nanoSSOC-A60

Sun Sensor for Nano-Satellites
Analog 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: 3.3V (5V under request)
Reduced size: 27.4 × 14 × 5.9 mm
Low weight: 3,7 g
Temperature range: -30 to +85 ºC

Qualification

> 100 kRad Total Ionizing Dose
Space-grade components
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 light and provides 4 analog outputs which can be processed to obtain both azimuth and elevation angles.

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-A60 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-A60 and provides information about the operating principle, design, interfaces, 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-A60 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-A60 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-A60 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 hundreds of units, orbiting since 2009.

All electronic components inside nanoSSOC-A60 are space-grade and have been tested at 100kRAD (TID), showing a correct operation.

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.
Field of view (FOV)	± 60 º	Performance field
Exclusion FOV	± 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	3.3 V	5V under request
Average consumption	< 0.1 mA	Dark
Average consumption	< 2 mA	Light: 1360 W/m^2, AM0
Thermal		
Temperature range	- 30 to +85 ºC	
Mechanical		
Dimensions (L × W × H)	27.4 × 14 × 5.9 mm	
Weight	3,7 g	
Mount holes	M2.5 x2	
Connector	DF13EA-10DP-1.25V(55)	From Hirose
Housing	Aluminum 6082	Alodine 1200S (ECSS-Q-70-71) Black anodized (ECSS-Q-ST-70-03C)
Qualification		
Total ionizing dose	> 100 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-A60 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-A60 sun sensor has a unique serial number, which is milled on its case. The serial number follows this format: NAXXXX, 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-A60 (Fig 3). Both angles are provided in degrees.

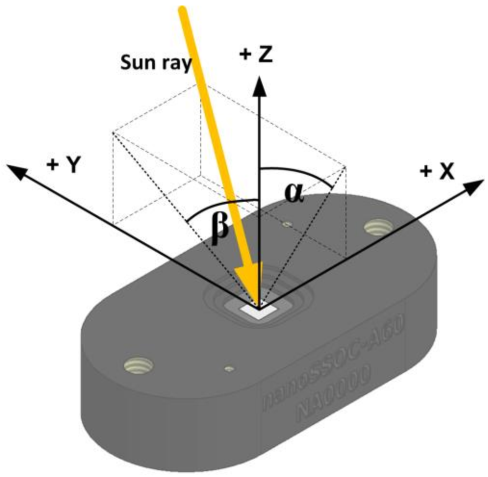

Fig 3. Angles reference

4.4. Mass

nanoSSOC-A60 mass is 3.7g

4.5. Dimensions

nanoSSOC dimensions are 27 x 14 x 5,9 mm (With the connector protruding 1,9mm). The following figure shows all the relevant dimensions of nanoSSOC-A60. All dimensions are in mm.

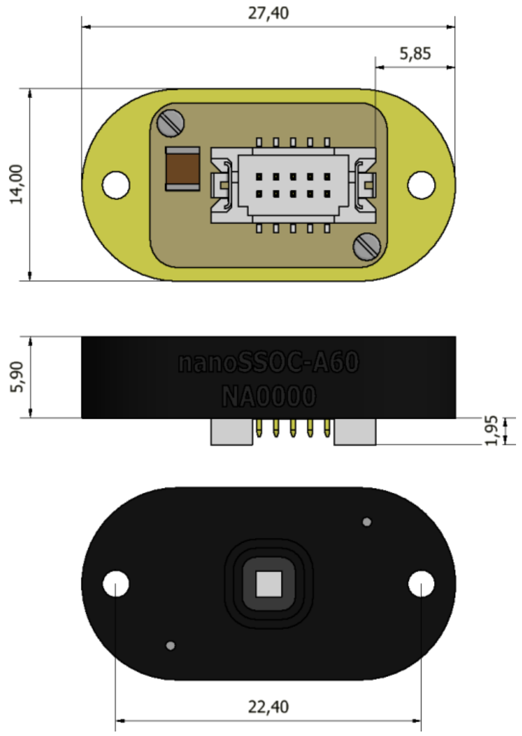

Fig 4. Dimensions

4.6. Fastening

nanoSSOC-A60 has two M2.5 threaded mounting holes. As can be seen in Fig 4, the distance between the centers of the two holes is 22.40±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-A60 can be fastened directly to the satellite or using an adaptor. Solar MEMS can provide an adaptor specially designed for placing a nanoSSOC-A60 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-A60 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-A60 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.

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-A60 is 297 mm^2 on top-side and 130 mm^2 on bottom-side. Direct contact areas are the main dissipation way for the unit.

5.3. Unit Temperature Range

nanoSSOC-A60 temperature range is -30ºC to +85ºC.

5.4. Power Dissipation

The unit power dissipation is <7mW.

6. ELECTRICAL

6.1. Power supply

nanoSSOC-A60 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	-	2	-	mA

Table 2. Electrical Characteristics

*nanoSSOC-A60 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-A60.

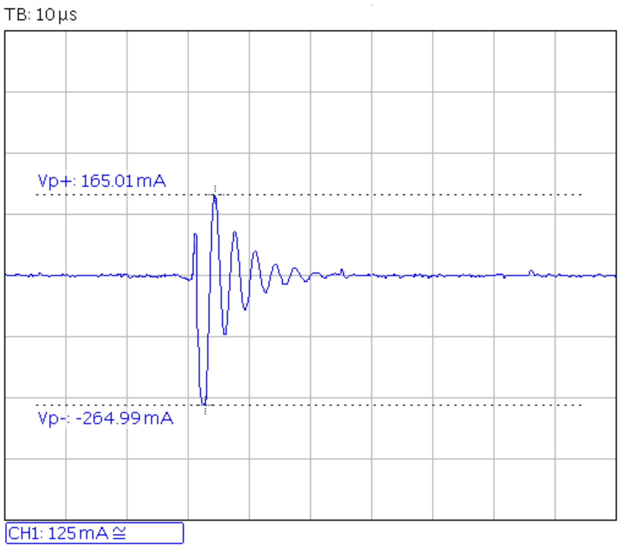

Fig 6. Inrush current

6.3. Connector and harness

nanoSSOC-A60 uses a micro-connector with 10 contacts installed on the bottom of the sensor. This connector is a 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:

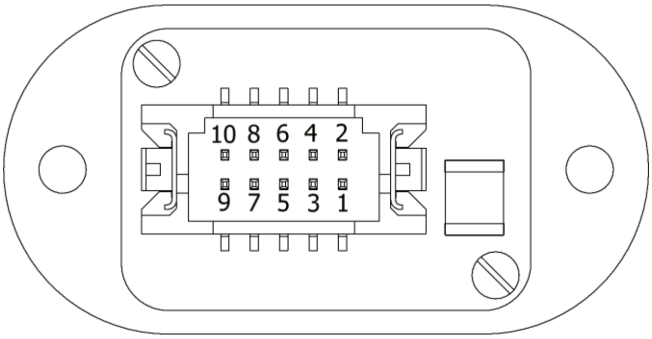

Fig 7. Connector pin numbering

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

Pin	Signal	Description	Type
1	µSSB-3	Photodetector 3	Analog output
2	µSSB-1	Photodetector 1	Analog output
3	3V3	Supply voltage	3.3V
4	GND	Ground	Power
5	GND	Ground	Power
6	GND	Ground	Power
7	GND	Ground	Power
8	Chassis	Connection to chassis	-
9	µSSB-4	Photodetector 4	Analog output
10	µSSB-2	Photodetector 2	Analog output

Table 3. Pin description

7. OPTICAL

7.1. 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:

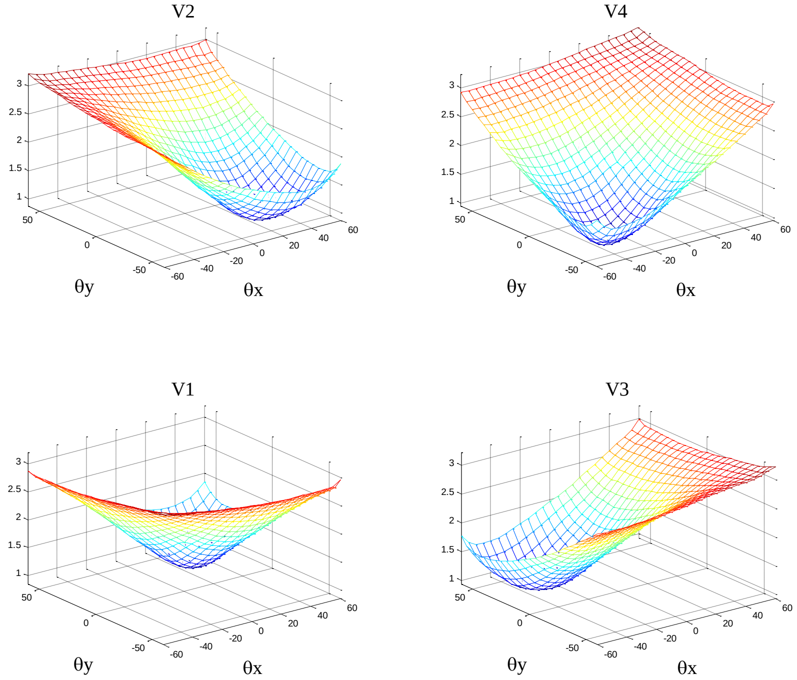

Fig 8. Photodiodes voltages obtained from the sun sensor calibration

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.

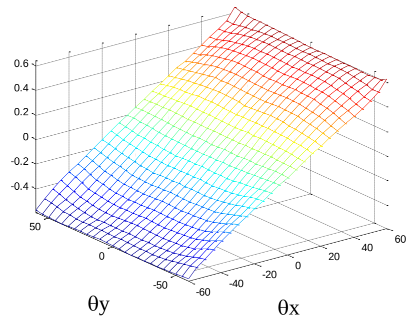

Fig 9. nanoSSOC-A60 calibration function

7.2. Spectral Responsivity

nanoSSOC-A60 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.

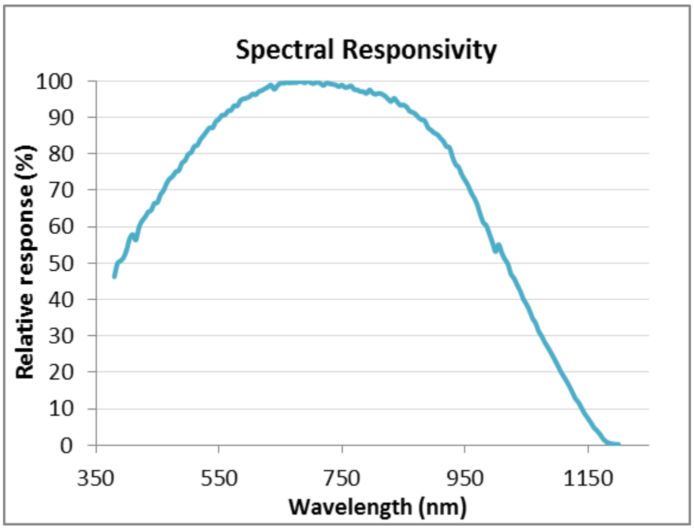

Fig 10. Spectral Responsivity.

8. OBC INTERFACE

The following algorithm and look-up-tables must be implemented in the OBC to translate output voltages of the sun sensor into angle measurement.

Algorithm and tables are delivered to the customer in ".h" files for integration.

Following sections are for description only.

8.1. Sun sensor transfer function

The four sun sensor signals (µSSB1 to 4) must be measured using an ADC of 10 bits of resolution as minimum to ensure performance.

Those values must be then used in the following formulas to get the sensor response factor, called Fx and Fy:

$$X1 = (Vcc \times 2) - (Vph1 + Vph2)$$
$$X2 = (Vcc \times 2) - (Vph3 + Vph4)$$
$$Y1 = (Vcc \times 2) - (Vph1 + Vph3)$$
$$Y2 = (Vcc \times 2) - (Vph2 + Vph4)$$

Vphx: photodetectors (µSSB1 to 4)

Vcc: 5V

$$Fx = (X1-X2) / (X1+X2)$$
$$Fy = (Y1-Y2) / (Y1+Y2)$$

Values Fx and Fy must be used according to algorithm described in section 5: double interpolation and look-up-table matrixes.

8.2. Look up table

Every delivered sun sensor shall include three look-up-table as follows:

- Angle X matrix.
  Matrix of 61x61 elements: 2 bytes unsigned integer per element.
- Angle Y matrix.
  Matrix of 61x61 elements: 2 bytes unsigned integer per element.
- Albedo matrix.
  Matrix of 625 elements: 2 bytes unsigned integer per element.

Three LUT matrixes shall be delivered in a .h file.

8.3. Algorithm

Algorithm to be implemented for angle measurement is as follows:

1. Get Fx and Fy values from uSSB1 to 4 signals.
2. Ensure detection inside performance FoV:
   a. Fx and Fy are compared with side-side margins delivered in LUT.h file.
   b. If Fx or Fy are out of margins, the Sun is not inside Performance FoV.
   c. If Fx and Fy are inside margins, go to step 3.
3. Apply double interpolation algorithm using LUT of Angle X and Angle Y.
   This algorithm shall be provided in C code (.h), to be included in OBC.
4. Results of double interpolation are the angle X and Y measurements.

This full algorithm shall be provided in C code (library_SSOCA60.h): it is a single function which inputs and outputs are:

- In: voltages of signals uSSB1to4 of SSOC-A60, in V.

- Out: angle measured or error if any.
- Out: albedo detection comparison (see next section).

List of errors are:

- Sun out of performance FoV.
- Albedo detection: Earth and Sun+Earth.
- No Sun detected.

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 4. 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 (or photodetection), 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-A60 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.
- Look-up table raw data in a spreadsheet file.
- Library of C codes, including the raw data and the angle calculation algorithm.
- Qualification Status document.

The unpacking of nanoSSOC-A60 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-A60 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-A60 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
e-mail: smt@solar-mems.com
Web: http://www.solar-mems.com
Phone: (+34) 954 460 113

Solar MEMS Technologies has a quality and environment management system according to the ISO 9001 and ISO 14001 standards.

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