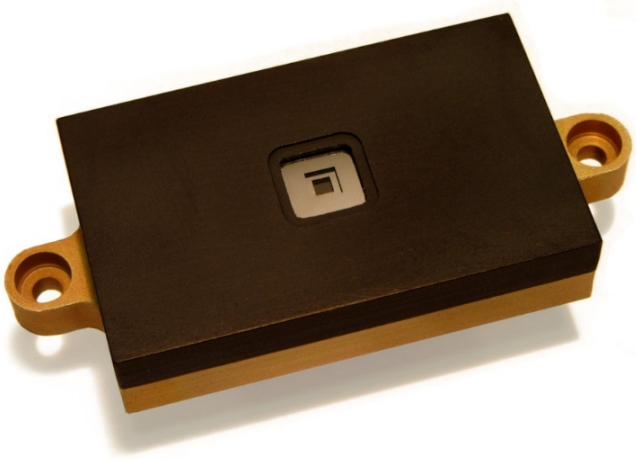

Sun Sensor on a Chip

SSOC-D60 - Digital interface

Technical specification, Interfaces & Operation

Specifications

Two orthogonal axes sun sensor
Wide field of view (FOV): ±60º
High accuracy: 0.3º
Precision: 0.05º
Power supply: 5.00 V
Max current: 63 mA
Reduced size: 50 × 30 × 12 mm
Low weight: 35.5 g
UART over RS-485 communication
Temperature sensing

Qualification

Temperature range: -45° to 85°C
Random vibration: 14g @ 2KHz
Mechanical shock: 3000g 1-100ms
TID radiation: 30 kRads
LET threshold: 6MeV/mg/cm^2
Vacuum thermal cycling qualified

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

Sun Sensor on a Chip (SSOC) is a two-axis, low cost sun sensor for high accurate sun-tracking and attitude determination. The device measures the incident angle of a sun ray in both orthogonal axes, providing a high sensitivity based on the geometrical dimensions of the design.

SSOC sun sensor is based on MEMS fabrication processes to achieve high integrated sensing structures.

Every sensor is characterized and calibrated for its application. It includes an internal thermistor. The use of materials as aluminum and cover glass minimizes the ageing of the device under high energy particle radiation.

SSOC-D60 includes a microprocessor that directly provides the sun light incident angles and other information useful for attitude determination, via UART over RS-485 communication.

SSOC-D60 sun sensor has reduced dimension, minimum weight and low power consumption. It provides a flexible solution for space programs.

Document information

Product:	SSOC-D60
Document Title:	Technical specification, Interfaces & Operation
Document ID:	SSOCD60-14-MAN-119 **Doc. Revision:** 1.19 **Doc. Date:** 21/11/2016

Responsibility exemption

Solar MEMS has checked the concordance of this document with the described software and hardware. However, as it is impossible to exclude deviations, Solar MEMS is not liable for full concordance. Solar MEMS reviews this document periodically. If necessary, possible corrections will be included in the next version.

Solar MEMS is not liable for the correct operation of the system if the user does not follow the instructions of this document or use replacement parts that are not covered by this guarantee.

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1 Introduction

The scope of this document is to define the Mechanical, Thermal, Electrical and Communications interfaces for SSOC-D60 Sun Sensors.

This document presents a brief description to enable customers to correctly use SSOC-D60 sun sensor, 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.

1.1 Design Review

SSOC-D60 sun sensor has been designed to withstand space conditions. It includes a transparent cover glass on the same silicon die to act as a shield to prevent space radiation damage. 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.

A printed circuit board with the electronics and the solar sensor is packaged in an anodized and alodined 3 mm thickness 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. The electronics assembly has been done considering the special requirements demanded by space applications.

The sensor is also protected with an additional external cover-glass placed on the package. The steps in the input window of the aluminum structure are designed to avoid light reflections inside the active area of the sensor.

1.2 Principles of Operation

SSOC-D60 is a miniaturized two axis sun sensor capable of measuring the incidence angle of a sun ray accurately in both azimuth and elevation. The sensor consists of four photodiodes fabricated monolithically in the same crystalline silicon substrate and placed orthogonally. The sunlight is guided to the detector through a window above the sensor, inducing photocurrents on each diode that depends on the angle of incidence. A simplified scheme of a pair of photodiodes to measure one particular sun incidence angle is illustrated in Figure 1.

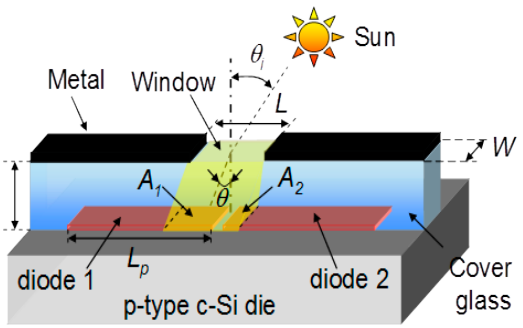


Figure 1. Operating principle

1.3 Spectral Responsivity

SSOC-D60 spectral responsivity range is from 380 nm to about 1200 nm. The light transmittance of the cover glass window presents an optical transmittance greater than 94% in the visible and near infrared. 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 following graph shows photodiodes spectral responsivity:

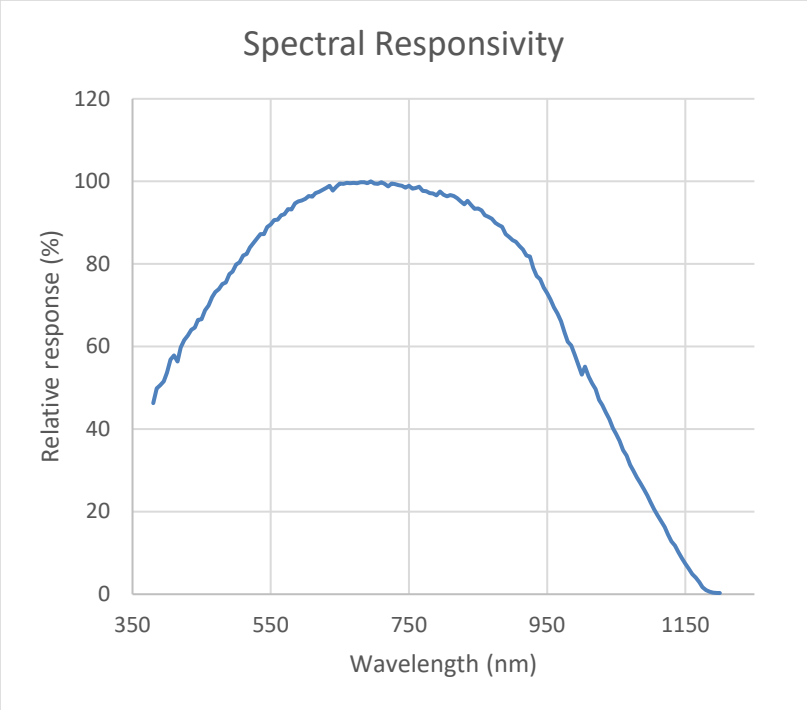


Figure 2. Spectral Responsivity

2 Specifications summary

2.1 Accuracy

Parameter	Value	Comments
Sensor type	2 axes	Orthogonal
Field of view (FOV)	± 60 °	Angular size of the view cone
Accuracy	0.3 °	3σ error
Sensitivity	0.05 °	
Calibration conditions: Tª = 25ºC, Vdd = 5.00V, Radiation = 1366 W/m2 (AM0 standard)		

Table 1. Accuracy

2.2 Filtering

Parameter	Value	Comments
Sampling frequency	50 Hz	
Butterworth filtering stage	3th order	
Cutting frequency	1 Hz	

Table 2. Filtering

2.3 Lifetime

Parameter	Value	Comments
Expected life time	3+ years	

Table 3. Lifetime

2.4 Electrical

Parameter	Value	Comments
Supply voltage	5.00 V	
Max current consumption	63 mA	
Connector (Cable side)	222S20M11	From Nicomatic
Connector (Sensor side)	221T20F22	From Nicomatic

Table 4. Electrical

2.5 Mechanical

Parameter	Value	Comments
Dimensions (L × W × H)	50 × 30 × 12 mm	68 x 30 x 12.61 mm including mounting feet and connector
Weight	35.5 ± 0.2g	
Mount holes Ø	Ø3.2 x2	
Mount holes separation	60 mm	
Mounting screws	M3	Recommended M3 Allen screws A2-70 s/UNE – EN-ISO 4762 -2005
Recommended torque	1.1 - 1.4 Nm	
Housing	Aluminum 6082	Alodine 1200S (ECSS-Q-70-71) Black anodized (ECSS-Q-ST-70-03C)

Table 5. Mechanical

2.6 Thermal

Parameter	Value	Comments
Temperature range	-40 to +85 ºC	
Temperature value accuracy	1 ºC	Internal thermistor

Table 6. Thermal

3 Mechanical

3.1 Material and Surface Treatments

SSOC-D60 sun sensor package is made of 3 mm aluminum 6082 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 of the back 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).

3.2 Labeling

Each sensor is labeled with an unique serial number. It can be seen in the following picture:

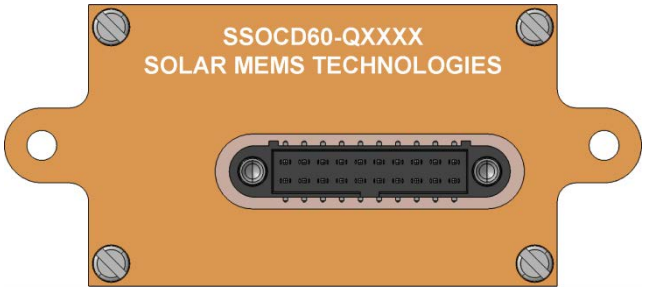


Figure 3. Sensors labeling

3.3 Venting Holes

Adequate venting is provided to preserve the structural integrity of the units during launch depressurization.

3.4 Mass

Mass of SSOC-D60 is 35.5 ± 0.2g.

3.5 Dimensions

SSOC-D60 dimensions are 50 x 30 x 12 mm (68 x 30 x 12.61 mm including mounting feet and connector). The following figure shows all the relevant dimensions of SSOC-D60. All dimensions are in mm.

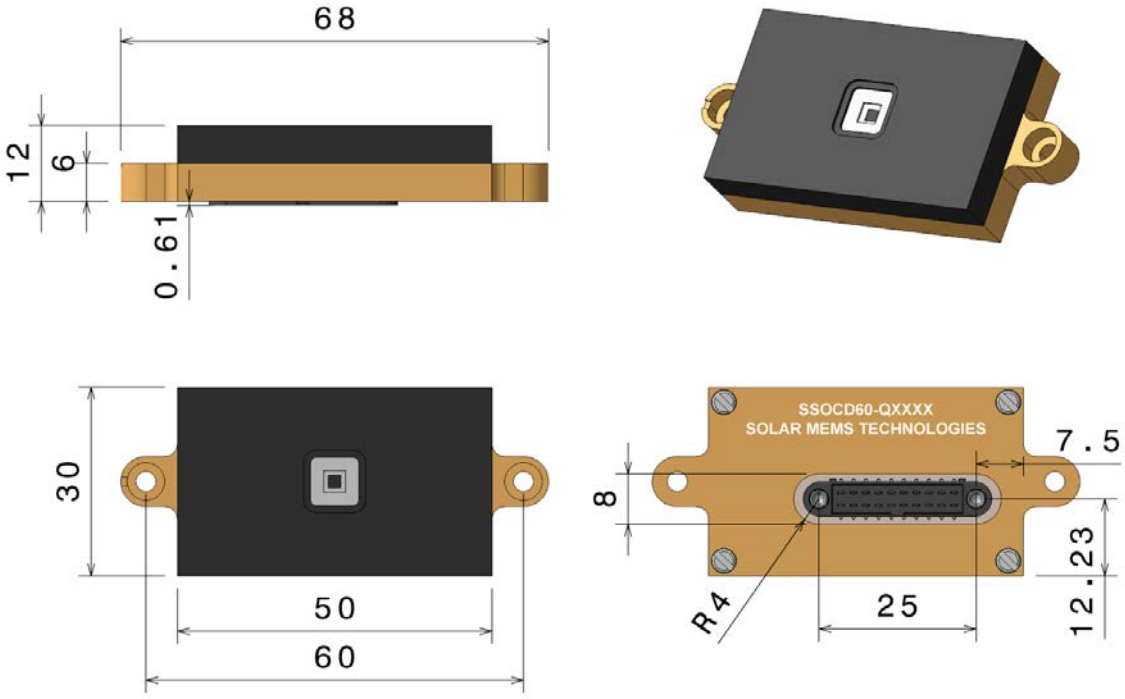


Figure 4. Dimensions

3.6 Reference System

The mechanical reference axes for sensor assembling are shown in Figure 5, where the origin of the coordinate system is located in the center of the left mounting hole (front view). The optical line of sight is perpendicular to the sensor base plane, which is called Z_M axis. The centerline of the two sensor mounting holes is by definition the X_M axis, and the Y_M axis is the third one of a right-handed orthogonal coordinate system.

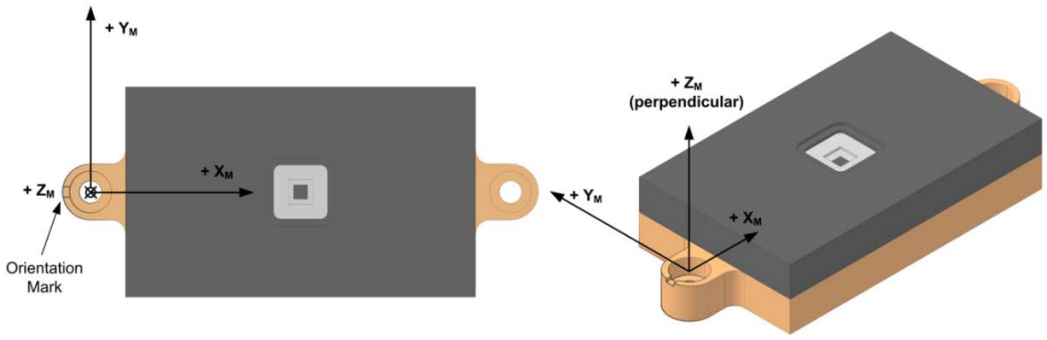


Figure 5. Mounting reference system

With the 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 SSOC-D60 (See Figure 6).

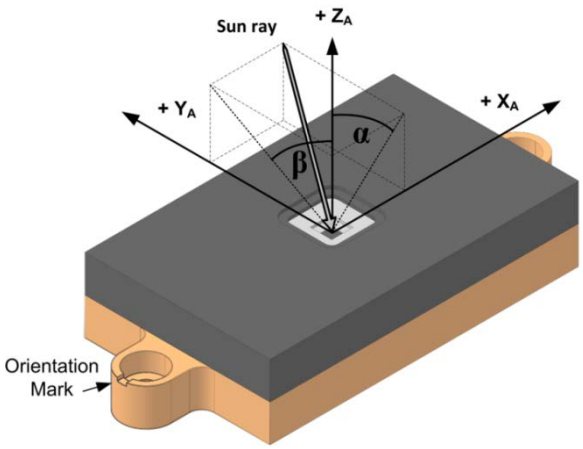


Figure 6. Reference for measured angles

3.7 Mounting Holes

The sensor package has two mounting feet for M3 screws. Both feet have precision holes with a diameter of 3.2 mm. The two mounting feet have interface planes which are co-planar to better than 0.01 mm. The distance between the centers of the two holes is 60 ±0.02 mm.

For fastening the sensor at the two precision holes, it is recommended the use of M3 threaded Allen screws A2-70 s/UNE – EN-ISO 4762 -2005, A2 stainless steel, 20mm length, and minimum and maximum torque levels of 1.1 Nm and 1.4 Nm. The choice of recommended fasteners as well as torque levels ensures appropriate sensor alignment.

3.8 Remove Before Flight Items

SSOC-D60 precision can be affected by dust particles. For that reason they have a protective film with an attached red 'REMOVE BEFORE FLIGHT' label.

Figure 7. Remove before Flight label

4 Thermal

4.1 Material Characteristics

The aluminum housing has been black-anodized according to the ECSS-Q-ST-70-03C, excepting the contact surface of the back which is subjected to alodine 1200S for space applications (ECSS-Q-70-71).

Black anodized has the following characteristics:

- $\alpha \geq 0.930$
- $\varepsilon \geq 0.853$

4.2 Contact Area

Contact area of SSOC-D60 is 13.17 cm^2. This is the main dissipation way for the unit

4.3 Unit Temperature Range

SSOC-D60 temperature range is -45° to 85°C.

4.4 Power Dissipation

The unit power dissipation is <0.32W.

5 Electrical

5.1 Electrical Characteristics

5.1.1 Power supply

SSOC-D60 electrical characteristics are shown in the following table:

Symbol	Parameter	Min	Typical	Max	Unit
V_{DD}	Supply voltage				
	Absolute Maximums	4.50	-	5.50	V
	Recommended	4.95	5.00*	5.05	V
I	Current Consumption	-	-	63	mA

Table 7. Electrical Characteristics

*SSOC-D60 0.3° 3-sigma precision is guaranteed for a supply voltage range from 4.50V to 5.50V. However, supply voltage should be precisely tuned to 5.00 V to achieve best precision results.

5.2 Pin Description

The electrical interface with SSOC-D60 lies in a male micro-connector with 20 contacts installed through the bottom cover of the sensor package. This connector is a Nicomatic 221T20F22, 2-row male connector straight SMT with fixing. The recommended connector for connection cable side is a Nicomatic

222S20M11, 2-row female connector with fixing crimp gauge AWG 24-28, 20 contacts (1 piece is included with the purchase of a SSOC-D60).

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

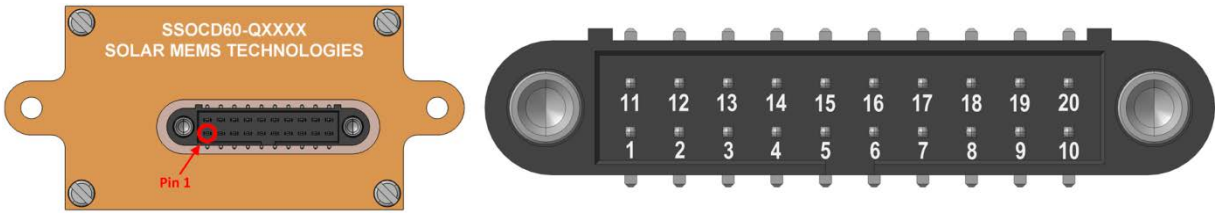


Figure 8. Pin numbering

The electrical signals of the sun sensor are detailed as follows:

- **Supply voltage:** 5V and 5V_RTN, corresponding to power supply and power return, respectively.
- **Digital signals:** Four digital input/output lines, corresponding to the two balanced signals involved in the UART communication protocol (TX+, TX-, RX+, RX-).
- **Chassis:** Two signals to connect the ground reference plane of the circuit to the spacecraft/satellite structure.

The functions of the micro-connector contacts and its internal connection to the sun sensor are summarized in the following table:

Pin number	Name	Description	Type
20	5V	5V Power supply	Power
16	5V_RTN	Power supply return	Power
10	5V_RTN	Power supply return	Power
3	TX+	Positive transmission line of RS-485	Digital output
4	TX-	Negative transmission line of RS-485	Digital output
13	RX+	Positive reception line of RS-485	Digital input
14	RX-	Negative reception line of RS-485	Digital input
9	Chassis	Chassis	-
19	Chassis	Chassis	-
5	Reserved	Reserved. Do not connect	-
6	Reserved	Reserved. Do not connect	-
15	Reserved	Reserved. Do not connect	-
1	NC	Not internally connected	-
2	NC	Not internally connected	-
7	NC	Not internally connected	-
8	NC	Not internally connected	-
11	NC	Not internally connected	-
12	NC	Not internally connected	-
17	NC	Not internally connected	-
18	NC	Not internally connected	-

Table 8. Pin description

Solar MEMS delivers no interface cable but recommends the use of a cable harness composed of AWG-24 wire gauge for the individual wires, twisted and shielded for best reduction of magnetic field and EMI. The grounding shall be at one point only. The sensor has no direct connection between the power zero and the chassis (electrically isolated).

5.3 RS-485 bus termination resistors

SSOC-D60 integrates separate driver and receiver for full-duplex RS-485 communication. By defect, driver and receiver do not include parallel termination resistors. 121 ohm resistors can be added by customer request.

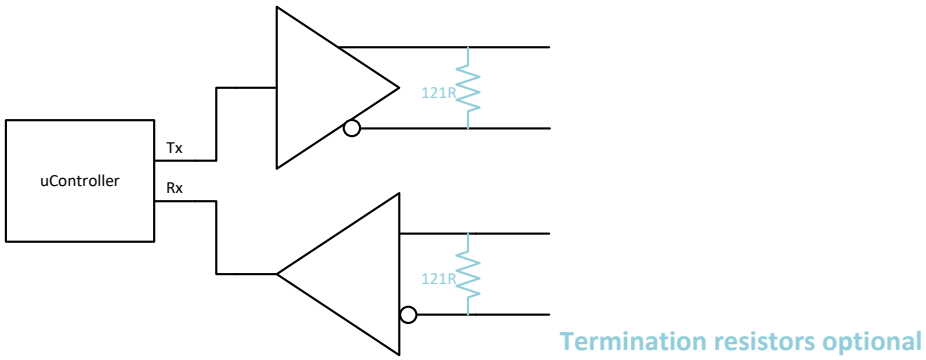


Figure 9. Termination resistors

5.4 Power on peak current

SSOC-D60 inrush current is showed in the following figure:

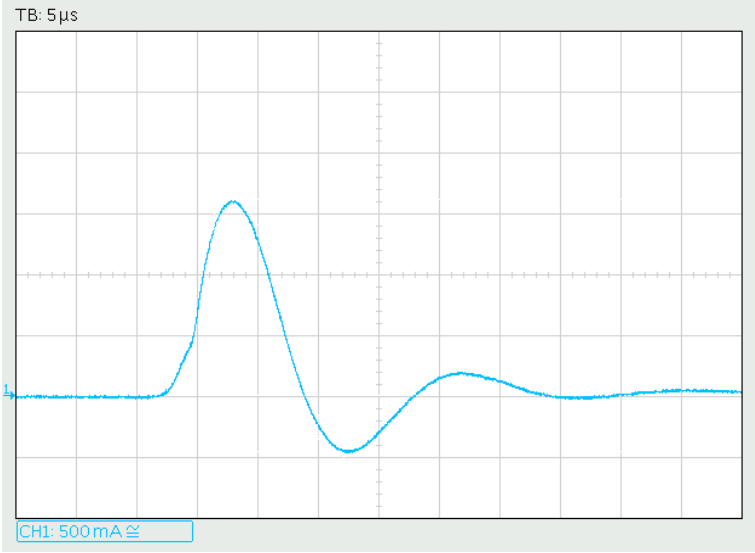


Figure 10. Inrush current

6 Communications

This section describes the features of the sun sensor UART communications interface and the different protocol messages and commands.

6.1 Main description

The protocol of the RS485 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 may be more than one master in the 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 disables TX driver when there is nothing to transmit: tri-state.
- RX driver of each sun sensor is always enabled.
- If sun sensor is switched off, TX and RX drivers get into tri-state mode.
- When a sun sensor identifies its address in a request message from the master, it actives TX to transmit the response message. After that, it deactivates TX when transmission ends.

6.2 UART Parameters

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

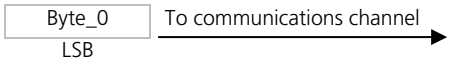
Baudrate	115200 bps
Data bits	8 bits
Parity	none
Stop bits	1
Handshaking	none

Table 9. UART Configuration

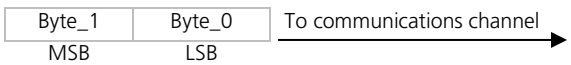
6.3 Data format

The data structure for RS485 communications transmission is explained below:

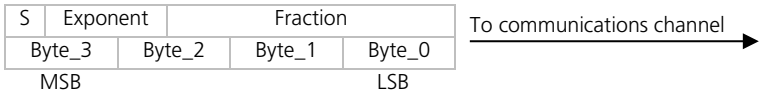
- Character transmission (*unsigned char*):



- Two byte Integer transmission (*int*):



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



Floating value= $S \times 2^{e} \times m$.

- Sign (S): 1 bit (1=positive, 0=negative)
- Exponent: 8 bits (e = Exponent – 127)
- Fraction: 23 bits (m = 1.Fraction)

6.4 Timing

The response times of SSOC-D60 sun sensors are showed in the following table. Response time is measured as the time since the last byte of received command is read by the SS and the first byte of the response is sent to the OBC.

	Response time (ms)		
Command	**Min.**	**Typ.**	**Max.**
Unfiltered cells	-	1,10	3,00
Temperature	-	1,10	3,00
Filtered cells	-	1,10	3,00
Angular position	-	5,10	7,00
Minimum time between commands	20	50	-

Table 10. Communication timing

6.5 Frame format

Every TC sent through the UART link shall comply with the format described in the table below.

Address	**Command Code**	**Length**	**Checksum**
0xXX	0xXX	0x01	0xXX
1 byte	1 byte	1 byte	1 bytes

Address:	Single and univocal identification of the sun sensor
Command Code:	It corresponds to the code of the incoming command.
Length:	For commands it is fixed to 0x01.
Checksum:	It is used to check the integrity of the packet. It is calculated adding all bytes in 'Address' + 'Command Code' + 'Length' fields and extracting the least significant byte of the result.

Table 11. TC format

Answers received through the RS485 link follows the format described in the table below.

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

Address:	It is the address of the sensor that is responding.
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'.
Application 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 'Address' + 'Command Code' + 'Length' + 'Application Data' fields and extracting the least significant byte of the result. E.g.: `03 02 05 42 12 87 2B  0D` Checksum is 0D. This checksum is calculated adding 0x02 + 0x05 + 0x42 + 0x12 + 0x87 + 0x2B = 0x10D. Least significant byte of 0x10D is 0x0D.

Table 12. TM format

6.6 Commands

The following table summarizes the UART protocol commands, which are widely described below.

Command	Name	Functionality
0x01	UNFILTERED CELLS	Request for the voltages values of the four photocells without filtering.
0x02	TEMPERATURE	Request for the temperature value of the sensor thermistor.
0x03	FILTERED CELLS	Request for the voltages values of the four photocells with filtering.
0x04	ANGULAR POSITION	Request for the angular position (α, β) and error code.

Table 13. Command codes

After SSOC-D60 is turned on, a minimum timeout of 2 seconds is required before the first data request, in order to reach the stabilization of amplifiers, converters, and specifically, the digital filters. The protocol consists of data request frames sent to the sun sensor and response frames received to the attitude control subsystem (AOCS), which format is explained below.

6.6.1 Command 01: Unfiltered photocells 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.

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

Table 14. Command 01 TC format

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

Table 15. Command 01 TM format

6.6.2 Command 02: Temperature

Request for the temperature value of the internal thermistor. The temperature value is represented by a 32-bit float.

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

Table 16. Command 02 TC format

Address	Command Code	Length	Application Data	Checksum
0xXX	0x02	0x05	Float [degC]	0xXX
1 byte	1 byte	1 byte	4 bytes	1 byte

Table 17. Command 02 TM format

6.6.3 Command 03: Filtered photocells 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.

Address	Command Code	Length	Checksum
0xXX	0x03	0x01	0xXX
1 byte	1 byte	1 byte	1 byte

Table 18. Command 03 TC format

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

Table 19. Command 03 TM format

6.6.4 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 Figure 6. Reference for measured angles) are represented by a floating format. The error code (see Table 22) format is represented in a char.

Address	Command Code	Length	Checksum
0xXX	0x04	0x01	0xXX
1 byte	1 byte	1 byte	1 byte

Table 20. Command 04 TC format

Address	Command Code	Length	Application Data			Checksum
0xXX	0x04	0x0A	Float (α) [°]	Float (β) [°]	Char (error code)	0xXX
1 byte	1 byte	1 byte	4 bytes	4 bytes	1 byte	1 byte

Table 21. Command 04 TM format

6.6.4.1 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
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 10%, so a reflected sun-light is affecting measurement.
Other values	Internal manufacturer information

Table 22. 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. This case is similar when no light.
- Code 12: Earth and Sun albedo.
  Sun sensor sees the Sun and the Earth, because received solar radiation level is higher than 1360 W/m2, 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/m2. When the measured radiation is lower or higher than this value considering the tolerance, the algorithm detects code 11 or 12.

7 Packing, Handling and Storage

SSOC-D60 packing to the end customer will be carried out by skilled operators of Solar MEMS Technologies in the cleanroom complex (class 8, temp 22 ± 2°C). Operators involved with packing shall 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 with respect to SSOC-D60 Technical Specification, Interfaces & Operation document for each individual serial numbered device.
- A functional test report.

It is recommended that the unpacking of SSOC-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 25 to 15 °C. 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 SSOC-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.

8 Warranty

Solar MEMS Technologies S.L. warrants SSOC-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.

Warranty is one year from the date of purchase.

If the product need to be repaired or replaced, it 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.
C/ Early Ovington 24, nave 1
C.P. 41309, La Rinconada (Sevilla)
Spain

Phone: +34 954460113

Solar MEMS has a system of quality and environment according to the ISO 9001 and ISO 14001 standards, provided by the certification company Applus CTC.

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