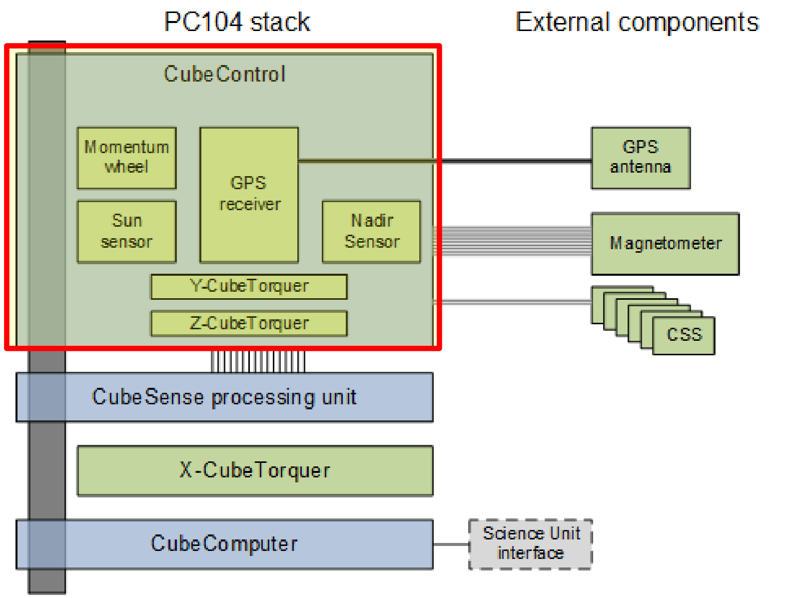
Hardware design - CubeSense

- Combined sun and nadir sensor
- PC104 sized processing unit interfaces to two CMOS cameras – one functioning as a sun sensor and the other functioning as a nadir/horizon sensor.
- Wide field-of-view optics (180°)
- Sun sensor has a neutral density filter to allow only sunlight onto the detector.

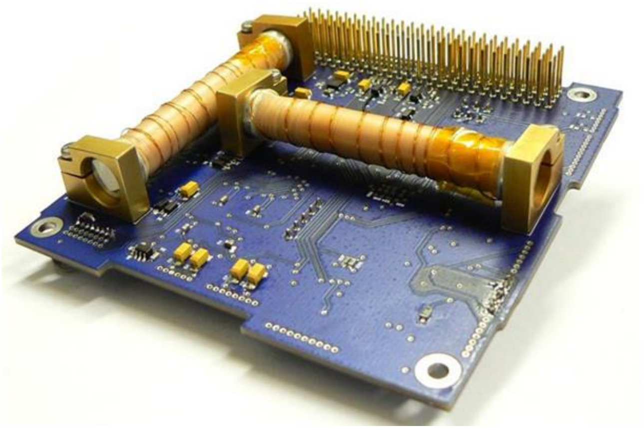


Design

Hardware design - CubeControl



- Interfaces to most of the sensors and the actuators
- Provides mounting for
  - Y-Momentum wheel
  - Y and Z torquer rods
  - optional GPS receiver
  - sun and nadir sensor cameras
- On-board MEMS rate sensor
- Interfaces to the external magnetometer and coarse sun sensors (CSS)



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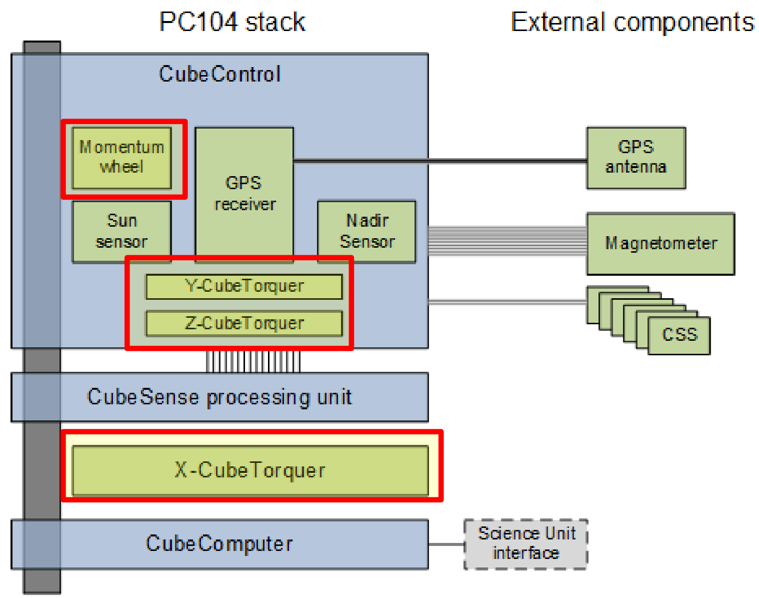

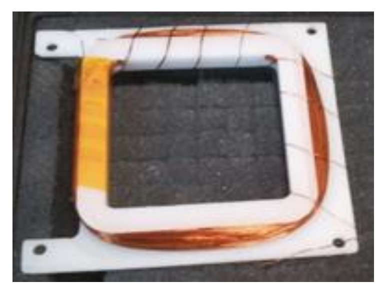

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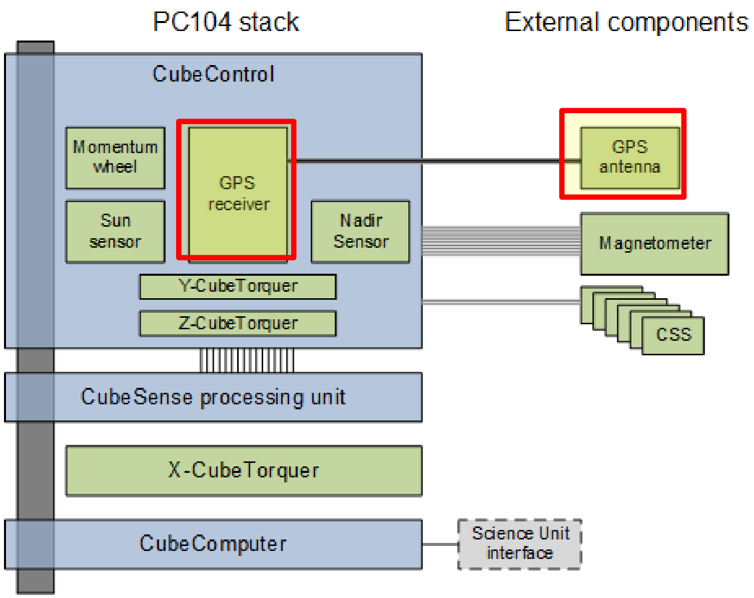

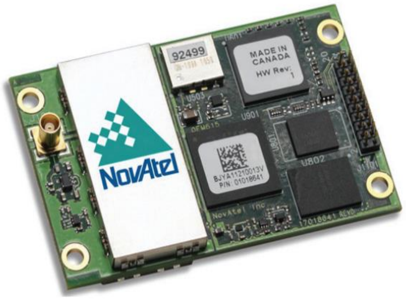

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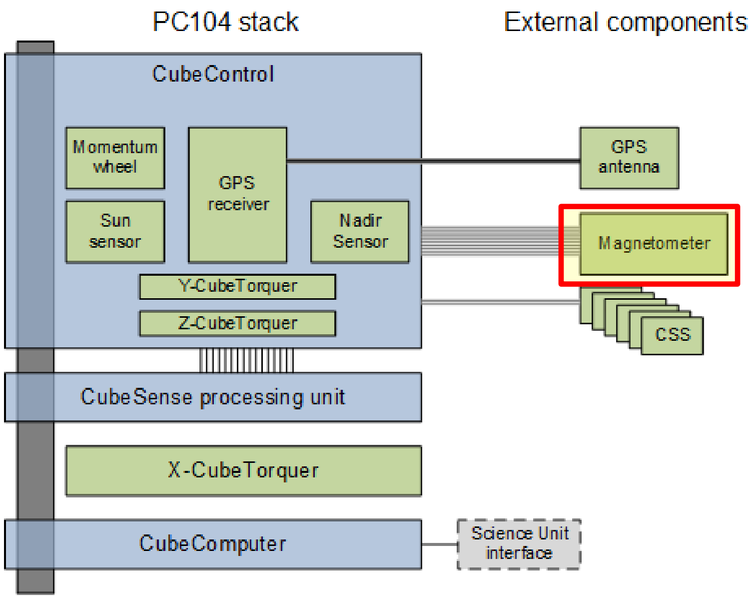
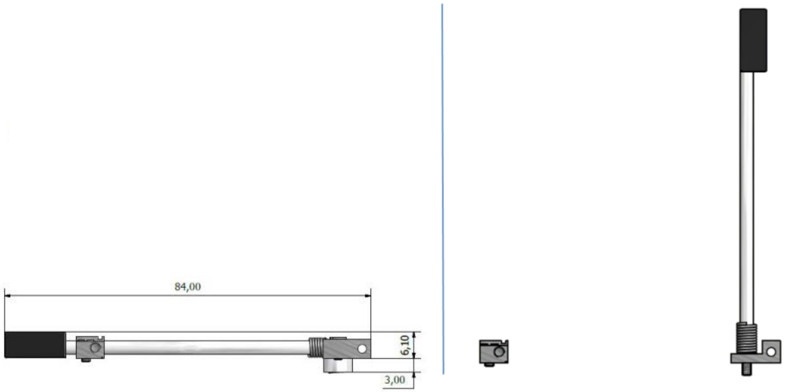


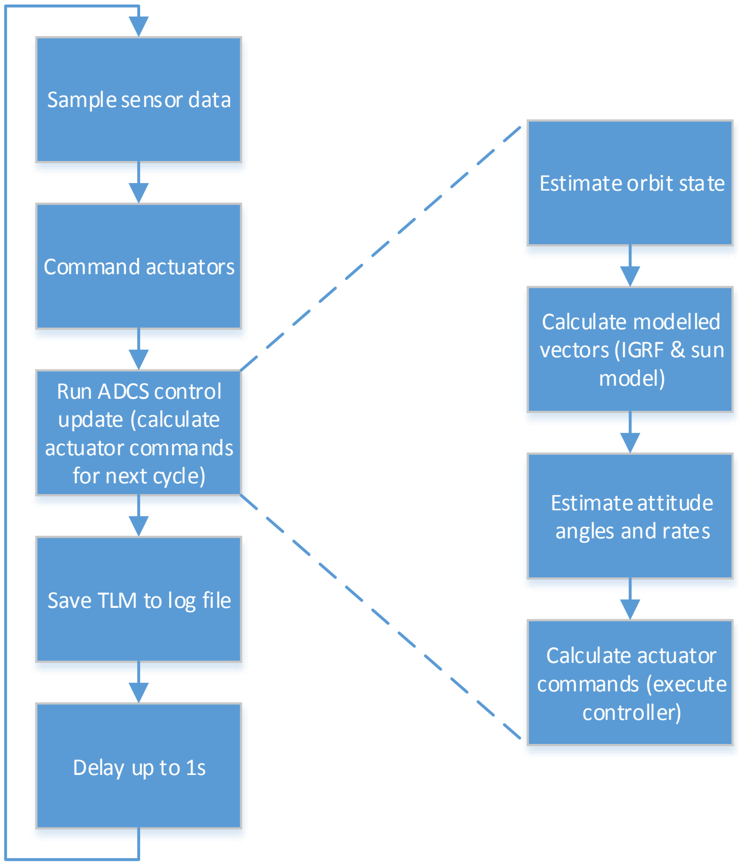


Design

Software

- ADCS control loop executes on CubeComputer at 1Hz
- CubeComputer is slave on system I2C bus (when used in the stand-alone ADCS system)
- Dedicated ADCS I2C bus for inter-component communication
- Includes logging functionality.
  - Logged data and frequency selected using TC
  - Log file can be downloaded using bulk “file” download

		execution time (ms)
Request sensor TLM		20 (TBC)
Command actuators		10 (TBC)
ADCS update	SGP4 orbit estimation	5
	Modelled vectors (IGRF & sun)	20
	EKF attitude estimator	2
	Control algorithm	1
TLM logging		20 (TBC)



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ADCS design and interface specification

Interface specification

Interface specification

ICD Status

- QB50 ADCS passed the PDR
- ICD due to be released (on QB50 website) in next 2 weeks
- STEP file is made available at the workshop or can be emailed later

Interface specification

Electrical interface

- Powered from (switched) 3.3V and 5V and V_battery

Power consumption

- <0.5W for all modes (excl. GPS receiver)
- GPS receiver uses 1W

Communications interface

- Communication to OBC via system I2C bus – CubeComputer is I2C slave
- Secondary I2C bus reserved by ADCS – CubeComputer is I2C master

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

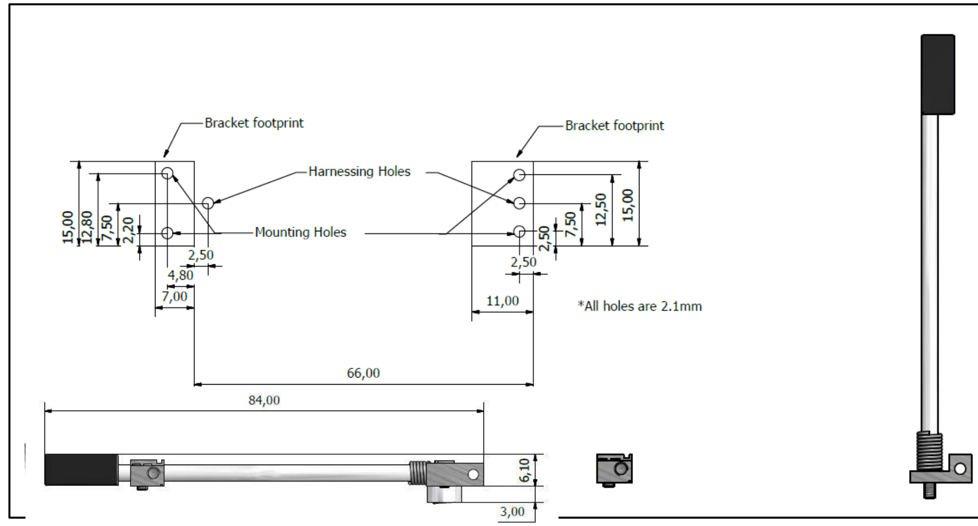
PC104 Interface pins				
	H1	21	ADCS I2C_SCL	ADCS I2C Clock
	H1	23	ADCS I2C_SDA	ADCS I2C Data
	H1	41	SYS I2C_SDA	System I2C Data
	H1	43	SYS_I2C_SCL	System I2C Clock
	H1	47	ADCS +5V	+5V ADCS supply
	H1	48	ADCS +3.3V	+3.3V ADCS supply
	H1	49	Alt ADCS +5V (1)	Alternate +5V ADCS supply (option)
	H1	50	Alt ADCS +3.3V (1)	Alternate +3.3V ADCS supply (option)
	H1	51	Alt ADCS +5V (2)	Alternate +5V ADCS supply (option)
	H1	52	Alt ADCS +3.3V (2)	Alternate +3.3V ADCS supply (option)
	H2	27	+3.3V bus	+3.3V power bus (only used with optional GPS receiver)
	H2	28	+3.3V bus	+3.3V power bus (only used with optional GPS receiver)
	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				
	H2	20	CubeSense Enable	Enable line to control CubeControl power switch

Interface specification

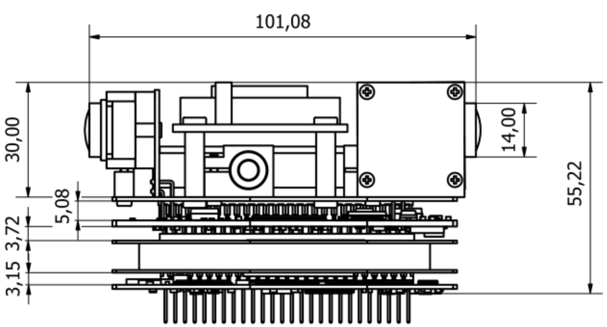
Mechanical interface

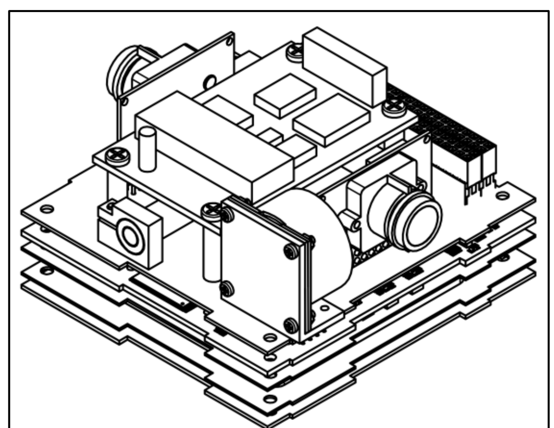
- Standard PC104 form factor for CubeComputer, CubeSense and CubeControl

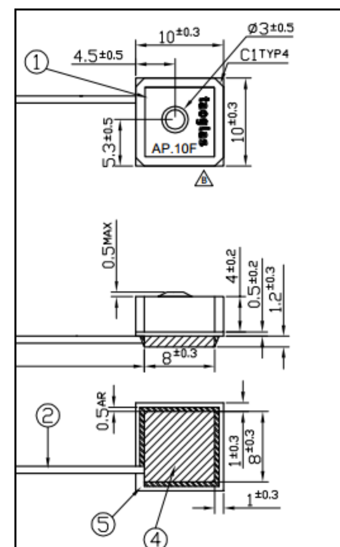


Mass

< 450g for fully integrated system (incl. GPS receiver)







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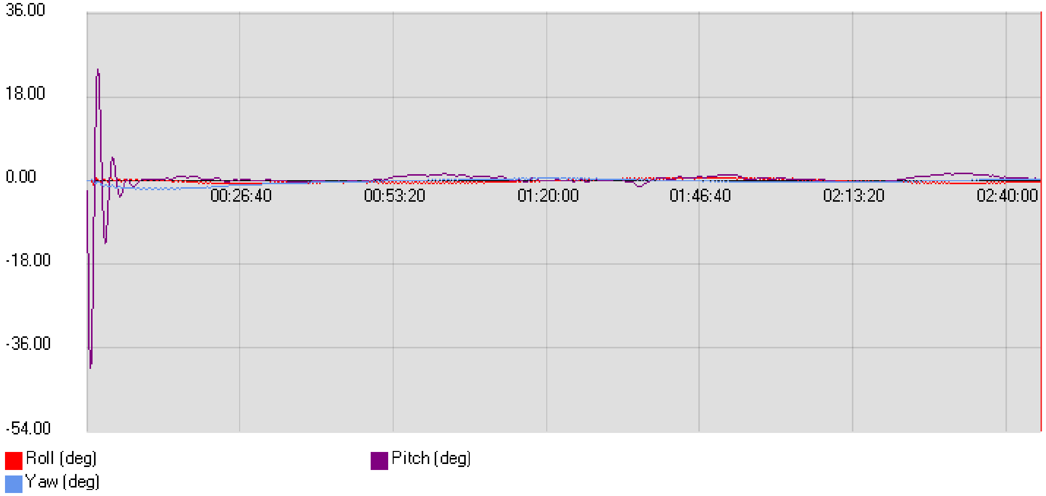
Test results

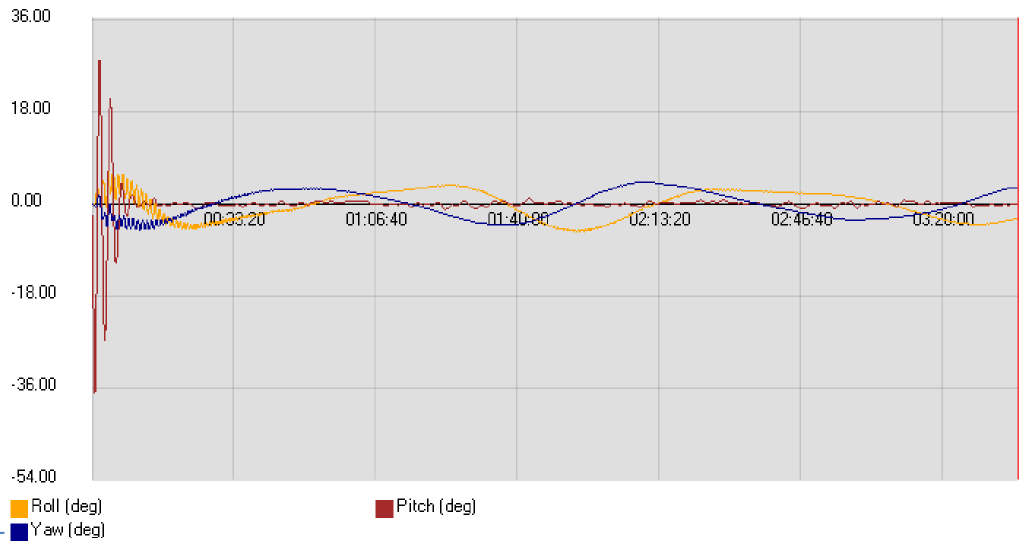
Test results

Y momentum control mode

2U CubeSat, CoG offset = 1cm



350 km	
Pointing error (1σ)	0.8 deg
Roll estimation error (1σ)	0.7 deg
Pitch estimation error (1σ)	0.7 deg
Yaw estimation error (1σ)	0.5 deg

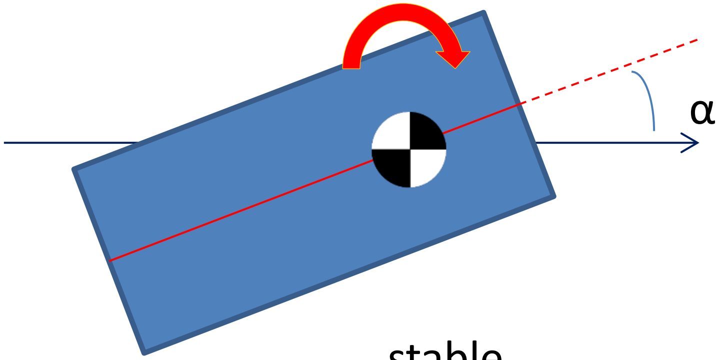


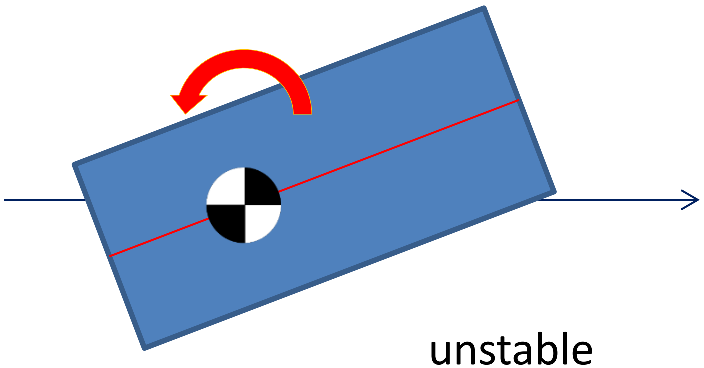
200 km	
Pointing error (1σ)	1.5 deg
Roll estimation error (1σ)	1.8 deg
Pitch estimation error (1σ)	0.8 deg
Yaw estimation error (1σ)	1.6 deg

Test results

Aerodynamic stability

- At low altitude aerodynamic disturbance torques are larger than what the actuators can achieve
- Attitude stability can only be achieved by having an aerodynamically stable satellite: aerodynamic torque should restore angle-of-attack to zero
- Can be achieved by:
  - For a 2U satellite without deployables: ensure centre-of-gravity is towards the RAM direction (relative to geometric centre)
  - Intelligent use of deployable panels/appendages



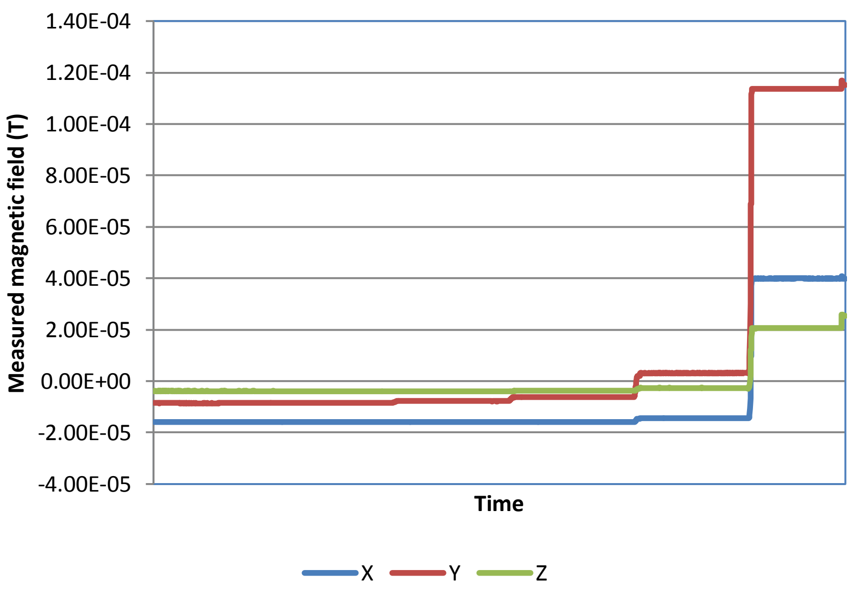


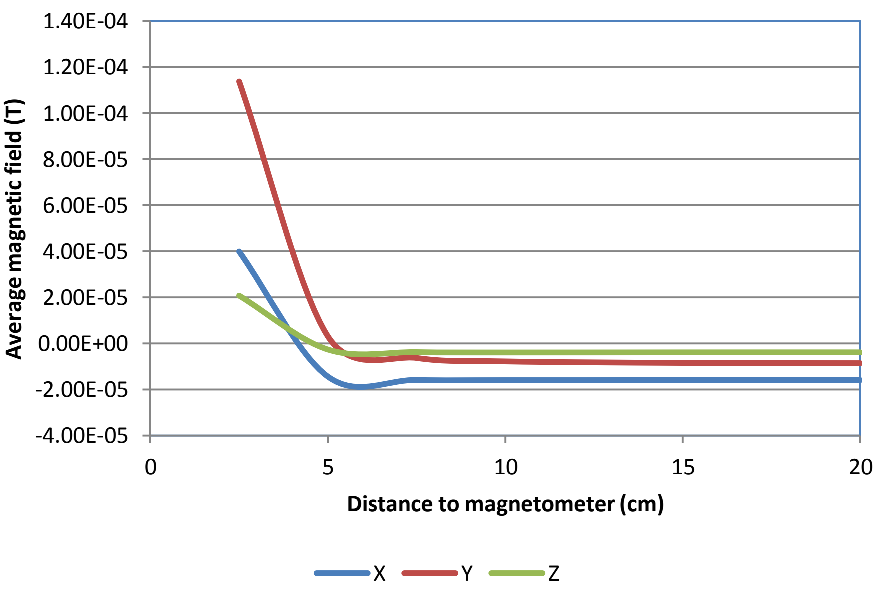
Test results

Magnetometer interference

- Permanent magnets will skew the magnetic field
- Brushless DC motor closer than 8cm will affect magnetometer measurements

<u>Stationary motor:</u>





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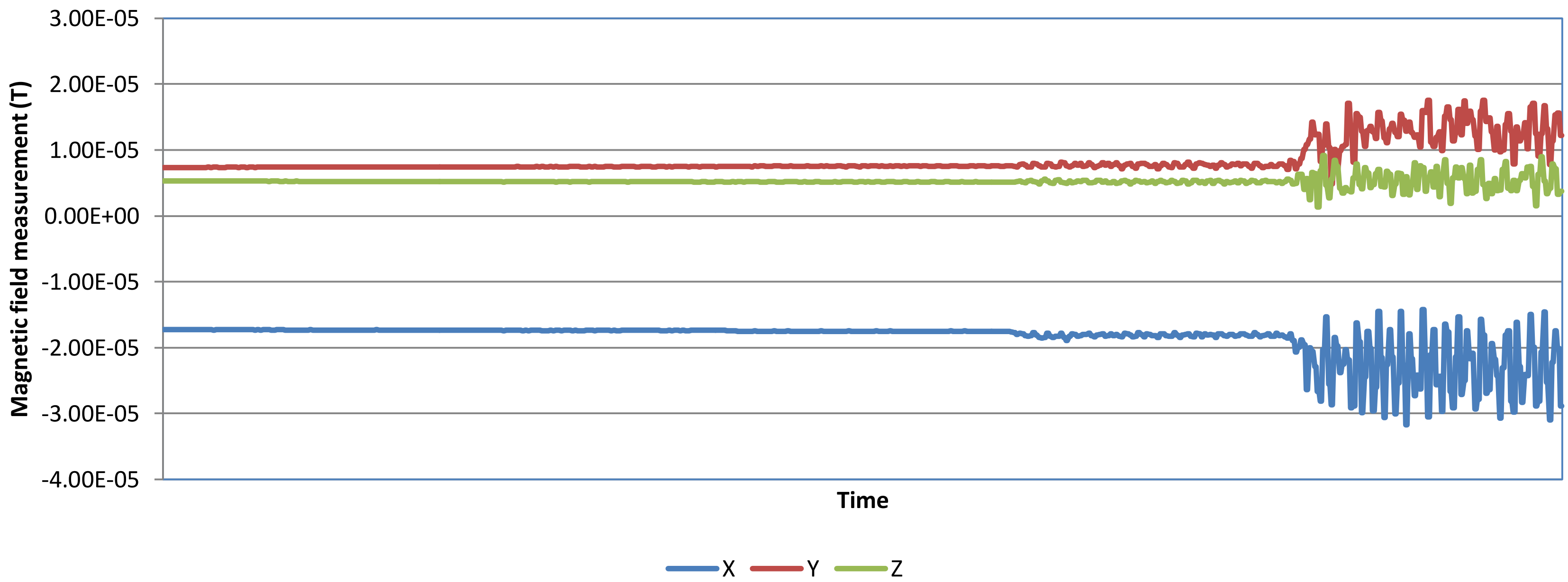
Spinning motor:



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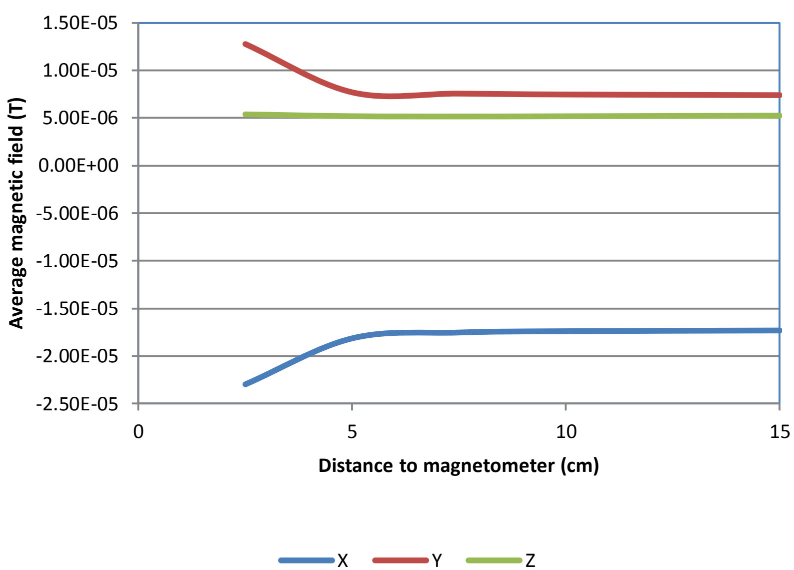
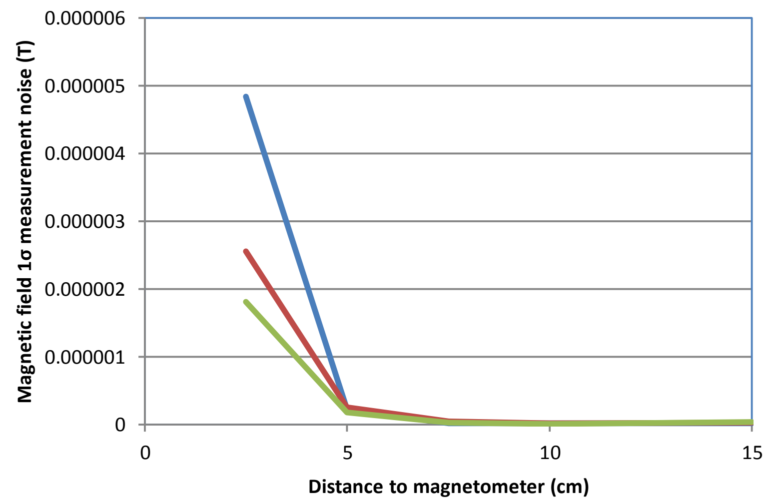
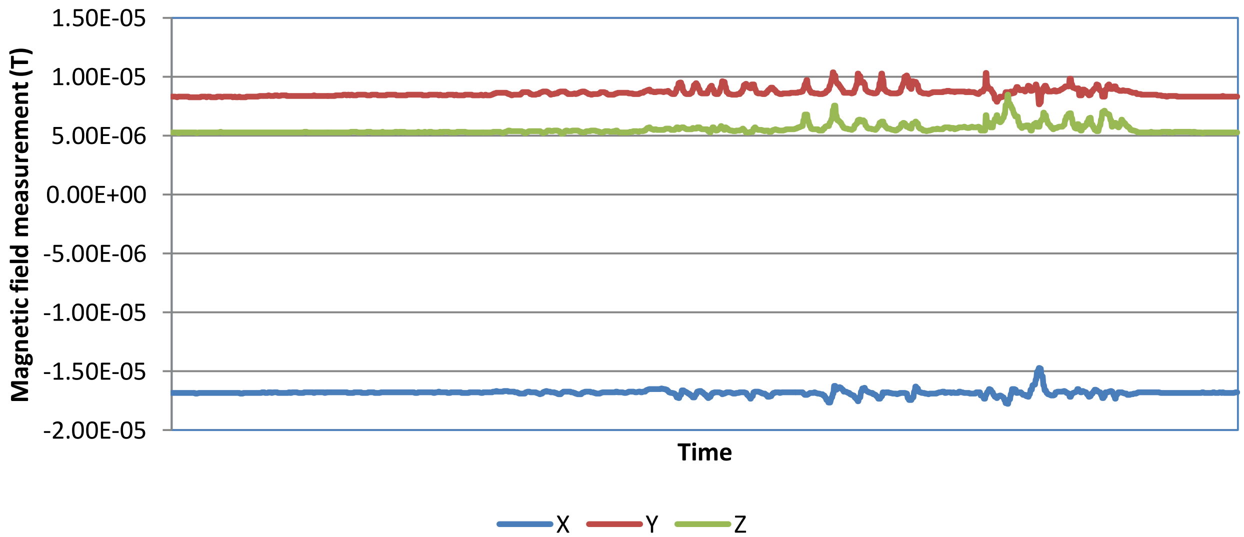




Test results

Magnetometer interference

- Bus electronics causes interference (increased noise)
- Simple CubeSat stack:
  - OBC
  - EPS
  - CubeControl (motor control & magnetorquer driver electronics)



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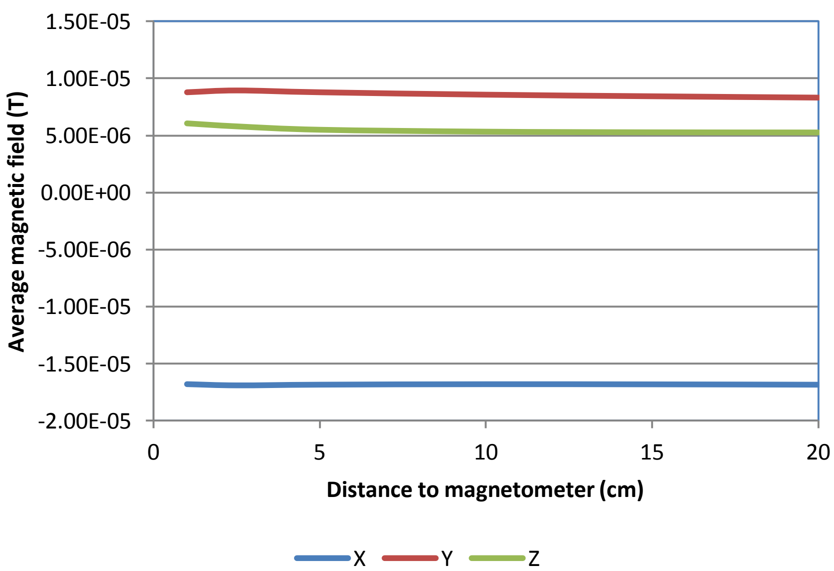

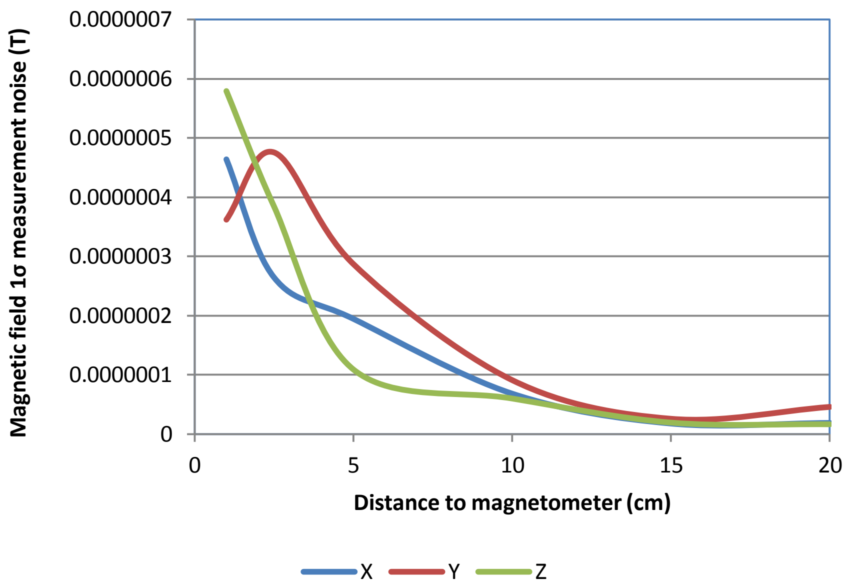

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Questions?

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