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ACSS

Advanced Coarse Sun sensor
Redundant analog sensor

Technical Specification, Interfaces & Operation

Specifications

Redundant sun sensor
Wide field of view (FOV): ±60º
Max. accuracy in FOV: < 0.5º
Precision: 0.05º
Power supply: 15-30 (unregulated)
Reduced size: 65 x 47 x 13 mm
Low weight: 40 g
Analog interface
Operative range: -45 to +85 ºC
Qualification range: -50 to 90 ºC
Reliability: 8 FIT @ 30ºC

Qualification

Space qualified unit
Rad-hard microsensor: 200 kRad, 8e11 10 MeV
Hundreds of sensor units in orbit, with a cumulated time > 500 years without failure.

Applications

Satellite attitude determination
Accurate Sun position determination
Satellite solar panel positioning
Attitude Failure Alarm
Satellite positioning in specific trajectory points

Advanced Coarse Sun Sensor (ACSS) is a device for sun-tracking and attitude determination. This sensor measures the incident angle of sun ray in two orthogonal axes, providing a high sensitivity based on the geometrical dimensions of the design. ACSS sensor is based on MEMS fabrication processes to achieve high integrated sensing structures.

ACSS sensor offers the highest reliability and radiation hardness for the most demanding LEO, MEO and GEO missions. ACSS technology has flight heritage since 2019 with hundreds of flight units in orbit, and its manufacturing process has been developed and industrialized for mass production.

ACSS is the perfect sun sensor for satellite constellations and high-demanding missions due to its redundancy, reliability, and hardness.

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Document history

Revision	Date	Change	Authors
100	05.03.2021	Initial version	MRH
101	26.08.2021	Updated pictures	JMM, MRH
102	26.10.2022	Table 5 updated	MRH
103	20.02.2023	Operative and qualification thermal ranges corrected	MRH

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1. INTRODUCTION

This user manual presents a brief description for a correct use of the sun sensor called ACSS 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.
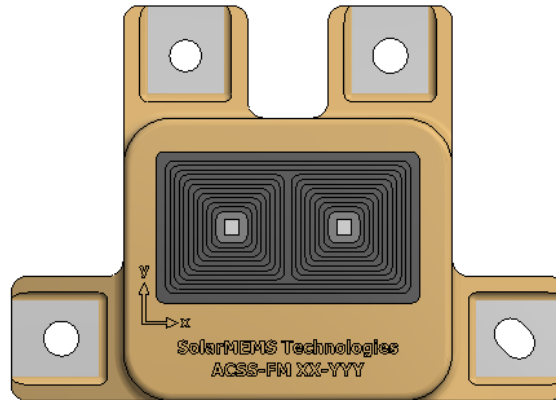

Fig 1. ACSS sun sensor device

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

ACSS includes two built-in iSSOC devices (Industrial Sun Sensor on a Chip), and each device includes a 4-quadrant photodiode capable of measuring the incidence angle of a sun ray accurately in both axes X and Y.
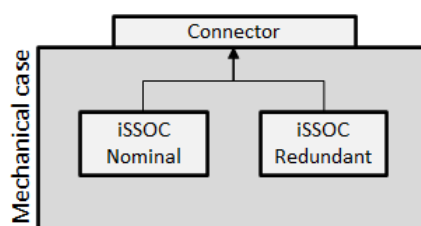
Fig 2. ACSS schematic

ACSS uses silicon photodiodes monolithically integrated, including a transparent glass on the same silicon die to act as a shield to prevent space radiation damage. ACSS 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.

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2.2.   Qualification & Flight heritage

ACSS has been developed following the most demanding mission requirements in terms of reliability and hardness. In addition to this, ACSS manufacturing process has been industrialized for mass production, in order to provide a cost-effective and lead-time reduced solution for satellite mega-constellations.

ACSS has been qualified according to the following conditions:

Stage	Object	Test	Conditions on ACSS
ACSS	Mechanical	Sine vibration	5 to 100 Hz 20g
		Random vibration	0.1g inplane 20-2000Hz 1.0g outplane 20-2000Hz
		Shock	20g at 100Hz 2000g at 10000 Hz
	Thermal	Thermal cycling	6 cycles, -55 to 85 °C Dwell time 10 mins
		Thermal vacuum cycling	6 cycles, -55 to 85 °C Dwell time 120 mins
	Lifetest	Lifetest	600 cycles, -55 to 105 °C 10 samples
	EMC/ESD	Bonding/Grounding	ECSS-E-ST-20-07C MIL-STD-461F
		Conducted susceptibility	
		Radiated susceptibility	
	Radiation	TID radiation	Gamma 200 kRad
		TNID radiation	Protons 2e11 p/cm^2, 10 MeV

Table 1. ACSS qualification status

All ACSS are calibrated, evaluated and verified with the following tests:

Stage	Object	Test	Conditions
ACSS Verification	Electrical performance	Thermal cycling	6 cycles, -45 to 75°C
	Functions	Optical and Electrical	625 different sun vectors in FoV
	Acceptance (batch sampling or under request)	Random vibration	0.05g inplane 20-2000Hz 0.5g outplane 20-2000Hz
		Thermal cycling	12 cycles, -45 to 75 °C Dwell time 10 mins

Table 2. ACSS production verification procedures

ACSS technology has a cumulated time in orbit larger than 500 years without failures. More than a thousand sun sensor flight units have been delivered so far, with hundreds launched since 2019.

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3. TECHNICAL SPECIFICATIONS

Parameter	Value	Comments
Global specifications		
Sensor type	2 axes	Orthogonal.
Redundancy	2 units	Nominal and Redundant
Performance field of view	± 60 º	Cone shape Tailoring available
Exclusion field of view	± 70 º	Squared shape Tailoring available
Accuracy with transfer function	< 3 º	3σ error Tailoring available
Accuracy with look-up-table	< 1 º	3σ error Tailoring available
Precision	< 0.05 º	
Electrical		
Supply voltage	15-30 V	Unregulated Better performance for higher voltage
Consumption	3 mA	Light: 1360 W/m², AM0
Connector	Micro-D 15 pins	Axon: P563917A
Analog signals	8 signals	per sensor, 0.27mA (1360 W/m2, AM0, normal vector)
Analog voltage levels	0 to 2.5 V	Tailored depending on polarization resistor (not included)
Thermal		
Operative range	- 45 to +85 ºC	
Qualification range	- 50 to +90 ºC	
Survival range	- 60 to +125 ºC	
Mechanical		
Dimensions (L × W × H)	65 x 47 x 13 mm	Not considering connector
Weight	40 g	
Mount holes	M4 x 4	
Housing	Aluminum 6082	Alodine 1200S (ECSS-Q-70-71) Black anodized (ECSS-Q-ST-70-03C)

Table 3. ACSS General specifications

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4. MECHANICAL

4.1. Material and Surface Treatments

ACSS case is made of 6082 aluminum with 4mm thickness 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) for straylight attenuation, and alodine 1200S has been applied for thermal performance improvement according to 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 sun sensor has a unique serial number, which is milled on its case. The serial number follows this format: ACSS-FM XX-YYY, where XX defines the manufacturing batch and YYY the serial number. It can be seen in the following picture:

Fig 3. Labeling
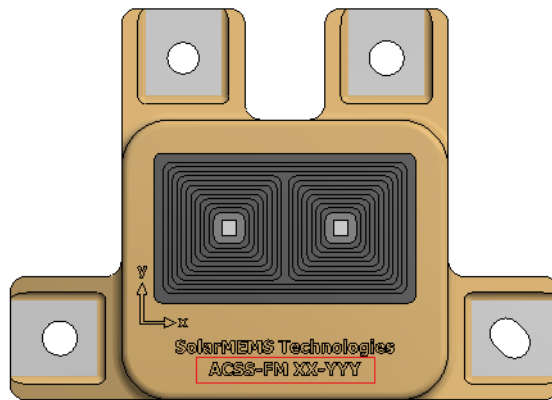
4.3. Reference system

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 ACSS.
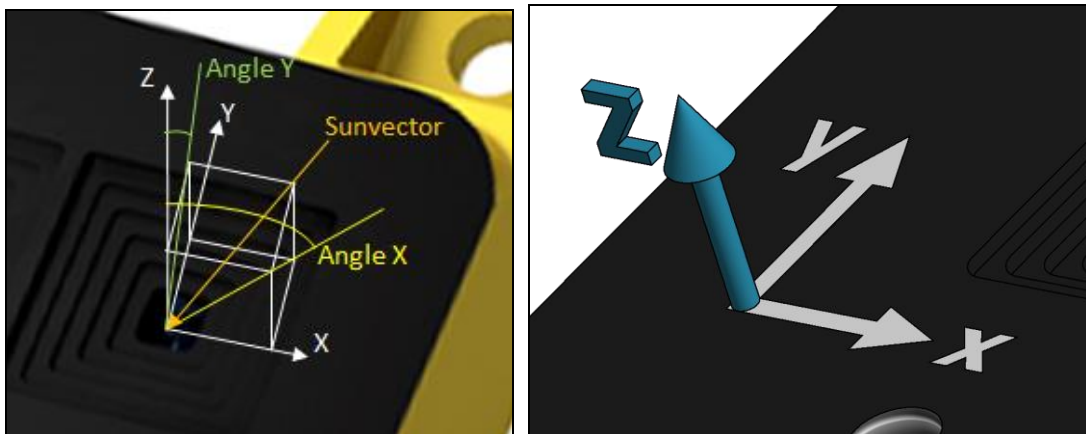

Fig 4. Angles reference

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4.4.   Mass

ACSS mass is 40 +/- 1 g.

4.5. Dimensions

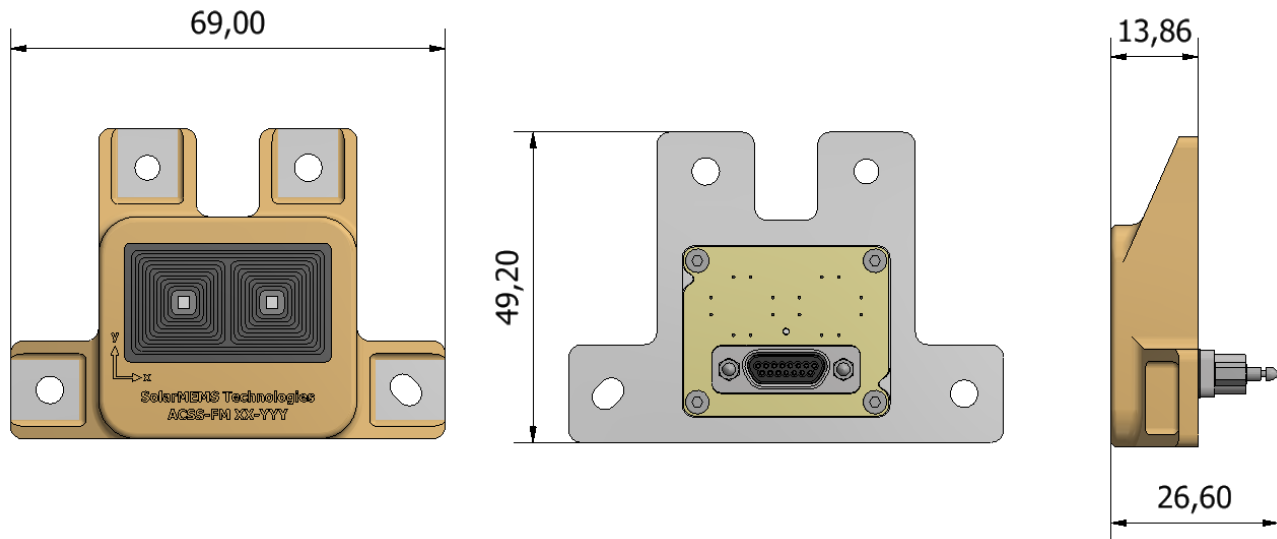The following figure shows all the relevant dimensions of ACSS. All dimensions are +/- 0.1 mm.

Fig 5. Mechanical interface

4.6. Fastening

Baseplate of the ACSS is 3 mm thickness, and the mounting bolts are M4. There are 4 mounting holes in total for increased mechanical robustness. The layout of those holes can be customized with the customer to improve the alignment accuracy during AIT procedures.

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.

ACSS can be fastened directly to the satellite or using a bracket or wedge. Custom brackets can be designed and manufactured by Solar MEMS under request.

4.7. Remove Before Flight Items

ACSS precision can be affected by stains and big contamination particles (>20 microns). For that reason, Solar MEMS delivers them with a protective kapton film that must be kept during integration operations. This cover must be removed for normal operation of the sensor.

4.8.   Field of view

Field of view of ACSS is characterized by two values:
- Performance FoV: where best accuracy and functionality is calculated. It is cone shape area of 120 degrees. This FoV can be tailored under request.
- 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 +/- 70 degrees in both axes X and Y. This FoV can be tailored under request.

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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 ACSS is 12 cm2 on mounting interface. Conduction is the main thermal dissipation way for the ACSS.

5.3. Unit Temperature Range

ACSS operating temperature range is -45ºC to +85 ºC for best performance, although it has been qualified for -50 to +90 ºC. In terms of survival, it has been tested up to -60 ºC and 125 ºC.

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6. ELECTRICAL

6.1. Power supply

ACSS 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	15	-	30	
	Recommended	20	24	28	V
I	Current consumption	-	3	-	mA

Table 4. Electrical Characteristics

ACSS sun sensors best performance is achieved with high power supply, recommended 24 V.

Additionally, its radiation hardness is better with high voltage, so for long missions, a high-power supply is recommended.

6.2. Electrical interface and signal acquisition

ACSS consists of two 4-quadrant photodiodes (nominal and redundant) connected directly to the unit connector. Each photodiode has 4 output signals that must be connected to the OBC in the following way:
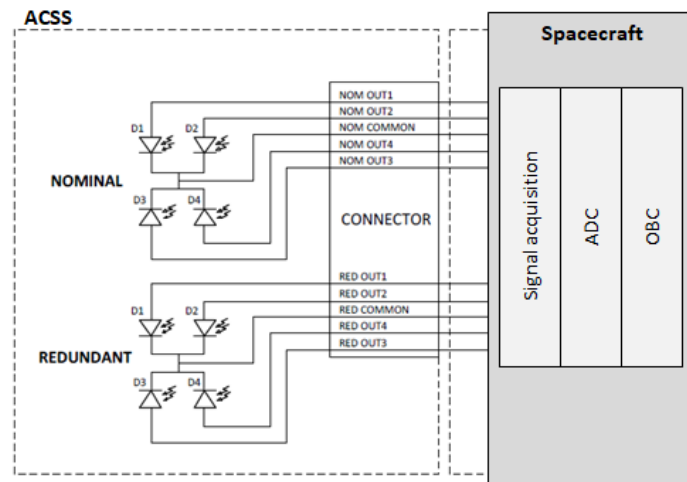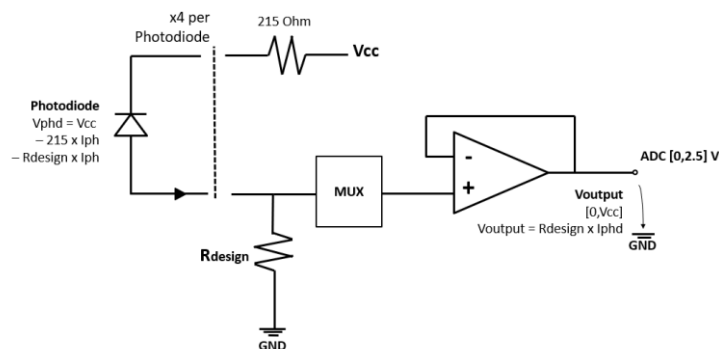

Fig 6. Electrical interface

Fig 7. Signal acquisition recommended

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R_{design} is a resistance value for the acquisition of the signal to adequate the photocurrent generated by the sun sensor to the expected output voltage by the Analog/Digital converter of the OBC of the Spacecraft. The value of this resistor is key for the correct balance of the output with respect to accuracy and any noise source, and it should be fitted according to the ADC range and considering high precision resistors. Standard and recommended value is 3650 Ohm.

6.3. Connector and harness

ACSS uses a micro-connector with 15 contacts installed on the bottom side of the sensor. This connector is a P563917A from Axon, 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 MDA215S connector type from Axon. More details under request. Additionally, 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.

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

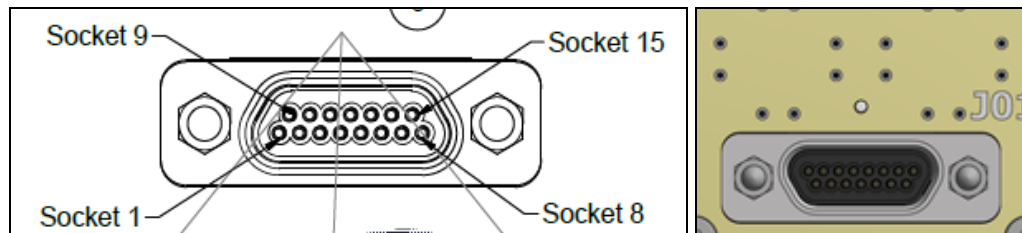The pin-out of the connector shall be as follows:

Fig 8. Connector pin numbering

Pin#	Signal	Description
1	NOM COMMON	Nominal sensor photodiodes common cathode (Vcc)
2	NOM OUT3	Nominal sensor photodiode 3 anode
3	CHASSIS	Connected to aluminum housing and connector
4	CHASSIS	Connected to aluminum housing and connector
5	RED OUT1	Redundant sensor photodiode 1 anode
6	CHASSIS	Connected to aluminum housing and connector
7	RED COMMON	Redundant sensor photodiodes common cathode (Vcc)
8	RED OUT3	Redundant sensor photodiode 3 anode
9	NOM OUT1	Nominal sensor photodiode 1 anode
10	NOM OUT2	Nominal sensor photodiode 2 anode
11	NOM OUT4	Nominal sensor photodiode 4 anode
12	CHASSIS	Connected to aluminum housing and connector
13	CHASSIS	Connected to aluminum housing and connector
14	RED OUT2	Redundant sensor photodiode 2 anode
15	RED OUT4	Redundant sensor photodiode 4 anode

Table 5. Connector pinout

Pins distribution to nominal or redundant sensors are separated in the connector to avoid short-circuits, according to double insulation rules.

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7. OPTICAL

7.1. Calibration on ground

In order to guarantee the best accuracy, every sun sensor is individually calibrated and tested, checking the outputs at more than 500 different sun vector positions. 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/m2).

More than 20 parameters from each sun sensor are collected to define the necessary coefficients to operate the sun sensor with a calibrated transfer function. This function could be changed by a more complex one to improve accuracy, as follows:

Model	Type	Variables	Coefficients	Function	Max order	3sigma accuracy
Transfer functions	Type 1 (Standard)	1	2	polinomial	1	3
	Type 2	2	4	polinomial	3	2
	Type 3	2	7	polinomial	5	1
LuT table	Type 4	2	Matrixes [61]x[61] elements	double interpolation	-	0.5

Table 6. Accuracy vs Transfer function

7.2. Spectral responsivity

The following curves show the spectrum of sensitivity of different ACSS units. The sensitivity covers visible range and low infrared margin, which made them perfect for Sun radiation and spectrum capture, maximizing the photocurrent in a very small active area.
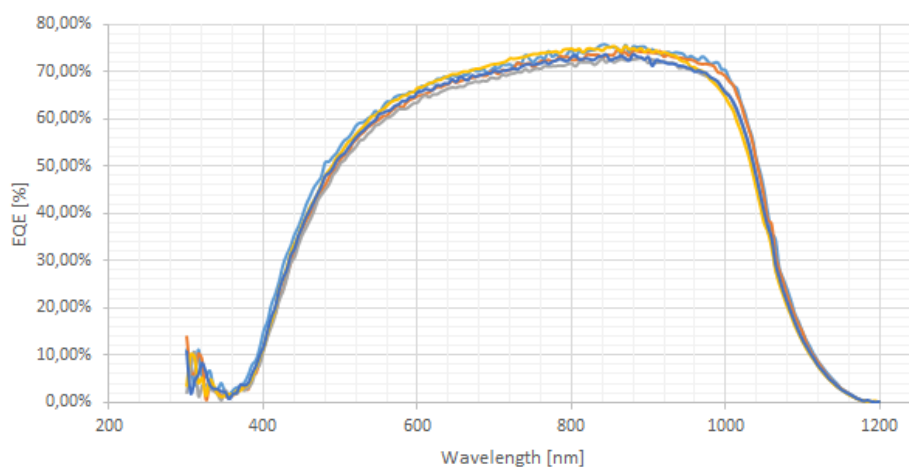

Fig 9. Spectral Responsivity

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8. OPERATION

8.1. OBC interface

Functional interface between ACSS and OBC is managed by two stages as commented before: signal acquisition and analog/digital converter. Inputs in the OBC are the voltage levels coming from each quadrant of each photodiode. Each output reading (voltage) is handled to get the sensor response (F value), and then the angle measurement by means of a transfer function with calibrated parameters, as follows:

First: output readings

$$X_1 = V_{ph2} + V_{ph4}$$
$$X_2 = V_{ph1} + V_{ph3}$$
$$Y_1 = V_{ph1} + V_{ph2}$$
$$Y_2 = V_{ph3} + V_{ph4}$$

Second: sensor response

$$F_x = {X_2 - X_1}/{X_1 + X_2}$$
$$F_y = {Y_2 - Y_1}/{Y_1 + Y_2}$$

Third: transfer function:

Theta X = Function (Fx, Fy)
Theta Y = Function (Fx, Fy)

Theta X and Theta Y are the incident angles (angle X and angle Y) of the sun vector. The transfer function to be used determines the quantity of coefficients (from 2 to 9) and the expected accuracy of the ACSS, and it depends on the variables Fx and Fy.

As example, polynomial 1st order transfer functions:

Angle X = C1 x Fx + C2
Coefficients: C1 and C2
Single variable: Fx
Not depending on Fy

Angle Y = C3 x Fy + C4
Coefficients: C3 and C4
Single variable: Fy
Not depending on Fx

8.2. Linear response

Response of the sun sensor is calculated following the formulas described in chapter "OBC interface" to get variables Fx and Fy. This response is linear, as follows:
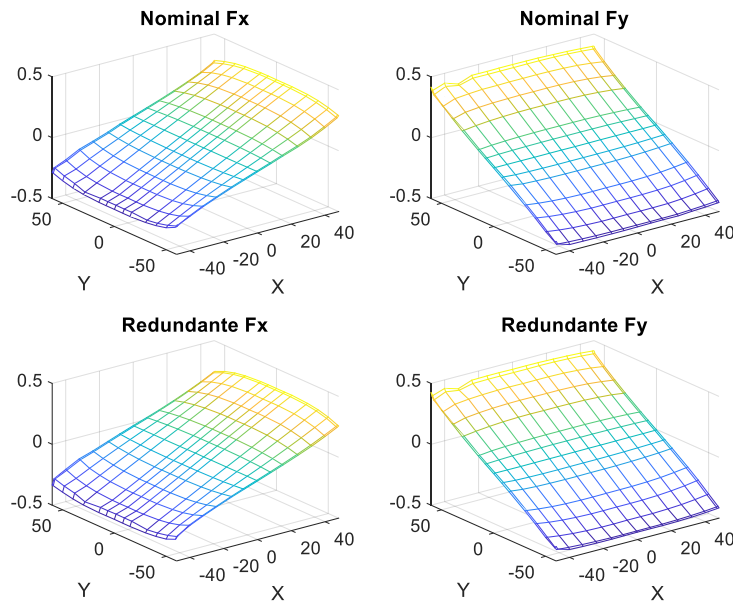

Fig 10. Sensor response of nominal and redundant units of ACSS

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The sensor response shape is a slope, so it can be managed to get maximum accuracy using a LUT matrix or a transfer function.

8.3. Sun detection out of performance field of view

When Sun vector is out of performance field of view but inside full field of view, accurate measurement cannot be done, but some calculations can be performed to determine where sunrays are coming from with respect to reference system, as follows:

Sensor response	Sections	Sunray from
$F_x < 0$	$X_1 > X_2$	-X
$F_x > 0$	$X_1 < X_2$	+X
$F_y < 0$	$Y_1 > Y_2$	-Y
$F_y > 0$	$Y_1 < Y_2$	+Y

Table 7. Sun detection out of field of view

8.4. Albedo detection

Albedo affects measurements of the sun sensor impacting on the expected accuracy, and in some cases getting values too far from real position of the sun vector. This event is typical when orbit is closer to Earth: it must be considered in LEO, while not so sensitive in GEO.
Albedo event must be analyzed for every mission profile.
Albedo can be detected but not corrected.

There are two ways to detect albedo events:

- By comparison of detected radiation to expected value according to the measured sun vector. Radiation is estimated by summation of four voltage outputs. This detection is accurate, but it requires processing lot of calibration data that must be included in the OBC. This way is precise and complex, and it allows to detect albedo with a margin of +/-10%.

- By comparison of voltage levels to maximum voltage level inside performance field of view. This method is easier because it only requires one parameter. However, it allows only to detect albedo when reflective surface on Earth is up to 50-60%.

In case of longer missions on which degradation is expected, it may be necessary to calibrate in orbit the expected voltages in a specific point, as follows:

- Set sun vector in normal direction to sun sensor.
- Get voltage outputs and calculate the offset (degradation).
- Correct albedo algorithm with that offset.

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9. PACKING, HANDLING AND STORAGE

ACSS 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 ACSS 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 ACSS 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.

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10. WARRANTY

Solar MEMS Technologies S.L. warrants ACSS 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.

END OF DOCUMENT