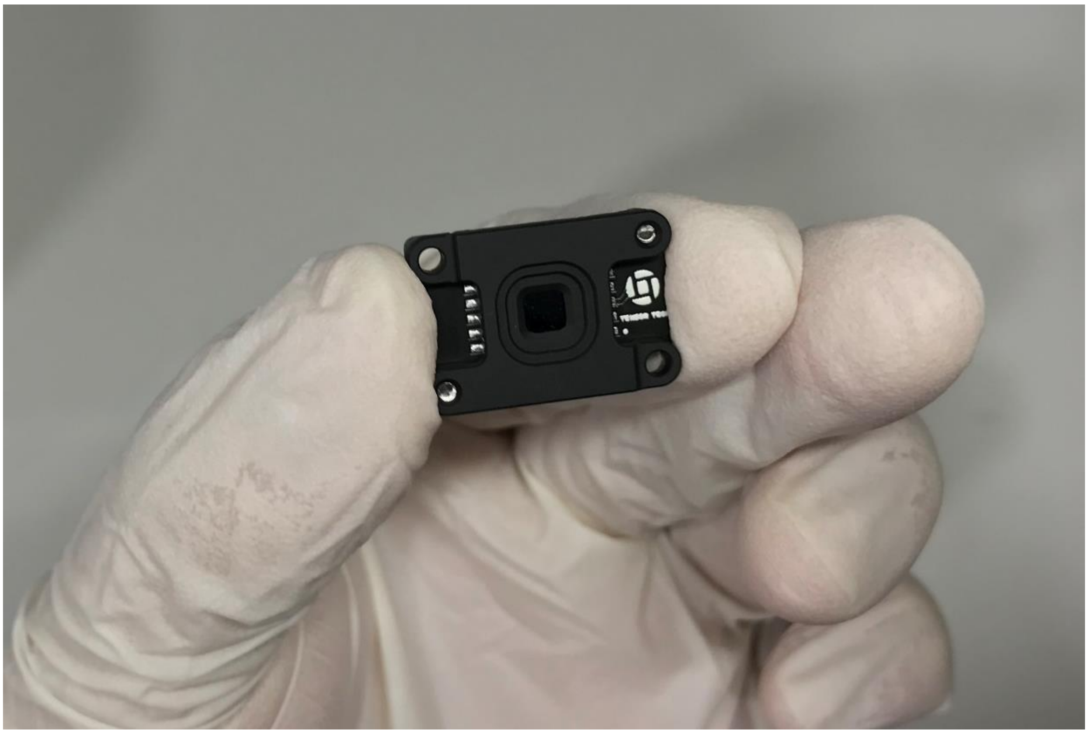
TENSOR TECH

User Manual for

FSS100 – Nano Fine Sun Sensor



V2.0

2021.08.30

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Table of Contents

Abbreviation List

PCBA	Printed Circuit Board Assembly
SMT	Surface Mount Technology for manufacturing of a PCBA
OBC	Onboard Computer on a satellite
ADCS	Satellite Attitude Determination and Control System
PC	Personal Computer
ICD	Interface Control Document
TID	Total Ionizing Dose radiation test
FM	Flight model. The product is used for integrating into the user's satellite that is planned to be launched into space. Therefore, disruptive environmental tests won't be performed by Tensor Tech before the shipment of the product
EM	Engineering Model. The product is used for conducting functional tests, destructive tests, or experiments in the user's laboratory.
DUT	Device Under Test. Herein refers to the product under functional or environmental tests.

Document Revisions

Date	Author	Revision	Descriptions
2020.12.11	Thomas Yen	V1.0	Establishing initial parameters and definitions
2021.08.30	Thomas Yen	V2.0	Updating critical specifications and drawings

A. Unpacking and Handling

1. Control the electrostatic discharges in the environment

FSS100 is an ESD-sensitive device. Please un-packaging and integrating it with proper equipment and procedures.

2. Control the contamination in the environment

FSS100 is assembled in a cleanroom environment certified with ISO 14644-1 ISO5 standard. This preparation is majorly set up to prevent dust from getting into FSS100. To conduct a proper integration of Tensor Tech's FSS100 into your CubeSat, we suggest having a cleanroom environment of ISO7 standard or at least having an air shower of ISO7 standard to wash out the dust on the lens before sending it to space.

3. Remove the Kapton Tape before launch

A Kapton tape covers the top of the lens before shipping. After the users finish their satellite integration and are ready for launch, please remove that Kapton tape to keep the FSS100 properly function. If users plan to conduct a functional test on the FSS100 under a solar simulator, remove the Kapton tape temporarily during the Test, then put it back after the Test.

4. Do not remove any electrical or mechanical components on the FSS100

The primary cause of the system errors on FSS100 is the imperfection of manufacturing the aperture and its mounting. Tensor Tech performs in-factory calibration on every shipped FSS100 to keep the sensor's error in the guaranteed range. This calibration includes biasing the center of the light spot on the photodiode and correct the error tabulated via the error table. This error table will be input into the FSS100 before the shipment. To keep the calibration result valid, Tensor Tech glues up the aperture with space-grade epoxy. Therefore, do not remove any mechanical parts on the FSS100. Otherwise, the sun vector determination accuracy may vary.

Every surface-mount-technology (SMT) electrical component will be glued with space-grade epoxy before the shipment of FSS100 to prevent possible fall off during the launch or users' vibration test. However, if users find any electrical or mechanical components fall off via visual inspection during proper environmental testing operations that this user manual allows, please contact Tensor Tech's team to ship you a new one.

B. Storage

In Tensor Tech, we storge our standard FSS100 in a dry environment with relative humility that is 2% or lower. To store this FSS100, we recommend having a moisture-proof box with relative humility 20% or lower. Moreover, the recommended storing temperature is listed in Table C-1.

C. Product Specifications

Table C-1. Mechanical Specifications

1	Weight	2.5 grams
2	Size	22 mm * 15 mm * 5.16 mm (Length*Width*Height)
3	Maximum Flock of View (FOV)	+/- 60 deg
4	Recommended Operation FOV	+/- 45 deg
5	Pointing Knowledge	less than +/- 0.5 deg in recommended FOV (3-sigma) without albedo
6	Operating Temperature Range	Absolute Maximum: -40~85 deg C[1] Recommend: -20~50 deg C
7	Storing Temperature Range	Absolute Maximum: -40~85 deg C Recommend: 10~30 deg C
8	PCB Production Standard	Following IPC-6012C Class 3
9	PCB Assembly Standard	Following IPC-A-610 Class 3

Table C-2. Electrical Specifications

1	Current Consumption	sampling: 2.4mA not sampling: 1.4mA
2	Supplied Voltage Range	Absolute Maximum: 2.3~5.5V Recommend: 3.2V~3.4V
3	Interface	I2C and UART
4	Connectors	Two Molex Pico- Ez Mate 0781710004. One for the UART and the other one for I2C communication. Customization on the connector is available; Please contact Tensor Tech's team.

[1] If the product is operate or storing in absolute maximum rages, its performane and reliability may degrade. The product may still function, but its out of Tensor Tech's warranty.

5	Pinout Definition	GND, VDD, SCL, and SDA for the I2C connector; GND, RX, TX, and VDD for the UART connector. Figure C-1 depicts such a pinout diagram. Please glue up the cable and connector before sending the satellite to space. Such a procedure prevents the cables from falling off. Only one of the connectors should be connected to the user's onboard computer (OBC) or Attitude Determination and Control System (ADCS) computer. Both provide the functionalities of supplying power, commanding, and outputting information from the product. To connect the product to the user's personal computer (PC) for calibration and functional tests, use the UART connector and a TTL to USB converter. (ship with the delivered product) Select the correct Com port on the user's PC with Tensor Tech's customer support software. Detailed instructions are provided in the interface control document (ICD).

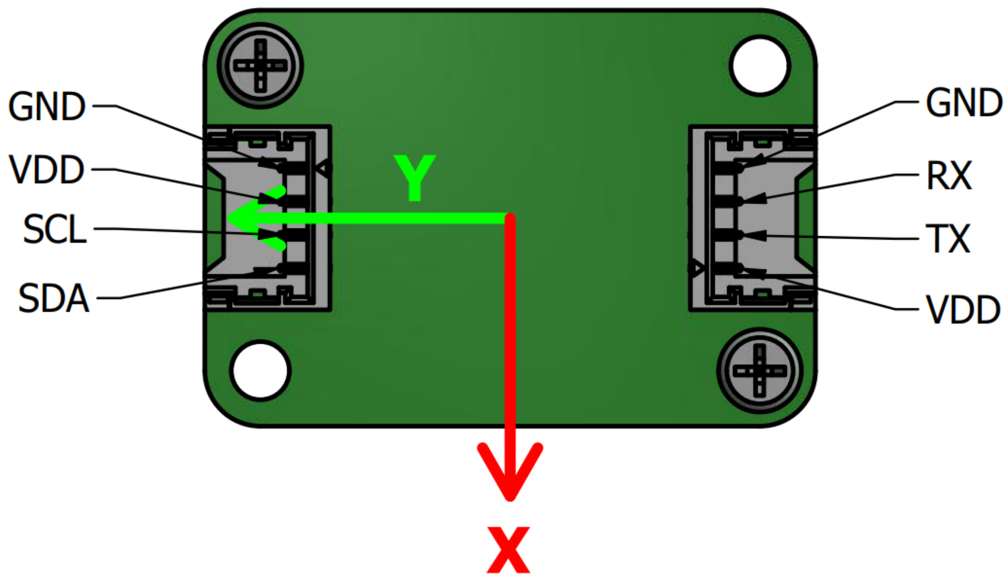


Figure C-1. Pinout Definition of the FSS100 (seen from the backside of the product)

D. Environmental Test Standards[2]

Tensor Tech's FSS100 thermal vacuum and vibration tests follow the ESA QB50 standard. For the total ionizing dose (TID) radiation test, we follow ESCC Basic Specification No. 22900- "TOTAL DOSE STEADY-STATE IRRADIATION TEST METHOD." For the single event effect radiation test, we follow ECSS Basic Specification No. 25100- "SINGLE EVENT EFFECTS TEST METHOD AND GUIDELINES." Our testing specifications are listed in Table D-1.

Table D-1. Environmental Test Standard for FSS100

1	Thermal Vacuum Baked-out Test	3 hours, 50 deg C, 10^{-5} mBar
2	Thermal Vacuum Cycling Test	4 cycles, the temperature varies from -20 to 50 degrees Celsius, 60 hours of testing time in total. The degree of vacuum is kept under 10^{-5} mbar for the whole process.
3	Random Vibration Test	20~2000Hz, 14 Grms for 120 seconds. Perform sine sweep vibration tests from 5 to 500Hz before and after the random vibration test. The acceptance requires a pass on QB50-SYS-2.6.1.
4	Total Ionizing Test[3]	10 krad using Co-60 radiation source
5	Single Event Effect Test	10^8 particles per cm^2 per second, with a 230 MeV proton beam, Lasting for 1000 seconds.

A self-communication check, an embedded function built in the customer support software, is executed after each environmental Test. This self-communication check inspects the survival of FSS100, including the ability to communicate to the user's OBC and the proper functioning of the circuitry. However, the performance spec like sun vector determination accuracy cannot be verified by this function.

Since the environmental tests may influence the product's performance, Tensor Tech calibrates the product and conducts the functional Test after the environmental tests. The detailed specs are listed in section E.

[2] Executed on every delivered flight model (FM). Self-communication check will be made after each environmental tests.

[3] Radiation tests including total ionizing test and single event effect test are disruptive tests. Tensor Tech only excuted these two tests on several finished samples. Therefore, the shipped FM or Engineering Model (EM) will not be excuted with radiation tests unless required by the user.

E. Functional Test Standards[4]

The in-factory calibration carried out by Tensor Tech's team is set up in an ISO7 clean room. An AM0 grade solar simulator and a two-axis rotational table that has accuracies up to arc-minute level are used for the calibration. A power supply is used for checking if the current consumption of the Device Under Test (DUT) is out of our guaranteed level. Moreover, the sun vector determination acracy will be post-validated and recorded in a test report with measured current consumption and environmental testing results. This test report will be shipped with the product, and the user may trace it back to that specific product with a unique serial number. Tensor Tech's customer support software can access that serial number. It helps Tensor Tech's team and the users to identify the differences between every shipped product.

Suppose the current consumption of the DUT or the sun vector determination error of the DUT exceeds the guaranteed specs listed in this user manual, that DUT will be deemed as a defective part. The shipped EMs are required to pass the functional tests. For the shipped FMs, they have to pass both the environmental and functional tests. Here are the conditions that we conduct such functional tests.

1. Testing Light source: ASTM AM0, Class AAA

2. Two angle errors will be measured in each testing condition, one in Phi and the other in Theta, defined in Figure E-1. Totally 108 testing conditions for completing the error table, exampled in Table E-1.

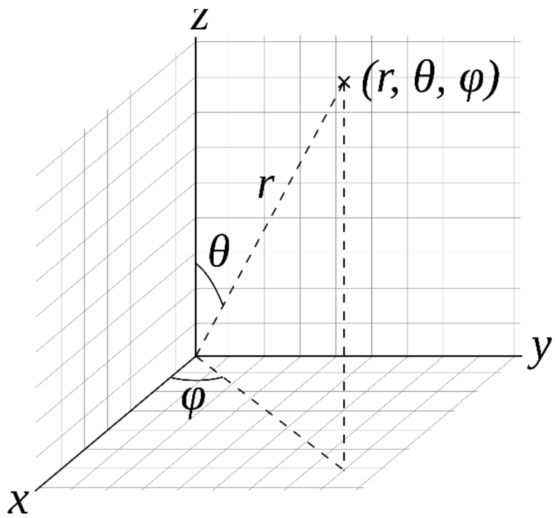


Figure E-1. Definition of the spherical coordinate that is being used for sun vector outputted and the construction of error table [1]

[4] Executed on every delivered EM and FM. For the FMs, functional tests will be executed after the environmental tests.

Table E-1. Example Error table that will be provided to the user and write into the shipped product. It contains the theta and phi angle error information of the DUT.

Phi\ Theta	Range	-60~ -50	-50~ -40	-40~ -30	-30~ -20	-20~ -10	-10~ 0	0~ 10	10~ 20	20~ 30	30~ 40	40~ 50	50~ 60
Range	Displayed value[5]	-55	-45	-35	-25	-15	-5	5	15	25	35	45	55
-90~ -70	-80	\	\	\	\	\	\	\	\	\	\	\	\
-70~ -50	-60	\	\	\	\	\	\	\	\	\	\	\	\
-50~ -30	-40	\	\	\	\	\	\	\	\	\	\	\	\
-30~ -10	-20	\	\	\	\	\	\	\	\	\	\	\	\
-10~ 10	0	\	\	\	\	\	\	\	\	\	\	\	\
10~ 30	20	\	\	\	\	\	\	\	\	\	\	\	\
30~ 50	40	\	\	\	\	\	\	\	\	\	\	\	\
50~ 70	60	\	\	\	\	\	\	\	\	\	\	\	\
70~ 90	80	\	\	\	\	\	\	\	\	\	\	\	\

F. Frame Definition and Sun Vector Calculations

The microcontroller (MCU) in FSS100 will automatically calculate the sun vector measured using the following algorithms. Firstly, we define the coordinate in figure F-1, calculation parameters in table F-1. The relative position of photodiode cells is shown in figure F-2. Secondly, the position of the light spot is calculated via equation F-1. Then, the Theta and Phi angle is calculated via equation F-2. [2]

[5] Customer support software has the function for users to conduct error table-cased calibration by themselves. The white-colored blanks show that the angle ranges that will use this error information for correction; the gray-colored blanks show that the displayed angle in the customer support software's screen, as well as the angle that should be used for obtaining that error information; the green-colored blanks show the two error angles, one for Phi, and the other for Theta

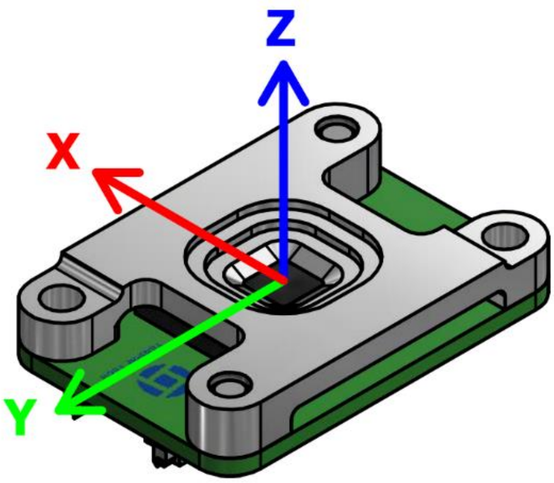


Figure F-1. Fine Sun Sensor frame definition

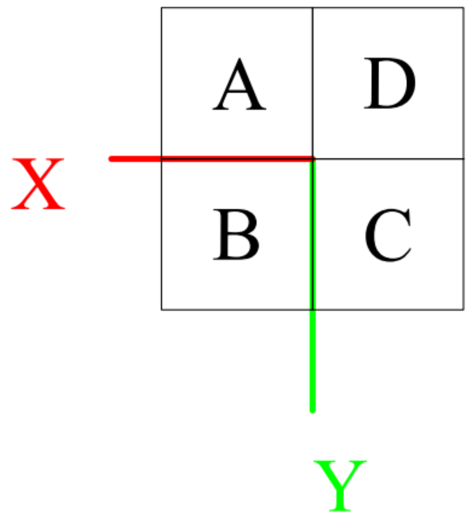


Figure F-2. quad-segmented photodiode cell position definition

Table F-1. Definition of the parameters

v_a	Voltage measurement of cell A defined in Figure F-2	p_x	Center of the light spot in X-axis
v_b	Voltage measurement of cell B defined in Figure F-2	p_y	Center of the light spot in Y-axis
v_c	Voltage measurement of cell C defined in Figure F-2	e_{theta}	Measured error for Theta angle in Table E-1. (According to the tilting range)
v_d	Voltage measurement of cell D	e_{phi}	Measured error for Phi angle in

	defined in Figure F-2		Table E-1. (According to the tilting range)
e_x	Error for biasing the light spot position in the X and Y-axis. The imperfection on the mounting of the aperture causes such error. Tensor Tech's team measures these errors and input them into FSS100 before shipping. Do not adjust these two values using customer support software unless consulting with Tensor Tech's team.		
e_y			

Finally, use equation F-3 to change the output theta and phi angle to be compatible with the defined fine sun sensor coordinate. The coefficient k_1 to k_4 are constant parameters relating to the FSS100 aperture structure.

$$\begin{pmatrix} p_x \\ p_y \end{pmatrix} = \begin{pmatrix} k_1 \cdot \dfrac{v_a + v_b - v_c - v_d}{v_a + v_b + v_c + v_d} - e_x \\ k_2 \cdot \dfrac{v_b + v_c - v_a - v_d}{v_a + v_b + v_c + v_d} - e_y \end{pmatrix}$$

Equation F-1

$$\begin{pmatrix} \theta \\ \varphi \end{pmatrix} = \begin{pmatrix} k_3 \cdot \arcsin\left(1.41 \cdot \sin\left(\dfrac{\sqrt{{p_x}^2 + {p_y}^2}}{\sqrt{{p_x}^2 + {p_y}^2 + 0.46^2}}\right)\right) + e_{theta} \\ k_4 \cdot \arcsin\left(\sin\left(\dfrac{{p_y}^2}{\sqrt{{p_x}^2 + {p_y}^2}}\right)\right) + e_{phi} \end{pmatrix}$$

Equation F-2

$$\text{if } p_x \geq 0, \theta = -\theta; \text{else: } \varphi = -\varphi$$

Equation F-3

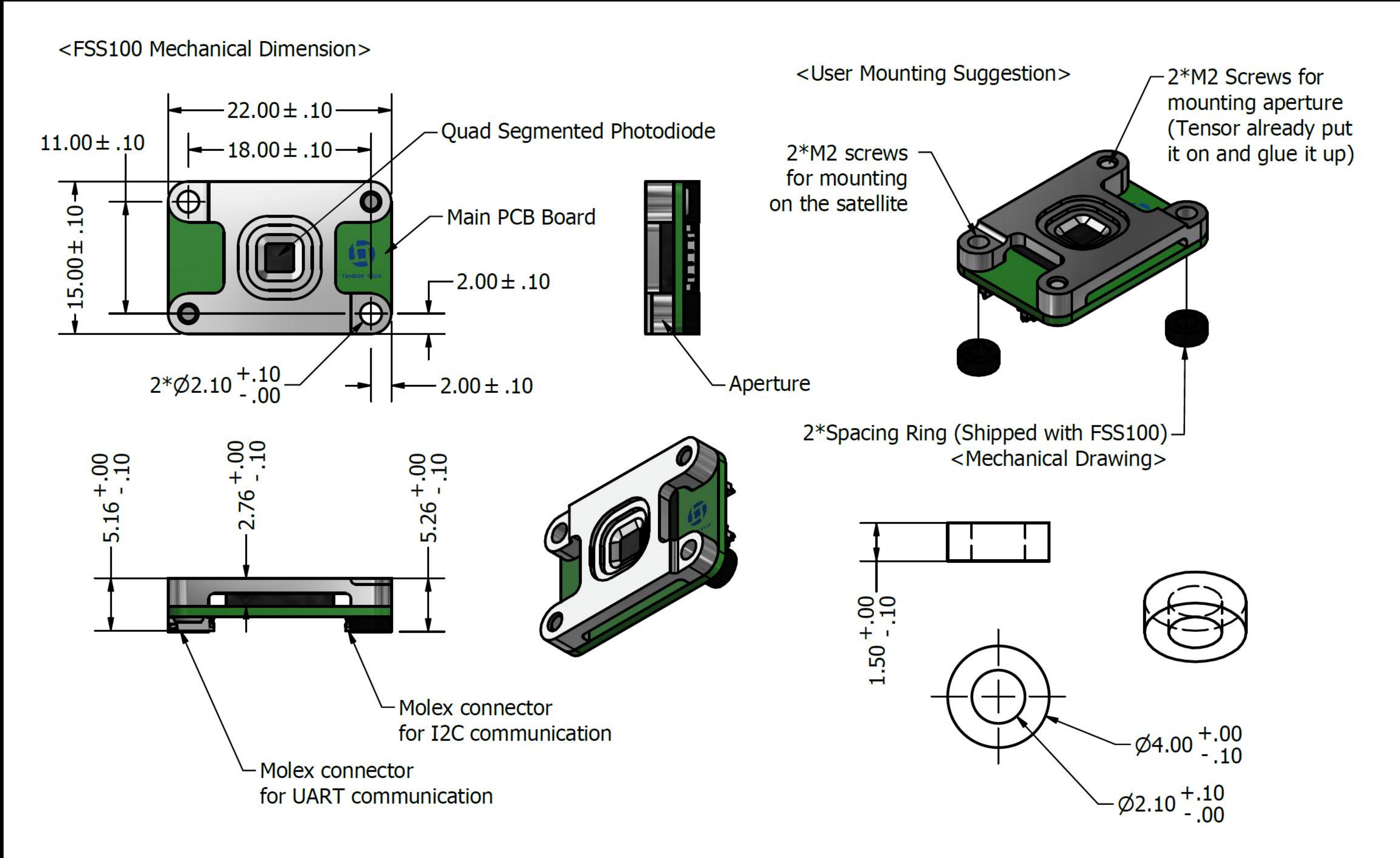
References and Attachments

[1] International Standard Organization (ISO). (2019, August). ISO 80000-2:2019 Quantities and units. https://www.iso.org/standard/64973.html

[2] E. Boslooper, N. Heiden, D. Naron, R. Schmits, J. Velde, and J. Wakeren. (2012). BepiColombo fine sun sensor. International Conference on Space Optics. https://www.spiedigitallibrary.org/conference-proceedings-of-spie/10564/105641P/BepiColombo-fine-sun-sensor/10.1117/12.2309172.full?SSO=1

[3] TENSOR TECH. (2021, June 12). An introduction to fine sun sensors –. https://tensortech.com.tw/an-introduction-to-fine-sun-sensors/

[4] FSS100 Mechanical Drawing



Updated Time	2020.12.23 (Wed.)
FSS100 V2	Attachment 1. FSS100 Dimensions

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