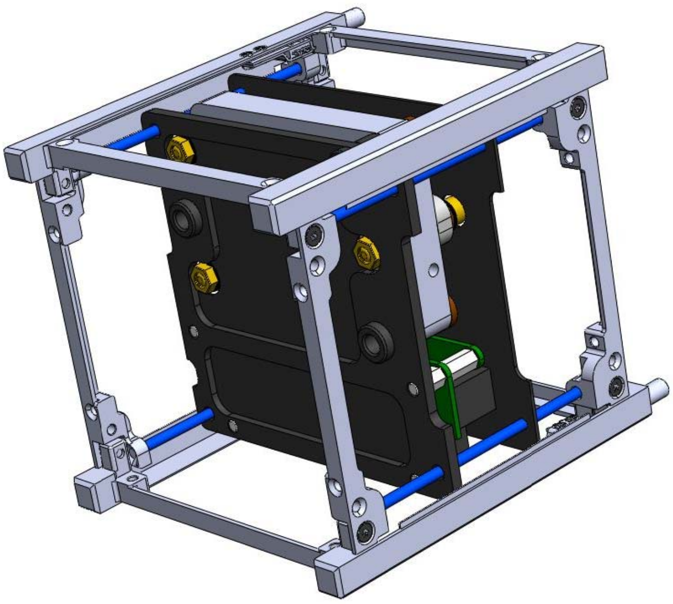
User Manual

AGI-Acc_CubeSat



ASSIST IN GRAVITATION AND INSTRUMENTATION

Assist in Gravitation and Instrumentation srl
AGI-Acc_CubeSat
AGI accelerometer for Cube Sat
User Manual

Contents

DOCUMENT CONTENTS

The present documents is the user manual of the AGI-Acc_CubeSat accelerometer developed by the AGI srl. The document reports the necessary informations to use it. After a brief introduction (Section 1) will follow two sections, which reports respectively:
a) Information for the use of the instrument on ground ie operations concerning the preliminary verification of its integrity, functionality and calibration.
b) Information for its installation and use on board of a CubeSat. Particularly this section reports the details of all the mechanical, electrical and software interfaces.

1 INTRODUCTION

The AGI-Acc_CubeSat (Accelerometer for CubeSat) is a very compact instrument with high accuracy, working at low frequencies and specially developed for space use, to integrate on board a CubeSat, as shown in the previous figure.

A CubeSat is a standard of nano-satellite for space research that can combining 1, 2 or 3 satellite units (U), each one having a volume of exactly one liter (10 cm cube), and a mass not larger than 1.33 kilograms, that uses commercial off the-shelf (COTS) components for its electronics, offering the advantages to permit space mission in short time-scale and with low cost, mainly because they are usually launched as 'piggyback'.

In order to save power the AGI-Acc_CubeSat is not thermal stabilized, but the temperature effects can be removed at some level using the measure performed with a high sensitive thermometer installed on it.

The data acquisition system (DAQ) is embedded and easy to use: the AGI-Acc_CubeSat only needs an RS232 communication channel and 5 V power supply to work.

In the figure_1 is shown the AGI-Acc_CubeSat accelerometer (the yellow lines are its maximum dimensions), while in the first page figure it is shown the accelerometer integrated in a standard CubeSat

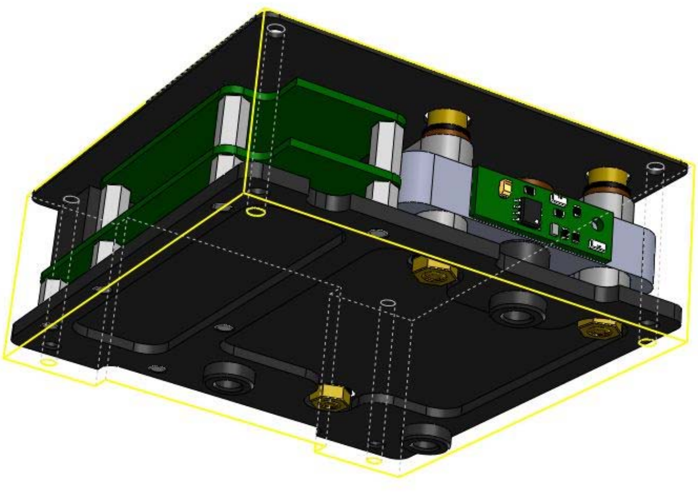


Figure_1 *AGI-Acc_CubeSat.*

1.1 Principle of operation

The AGI-Acc_CubeSat is basically one single axis accelerometer which measures the acceleration along one direction (i.e. the along-track direction). Indeed, this acceleration produces the displacement of a harmonic-oscillator proof-mass which is measured by a pick-up electronic. The output voltage $Vout$ changes with the acceleration a according with a linear relation:

$$V_{out} = a\rho - \beta.$$

Finally, the DAQ samples and acquires this voltage and then converts it to m/s^2 acceleration using the following formula:

$$a_g = (V_{out} + \beta) \cdot \alpha$$

Temperature Rejection - As already told, in order to reduce the false signals due to the temperature variations is used a thermometer.

The temperature measurements (T_S) are useful during the data analysis phase to remove part of the fake signal a_T detected as an acceleration, indeed the correct acceleration a is deduced by the measured one (a_m) using the following formula:

$$a = a_m - a_T$$

a_T is in first approximation given by the following relation:

$$a_T \approx \gamma \cdot T_S$$

in which γ is the conversion-factor of the temperature into acceleration assuming different values between different accelerometer; it is experimentally evaluated in the lab or from the acquired data; it mainly depends on the material used to build the sensor (aluminium) and its value is $|\gamma| \approx -5 \cdot 10^{-3}\ m/s^2/°C$. In order to correctly use the Eq. 1, it may also be necessary to adjust the phase misalignment. The DAQ makes the AGI-ACC_CubeSat very easy to use and to interface with other acquisition systems: it is able to sample, acquire, filter the measurements and send them through an RS232 port with NMEA serial standard.

2 ON-GROUND USE OF THE AGI-ACC_CUBESAT

2.1 List of the deliverable and first verifications and operation.

In the following is reported the list of the delivered parts.

1) AGI-Acc_Cubesat accelerometer.
2) Mechanical Structure for on ground calibration.
3) USB cable for the connection to a PC for operation on ground.
4) Integration cable with connector for use with the CubeSat.
5) Spare Part (auxiliary screws).
6) Windows compatible software for data acquisition and calibration.

In the following figure is shown the hardware parts placed inside of the transport case. It is necessary to note that the AGI-Acc_Cubesat accelerometer is already assembled into the mechanical structure for ground calibration.

Figure_2 *In the following figure is shown the hardware parts placed inside of the transport case.*

In the first phases of on ground calibration, the AGI-Acc_Cubesat accelerometer must be maintained in the Mechanical Structure for on ground calibration in order to guaranty its integrity and functionality.

Assembly and disassembly of the AGI-Acc_Cubesat accelerometer from the Mechanical Structure for on Ground Calibration (MSGC) can be done removing the lateral face of the MSGC marked by the four protruding screws of light gray color; the four screws (also gray) embedded on the rear side are then unscrewed. In the following figure is shown the AGI-Acc_Cubesat accelerometer inside the MSGC with a lateral face removed.

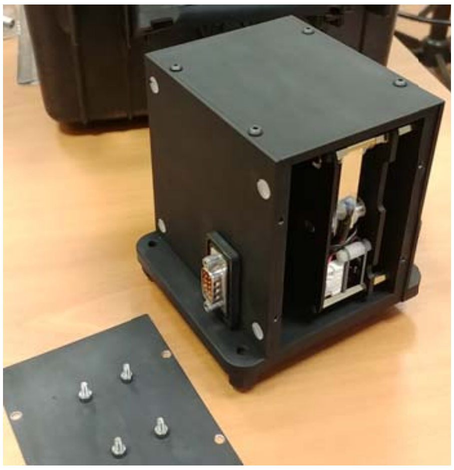


Figure_3 *In the figure is shown the AGI-Acc_Cubesat accelerometer inside the MSGC with a lateral face removed.*

At this stage it is possible to proceed extracting gently the AGI-Acc_Cubesat accelerometer and disconnecting the blue connector.

2.2 Use of the AGI-Acc_Cubesat accelerometer on ground.

To use the AGI-Acc_Cubesat accelerometer on ground is necessary to maintain it installed in the MSGC and proceed with the following steps:

a) The MSGC must be placed over a flat horizontal plane.
b) Connect the MSGC port DB9 to a computer using the USB cable.
c) Installation of the Driver on the PC.
d) Installation of the "CubeSatTool.exe" application.

Figure_4 *In the figure is shown the MSGC with the USB cable connected to it.*

In the previous figure are shown the MSGC with the USB cable connected to it and disposed over a horizontal plane (steps one and two)

2.2.1 Installation of the drivers in the PC

Concerning the installation of the drivers in your PC with a Windows operative system, in the majority of the case they will be installed automatically, otherwise the easiest way to install them for

Windows Windows 7,
Windows Server 2008 R2,
Windows 8, 8.1,
Windows server 2012 R2,
Windows 10.

is by downloading and installing the program at the following link:
http://www.ftdichip.com/Drivers/CDM/CDM21228_Setup.zip

It works for both 32bit and 64bit Windows operating systems.

For old Windows operating systems including:

Windows XP, Vista, Server 2003, Server 2008, download the VCP driver from the FTDI website near the bottom of the page under "No Longer Supported":
http://www.ftdichip.com/Drivers/VCP.htm

After the correct drivers installation the system has to show a new virtual serial port, check it on your Windows Device Manager list.

2.2.2 Installation of the “CubeSatTool.exe”:

After the successful installation of the driver, for install the “CubeSatTool.exe” application on the PC, it is sufficient to copy the executable file supplied with the accelerometer into a folder you prepared. The application is compatible with all Windows systems (32/64 bit). When the executable will be launched, on the screen will appear the following window image.

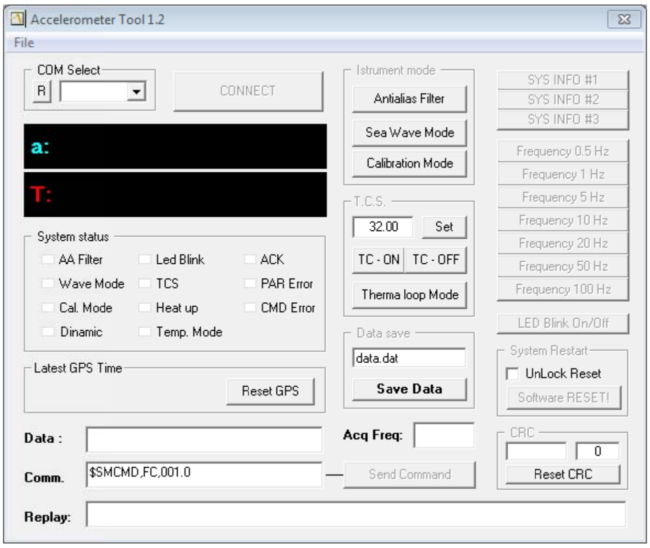


Figure_5 *Appearance of the display after that the executable will be launched.*

- As first step it is necessary to select the communication port where it is installed the Virtual COM, as show in the following figure_6.

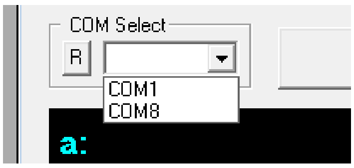


Figure_6 *Particular of the COM Select appearance of the display after that the executable will be launched.*

If no COM will appear, it is necessary to control the correctness installation of the drive, in the Windows Device Manager.

- As second step it is necessary to click on the CONNECT button to start the data reading of the AGI-Acc_Cubesat accelerometer. The following figure shows the image of what will appear on the display of the PC, indicating the commands at disposition.

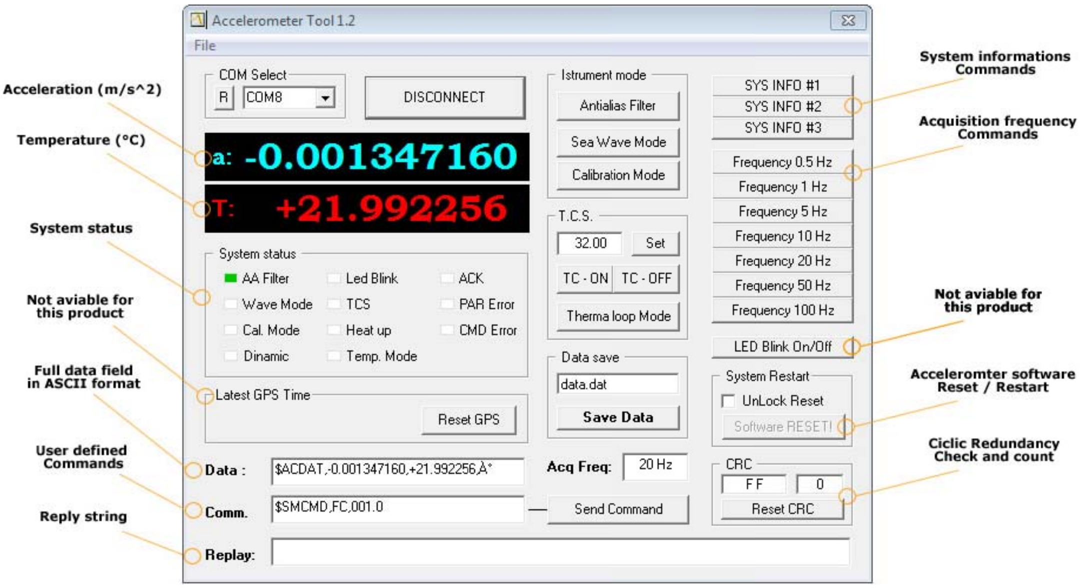


Figure_7 *Appearance of the display after that the connect button will be pressed.*

2.3 Tests of the AGI-Acc_Cubesat accelerometer.

2.3.1 Calibration structure

As we will see in the following paragraph the procedure of the accelerometer calibration in laboratory, uses the well know small components of the local Earth gravity to impose to the accelerometer and controlling the corresponding read-out. The validity also in space of the evaluated transducer-factor in laboratory is ensured if the main parameters of the accelerometer remain unchanged from the laboratory calibration procedure to space operations. The transducer factor is determinate by the following parameters:

a) Mechanical frequency of the harmonic oscillator.
b) Factor converting the mass test displacements into voltage (capacitive transducer).
c) Amplification factor.

Usually the last two parameters remain unchanged between the lab and space condition, this is not the case for the first parameter if the calibration will not be performed keeping the oscillator in order that it is as in a free-fall condition with no effects of the Earth gravity, otherwise its natural frequency will be affected by a pendulum effects that increase its value. The necessary condition of free-fall (zero g) during the calibration is obtained keeping the proof mass in a “flag condition” as shown in the figure_8

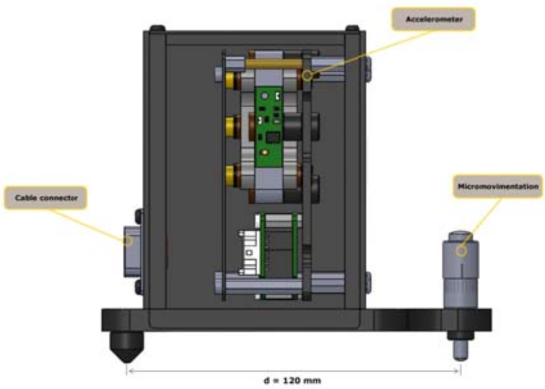


Figure_8 *Disposition of the AGI-Acc_CubeSat for the on ground calibration with the proof mass in a “flag position”*

This is one of the main requirements for the implementation of the AGI_Acc-CubeSat calibration structure.

Usually the procedure of calibration are performed putting the accelerometer sensitive axis in a plane perpendicular to the local gravity, successive micro inclination of this plane will produce small component of accelerations that act on the accelerometer. Small values of the inclination of the plane in radiants will gives accelerations components in g.
When the accelerometer is installed in the calibration structure and this is placed in the horizontal plane, so that the local gravity is perpendicular to it, factory adjustments was been performed in order that the accelerometer output is close to zero and this is what we aspect when the system is in orbit.
In the figure_9 is shown the pictures of the calibration facility with a precise level and the display of the accelerometer so to verifying the correctness of the close to zero exit when it's sensitive axis is in an horizontal plane.

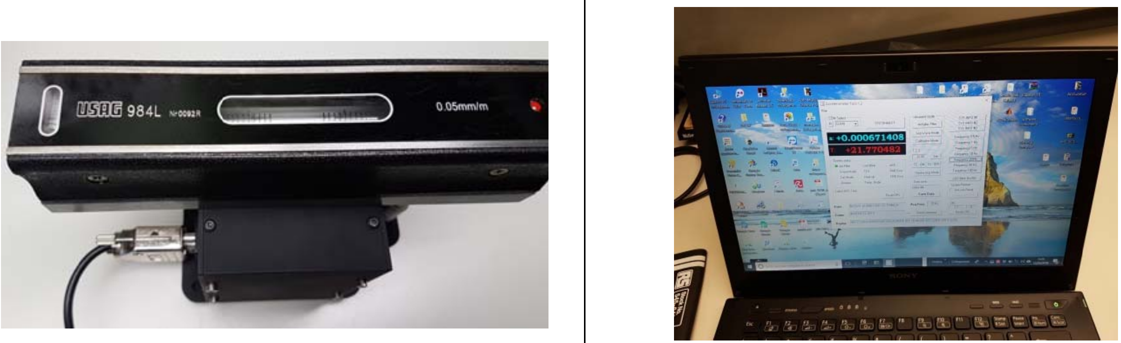
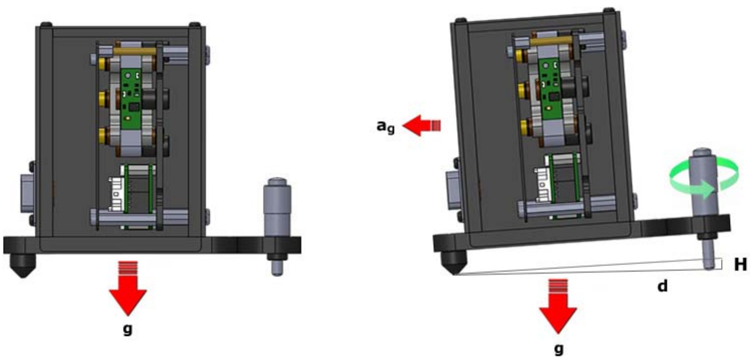


Figure_9 *In the figures are shown the pictures of the calibration facility with a precise level and the display of the accelerometer exit, so to verifying the correctness of the close to zero exit when it's axis is in an horizontal pane.*

In the following are reported the drawing of the calibration principle showing the structure, installed on it the AGI-Acc_CubeSat and the micrometric screw permitting to change the components of g acting on the accelerometer.



$$a_g = g * \sin(H/d)$$

Figure_10 *Drawing of the principle of calibration showing the CS structure unit with the AGI-Acc_CubeSat installed on it and the micrometric screw permitting to change the components of g acting on the accelerometer.*

2.3.2 Calibration procedure

2.3.2.1 Transducer factor determination

The well-known acceleration of gravity is used to calibrate the instrument. This had already been done before the delivery, but the calibration must be repeated to ensure functionality of the unit. For this test, the calibration test with the AGI-Acc_CubeSat installed on it was posed on an adjustable inclinable plane, as shown previously in figure_9. Starting whit a position far from the equilibrium position, it is possible to change the position of the micrometric screw making steps of $100\mu m$ and recording the exit values of the instrument. The result of this calibration is shown in the figure_10 reporting the accelerometer output values as function of angle transformed also in acceleration in m/s^2.

Note.
For this last transformation it is necessary to remember that the angle of inclination in radiants (for small angle) is equal to an horizontal component of the Earth gravity in g. For example, one step with the micro-metric screw of $100\ \mu m$ for a distance $H = 120mm$ as shown in the figure_10, is equal to an angle of $0{,}83\ 10^{-3}\ rad$ corresponding at an acceleration of $0{,}833\ 10^{-3}\ g = 0{,}814\ 10^{-2}\ m/s^2$

The slope of this curve is $-0{,}98\ \left[\frac{m}{s^2}/\frac{m}{s^2}\right]$ while the expected value must be 1, indicating that the used calibration factor is correct into 2%.

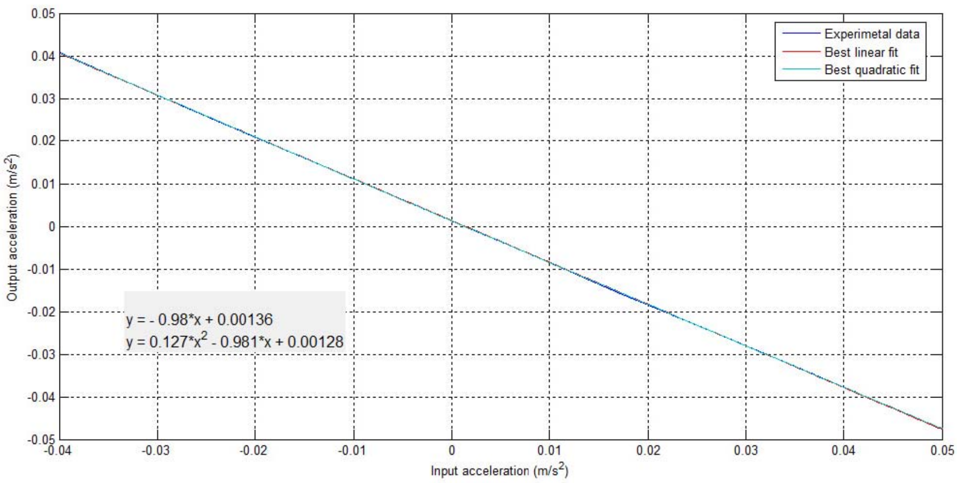


Figure_11 *Accelerometer gravity calibration curve.*

2.3.2.2 Linearity

From the previous calibration it is possible to see that the Acc_AGI is quite linear for signals ranging from $\mp 0{,}04\ m/s^2$. It can respond also at more big signals but the quadratic effects will increase.

Considering the that the coefficient for the quadratic effects is equal to $K_q = 0{,}127$ its effect is down -80dB for signals below $10^{-3}\ m/s^2$ (To remember that the quadratic effects increase with the amplitude of the signal to detect).

2.4 Test of the AGI-Acc_Cubesat accelerometer seismic noise acquisition.

For this test, the AGI-Acc_CubeSat was optimally protected from external perturbations and positioned in a very quite place, see Figure_11. The measured time series, acquired with a sampling frequency of $20Hz$ during several hours was then Fourier analysed, see power spectrum in Figure_12. The expected noise level of $10 - 7g/\sqrt{Hz}, i.e. 10 - 6m/s\ ^{2}/\sqrt{Hz}$ is seen to be verified.

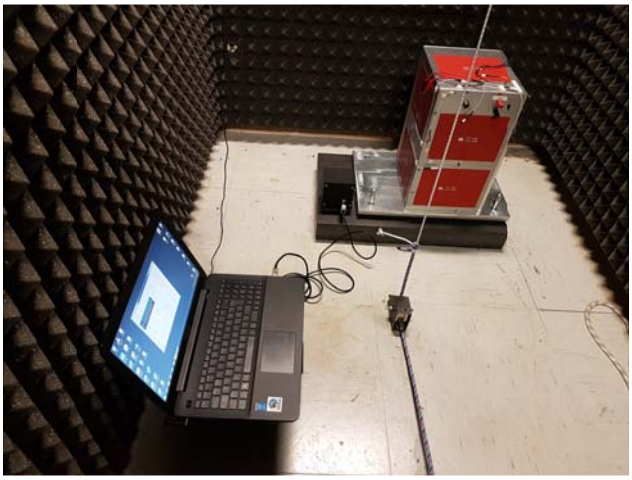


Figure_12 *AGI-Acc_CubeSat disposed in a quiet place to perform the test noise.*

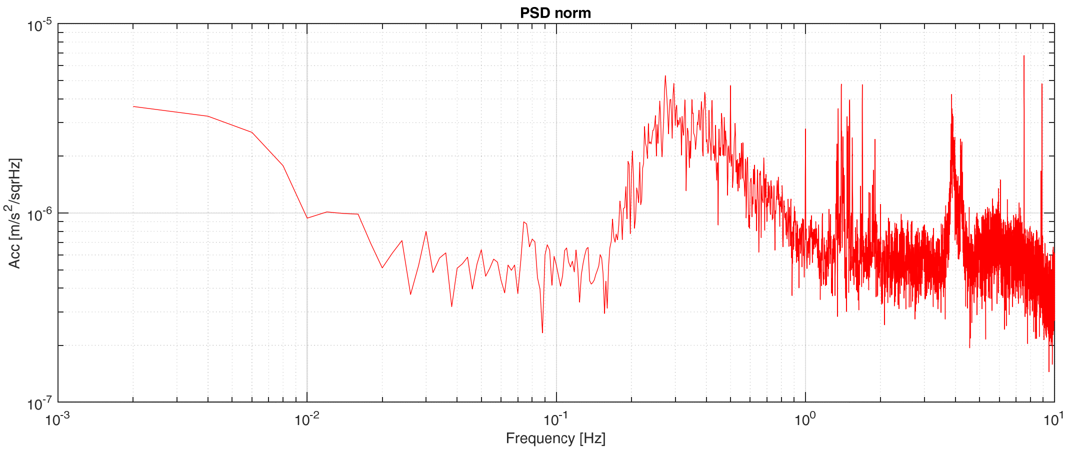


Figure 13 *Accelerometer noise power spectrum.*

3 USE OF THE AGI-ACC_CUBESAT WHIT THE CUBESAT

In the following of this section, divided into four subsections are reported the data sheet and the interfaces for the use of the AGI-Acc_CubeSat on board of a standard CubeSat.

a) AGI-Acc_CubeSat data sheet.
b) Electrical interfaces.
c) Software interfaces.
d) Mechanical Interfaces

3.1 Accelerometer Data Sheet

In the table_1 is reported the accelerometer data sheet.

Table_1 Acc_AGI main characteritics

Caracteristics	Value
Sensitivity	$10^{-6} - 10^{-7}\ {}^{m}/_{s^2}/\sqrt{Hz}$
Acquisition Frequency (Hz)	0.5, 1.5, 10, 20
Output	Digital
Data rate (10Hz acc and T)	$330\ (byte/sec)$
Internal thermometer Pt10000	Sensitivity better than $10^{-4}\ (°C)$
Interface of communication	RS232 full-duplex/rate; RS485 with adapter
Standard of communication	NMEA
Dimension	80X55X25 (mm)
Weighs	0,320 (Kg)
Voltage supply via USB or exter-nal	5 (V)
Dynamic	120 dB
Power Dissipation	150 (mW)
Linearity	> 80 dB

There is also the possibility to implement an active thermal control, with the necessary power dissipation strictly connected to the temperatures variations to compensate, to their frequencies and to the preliminary knowledge of the average value of the in orbit temperature.

3.2 Electrical interface

3.2.1 Connector position

The accelerometric module is provided with eight pin male connector (P6), it is the primary electrical interface connector. Here are reported the connector pin-out and functionality as well as electrical signal specification. The following picture shows the P6 connector position:

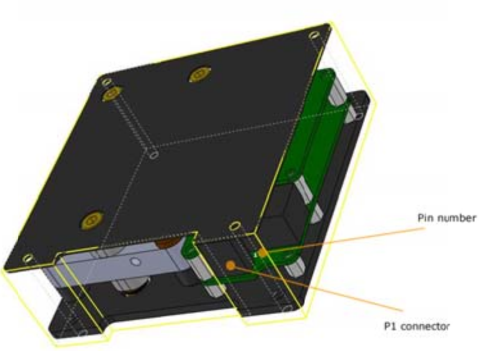


Figure_14 *Position of the connector in the AGI-Acc_CubeSat*

The connector number and the pin number 1 is show on the printed circuit board too; a one-side, wired, 0.4m length cable with female connector is provided with the accelerometer.

3.2.2 Connector pin-out and functionality

The following picture shows the P6 connector pin-out:

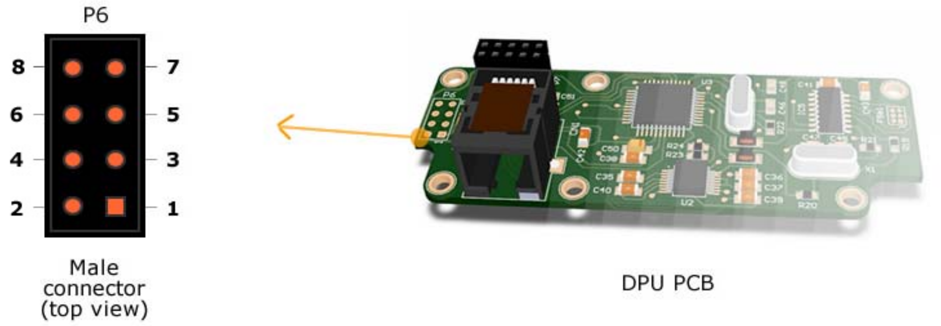


Figure_15 *AGI-Acc_CubeSat electronic indicating the P6 Connector*

The following table shows pins functionality :

Pin number:	Electrical type:	Max:	Min:	Functionality:	Cable wire color:
1	Input			GND	Black
2	Input	+4.8 V	+5.2 V	+5 V	Red
3	N.a.			N.C.	N.a.
4	N.a.			N.C.	N.a.
5	Input			Rs232-GND	Blue
6	N.a.			N.C.	N.a.
7	Input	+5.2 V	+4.8 V	Rs232-RX	Green
8	Output	+5.2 V	+4.8 V	Rs232-TX	Yellow

3.2.3 Serial interface specification

Data telemetry and commands are managed via three pin serial asynchronous interface. The asynchronous link is a fully compliant RS232 standard with the following parameters:

Parameter:	Value:
Boudrate:	115200 bit/s
Voltage levels:	+/- 5V
Parity:	None
Data bit:	8 bit
Stop bit:	Yes (1)

3.2.4 Power consumption

The system total average power consumption is 150mW +/- 10% in standard operation mode. Boot sequence takes 1.5 seconds to complete, in this short time the system power consumption can arise to 300mW +/- 10%.

3.3 Software interface

The accelerometer provide telemetry as well as telecommand via NMEA 0183 standard serial protocol. More information about NMEA protocol can by find at following link:

http://www.nmea.org/content/nmea_standards/nmea_0183_v_410.asp

3.3.1 Accelerometer telemetry format:

After power up sequence, accelerometer starts to send telemetry via serial interface at desired frequency that can be chosen via telecommand. Factory made frequency is fixed at 20Hz (twenty samples per second). The data in ASCII format is 38 bytes long string, showed in the following picture:

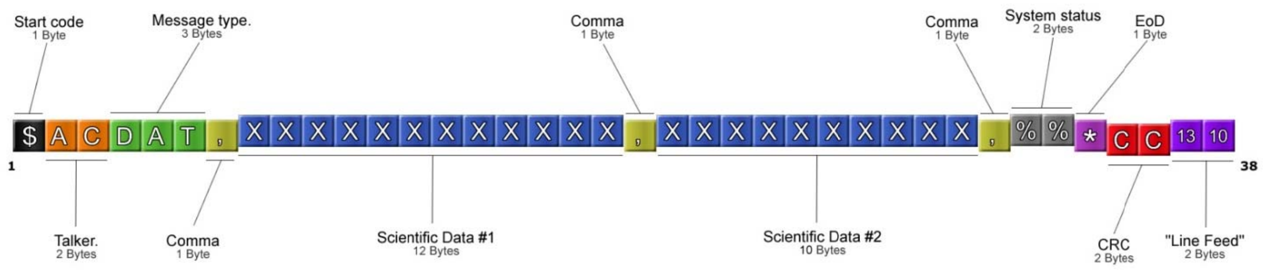


Figure_16 *Data in ASCII format is 38 bytes long string.*

The following table describes the data field in detail:

Data	Bytes	Offset	Description	Min value	Max value
$	1	1	Fixed start code	N.a.	N.a.
AC	2	2	Fixed talker code	N.a.	N.a.
DAT	3	4	Fixed telemetry type	N.a.	N.a.
,	1	7	Fixed comma data delimiter	N.a.	N.a.
Scientific data #1	12	8	Acceleration (m/s^2)	-9.999999999	+9.999999999
Scientific data #2	10	21	Temperature (°C)	-99.999999	+99.999999
System status	2	32	System status register	*See table below*	*See table below*
*	1	34	Fixed End-Of-Data code	N.a.	N.a.
CRC	2	35	Cyclic redundancy check	*See description*	*See decription*
13 10	2	37	Fixed Line feed	N.a.	N.a.

Start code, talker, message type:

This string is fixed, and it is always "$ACDAT" for data telemetry. This Ascii code identify the data telemetry coming from the accelerometer, the "$" code have to be used as data starting "lock" code.

Scientific data #1:

This telemetry field contain the signed measured acceleration in m/s^2.

Scientific data #2:

This telemetry field contain the signed measured temperature in C°.

System status register:

This 16 bit (2 Bytes starting from index 32) register store the accelerometer status as well as housekeeping messages, the following picture show the bit detailed fields of the register:

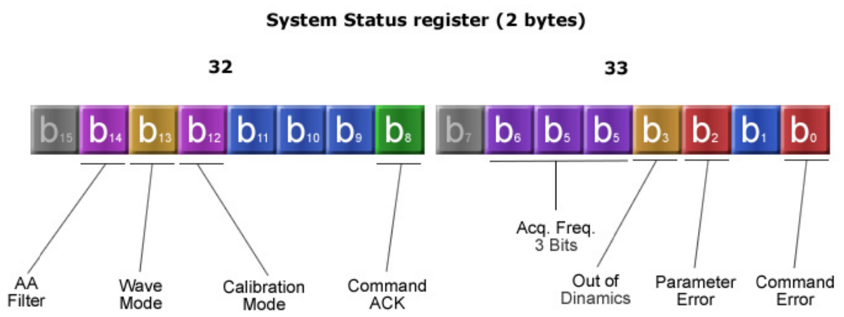


Figure_17 *System status register.*

The following table describes the system status register bits functionality in detail:

Bit number:	Name:	Description:	Note:
0	CMD Error	Command Error flag (0 = No errors)	
1	TMP Ctrl ON	Temperature control mode (0 = No TMP Ctrl)	*Not used*
2	PRM Error	Command parameter error (0 = No errors)	
3	O.o.D.	Out of dynamics warning (0 = No O.o.D.)	
4 5 6	Acq. Freq.	Acquisition frequency (see Note)	110 = 0.5 Hz 000 = 1 Hz 001 = 5 Hz 010 = 10 Hz 011 = 20 Hz 100 = 50 Hz 101 = 100 Hz
7	Spare	Spare	*Not used*
8	CMD Ack	Command Acknowledge (1 = Ack)	
9	Heat Flag	Temperature heat flag	*Not used*
10	TMP TCS	Thermal Control System ON/OFF	*Not used*
11	Ext. LED	External Led ON/OFF	*Not used*
12	Cal. Mode	Calibration mode ON (0 = Cal.Mode OFF)	
13	Wave Mode	Low pass filter mode (0 = Wave Mode OFF)	
14	A.A. Filter	AntiAliasing Filter (1 = A.A Filter ON)	
15	Spare	Spare	*Not used*

CRC:
This field contain the cyclic redundancy check code in ASCII HEX format, it is calculated as exclusive OR (XOR) of data starting after “$” code and ending before “*” code.

Line Feed and Carriage Return (13 10):
The last two bytes are the telemetry terminators.

Valid data telemetry examples:
Telemetry examples for 20Hz acquisition frequency with AntiAliasing filter ON:
$ACDAT,+0.000418246,+29.875020,À°*01
$ACDAT,+0.000504345,+29.879159,À°*0C

Telemetry examples for 10Hz acquisition frequency with AntiAliasing filter ON and CalibrationMode ON:
$ACDAT,+0.001435824,+04.119101,Ð *0F
$ACDAT,+0.000719788,+04.119503,Ð *0C

3.3.2 Accelerometer telecommand format:

The accelerometer is able to accept a set of telecommand in order to change functional parameters. Commands are always 15 ASCII long string with no CRC or terminators.

The following table shows the list of the acceptable commands:

Command name	Command description	String format	Parameters	Note
ACQ-FC	Change acquisition frequency	$SMCMD,FC,XXX.X	XXX.X: 000.5 001.0 005.0 010.0 020.0 050.0 100.0	*Permanent mode.*
CAL-Mode	Enter/Exit calibration mode	$SMCMD,SM,SWCAL	*Toggle mode.*	*Not permanent.*
AA-Filter	Enable/Disable AA-Filter.	$SMCMD,SM,SWAAF	*Toggle mode.*	*Not permanent.*
W-Mode	Enable/Disable LP-Filter.	$SMCMD,SM,SWAVE	*Toggle mode.*	*Permanent mode.*
SW-RST	Software Reset	$SMCMD,SM,SWRST		

"Permanent mode" has to be intended as a mode that is stored into instrument memory and not affected by instrument reboot.
The following picture shows the detailed description of ACQ-FC telecommand:

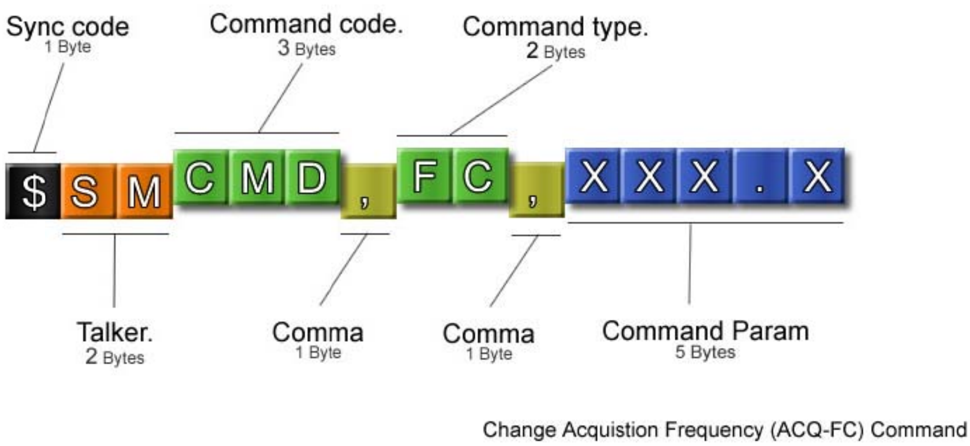


Figure_18 *Detailed description of ACQ-FC telecommand*

Telecommands description:

<u>ACQ-FC:</u>

Command format: ***$SMCMD,FC,XXX.X*** Effected status param.: **Acq. Freq., CMD Ack, PRM Error**

This telecommand change the accelerometer acquisition frequency, factory made acquisition frequency is 20 Hz (twenty samples per seconds). The execution store the acquisition frequency into instrument non volatile memory and it has a permanent effect after reboot or power up sequence.

Command Parameters: XXX.X
Acquisiton Frequency values (Hz): 000.5, 001.0, 005.0, 010.0, 020.0, 050.0, 100.0

Note:
*This command effect the status register **Acq. Freq.***
If correctly executed enable CMD AcK status bit for 2 seconds, if parameters is not correct it enables PRM Error status bit for 2 seconds.

<u>CAL-Mode:</u>

Command format: ***$SMCMD,SM,SWCAL*** Effected status param.: **Cal. Mode**, **CMD Ack**

This telecommand change the accelerometer acquisition mode; into calibration mode the accelerometer sends scientific data in a voltage format, this allow the user to calibrate the accelerometer.
Command Parameters: No parameters, this is an a "Toggle command" (see note).

Note:
*This command effects the status register **Cal. Mode** bit, this command is a "toggle command", it enables the calibration mode if it is not enabled and viceversa, you can check the status of the instrument by reading the status register bytes.*
If correctly executed enable CMD AcK status bit for 2 seconds.

<u>AA-Filter:</u>

Command format: ***$SMCMD,SM,SWAAF*** Effected status param.: **A.A. Filter**, **CMD Ack**

This telecommand enable/disable the accelerometer antialiasing filter, this filter is factory made enabled to avoid high frequency aliasing into measured band.
Command Parameters: No parameters, this is an a "Toggle command" (see note).

Note:
*This command effects the status register **A.A. Filter** bit, this command is a "toggle command", it enables the Antialias Filter if it is not enabled and viceversa, you can check the status of the instrument by reading the status register bytes.*
If correctly executed enable CMD AcK status bit for 2 seconds.

<u>W-Mode:</u>

Command format: ***$SMCMD,SM,SWAVE*** Effected status param.: **Wave Mode**, **CMD Ack**
This telecommand enable/disable the accelerometer 1Hz cut off frequency low pass filter. This filter can be useful in calibration mode to remove high frequency signal.

Command Parameters: No parameters, this is a "Toggle command" (see note).

Note:
*This command effects the status register **Wave Mode** bit, this command is a "toggle command", it enables the Low Pass Filter if it is not enabled and viceversa, you can check the status of the instrument by reading the status register bytes.*
If correctly executed enable CMD AcK status bit for 2 seconds.

<u>SW-RST:</u>

Command format: ***$SMCMD,SM,SWRST*** Effected status param.: **CMD Ack**
This telecommand reboot internal instrument software, this command take effect after 2 seconds.
Command Parameters: No parameters.

Note:
If correctly executed enable CMD AcK status bit for 2 seconds.

3.4 Mechanical interface

In the following drawings are reported the mechanical interfaces concerning the ACC_AGI one-axis accelerometer with the cube-sat.

Accelerometer Max external dimension.

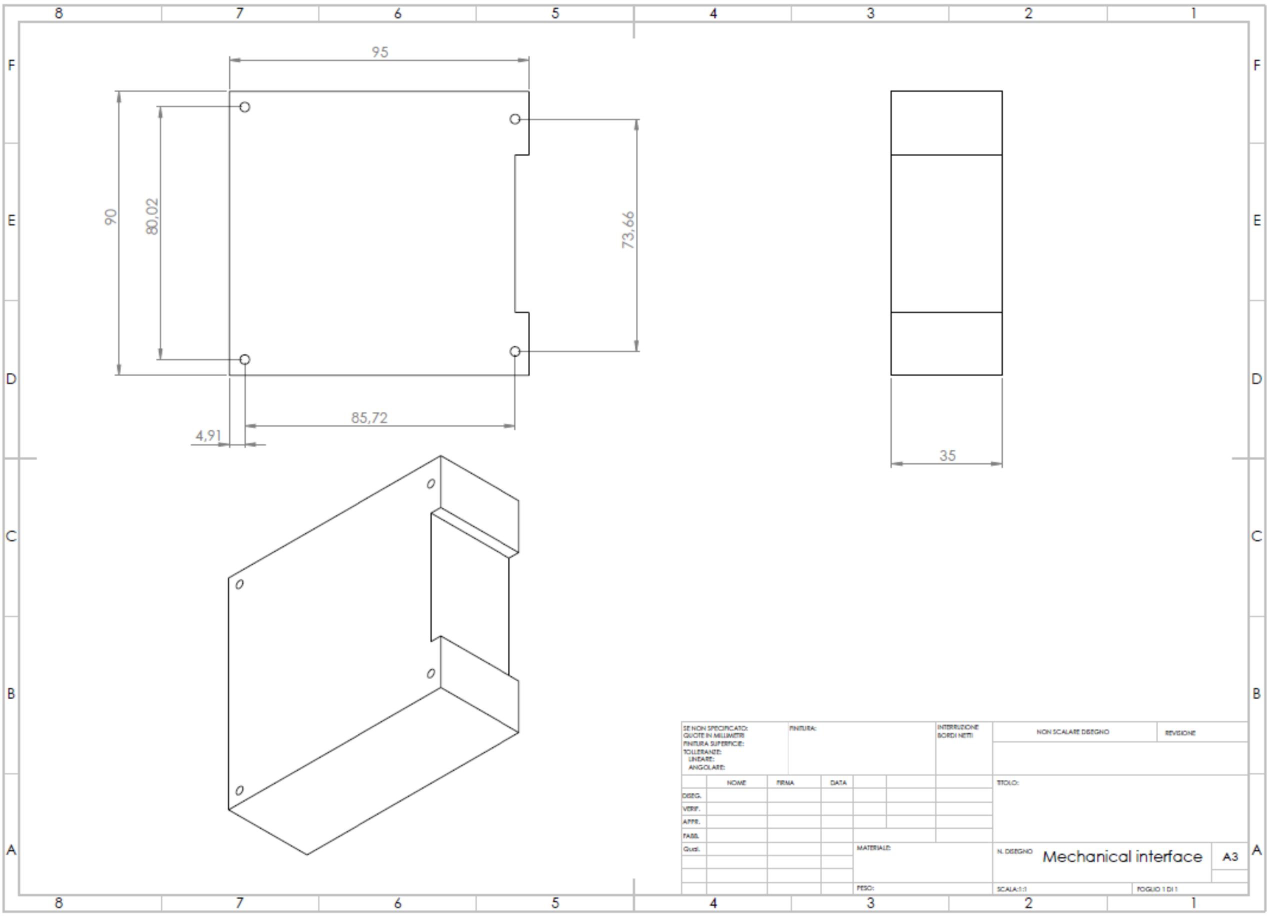


Figure_19 *Accelerometer Max external dimension.*

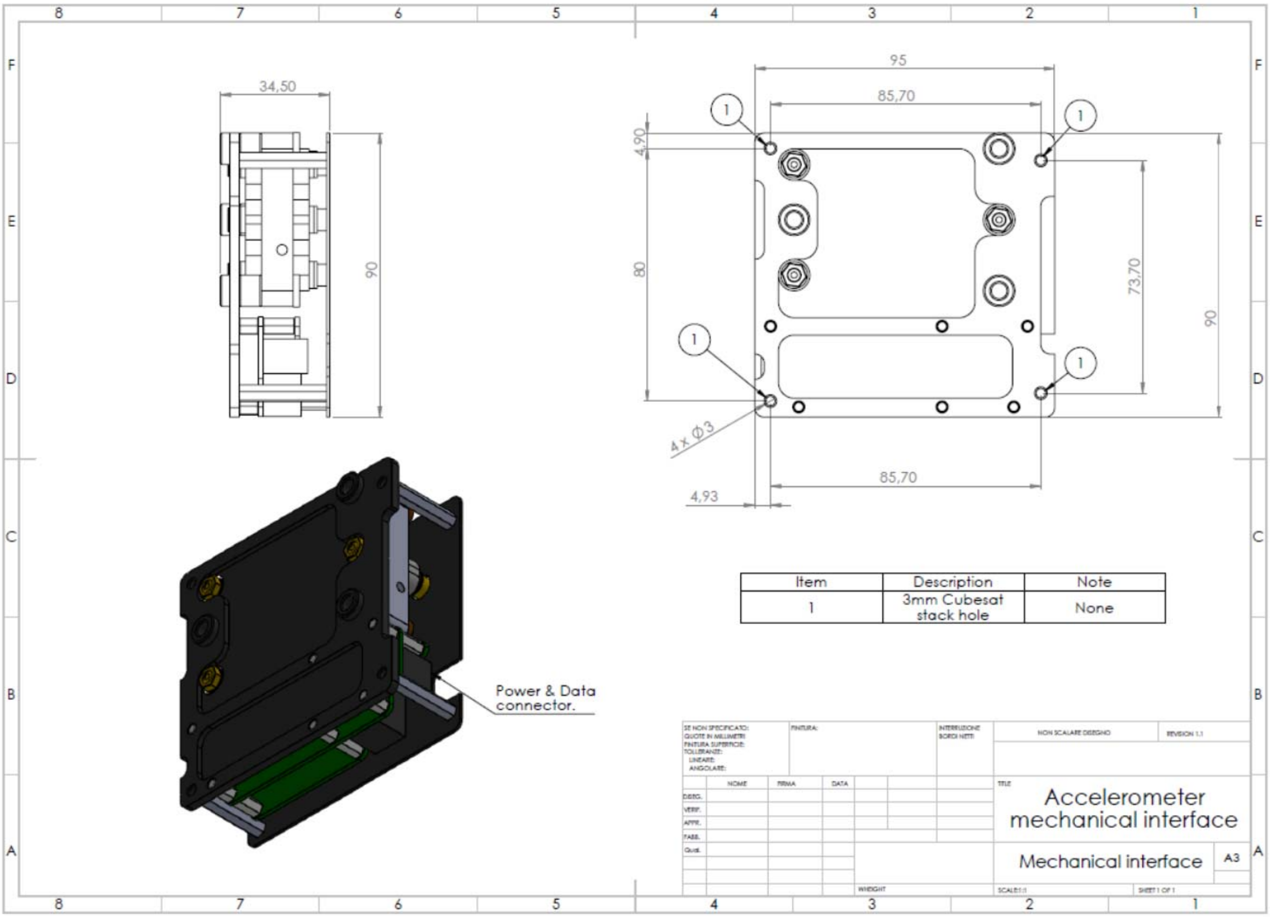


Figure_20 *Accelerometer mechanical interface.*

Accelerometer Mechanical Interface

The main elements are:

1) the supporting plates on the top and on the bottom of the accelerometer;
2) the sensor;
3) the electronic pre-amplifier for the accelerometer;
4) the analog electronics;
5) the digital electronics.

In the following figures are shown some prospective view of the accelerometer installed in one-element of CubeSat.

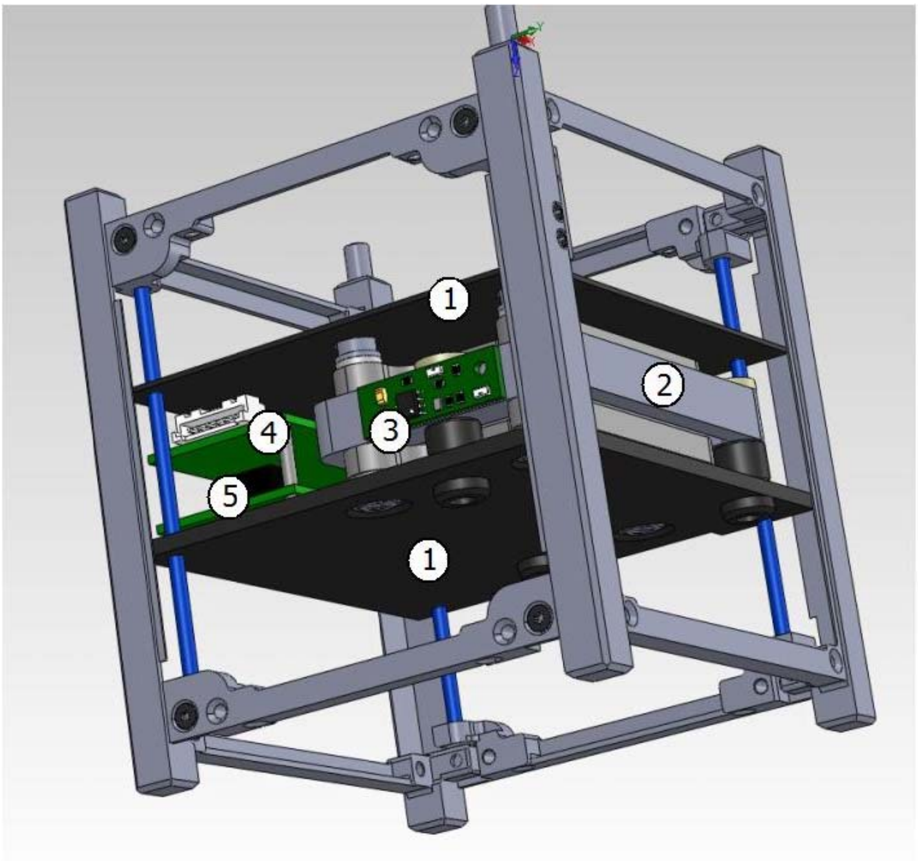


Figure_21a *Accelerometer mechanical interface prospective.*

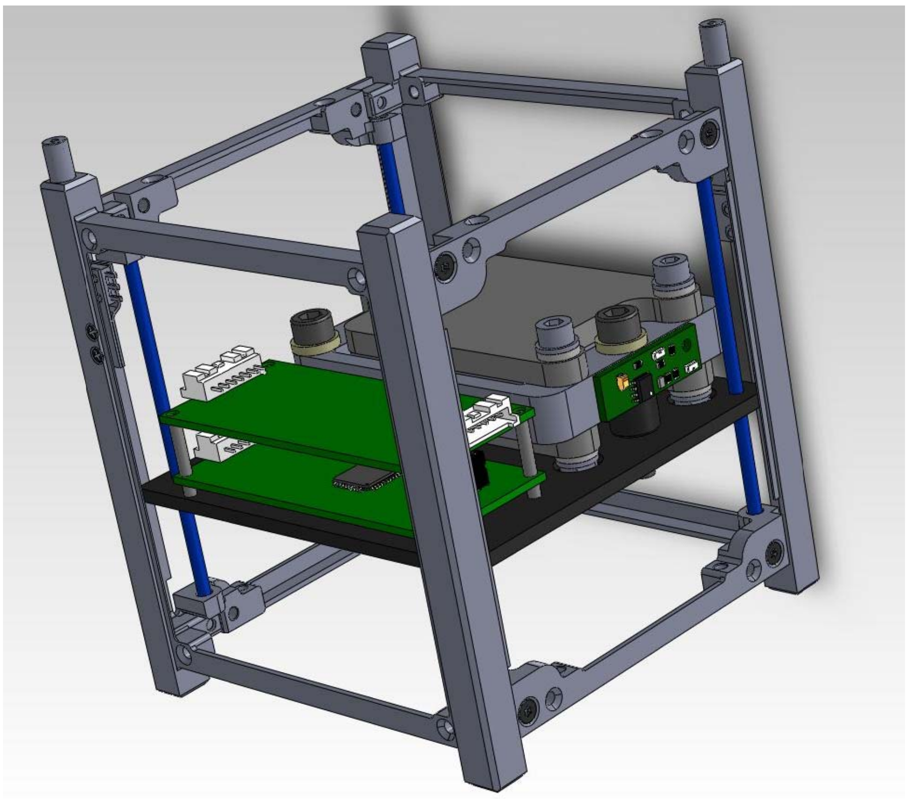


Figure_21b *Accelerometer mechanical interface prospective (In this picture the supporting plate on the top is not shown)*

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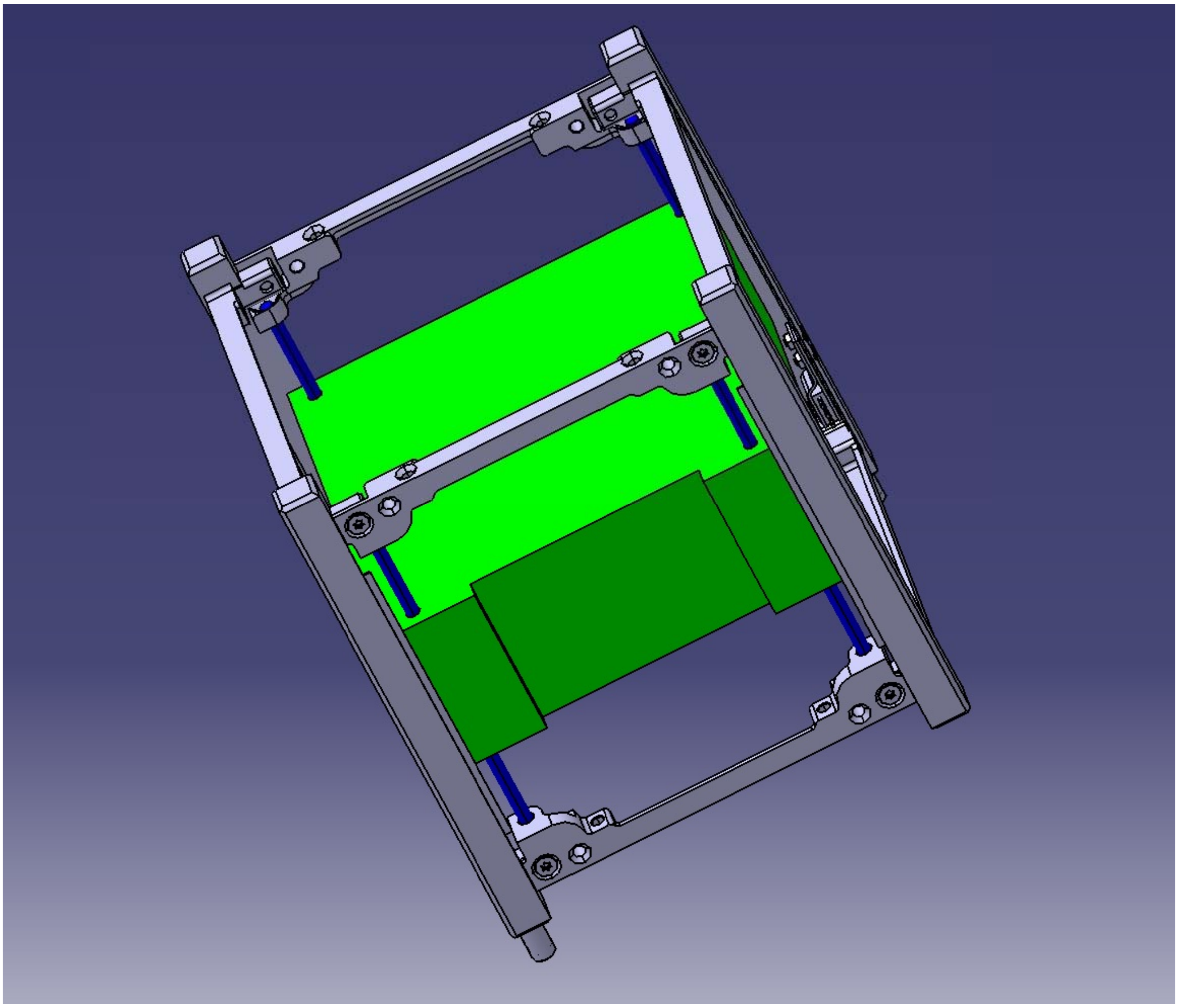

Figure_21c *Accelerometer mechanical interface prospective (The volume reserved to the accelerometer in the CubeSat is the one in green colour).*

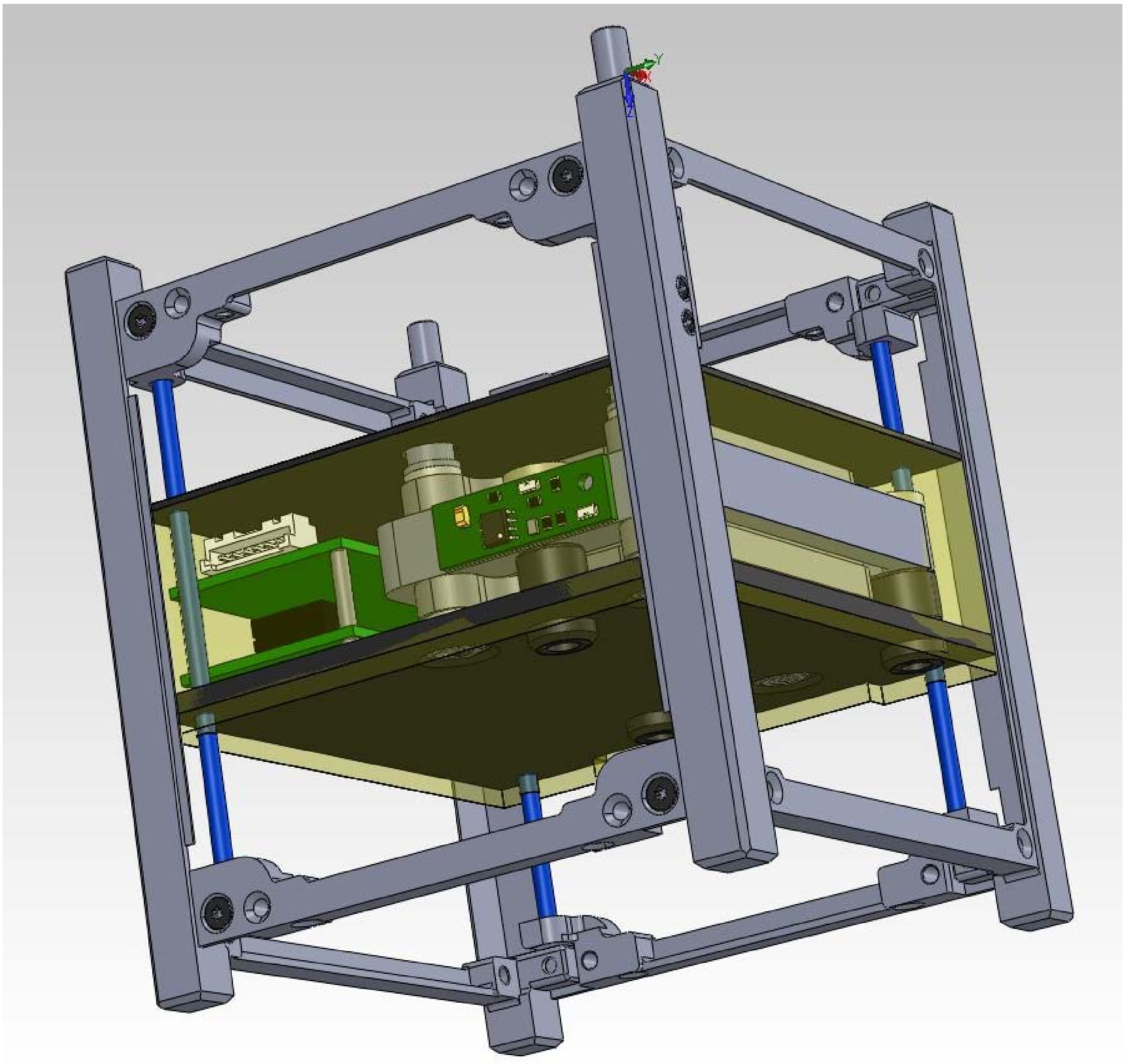

Figure_21d *Accelerometer mechanical interface prospective (The accelerometer fits in the volume (green) reserved to it).*

AGI

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AGI-Acc_CubeSat

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