QB50

System Requirements
and Recommendations

Interface Control Documents

Issue 3

5 February 2013

Issue 1	**Issue Date:** 19 March 2012
Issue 2	**Issue Date:** 24 August 2012
Issue 3	**Issue Date:** 5 February 2013

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List of acronyms

1U, 2U, 3U	**1**-**U**nit, **2**-**U**nit and **3**-**U**nit CubeSat sizes, respectively
ABF	**A**pply **B**efore **F**light
ACRR	**A**djacent **C**hannel **R**ejection **R**atio
BPSK	**B**inary **P**hase **S**hift **K**eying
CalPoly	**Cal**ifornia **Poly**technical State University, SLO
CDMA	**C**ode **D**ivision **M**ultiple **A**ccess
CDR	**C**ritical **D**esign **R**eview
CVCM	**C**ollected **V**olatile **C**ondensable **M**aterial
DPAC	QB50 **D**ata **P**rocessing and **A**rchiving **C**entre
EMC	**E**lectro-**M**agnetic **C**ompatibility
ESD	**E**lectro-**S**tatic **D**ischarge
FDMA	**F**requency **D**ivision **M**ultiple **A**ccess
FIPEX	**F**lux-**Φ**-**P**robe **Ex**periment
IARU	**I**nternational **A**mateur **R**adio **U**nion
ICD	**I**nterface **C**ontrol **D**ocument
INMS	**I**on/ **N**eutral **M**ass **S**pectrometer
ISIS	**I**nnovative **S**olutions **I**n **S**pace BV
ITU	**I**nternational **T**elecommunication **U**nion
Kbps	**k**ilo-**b**its **p**er **s**econd
LEO	**L**ow-**E**arth **O**rbit
LV	**L**aunch **V**ehicle
MCC	**M**ission **C**ontrol **C**entre
MNLP	**M**ulti-**N**eedle **L**angmuir **P**robe
MSSL	**M**ullard **S**pace **S**cience **L**aboratory
N/A	**N**ot Applicable
OBC	**O**n-**B**oard **C**omputer
OBDH	**O**n-**B**oard **D**ata **H**andling
PDR	**P**reliminary **D**esign **R**eview
QPSK	**Q**uadrature **P**hase **S**hift **K**eying
RBF	**R**emove **B**efore **F**light
RDY	**R**ea**dy**
SCS	**S**atellite **C**ontrol **S**oftware
SLO	**S**an **L**uis **O**bispo, California, United States of America
TBC	**T**o **B**e **C**onfirmed
TBD	**T**o **B**e **D**etermined
TDMA	**T**ime **D**ivision **M**ultiple **A**ccess
TT&C	**T**elemetry, **T**racking and **C**ommand
TML	**T**otal **M**ass **L**oss
UHF	**U**ltra **H**igh **F**requency
VHF	**V**ery **H**igh **F**requency
VKI	**v**on **K**arman **I**nstitute for Fluid Dynamics

Reference documents

Ref. No.	Document Name	Document Title
[R01]	call_proposals_QB50.pdf	*Call for CubeSat Proposals for QB50*, von Karman Institute for Fluid Dynamics (VKI), Brussels, Belgium, 15 February 2012
[R02]	cds_rev12.pdf	*CubeSat Design Specification Rev. 12*, The CubeSat Program, Cal Poly SLO, 2009
[R03]	EN-13445-1	EN 13445, European Standard for Unfired Pressure Vessels, Comité Européen de Normalisation
[R04]		Recommended Set of Models and Input Parameters for the Simulations of Orbital Dynamics of the QB50 CubeSats

1. CubeSat System Requirements

1.1 Structural Subsystem

Several standard CubeSat sizes are identified in ‘Units’ relative to the original 1-Unit (1U) CubeSat. The rail dimensions are shown in Table 1. Only 2U and 3U CubeSats are anticipated for QB50.

QB50-SYS-1.1.1. The CubeSat dimensions shall be as shown in Table 1.

Table 1: Generic CubeSat dimensions

Property	2U	3U
Footprint	100 x 100 ± 0.1 mm	100 x 100 ±0.1 mm
Height	227 ± 0.1 mm	340.5 ± 0.1 mm
Feet	8.5 x 8.5 ± 0.1 mm	8.5 x 8.5 ± 0.1 mm
Rails	External edges shall be rounded Rx1mm or chamfered 45°x 1mm	External edges shall be rounded Rx1mm or chamfered 45°x 1mm

The StackPack – the deployment system for the QB50 mission –can accommodate 2U and 3U CubeSats. It provides extra volume to accommodate deployables, appendices, booms, antennas and solar panels. It offers lateral clearance between the CubeSat lateral sides and the StackPack Side Panels. Moreover the StackPack provides the capability to accommodate CubeSats with both, front and back extended volumes. However, for the CubeSats carrying the science payload, only the front could be used as the back extended volume is allocated for the science payload.

Figure 1 shows the StackPack extended volumes provided for the QB50 CubeSats; lateral extensions (-X, +X, -Y and +Y) are depicted in green, while front one (+Z) in yellow and back one (-Z) in blue.

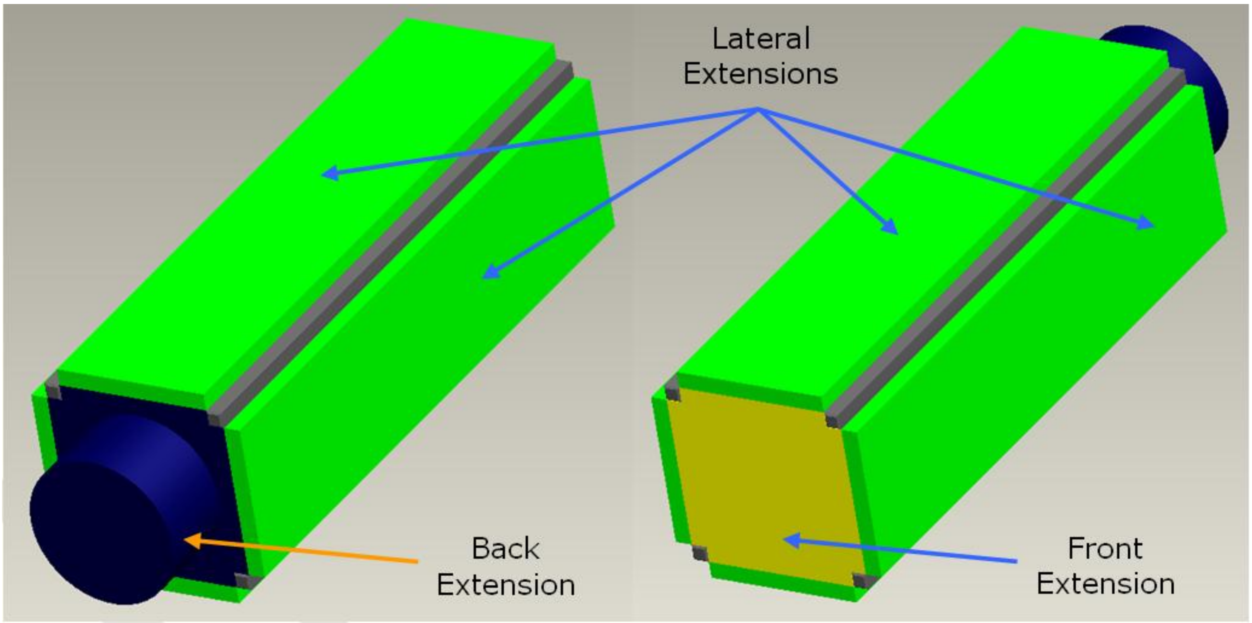

Figure 1: CubeSats lateral (green), front (yellow) and back (blue) extended volumes.

QB50-SYS-1.1.2. **In launch configuration the CubeSat shall fit entirely within the extended volume dimensions shown in Figure 2 for a 2U CubeSat or Figure 3 for a 3U CubeSat, including any protrusions.**

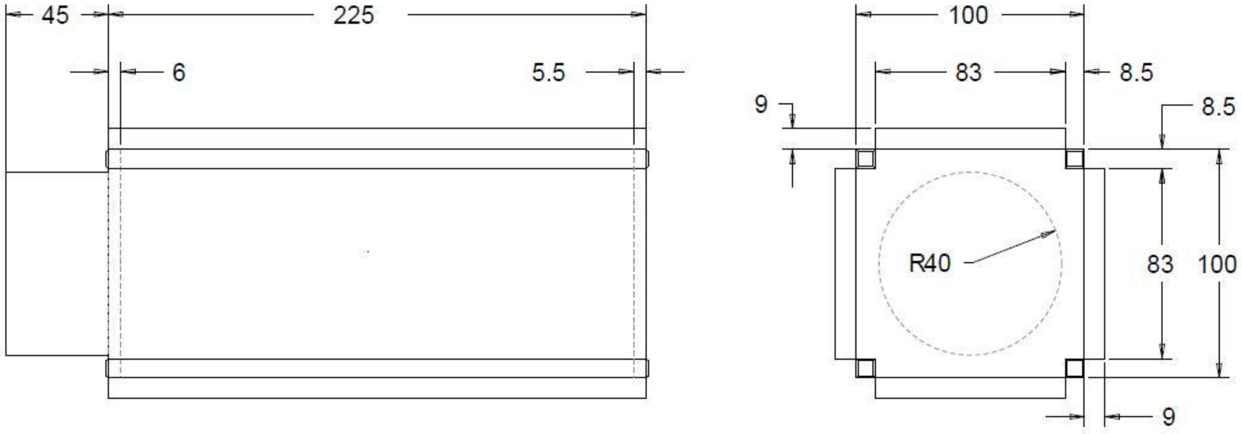

Figure 2: 2U CubeSat extended volume dimensions in millimetres.

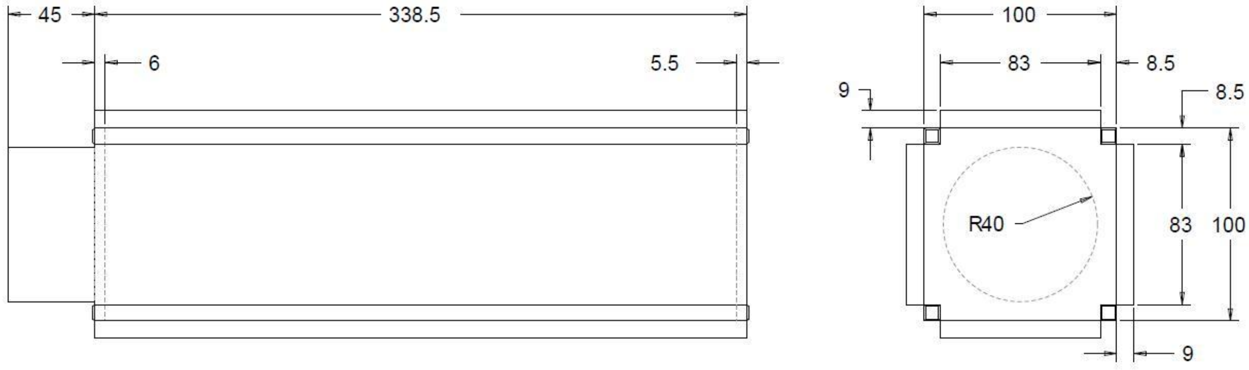

Figure 3: 3U CubeSat extended volume dimensions in millimetres.

QB50-SYS-1.1.3. The CubeSat mass shall be no greater than that shown in Table 2 .

Table 2: CubeSat masses admitted by the StackPack for QB50.

CubeSat Size	Maximum Mass
2U CubeSat	2.0 kg
3U CubeSat	3.0 kg

QB50-SYS-1.1.4. The CubeSat centre of gravity shall be located within a sphere of 20 mm diameter, centred on the CubeSat geometric centre.

This is required in order to control misalignments of the StackPack centre of gravity position on the launch vehicle.

QB50-SYS-1.1.5. Total Mass Loss (TML) shall be < 1.0% and Collected Volatile Condensable Material (CVCM) shall be < 0.1% [R02].

QB50-SYS-1.1.6. The CubeSat rails and standoffs, which contact the deployer rails, pusher plate, door, and/or adjacent CubeSat standoffs, shall be constructed of a material that cannot cold-weld to any adjacent materials.

1.2 Attitude Determination and Control Subsystem (ADCS)

The ADCS is responsible for detumbling the satellite after deployment, pointing the satellite in a favourable attitude to meet the mission requirements as well as for recovering it from any spin ups during the mission. It is also responsible for determining the satellite's attitude. System level requirements that are applicable to the ADCS are the following:

QB50-SYS-1.2.1. The CubeSat shall be able to recover from tip-off rates of up to 10 degrees/second within 2 days (TBC before CDR).

The most valuable science data is expected to be from the lower altitudes, however this is also the most difficult region to collect data due to high disturbance torques, short lifetime due to drag, short ground station pass times and friction heating of the spacecraft.

QB50-SYS-1.2.2. The CubeSats carrying the science sensors shall have an attitude control with pointing accuracy of ±10° and pointing knowledge of ±2° from its initial launch altitude at 350 km down to at least 200 km (TBC before CDR).

1.3 Electrical Power Subsystem (EPS)

The main purpose of the EPS is to provide enough electrical power to the rest of the subsystems such that the satellite is able to function during the entire length of the mission. The following are system level requirements that are applicable to the EPS:

QB50-SYS-1.3.1. The CubeSat shall provide sufficient power at the appropriate voltage, either by solar array generation or battery, to meet the power requirements of all satellite subsystems in all modes of operation.

QB50-SYS-1.3.2. The CubeSat shall be able to be commissioned in orbit following the last powered-down state without battery charging, inspection or functional testing for a period of up to 4 months (TBC before CDR).

QB50-SYS-1.3.3. The CubeSat shall be powered OFF during the entire launch and until it is ejected from the deployment system.

1.4 On-Board Computer (OBC) and On-Board Data Handling (OBDH)

As the ‘brain’ of the satellite, the OBC/OBDH subsystem is responsible for communicating with the rest of the subsystems and for relaying information between them. The following are system level requirements that are applicable to the OBC/OBDH subsystem:

QB50-SYS-1.4.1. **The CubeSat shall have 2 independent memory storage units of at least 2 GB to store all the science, telemetry and housekeeping data.**

QB50-SYS-1.4.2. **The CubeSat shall collect whole orbit data and log telemetry every minute.**

This is so that the information could be used to determine the causes of any problems in the case of a CubeSat anomaly.

QB50-SYS-1.4.3. **Any computer clock used on the CubeSat shall exclusively use Coordinated Universal Time (UTC) / Greenwich Mean Time (GMT) as time reference.**

Satellite Control Software (SCS)

The QB50 management team has arranged that each CubeSat team can have access to an existing Satellite Control Software (SCS) package for use in ground stations under a bilateral license agreement. The SCS will provide:

- Ground station interface software
- TM/TC Front End
- CubeSat Control System
- Operations User Interfaces software
- Communications handling with the Data Processing and Archiving Centre (DPAC) and Mission Control Centre (MCC)

It is not a requirement to use the SCS, and teams may propose an alternative solution provided it meets the requirements for controlling the satellite and communicating with the DPAC and MCC.

If utilized, the SCS will allow the CubeSat teams to assist each other with any difficulties with the common interface and will provide the CubeSat teams with a lighter software development. This will contribute to the overall project success by offloading some ground tasks that teams might not have expertise in.

Another advantage is that the teams will benefit from compatibility with other teams and could collaborate on their on-board software implementations. This option also facilitates the possibility of using other team's ground stations. The software provided is extremely flexible and individual teams can integrate their own specifics at many levels, for instance integrating their own payload-specific data processing or visualization.

For the teams who chose to use the QB50 SCS, the packet and frame protocol is defined and the teams will need to comply with it.

1.5 Telemetry, Tracking and Command (TT&C)

Note:

*** The requirements in section (1.5 Telemetry, Tracking and Command) should be taken as guidelines. If a QB50 ground station **network** is deemed necessary by the QB50 team, a more defined set of TT&C requirements will be released in the near future.***

Downlink frequency and data volume

QB50-SYS-1.5.1. **If UHF is used for downlink, the CubeSat shall use a downlink data rate of 9.6 kbps.**

QB50-SYS-1.5.2. **Each CubeSat carrying a set of standard QB50 science sensors shall communicate a volume of at least 2 Megabits of science data per day to the ground station that is operated by the university providing the CubeSat.**

In the case of a grounds station network, a volume of at least 8 Megabits (TBC before CDR) of science data per day shall be communicated to the ground station network. This ensures the return of a reasonable amount of science data. The total data volume transmitted to the ground will be significantly higher as it includes not only science data but also data for the teams' own experiment(s), housekeeping data, data for protocol overhead (AX.25, QB50 block protocol) and error detection / error correction (CRC, FEC, Interleaving).

QB50-SYS-1.5.3. **Each team shall ensure that their transmit frequency is stable to better than ±500Hz across all temperatures and operating conditions, so that the entire transmit spectrum falls around the allocated centre frequency within the given bandwidth.**

This will help ensure that each satellite can be quickly identified even at the start of the mission when many or all of the spacecraft may be overhead a single ground station.

QB50-SYS-1.5.4. **If UHF is used for downlink, the transmission shall fit in 16 kHz at -30 dBc (measured without Doppler).**

QB50-SYS-1.5.5. **If UHF is used for downlink, frequency stability shall be better than 10 ppm (TBC), over entire operating temperature range.**

QB50-SYS-1.5.6. **Every downlink signal shall carry a unique identifier of which satellite is transmitting.**

This should be included as part of the data sent and should easily be readable even without extensive knowledge of the structure of the transmitted data.

Recommendation 1 **It is recommended to implement BPSK or QPSK downlinks because of their spectral efficiency.**

Recommendation 2 **It is recommended to use different bands for uplink and downlink.**

Recommendation 3 **It is recommended to use CDMA as the downlink multiple access scheme.**

Recommendation 4 **It is recommended that all spacecraft should also have and make use of a national amateur radio call sign in the telemetry downstream.**

Uplink frequency and telecommands

QB50-SYS-1.5.7. **The CubeSat shall use an uplink data rate of 1.2 kbps.**

QB50-SYS-1.5.8. **All CubeSats shall have the capability to receive a transmitter shutdown command at all times later than 30 minutes after the CubeSat's deployment switches being activated from deployer ejection.**

QB50-SYS-1.5.9. **The CubeSat provider shall have access to a ground station which has the capability and permission to send telecommands through an uplink to control its satellite and to upload and execute timed Instrument Command Files. The format of these commands is TBD.**

QB50-SYS-1.5.10. **The CubeSat shall determine its position to within 1 km accuracy.**

QB50-SYS-1.5.11. Every science packet shall be tagged with the position of the CubeSat at the time that the RDY line goes high (indicating that that packet is ready in the science instrument), accurate to within 1 km. Position error estimates shall be provided for each position tag.

QB50-SYS-1.5.12. Every science packet shall be tagged with the real time that the RDY line goes high (indicating that that packet is ready in the science instrument), accurate to within 1 seconds. Time error estimates shall be provided for each time tag.

QB50-SYS-1.5.13. CubeSats shall be fitted with devices to ensure immediate cessation of their radio emissions by telecommand, whenever such cessation is required under the provisions of these Regulations. (This requirement is adopted from the ITU).

QB50-SYS-1.5.14. If UHF is used for uplink, the radio receiver shall have an Adjacent Channel Rejection Ratio (ACRR) of at least 100dB.

This is to avoid possible blocking of the receiver or interference from nearby QB50 satellites. Teams should also be aware that such operation will require very quick <2ms changeover time between transmit and receive when working with short frames.

QB50-SYS-1.5.15. The CubeSat shall use the AX.25 Protocol.

Recommendation 5 If VFH is chosen, in order to share the same channels, 1200bd AFSK should be used.

Downlink / uplink framing protocol

Recommendation 6 The recommended data format to be used inside the AX.25 packet is TBD.

1.6 Thermal Control

QB50-SYS-1.6.1. The CubeSat shall maintain all its electronic components within its operating temperature range while in operation and within survival temperature range at all other times.

The operational and survival temperature range for components will vary between teams based on hardware specification.

1.7 General

QB50-SYS-1.7.1. **The CubeSat shall be designed to have an in-orbit lifetime of at least 3 months.**

QB50-SYS-1.7.2. **The CubeSat shall not use any materials that have the potential to degrade during the 2 years storage duration after assembly.**

QB50-SYS-1.7.3. **Deployment switches shall be non-latching (electrically or mechanically).**

QB50-SYS-1.7.4. **Remove Before Flight (RBF) and Apply Before Flight (ABF) items, including tags and/or labels, shall not protrude past the dimensional limits of the CubeSat extended volumes (as defined in Figure 2 and Figure 3) when fully inserted.**

QB50-SYS-1.7.5. **All RBF items shall be identified by a bright red label of at least four square centimetres in area containing the words "REMOVE BEFORE FLIGHT" or "REMOVE BEFORE LAUNCH" and the name of the satellite printed in large white capital letters. (See Figure 4)**

REMOVE BEFORE LAUNCH

QB50 – MYCUBESAT

Figure 4: Example of RBF label

QB50-SYS-1.7.6. **The CubeSat provider shall transfer housekeeping and "quick look" sensor data to the Mission Control Centre (MCC) in near real time following reception on the ground. The format of this data, and the composition of "quick look" sensor data, is TBD.**

Mission Control Centre (MCC) Interface

The QB50 MCC will perform the following functions:

1. Receive "quick look" science data from all of the CubeSat operation centres, from their respective CubeSat(s)
2. Receive telemetry and house-keeping data from all of the CubeSat operation centres, from their respective CubeSat(s)

3. Display which ground station is in contact with which CubeSat, where applicable
4. Pre-process “quick look” science data and telemetry and house-keeping data
5. Compare predicted with actual trajectories
6. Monitor the status and health of the CubeSats and the deployment system
7. Predict and continuously updating the approximate time and latitude/ longitude of atmospheric re-entry for the CubeSats
8. Distribute data products to the science operations team, QB50 teams and the general public (detailed data dissemination plan is TBD)

Parallel QB50 MCCs will be set up at VKI, Stanford in the USA and NPU in China.

2. Environmental Requirements for Launch

The following launch vehicles (LVs) are being considered for QB50: VEGA, Cyclone-4, Dnepr, PSLV, Rokot and Soyuz. Included in this chapter are the environmental requirements **for launch**. The CubeSats shall consider the given values in the requirements for design of their CubeSats but these numbers are TBC before CDR.

It will most likely be a sun-synchronous circular orbit with an altitude of 350 – 400km (TBC before CDR) ± 7km, an inclination of 98.6±0.08°, eccentricity of ±0.04, and a local time of descending node of 11:00AM (TBC) ± 60 sec.

Note:

Section 2.1 (Gas Dynamic Environment and section 2.2 (Thermal Environment) refers to the environment* ***outside *the deployment system. As such, they are not necessarily applicable to CubeSats, but to the dispenser. These sections are included in this chapter for completeness.*

2.1 Gas Dynamic Environment

QB50-SYS-2.1.1. **The payload shall withstand a maximum pressure drop rate of 3.92kPa/sec (TBC before CDR).**

QB50-SYS-2.1.2. **The payload shall withstand an airstream velocity of 2m/sec at a pressure 0.8...1.1bar (TBC before CDR).**

2.2 Thermal Environment

QB50-SYS-2.2.1. **The payload shall withstand a maximum radiant heat flux from the payload fairing of 400W/m^2 (TBC before CDR) at prelaunch processing and in flight.**

QB50-SYS-2.2.2. **The payload shall withstand a maximum free molecular heating of 1135W/m^2 (TBC before CDR) following payload fairing jettison.**

QB50-SYS-2.2.3. **The payload shall withstand a maximum thermal effect of 3.0 kW·sec/m^2 (TBC before CDR) from the retrorockets.**

2.3 Spacecraft Contamination

QB50-SYS-2.3.1. **The CubeSat shall withstand a total contamination of 3.1mg/m^2 (TBC before CDR) at all phases of the launch vehicle ground operation and in flight.**

2.4 Electromagnetic Compatibility (EMC)

QB50-SYS-2.4.1. **During prelaunch processing and launch, the spacecraft onboard equipment and ground support equipment (GSE) shall sustain the electromagnetic fields of up to 10V/m (TBC) within 10 kHz to 40 GHz.**

3. Qualification and Acceptance Testing Requirements for Launch

The launch vehicle (LV) for QB50 is pending approval by EC/ REA. As it is not certain what the final selection will be, a **launcher envelope** is provided to which the CubeSats should be designed. This chapter describes the qualification testing requirements. These requirements are the worst case among the six considered launch vehicle: VEGA, Cyclone-4, Dnepr, PSLV, Rokot and Soyuz.

These values might change before the CDR following the design of the deployment system by ISIS. Depending on the quality assurance policy, the acceptance testing requirements will be either at the CubeSat level (acceptance testing each CubeSat as a standalone) or at a System level (CubeSat integrated with the launch structure and in launch configuration). This will be clarified before CDR. Until then, it is recommended that the CubeSat teams consider the given values and test conditions for the design of their CubeSats.

3.1. Quasi-static and G-loads

The orientation with respect to the launch vehicle interface is not yet defined. And since this may vary from team to team, all the CubeSats shall be qualified against the maximum load on all three axes.

QB50-SYS-3.1.1. CubeSat shall withstand accelerations of up to 8.3g in all three axes.

3.2. Resonant Frequency

QB50-SYS-3.2.1. The CubeSat shall pass a resonance survey and the lowest natural frequency of the CubeSat shall be > 90Hz.

3.3. Sinusoidal Vibration

QB50-SYS-3.3.1. The CubeSat shall pass the sinusoidal vibration tests as per Table 3 (TBC before CDR).

Table 3: Sinusoidal vibration test characteristics

Frequency, Hz	Amplitude, g
5	1.8
12	1.8
45	1.8
45	3
60	3
60	2
200	2
200	1
2000	1

3.4. Random Vibration

QB50-SYS-3.4.1. The CubeSat shall pass the random vibration tests as per Table 4 (TBC before CDR).

Table 4: Random vibration test characteristics

Frequency, Hz	Amplitude, g^2/Hz
20	0.091
60	0.2
1000	0.2
2000	0.068

3.5. Shock Loads

QB50-SYS-3.5.1. The CubeSat shall pass the shock tests as per Table 5 (TBC before CDR) taking into account the shock loads damping during propagation within the spacecraft structure.

Table 5: Shock test characteristics

Frequency, Hz	Amplitude, g
30	5
100	50
800	1410
5000	3000
10000	1410

4. Deployment System Requirements and Interface Specification

The StackPack provides the interface between the QB50 CubeSats and the Launch Vehicle. It is a custom integrated platform that is optimized in terms of mass, volume and connectivity. The innovative concept of StackPack consists of a collection of dispenser modules and is able to accommodate and deploy the whole set of QB50 CubeSats. The StackPack launch adapter will be mounted on the payload deck of the Launch Vehicle. The StackPack holds the CubeSats until they are deployed. For reference purposes the main components of each of the StackPack modules are pointed out in Figure 5 and explained below.

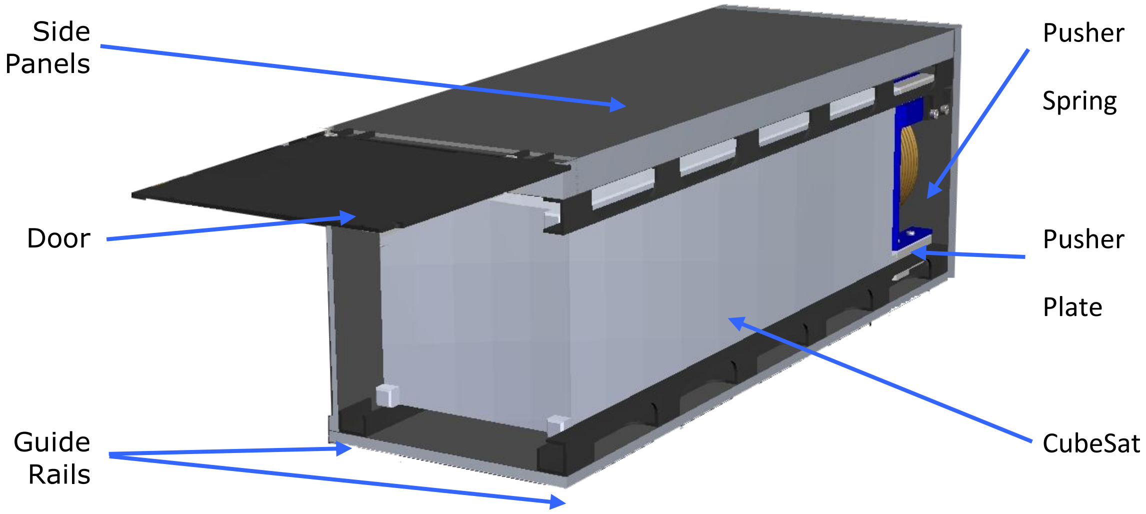

Figure 5: Overview of the major components of a single StackPack module

Main StackPack Elements

Guide Rails	The Guide Rails transfer the launch loads from the Launch Vehicle to the CubeSats. Their final function is to guide the CubeSats during their deployment.
Side Panels	The Side Panels form an enclosure around the CubeSats to protect it from hazards coming from other CubeSats, payloads or the Launch Vehicle itself.
Door	The Door retains the CubeSat during the launch and once it is opened, allows the CubeSat deployment.
Pusher Plate	The Pusher Plate is the element in charge of deploying the CubeSats out of the StackPack.
Pusher Spring	The Pusher Spring provides the mechanical energy needed for the deployment. The calculated deployment velocity of the CubeSats is TBD but varies from 1 to 2 [m/s].

4.1 Mechanical

As shown in Figure 5, the mechanical interfaces between the CubeSats and the StackPack are the following:

- The StackPack Guide Rails with the CubeSat Guide Rails,
- The StackPack Pusher Plate with the back CubeSat feet,
- The StackPack Door with the front CubeSat feet.

4.2 Accessibility

The StackPack provides accessibility to the CubeSat through the hatch situated on the front door (TBC before CDR). This accessibility area can be used for various activities such as:

- Remove the RBF mechanism
- Plug an umbilical connection
- Supply power connection to the CubeSat
- Provide data connection with the CubeSat
- Read CubeSat name

QB50-SYS-4.2.1. **After integration into the deployer, the CubeSat shall only require access, for any purpose, through the access hatch in the door of the deployer.**

4.3 Naming

QB50-SYS-4.3.1. **The CubeSat name shall be printed, engraved or otherwise marked on the CubeSat and visible through the access hatch in the door of the deployer.**

4.4 Thermal

The thermal interfaces between the CubeSats and the StackPack are formed by the conductive mechanical interfaces (Guide Rails and Feet). Apart from that, there exists convection (until vacuum conditions) and heat exchange by radiation between the CubeSats and the StackPack.

4.5 Electrical

The StackPack will provide electrical interface to the CubeSat before launch while it is integrated in the dispenser. The concept is to plug a connector to perform the correspondent power supply and battery charging activities of the CubeSat. The electrical connection will be implemented through the front door hatch. The specific connector is TBD.

4.6 Grounding

All mechanical interfaces between the CubeSat and the StackPack take place via non-conductive elements such as hard anodized (non-conductive) guiderails. The CubeSat inside the StackPack will therefore not be connected to a "common ground". Appropriate precautions will be taken during the loading/unloading of the CubeSat into/from the StackPack in order to protect the CubeSat against electrostatic discharge (ESD).

4.7 Remote Data Interface

The StackPack will provide remote data interface to the CubeSat before launch while it is integrated in the dispenser. The concept is to plug a connector to perform remote data communication and check-out activities of the CubeSat. The data connection will be implemented through the front door hatch. The specific connector is TBD.

4.8 Cleanliness, Handling, Storage and Shipment

Cleanliness: The whole set of QB50 CubeSats will undergo checkout and integration into the StackPack at ISO Class 8 clean room ISIS facility.

Shipment: The StackPack is shipped in a dedicated case. It is advised to use a case for transport and storage each CubeSat.

QB50-SYS-4.8.1. **If a CubeSat has any special requirement in terms of cleanliness, handling, storage or shipment, these shall be communicated to the deployer integrator (ISIS BV) 12 months before delivery of the CubeSat and also highlighted in the User Manual.**

Science Payload Interface Control Documents

Note:

*** At present, the science payloads (INMS, FIPEX, m-NLP) are still in the design phase. The PDR for them will happen in the near future. The following attachments contain the ICDs of the INMS, FIPEX, and the m-NLP in their* ***current state*** *as they are written by the designers of the corresponding payload. These three documents are still* ***DRAFT versions****.***

Attachment A: INMS Interface Control Document (DRAFT)

TITLE: QB50 INMS Science Unit Interface Control Document

Document Number: MSSL/QB50/ID/12001 Issue 2 Rev DRAFT

MSSL		**VKI**	
Dhiren Kataria	X	Jean Muylaert	X
Alan Smith	X	Ruedeger Reinhard	X
Craig Leff	X	Cem Ozan Asma	X
Mark Hailey	X	Fiona Singarayar	X
Rahil Chaudery	X		
Hubert Hu	X	**ISIS**	
Berend Winter	X	Jeroen Rotteveel	X
Peter Coker	X	Cesar Bernal	X
Alan Spencer	X	Joost Elstak	X
Matthew Whillock	X		

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CHANGE RECORD

Issue	Date	Sections changed	Comments
Draft A	21/01/2012	All new	First draft
Issue 1	28/02/2012	Major revision of most sections	Focus on Science Unit rather than INMS
Issue 2 DRAFT	01/02/2013	Major revision of most sections	Added OBC Software requirements

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CONTENTS

1 Introduction

This document controls the required interfaces between a QB50 CubeSat and the INMS Science Unit.

Science Unit: As described in the call for proposals, the menu of sensors selected for the science units are:

- Ion Mass Spectrometer (IMS)
- Neutral Mass Spectrometer (NMS)
- Flux-Φ-Probe Experiment (FIPEX)
- Multi-Needle Langmuir Probe (MNLP)
- Corner Cube Laser Retro-reflectors (CCR)
- Thermistors/thermocouples/RTD (TH)

A Science Unit will comprise one of the following options:

1) IMS + NMS, plus Thermistors and CCR
2) FIPEX, plus Thermistors and CCR
3) MNLP, plus Thermistors and CCR

The design objective for the Science Unit is to remain within a 600 mW power budget (duty-cycled, orbit averaged), 600 g mass budget and half a CubeSat unit volume budget (excluding forward protuberance). 20% design margin is being held within these budgets. As the final configuration of the Science Unit to be provided to each of the CubeSat teams will only be made known after selection, representative mechanical and electrical interfaces with an overall resource envelope of the design objective are provided here.

The location of the Science Unit Thermistors (TH) within the body of the CubeSat will be included in a later version of this document.

If a CubeSat team selects to implement the Corner Cubes (CCR), it shall be their responsibility to select the location and interface of the Corner Cubes (CCR). Provision for mounting a Sun Sensor on the external body of the SU, and a CubeSat System Thermistor within the Science Unit is TBC. Details shall be included in a later version of this document.

2 Normative and Informative documents

2.1 Normative Documents

ND1: UM-3: CubeSat Kit User manual Rev D2 issued 17 Sep 2003.

ND2: CubeSat Design Specifications Rev. 12

ND3: INMS Science Unit Science Requirements Document – DRAFT

ND4: INMS Science Unit Detailed Design Document – DRAFT

ND5: QB50 CubeSat Requirements Specification Ver 2.0 24 Aug 2012

2.2 Informative Documents

ID1: Call for CubeSat Proposals for QB50 issued 15 Feb 2012

ID2: QB50 SSWG Final Report to be issued 1 Mar 2012

ID3: National Semiconductor DAC121S101/DAC121S101Q Data sheet

ID4: National Semiconductor ADC128S052 Data sheet

ID5 : http://www.analog.com/static/imported-files/data_sheets/AD590.pdf

3 Abbreviations

ADC	Analogue to Digital Converter
CEM	Channel Electron Multiplier
DAC	Digital to Analogue Converter
EGSE	Electronic Ground Support Equipment
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electro-Static Discharge
FMMU	Flash Mass Memory Unit
FPGA	Field Programmable Gate Array
HSDR	High Speed Data Recorder
HV	High Voltage
I/F	Interface
IMS	Ion Mass Spectrometer
kbps	Kilo-bits per second
LEO	Low Earth Orbit
LUT	Look Up Table
LV	Low Voltage
LVDS	Low Voltage Differential Signalling
Mb/day	Mega-bit per day
MSSL	Mullard Space Science Laboratory
NMS	Neutral Mass Spectrometer
OBC	CubeSat On-Board Computer
PCB	Printed Circuit Board
PWM	Pulse Width Modulator
S/C	Spacecraft
SEE	Single Event Effects
SMD	Surface Mount Device
SPI	Serial Peripheral Interface
SU	Science Unit
TBC	To be confirmed
TBD	To be decided
TBI	To be included

4 Electrical Interfaces

There will be a single electrical connector between a Science Unit (SU) and a

The Science Unit shall provide a 25-way STRAIGHT MDM-female connector for

CUBESAT side connector to attach to. Position of the connector shall be as shown in

Appendix 1. The CubeSat connector shall provide the signals as shown in Table 4-1.

4.1 Science Unit Connector Definition

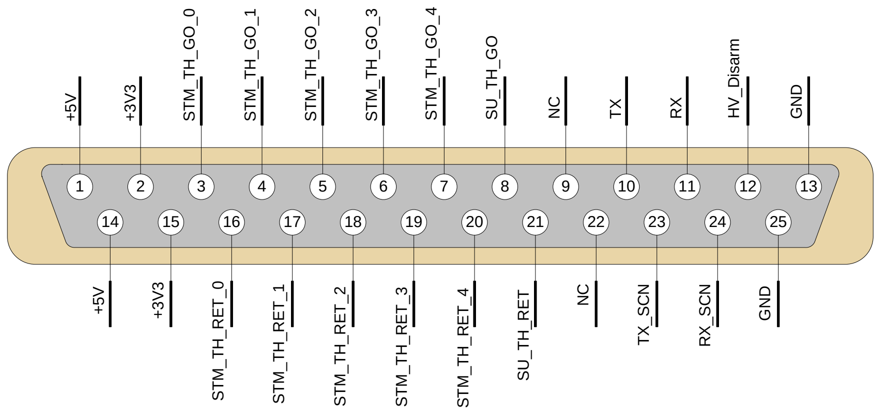

Figure 4-1 R/A MDM25_F Connector Pin-Out

Pin	Signal Name	Comment
1	+5	**SWITCHED** Power for +5V logic
2	+3V3	**SWITCHED** Power for +3V3 logic
3	STM_TH_GO_0	Surface Thermal Monitor THERMISTOR – signal for CH0
4	STM _TH_GO_1	Surface Thermal Monitor THERMISTOR – signal for CH1
5	STM _TH_GO_2	Surface Thermal Monitor THERMISTOR – signal for CH2
6	STM _TH_GO_3	Surface Thermal Monitor THERMISTOR – signal for CH3
7	STM _TH_GO_4	Surface Thermal Monitor THERMISTOR – signal for CH4
8	SU_TH_GO	Science Unit THERMISTOR – signal GO
9	NC	No connection
10	TX	Serial line to **SEND** data from SU to CubeSat
11	RX	Serial line to **RECEIVE** data from CubeSat to SU
12	HV_Disarm	**RED TAG** plug situated in CubeSat Access Hatch to DISABLE HV
13	GND	System GROUND
14	+5	**SWITCHED** Power for +5V logic
15	+3V3	**SWITCHED** Power for +3V3 logic
16	STM _TH_RET_0	Surface Thermal Monitor THERMISTOR - RETURN for CH0
17	STM _TH_RET_1	Surface Thermal Monitor THERMISTOR - RETURN for CH1
18	STM _TH_RET_2	Surface Thermal Monitor THERMISTOR - RETURN for CH2
19	STM _TH_RET_3-	Surface Thermal Monitor THERMISTOR - RETURN for CH3
20	STM _TH_RET_4	Surface Thermal Monitor THERMISTOR - RETURN for CH4
21	SU_TH_RET	Science Unit THERMISTOR – signal RETURN
22	NC	No connection
23	TX_SCN	Screen for TX
24	RX_SCN	Screen for RX
25	GND	System GROUND

Table 4-1 Instrument Connector Pin Assignment

4.1.1 SWITCHED Power Pins

The +5, +3V3 and the GND connections are duplicated to provide redundancy in the harness. These have to be controlled by the CubeSat in order to control switching the SU power **ON** or **OFF by SCRIPT command**.

The CubeSat electrical switch characteristics shall be that BOTH +5V and +3V3 rails shall be switched ON together. The switch ON timing specification is TBD.

NOTE: The SU CANNOT switch itself ON or OFF. That can ONLY be done by the CubeSat OBC: either by running a SCRIPT command (to turn ON or OFF), or due to an ERROR condition in which case the CubeSat OBC shall ONLY be able to autonomously turn OFF the SU.

4.1.2 Grounding

The Science Unit electronics shall be electrically grounded to the SU structure via GND. As some CubeSat teams have suggested that their CubeSat structure may not be metallic, and that a large area the Solar-panel is also not metallic, the SU to CubeSat GROUND connection shall be made through the SU Connector GND pin. The electrical resistance shall be <50 mΩ between the analyser GND connection at the interface connector and the metalwork of the analyser head.

If the SU is attached to a metallic structure another measurement should be made between the analyser head and the metallic structure, as this structure could introduce a ground loop where current passes through the structure.

The SU is not electrically isolated from the S/C and the SU analyser head must be grounded.

If the structure is metallic and connected to the power return, no link shall be made between the SU and the analyser head metalwork.

If the structure is not metallic and not connected to the power return, a link shall be made internally between the SU analyser metalwork and GND.

4.1.3 Surface Thermal Monitor (STM) Thermistors

There are six thermistor channels for the Surface Thermal Monitor (STM) experiment.

Five channels are brought out to the SU_Connector.

The sixth channel is mounted **inside** the SU.

The temperature sensors are AD590 surface mount devices, 2-lead flat-pack ID5.

The specific temperature sensor part number is: AD590MF

These sensors will be glued to the structure directly using TBD epoxy.

The harness between the connector and temperature sensor should be twisted pair.

4.1.4 Surface Thermal Monitor Thermistor Locations

Channels STM_TH[0,1,2,3,4] are located at TBD positions on the CubeSat solar panels.

Channels STM_TH[5] is located at TBD position on inside of the Science Unit.

4.1.5 Science Unit Thermistor

The Instrument Connector provides connections to an internal Science Unit thermistor. This allows the OBC to monitor the temperature of the SU, even when the SU is switched OFF.
The position of the Thermistor inside the SU is TBD.

4.1.6 Science Unit Serial Interface

The 3V3 I/O standard UART serial interface shall be used to control the SU from the OBC.

The serial I/F settings to use shall be:

BAUD Rate: 38400
Data Width: 8-bit
Parity bit: No Parity
START bit: ONE
STOP bit: ONE

This BAUD rate is the minimum required in order to meet the science requirement for BURST mode, where data packets can be will be generated at up to every 259 msec. NOTE: The CubeSat team should account for the relatively slow times required to write SU data packets to MASS-STORAGE cards in their design.

Serial interface packet formats and ERROR handling are described in section 5.

4.2 Sun Sensor

The trade-off carried out for the INMS has shown that It is not feasible to mount the sun-sensor on the top surface of the SU (ram-direction).

4.3 EMC requirements

TBI

4.4 Power Budget

The power budget is shown in Table 4-2. These numbers are preliminary and are TBC.

Mode	Power at +5V (mW)		Power at +3.3V (mW)	
	Orbit average (Duty cycle averaged)	Maximum during Unit operations	Orbit average (Duty cycle averaged)	Maximum during Unit operations
Standby	3	279	1	100
Full/BURST State	499	640	77	200

Table 4-2 - Power Budget

Some further power saving may be possible by disabling internal power converter modules (TBC).

The maximum current capability will be approximately 0.2A for the power supply (including connector.)

5 CubeSat OBC Software Requirements

The following sections describe SU Command and Response packet structures and the software requirements that the CubeSat OBC shall follow to implement servicing the INMS instrument.

5.1 Overview of SU Control Strategy

In order simplify the SU operation; a very straight forward procedure of control has been implemented:

The CubeSat OBC shall send a command to the SU, and within a set TIME-OUT period, the SU shall respond with a data packet. The data packet could be one of three types:

- INMS specific science data packet
- STM thermistor reading data packet
- House-Keeping data packet.

As the SU is an autonomous system, that will be out of range for real-time control, any anomaly detected shall generate an ERROR HK-packet (either by the SU, or CubeSat OBC – see details later in chapter), and the SU shall be turned OFF. The SU team shall then investigate any actions is to be taken by reviewing telemetry.

As there is very little scope for debug or correct errors in real time on board, the OBC-SU communication protocol has been simplified too. There is NO checksum, or ACK/NACK system implemented to reduce complexity.

In every situation that a command fails, then the following command shall generate an ERROR packet: the outcome being that the SU shall be switched OFF. Conversely, if the SU cannot generate data packets (due to an internal error), the OBC shall detect this, and again, the SU shall be switched OFF.

5.2 Data Handling and Control

On receiving a data packet from the INMS instrument, the OBC shall attach the following information to it:

- Current space-craft time
- Current space-craft attitude position

The full packet shall be stored in the OBC MASS_MEMORY.

The time needs to be accurate to 1 sec. Time fields may be attached either on receiving the first byte of the packet or on receipt of the full packet.

The accuracy required for the attitude information can be found in ND5.

NOTE: The data in OBC MASS_ MEMORY will need to be re-packetised into an appropriate CubeSat downlink protocol structure (e.g. AX.25 packet, or GamaNet File etc.) when commanded from ground.

5.3 Command & Response Handling

5.3.1 OBC Sending a Command Packet

There is no checksum or handshake scheme implemented in order to keep the operation of the SU as simple as possible.

5.3.2 OBC Error Handling of Science Unit

There shall be a nominal time-out set at 60 sec (TBC) in the OBC for responses to commands. The maximum time-out period shall be 220 sec.

On a time-out, the OBC shall ABORT the current script, and TURN OFF the SU. The OBC shall also generate an ERROR report packet to indicate the error. The implementation of the ERROR packet is specific to each CubeSat team.

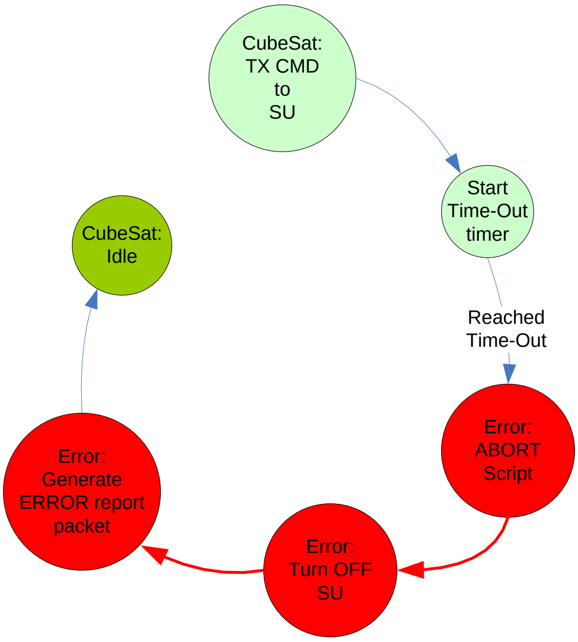

Figure 5-1 OBC SU-Error Handling State Diagram

5.3.3 SU Error Handling: Command Execution Error Handling

If there is an error in execution of a command, the SU state sequencer shall **ABORT** the on-going operation, set an ERROR_FLAG in the HK_STATUS_REG, and send an updated HK packet. It will then turn OFF HV, and go to STDBY state.

If the SU does NOT send a response within the time-out period, the OBC shall turn OFF the SU. The SU does not have the capability to turn itself ON or OFF.

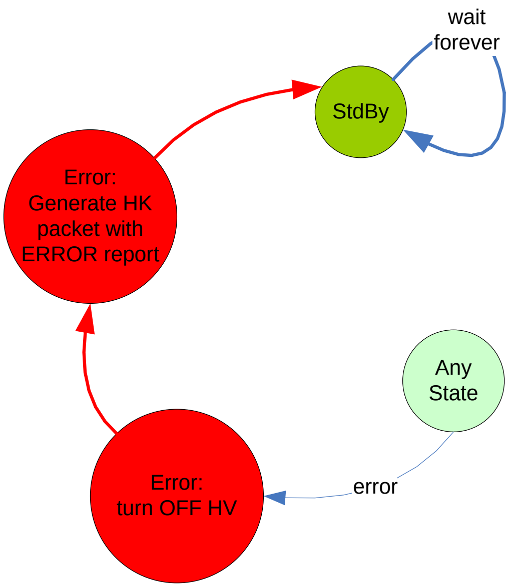

Figure 5-2 SU Error Handling State Diagram

5.3.4 SU Error Handling: Sending a Response Packet

On the SU detecting an error, it shall send an HK packet with the current ERROR conditions set, and then go to STDBY mode. In this mode the SU is in a safe state, and HV is OFF. The SU shall stay in this state until correctly commanded to switch to a valid state. However, in reality, if the SU does NOT send any more responses within the time-out period, the OBC shall turn OFF the SU.

5.4 Command Packet Structure to Science Unit

The following packet structure shall be used to transmit commands from the OBC to the SU:

CMD_ID, LEN, param_0, param_1…param_LEN-1

where:

CMD_ID: 8-bit value for command identifier

LEN: 8-bit value representing the number of BYTES to follow the LEN parameter

Param_n: parameters sent in BYTE format - LS BYTE is sent first for 16-bit WORD parameters.

See section 5.9 for details of commands/responses..

5.5 Reponses Packet Structure to CubeSat

Response packets are of a FIXED size. The following packet structure shall be used to transmit responses from the SU to the OBC:

RSP_ID, SEQ_CNT, 518 DATA BYTES

Where:

RSP_ID: 8-bit value is a copy of the **CMD_ID** field from the originating command.

SEQ_CNT: 8-bit value representing a sequential count of packets. The counter value shall roll-over to X”00” having reached maximum count (X”FF”).

DATA: This is of a fixed packet size: 518 BYTES. 16-bit WORDs shall be sent LS BYTE is sent first

Total Response packet length is therefore 520 BYTES.

See section 5.9 for details of commands/responses.

5.6 Data Rates and Volumes

Data rates & volumes are all aspects of Concept-of-Operation (Con-Ops). As such, cadence, duty cycle & instrument resolution can vastly impact the size of data generated by the INMS instrument.

The aim is to write the INMS control script so that the allocated SCIENCE data rate (2Mb/day TBC) is generated by the instrument.

5.6.1 Example INMS Operation Scenario

As an example to illustrate how this could be achieved a script could be developed to do the following:

- Generate SCIENCE data packets every 120 sec
- Generate STM data packets every 5 mins with STM samples taken every 60 sec
- Take HK data packets every 10 mins

With the above example, the various SCRIPT parameters for the INMS commands would achieve approx. 1.8Mb/day of SCIENCE DATA.

Note: These figures DO NOT include downlink data-rate budgets.

Detailed design is on-going, so more detailed information of operation will be provided at a later stage.

5.7 SU State Transition Diagram

The diagram shows all the valid state transitions that commands from the SCRIPT may make upon execution. Note, for instance, that SCIENCE mode cannot be run until HV has been turned ON and the Health Check performed correctly.

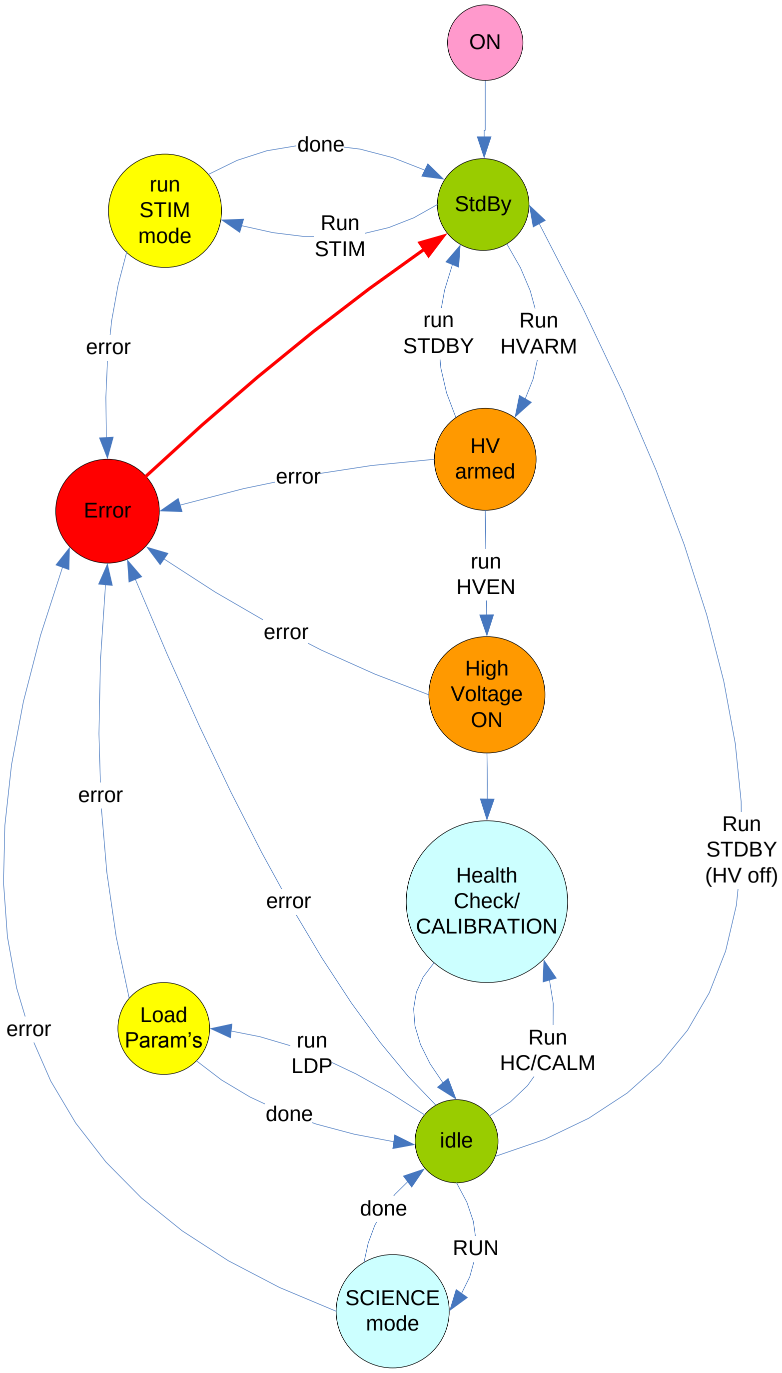

Figure 5-3 SU State Transition Diagram

5.8 OBC Script Commands

The following table lists the SCRIPT commands to control the SU operation from the OBC.

Command	CMD_ID	Parameters
OBC_SU_ON	0xFB	@t
OBC_SU_OFF	0xFC	@t
OBC_SU_END	0xFF	@t
SU_STDBY	0x02	LEN, @t
SU_TH	0x03	LEN, VTH @t
SU_STIM	0x04	LEN, PULSE_CNT @t
SU_LDP	0x05	LEN, ADDR, B0, B1, …B_LEN-2, @t
SU_HC	0x06	LEN, t_del, n_step, v_step, sw_ana, @t
SU_CALM	0x07	LEN, t_del, n_step, v_step, sw_ana, @t
SU_SCI	0x08	LEN, MODE, V_start, t_dwell, t_delay, seq_rpt @t
SU_HK	0x09	LEN, t_sample, @t
SU_STM	0x0A	LEN, t_sample@t
SU_HVARM	0x53	LEN, @t
SU_HVEN	0xC9	LEN, @t

Table 5-1 - Science Unit Commands

5.9 OBC Script Command Description

5.9.1 OBC and SU Specific Commands

Any SCRIPT command prefixed by “OBC_” is an instruction to the OBC, and is NOT sent to the Science Unit.

Any SCRIPT command prefixed by “SU_”, together with LEN, and any additional parameters form the command to be sent to the SU.

The time field - “@t” shall be read by the OBC and interpreted as a time code – see 5.9.2.

Note: The command names shown are just MNEMONICS to help human users to write scripts in an understandable manner: these are encoded into binary codes for actual uplink to CubeSats. And of course, the parameters encode into 8 or 16-bit numbers as required.

5.9.2 Script TIME Field - @t

Time-tagged command sequence scripts shall be uploaded to the CubeSat. The CubeSat OBC shall read the script commands and execute them at the time given by the 3-BYTE @t TIME field

TIME is a 3-BYTE value:

1st BYTE	Hours	range 0-24*
2nd BYTE	Mins	range 0-59*
3rd BYTE	Sec	range 0-59*

The @t TIME field is ONLY read by the OBC, but NOT sent to the SU as part of the command.

The Science Unit shall execute commands immediately upon receipt.

Time is to an accuracy of 1 sec.

*Note: The SCRIPT mnemonic @NOW is encoded as time = FF:FF:FF – this shall be interpreted by the OBC script handler to send the script command immediately.

NOTE: by having TIME in a 24 hour format, it is envisaged that the same script could be repeated each day.

5.9.3 Script Encoder Software Tool

An ASCII - user-readable “Command Sequence Script” shall be encoded into a BYTE stream using the SU_SCRIPT_ENCODER software tool provided by the SU team.

As an example, the script commands:

```
OBC_SU_ON @19:00:00
SU_HK 60 @19:04:09
```

Would be encoded into the following BYTE stream by the SU_SCRIPT_ENCODER tool:

```
0x09, 0x04, 0x13, 0x3C, 0x13, 0x04, 0x09
```

The SU_SCRIPT_ENCODER shall parse the script file; parameter range errors and logical errors, such as attempting to send a SCIENCE MODE command before turning ON the high voltages, will prevent a byte file being generated.

5.9.4 OBC_SU_ON (0xFB)

This SCRIPT command is ONLY read & interpreted by the OBC to turn ON the SU at time given by “@t”.

5.9.5 OBC_SU_OFF (0xFC)

This SCRIPT command is ONLY read & interpreted by the OBC to turn OFF the SU at time given by “@t”.

5.9.6 OBC_SU_END (0xFF)

This SCRIPT command is ONLY read & interpreted by the OBC to stop running the SCRIPT at time given by “@t”.

5.9.7 SU_STDBY (0x02)

This command is sent to the SU to put the SU into the STANDBY state at time given by “@t”.

CMD_ID = 0x02
LEN = 0x01 number of BYTES to follow

The HV line is turned OFF when going to STDBY state

5.9.8 SU_TH (0x03)

Set V_TH, the A121 threshold voltage at time given by “@t

CMD_ID = 0x04
LEN = 0x03 number of BYTES to follow
VTH: = 2-BYTE value of A121 voltage threshold (default TBD)

See DAC121 data sheet [ID3].

5.9.9 SU_STIM (0x04)

This command will run the STIM check at time given by “@t”.

Command format is:

CMD_ID = 0x04
LEN = 0x02 number of BYTES to follow
PULSE_CNT = number of pulse to send to STIM electronics in range <0x00 to 0xFF>
(default = 0x40 [64dec])

Response packet format:

RSP_ID = 0x04
SEQ_CNT = next sequential count of packet.
DATA = 518 BYTES of data.

The details of the STIM data packet structure are given ND4

5.9.10 SU_LDP (0x05)

This command allows any often used parameters to be loaded into the SU FPGA look-up-table (LUT) at time given by “@t”.

Command format is:

CMD_ID = 0x05
LEN = number of BYTES to follow in the packet
ADDR = 1-BYTE address of where to start loading the parameters from
Bn = BYTE value of each LUT parameter. LS BYTE sent first (LITTLE ENDIAN)

5.9.11 SU_HC (0x06)

This command runs a HEALTH CHECK of INMS.

NOTE: The HEALTH_CHECK command “SU_HC” can ONLY be run from IDLE state, once the HV circuit has been successfully ARMED and ENABLED – see SU_HVARM & SU_HVEN command for details.

“SU_HC” command format is:

CMD_ID = 0x07
LEN = 0x06
t_del = 1-BYTE value of msec. at each step (default TBD ms)
n_step = 1-BYTE value of steps in total. (default 50 steps)
v_step = 2-BYTE value of volts per step (default -20V)
sw_ana = 1-BTYE : 0000_0,b2, b1, b0 : b2 = sw_ana3, (default ON = ‘1’)
b1 = sw_ana2 (default ON = ‘1’)
b0 = sw_ana1 (default ON = ‘1’)

Response packet format:

RSP_ID = 0x06
SEQ_CNT = next sequential count of packet.
DATA = 518 BYTES of data.

The details of the BYTES in a health check data packet structure are given ND4

5.9.12 SU_CALM (0x07)

This command runs a CALIBRATION of INMS.

NOTE: The CALIBRATION command “SU_CALM” can ONLY be run from IDLE state, once the HV circuit has been successfully ARMED and ENABLED – see SU_HVARM & SU_HVEN command for details.

“SU_CALM” command format is:

CMD_ID = 0x07

LEN = 0x06

t_del = 1-BYTE value of msec. at each step (default 1 ms)

n_step = 1-BYTE value of steps in total. (default 50 steps)

v_step = 2-BYTE value of volts per step (default -20V)

sw_ana = 1-BTYE : 0000_0,b2, b1, b0 : b2 = sw_ana3, (default ON = ‘1’)
b1 = sw_ana2 (default ON = ‘1’)
b0 = sw_ana1 (default ON = ‘1’)

Response packet format:

RSP_ID = 0x07

SEQ_CNT = next sequential count of packet.

DATA = 518 BYTES of data.

The details of the BYTES in a calibration data packet structure are given ND4.

5.9.13 SU_SCI (0x08)

This command starts the SCIENCE operation.

NOTE: The “SU_SCI” command can ONLY be run from IDLE state, once the HV circuit has been successfully ARMED and ENABLED – see 5.9.16 for details.

“SU_SCI” should normally be run AFTER a “SU_HC” command has been run once to set the HV rail to the required voltage before sweeping.

“SU_SCI” command format is:

CMD_ID = 0x08
LEN = 0x07
MODE = 1-BTYE to set Science Mode: “0x01” = NORMAL, “0x02” = BURST (default 0x01)
V_start = 2-BYTE: start voltage for sweep (default 28V)
T_dwell = 1-BYTE: time between BURST_SWEEPS in 500 usec units (default 1ms)
T_delay = 1-BYTE: time delay between BURST_BLOCKs in 500 usec units (default 1 sec)
seq_rpt = 1-BYTE value of number of times to repeat SEQUENCE (default 1)

Response packet format:

RSP_ID = 0x08
SEQ_CNT = next sequential count of packet.
DATA = 518 BYTES of data.

The details of the BYTES in a SCIENCE data packet structure are given ND4

5.9.14 SU_HK (0x09)

The HOUSE_KEEPING command “SU_HK” is used to read the current house-keeping parameters table. House-keeping parameters are updated every t_sample sec.

CMD_ID = 0x09
LEN = number of BYTES to follow in the packet
T_sample = time unit at which to generate an HK packet to send to the OBC

Response packet format:

RSP_ID = 0x09
SEQ_CNT = next sequential count of packet.
DATA = 518 BYTES of data.

The details of the BYTES in House-Keeping data packet structure are given ND4

5.9.15 SU_STM (0x0A)

This command is sent to the SU to START collecting the STM readings into the STM data buffer at time given by “@t”.

CMD_ID = 0x0A
LEN = 0x01 number of BYTES to follow
T_sample = time unit at which to generate an HK packet to send to the OBC

Response packet format:

RSP_ID = 0x0A
SEQ_CNT = next sequential count of packet.
DATA = 518 BYTES of data.

The details of the BYTES in a STM data packet structure are given ND4

5.9.16 SU_HVARM (0x53) & SU_HVEN (0xC9)

NOTE: To enable high-voltage circuitry, the **RED-TAG** “**HV_Disarm**” plug MUST be removed first.

The CubeSat access hatch cannot be closed until the **RED-TAG** plug has been removed.

In order to turn ON high-voltages, the HV circuit needs to be armed & enabled by command. Two separate AND sequential commands have to be sent in order to achieve this:

SU_HVARM

..followed by:

SU_HVEN

If there is an ERROR in the command, or the sequence is not sent in the correct order, the SU shall send an HK packet with error flags set, then goto the STDBY state, where, high-voltages are automatically disabled.

The “SU_HVARM” command format is:

CMD_ID = 0x53

LEN = 0x01

The “SU_HVEN” command format is:

CMD_ID = 0xC9

LEN = 0x01

5.10 Example SU Command Sequence Script

An example of the user-readable ASCII command sequence script is shown below:

OBC_SU_ON @19:00:00
SU_STIM 0xF0 @19:02
SU_HVARM @19:03
SU_HVEN @19:04
SU_HK 60 @19:06
SU_CALM 5 64 28 ON ON ON @NOW
SU_LDP 0x09, 0x04,0x41,0x80,0x00, 0xFE,0x00,0x00,0x02,0xFF @NOW
SU_HC 100 64 24 ON ON ON @ 19:15
SU_SCI 01 28 90 5 10 32 @19:16
SU_SCI 02 28 90 5 10 500 @19:17
SU_SCI 02 28 90 5 10 500 @19:50
SU_SCI 02 28 90 5 10 500 @20:15
OBC_SU_OFF @20:02
OBC_SU_END

Table 5-2 - SU Commanding Script Example

NOTES:

1) Commands prefixed by “OBC_” are attended for the OBC script handler to interpret and execute.
2) Commands prefixed by “SU_” are to be sent to the Science Unit.
3) The TIME field “@t” is NOT sent to the SU, but interpreted by the OBC as the time at which the script command is to be executed. When “@t” is set to “@NOW”, the OBC shall execute the command immediately.

The above ASCII script is parsed by the SCRIPT_ENCODER tool (provided by SU team) that shall produce the encoded BYTE packet of the script to be uplinked to the CubeSat.

6 Mechanical interface

6.1 Accommodation and Field of View

The Science Unit will be accommodated at one end of the CubeSat, on a 10 x 10 face. The vector normal to this face shall be in the spacecraft ram velocity direction. This face shall not be available for Solar cells, any other sensor or subsystem and nothing must project forward of this face.

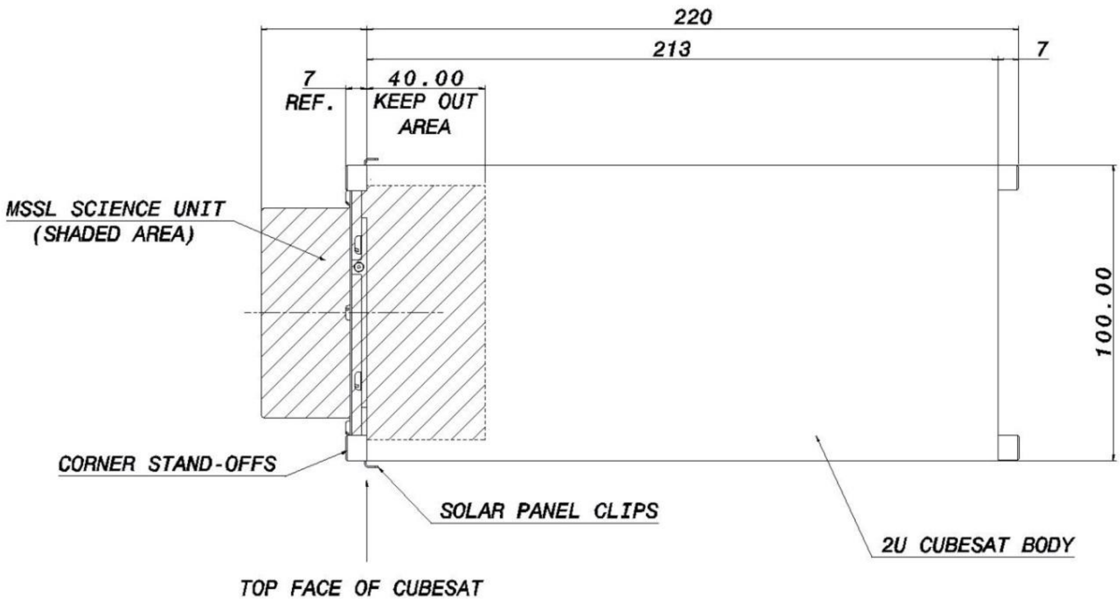

Figure 6-1 – INMS Science Unit Keepout Areas within CubeSat

6.2 Interface control drawing

The mechanical interface drawing is provided in Appendix 1. The Science Unit is designed to interface to commercially available CubeSat structures either through an adapter or through appropriate relocation of mounting holes on the structures.

6.3 Surface finish

The overall finish for the Aluminium structure of the Science Unit shall be Alocrom 1200.

6.4 Mass

The total Science Unit mass shall be < 600 grams.

7 Attitude Control

The CubeSat shall provide attitude control with a pointing accuracy of +/-10° and pointing knowledge of +/-2° (TBC).

8 Cleanliness and Contamination

All materials shall meet or exceed the following outgassing criteria:

TML ≤ 1.0% .

CVCM ≤ 0.1% .

Where possible, materials shall be selected from ESA and NASA approved lists and processed in such a way as to minimize contamination.

9 Operating Conditions

The particular operating conditions will depend upon the selection of sensors for a given Science Unit. These will be made known at the time of selection.

10 Handling

The Science Unit shall be handled in a cleanroom environment (details TBI).

ESD protection protocols shall be followed (details TBI).

11 Thermal

At least one thermal sensor will be used to monitor the temperature inside the CubeSat enclosure. This will be in addition to the thermistors in the Science Unit which are used for scientific measurement.

Item	Science Unit
Operational Temperature Range	-20°C to +40°C (TBC)
Non-Operational Temperature Range	-30°C to 65°C (TBC)
Minimum Standby temperature	-25°C (TBC)

Figure 11-1 Thermal operating requirements

Item	Science Unit
Thermal capacity	TBD J/K
Radiative properties	Alpha = TBD epsilon = TBD
Contact area	TBD mm²
I/F conductance	TBD W/m^{2}K
Thermal interface filler	TBD

Figure 11-2 Thermal properties

12 Appendix 1

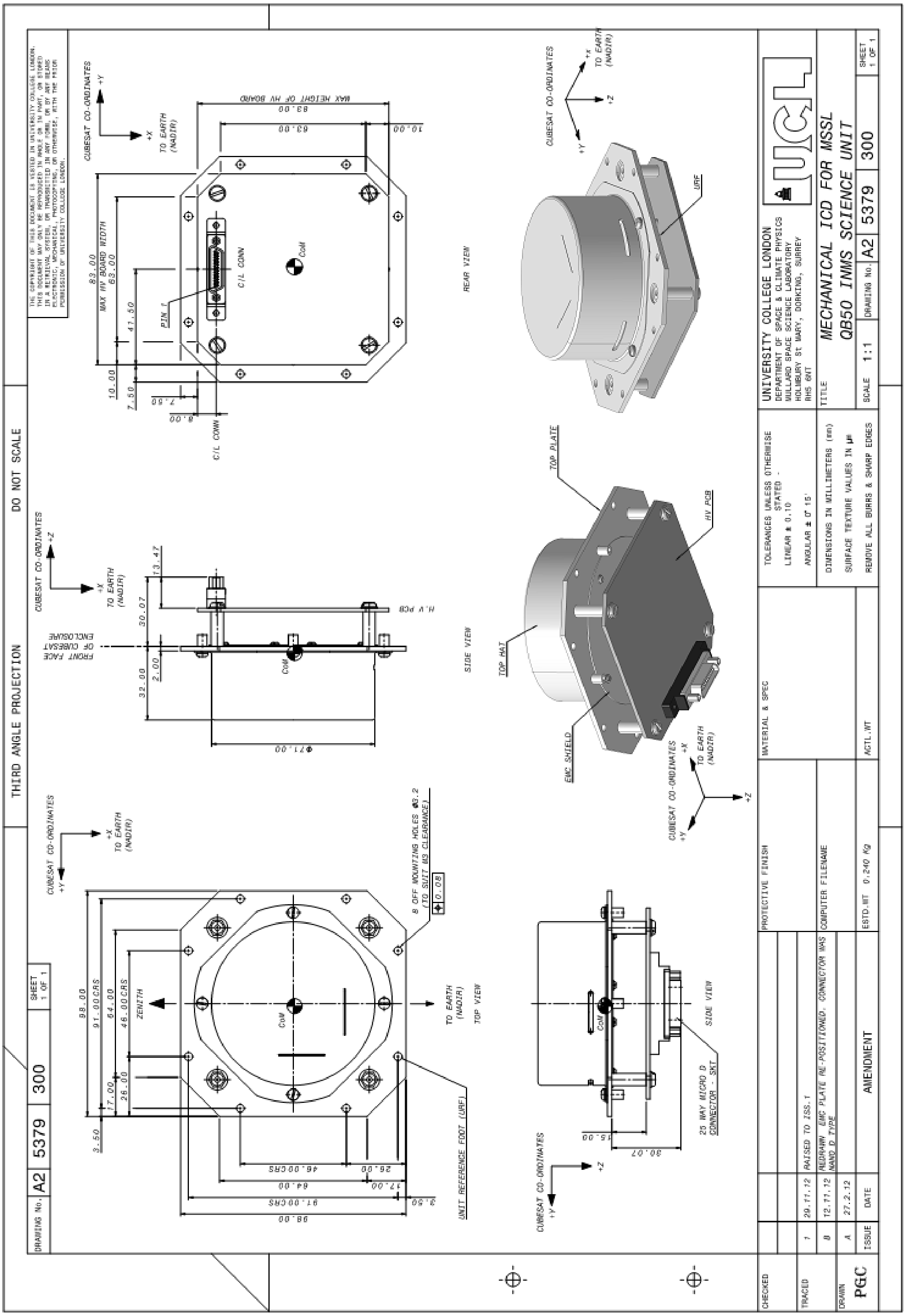

Figure 12-1 - QB50 Science Unit Mechanical Interface Drawing

Attachment B: FIPEX Interface Control Document (DRAFT)

TECHNISCHE
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Professur für Raumfahrtsysteme

DRAFT

QB50 FIPEX Science Unit Interface Control Document

This document contains the specification for FIPEX Science Unit on QB50

Authors: A. Weber Date:

J. Heisig Date:

Manager/Project Office T. Schmiel Date:

Revision List

Version	**Date**	**Changes**	**Author**
1.0 Draft	03.12.2012	New Draft based on MSSL QB50 Science Unit	A. Weber
0.1 Draft	04.01.2012	First draft	P. Roßmann

Abbreviations

ADC	Analogue to Digital Converter
CEM	Channel Electron Multiplier
DAC	Digital to Analogue Converter
EGSE	Electronic Ground Support Equipment
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electro-Static Discharge
FMMU	Flash Mass Memory Unit
FPGA	Field Programmable Gate Array
HSDR	High Speed Data Recorder
HV	High Voltage
I/F	Interface
IMS	Ion Mass Spectrometer
kbps	Kilo-bits per second
LEO	Low Earth Orbit
LUT	Look Up Table
LV	Low Voltage
LVDS	Low Voltage Differential Signalling
MSSL	Mullard Space Science Laboratory
NMS	Neutral Mass Spectrometer
OBC	CubeSat On-Board Computer
PCB	Printed Circuit Board
PWM	Pulse Width Modulator
S/C	Spacecraft
SEE	Single Event Effects
SMD	Surface Mount Device
SPI	Serial Peripheral Interface
SU	Science Unit
TBC	To be confirmed

TBD	To be decided
TBI	To be included

Applicable Documents

[AD-1]	Chaudery, R.A.: QB50 INMS Science Unit Interface Control Document. MSSL/QB50/ID/12001 Issue 2 Rev DRAFT. 2012
[AD-2]	UM-3: CubeSat Kit User manual Rev D2 issued 17 Sep 2003
[AD-3]	I2C Bus Specification Ver 2.1 Jan 2000
[AD-4]	CubeSat Design Specifications Rev. 12
[AD-5]	FIPEX Science Unit Science Requirements Document – Issue X
[AD-6]	FIPEX Science Unit Detailed Design Document – Issue X
[AD-7]	

Referenced Documents

[RD-1]	Call for CubeSat Proposals for QB50 issued 15 Feb 2012
[RD-2]	QB50 SSWG Final Report to be issued 1 Mar 2012
[RD-3]	

Content

1. Introduction

This document controls the required interfaces between a QB50 CubeSat and the FIPEX Science Unit. It is mainly based on the interfaces control document for INMS Science Unit [AD-1].

Science Unit: As described in the call for proposals [RD-1], the menu of sensors selected for the science units are:

- Ion Mass Spectrometer (IMS)
- Neutral Mass Spectrometer (NMS)
- Flux-Φ-Probe Experiment (FIPEX)
- Multi-Needle Langmuir Probe (MNLP)
- Corner Cube Laser Retro-reflectors (CCR)
- Thermistors/thermocouples/RTD (TH)

A Science Unit will comprise one of the following options:

1) IMS + NMS, plus Thermistors and CCR
2) FIPEX, plus Thermistors and CCR
3) MNLP, plus Thermistors and CCR

The design objective for the Science Unit is to remain within a 600 mW (duty-cycled, orbit averaged), 600 g mass budget and half a CubeSat unit volume budget (excluding forward protuberance). 20% design margin is being held within these budgets. This document provides the detailed interface

As the final configuration of the Science Unit to be provided to each of the CubeSat teams will only be made known after selection, representative mechanical and electrical interfaces with an overall resource envelope of the design objective are provided here.

The location of the Science Unit Thermistors (TH) within the body of the CubeSat will be included in a later version of this document.

If a CubeSat team selects to implement the Corner Cubes (CCR), it shall be their responsibility to select the location and interface of the Corner Cubes (CCR). Provision for mounting a Sun Sensor on the external body of the SU, and a CubeSat System Thermistor within the Science Unit is TBC. Details shall be included in a later version of this document.

2. Electrical Interfaces

There will be a single electrical connector between a Science Unit (SU) and a CubeSat. The Science Unit shall provide a 25-way Right-Angle MDM-female connector for the CUBESAT side connector to attach to. Position of the R/A connector shall be as shown in

Appendix 1. The CubeSat connector shall provide the signals as shown in **Table 2-1**.

2.1 Science Unit Connector Definition

Figure 2-1 R/A MDM25_F Connector Pin-Out

Pin	Signal Name	Comment
1	+5	Power for +5V logic
2	+3V3	Power for +3V3 logic
3	STM_TH_GO_0	Surface Thermal Monitor THERMISTOR – signal for CH0
4	STM _TH_GO_1	Surface Thermal Monitor THERMISTOR – signal for CH1
5	STM _TH_GO_2	Surface Thermal Monitor THERMISTOR – signal for CH2
6	STM _TH_GO_3	Surface Thermal Monitor THERMISTOR – signal for CH3
7	STM _TH_GO_4	Surface Thermal Monitor THERMISTOR – signal for CH4
8	SU_TH_GO	Science Unit THERMISTOR – signal GO
9	RDY	Flag to indicate to CubeSat when data packet is ready to read
10	SDA	I2C serial data signal
11	SCL	I2C serial clock signal (100 kHz)
12	not used	not yet used
13	GND	System GROUND
14	+5	Power for +5V logic
15	+3V3	Power for +3V3 logic
16	STM _TH_RET_0	Surface Thermal Monitor THERMISTOR - RETURN for CH0
17	STM _TH_RET_1	Surface Thermal Monitor THERMISTOR - RETURN for CH1
18	STM _TH_RET_2	Surface Thermal Monitor THERMISTOR - RETURN for CH2

19	STM _TH_RET_3-	Surface Thermal Monitor THERMISTOR - RETURN for CH3
20	STM _TH_RET_4	Surface Thermal Monitor THERMISTOR - RETURN for CH4
21	SU_TH_RET	Science Unit THERMISTOR – signal RETURN
22	RDY_SCN	Screen for RDY
23	SDA_SCN	Screen for SDA
24	SCL_SCN	Screen for SCL
25	GND	System GROUND

Table 2-1 Instrument Connector Pin Assignment

Power Pins

The +5, +3V3 and the GND connections are duplicated to provide redundancy in the harness.

Grounding

The Science Unit electronics shall be electrically grounded to the CubeSat structure via GND. The Science Unit Chassis is electrically connected to the CubeSat structure at its points of attachment. The electrical resistance shall be <50 mΩ.

Surface Thermal Monitor (STM) Thermistors

For the Surface Thermal Monitor (STM) experiment, there are six thermistor channels are provided. Five channels are brought out to the SU_Connector. The sixth channel is mounted inside the SU.

Channels STM_TH[0,1,2,3,4] are located at TBD positions on the CubeSat solar panels.

Channels STM_TH[5] is located at TBD position on inside of the Science Unit.

Science Unit Thermistor

The Instrument Connector provides connections to an internal Science Unit thermistor. This allows the OBC to monitor the temperature of the SU, even when the SU is switched OFF.

The position of the Thermistor inside the SU is TBD.

RDY Signal

The Science Unit shall provide a RDY, level sensitive, flag to the CubeSat computer to indicate when a SCIENCE ACQUISITION data packet is available.

When an acquisition cycle in the Science Unit has finished, the RDY flag shall be asserted, and a full buffer of data shall be available to be read by the CubeSat.

The CubeSat computer shall read the science data packet and time-stamp the packet within 1 second of the RDY flag being asserted

2.2 Science Unit I2C Control Interface

The I2C interface shall be used to control the SU from the OBC.

The I2C interface shall be designed to the specifications given in [AD-3].

The CubeSat OBC shall be the I2C MASTER, all other I2C interfaces shall be SLAVES.

The I2C I/F shall operate at 100 kHz clock speed.

The I2C interface shall use a 7-bit address field.

The I2C address of the Science Unit shall be fixed as TBC.

The capacitance of the I2C bus shall be as specified in [AD-3].

The I2C shall have a timeout of 200ms. After this timeout the I2C interface shall be reset.

The only asynchronous signal from the SU to OBC is the **RDY**.

All other SU communication is in response to explicit commands issued by the OBC.

Science Unit I2C Command Packet Structure

The following packet structure shall be used to transmit commands from the OBC to the SU:

<CMD_ID, LEN, param_0, param_1…param_LEN-2, XOR>

CMD_ID:	one BYTE value for command identifier
LEN:	one BYTE value representing the number of 8-bit BYTES to follow the LEN parameter. Value ranging from 2 to 252
Param_n:	parameters sent in BYTE format - LS BYTE is sent first if parameter is a 16-bit WORD
XOR:	two BYTE XOR

See section 0 for details of commands. The packet size is limited to 256 Byte.

Science Unit I2C Reponses Packet Structure

The following packet structure shall be used to transmit responses from the SU to the OBC:

<RSP_ID, LEN, data_0, data_1…data_LEN-2, XOR>

RSP_ID:	one BYTE value for command identifier
LEN:	one BYTE value representing the number of 16-bit WORDS to follow the LEN parameter. Value ranging from 1 to 254
data_n:	data represented in 16-bit WORD format - LS BYTE is sent first
XOR:	2 BYTE XOR

See section 0 for details of commands/responses. The maximal science packet size is 512 Byte.

2.3 Command Error Handling

ACK and NACK TBD

2.4 EMC requirements

TBI

2.5 Power Budget

The power budget is shown in **Table 2-2**. These numbers are preliminary and are TBC.

Mode	**Power at +5V (mW)**		**Power at +3.3V (mW)**	
	Orbit average (Duty cycle averaged)	Maximum during Unit operations	Orbit average (Duty cycle averaged)	Maximum during Unit operations
Standby	3	10	1	100
Full State	530	2400	77	200

Table 2-2 - Power Budget

3. Science Unit Command and Control Interface

3.1 Science Unit State Transition Diagram

Figure 3-1 shows the state diagram depicting the valid state transitions. These state changes are accomplished by sending commands to the SU.

On any ERROR, the SU shall go to StdBy state. The STATUS_REG shall set the ERROR bit.

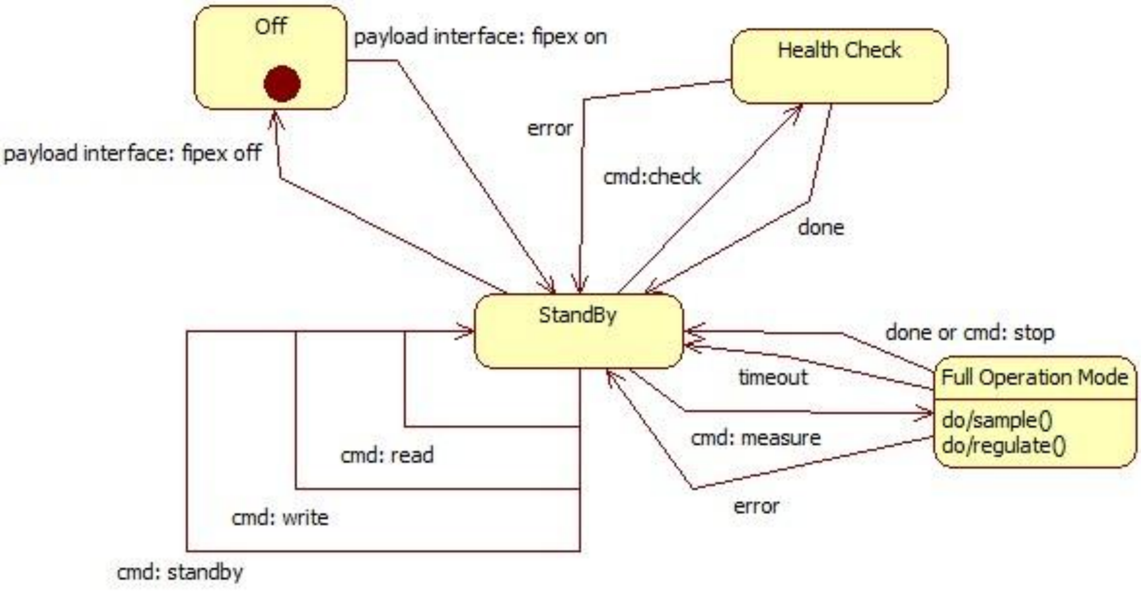


Figure 3-1 – FIPEX Science Unit State Transition Diagram

3.2 OBC Script Commands

The following table lists the SCRIPT commands to control the SU operation from the OBC.

Command	CMD_ID	Parameters	Description
OBC_SU_ON	0x0F	@t	Switch on Sensor Unit
OBC_SU_OFF	0xF0	@t	Switch off Sensor Unit
OBC_SU_END	0xFF	@t	
SU_STDBY	0x02	LEN, @t	Switch to STDBY Mode
SU_RSP	0x03	LEN, @NOW	Request Science data packet
SU_SP	0x04	LEN, PARAMID, VALUE @t	Set parameter
SU_GP	0x05	LEN, PARAMID @t	Read parameter
not used	0x06	-	-
SU_HC	0x07	LEN, @t	Switch to Health Check Mode
SU_FULL	0x08	LEN, TIME, @t	Start Measurement sequence
not used	0x09	-	-
not used	0x0a	-	-
SU_HK	0x0B	LEN, HK_TBL_LEN, @t	Request Housekeeping data packet

Table 3-1 - Science Unit Commands

3.3 OBC Script Command Description

OBC and SU Specific Commands

Any SCRIPT command prefixed by “OBC_” is an instruction to the OBC, and is NOT sent to the Science Unit.

Any SCRIPT command prefixed by “SU_”, together with LEN, and any additional parameters from the command to be sent to the SU.

The time field - “@t” shall be read by the OBC and interpreted as a time code – see 3.2.

The OBC shall execute each SCRIPT command consecutively. Waiting for the time condition on each command before executing the next command.

Script TIME Field - @t

Time-tagged command sequence scripts shall be uploaded to the CubeSat. The CubeSat OBC shall read the script commands and execute them at the time given by the 3-BYTE @t TIME field

TIME is a 3-BYTE value:

1st BYTE	Hours	range 0-24*
2nd BYTE	Mins	range 0-59*
3rd BYTE	Sec	range 0-59*

The @t TIME field is ONLY read by the OBC, but NOT sent to the SU as part of the command.

The Science Unit shall execute commands immediately upon receipt.

Time is to an accuracy of 1 sec.

*Note: The SCRIPT mnemonic @NOW is encoded as time = FF:FF:FF – this shall be interpreted by the OBC script handler to send the script command immediately.

Script Encoder Software Tool

An ASCII - user-readable “Command Sequence Script” shall be encoded into a BYTE stream using the SU_SCRIPT_ENCODER software tool.

As an example, the script commands:

```
OBC_SU_ON @19:00
SU_HK 41 @19:04
```

Would be encoded into the following BYTE stream by the SU_SCRIPT_ENCODER tool:

```
0x0F, 0x13, 0x00, 0x00, 0x0B, 0x01, 0x29, 0x13, 0x04, 0x00
```

The SU_SCRIPT_ENCODER shall parse the ASCII script for parameter range errors, and logical errors.

OBC_SU_ON (0x0F)

This SCRIPT command is ONLY read & interpreted by the OBC to turn the ON SU at time given by “@t”.

OBC_SU_OFF (0xF0)

This SCRIPT command is ONLY read & interpreted by the OBC to turn the OFF SU at time given by “@t”.

OBC_SU_END (0xFF)

This SCRIPT command is ONLY read & interpreted by the OBC to stop running SCRIPT at time given by “@t”.

SU_STDBY (0x02)

This command is sent to the SU to put the SU into the STANDBY state at time given by “@t”.

CMD_ID = 0x02
LEN = 0x00 number of BYTES to follow

The sensors are turned OFF when going to STDBY state

SU_RSP (0x03)

This command is sent to the SU to request the science response packet (after running SU_FULL or SU_BURST command), when the RDY signal is asserted at time given by “@t”.

CMD_ID = 0x03
LEN = 0x00 number of BYTES to follow

Response packet format is:

RSP_ID = 0x03
LEN: = one BYTE value representing the number of 16-bit WORDS to follow the LEN parameter
Bn = packet data in BYTES

SU_SP (0x04)

Set Parameter to value at time given by "@t

CMD_ID = 0x04
LEN = 0x06 number of BYTES to follow
PARAMID: = 2-BYTE parameter identifier (default TBD)
VALUE: = 4-BYTE parameter value. LS BYTE sent first (LITTLE ENDIAN) (default TBD)

SU_GP (0x05)

This command returns the set of parameters "@t".

Command format is:

CMD_ID = 0x05
LEN = 0x02 number of BYTES to follow
PARAMID = 2-BYTE parameter identifier (default 0)

Response packet format is:

RSP_ID = 0x05
LEN: = one BYTE value representing the number of 16-bit WORDS to follow the LEN parameter
Bn = packet data in BYTES

SU_HC (0x07)

NOTE: The HEALTH_CHECK command "SU_HC" can ONLY be run from Standby state.

"SU_HC" command format is:

CMD_ID = 0x07
LEN = 0x00

This command turns ON sensor heating. The RDY flag shall be asserted when SU_HC has finished, and the health check data packet is read by the OBC using <SU_RSP >

Response packet format is:

RSP_ID = 0x03
LEN: = one BYTE value representing the number of 16-bit WORDS to follow after the LEN parameter
Bn = packet data in BYTES

The details of the BYTES in a health check data packet structure are given [AD-5]

SU_FULL (0x08)

This command runs a FULL measurement cycle for one sensor with predefined parameters. This switches on the sensor heating.

“SU_FULL” command format is:

CMD_ID = 0x08
LEN = 0x01
TIME = 1-BYTE value of number of times to repeat measurement (default 1)

The RDY flag shall be asserted when SU_FULL has finished, and the data packet is read by the OBC using <SU_RSP >

Response packet format is:

RSP_ID = 0x03
LEN: = one BYTE value representing the number of 16-bit WORDS to follow after the LEN parameter
Bn = packet data in BYTES

The details of the BYTES in a FULL SCAN data packet structure are given [AD-5]

SU_HK (0x0B)

The HOUSE_KEEPING command "SU_HK" is used to read the current house-keeping parameters table. House-keeping parameters are updated every TBD sec.

CMD_ID = 0x07

LEN = number of BYTES to follow in the packet

HK_TBL_LEN = 1-BYTE count of number of HK parameters to send to OBC

Bn = BYTE value of each parameter. LS BYTE sent first (LITTLE ENDIAN)

HK response packet format is:

RSP_ID = 0x0B

LEN = number of 16-bit WORDS to be transmitted

Bn = packet data in BYTES

HK Table

The HK table is:

HK Table Addr	HK Parameter (16-bit)
0x00	SEN_NO (selected sensor)
0x01	SEN_HV (Heater voltage)
0x02	SEN_HC (Heater current)
0x03	SEN_SV (sensor voltage)
0x04	SEN_SC (sensor current)
0x05	SEN_GAIN (sensor gain)
0x06	not used (tbc)
0x07	not used (tbc)
0x08	not used (tbc)
0x09	STM_TH_ch0
0x0A	STM_TH_ch1

0x0B	STM_TH_ch2
0x0C	STM_TH_ch3
0x0D	STM_TH_ch4
0x0E	STM_TH_ch5
0x0F	STATUS_REG

STATUS Register

The STATUS_REG bits are defined as:

STATUS_REG	Comment -16-bit register
B15	RDY flag
B14	not used = ‘0’ (tbc)
B13	not used = ‘0’ (tbc)
B12	not used = ‘0’ (tbc)
B11	not used = ‘0’ (tbc)
B10	not used = ‘0’ (tbc)
B9	not used = ‘0’ (tbc)
B8	not used = ‘0’ (tbc)
B7	not used = ‘0’ (tbc)
B6	not used = ‘0’ (tbc)
B5	not used = ‘0’ (tbc)
B4	not used = ‘0’ (tbc)
B[3,2,1,0]	MODE: 0000 STDBY
	0001 ERROR
	0010 not used
	0011 not used
	0100 not used
	0101 not used
	0110 MEASUREMENT
	0111 HEALTH CHECK

	1001 not used
	1010 not used
	1011 not used
	1100 not used
	1101 not used
	1110 not used
	1111 not used

3.4 Example SU Command Sequence Script

An example of the user-readable ASCII command sequence script is shown below:

OBC_SU_ON @19:00:00
SU_HC @ 19:02
SU_SP 0x06 0x10 0x10 @19:03
SU_SP 0x06 0x11 0x0a @19:04
SU_SP 0x06 0x11 0x23 @19:05
SU_FULL @19:06
SU_HK 32 @19:20
OBC_SU_OFF @20:02
OBC_SU_END

Table 3-2 - SU Commanding Script Example

NOTES:

1) Commands prefixed by “OBC_” are attended for the OBC script handler to interpret and execute.
2) Commands prefixed by “SU_” are to be sent to the Science Unit.
3) The TIME field “@t” is NOT sent to the SU, but interpreted by the OBC as the time at which the script command is to be executed. When “@t” is set to “@NOW”, the OBC shall execute the command immediately.
4) The RDY flag will be asserted in response to SU_HC, SU_FULL commands, and the OBC shall collect the SU data packet, time-stamp the packet, and store it to local mass-storage for download when required.

The above ASCII script is parsed by the SCRIPT_ENCODER tool that shall produce the encoded BYTE packet of the script to be uplinked to the CubeSat.

3.5 Data Handling and Control

TBD

4. Mechanical interface

4.1 Accommodation and Field of View

The Science Unit will be accommodated at one end of the CubeSat, on a 10 mm x 10 mm face. The vector normal to this face shall be in the spacecraft ram velocity direction. This face shall not be available for solar cells and nothing must project forward of this face.

Depending on the integration procedure of the payload module it might be possible to use the outer free area of the sensor unit top plate for mounting sensors or other small components. These components must be smaller than 4.5 mm. Please refer to the ICD Drawing in Appendix 1 for details. (TBC)

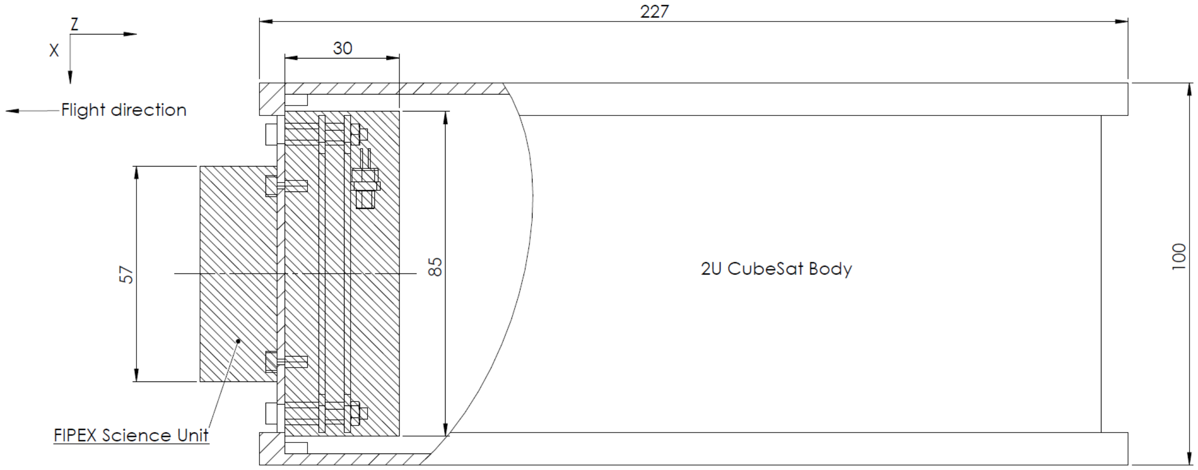


Figure 4-1 – FIPEX Science Unit Keepout Areas within CubeSat

4.2 Interface control drawing

The mechanical interface drawing is provided in Appendix 1. The Science Unit is designed to interface to commercially available CubeSat structures either through an adapter or through appropriate relocation of mounting holes on the structures.

4.3 Surface finish

The overall finish for the Aluminium structure of the Science Unit shall be Alocrom 1200.

4.4 Mass

The total Science Unit mass shall be < 400 grams.

5. Attitude Control

The CubeSat shall provide attitude control during measurement with a pointing accuracy of +/-10° and pointing knowledge of +/-2° (TBC).

6. Cleanliness and Contamination

All materials shall meet or exceed the following outgassing criteria:

TML	$\leq$ 1.0% .
CVCM	$\leq$ 0.1% .

Where possible, materials shall be selected from ESA and NASA approved lists and processed in such a way as to minimize contamination.

7. Handling, Operating and Ground Conditions

The Science Unit shall be handled in a cleanroom environment (class 100.000, ISO 8). ESD protection protocols shall be followed (details TBI).

The sensor unit mounted with tests sensors can be fully operated under standard environmental conditions for ground testing. In operation (Full operation mode of the sensor unit) the sensitive element of the sensor is heated to about 600 degree. Therefore no flammable materials shall be placed nearby. The sensor should not be touched.

Sensor Units with Flight sensors shall only be operated under low pressure conditions (max. allowed pressure 10^{-4} bar). Flight sensors must not be touched.

8. Storage Conditions

The sensor unit with tests sensors should be stored under constant standard conditions (about 20 degree, relative humidity < 80%). The storage time should not exceed 2 years.

Flight sensors (and sensor units with flight sensors attached) can only be stored for 3 month under these specified conditions.

Is a storage time of more than 3 month necessary the sensors must be stored under a nitrogen protection atmosphere during the whole storage time.

9. Thermal

At least one thermal sensor will be used to monitor the temperature inside the CubeSat enclosure. This will be in addition to the thermistors in the Science Unit which are used for scientific measurement.

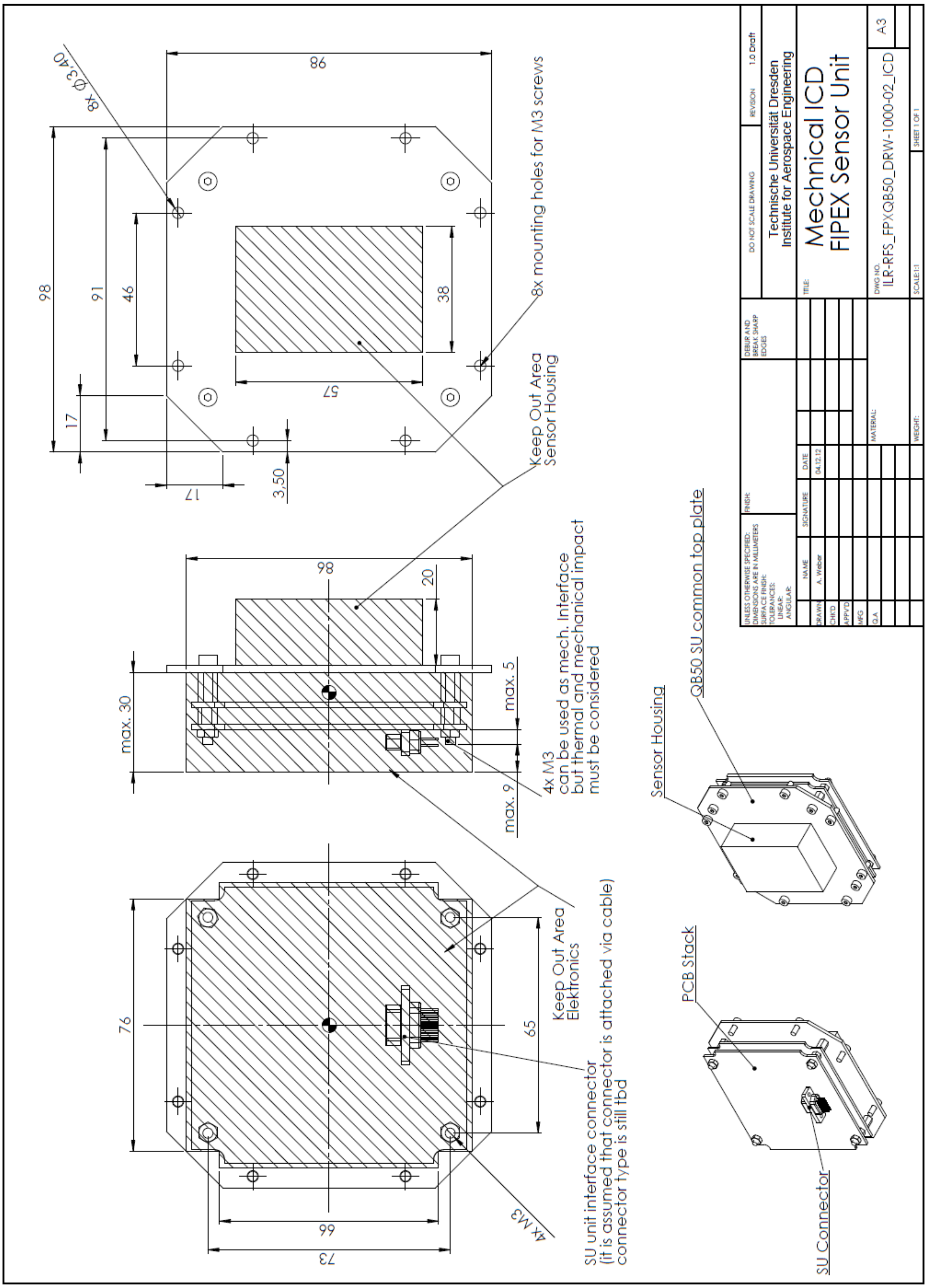
Item	Science Unit
Operational Temperature Range	-20°C to +40°C (TBC)
Non-Operational Temperature Range	-30°C to 65°C (TBC)
Minimum Standby temperature	-25°C (TBC)

Figure 9-1 Thermal operating requirements

Item	Science Unit
Thermal capacity	TBD J/K
Radiative properties	Alpha = TBD epsilon = TBD
Contact area	TBD mm²
I/F conductance	TBD W/m^{2}K
Thermal interface filler	TBD

Figure 9-2 Thermal properties

10. Appendix 1



Attachment C: m-NLP Interface Control Document (DRAFT)

Project: QB50

MULLARD SPACE SCIENCE LABORATORY

UNIVERSITY COLLEGE LONDON

Author: T A Bekkeng

TITLE: QB50 m-NLP Science Unit Interface Control Document

Document Number: MSSL/QB50/ID/1200X Issue 2 Rev DRAFT

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CHANGE RECORD

Issue	Date	Sections changed	Comments
Draft A	21/02/2012	All new	First draft
Issue 1	28/02/2012	Major revision of most sections	Focus on Science Unit rather than INMS
Iss 2 DRAFT	04/12/12	Major revision of m-NLP content	Revision for implementation of m-NLP instead of INMS

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T A Bekkeng	UiO

CONTENTS

1 Introduction

This document controls the required interfaces between a QB50 CubeSat and the m-NLP Science Unit.

Science Unit: As described in the call for proposals, the menu of sensors selected for the science units are:

- Ion Mass Spectrometer (IMS)
- Neutral Mass Spectrometer (NMS)
- Flux-Φ-Probe Experiment (FIPEX)
- Multi-Needle Langmuir Probe (m-NLP)
- Corner Cube Laser Retro-reflectors (CCR)
- Thermistors/thermocouples/RTD (TH)

A Science Unit will comprise one of the following options:

1) IMS + NMS, plus Thermistors and CCR
2) FIPEX, plus Thermistors and CCR
3) m-NLP, plus Thermistors and CCR

The design objective for the Science Unit is to remain within a 600 mW power budget (duty-cycled, orbit averaged), 600 g mass budget and half a CubeSat unit volume budget (excluding forward protuberance). 20% design margin is being held within these budgets. As the final configuration of the Science Unit to be provided to each of the CubeSat teams will only be made known after selection, representative mechanical and electrical interfaces with an overall resource envelope of the design objective are provided here.

The location of the Science Unit Thermistors (TH) within the body of the CubeSat will be included in a later version of this document.

If a CubeSat team selects to implement the Corner Cubes (CCR), it shall be their responsibility to select the location and interface of the Corner Cubes (CCR). Provision for mounting a Sun Sensor on the external body of the SU, and a CubeSat System Thermistor within the Science Unit is TBC. Details shall be included in a later version of this document.

2 Normative and Informative documents

2.1 Normative Documents

ND1: UM-3: CubeSat Kit User manual Rev D2 issued 17 Sep 2003.

ND2: I2C Bus Specification Ver 2.1 Jan 2000

ND3: CubeSat Design Specifications Rev. 12

ND6: m-NLP Science Unit Science Requirements Document – Issue X (TBI)

ND7: m-NLP Science Unit Detailed Design Document – Issue X (TBI)

2.2 Informative Documents

ID1: Call for CubeSat Proposals for QB50 issued 15 Feb 2012

ID2: QB50 SSWG Final Report to be issued 1 Mar 2012

ID3: National Semiconductor DAC121S101/DAC121S101Q Data sheet

ID4: National Semiconductor ADC128S052 Data sheet

3 Abbreviations

ADC	Analogue to Digital Converter
CEM	Channel Electron Multiplier
DAC	Digital to Analogue Converter
EGSE	Electronic Ground Support Equipment
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electro-Static Discharge
FMMU	Flash Mass Memory Unit
FPGA	Field Programmable Gate Array
HSDR	High Speed Data Recorder
HV	High Voltage
I/F	Interface
IMS	Ion Mass Spectrometer
kbps	Kilo-bits per second
LEO	Low Earth Orbit
LUT	Look Up Table
LV	Low Voltage
LVDS	Low Voltage Differential Signalling
m-NLP	multi-Needle Langmuir Probe
MSSL	Mullard Space Science Laboratory
NMS	Neutral Mass Spectrometer
OBC	CubeSat On-Board Computer
PCB	Printed Circuit Board
PWM	Pulse Width Modulator
S/C	Spacecraft
SEE	Single Event Effects
SMD	Surface Mount Device
SPI	Serial Peripheral Interface
SU	Science Unit
TBC	To be confirmed
TBD	To be decided
TBI	To be included

4 Electrical Interfaces

There will be a single electrical connector between a Science Unit (SU) and a The Science Unit shall provide a 25-way Right-Angle MDM-female connector for CUBESAT side connector to attach to. Position of the R/A connector shall be as in

Appendix 1. The CubeSat connector shall provide the signals as shown in Table 4-1.

4.1 Science Unit Connector Definition

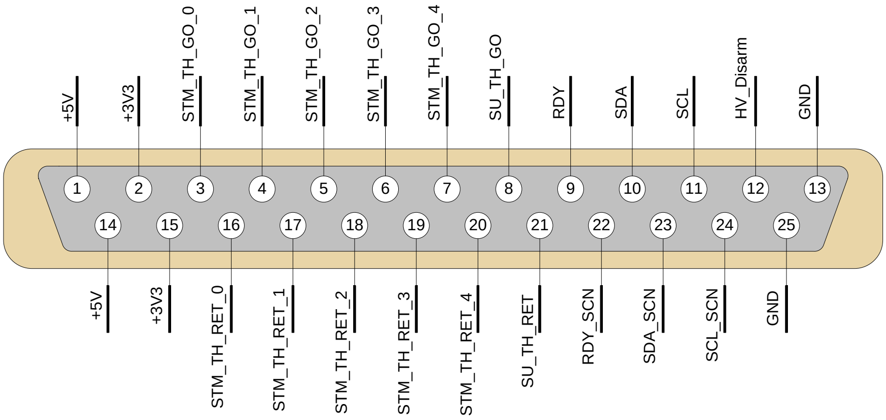

Figure 4-1 R/A MDM25_F Connector Pin-Out

Pin	Signal Name	Comment
1	+5	Power for +5V logic
2	+3V3	Power for +3V3 logic
3	STM_TH_GO_0	Surface Thermal Monitor THERMISTOR – signal for CH0
4	STM _TH_GO_1	Surface Thermal Monitor THERMISTOR – signal for CH1
5	STM _TH_GO_2	Surface Thermal Monitor THERMISTOR – signal for CH2
6	STM _TH_GO_3	Surface Thermal Monitor THERMISTOR – signal for CH3
7	STM _TH_GO_4	Surface Thermal Monitor THERMISTOR – signal for CH4
8	SU_TH_GO	Science Unit THERMISTOR – signal GO
9	RDY	Flag to indicate to CubeSat when data packet is ready to read
10	SDA	I2C serial data signal
11	SCL	I2C serial clock signal (100 kHz)
12	Bias_Disarm	**RED TAG** plug situated in CubeSat Access Hatch to DISABLE Bias
13	GND	System GROUND
14	+5	Power for +5V logic
15	+3V3	Power for +3V3 logic
16	STM _TH_RET_0	Surface Thermal Monitor THERMISTOR - RETURN for CH0
17	STM _TH_RET_1	Surface Thermal Monitor THERMISTOR - RETURN for CH1
18	STM _TH_RET_2	Surface Thermal Monitor THERMISTOR - RETURN for CH2
19	STM _TH_RET_3-	Surface Thermal Monitor THERMISTOR - RETURN for CH3
20	STM _TH_RET_4	Surface Thermal Monitor THERMISTOR - RETURN for CH4
21	SU_TH_RET	Science Unit THERMISTOR – signal RETURN
22	RDY_SCN	Screen for RDY
23	SDA_SCN	Screen for SDA
24	SCL_SCN	Screen for SCL
25	GND	System GROUND

Table 4-1 Instrument Connector Pin Assignment

4.2 Power Pins

The +5, +3V3 and the GND connections are duplicated to provide redundancy in the harness.

4.3 Grounding

The Science Unit electronics shall be electrically grounded to the CubeSat structure via GND. The Science Unit Chassis is electrically connected to the CubeSat structure at its points of attachment. The electrical resistance shall be <50 mΩ.

4.4 Surface Thermal Monitor (STM) Thermistors

For the Surface Thermal Monitor (STM) experiment, there are six thermistor channels are provided. Five channels are brought out to the SU_Connector. The sixth channel is mounted inside the SU.

4.4.1 Surface Thermal Monitor Thermistor Locations

Channels STM_TH[0,1,2,3,4] are located at TBD positions on the CubeSat solar panels.

Channels STM_TH[5] is located at TBD position on inside of the Science Unit.

4.5 Science Unit Thermistor

The Instrument Connector provides connections to an internal Science Unit thermistor. This allows the OBC to monitor the temperature of the SU, even when the SU is switched OFF.

The position of the Thermistor inside the SU is TBD.

4.6 Sun Sensor

The mounting possibility for Sun Sensor on SU is TBD

4.7 RDY Signal

The Science Unit shall provide a RDY, level sensitive, flag to the CubeSat computer to indicate when a SCIENCE ACQUISITION data packet is available.

When an acquisition cycle in the Science Unit has finished, the RDY flag shall be asserted, and a full buffer of data shall be available to be read by the CubeSat.

The CubeSat computer shall read the science data packet and time-stamp the packet within 1 second of the RDY flag being asserted

4.8 Science Unit I2C Control Interface

The I2C interface shall be used to control the SU from the OBC.

The I2C interface shall be designed to the specifications given in ND2.

The CubeSat OBC shall be the I2C MASTER, all other I2C interfaces shall be SLAVES.

The I2C I/F shall operate at 100 kHz clock speed.

The I2C interface shall use a 7-bit address field.

The I2C address of the Science Unit shall be fixed as TBC.

The capacitance of the I2C bus shall be as specified in ND2.

The only asynchronous signal from the SU to OBC is the **RDY**.

All other SU communication is in response to explicit commands issued by the OBC.

4.8.1 Science Unit I2C Command Packet Structure

The following packet structure shall be used to transmit commands from the OBC to the SU:

<CMD_ID, LEN, param_0, param_1…param_LEN-2>

CMD_ID: one BYTE value for command identifier

LEN: one BYTE value representing the number of 8-bit BYTES to follow the LEN parameter

Param_n: parameters sent in BYTE format - LS BYTE is sent first if parameter is a 16-bit WORD

See section 0 for details of commands.

4.8.2 Science Unit I2C Reponses Packet Structure

The following packet structure shall be used to transmit responses from the SU to the OBC:

<RSP_ID, LEN, data_0, data_1…data_LEN-2>

RSP_ID: one BYTE value for command identifier

LEN: one BYTE value representing the number of 16-bit WORDS to follow the LEN parameter

data_n: data represented in 16-bit WORD format - LS BYTE is sent first

See section 0 for details of commands/responses.

4.9 Command Error Handling

ACK and NACK TBD

4.10 EMC requirements

TBI

4.11 Power Budget

The power budget is shown in Table 4-2. These numbers are preliminary and are TBD and TBC.

Mode	Power at +5V (mW)		Power at +3.3V (mW)	
	Orbit average (Duty cycle averaged)	Maximum during Unit operations	Orbit average (Duty cycle averaged)	Maximum during Unit operations
Standby	10	300	2	100
CONT/BURST State	TBD	500	TBD	200
Boom deployment	N/A (only run once, 4x3sec TBC)	1500	0	0

Table 4-2 - Power Budget

5 Science Unit Command and Control Interface

5.1 Science Unit State Transition Diagram

Figure 5-1 shows the state diagram depicting the valid state transitions. These state changes are accomplished by sending commands to the SU.

Figure TBI

Figure 5-1 – m-NLP Science Unit State Transition Diagram

5.2 OBC Script Commands

The following table lists the SCRIPT commands to control the SU operation from the OBC.

Command	CMD_ID	Parameters
OBC_SU_ON	0x0F	@t
OBC_SU_OFF	0xF0	@t
OBC_SU_END	0xFF	@t
SU_STDBY	0x02	LEN, @t
SU_RSP	0x03	LEN, @NOW
SU_DEPLOY	0x04	LEN, d_time, n_boom, @NOW
TBD	0x05	TBD
TBD	0x06	TBD
TBD	0x07	TBD
SU_CONT	0x08	LEN, n_rpt, dwell, %X, V_start, sw_ana, @t
SU_BURST	0x09	LEN, $Pn, %X, V_start, sw_ana, @t
SU_CAL	0x0A	LEN, t_del, n_step, v_step, sw_ana, @t
SU_HK	0x0B	LEN, HK_TBL_LEN, @t
SU_BIAS_EN	0x53	LEN, @t
SU_BIAS_DIS	0xC9	LEN, @t

Table 5-1 - Science Unit Commands

5.3 OBC Script Command Description

5.3.1 OBC and SU Specific Commands

Any SCRIPT command prefixed by “OBC_” is an instruction to the OBC, and is NOT sent to the Science Unit.

Any SCRIPT command prefixed by “SU_”, together with LEN, and any additional parameters form the command to be sent to the SU.

The time field - “@t” shall be read by the OBC and interpreted as a time code – see 5.3.2.

5.3.2 Script TIME Field - @t

Time-tagged command sequence scripts shall be uploaded to the CubeSat. The CubeSat OBC shall read the script commands and execute them at the time given by the 3-BYTE @t TIME field

TIME is a 3-BYTE value:

1st BYTE	Hours	range 0-24*
2nd BYTE	Mins	range 0-59*
3rd BYTE	Sec	range 0-59*

The @t TIME field is ONLY read by the OBC, but NOT sent to the SU as part of the command.

The Science Unit shall execute commands immediately upon receipt.

Time is to an accuracy of 1 sec.

*Note: The SCRIPT mnemonic @NOW is encoded as time = FF:FF:FF – this shall be interpreted by the OBC script handler to send the script command immediately.

5.3.3 Script Encoder Software Tool

An ASCII - user-readable “Command Sequence Script” shall be encoded into a BYTE stream using the SU_SCRIPT_ENCODER software tool.

As an example, the script commands:

```
OBC_SU_ON @19:00
SU_HK 41 @19:04
```

Would be encoded into the following BYTE stream by the SU_SCRIPT_ENCODER tool:

```
0x0F, 0x13, 0x00, 0x0B, 0x01, 0x29, 0x13, 0x04
```

The SU_SCRIPT_ENCODER shall parse the ASCII script for parameter range errors, and logical errors, i.e. attempting to send a SCIENCE MODE command before turning ON the high voltages.

5.3.4 OBC_SU_ON (0x0F)

This SCRIPT command is ONLY read & interpreted by the OBC to turn the ON SU at time given by “@t”.

5.3.5 OBC_SU_OFF (0xF0)

This SCRIPT command is ONLY read & interpreted by the OBC to turn the OFF SU at time given by “@t”.

5.3.6 OBC_SU_END (0xFF)

This SCRIPT command is ONLY read & interpreted by the OBC to stop running SCRIPT at time given by “@t”.

5.3.7 SU_STDBY (0x02)

This command is sent to the SU to put the SU into the STANDBY state at time given by “@t”.

CMD_ID = 0x02
LEN = 0x00 number of BYTES to follow

The HV line is turned OFF when going to STDBY state

5.3.8 SU_RSP (0x03)

This command is sent to the SU to request the science response packet (after running SU_FULL or SU_BURST command), when the RDY signal is asserted at time given by “@t”.

CMD_ID = 0x03
LEN = 0x00 number of BYTES to follow

Response packet format is:

RSP_ID = 0x03
LEN: = one BYTE value representing the number of 16-bit WORDS to follow the LEN parameter
Bn = packet data in BYTES

5.3.9 SU_DEPLOY (0x04)

NOTE: The DEPLOYMENT command “SU_DEPLOY” can ONLY be run from IDLE state, after the BIAS levels has been DISABLED – see SU_BIAS_EN & SU_BIAS_DIS commands for details.

“SU_DEPLOY” command format is:

CMD_ID = 0x04

LEN = 0x02

d_time = 1-BYTE : Boom deployment time (sec) (default 3 sec)

n_boom = 1-BYTE : 0000_00, b1, b0 : b1 = 0, b0 = 0 (Boom 1)

b1 = 0, b0 = 1 (Boom 2)

b1 = 1, b0 = 0 (Boom 3)

b1 = 1, b0 = 1 (Boom 4)

The RDY flag shall be asserted when SU_CALM has finished, and the deployment data packet with confirmation on boom number is read by the OBC using <SU_RSP >

Response packet format is:

RSP_ID = 0x03

LEN: = one BYTE value representing the number of 16-bit WORDS to follow the LEN parameter

Bn = packet data in BYTES

The details of the BYTES in a deployment data packet structure are given in ND7

5.3.10 SU_CONT (0x08)

This command runs a CONTINOUS measurement series to take low time resolution electron density measurements, with continuous spatial coverage.

NOTE: The “SU_CONT” command can ONLY be run from IDLE state, after the BIAS levels has been ENABLED – see SU_BIAS_EN & SU_BIAS_DIS commands for details.

“SU_CONT” command format is:

TBD

For each CONTINOUS run, the measured continuous densities will be a part of the CONTINOUS data packet.

The RDY flag shall be asserted when SU_CONT has finished, and the data packet is read by the OBC using <SU_RSP >

Response packet format is:

RSP_ID = 0x03

LEN: = one BYTE value representing the number of 16-bit WORDS to follow after the LEN parameter

Bn = packet data in BYTES

The details of the BYTES in a CONTINOUS data packet structure are given in ND7

5.3.11 SU_BURST (0x09)

This command runs a BURST measurement series at full sampling rate (TBD kHz), to get a measurement of electron density at TBD meter spatial resolution.

NOTE: The "SU_BURST" command can ONLY be run from IDLE state, after the BIAS levels has been ENABLED – see SU_BIAS_EN & SU_BIAS_DIS commands for details.

The "SC_BURST" command format is:

TBI

For each BURST run, the measured continuous densities will be a part of the BURST data packet.

The RDY flag shall be asserted when SU_BURST has finished, and the data packet is read by the OBC using <SU_RSP >

Response packet format is:

RSP_ID = 0x03

LEN: = one BYTE value representing the number of 16-bit WORDS to follow after the LEN parameter

Bn = packet data in BYTES

The details of the BYTES in a BURST data packet structure are given in ND7

5.3.12 SU_CAL (0x0A)

NOTE: The CALIBRATION command “SU_CAL” can ONLY be run from IDLE state, after the BIAS levels has been ENABLED – see SU_BIAS_EN & SU_BIAS_DIS commands for details.

“SU_CAL” command format is:

CMD_ID = 0x0A
LEN = 0x03
t_del = 1-BYTE value of msec. at each step (default 10 ms)
n_step = 1-BYTE value of steps in total. (default 255 steps)
up_down = 1-BYTE : 0000_00, b1, b0 : b1 = 1, b0 = 0 (-10 V → 10 V → -10V)
b1 = 0, b0 = 1 (10 V → -10 V → 10V)

At each voltage step, the collected probe current is measured and recorded as part of the CALIBRATION data packet.

The RDY flag shall be asserted when SU_CAL has finished, and the health check data packet is read by the OBC using <SU_RSP >

Response packet format is:

RSP_ID = 0x03
LEN: = one BYTE value representing the number of 16-bit WORDS to follow the LEN parameter
Bn = packet data in BYTES

The details of the BYTES in a calibration data packet structure are given in ND7

5.3.13 SU_HK (0x0B)

The HOUSE_KEEPING command “SU_HK” is used to read the current house-keeping parameters table. House-keeping parameters are updated every TBD sec.

CMD_ID = 0x07
LEN = number of BYTES to follow in the packet
HK_TBL_LEN = 1-BYTE count of number of HK parameters to send to OBC
Bn = BYTE value of each parameter. LS BYTE sent first (LITTLE ENDIAN)

HK response packet format is:

RSP_ID = 0x0B
LEN = number of 16-bit WORDS to be transmitted
Bn = packet data in BYTES

5.3.13.1 HK Table

The HK table is:

HK Table Addr	HK Parameter (16-bit)
0x00	BIAS_ON_OFF
0x01	V_Probe_Biases
0x02	V_+12V
0x03	V_-12V
0x04	V_+5V
0x05	V_+3V3
0x06	V_+2V5
0x07	V_+1V2
0x08	TBD
0x09	STM_TH_ch0
0x0A	STM_TH_ch1
0x0B	STM_TH_ch2
0x0C	STM_TH_ch3
0x0D	STM_TH_ch4
0x0E	STM_TH_ch5
0x0F	STATUS_REG

5.3.13.2 STATUS Register

The STATUS_REG bits are defined as:

STATUS_REG	Comment -16-bit register
B15	RDY flag
B14	BIAS ON
B13	BIAS OFF
B12	not used = ‘0’
B11	not used = ‘0’
B10	not used = ‘0’
B9	not used = ‘0’
B8	not used = ‘0’
B7	not used = ‘0’
B6	not used = ‘0’
B5	not used = ‘0’
B4	not used = ‘0’
B[3,2,1,0]	MODE: 0000 TBC
	0001 TBC
	0001 TBC
	0010 TBC
	0011 TBC
	0100 TBC
	0101 TBC
	0110 TBC
	0111 TBC
	1001 TBC
	1010 TBC
	1011 TBC
	1100 TBC
	1101 TBC
	1110 TBC
	1111 TBC

5.3.14 SU_BIAS_EN (0x53) & SU_BIAS_DIS (0xC9)

NOTE: To enable probe biasing, the **RED-TAG** “**BIAS_Disarm**” plug MUST be removed first.

The CubeSat access hatch cannot be closed until the **RED-TAG** plug has been removed.

In order to turn ON bias voltages, the bias DACs needs to be enabled. The control of bias voltages on/off is set by to separate commands:

SU_BIAS_EN

..followed by:

SU_BIAS_DIS

The “SU_BIAS_EN” command format is:

CMD_ID = 0x53
LEN = 0x00

The “SU_BIAS_DIS” command format is:

CMD_ID = 0xC9
LEN = 0x00

5.4 Example SU Command Sequence Script

An example of the user-readable ASCII command sequence script is shown below:

TBI
TBI
TBI
TBI
TBI
TBI
TBI
TBI
TBI
TBI
TBI
TBI
TBI
TBI
TBI
TBI

Table 5-2 - SU Commanding Script Example

NOTES:

1) Commands prefixed by “OBC_” are addressed to the OBC script handler to interpret and execute.
2) Commands prefixed by “SU_” are to be sent to the Science Unit.
3) The TIME field “@t” is NOT sent to the SU, but interpreted by the OBC as the time at which the script command is to be executed. When “@t” is set to “@NOW”, the OBC shall execute the command immediately.
4) The RDY flag will be asserted in response to SU_SM, SU_STIM, SU_HC commands, and the OBC shall collect the SU data packet, time-stamp the packet, and store it to local mass-storage for download when required.

The above ASCII script is parsed by the SCRIPT_ENCODER tool that shall produce the encoded BYTE packet of the script to be uplinked to the CubeSat.

5.5 Data Handling and Control

TBD

6 Mechanical interface

6.1 Accommodation and Field of View

The Science Unit will be accommodated at one end of the CubeSat, on a 10 x 10 face. The vector normal to this face shall be in the spacecraft ram velocity direction. This face shall not be available for Solar cells, any other sensor or subsystem and nothing must project forward of this face.

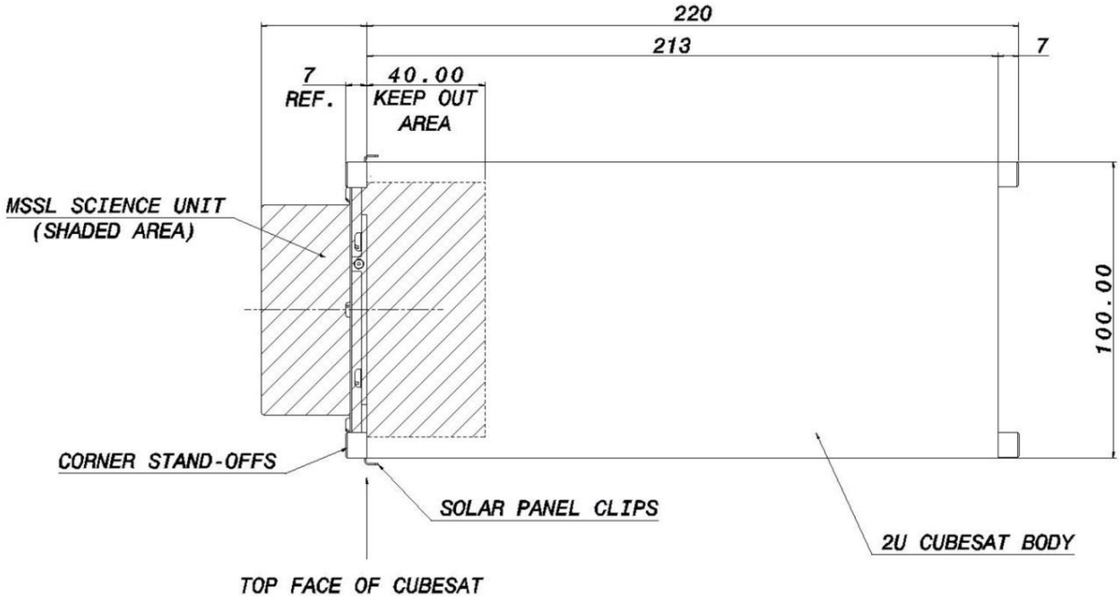

Figure 6-1 – m-NLP Science Unit Keepout Areas within CubeSat

6.2 Interface control drawing

The mechanical interface drawing is provided in Appendix 1. The Science Unit is designed to interface to commercially available CubeSat structures either through an adapter or through appropriate relocation of mounting holes on the structures.

6.3 M-NLP boom system

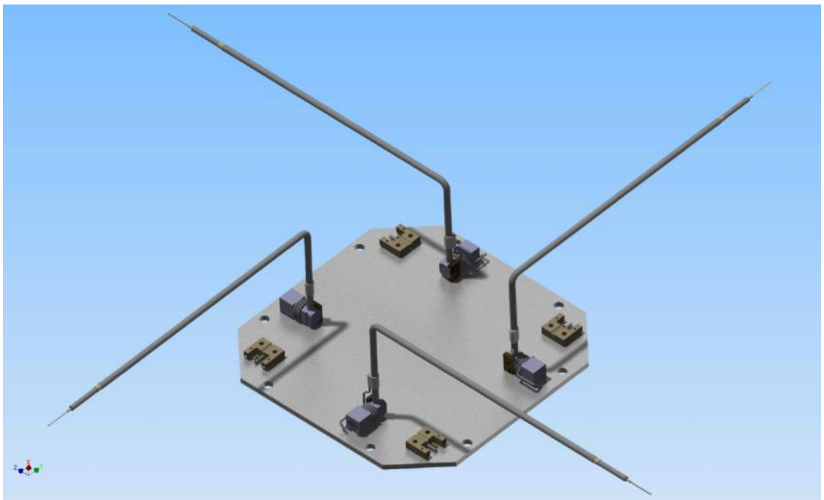

Figure 6-2 – m-NLP Science Unit Boom System

The m-NLP boom system consists of four separate booms, mounted on the common top plate of the SU. Each of the booms has an individual deployment mechanism, operated by the m-NLP PCB on command from the OBC. The m-NLP boom system drawing is provided in Appendix 2.

6.4 Surface finish

The overall finish for the Aluminium structure of the Science Unit shall be Alocrom 1200.

6.5 Mass

The total Science Unit mass shall be < 600 grams.

7 Attitude Control

The CubeSat shall provide attitude control with a pointing accuracy of +/-10° and pointing knowledge of +/-2° (TBC).

8 Cleanliness and Contamination

All materials shall meet or exceed the following outgassing criteria:

TML ≤ 1.0% .

CVCM ≤ 0.1% .

Where possible, materials shall be selected from ESA and NASA approved lists and processed in such a way as to minimize contamination.

9 Operating Conditions

The particular operating conditions will depend upon the selection of sensors for a given Science Unit. These will be made known at the time of selection.

10 Handling

The Science Unit shall be handled in a cleanroom environment (details TBI).

ESD protection protocols shall be followed (details TBI).

11 Thermal

At least one thermal sensor will be used to monitor the temperature inside the CubeSat enclosure. This will be in addition to the thermistors in the Science Unit which are used for scientific measurement.

Item	**Science Unit**
Operational Temperature Range	-20°C to +40°C (TBC)
Non-Operational Temperature Range	-30°C to 65°C (TBC)
Minimum Standby temperature	-25°C (TBC)

Table 11-1 Thermal operating requirements

Item	**Science Unit**
Thermal capacity	TBD J/K
Radiative properties	Alpha = TBD epsilon = TBD
Contact area	TBD mm^2
I/F conductance	TBD W/m^2K
Thermal interface filler	TBD

Table 11-2 Thermal properties

12 Appendix 1

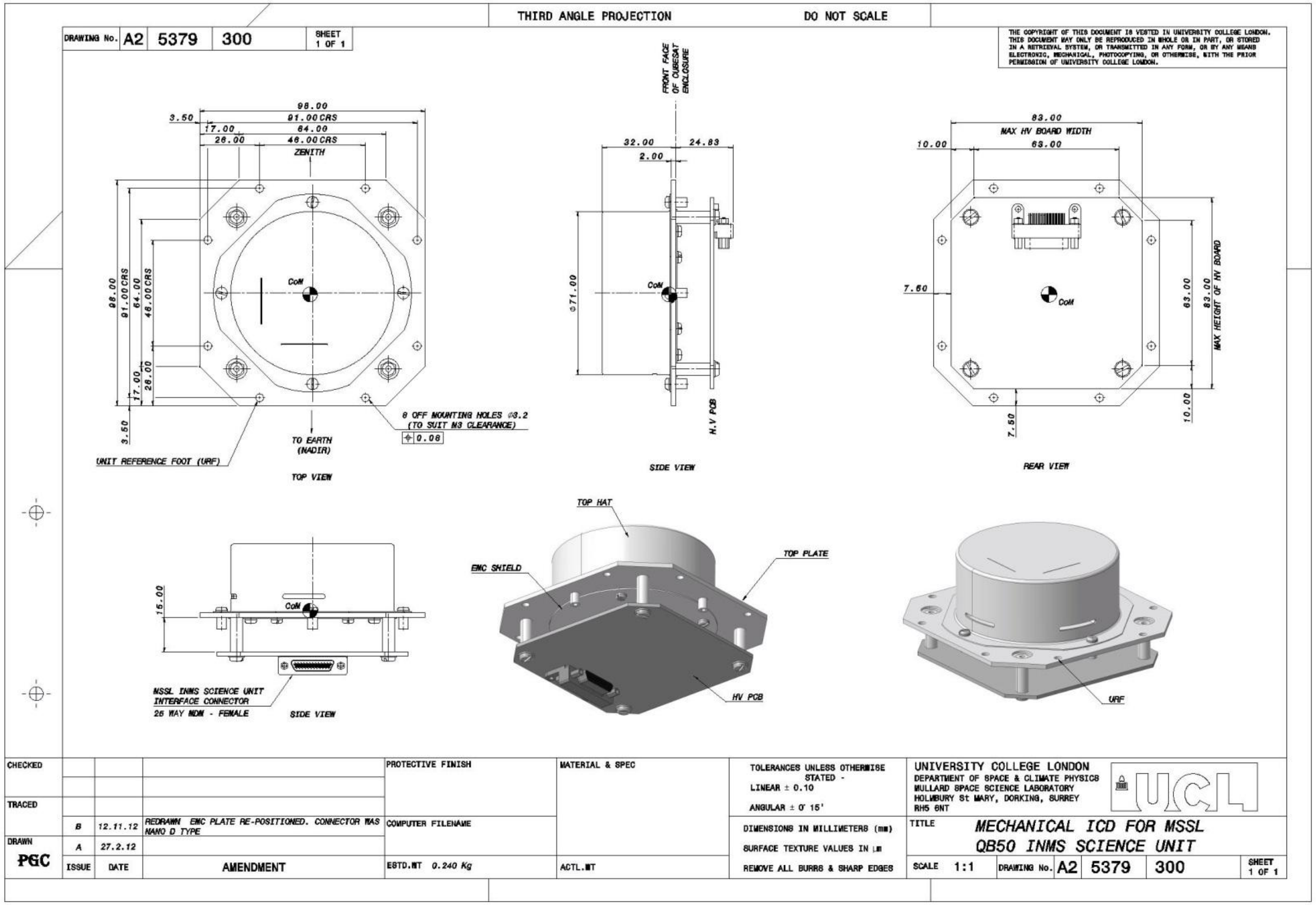

Figure 12-1 - QB50 Science Unit Mechanical Interface Drawing

13 Appendix 2

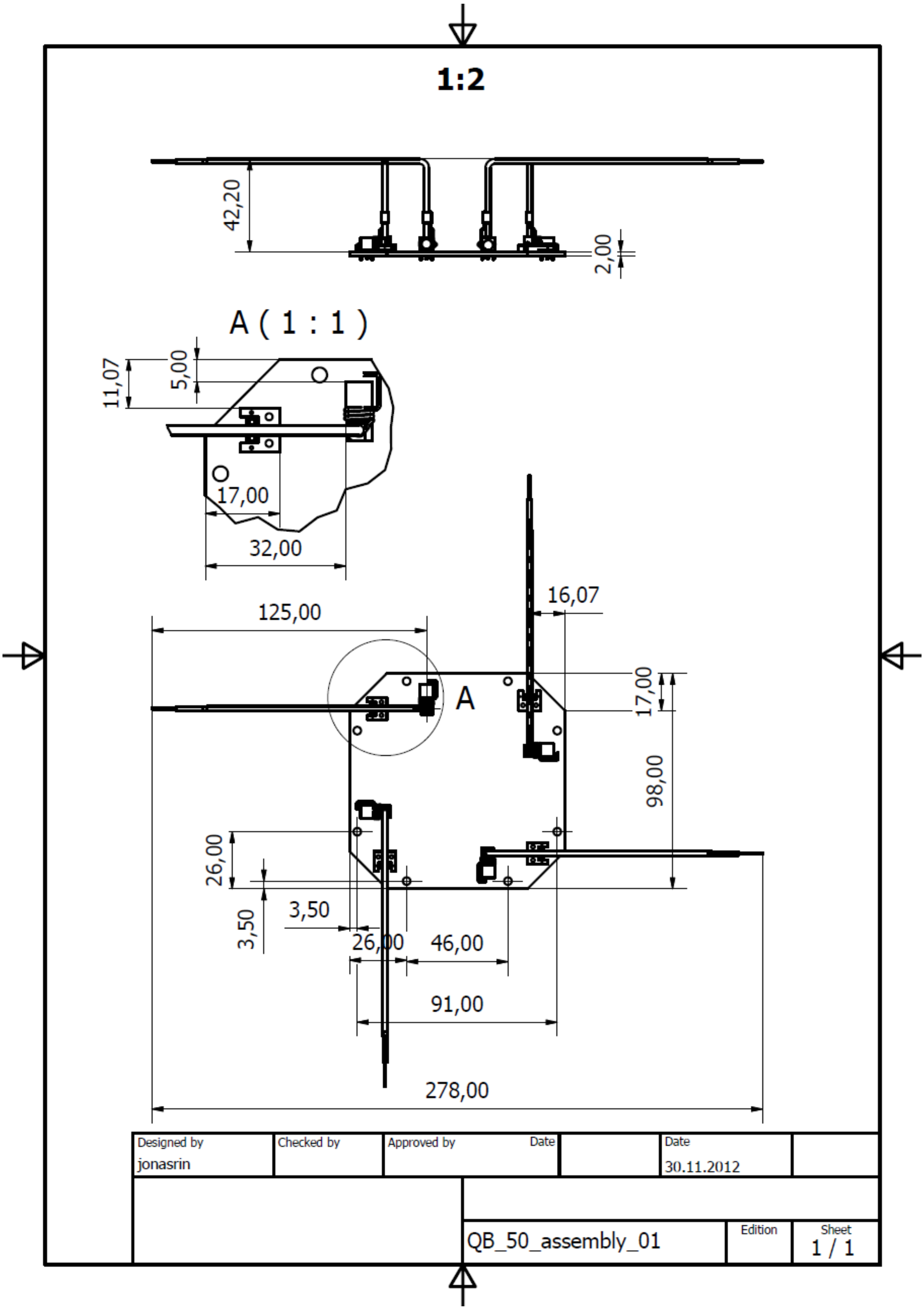

Figure 13-1 - QB50 Science Unit m-NLP boom system drawing