nanoSSOC-D60

Sun Sensor for Nano-Satellites
Digital interface

Technical Specification, Interfaces & Operation

Specifications

Two orthogonal axes sun sensor
Wide field of view (FOV): ±60º
High accuracy in FOV: 0.5º
Precision: 0.1º
Power supply: 3V3 (5V under request)
Reduced size: 43 × 14 × 5.9 mm
Low weight: 6.2 g
UART, I2C or SPI
Temperature range: -30 to +85 ºC

Qualification

30 kRad Total Ionizing Dose
Space-grade components
Space qualified microcontroller
Space qualified internal 4Q sensor

Applications

Low cost satellite attitude determination
Accurate Sun position determination
Satellite solar panel positioning
Attitude Failure Alarm
Satellite positioning in specific trajectory points
Balloons and UAVs control

Nano Sun Sensor on a Chip (nanoSSOC) is a two-axis low cost sun sensor for high accurate sun-tracking and attitude determination. This device measures the incident angle of a sun ray in both azimuth and elevation, providing an accurate angle reading. nanoSSOC sun sensor is based on MEMS fabrication processes to achieve high integrated sensing structures.

Every sensor is individually characterized and calibrated. The use of materials as aluminum 6082 minimizes the ageing of the device under high energy particle radiation.

nanoSSOC-D60 includes a microcontroller that directly provides the sun light incident angles and other information useful for attitude determination, via UART, I2C or SPI protocol.

nanoSSOC-D60 has minimum size, weight and power consumption to be the perfect ADCS solution for nano-satellite platforms like Cubesats.

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1. INTRODUCTION

This user manual presents a brief description for a correct use of the sun sensor called nanoSSOC-D60 and provides information about the operating principle, design, interfaces, communications protocol and operations of the device. Instructions and recommendations are also included for operator handling and other relevant activities with the sun sensor.

Fig 1. nanoSSOC-D60 sun sensor device

Besides this specification document, the sun sensor is delivered with a certificate of conformance. For further assistance in design, interfacing, or sensor operation, Solar MEMS Technologies can offer a dedicated quotation for product support based on each customer specific requirements.

2. DESIGN REVIEW

2.1. Technology

nanoSSOC-D60 uses four silicon photodiodes monolithically integrated, including a transparent glass on the same silicon die to act as a shield to prevent space radiation damage. nanoSSOC device fabrication combines microelectronics technology with a high efficiency solar cell fabrication process, leading to small area and low weight device. All materials used in the silicon sensor fabrication process are compatible with space requirements in terms of thermal and vibration resistance, and low degasification.

The printed circuit board with the electronics and the solar sensor is packaged in an anodized and alodined aluminum box to attenuate the influence of the outer-space radiation effect. The layout of the electronic components has been determined according to its functionality and maximizing their protection against high energy particle radiation. Electronics assembly has been done considering the special requirements demanded by space applications.

2.2. Qualification & Flight heritage

nanoSSOC-D60 sensing element has been developed following the same proprietary MEMS technology than other SSOC devices from Solar MEMS Technologies: SSOC-D60 and SSOC-A60. Its flight heritage includes around 30 SSOC units in more than 10 missions, orbiting since 2009.

All electronic components inside nanoSSOC-D60 are space-grade, except for the internal COTS microcontroller, which has flight heritage and has been tested showing a correct working up to 30 kRad TID.

SSOC technology has been qualified in the frame of different tests, including radiation (absorbed dose and proton beam), random vibration, shock response, outgassing, thermal and EMC. For a detailed description of qualification test campaign and proof of heritage, please contact with Solar MEMS.

3. TECHNICAL SPECIFICATIONS

Parameter	Value	Comments
Angles reading		
Sensor type	2 axes	Orthogonal.
Performance field of view	± 60 º	Performance field
Exclusion field of view	± 75 º	It must be clear of obstacles or reflective surfaces (recommendation)
Accuracy	< 0.5 º	3σ error
Precision	< 0.1 º	
Electrical		
Supply voltage	3.3V	5V under request
Average consumption	< 21 mA	Dark
Average consumption	< 23 mA	Light: 1360 W/m², AM0
Thermal		
Temperature range	- 30 to +85 ºC	
Mechanical		
Dimensions (L × W × H)	43 × 14 × 5.9 mm	
Weight	6.2g	
Mount holes	M2.5 x2	38mm separation
Connector	DF13 EA-10DP-1.25V	From Hirose
Housing	Aluminum 6082	Alodine 1200S (ECSS-Q-70-71) Black anodized (ECSS-Q-ST-70-03C)
Response time		
Filtering stage	50 Hz sampling 1 Hz cutting freq.	3th order Butterworth
Qualification		
Total ionizing dose	30 kRad	Gamma radiation
Beam energy	6 MeV	Proton beam
Random vibration	14,1g @ 20-2000 Hz	
Shock	3000 g @ 1-100 ms	

Table 1. General specifications

4. MECHANICAL

4.1. Material and Surface Treatments

nanoSSOC-D60 case is made of 6082 aluminum to attenuate the influence of the outer-space radiation. It is black-anodized according to the ECSS-Q-ST-70-03C (MIL-A-8625 type II class 2, hard black anodize), excepting the contact surface which is subjected to alodine 1200S for space applications (ECSS-Q-70-71). It includes a staircase-shaped aperture to collect the light with an angle of 120º (±60º).

4.2. Labeling

For traceability purposes, each nanoSSOC-D60 sun sensor has a unique serial number, which is milled on its case. The serial number follows this format: NDXXXX, where XXXX is a number between 0000 and 9999. It can be seen in the following picture:

Fig 2. Labeling

4.3. Reference system

With X_A, Y_A, Z_A coordinate system as the sensor angles references, the angle α and angle β specify the angular position of the incident sun ray inside the field of view of nanoSSOC-D60 (Fig 3). Both angles are provided in degrees.

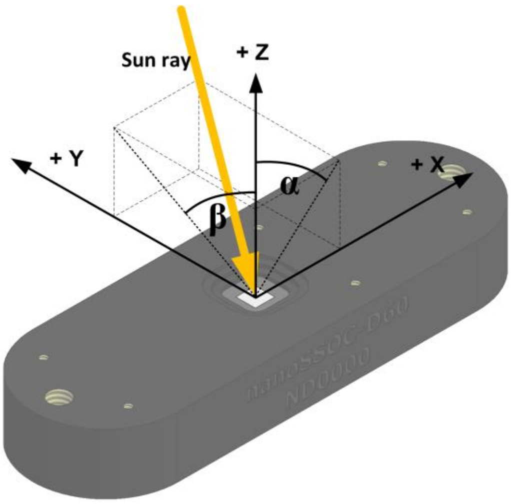

Fig 3. Angles reference

4.4. Mass

nanoSSOC-D60 mass is 6.2g

4.5. Dimensions

nanoSSOC dimensions are 43 x 14 x 5,9 mm (With the connector protruding 1,9mm). The following figure shows all the relevant dimensions of nanoSSOC-D60. All dimensions are in mm.

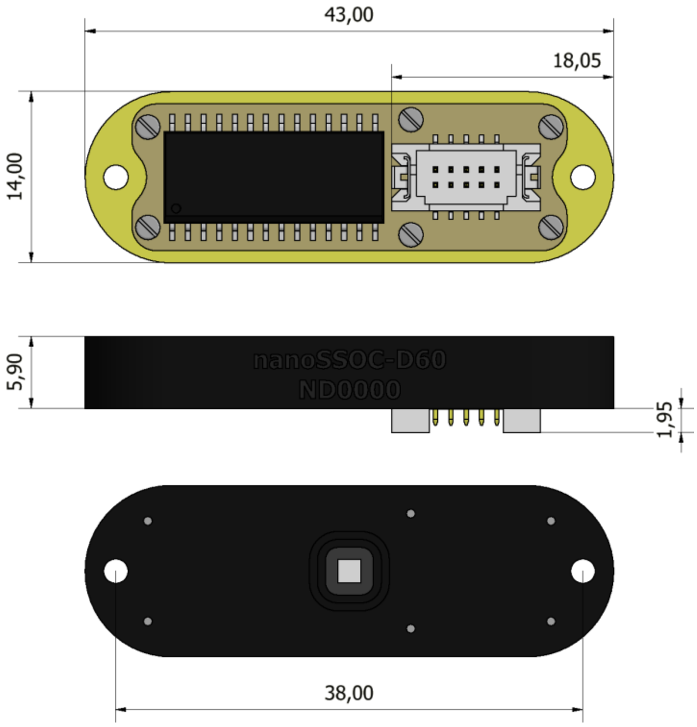

Fig 4. Dimensions

4.6. Fastening

nanoSSOC-D60 has two M2.5 threaded mounting holes. As can be seen in Fig 4, the distance between the centers of the two holes is 38±0.02 mm. For fastening the sensor at the two precision holes and assure the alignment, it is recommended the use of M2.5 threaded countersunk screws. Recommended minimum and maximum torque levels are 0.65 Nm and 0.86 Nm respectively. The choice of recommended fasteners as well as torque levels ensures appropriate sensor alignment.

nanoSSOC-D60 can be fastened directly to the satellite or using an adaptor. Solar MEMS can provide an adaptor specially designed for placing a nanoSSOC-D60 between two units of most commons Cubesat structures. It can be seen in Fig 5.

Custom brackets can be designed and manufactured by Solar MEMS under request.

Fig 5. Cubesat bracket example

4.7. Remove Before Flight Items

nanoSSOC-D60 precision can be affected by dust particles. For that reason they have a protective kapton film that must be kept during integration operations. For normal operation of the sensor it must be removed.

4.8. Connector gluing

nanoSSOC-D60 has been subjected to vibration test with successful and during this test the connector was unglued to test it reliability. However, once finished all the integration tasks and just before launch, it is recommended to assure the connector by gluing it with some space approved epoxy.

Another recommendation is to insert in the connector all the terminals even if they are not going to be used. It ensures the maximum strength in the connector mechanical connection.

4.9. Field of view

Field of view of nanoSSOC-D60 is characterized by two values:

- Performance FoV: where best accuracy and functionality is determined. It is squared shape area of +/- 60 degrees in both axes X and Y.

- Exclusion FoV: where clearance is defined. Sun sensor does not see anything out of this area, and it should be clear of reflective surfaces to avoid albedo. It is squared shape area of +/- 72 degrees in both axes X and Y.

5. THERMAL

5.1. Material Characteristics

The aluminum housing has been black-anodized according to the ECSS-Q-ST-70-03C. Black anodized emission and refraction coefficients are the following:

- $\alpha \geq 0.935$
- $\varepsilon \geq 0.855$

5.2. Contact Area

Contact area of nanoSSOC-D60 is 513 mm^2 on top-side and 140 mm^2 on bottom-side. Direct contact areas are the main dissipation way for the unit.

5.3. Unit Temperature Range

nanoSSOC-D60 temperature range is -30ºC to +85ºC.

5.4. Power Dissipation

The unit power dissipation is <76mW.

6. ELECTRICAL

6.1. Power supply

nanoSSOC-D60 electrical characteristics are summarized in the following table. Electrical behavior of the sensor has been measured using AM0 filter with solar light spectrum of 1360 W/m2 at ambient temperature and normal incidence.

Symbol	Parameter	Min	Typical	Max	Unit
V_{DD}	Supply voltage				
	Absolute Maximums	3.00	-	3.60	V
	Recommended	3.25	3.3*	3.35	V
I	Current consumption	-	21	23	mA

Table 2. Electrical Characteristics.

*nanoSSOC-D60 sun sensors accuracy is guaranteed in the 3.00V to 3.60V range. However, supply voltage should be precisely tuned to 3.3V to achieve the best sensor performance. 5V version under request.

6.2. Inrush current

In the following figure it can be seen the inrush current plot of nanoSSOC-D60.

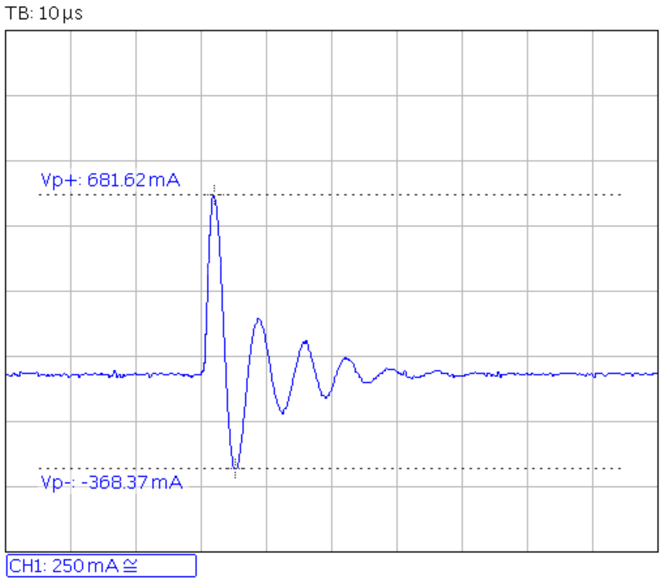

Fig 6. Inrush current

6.3. Connector and harness

nanoSSOC-D60 uses a micro-connector with 10 contacts installed on the bottom of the sensor. This connector is a Hirose DF13EA-10DP-1.25V(55), 2-row male connector straight with fixing, suitable for space applications and with flight heritage (refer to manufacturer for more information).

The connector for platform side is a Hirose DF13-10DS-1.25C, 2-row female connector crimp gauge. It is recommended to use a space-grade adhesive to secure the fixed connectors.

Solar MEMS delivers interface cable under request. We recommend the use of a cable harness composed of AWG-26 to AWG-30 wire gauge for the individual wires, and a cable length shorter than 1.5 m.

Grounding shall be at one point only. The sensor has no direct connection between the negative supply and the chassis (electrically isolated).

6.4. Pin Description

The pin numbering of connector is described in the following figure:

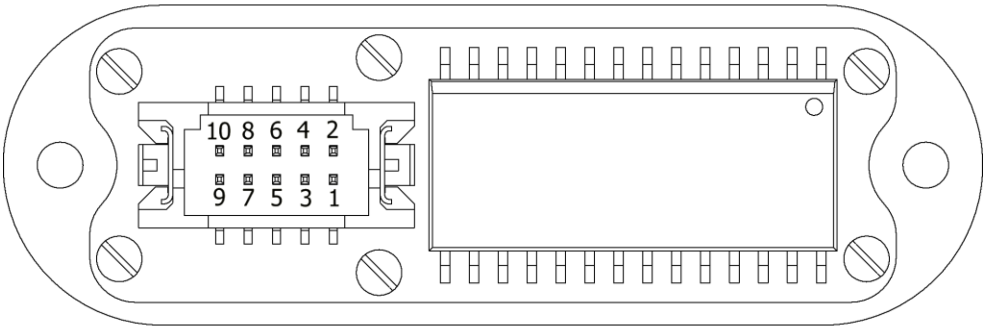

Fig 7. Connector pin numbering

The electrical signals of the sun sensor are detailed in the following table:

Pin	Signal	Description	Type
1	SCK	SPI-Serial clock	Digital input
2	SS	SPI-Slave synchronization	Digital input
3	UTX SCL MISO	UART-TX I2C-CLK SPI-Data out	Digital output
4	Reserved	Do not connect	-
5	URX SDA MOSI	UART-Rx I2C-Data SPI-Data in	Digital input
6	VCC	3V3 Supply Voltage (5V under request)	Power
7	Chassis	Connection to chassis	-
8	GND	Ground	Power
9	GND	Ground	Power
10	GND	Ground	Power

Table 3. Pin description

7. COMMUNICATIONS

nanoSSOC-D60 sensors can communicate via three different protocols: UART, I2C or SPI. This must be chosen at the time of the purchase because the pins of the different protocols are shared and they cannot be enabled simultaneously. The following sections describe the protocol and command codes.

7.1. Data format

The data structure for communications is explained below:

- Character transmission (*unsigned char*):

Byte_0
LSB

To communications channel →

- Two byte Integer transmission (*int*):

Byte_1	Byte_0
MSB	LSB

To communications channel →

- Floating data transmission (*float*): Float codification according to IEEE 754-1985 standard for single-precision floating 32 bits:

S	Exponent	Fraction	
Byte_3	Byte_2	Byte_1	Byte_0
MSB			LSB

To communications channel →

Floating value= $S \times 2^{e} \times m$.
- Sign (S): 1 bit (0=positive, 1=negative)
- Exponent: 8 bits (e = Exponent – 127)
- Fraction: 23 bits (m = 1.Fraction)

7.2. Frame format

The same protocol is implemented in the three communication options: UART, I2C and SPI. This protocol uses two messages:

- Request message: from master to slave.
- Response message: from slave to master.

The master is the on-board computer of the satellite, or the master of the communication bus, and the slave is the nanoSSOC-D60 device.

Every command sent to the sensor shall comply with the format described in the table below.

Command Code	Length	Checksum
0xXX	0x01	0xXX
1 byte	1 byte	1 byte

Table 4. Command format

Command message:
- Command code: It corresponds to the code of the incoming command.
- Length: For commands it is fixed to 0x01.
- Checksum byte: For commands the values of the checksum field are:

Command code	Checksum
0x01	0x02
0x03	0x04
0x04	0x05

Table 5. Checksum

Every response sent to the master shall comply with the format described in the table below:

Command Code	Length	Application Data	Checksum
0xXX	0xXX	-	0xXX
1 byte	1 byte	2 – 16 bytes	1 byte

Table 6. Response format

Response message:

- Command Code: It corresponds to the code of the command which this answer refers to.
- Length: It is the sum of the number of bytes of the fields 'Application Data' + 'Checksum'.
- Data: It is the answer with the data previously requested by the corresponding command.
- Checksum: it is used to check the integrity of the packet. It is calculated adding all bytes in 'Command Code' + 'Length' + 'Data' fields and extracting the less significant byte of the result.
  E.g.:

  1A CF FC 1D 02 05 42 12 87 2B 0D

  Checksum is 0D. This checksum is calculated adding 0x02 + 0x05 + 0x42 + 0x12 + 0x87 + 0x2B = 0x10D. Less significant byte of 0x10D is 0x0D.

7.3. Commands

There are several command codes implemented in UART, I2C and SPI communication of nanoSSOC-D60 sun sensor. The frame and information of these command codes are the same for these three protocols. The command codes are:

Command	Name	Functionality
0x01	UNFILTERED CELLS	Request for the voltage values of the four photocells without filtering
0x03	FILTERED CELLS	Request for the voltage values of the four photocells with filtering
0x04	ANGULAR POSITION	Request for the angular position (α,β) and error code.

Table 7. Command codes

After nanoSSOC-D60 is turned on, a minimum timeout of 2 seconds is required before the first data request, in order to reach the stabilization of the digital filters.

7.3.1. Command 01: Unfiltered photocell voltages

Request for the voltages values of the four photocells without filtering: four unfiltered cells are obtained by means of an analog to digital converter (ADC) of 10 bits and 50 Hz.

The voltage of each cell is represented by a 32-bit float.

Command Code	Length	Checksum
0x01	0x01	0x02
1 byte	1 byte	1 byte

Table 8. Command 01 TC format

Command Code	Length	Application Data				Checksum
0x01	0x11	Float (uSSA1)	Float (uSSA2)	Float (uSSA3)	Float (uSSA4)	0xXX
1 byte	1 byte	4 bytes	4 bytes	4 bytes	4 bytes	1 byte

Table 9. Command 01 TM format

7.3.2. Command 03: Filtered photocell voltages

Request for the voltages values of the four photocells with filtering: four filtered cells are obtained with the ADC conversion (10 bits, 50 Hz), and an internal filtering stage (Butterworth filter).
The voltage of each cell is represented by a 32-bit float.

Command Code	Length	Checksum
0x03	0x01	0x04
1 byte	1 byte	1 byte

Table 10. Command 03 TC format

Command Code	Length	Application Data				Checksum
0x03	0x11	Float (uSSA1F)	Float (uSSA2F)	Float (uSSA3F)	Float (uSSA4F)	0xXX
1 byte	1 byte	4 bytes	4 bytes	4 bytes	4 bytes	1 byte

Table 11. Command 03 TM format

7.3.3. Command 04: Angular position

Request for the angular position and the corresponding error code on each axis: the estimated results are taken from the ADC converted values (10 bits and 50 Hz) of both sensor direction angles, the internal Butterworth filter, and from the obtained error code calculations.

The two angles which determine the angular position (α and β, see Fig 3) are represented by a single-precision floating-point format. The error code (see Table 14) format is represented in a char.

Command Code	Length	Checksum
0x04	0x01	0x05
1 byte	1 byte	1 byte

Table 12. Command 04 TC format

Command Code	Length	Data				Checksum
0x04	0x0E	Float (Angle X or Alpha) [º]	Float (Angle Y or Beta) [º]	Float (Sun Detection) [%]	Char (error code)	0xXX
1 byte	1 byte	4 bytes	4 bytes	4 bytes	1 byte	1 byte

Table 13. Command 04 TM format

7.3.4. Error codes

The error code byte will always inform if angles calculation operation was done successfully or if it was any problem detected.

Error Code	Information
0	No error. Angles were calculated successfully
10	Not enough radiation detected. Angle measurements should not be considered.
11	Albedo: Earth; Sun sensor does not see the Sun, but Earth, and the reflected sun-light is affecting measurement of the sensor.
12	Albedo: Earth + Sun; Sun sensor sees the Sun and the Earth, because received solar radiation level is higher than 1360 W/m2, with a tolerance of 20%, so a reflected sun-light is affecting measurement.
13	Detected light source, but out of FoV. Check sign of angle measurement to know the direction.

Table 14. Error codes

The albedo codes (11 and 12) describe the following situations:

- Code 11: Earth albedo.
  Sun sensor does not see the Sun, but Earth, and the reflected sun-light is affecting measurement of the sensor.
- Code 12: Earth and Sun albedo.
  Sun sensor sees the Sun and the Earth, because received solar radiation level is higher than 1360 W/m^2, so a reflected sun-light is affecting measurement.

These codes are just informative and do not affect angles calculation.

This algorithm depends on a tolerance of 20% around the solar radiation during calibration of the sun sensor, this is 1366 W/m^2. When the measured radiation is lower or higher than this value considering the tolerance, the algorithm detects code 11 or 12.

7.3.5. Sun Detection parameter

This parameter is calculated internally dividing the amount of radiation measured by the amount of radiation expected at the measured sun vector (Angles X and Y). This parameter allows the spacecraft to decide if Sun of Albedo have been detected.

See section about “albedo and sun detection” (chapter 7).

7.4. UART communication protocol

This section describes the features of the sun sensor UART communications interface and the different protocol messages and commands. Please refer to the manufacturer for any other particular configuration.

7.4.1. UART configuration

The following table summarizes the characteristics of the UART communications interface.

Baud rate	115200 bps
Data bits	8 bits
Stop bits	1
Handshaking	none
Bit-level transmission	Little Endian
Byte-level transmission	Little Endian

Table 15. UART communications interface configuration

Interface configuration can be changed under request, i.e., baud rate. Please contact Solar MEMS for special requirements.

7.4.2. UART with SYNC word

Every request and response message will be preceded by a synchronization word that indicates the start of a new frame.

Sync Word	Request message	Length	Checksum
0x1ACFFC1D	0xXX	0x01	0xXX
4 bytes	1 byte	1 byte	1 byte

Table 16. UART request message from master to nanoSSOC-D60

Sync Word	Command Code	Length	Data	Checksum
0x1ACFFC1D	0xXX	0x01	-	0xXX
4 bytes	1 byte	1 byte	2 – 16 bytes	1 byte

Table 17. UART response message, from nanoSSOC-D60 to master

Response messages are sent 10 ms after command reception.
Response to message 04 is sent 30 ms after command reception.
Other sync word under request.

7.4.3. UART addressable protocol

SMT has developed an UART addressable protocol based on UART layer, to connect several nanoSSOC-D60 units to the same UART network, in a master/slave configuration. This protocol has been tested with 6 units and 50 cm of cable length, network with star configuration.

Every request and response message will be preceded by an address byte word (instead of SYNC word) that indicates the identification of the sensor to communicate. If customer does not request any address, it will be 0x60 by default.

Address of each unit must be set during manufacturing, and it must be unique in its network.

The protocol of the UART addressable communication interface works as follows:

- Every sun sensor is a slave.
- Each sensor has a single and univocal address for identification in the same network.
- There is only one master in the same network.
- The master can communicate with a single sensor using its single address.
- Every sun sensor reads every message in the network, but only the one with the same address than the message will respond the request.
- Every sun sensor has a TX pin and a RX pin, and the TX pin of every sun sensor works as an input to avoid electrical failures and collisions.
- When a sun sensor identifies its address in a request message from the master, it actives TX (set it as output) to transmit the response message, and it deactivates TX (set it as input) when transmission ends.
- Max. recommended number of slaves connected to a single master is 5, with a max. cable length of 50cm for each.

Response messages are sent 10 ms after command reception.
Response to message 04 is sent 30 ms after command reception.

7.5. I²C communication protocol

This section describes the features of the sun sensor I²C communications interface and the different protocol messages and commands. Please refer to the manufacturer for any other special configuration.

7.5.1. I²C Configuration

The following table summarizes the characteristics of the I2C communications interface.

I²C clock signal	PIN 3
I²C data signal	PIN 5
Type of node	Slave
Address	0x60 (hex)
Bit rate	Up to 400 kHz

Table 18. I²C communications interface characteristics

7.5.2. I²C protocol format

nanoSSOC-D60 responses to the master according to the I²C standard, as follows:

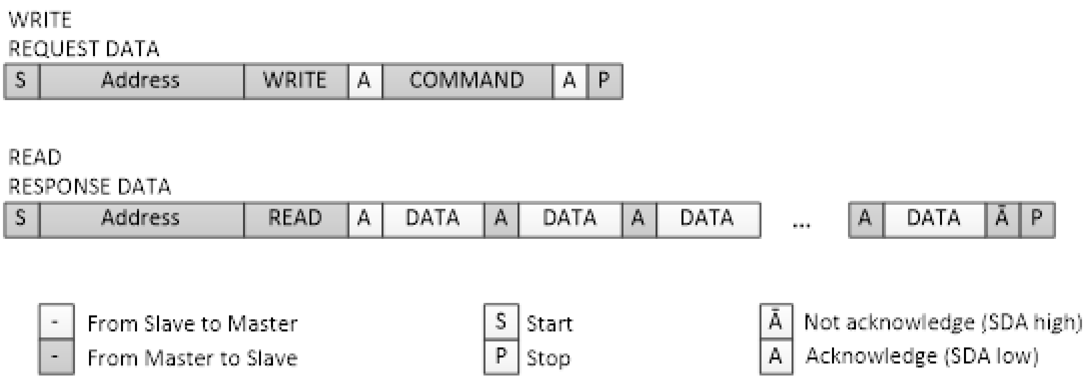

Fig 8. I2C Message protocol: write and read, request and response

The following describes the elements in the Fig 8 about message protocol:

- From master to slave:
  - Address (7 bits): the address of the sun sensor (0x60 by default). If you need a different value, please contact Solar MEMS.
  - Command (1 byte): as described above. (command code).

- From slave to master:
  - Address (7 bits): the address of the sun sensor (0x60 by default). If you need a different value, please check with Solar MEMS.
  - Data (n + 2 bytes):
    - Length (1 byte): as described above.
    - Information (n byte): as described above. (data).
    - Checksum (1 byte): as described above.

7.6. SPI communication protocol

This section describes the features of the sun sensor SPI communications interface and the different protocol messages and commands. Please refer to the manufacturer for any other special configuration.

7.6.1. SPI Configuration

The following table summarizes the characteristics of the SPI communications interface.

Transmission frequency	115 Kbps
Synchronism	Enabled
Data format	8 bits
Clock polarity (idle)	High level
Transmission edge	Rising edge
Operation mode	Slave
Slave selection	Low Level

Table 19. SPI communications interface characteristics

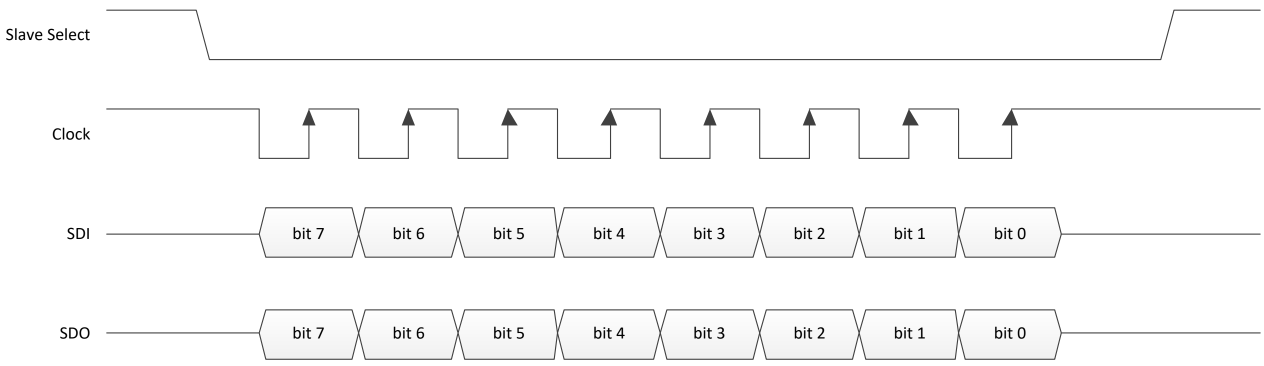

Fig 9. SPI slave mode bus configuration

7.6.2. SPI protocol format

Every request and response message will be preceded by a synchronization word than indicates the start of a new frame.

Sync Word	Request message	Length	Checksum
0x1ACFFC1D	0xXX	0x01	0xXX
4 bytes	1 byte	1 byte	1 bytes

Table 20. SPI request message from master to nanoSSOC-D60

Sync Word	Command Code	Length	Data	Checksum
0x1ACFFC1D	0xXX	0x01	-	0xXX
4 bytes	1 byte	1 byte	2 – 16 bytes	1 bytes

Table 21. SPI response message, from nanoSSOC-D60 to master

The following figure describes an example of a message 01 communication via SPI:

AOCS → **nanoSSOC-D60**

Sync Word	Command Code	Length	Checksum
0x1ACFFC1D	0x01	0x01	0x02
4 bytes	1 byte	1 byte	1 byte

AOCS ← **nanoSSOC-D60**

Char (IDLE)	Char (IDLE)	Char (IDLE)	Char (IDLE)	Char (IDLE)	Char (IDLE)	Char (IDLE)
1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte

Fig 10. SPI request message example

AOCS → **nanoSSOC-D60**

Char (IDLE)	Char (IDLE)	Char (IDLE)	Char (IDLE)	Char (IDLE)	Char (IDLE)	Float (IDLE)	Float (IDLE)	Float (IDLE)	Float (IDLE)	Char (IDLE)
1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	4 bytes	4 bytes	4 bytes	4 bytes	1 byte

AOCS ← **nanoSSOC-D60**

Sync Word	Command Code	Length	Application Data				Checksum
0x1ACFFC1D	0x01	0x11	Float (uSSA1)	Float (uSSA2)	Float (uSSA3)	Float (uSSA4)	0xXX
4 bytes	1 byte	1 byte	4 bytes	4 bytes	4 bytes	4 bytes	1 byte

Fig 11. SPI response message example

IDLE byte is a 0xFF value.

8. OPTICAL

8.1. Calibration

In order to guarantee the best accuracy, every sun sensor is individually tested and characterized, and a unique look-up table is included with each sensor. A ground calibration of the sensor is carried out to compensate all manufacturing tolerances and misalignment respect to the sensor positional reference.

Calibration procedure consists in the use of a High-Accurate Angular Positioning System (HAAPS), which is necessary to achieve high precision calibration curves. The HAAPS has been specifically developed by Solar MEMS for this purpose. The calibration process is carried out with the standard AM0 irradiance (1360 W/m^2).

As an example of the calibration results, the surface resulting from the outputs corresponding to each photodiode cell for each defined angular position in both orthogonal axes within the sensor field of vision is as follows:

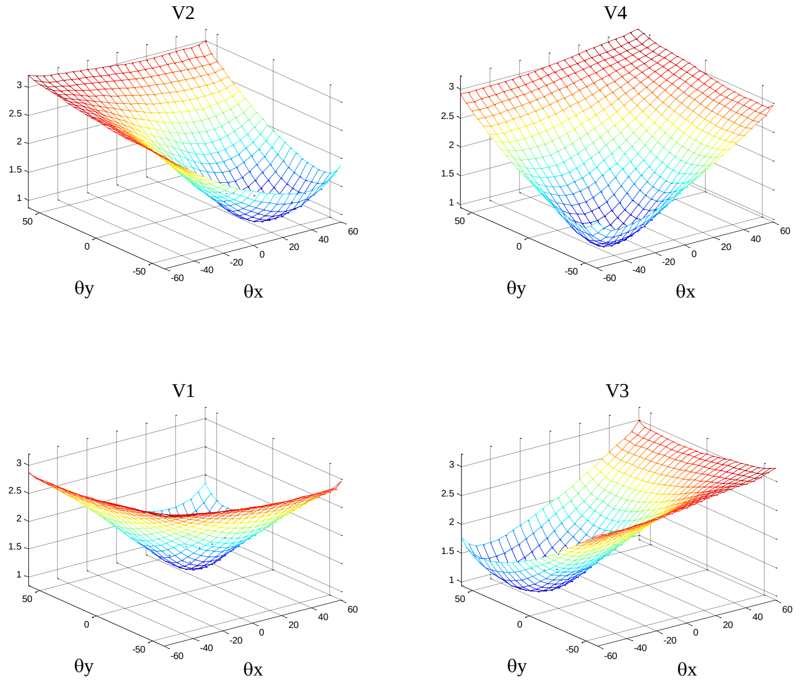

Fig 12. Photodiodes voltages obtained from the sun sensor calibration

Proprietary software characterizes and post-processes the response of the unit and generates the corresponding calibration tables. Following figure illustrates an example of a sun sensor calibration function obtained in the calibration process. Sensor calibration is performed at Solar MEMS Clean Room class ISO 8.

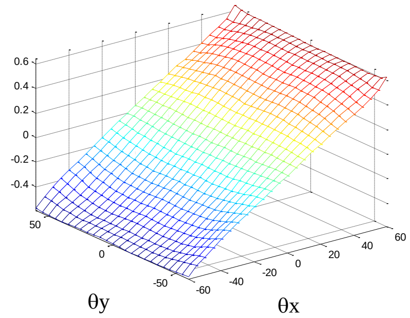

Fig 13. nanoSSOC-D60 calibration function

8.2. Spectral Responsivity

nanoSSOC-D60 spectral responsivity range is from 380 nm to about 1200 nm. The light transmittance of the Borofloat used for the window presents an optical transmittance approximately of 90% in the 380-1200 nm range. The electrical behavior of the sensor photodiodes has been measured using AM0 filter with solar light spectrum of 1366 W/m2 at ambient temperature (25ºC) and normal incidence. The spectral responsivity in the 380-1200nm range is show in the following picture.

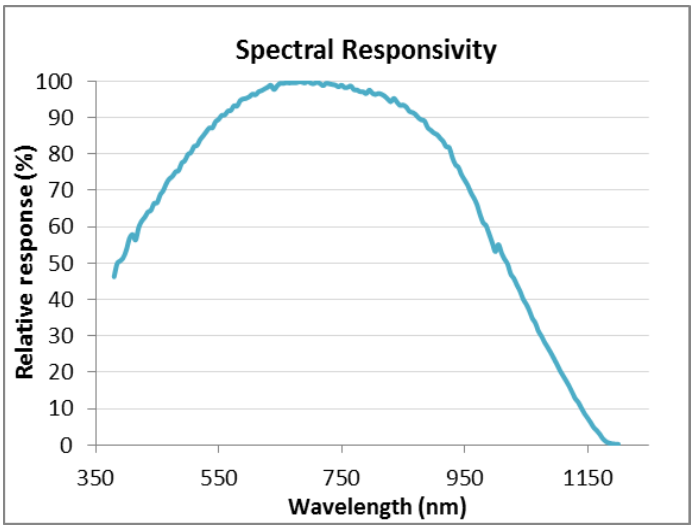

Fig 14. Spectral Responsivity

8.3. Look-up Table

Each sun sensor delivered already includes its own calibration data in the internal microcontroller, so the look-up table is not delivered to the customer.

9. ALBEDO AND SUN DETECTION

Sun Sensor includes some parameters to detect when Sun is inside FoV and if any albedo is affecting measurement. Albedo affects sun detection because it introduces a drift into angle measurement that may reach several to dozens of degrees, depending on its intensity. Some albedo cases are:

- Earth inside FoV reflecting sun vector into the sun sensor.
- Earth inside FoV affecting the sun vector detected.
- Any obstacle or part of the satellite affecting measurements by reflections or light generation, like thrusters.

Albedo can be detected comparing the amount of radiation detected (by summation of four sun sensor signals) with the amount of radiation expected, at a specific sun vector and according to calibration data collected on ground.

When comparing both values, it is possible to detect if any light source is affecting the expected measurement, as follows:

- When Earth (or any other albedo) and Sun are inside FoV, reflection of sunrays in Earth would be added to the normal solar radiation coming from the Sun. This means that the sensor would detect more voltage than expected.

- When only Earth is inside FoV, only reflected sunrays are coming inside FoV, and this reflection will never be more than 90% of expected solar radiation.

- In case of some elements of the spacecraft go inside FoV of the sun sensor, it can reflect sunrays, generating a secondary light source and affecting measurements. This may not be detected, so it is very important to ensure that any part of the spacecraft will never be inside the FoV of the sensor.

The comparison done to detect albedo has some margins for success (thresholds), because solar radiation is not constant all year, and other contributors affect to the accuracy of this comparison. The following table describes the margin for detection:

SPECIFICATIONS	Value	Unit	Margin	Comments
Average solar radiation	1360	W/m^2	0%	AM0 spectrum
Minimum solar radiation	1320	W/m^2	-3%	June-July
Maximum solar radiation	1415		+4%	December-January
Calibration accuracy	1360 +/-5%	W/m^2	+/-5%	Solar Simulator for SSOC-A60 calibration
Degradation per year	-	-	X%	Depending on expected degradation, typically 0% in a 500 km mission of 3 years.
Top margin	+9	%		Recommended 20%
Bottom margin	-8	%		Recommended -20%

Table 22. Albedo detection margins

Detection capability of the algorithm depends on:

- Sun vector and Earth vector are close: Sun in the Earth Horizon.
- Earth vector coming from a surface with a very low reflectance (<10%), meaning a minor impact of albedo.
- When Sun vector is close to normal vector of the sun sensor, the detection capability is higher because any drift is more easily detected due to higher signal from the Sun.

Albedo detection algorithm does not detect 100% of albedo cases, so it is necessary to use information of other sensors of the satellite to detect possible albedo cases.

9.1. Albedo detection by error code

Albedo can be detected using the error code delivered by sun sensor and checking its value: see table 17. In this case, threshold considered is 20%.

9.2. Sun detection managed by spacecraft

Sun sensor delivers a specific parameter called SunDetection, in %, that is calculated dividing amount of radiation detected by the expected value. This parameter allows spacecraft to apply its own threshold. However, it is not recommended to apply less than 10%.

On the other hand, this parameter could be calibrated to make the threshold more and more accurate:

1. Ensure a Sun vector measurement with no albedo, using other sensors or by positioning.
2. Check SunDetection value, and consider an offset to make this new value as the center of the algorithm
3. Apply thresholds to the new calibrated value.

This way, some contributors to the sun detection algorithm can be removed:

- Degradation, if any.
- Calibration tolerance can be removed.
- Solar annual variation can be removed if calibration is done every month.

10. PACKING, HANDLING AND STORAGE

nanoSSOC-D60 packing to the end customer is carried out by skilled operators of Solar MEMS Technologies in the clean room complex (class 10000, temp 23 ± 2°C). Operators involved with packing follow the standard environment and handling precautions. Devices are individually packed in antistatic plastic bags protected from ESD. These bags carry the serial number of each product and are hermetically sealed. The sealed bags are further packed in an appropriate box, surrounded by shock-absorbing soft foam, correctly labeled and suitable for air and road transport. The delivery will be associated with the following documents:

- Certificate of Conformity.
- Test report with the calibration results.
- Qualification Status document.

The unpacking of nanoSSOC-D60 shall take place in a controlled environment by skilled operators. The items under treatment are delicate and high-reliability optical and electronic instruments, which require handling with the most care.

Storage of the device may take place in an anti-static plastic bag. For long-term periods, it shall be stored in a controlled cleanroom environment. The package shall be maintained in a controlled environment with a temperature in the range of 15 to 25 ºC. The relative humidity shall be between 40% and 65%.

During device handling gloves shall be worn by the personnel, as well as the clothing required for the environment. The operator shall be grounded by an electrically conductive wrist-strap to minimize the risk of damage by electro-static discharges. The total allowable number of connects / disconnects on the connector itself shall be limited to 50. The sensor window surface shall never be touched.

If in spite of the precautions nanoSSOC-D60 package requires cleaning, the operator can use dry nitrogen gas to remove particle contamination. The maximum allowable pressure of the dry nitrogen gas flow leaving the pistol is 1 bar. If blowing is insufficient, the particular surface may be wiped with a wetted nylon woven cloth with isopropyl alcohol (IPA), or a cotton wool stick.

11. WARRANTY

Solar MEMS Technologies S.L. warrants nanoSSOC-D60 sun sensor to the original consumer purchaser any product that is determined to be defective for the following terms will be repaired, or replaced.

The limited warranty is 2 years from the date of purchase:

The product in question must be sent to Solar MEMS Technologies S.L. (address is shown below) within the warranty period and the original consumer purchaser must comply with the following conditions, to be eligible for repair or replacement under this warranty:

- The product must not have been modified or altered in any way by an unauthorized source.
- The product must have been installed in accordance with the installation instructions and handled and stored following the technical specification interfaces & operation document recommendations.

This limited warranty does not cover:

- Damage due to improper installation.
- Accidental or intentional damages.
- Misuse, abuse, corrosion, or neglect.
- Product impaired by severe conditions, such as excessive wind, ice, storms, lightning strikes or other natural occurrences.
- Damage due to improper packaging on return shipment.

Any and all labor charges for troubleshooting, removal or replacement of the product are not covered by this warranty and will not be honored by Solar MEMS Technologies S.L.

Return shipping to Solar MEMS Technologies S.L. must be pre-paid by the original consumer purchaser. Solar MEMS Technologies S.L. will pay the normal return shipping charges to original consumer purchaser within the European Union countries only.

Address of Solar MEMS Technologies S.L.
Solar MEMS Technologies S.L.
Parque Empresarial Aerópolis
C/ Early Ovington 24, nave 1
C.P. 41309 La Rinconada (Sevilla) — Spain
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Solar MEMS Technologies has a quality and environment management system according to the ISO 9001 and ISO 14001 standards.

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