TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Maschinenwesen Institut für Luft- und Raumfahrttechnik

Professur für Raumfahrtsysteme

QB50 FIPEX Science Unit

Interface Control Document

ILR-RFS_FPXQB50_ICD_1000_11

Date: 08.10.2015

Issue: 2.5.0

This document contains the specification for FIPEX Science Unit on QB50.

Some minor changes may be induced by the on-going development and QB50 precursor flight activities.

Authors:	Paul Roßmann	Date:	
	Tom Henschel	Date:	
Manager/Project Office (approval)	Tino Schmiel	Date:	

For questions or remarks please contact: T. Henschel tom.henschel1@tu-dresden.de

Revision List

Version	Date	Changes	Author
2.5.	08.10.2015	OBC_SU_HK removed STM formula updated (2.1)	T. Henschel
2.4.1	09.12.2014	Changed 'second' FPX-E-0150 to FPX-E-0155 SU_CAL set to Req: FPX-SW-0585 SU_R_ID set to Req: FPX-SW-0625 Temperature readout circuit reference added	T. Henschel
2.4	30.9.2014	Added calibration command	P. Roßmann
2.3.1	18.9.2014	Added "[…] OBC shall remove trailing zeroes after the XOR field and attach […]" to Req: FPX-SW-0300	P. Roßmann
2.3	23.7.2014	Corrected issue numbers	P. Roßmann
		Clarified grounding procedure in FPX-E-0120 (added NOTE)	
		Clarified FPX-E-0300	
		corrected pin description (24) in Figure 2-1	
2.2	17.07.2014	Corrected wording of the introduction	P. Roßmann
		Changed FPX-E-0030 to be a recommendation	
		Updated Figure 2-1 and caption for clarity	
		Added Figure 2-2 to clarify STM connections	
		changed power budget table for more clarity	
		Removed "is specific to each team but" from FPX-SW_0040	
		Rectified wording of FPX-SW-0060	
		Switched decision results (yes/no) at "Reached OBC_SU_END?" at Figure 3-1	
		Fixed wording of FPX-SW-0140	
		Increased timeout value in FPX-SW-0270 to 500ms	
		Clarified FPX-SW-0320 (given storage sizes are per packet), added size calculation example	
		clarified the SU command script structure (3.2.1)	
		changed wording of FPX-SW-0120 for clarity	
		Clarified FPX-SW-0240	
		Removed "Unused bytes in a command in the command script (in the case of LEN < 3) shall be ignored" from FPX-SW-0180	
		Change wording of FPX-SW-0180	
		Clarified byte order in table Table 3-1, Table 3-2 and Table 3-3	
		Clarified attitude data definition at FPX-SW-0320	
		Removed TBC tag at FPX-E-0300	
		Removed TBC tag at FPX-E-0321	
		Deleted FPX-E-0260	
		Removed TBC flags at FPX-E-0475	
		Reduced Mass and margin at FPX-E-0290	
		Removed " from its initial launch altitude down to at least 200 km" from FPX-E-0300	

		Removed TBC flag rom FPX-E-0460	
		Added IEC 61340-5-1 as reference for ESD handling	
		Added Req. FPX-E-0461 and a note clarifying the integration procedure	
		Added reference to proposed corner cube reflectors (FPX-E-0480)	
		Corrected bit numbering in Table 3-14 (last bit is 55, not 59)	
		Corrected Description of SAMPLE1 entry in Table 3-11	
		Added example positions for the POSITION definition at FPX-E-0320	
2.1	20.02.2014		P. Roßmann
		corrected Figure 2-1 and Table 2-1, pin 23/24	
		Detailed switch on/off routine in 2.4	
		Extended peak power consumption in Table 2-3 (5V). Removed TBC note.	
		Corrected byte numbering in Table 3-1	
		Corrected unit of parameter 0x65 and 0x66 in Table 3-5	
		Removed unused abbreviations	
		Added sentence about unused bytes in Req: FPX-SW-0180	
2.0	15.01.2014	Major revision of most sections	T. Schmiel, P. Roßmann
2.0 Draft		Renewed draft for compatibility to INMS QB50 science Unit ICD V7.0. ICD released by MSSL	P. Roßmann
1.5 Draft	12.2013	- Added comment to script generation - correct typos in whole document - Renamed SU_TH to FIPEX_TH (section 2.1) - Added explanations to Script Execution to prevent confusion about never ending loops. (Section 3.2) - Updated Figure 3-1 for better clarity -	A. Weber
1.4 Draft	19.06.2013	Reviewed Draft - added Requirement section - rephrased some paragraphs for more clarity. - corrected Figure 2-1 - commands and responses redefined	A. Weber
1.3 Draft	20.02.2013	Reviewed Draft	A. Weber, P. Roßmann
1.2 Draft	13.02.2013	Reviewed Draft	A. Weber, J. Heisig
1.1 Draft	05.02.2013	Renewed draft based on MSSL QB50 Science Unit	A. Weber
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
DAC	Digital to Analogue Converter
ESD	Electro-Static Discharge
FIPEX	ϕ-(Phi=Flux)-Probe-Experiment
FPX	FIPEX
I/F	Interface
LS	Least Significant (Byte)
LSB	Least Significant Bit
LV	Low Voltage
MSSL	Mullard Space Science Laboratory
INMS	Ion/Neutral Mass Spectrometer
OBC	CubeSat On-Board Computer
PFC	Parameter Format Code according to ECSS–E–70–41A
PTC	Parameter Type Code according to ECSS–E–70–41A
PCB	Printed Circuit Board
S/C	Spacecraft
SU	Science Unit
TBC	To be confirmed
TBD	To be decided
TBI	To be included

Applicable Documents

[AD-1] Singarayar, Fiona: QB50 System Requirements and Recommendations. VKI. Issue 4. June 2013.

[AD-2] Manual for the FIPEXonQB50_Precursor Science Unit ILR-RFS_FPXQB50_MAN_1000_01

[AD-3] Manual for the Software Simulator of FIPEXonQB50_Precursor Science Unit ILR-RFS_FPXQB50_MAN_2000_01

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] ESA-ESTEC: Ground systems and operations — Telemetry and telecommand packet utilization. ECSS–E–70–41A, 30 January 2003.

[RD-4] Chaudery, R.A.: QB50 INMS Science Unit Interface Control Document. MSSL/QB50/ID/12001 Issue 7 – 04 Dec 2013

[RD-5] UM-3: CubeSat Kit User manual Rev D2 issued 17 Sep 2003

[RD-6] CubeSat Design Specifications Rev. 12

Content

1. Introduction

This document controls the required interfaces between a CubeSat as foreseen for QB50 precursor and main flight mission and the FIPEX Science Unit. It is derive from the common science unit interface via the INMS Science Unit ICD [RD-4]. Please be aware that there are substantial differences between the interfaces.

The FIPEX Science Unit consists of the following experiments:

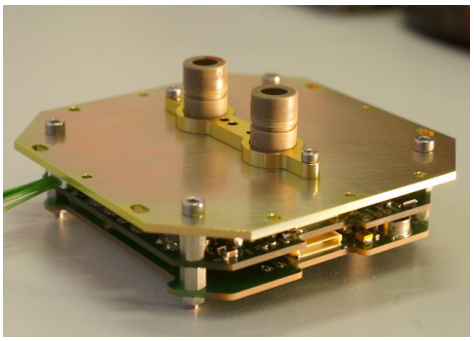
- ϕ-(Phi=Flux)-Probe-Experiment (FIPEX) by Institute of Aerospace Engineering, Technische Universität Dresden (TU Dresden), Germany
- Surface thermal monitors (STM) (supplied by MSSL) by Belgium

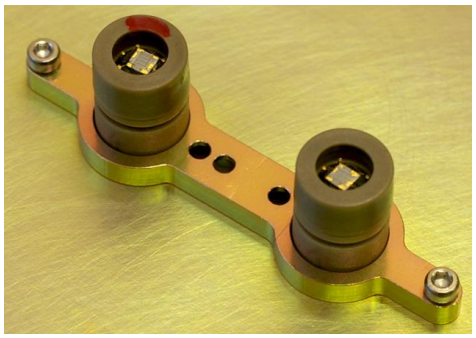
FIPEX of TU Dresden (ϕ-(Phi=Flux)-Probe-Experiment) is able to distinguish and measure the time resolved behavior of atomic oxygen as a key parameter of the lower thermosphere. Atomic oxygen is the dominant species in these regions and therefore its measurement is crucial in the correlation and validation of atmosphere models. Moreover, erosion of spacecraft surfaces due to interaction with atomic oxygen is a serious concern and merits in-situ study in its own right.

The measurement is based on solid oxide electrolyte micro-sensors. For oxygen conducting solid state electrolytes, e.g. yttrium-doped zirconia, the conductivity starts at high temperatures and so the sensor operates at an elevated temperature of 600-700°C, heated by an electrical resistance. Oxygen is “pumped” from one electrode to the other by an applied direct voltage and in accordance with Faradays’ law; the measured current is proportional to the mass flux by electrolysis.

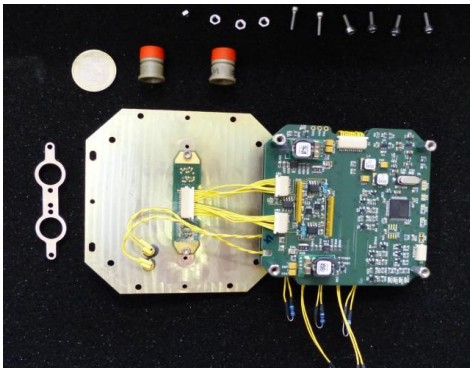
The sensor needs to be in free flow and to determine the actual flux the attitude of the satellite with respect to its direction of motion needs to be known.

FIPEXonISS, was an experiment launched on STS-122 (1E) Shuttle flight on 7 February 2008 and deployed on the COLUMBUS External Payload Facility on the platform EuTEF (European Technology Exposure Facility). It provided the first measurements of the time resolved behaviour of atomic oxygen and oxygen molecules. The next natural step would be a time and spatial resolved measurement, which is possible with QB50.

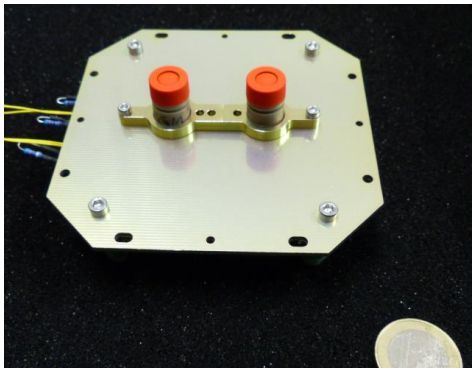




FIPEXonQB50_precusor Engineering model during development tests



FIPEXonQB50 precursor flight model during assembly, test and integration



FIPEXonQB50 precursor flight model ready for final checkout

2. Electrical Interfaces

Req: FPX-E-0010

There will be a single electrical connector between the FIPEX science unit and a CubeSat. The Science Unit will provide a straight 25-way MDM female connector (NORCOMP – 380-025-213L001) for the CUBESAT side connector to attach to. Position of the connector is as shown in Appendix 1. The CubeSat connector shall provide the signals as shown in **Table 2-1**.

Req: FPX-E-0020

To preserve the flight MDM25 connector on the SU, teams will be limited to a total of 10 mate/de-mate cycles to the flight connector.

Rec: FPX-E-0030

Teams are advised to use a harnessed connector saver for bench testing of the SU.

Depending on the CubeSat design, at integration on the FIPEX into the Cubesat structure, there may be no space for a connector saver.

2.1 Science Unit Connector Definition

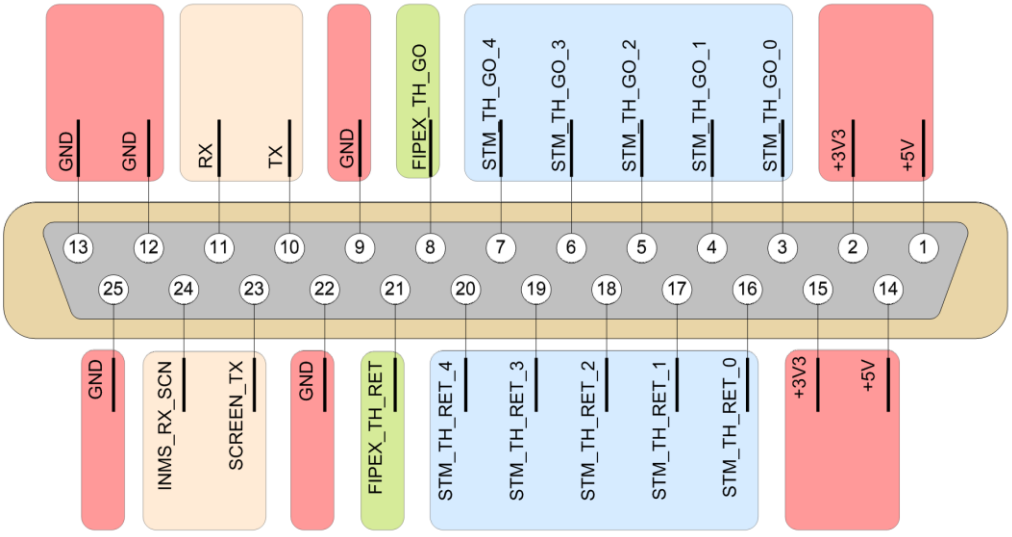


Figure 2-1 Science Unit connector pinout, view of the mating side of the unmated female connector

Pin	Signal Name	Comment
1	+5	SWITCHED Power for +5V
2	+3V3	SWITCHED Power for +3V3 (logic power supply)
3	STM_TH_GO_0	Surface Thermal Monitor– signal for CH0, positive lead on AD590
4	STM _TH_GO_1	Surface Thermal Monitor– signal for CH1, positive lead on AD590
5	STM _TH_GO_2	Surface Thermal Monitor– signal for CH2, positive lead on AD590
6	STM _TH_GO_3	Surface Thermal Monitor– signal for CH3, positive lead on AD590
7	STM _TH_GO_4	Surface Thermal Monitor– signal for CH4, positive lead on AD590
8	FIPEX_TH_GO	SU temperature sensor – signal GO, positive lead on AD590
9	GND	System GROUND
10	TX	SWITCHED Serial line to **SEND** data from SU to CubeSat
11	RX	SWITCHED Serial line to **RECEIVE** data from CubeSat to SU
12	GND	System GROUND
13	GND	System GROUND
14	+5	SWITCHED Power for +5V
15	+3V3	SWITCHED Power for +3V3 logic power supply
16	STM _TH_RET_0	Surface Thermal Monitor – RETURN for CH0, negative lead on AD590
17	STM _TH_RET_1	Surface Thermal Monitor – RETURN for CH1, negative lead on AD590
18	STM _TH_RET_2	Surface Thermal Monitor – RETURN for CH2, negative lead on AD590
19	STM _TH_RET_3	Surface Thermal Monitor – RETURN for CH3, negative lead on AD590
20	STM _TH_RET_4	Surface Thermal Monitor – RETURN for CH4, negative lead on AD590
21	FIPEX_TH_RET	SU temperature sensor– signal RETURN, negative lead on AD590
22	GND	System GROUND
23	SCREEN_TX	Screen for TX
24	SCREEN_RX	Screen for RX
25	GND	System GROUND

Table 2-1: Instrument Connector Pin Assignment

2.2 Power Pins

Req: FPX-E-0040

The +5, +3V3 connections are duplicated to provide redundancy in the harness. Tolerance for the provided voltage shall be ±5.0%. The power lines shall tolerate a switch on peak current of 50% above the specified maximum current (see section 2.9) for 50ms.

Req: FPX-E-0045

The power supply interface at the CubeSat shall be designed in a way that a short circuit in the SU cannot damage the CubeSat.

2.3 Supply rail monitoring by CubeSat

Req: FPX-E-0050

The CubeSat shall monitor the +5V and +3V3 currents and voltage levels of the switched SU power supply rails at a frequency of once every minute when the SU is switched on.

Req: FPX-E-0060

In an event of an over-current or voltage drop/brown-out the **Error handling** procedure from **3.2.3** shall be followed.

Req: FPX-E-0070

An over-current event shall be detected when one of the current consumption values from **Table 2-2** is exceeded by more than 75% for two consecutive measurements (1 min interval).

A voltage drop/brown-out event shall be detected when the supply voltages fall below 90% of the nominal value for two consecutive measurements (1 min interval).

Mode	Current at +5V (mA)	Current at +3.3V (mA)
Standby	5	35
Full State	380	35

Table 2-2: over current limits

2.4 Switched Pins

Req: FPX-E-0080

The electrical Interface must be controlled by the CubeSat in order to control switching the SU ON or OFF by SCRIPT command. The CubeSat electrical switch characteristics shall be that:

+5 V, 3V3, TX, RX are switched ON/OFF together OR in the following order:

ON: +3V3, +5V, RX/TX

OFF: RX/TX, +5V, +3V3

The +5V line shall never be switched on alone. To minimize static power consumption the +5V line shall not be switched on later than 0.5s after the +3V3 line is switched on.

Both rails should achieve nominal voltage levels and stabilize within 120ms (max) from switch on.

NOTE: The SU CANNOT switch itself ON or OFF. That can only be done by switching the power lines.

2.5 Grounding

Req: FPX-E-0100

The FIPEX science unit electronics shall be electrically grounded to the SU CubeSat ground through the SU Connector GND. The electrical resistance shall be <50mΩ.

Req: FPX-E-0101

The Science Unit Chassis shall be electrically connected to the CubeSat structure (and thereby the CubeSat ground and the SU electronics ground) at its points of attachment. The electrical resistance shall be <1 Ω.

Req: FPX-E-0110

In case of a non-conducting (e.g. non-metallic) CubeSat structure or a structure which is not connected to the CubeSat ground the SU will be grounded through the SU connector GND pin.

Req: FPX-E-0120

The connection between SU structure and SU electronics shall be made using a 0 Ohm shunt (SMT resistor, 0 Ohm, 1210) on the second SU electronics PCB on the marked position in Appendix 1 – Mechanical Interface Control Drawing.

NOTE: This will be done by TU Dresden before shipping the SU. Therefore it is necessary to define if the shunt is needed before shipping the SU.

2.6 Surface Thermal Monitor (STM)

Req: FPX-E-0130

The Surface Thermal Monitor (STM) experiment consists of six temperature transducers mounted as follows:

- Five channels are mounted on the CubeSat (on the inner side of solar panels).
- Sixth channel is mounted inside the FIPEX.

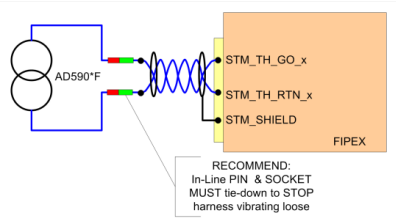


Figure 2-2: connections of the STM. Sixth channel is not visible on connector

As soon as the SU is switched ON, the STM experiment starts to run according to the value of the “stm_interval” parameter. See 3.7.4 for details.

NOTE: STM is an SU experiment. CubeSat teams are NOT required to perform any control, or action to run the STM experiment – SU shall control the running of STM.

CubeSat teams only need to provide harnessing and the correct mounting of the transducers.

Req: FPX-E-0140

The AD590*F transducer shall be used for the STM circuit.

Req: FPX-E-0150

CubeSat teams shall provide harnessing for FIVE STM transducers, with each STM transducer harness consisting of a pair of TWISTED wire

Req: FPX-E-0155

The temperature T in kelvin of every STM shall be calculated from the digital value D as follows:

$$T = \frac{D}{10} K \tag{2.1}$$

2.6.1 STM positions

Req: FPX-E-0160

CubeSat side STM channels (STM_TH[0,1,2,3,4]) shall be mounted on the back of the solar panel substrate (or mechanical panel if available), at the locations shown in section 18 of [RD-4].

Req: FPX-E-0170

Mounting procedure from Req. INMS-I-340 of [RD-4] shall be followed for STMs.

2.7 Science Unit Temperature Sensor

Req: FPX-E-0180

The FIPEX_TH GO/RTN pair are connected to the positive and negative lead of the AD590*F transducer inside the SU, used by the CubeSat to measure the SU temperature. The readout circuit for the temperature sensor can be found in INMS-I-360 of [RD-4]. The SU temperature sensor shall be used to guarantee that the thermal requirements from section 10 Thermal are met.

Req: FPX-E-0200

The minimum resolution of the SU temperature measurement shall be 1°C, with a measurement range of -30°C to 80°C. Minimum measurement accuracy shall be ±3°C.

2.8 Science Unit Serial Interface

Req: FPX-E-0210

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: 9600

Data Width: 8-bit

Parity bit: No Parity

Start bit: ONE

Stop bit: ONE

Req: FPX-SW-0015

Data is transmitted in LITTLE ENDIAN BYTE order, i.e. LS byte first.

LS Bit of every byte is sent first, then the MS byte.

2.9 Power Budget

Req: FPX-E-0220

The power budget averages & maximum values over an orbit are shown in **Table 2-3**.

SU state	Power at +5V (mW)		Power at +3.3V (mW)	
	Orbit average (Duty cycle averaged)	during Unit operations (maximum)	Orbit average (Duty cycle averaged)	during Unit operations (maximum)
STANDBY, ERROR	5	50(100)	40	50(100)
SCIENCE, HEALTH CHECK	422	1900 (3000 for 2s during sensor switch on)	77	50(100)

Table 2-3: Power Budget

3. Science Unit Command and Control Interface

The following sections describe the software requirements that the CubeSat OBC is required to implement to service the science unit.

3.1 OBC Requirements for SU commanding

The CubeSat OBC shall have:

Req: FPX-SW-0010

- real time clock information (UTC), see QB50-SYS-1.4.4.

Req: FPX-SW-0020

- attitude and position information with an accuracy as specified in section 5 upon reception of science data.

Req: FPX-SW-0030

- the ability to receive data from the SU, temporarily store these data in memory and transmit the data on request to the ground station.

Req: FPX-SW-0040

- OBC shall have at least two independent mass memory units with at least 10Mbyte reserved for SU science and housekeeping data.
- The implementation of error handling (e.g. full storage) should ensure that the latest data can be transferred to ground.

Req: FPX-SW-0050

- the ability to receive byte encoded command scripts (see section 3.2) with an error detection mechanism (at least CRC16) assuring consistency of the command script and feedback to the ground station (ACK/NACK). (QB50-SYS-1.5. 7 and QB50-SYS-1.5. 11)

Req: FPX-SW-0060

- the ability to overwrite an existing script with a new script from the ground station. It shall be possible to specify the script to be overwritten.

Req: FPX-SW-0070

- the ability to store up to 7 command scripts (the first 7 scripts will be stored on the OBC prior to launch), set a command script as active for execution, to run a command script at the specified time, repeat the execution in defined time intervals and to abort this cycle (deactivate the command scripts). (QB50-SYS-1.5. 7). One script shall be marked as active prior to launch.

Req: FPX-SW-0080

- Scripts to run on the FIPEX flight model shall ONLY be written by the CONOPS, MSSL and FIPEX personnel.

3.2 SU command script

3.2.1 Format of the byte encoded script

Req: FPX-SW-0090

The SU will be commanded by uploading a byte encoded script, containing time tagged commands for the OBC. The command script has the byte encoded format from **Table 3-1**. The length of every command can be either 5 or 7 byte, and the OBC shall determine the length of every command using the LEN field of the respective command (see 3.3.1).

NOTE: As the length varies, the starting position of the next element in the bytestream varies, too.

First Byte	Field	Description
0	LEN	one BYTE value representing the number of 8-bit BYTES to follow the LEN parameter. Maximum value is 254
1..4	STARTTIME	four BYTE value (LS BYTE first) according to chapter 5. This specifies the first execution time
5..6	REPEATTIME	two BYTE value (LS BYTE first) in seconds, defining the script execution interval
7	CMD_CNT	one BYTE value containing the number of commands to follow
8	CMD0	First Command to execute. Details are defined in section 3.3.
12+LEN(CMD0)	DELAY0	two BYTE Delay to wait after CMD0 in seconds (LS BYTE first) until next command is executed. The DELAY field (@d) shall ONLY be read by the OBC, but NOT sent to the SU as part of the command
14+LEN(CMD0)	CMD1	Second command to execute (after DELAY0 seconds)
. . .		more commands
LEN-2.. LEN	SCRIPT_END	Three Byte command OBC_SU_END signalling the end of the script: 0xFF 0x01 0xFE. See section 3.7.1 for details.

Table 3-1: SU command script structure

3.2.2 Script execution

Req: FPX-SW-0100

The SU is commanded by the OBC running a command script. As long as the script is set to “active”, the script is run in a continuous cycle.

Req: FPX-SW-0120

The script shall be started the first time at STARTTIME. The OBC shall execute each command consecutively. The OBC shall wait for the delay condition DELAYx after each

command, before executing the next command. A command can contain an instruction for the OBC only, or an instruction which shall be send to the SU, see section 3.7.

Req: FPX-SW-0130

With the end of the script the OBC shall stop payload operation. The next start time for the script shall be STARTTIME + REPEATTIME.

3.2.3 Error handling

Req: FPX-SW-0140

If there is an ERROR during script execution, the OBC shall:

- ABORT the current script
- request a SU_R_SDP packet
- request a SU_R_HK packet
- produce a OBC_SU_ERR packet, even if the SU doesn't respond
- OBC shall not start error handling during error handling
- TURN OFF the SU

Req: FPX-SW-0150

The script shall remain "Active" (be repeated) even though it may have failed the last execution time.

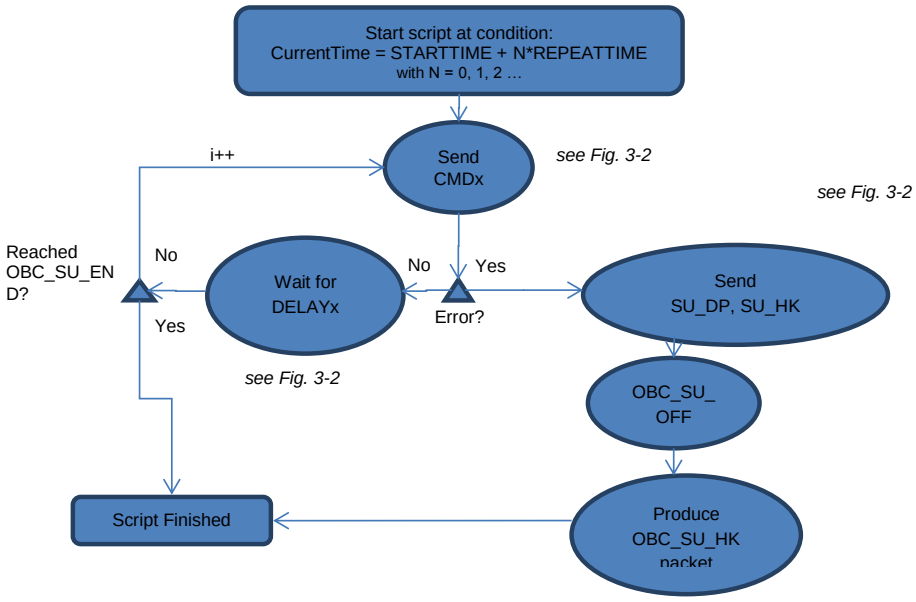


Figure 3-1 – FIPEX Science Unit OBC script execution and error handling

3.3 SU Command and Response Handling

Req: FPX-SW-0160

SU shall reply to every command. The SU sends responses automatically in two cases:

1. A SU_R_HK is produced after SENSOR CHECK state.
2. When a SU_R_SDP has reached maximum packet length. For details refer to 3.5.1.

The following two flowcharts describe the SU commanding and response handling. An ERROR in these handling routines shall be handled as defined in 3.2.3.

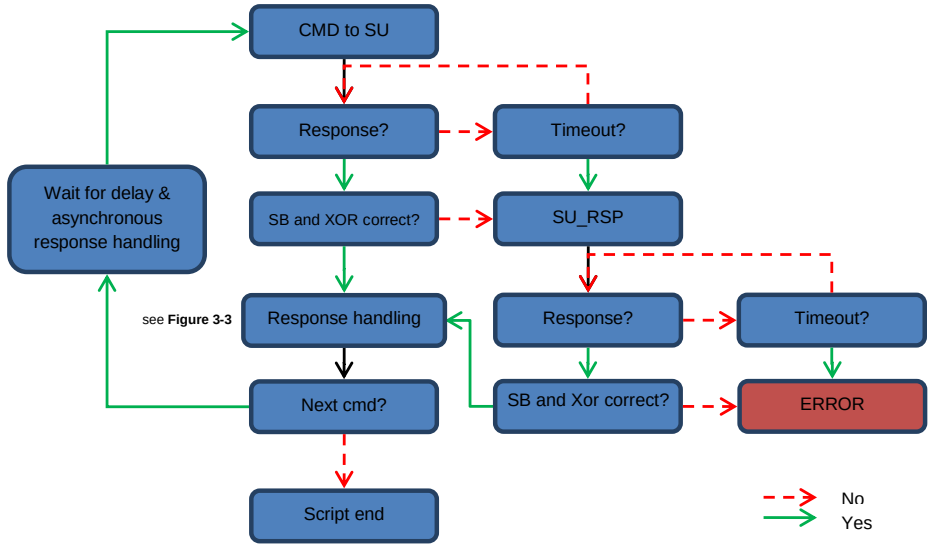


Figure 3-2: **OBC Science Unit Command and Response Handling**

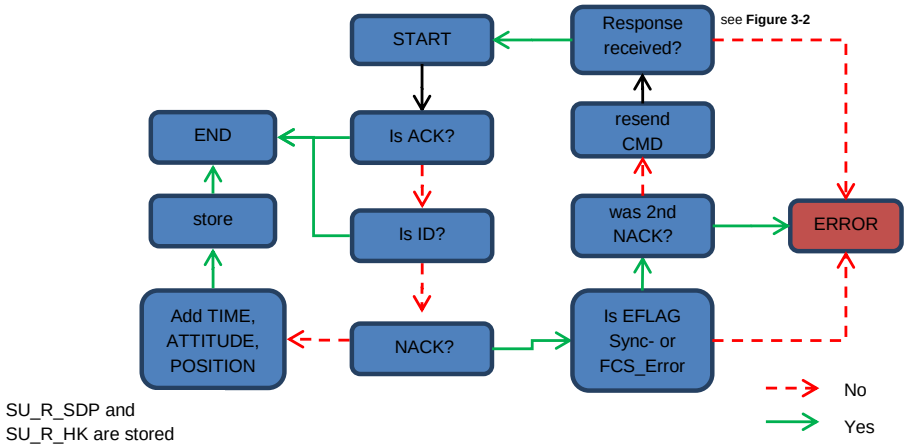


Figure 3-3 – Reception of SU Data

3.3.1 Science Unit Command Packet Structure

Req: FPX-SW-0170

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

First Byte	Field	Description
0	SB	Start byte: 0x7E. SB is a fixed value for detected the frame start.
1	CMD_ID	one BYTE value for command identifier
2	LEN	one BYTE value representing the number of 8-bit BYTES of DATA. Value is ranging from 0 to 251. Total frame length is LEN+4
-/3	DATA	optional, LEN Byte of DATA
LEN+3	XOR	one BYTE bitwise XOR of CMD_ID, LEN and DATA

Table 3-2: SU command structure

Req: FPX-SW-0180

The SB, CMD_ID, LEN, DATA and XOR fields are contained in CMDx field in the command script. The OBC shall use the LEN field of a command to determine the position of the respective delay field in the command script and the beginning of the next command. See section 3.7 for details of commands.

Req: FPX-SW-0190

The command packet size shall not exceed 32 Byte. The response packet size shall be 205 Byte.

Req: FPX-SW-0200

The frames shall be sent starting from byte 0.

Req: FPX-SW-0210

The OBC shall not send a second command packet without receiving a response to the first one OR detecting a timeout (see FPX-SW-0270 for definition), leading to an ERROR (see 3.2.3 for ERROR handling).

3.3.2 Science Unit Reponses Packet Structure

Req: FPX-SW-0220

The following packet structure is used to transmit responses from the SU to the OBC.

First Byte	Field	Description
0	SB	Start byte: 0x7E. SB is a fixed value for detecting the frame start.
1	RSP_ID	1 BYTE value for response identifier

2	LEN	1 BYTE value representing the number of 8-bit BYTES of DATA. Value is ranging from 0 to 200. Total packet length is LEN+5
3	SEQ_CNT	1 Byte value representing a sequential count of packets. The counter value shall roll-over to 0x00 having reached maximum count 0xFF. The counter starts with “0” after activating the SU and after a soft reset (SU_INIT)
- / 4	DATA	optional, LEN Byte of DATA
LEN+4	XOR	one BYTE XOR of RSP_ID, SEQ_CNT, LEN and DATA
LEN+5	fill	0x00 fill bytes to reach fixed response packet size

Table 3-3: SU response packet structure

3.3.3 Receiving Data

Req: FPX-SW-0230

The minimum interval between response packets generated by the SU shall be 200ms.

Req: FPX-SW-0240

The OBC shall wait 500ms before initializing the UART interface after any power cycle is complete. Data received during this time shall be discarded.

Req: FPX-SW-0250

The OBC shall verify that the first byte received in a packet is a start byte (SB) and XOR is correct. If this is not the case, the OBC shall take the following actions:

a) Request a retransmission of the last packet using the SU_RSP command
b) Receive a new packet and verify (as before) that the first byte is SB and XOR is correct. If this is correct, the OBC shall discard the previous packet and use the new packet AND NOT PERFORM STEP c)
c) If b) fails, the OBC shall use the ERROR handling procedure from 3.2.3.

Valid frames are further handled as defined in section 3.4.

Req: FPX-SW-0270

The Science Unit shall execute commands immediately upon reception. Timeout for a response from the SU shall be 500ms. A timeout should be handled like a wrong XOR or missing start byte in Req: FPX-SW-0250

Req: FPX-SW-0280

The possible responses are defined in **Table 3-7**. Reception of a valid response is considered as successful command execution.

Req: FPX-SW-0290

If there is an error in the execution (not reception) of a command in the SU, the SU will ABORT on-going operation, set an ERROR_FLAG in the status register and go to Error state without sending an ACK message, see section 3.5.

3.4 SU Data Handling

Req: FPX-SW-0300

On receiving a SU_R_SDP or SU_R_HK packet from the SU, the OBC shall remove trailing zeroes after the XOR field and attach the following information to it within 500 ms after receiving the first Byte:

- current real time (UTC)
- current spacecraft attitude and position

Req: FPX-SW-0310

The packet shall be stored in the OBC Mass Memory for later transmission to ground on request. The data format shall be:

<RSP_ID, LEN, SEQ_CTN, DATA, XOR><TIME, ATTITUDE, POSITION>

--- SU RSP Packet without SB --- --- OBC added part ---

Req: FPX-SW-0320

The time, attitude and position parameters shall be defined as follows:

TIME: four BYTE value counting seconds of UTC as defined in QB50-SYS-1.4.4.The parameter code is PTC=3, PFC=14

ATTITUDE: Contains the quaternion of the altitude, the angular rate as defined in section 5. Data represented in 16-bit WORD format – LS BYTE is sent first

<q1, q2, q3, q4><xdot, ydot, zdot>

The parameter code of each value is PTC=4, PFC=12[1]. The LSBs value of q1, q2, q3 and q4 is defined as $1/ (2^{15}-1)$, resulting in a range of -1 to 1. The LSBs value of xdor, ydot and z dot is defined as $2\pi s^{-1}/(2^{15}-1)$, resulting in a range of -2π/s to 2π/s.

POSITION: Contains the position <x_ECEF,y_ECEF,z_ECEF> as defined in section 5. Data represented in 16-bit WORD format – LS BYTE is sent first.

[1] For details please refer to [RD-3] ch. 23.5

The parameter code of each value is PTC=4, PFC=12[2]. The LSB is defined as 0.5 km.

The minimum overall size of the stored data will be 37 bytes per packet, calculated as follows (SU_RSP_SDP with 0 samples):

Data Field	RSP_ID	LEN	SEQ_CTN	DATA			XOR	TIME	ATTITUDE	POSITION
				TIME_FIPEX	TIME_STM	ID				
Bytes	1	1	1	4	4	1	1	4	7*2	3*2

The maximum size will be 227 bytes per packet, calculated as follows (SU_RSP_SDP with, e.g., 19 STM samples):

Data Field	RSP_ID	LEN	SEQ_CTN	DATA				XOR	TIME	ATTITUDE	POSITION
				TIME_FIPEX	TIME_STM	ID	HEADERES +SAMPLES				
Bytes	1	1	1	4	4	1	19*(1+9)	1	4	7*2	3*2

Req: FPX-SW-0330

- It shall be possible to request and transmit saved science and housekeeping packets from OBC memory separately.

Req: FPX-SW-0340

- The downlink protocol shall include an error detection mechanism.

3.4.1 Data Rates and volume

Req: FPX-SW-0360

Data rates and volume are aspects of Concept-of-Operation. As baseline the FIPEX SU will be in science state for 25% of the time, using a “meas_interval” of 6 seconds. STM will be sampling for 50% of the time, using a “stm_interval” of 120 seconds. The science data volume per day will be 0,3Mbits

3.5 Science Unit States

Req: FPX-SW-0370

Figure 3-4 shows the state diagram depicting the valid state transitions. These state changes are accomplished by sending commands to the SU or by events like detection of an internal error or finishing the execution of a state.

[2] For details please refer to [RD-3] ch. 23.5

Req: FPX-SW-0380

On any error, the SU shall go to ERROR state. The STATUS_REG shall set the ERROR bits according to the error.

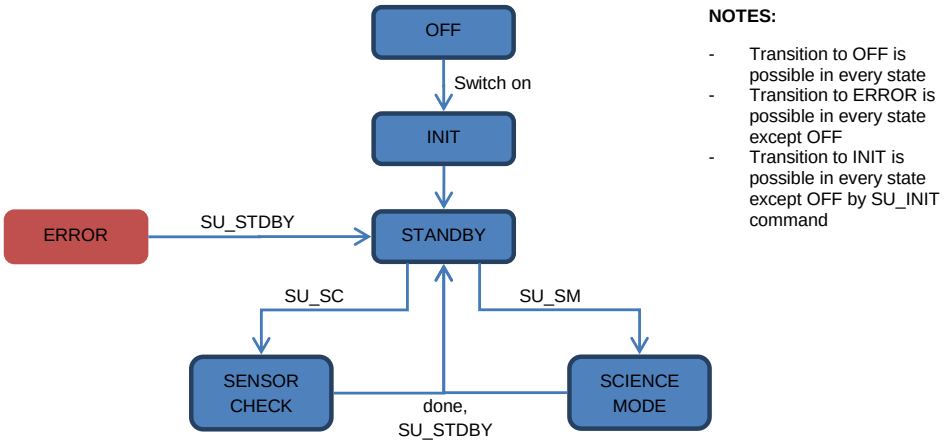


Figure 3-4 – FIPEX Science Unit State Transition Diagram

3.5.1 SU State description

Req: FPX-SW-0381

The OBC shall handle the following FIPEX SU state description:

OFF

Req: FPX-SW-0390

In the OFF state the SU is SWITCHED OFF as defined in 2.4. No communication is possible. Internal data is not maintained.

INIT

Req: FPX-SW-0391

The INIT state is used for initializing all hardware modules of the SU for lowest power consumption and active communication via UART. The INIT state shall be left immediately after completion of the initialisation. The SU will then switch to the STANDBY state. The internal time reference of the SU is active, counting seconds from switch on of the SU or the last SU_INIT command. The response sequence counter is reset to 0. In case an internal error is detected, the SU switches to the error state. The SU parameters will be reset to the default values (see **Table 3-5** for values).

STANDBY

Req: FPX-SW-0400

The STANDBY state is the default state of the SU, which is reached automatically after successful initialization. This state can be used to set basic parameters for the science state. In STANDBY state the SU performs automatic sampling of the STM experiment and produces SU_R_SDP packages at a rate depending on the “stm_interval” parameter (see 3.7.4). The default value of this parameter is 0, meaning there is no sampling done.

SCIENCE

Req: FPX-SW-0410

In the SCIENCE state the SU runs a FIPEX measurement automatically according to the set parameters (refer to 3.7.4). After successfully running a measurement cycle (shown in Req: FPX-SW-0430

Figure 3-5) the SU returns to the STANDBY state.

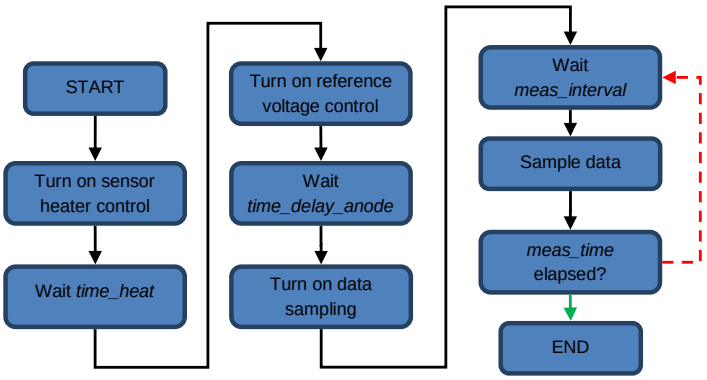
The SU_STDBY or the SU_INIT command returns the SU to the STANDBY state or init state respectively.

If an error occurs during science state, the SU switches to ERROR state. During the SCIENCE state the SU automatically sends SU_R_SDP packets at a rate depending on “meas_interval”

SENSOR CHECK

Req: FPX-SW-0420

The SENSOR CHECK state runs a measurement cycle with predefined parameters (stored in SU memory) to check the sensor functionality. At the end of the measurement cycle a SU_R_HK packet is send to the OBC. SU returns to STANDBY or ERROR state.



Req: FPX-SW-0430

Figure 3-5: SU measurement cycle

ERROR

Req: FPX-SW-0440

The error state is entered if the SU detects an internal hardware fault. The SU stays in the ERROR state until power cycling or until the SU_STDBY or SU_INIT command. Hardware modules are configured for lowest power consumption. Communication is active.

3.6 SU Commands

Req: FPX-SW-0450

The **Table 3-4** lists the commands to control the SU operation. Any command prefixed by "OBC_" is an instruction to the OBC, and shall NOT be sent to the Science Unit. Any commands prefixed by "SU_" shall be send to the SU.

Req: FPX-SW-0590

Table 3-7 lists the possible replies of the SU. (Req: FPX-SW-0590)

Command	CMD_ID	Data	Expected reply	Description
OBC_SU_ON	0x0F	-	-	Switch on Sensor Unit
OBC_SU_OFF	0xF0	-	-	Switch off Sensor Unit
OBC_SU_END	0xFF	-	-	Stop running command script
SU_PING	0x00	-	SU_R_ACK/ SU_R_NACK	Test packet. Expected answer is a SU_ACK
SU_INIT	0x01	-	SU_R_ACK	SU Soft Reset
SU_ID	0x04	-	SU_R_ID	Request SU ID
SU_RSP	0x10	-	SU_R_*	Request last package
SU_SP	0x11	PARAMID, VALUE	SU_R_ACK/ SU_R_NACK	Set parameter
SU_HK	0x20	-	SU_R_HK	Request Housekeeping packet
SU_DP	0x21	-	SU_R_SDP	Request science data packet
SU_STDBY	0x0A	-	SU_R_ACK	Switch to STDBY Mode. Cancels Measurement
SU_SC	0x0B	-	SU_R_ACK	Switch to Health Check Mode
SU_SM	0x0C	-	SU_R_ACK	Start Measurement sequence
SU_CAL	0x33	MODE, CALIBRATION DATA	SU_R_CAL	Start the specified calibration cycle

Table 3-4: Science Unit Commands

3.7 SU Command Description

3.7.1 OBC Commands

OBC_SU_ON

Req: FPX-SW-0460

This SCRIPT command shall be ONLY read & interpreted by the OBC to turn ON the SU as defined in section 2.4.

OBC_SU_OFF

Req: FPX-SW-0470

This SCRIPT command shall be ONLY read & interpreted by the OBC to turn OFF the SU as defined in section 2.4.

OBC_SU_END

Req: FPX-SW-0480

This SCRIPT command shall be ONLY read & interpreted by the OBC to stop running the SCRIPT and switching OFF the SU as defined in section 2.4. The command indicates the end of the script. The command sequence is not escaped in a byte encoded script, so it cannot be used to find the end of the script in a byte stream.

3.7.2 Basic Protocol Commands

SU_PING

Req: FPX-SW-0490

This commands requests an ACK from the SU unit and is intended for testing the communication between OBC and SU.

SU_INIT

Req: FPX-SW-0500

This command resets the SU to the initial state (soft reset) and switches to STANDBY state if successful. Switches to ERROR state if not successful.

SU_RSP

Req: FPX-SW-0510

This command is sent to the SU to request the last packet once again.

The response is the last sent packet. The sequence counter will not be incremented.

SU_ID

Req: FPX-SW-0520

Identification request. This command requests the serial number of the SU.

3.7.3 State Switching Commands

SU_STDBY

Req: FPX-SW-0530

This command is sent to the SU to put the SU into the STANDBY state.

The sensors are turned OFF when going to STDBY state. This command can be used to abort Science state and Sensor Check operations and to erase the error state. However, if the error is still detected in STANDBY state, the error state will be reached again immediately.

SU_SC

Req: FPX-SW-0540

The SU_SC command runs a check of the sensors. This command turns ON sensor heating and operates the sensor for a short time. Finally a SU_R_HK packet is send.

NOTE: The SENSOR_CHECK command “SU_SC” can ONLY be run from Standby state. The overall SU operation time is 20 seconds.

SU_SM

Req: FPX-SW-0550

This command runs a measurement cycle for one sensor with predefined parameters. This switches on the sensor heating.. Science operation can be aborted by sending a SU_STBY or SU_INIT command.

3.7.4 Parameter and Data requests

SU_SP

Command to set a SU Parameter to the value given. The DATA field is defined by:

PARAMID: = 1-BYTE parameter identifier

VALUE: = 2-BYTE parameter value. LS BYTE sent first (LITTLE ENDIAN)

Req: FPX-SW-0560

Setting SU Parameters with the IDs 0x00-0x04, 0x07,0x08 during a measurement cycle has no effect for the running measurement cycle, but will be effective for the next measurement cycle. Changing the other parameters has an immediate effect. All parameters have default values which are set after the INIT state.

The cold_resistance_1/2 parameters may be stored in persistent memory in a later software version. If so, they will not be reset during any state or command (except SU_SP).

PARAM ID	Name	Unit	Range [in Units]	Default	Description
0x00	time_ heat	1s	0 to 300	10	Timer delay for settling of the heater controller
0x01	time_ delay_anode	1s	0 to 300	10	Time delay for settling of the reference controller
0x02	meas_ time	1s	0 to 2000	180	Time for the next measurement cycle to run
0x04	sensor	-	1 or 2	1	selected sensor for measurement
0x05	cold_ resistance_1	0.001 Ohm	1000 to 10000	3000	Cold resistance of sensor 1 heater resistor
0x06	cold_ resistance_2	0.001 Ohm	1000 to 10000	3000	Cold resistance of sensor 2 heater resistor
0x07	meas_ interval	10ms	10 to 5000	100	Interval between FIPEX sensor data samples
0x08	stm_interval	1s	0 to 1000	0	Sample time for STM experiment. 0 means no sampling.
0x64	set_temp	0.001	1000 to 3500	2400	Set point of ration between heater hot and cold resistance for heater controller
0x65	set_max_ anode	3.3V/4095	0 to 4095	1240	maximum allowed control voltage for reference voltage controller
0x66	set_ reference	3.3V//4095	0 to 4095	600	Set point for reference voltage controller

Table 3-5: SU measurement parameters

SU_HK

Req: FPX-SW-0570

The HOUSE_KEEPING command “SU_HK” is used to request a SU_R_HK packet with the current housekeeping data.

SU_DP

Req: FPX-SW-0580

The SU_DP requests the current science data packet from the SU. The SU shall send the current science data packet. The OBC shall issue this command before switching OFF the SU. in case of an ERROR, to avoid loss of unfinished (and thereby not automatically send by the SU) science data packets. It is possible that the science data packet contains no samples.

SU_CAL

Req: FPX-SW-0585

The SU_CAL sets the SU into the selected calibration mode. If any of the calibration modes are used after calibration at TU Dresden, the SU will not enter calibration mode and return a

SU_R_CAL package with the current calibration values instead. This command shall only be used by TU Dresden!

MODE	Name	Description
0x00	CAL_REQ	Issues a request of all calibration values from the SU
0x01	CMC_10K0	10kΩ calibration
0x02	CMC_100K	100kΩ calibration
0x03	CMC_1M00	1MΩ calibration
0x04	CMC_10M0	10MΩ calibration
0x05	CMC_100M	100MΩ calibration
0x06	HRC_1	Heater resistance measurement calibration with 3Ω load resistor
0x07	HRC_2	Heater resistance measurement calibration with 9Ω load resistor
0x10	WRITE_1	Writing the calibration data set from this command to the persistent flash memory data set 1.
0x20	WRITE_2	Writing the calibration data set from this command to the persistent flash memory data set 2.
0xFF	STORE	SU exits calibration mode and discards the measured calibration values
0xF0	ABORT	SU exits calibration mode and stores the measured calibration values to the persistent flash memory

Table 3-6: Science Unit responses

Kommentar [PR1]: Redefine the Modes according to real software

3.8 SU responses

Response	RSP_ID	DATA LEN	DATA	Description
SU_R_ACK	0x02	0	-	acknowledge response
SU_R_NACK	0x03	1	EFLAG	negative acknowledge response
SU_R_ID	0x04	1	IDFLAG	identification message
SU_R_HK	0x20	46	HK Data	Housekeeping data packet
SU_R_SDP	0x30	variable	Science Data	Science Data Package
SU_R_CAL	0x33	40	Calibration Data	All calibration values

Req: FPX-SW-0590

Table 3-7: Science Unit responses

SU_R_ACK

Req: FPX-SW-0600

Acknowledge message for successful reception of the last command.

SU_R_NACK

Req: FPX-SW-0610

Non-acknowledge message for an error during reception of the last command.

The DATA contains a 1 Byte Flag, called EFLAG. The EFLAG is defined as in **Table 3-8**.

EFLAG value	Name	Description
0x00	-	not used
0x01	SyncError	Packet reception timeout. Shall be issued when a packet is not completed and no new bytes are received for 100ms.
0x02	FCSError	Frame Check Sum (XOR) wrong. Shall be issued when a packet is received completely, but the XOR checksum is wrong.
0x03	wPID	Parameter ID unknown. Shall be issued when a parameter ID should be set with SU_SP which is not known
0x04	POOR	Parameter out of range. Shall be issued when a parameter should be set out of the defined range.
0x05	wMode	Shall be used if a commanded state change is not allowed
0x06	wCMD	Wrong command. Shall be issued when the CMD_ID is not known.
0x07	wLEN	LEN wrong

Table 3-8: Req: FPX-SW-0620 EFLAG values

SU_R_ID

Req: FPX-SW-0625

This response contains the serial number of the SU.

SU_R_HK

Req: FPX-SW-0630

This response contains the latest housekeeping data. The DATA field of this packet is shown in **Table 3-9**.

Req: FPX-SW-0631

If the OBC receives a SU_R_HK packet, it shall store the packet according to chapter 3.4.

Byte	Name	Size (Byte)	Description
0	VERSION	1	SU software version
1	ID	1	SU serial number
2	TIME	4	Current SU internal timer reference in 0.1s since switch on
6	time_heat	2	PARAMID 0x00
8	time_delay_anode	2	PARAMID 0x01
10	meas_time	2	PARAMID 0x02
12	sensor	2	PARAMID 0x04
14	cold_resistance_1	2	PARAMID 0x05

16	cold_resistance_2	2	PARAMID 0x06
18	meas_interval	2	PARAMID 0x07
20	stm_interval	2	PARAMID 0x08
22	set_temp	2	PARAMID 0x64
24	set_max_anode	2	PARAMID 0x65
26	set_reference	2	PARAMID 0x66
28	STATUS_REG	2	See **Table 3-10**
30	STM sample	9	STM sample
39	FIPEX sample	7	FIPEX sample (only if available, e.g. in case of SENSOR CHECK operation)

Kommentar [PR2]: Add CALIBRATION Mode

Table 3-9: HK DATA field structure

STATUS Register

Req: FPX-SW-0640

The STATUS_REG bits are defined as:

Bit	Comment -16-bit register
15	ADC error: ADC test fails, which can be caused by ADC, DAC or microcontroller failure.
14	Heater error: heater can't reach set point resistance/temperature
13	Anode regulation error: cannot reach set point reference voltage
12	Data buffer error: undefined, to be ignored
11	Heater_State: 0: off, 1: on
10	Supply Voltage error: 5V supply cannot be read back
9	Sensor Voltage error: set anode voltage cannot be read back
8	Sensor Current error: undefined, to be ignored
7	Heater voltage error: set voltage cannot be read back
6	Heater Current error: set heater voltage does not lead to current flow
5	XOR error
4..2	Undefined, to be ignored
1-0	STATE: 00 STANDBY 01 ERROR 10 SCIENCE 11 SENSOR CHECK

Table 3-10: Housekeeping Status Register

SU_R_SDP

Req: FPX-SW-0650

The SU_R_SDP is the SU science data package. It will be send by the SU during the SCIENCE and STANDBY state.

The structure of the DATA field of the SU_R_SDP is shown in **Table 3-11**. It contains multiple samples of FIPEX and/or STM. Every sample is preceded by a 1-byte sample header. The header contains a type field, which indicates what type of sample is following the header. The size of the samples is 7 byte for FIPEX and 9 byte for STM. The rest of the SU_R_SDP packet is as defined in **Table 3-3**.

Req: FPX-SW-0660

Byte	Name	Size (Byte)	Description
0	TIME_FIPEX	4	Time of first FIPEX sample in this packet since SU switch on in 0.1s
4	TIME_STM	4	Time of first STM sample in this packet since SU switch on in 0.1s
8	ID	1	SU serial number
9	SAMPLE_HEADER1	1	See **Table 3-12**
10	SAMPLE1	7/9	STM (9 Byte) or FIPEX (7 Byte) data sample. See **Table 3-13** and **Table 3-14** for details.
18/20	SAMPLE_HEADER2	1	
	…		
	SAMPLE_HEADERn	1	
	SAMPLEn	7/9	

Table 3-11: SU_R_SDP DATA field structure

Req: FPX-SW-0680

Bit	Name	Size (Bit)	Description
0..2	GAIN	3	sensor gain
3..5	Sensor	3	selected sensor
6	Type	1	Indicating the sample data block type to follow the header. 0: STM sample, 1: FIPEX sample
7	Last	1	indicating the last in packet

Table 3-12: SAMPLE_HEADER bit definitions

Req: FPX-SW-0690

Bit	Name	Size (Bit)	Description
0..11	CH0	12	raw ADC value of STM channel 0
12..23	CH1	12	raw ADC value of STM channel 1
24..35	CH2	12	raw ADC value of STM channel 2
36..47	CH3	12	raw ADC value of STM channel 3
48..59	CH4	12	raw ADC value of STM channel 4
60..71	CH5	12	raw ADC value of STM channel 5

Table 3-13: STM sample data structure

Req: FPX-SW-0700

Bits	Name	Size (Bit)	Description
0..11	SENSOR_CURRENT	12	raw ADC sensor current
12..23	HEATER_VOLTAGE	12	raw ADC heater voltage
24..35	HEATER_CURRENT	12	raw ADC heater current
36..47	ANODE_VOLTAGE	12	raw ADC anode voltage
48..55	REFERENCE_DELTA	8	reference voltage controller error

Table 3-14: FIPEX sample data structure

SU_R_CAL

SU_R_CAL contains the calibration values of the sensor electronic.

Byte	Name	Size (Byte)	Description
0	HEATER_OFFSET	2	Time of first FIPEX sample in this packet since SU switch on in 0.1s
2+2n	SENSOR_CURRENT_SCALE_FACTORn	2	Time of first STM sample in this packet since SU switch on in 0.1s

3.9 Example SU Command Sequence Script

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

OBC_SU_ON @01:00	
SU_SC @01:00	
SU_SP 0x04 0x01 00 00 @NOW	Sensor = 1

SU_SP 0x05 0x10 0a 00 @NOW	cold_resistance_1 = 0x0a10
SU_SP 0x02 0xC8 00 00 @NOW	meas_time = 200
SU_SM @05:00	
SU_HK @NOW	
SU_DP @NOW	
OBC_SU_OFF @NOW	
OBC_SU_END	

Table 3-15- SU Commanding Script Example

Req: FPX-SW-0710

1) The Delay field "@d" is NOT sent to the SU, but interpreted by the OBC as the delay to wait until the next is to be executed. @d is given in the format: mm:ss. When "@d" is set to "@NOW", the OBC shall execute the next command immediately.

A byte encoded command script for the initial start time 01.01.2014 12:00 UTC and a defined repeat interval of 1 hour will look like:

Header:

43 C0 BF 56 1A 10 0E 0A

Commands:

7E 0F 00 0F 3C 00

7E 0B 00 0B 3C 00

7E 11 03 04 01 00 17 FF FF

7E 11 03 05 10 0A 0D FF FF

7E 11 03 02 C8 00 D8 FF FF

7E 0C 00 0C 2C 01

7E 20 00 20 FF FF

7E 21 00 21 FF FF

7E F0 00 F0 FF FF

7E FF 01 FE

4. Mechanical interface

4.1 Coordinate System

Req: FPX-E-0230

The body fixed coordinate system of the science unit is defined in Appendix 1. The Z-Axis points in the direction of the connector into the Cubesat structure. The Y-Axis is defined along the longer side of the sensor unit housing and the X-Axis is defined accordingly for a right-handed orthogonal coordinate system.

4.2 Accommodation and Field of View

The Science Unit will be accommodated at one end of the CubeSat, on a 100 mm x 100 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 (see **Figure 4-1**).

Req: FPX-E-0240

The electrical interface connector shall be attached via cable to take manufacturing uncertainties into account.

Req: FPX-E-0250 [deleted]

Req: FPX-E-0260 [deleted]

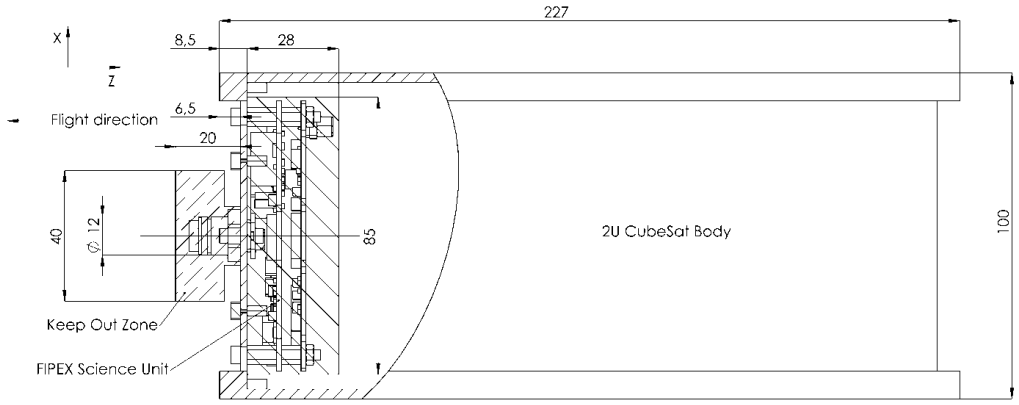


Figure 4-1 – FIPEX Science Unit Keepout Areas within CubeSat details see Interface control drawing

Req: FPX-E-0270

The mechanical interface drawing is provided in Appendix 1. The Science Unit is designed to interface to commercially available CubeSat structures through the location of mounting holes as given in Appendix 1. The CubeSat shall provide the required accommodation according to the Interface Control Drawing.

4.3 Surface finish

Req: FPX-E-0280

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

4.4 Mass

Req: FPX-E-0290

The total Science Unit mass shall be 160 grams. This includes a margin off 10%

5. Attitude Control

Req: FPX-E-0300

The CubeSat shall provide attitude control during measurement with a pointing accuracy of +/-10° and pointing knowledge of +/-2°. The Z- direction shall be pointing in RAM direction.

Req: FPX-E-0310

The ATTITUDE shall be defined in a local horizontal, local vertical coordinate system (RST). R is pointing in flight direction, S is pointing to earth (NADIR) and T is defined accordingly for a right-handed orthogonal coordinate system.

The attitude information shall be attached as quaternion and angular rate as defined in section 3.4.

The attitude quaternion defines the rotated position of the body fixed coordinate system in RST. It is defined through the rotation axis E and the angle θ. The quaternion follows as:

$$q = i\,q_1 + j\,q_2 + k\,q_3 + \,q_4 = \left[E^T \cdot sin\frac{\theta}{2} \quad cos\frac{\theta}{2}\right]^T, i^2 = j^2 = k^2 = -1$$

The angular rates xdot, ydot, zdot define the rotation rate around each of the body fixed axes X, Y and Z.

Req: FPX-E-0320

The POSITION shall be given in an earth centered, earth fixed coordinate system (XYZ) where X and Y are in the equatorial plane and X is pointing to the prime meridian (International Reference Meridian, IRM). Z is pointing in the direction of the International Reference Pole (IRP).

NOTE: Example positions are (X,Y,Z)=(13142,0,0) at latitude = 0, longitude = 0, altitude = 200km and (X,Y,Z) = (0,0, -13142) at latitude=-90°, altitude =200km, longitude = 0..360°

Req: FPX-E-0321

The CubeSat carrying the FIPEX SU shall determine its position to within 10 km accuracy

6. Cleanliness and Contamination

Req: FPX-E-0330

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.

7. Handling, Operating and Ground Conditions

Req: FPX-E-0340

The Science Unit shall be handled in a cleanroom environment (class 100.000, ISO 8). ESD protection shall be followed according to IEC-61340-5-1.

Req: FPX-E-0341

Handling, storage, transportation, tests und operation shall be according to FIPEX handling manual [AD-2]

Req: FPX-E-0350

All operation cases, tests, non-ambient environment, commands sent to FIPEX shall be recorded using a standard logbook as live cycle record and shall be kept with the FIPEX unit.

Req: FPX-E-0360

A log of ALL mate/de-mates of the connector to FIPEX MDM25 connector shall be recorded.

Req: FPX-E-0370

The sensor unit mounted with tests/dummy sensors can be fully operated under standard environmental conditions for ground testing.

In operation (SCIENCE state of the sensor unit) the sensitive element of the sensor is heated to about 600 degree. Therefore no flammable materials shall be placed nearby.

Req: FPX-E-0380

The sensors shall not be touched in operation mode.

Req: FPX-E-0390

The sensors shall not be touched in non-operation mode.

In case of an accidental touch, the complete unit shall not be switch on. TU Dresden personnel shall exchange the sensors, only.

Req: FPX-E-0400

Sensor Units with Flight sensors shall only be operated under low pressure conditions (max. allowed pressure 10^{-4} mbar). Flight sensors must not be touched at all. The Sensor Unit shall only be integrated a maximum of 10 times. This includes also if only the connector cable is attached without using a connection saver. Each handling must be documented in the life book.

Req: FPX-E-0440

The FIPEX red painted covers are provided as part of the deliverable unit and shall not be removed during ground tests.

Req: FPX-E-0450

The FIPEX red painted covers shall be removed as late as possible before flight by trained personal.

8. Verification

Req: FPX-E-0455

A minimum of one fit check shall be conducted, in which SU shall be integrated into the CubeSat.

Req: FPX-E-0456

A minimum of one interface test shall be conducted, in which the OBC operates the SU according to predefined test command files

Req: FPX-E-0460

The verification will be done with the flight model and test/dummy sensors. Two tests are mandatory:

- Fit check
- Operation Test

For the operation tests command scripts and the expected OBC behaviour will be provided.

Req.: FPX-E-0461

The SU shall remain mounted into the CubeSat after verification.

NOTE:

The flight model SU shall be mounted to the CubeSat by the regarding team. At this stage the mounted sensors are dummy sensors. The replacement of those sensors will take place at ISIS and will be conducted by either ISIS, MSSL or TU Dresden personnel.

9. Storage Conditions

Req: FPX-E-0470

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) must be stored under defined and known conditions. Storage conditions should be purged, dry air, slightly increased standard pressure and standard temperature. Storage conditions must be supervised and logged.

Storage under a nitrogen protection atmosphere at residual oxygen level is possible, but must be specified.

10. Thermal Requirements

Req: FPX-E-0475

Operational Temperature Range	-20°C to +40°C
Non-Operational Temperature Range	-30°C to 65°C
Minimum Switch-On temperature	-10°C

Table 16 – Thermal operating requirements

11. Corner Cubes

Req: FPX-E-0480

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).

CCRs can be supplied to teams who wish to implement them. These are supplied by Edmund Optics. The proposed CCR lens material is N-BK7.

The options for the CCR are:

- Part number: #45-203 (12.7 mm Mounted Corner Cube Reflector)
  URL: http://www.edmundoptics.com/optics/prisms/retroreflection-prisms/mounted-n-bk7-corner-cube-retroreflectors/45203
- Part number: #45-296 (12.7 mm Unmounted Corner Cube Prism)
  URL: http://www.edmundoptics.com/optics/prisms/retroreflection-prisms/n-bk7-corner-cube-retroreflectors/43296

Appendix 1 – Mechanical Interface Control Drawing

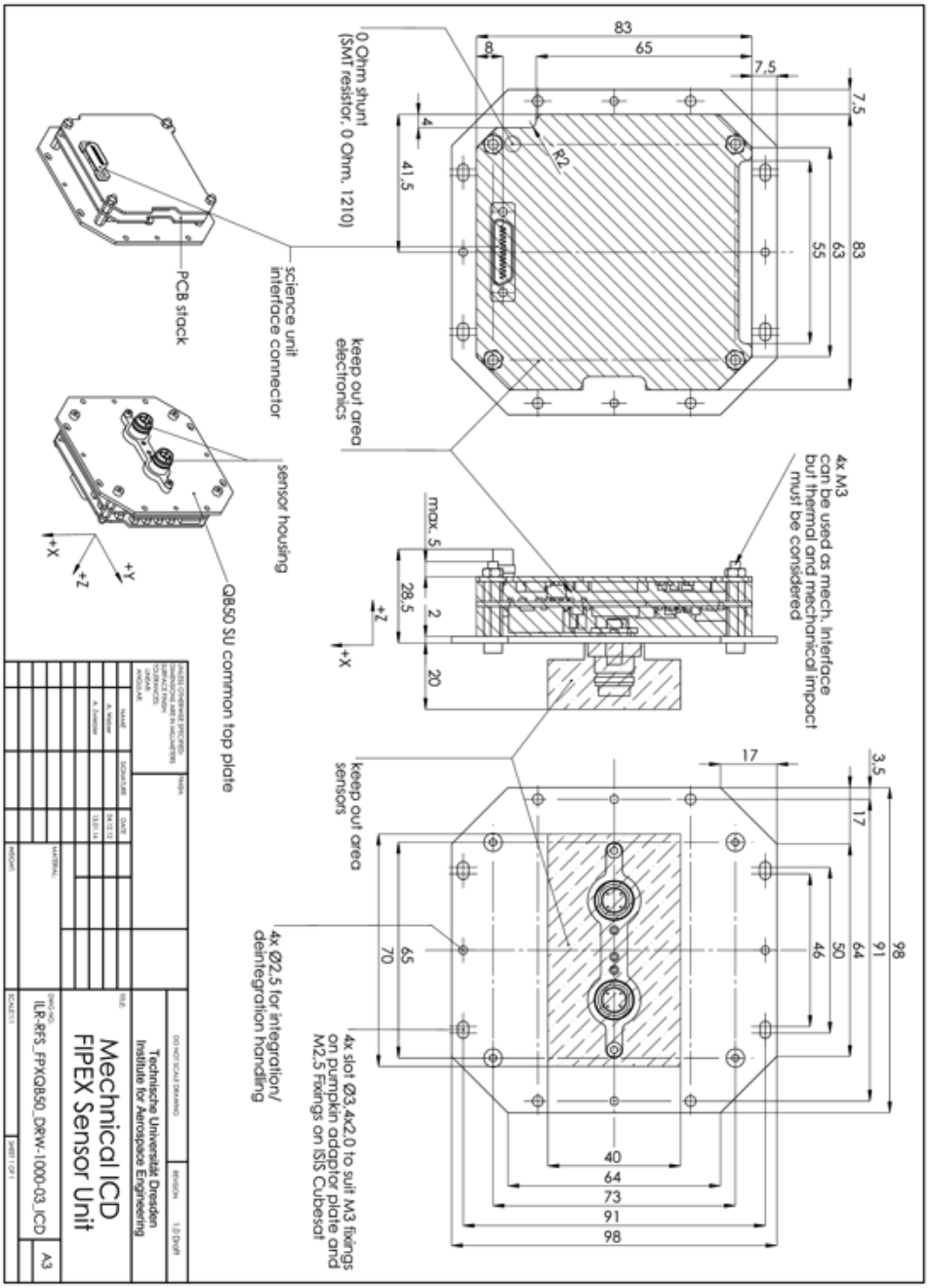


Figure **0-1**: FIPEX SU mechanical drawing