STUDENTS' SPACE ASSOCIATION
THE FACULTY OF POWER AND AERONAUTICAL ENGINEERING
WARSAW UNIVERSITY OF TECHNOLOGY

# PRELIMINARY DESIGN REVIEW

# SUN SENSOR

June 2015

Issue 2 (November 2016 update)

**Changes**

| Date | Changes | Responsible |
|---|---|---|
| 2015-02-16 | Initial issue | Mateusz Sobiecki |
| 2015-02-21 | Second issue | Mateusz Sobiecki |
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**Attention** Phase B documentation may be outdated in many points. Please be aware of that and do not depend on Phase B or Phase A documents only. More recent documentation is available on project website.

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**Abbreviated terms**

ADCS – Attitude Determination and Control System

COMM – Communication subsystem

DT – Deployment Team (mechanical team, responsible for sail system and solar arrays opening mechanism)

EPS – Electrical Power System

ESA – European Space Agency

ESEO – European Students Earth Orbiter

FRR – Flight Readiness Review (as defined in [RD. 1])

PDR – Preliminary Design Review (as defined in [RD. 1])

RAAN – Right Ascension of the Ascending Node

SC – Spacecraft

SKA – Studenckie Koło Astronautyczne (Students' Space Association)

SSO – Sun-Synchronous Orbit

TBC – To Be Confirmed

TBD – To Be Defined

WUT – Warsaw University of Technology

# 1 INTRODUCTION

During phase B of the PW-Sat2 project, the Sun Sensor team has focused on testing the performance of created Test Stand, resolving the problem with Sun Simulator and preparing the concepts of Sun Sensor case. Also the analysis of the Sun Sensor's algorithm are being made and preparing the prototype of the flight electronics is in final phase. In this document all of the work is described.

**Attention** Phase B documentation may be outdated in many places. Please be aware of that and do not depend on Phase B or Phase A documents only. More recent documentation is available on project website.

# 2 REFERENCES

## 2.1 PROJECT DOCUMENTS

**Table 2-1 List of applicable project documents**

| Ref. | Title | Code | Version | Date |
|---|---|---|---|---|
| [PD. 1] | PW-Sat2 – Preliminary Requirements Review – Sun Sensor | ~~PW-Sat2_10_PRR_SunS_EN~~ PW-Sat2-A-06.00-SunS-PRR | 1.0.1 EN | 2014-07-02 |
| [PD. 2] | PW-Sat2 – Preliminary Design Review - Overview | ~~PW-Sat2_00_PDR_Overview~~ PW-Sat2-A-00.00-Overview-PRR | 1.0 | 2015-05-18 |
| [PD. 3] | | | | |

## 2.2 REFERENCE DOCUMENTS

**Table 2-2 List of applicable reference documents**

| Ref. | Title | Version | Date |
|---|---|---|---|
| [RD. 1] | ECSS-M-ST10C – “Space project management.” | Rev.1 | 2009.03.06 |
| [RD. 2] | | | |

# 3 SUN SENSOR OBJECTIVES

The aim of this experiment is to build and to test the performance of the Sun Sensor working on board of the orbiting satellite. The Sun Sensor will be an analogue two-axis device, based on solar cells. We want to achieve possibly small dimensions and sufficient accuracy (better than photodiodes), in order to create a low-cost sensor for CubeSat missions.

## 3.1 DESIGN REQUIREMENTS

After detailed design verification there have been prepared final requirements, that are listed below:

- Small dimensions – less than 1U wall with depth <20mm;
- Relatively wide field of view – 120°-160° on two axes;
- Sensor accuracy – as good, as it is possible, 0.1°-5°;
- Sensor structure easy to produce and relatively cheap;
- Using commercial off-the-shelf photovoltaic cells;
- Power consumption – less than 0.5W.

Because of a need to test the Sun Sensor on orbit, there will be required also the reference sensor mounted on the satellite, with better accuracy. Therefore we need a part of 1U wall, and this wall cannot be used for EPS solar cells.

The Sun Sensor performance has to be checked on the ground also. This requires preparing the Test Stand and the Sun Simulator to test and validate the designed Sun Sensor.

# 4 DESCRIPTION OF ACTIVITIES

In this part the additional works connected with designing the Sun Sensor are presented. There is a need to prepare the systems for testing and validating the Sun Sensor and it's mechanics, electronics and calculation algorithms.

## 4.1 SUN SIMULATOR

In the earlier phase we have had a few problems with our Sun Simulator. The Sun Simulator "Słonecznik" (Sunflower) was designed for another project, for thermal tests in the vacuum chamber. We tried to make use of it in our tests of the Sun Sensor. But mainly because of the type of the power supply, it was impossible. The metal-halide lamp, the arc lamp, has very good light spectrum, but the intensity significantly oscillates with the oscillations of the mains electricity. Fixing the problem appeared to be too expensive and we decided to find another solution to test our Sun Sensor.

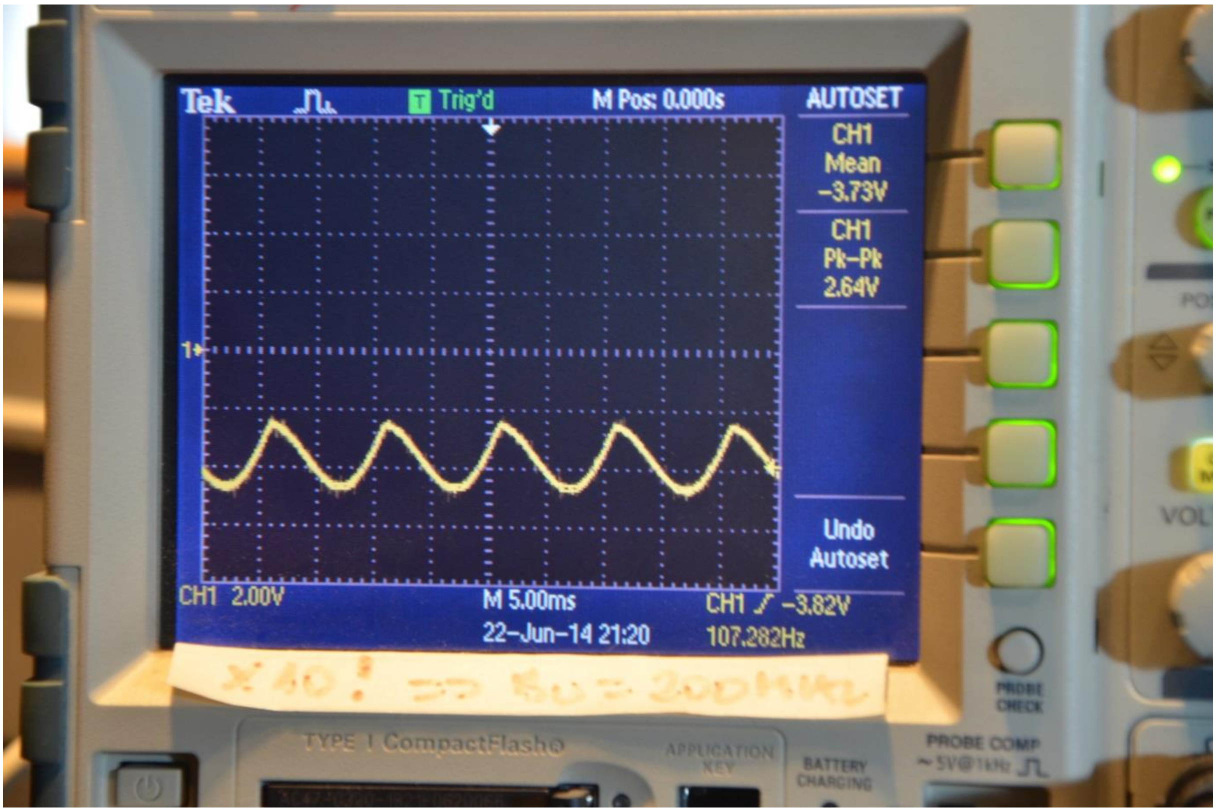



**Figure 4-1 The metal-halide lamp's light intensity oscillations**

We cared to have the lighting system able to radiate the collimated beam with the energy similar to the energy of the Sun radiation on the orbit. We tried to achieve this with longer distance from lamp to Sun Sensor and high lamp power. Firstly we have bought a 700W halogen lamp  PAR64, with pre-prepared reflector, as a cheap solution. Unfortunately the beam of this lamp has appeared significantly inhomogeneous. This makes this lamp inappropriate for our main Sun Sensor tests, but because of radiating a lot of heat it is good for the measurements of the dark current on the solar cells, which depends on the Sun Sensor temperature, which is an important factor for on-orbit operation.

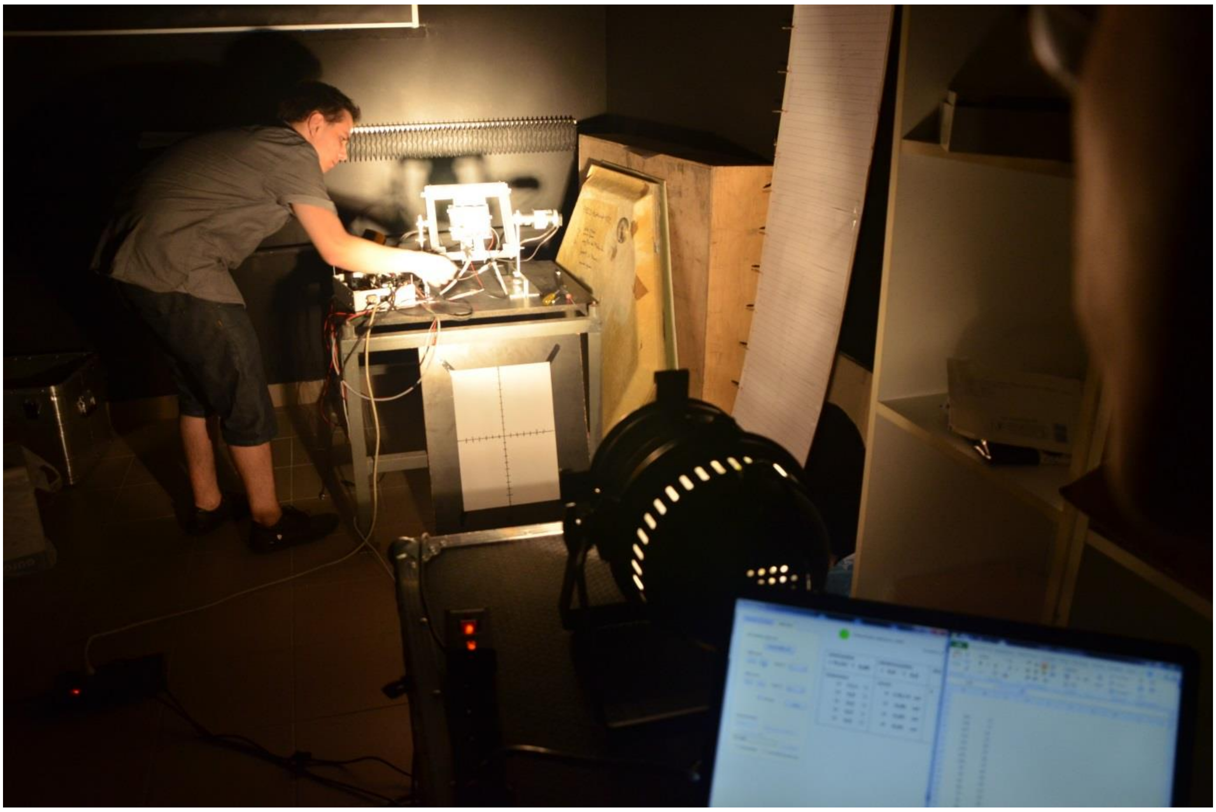


**Figure 4-2 PAR-64 lamp test**

We have also tested the follow-spot reflector, which we borrowed from the LTT company, but unfortunately this was also the metal-halide lamp with passive ballast.

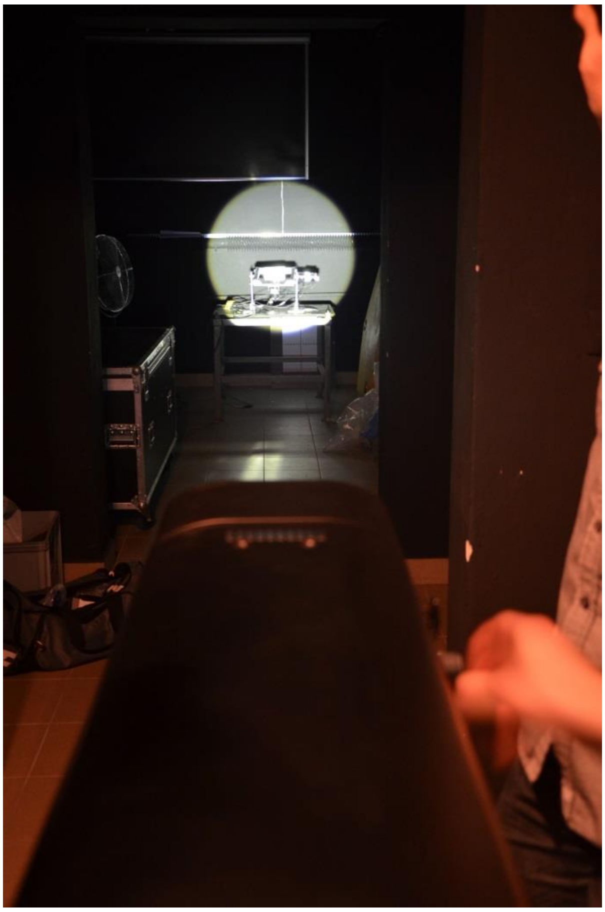


**Figure 4-3 The follow-spot reflector test**

Summarizing, we have two solutions. First, we can borrow the follow-spot reflector with halogen lamp and place the Test Stand in a few meter distance from the lamp. We will have the homogeneous beam and quite good light collimation. The second solution is to create a Sun Simulator with weaker source than lamps used earlier, with smaller source dimensions, and use it in the optical system using refractive optics. The idea is to buy the 400W, 32V halogen lamp with few-millimetre filament, and place it in the focus of the lens, with the aperture little bigger than the sensor area (about 100-150mm in diameter). For the source dimension 4mm and the lens focus 100mm we have the beam divergence of 2,3°, what can be accepted.

## 4.2 TEST STAND STRUCTURE AND ELECTRONICS

The Test Stand structure, created during the earlier phase, works well. The electronics and software still require several improvements, but in general the tests can be performed. So far in the tests there was used the first prototype of the Sun Sensor's electronic board with measuring unit, and despite the imprecise photovoltaic cells, the electronics also generated significant noise. But for the first tries in was enough. The next step is to use the prototype of the flight electronics, new prototypes of the Sun Sensor's cases and tested photovoltaic cells for performing the more advanced tests.

## 4.3 TEST STAND – CALIBRATION AND PRECISION

Every time before starting measurements the Test Stand should be calibrated. It means the Test Stand position and Sun Sensor case position must be adjusted in reference to the light beam direction and cells mounting errors must be determined. For the calibration there is used a laser pointer. The beam is reflected from the cell (covered with reflective foil) back to the source. The differences between the demanded angle position of the cell and the sensor position are measured with the Test Stand's stepper motors' position.

There were performed the preliminary measurements of the precision of the Test Stand [3]. The measurements showed, that the maximum error of the Test Stand's platform position is 0,01°, what is very satisfying. The Test Stand has far better precision than expected accuracy of the designed Sun Sensor, and can be used for our purpose. The Sun Sensor's case with cells can be adjusted to minimize the error between the platform and the case.

# 5 SENSOR MECHANICAL DESIGN

## 5.1 SUN SENSOR CASE STRUCTURE

So far there were tested only Sun Sensor cases with initial configuration of cells, considered in the engineering thesis describing the idea of such sun sensor [1]. But there have been also prepared a few more configurations, taking into account different cells dimensions, available space on the satellite, production technology and optimal algorithm performance.

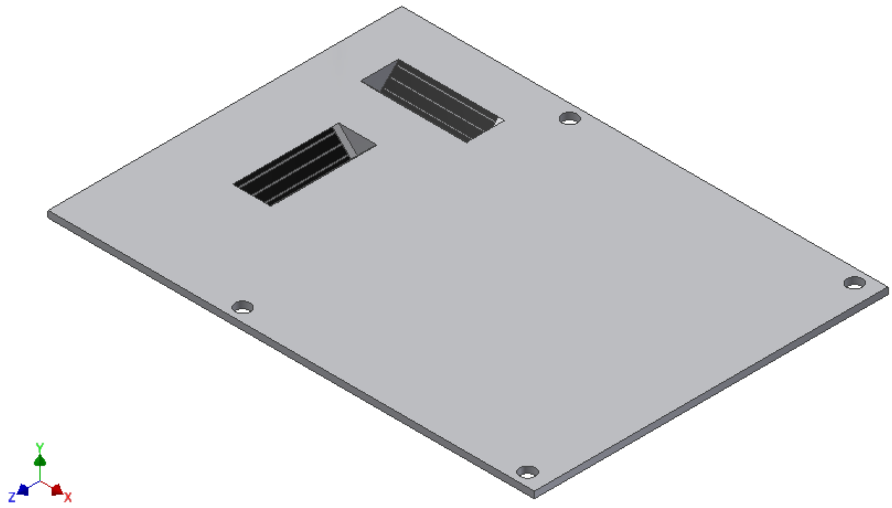



**Figure 5-1 First concept of solar cells configuration**

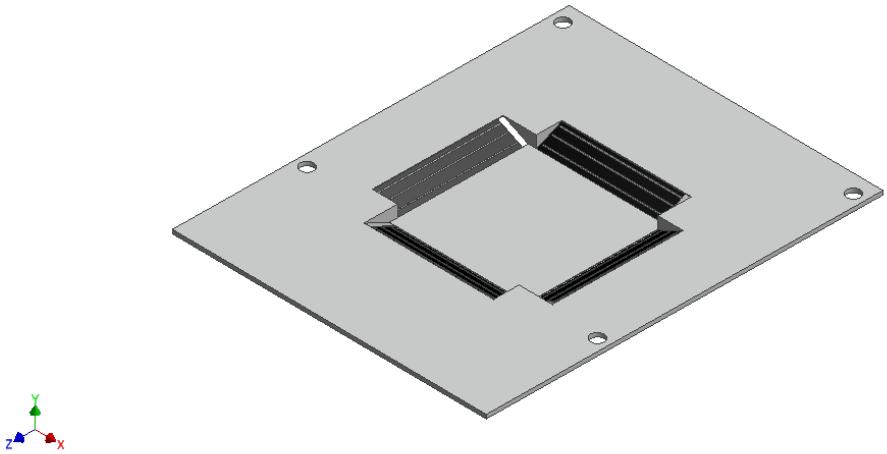



**Figure 5-2 Second concept of solar cells configuration**

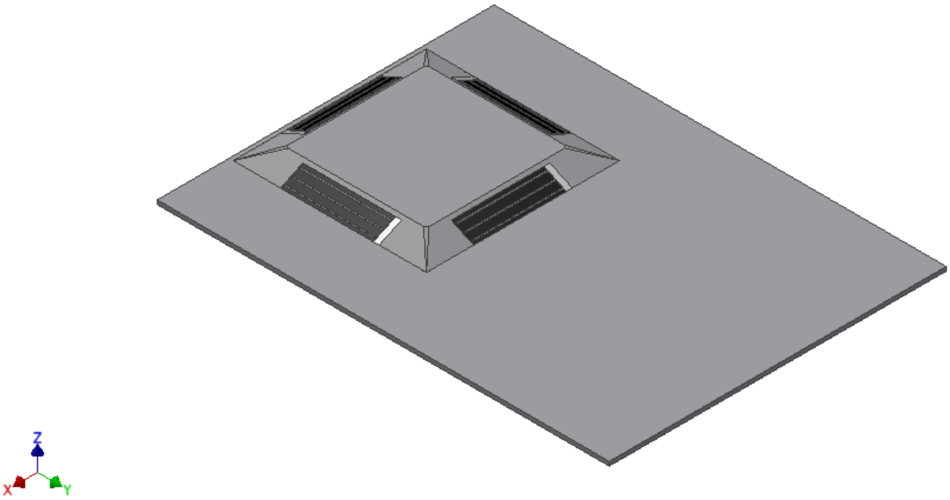



**Figure 5-3 Third concept of solar cells configuration**

Two of the presented configurations are designed to have the upper edge of every cell on the top surface of the satellite wall. The differences between them is bigger or smaller shade effect. The important parameter in design is the depth of sensor elements inside the satellite structure, because we do not want to limit the space for other systems inside. The depth of the sensor is mainly defined by the photovoltaic cells' width and the mounting angle. Other factors are the height of electronic components mounted to the cells' PCB, which is assumed to be about 4mm and the cable management from the cells to Payload PCB.

In the third concept the cells are directed to opposite sides and the shade effect is totally eliminated. The only restriction is the height of the case, which can be maximum 6mm over the satellite rails surface, regarding to the CubeSat standard.

Selection of the final design will be determined by the tests results and the Sun Sensor's algorithm performance in every of the cells' configuration.

## 5.2 SOLAR CELLS

The solar cells used in the Sun Sensor require small dimensions. So small solar cells are not produced and cannot be bought anywhere. Therefore we decided to cut bigger cells to small pieces. But this also involves difficulties. The polycrystalline solar cells, which we tried firstly, are difficult to cut with glass cutter, because they are braking easier along the grain boundaries. We tried also water jet cutting and laser cutting. Water jet gives jagged edge and it is very hard to cut solar cells properly, while laser can damage the cell by creating a short between cell junctions or scorching of the cell's surface locally. We will try also cutting with the diamond blade, but this may be hard to reach and quite expensive. It seems, that we will choose the laser cutting, optimising the cutting parameters and later improving the edge quality with additional works, like grinding, because this is supposed to give the best results. The edge quality can be checked indirectly by the current-voltage characteristics of the cells before cutting, after cutting and after grinding the edge.

To the first tests, while checking the Sun Sensor's overall performance, we were using the polycrystalline cells. In the final version we would like to use better quality cells, for example monocrystalline cells, which can give us better SNR ratio and better performance stability with temperature changes. We would like to take measurements of all prepared cells, check the current-voltage and temperature-dark current characteristics. Only such research can give us the information what is the achievable accuracy of the Sun Sensor.

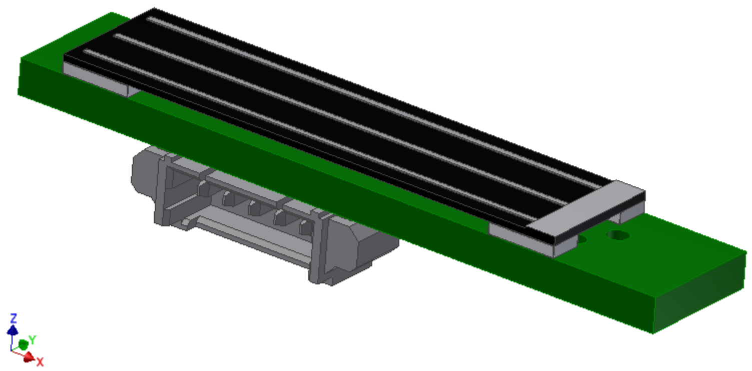



**Figure 5-4 Solar cell mounted to the PCB**

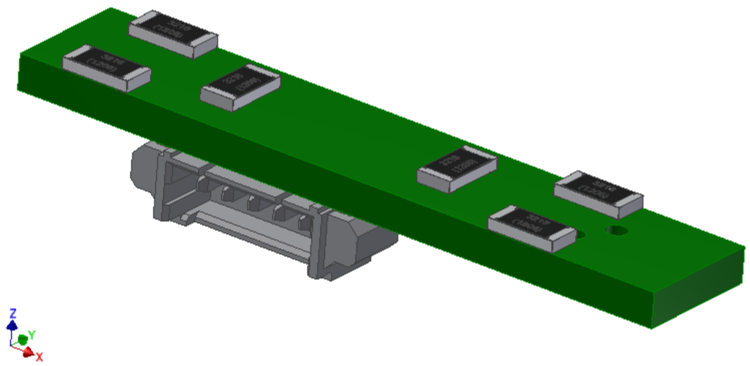



**Figure 5-5 Placement of supporting elements under the cell**

Mounting of the cell to the PCB board, as showed above, is realized by placing the cell on the resistors (as a supporting elements) and thermometers (in the center) and cementing.. The PCB is longer than the cell, what gives the small surfaces for positioning to the case and mounting. The connector showed in the figures will be replaced with direct cables mounting.

# 6 SUN SENSOR ELECTRONICS

## 6.1 BLOCK DIAGRAM OF THE SYSTEM

The SunS consists of a few main subsystems:

- light-sensing devices: 4 solar cells
- solar cells analogue interfaces (current-to-voltage converters, amplifiers and filters)
- 8 temperature sensors measuring temperature on solar cells (two for each cell)
- analogue interfaces for temperature sensors (amplifiers and filters)
- analog to digital converter, common for both solar cells and thermometers
- MCU that controls an operation of the sensor as well as plays a role of the external interface

Interconnections between subsystems are shown in the figure below:

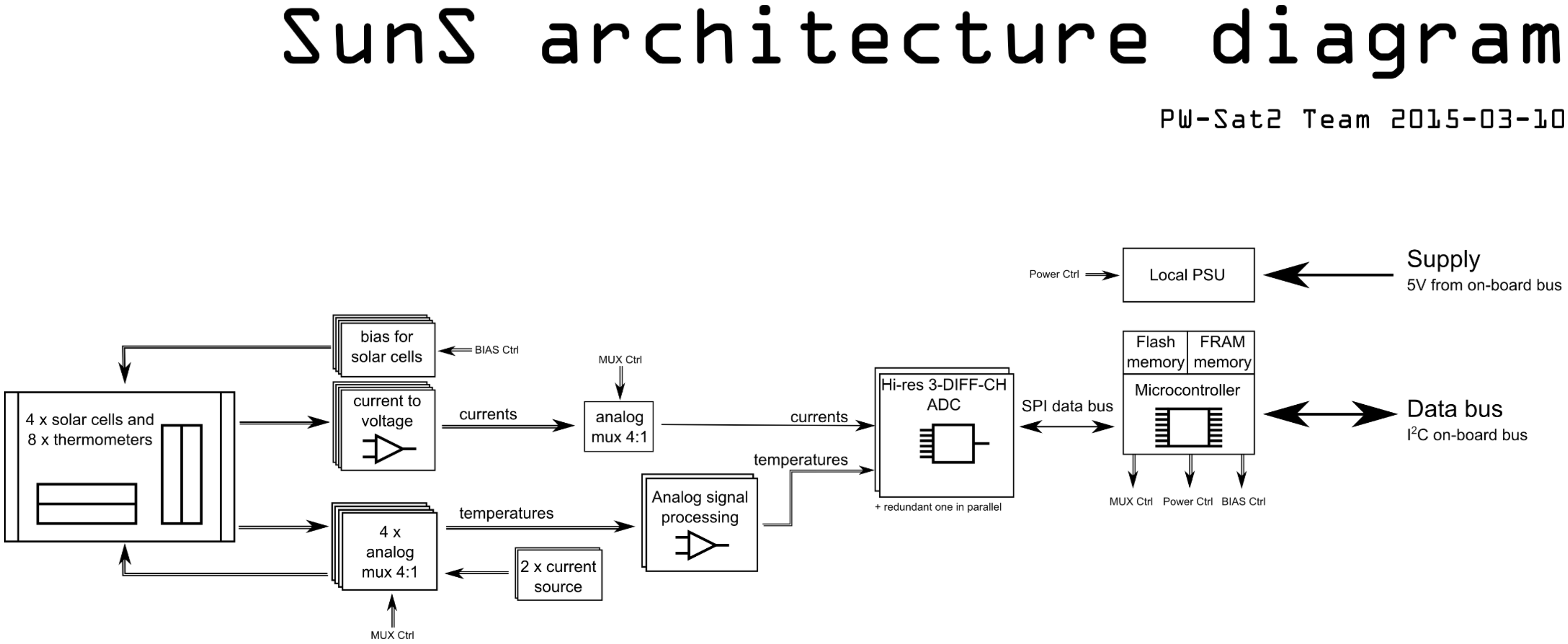
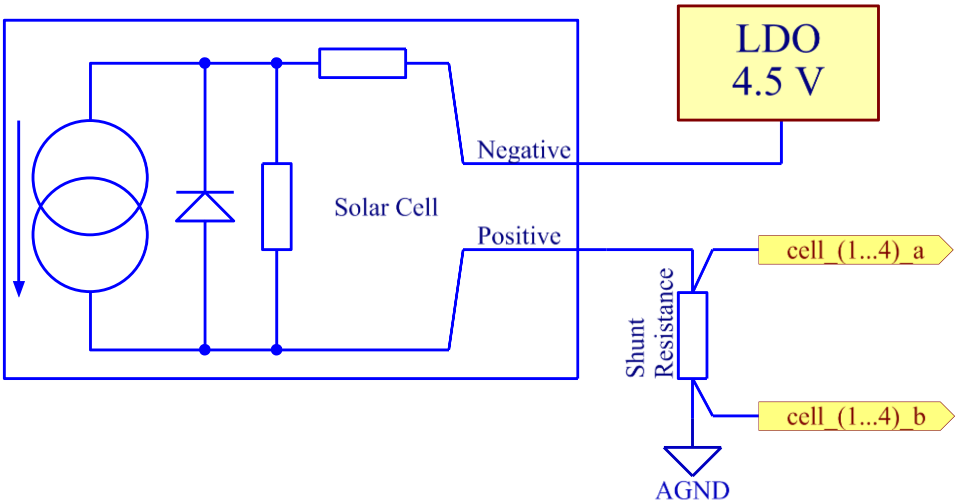



**Figure 6-1 The diagram is showing main blocks of SunS**

## 6.2 SOLAR CELLS BIASING AND READOUT CIRCUITS

There are four solar cells, all of them powered by 4.5 V from LDO linear regulator. The current is measured by sensing voltage drop across shunt resistance.




Due to limited number of inputs in analog to digital converter, all of the solar cells are connected to the circuit presented in figure below. Then, the output of the multiplexer is connected directly to analog to digital converter. Amplification of signal is realized by programmable gain (PGA) in range 1-128.

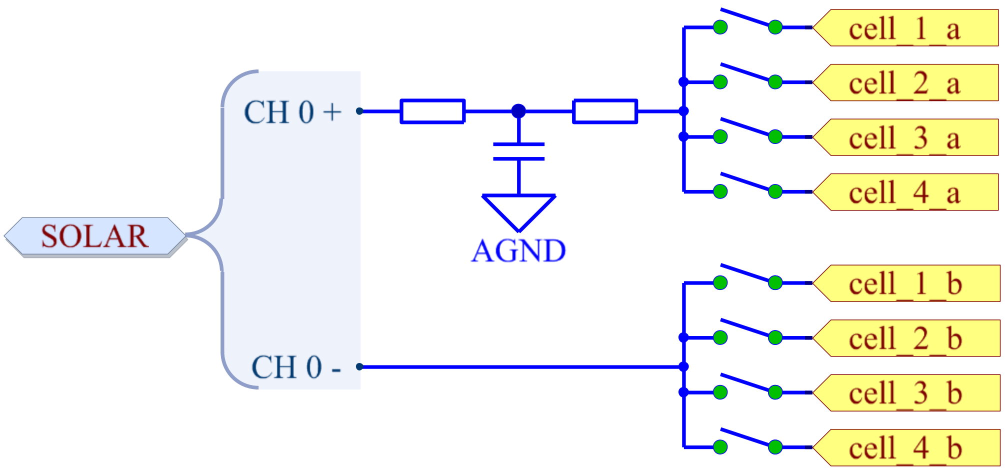


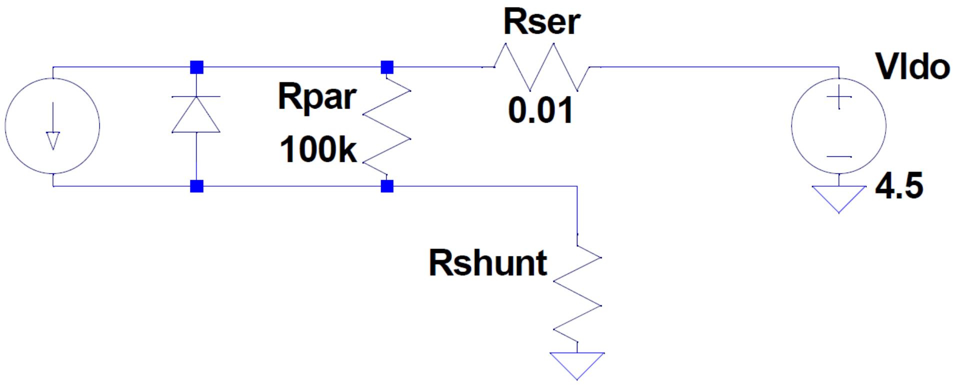

**Figure 6-2 Multiplexing scheme of solar cells, utilizing by ADG709. Label "SOLAR" corresponds to the label in the ADC chapter**

The simulation of solar panel interface was made, using basic solar panel model. LTSpice software was used.

Basic assumptions:

- current source changes from 0mA – worst case of dark current to about 150 mA– full sun exposure,
- LDO is able to supply current of about 0.5A

Scheme:

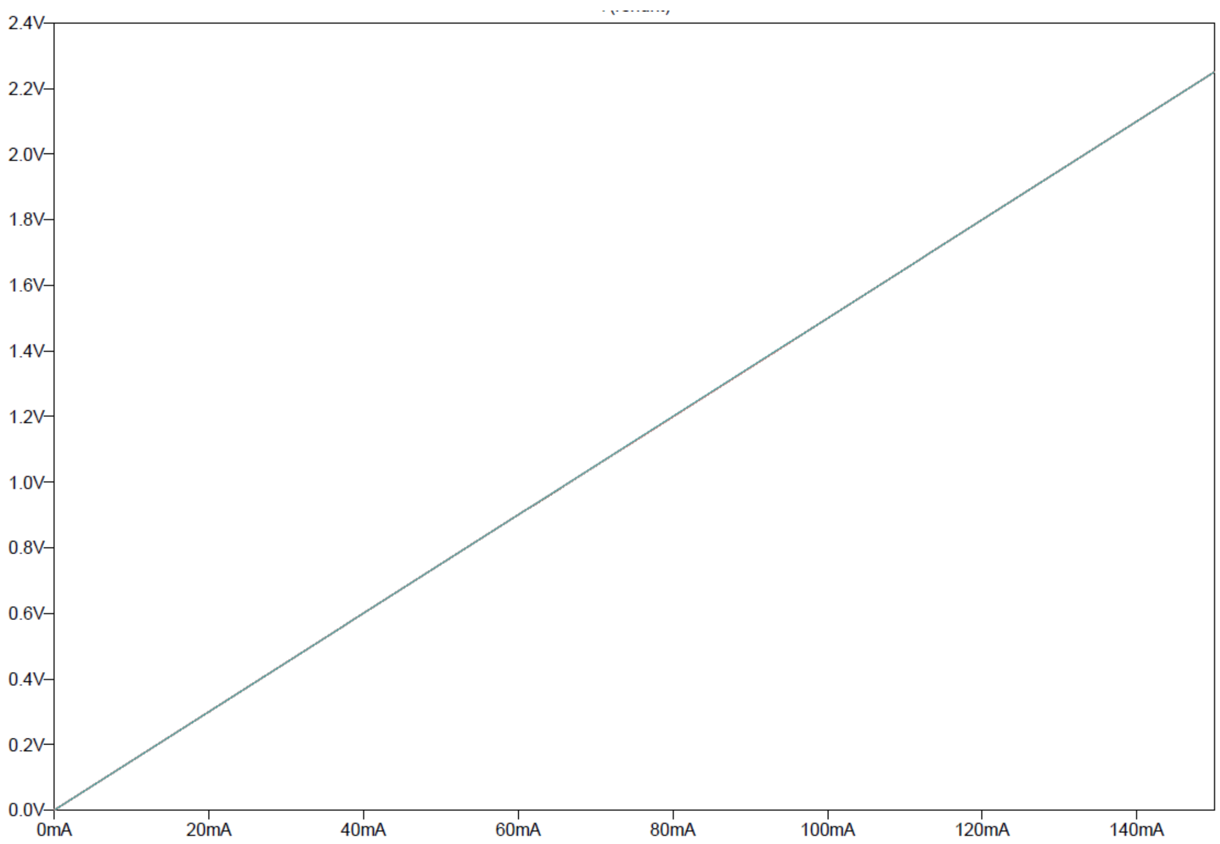



Resistance $R_{SHUNT}$ have to be determined using following rules:

- It have to be small enough to prevent saturation of solar panel
- It have to be large enough to make measurement more accurate

Assuming 150 $mA$ current source, a shunt resistor of value 15 Ω was chosen.

When Sun exposure decreases the voltage across this resistor also decreases – to make sure the readings are the best accuracy it was proposed to use PGA build in ADC when possible. With this assumptions the dynamics of resistor voltage is about 2.25 $V$ and it's nearly linear with current change




Further tests of solar panels have to be conducted to determine the maximum current – it strongly depends on various parameters like panel size, material etc. Final resistor value will have to be chosen when solar panels are finished.

## 6.3 Temperature Sensors and Analog Interface

There are eight thermometers in the SunS. Two of them for each solar cell, located on opposite endings of the cell. As the temperature sensors platinum resistance thermometers PT1000 were chosen. Among others, their main advantages are: wide temperature range, well known calibration curves, durability on other environmental influences. Actually, the operation of the sensor (self-heating, accuracy of the measurements etc.) strongly depends on read out interface, hence other elements have to be chosen very carefully, to not spoilt performance of the PT1000 itself.

### 6.3.1 Requirements

- measurement range: -55 ºC – 150 ºC
- resolution: better than 0.1 ºC
- channels: 8
- sample rate: 100 Sps

### 6.3.2 Platinum Resistive Temperature Sensors - PT1000

The resistance of PT1000 RTD in given interval of the temperatures varies from 783.19 Ω up to 1573.1 Ω. Temperature dependence on resistance, according to IEC751 / ITS-90 standards, is described by the formulas[1]:

- -200 °C to 0 °C: $R(T) = R_0 \cdot (1 + A \cdot T + B \cdot T^2 + C \cdot (T - 100) \cdot T^3)$
- 0 °C to 850 °C: $R(T) = R_0 \cdot (1 + A \cdot T + B \cdot T^2)$

where $R_0$ is resistance at 0 °C (1000 Ω for PT1000), and $A, B, C$ are coefficients specified by the standard as $A = 3.9083 \cdot 10^{-3}\ °C^{-1}$, $B = -5.775 \cdot 10^{-7}\ °C^{-2}$, $C = -4.183 \cdot 10^{-12}\ °C^{-4}$. Since coefficients B and C are orders of magnitude smaller than A, the response is almost linear. Although in precise measurement system this nonlinearity must be taken into account, the effective resolution (in °C) is almost unaffected over whole range of interests

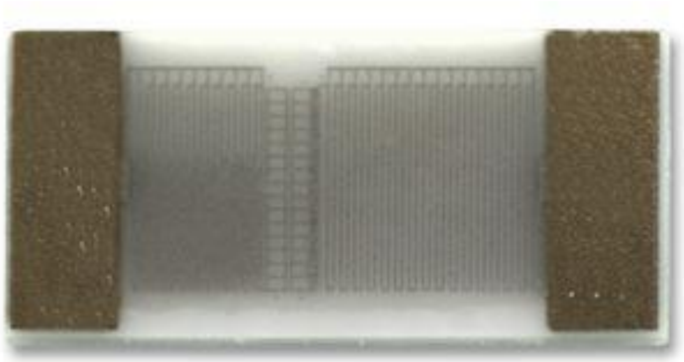


**Figure 6-3 A PT1000 RTD platinum sensor in SMD 0805 package**

PT1000 thermometers are available in two tolerance classes, A and B. For class A, tolerance (in °C) is given by the formula: $\Delta T = 0.15 + 0.002\,|T|$, where $|T|$ is the modulus of temperature in °C. In case of measurement range needed in SunS, max. deviation is $\Delta T = 0.45$ °C @ 150 °C.

[1]http://www.km.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/A707D00EE0F558D6C12574E1002C2D1C/$file/tsiec751_ce.pdf?OpenElement (access on 2015-03-13)

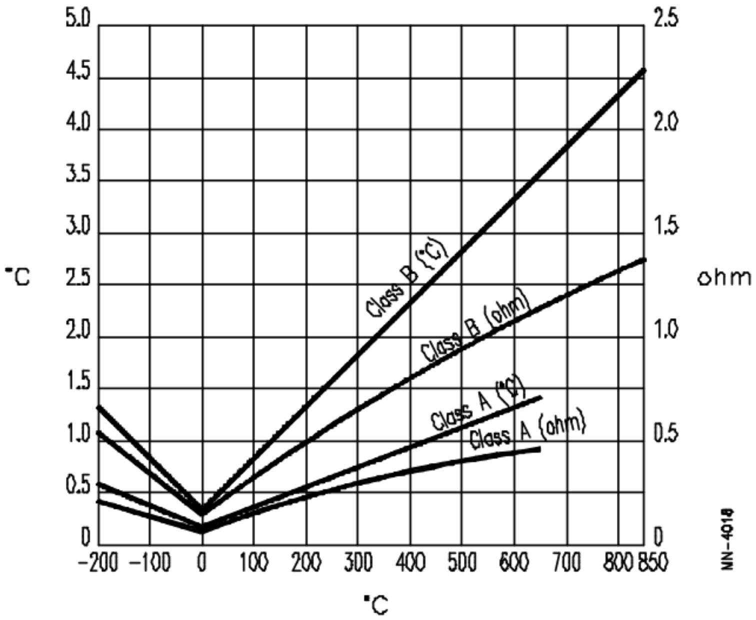



**Figure 6-4 The plot is showing maximal tolerance of PT1000 RTDs as the function of temperature**[2]

### 6.3.3 Current Source

The circuitry of current sources is presented in fig. xx. Since a thermal stability of current sources driving RTDs has a very high priority, astute analysis must be carried out.

In the circuit there are two very critical part – resistor R3 and reference voltage source – see fig. xx. The output current is set by the ratio of these two parameters: $I_{out} = V_{ref}/R_3$. To omit dependence on $V_{ref}$ in the final result, analog-to-digital converter that measures output from RTDs, must be connected to the same reference voltage source as the current source. The resistor R3 should have as low TCR as possible, preferably not greater than ±10 ppm/K. In worst case, the resistor would introduce an error of 0.1% in current. It would yield an error in RTDs measurements of 0.4 ºC (when PT1000 heated up to 150 ºC).

[2] http://de.farnell.com/productimages/standard/de_DE/126693207-40.jpg

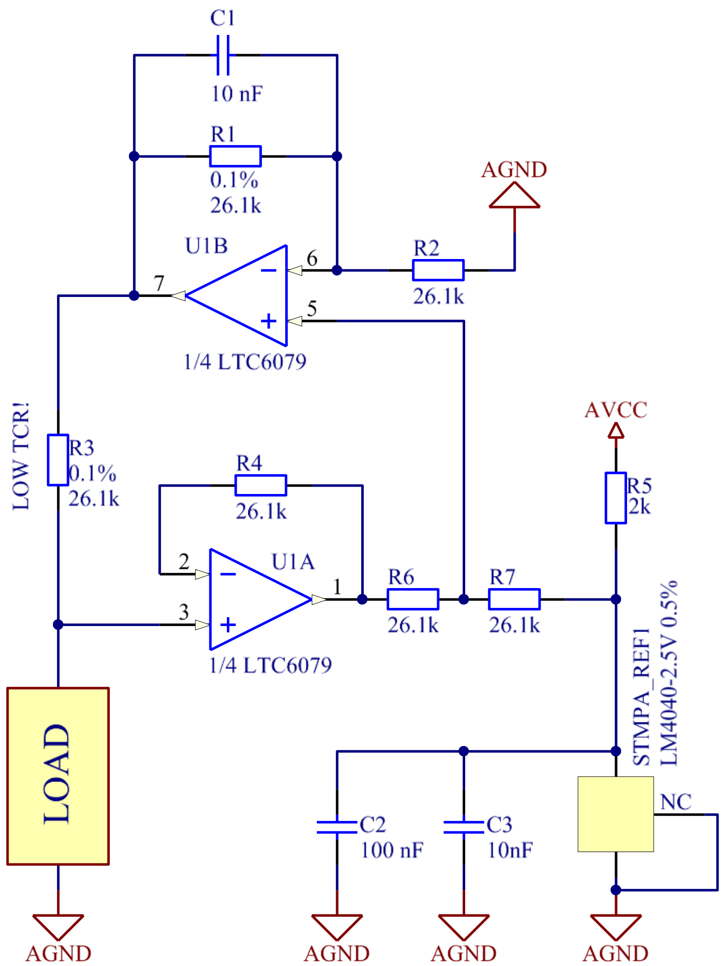



**Figure 6-5 Schematic of current source**

### 6.3.4 Analog Interface

To prevent from self-heating phenomenon a small constant current of 100 µA flowing through RTDs was chosen. It yields to 16 µW of power dissipation only. Thus, the voltage across the RTDs may vary in range from 78 mV up to 160 mV. Because of very low voltages, as well as high output impedances, it is necessary to include amplifiers and filters into the circuit. At the output of analog part of the circuit, signal should vary in range 2.5-5 V. Moreover, at differential input of ADC, an offset of 2.5V is subtracted.

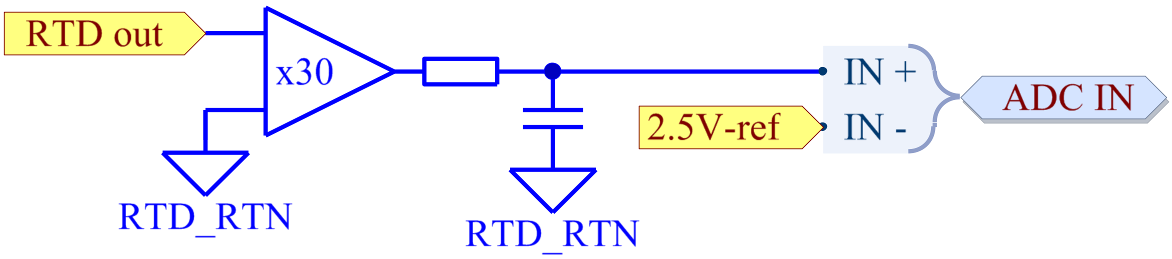



**Figure 6-6 Analog signal processing circuit – starting from left hand side: amplifier, passive low-pass filter**

### 6.3.5 MULTIPLEXING

Having in mind that in satellites space on PCB is at premium, and it does not make any sense to have eight separate interfaces, multiplexing of sensors was proposed. Two different schemes of multiplexing had been proposed. Usage of Analog Devices' ADG708/9, dual (conjugated) 4:1 multiplexers was proposed – see chapter "Components review".

In the first scenario (fig. xx), voltage sense takes place at the common output of the multiplexer carrying current of 100 uA (the current drawn by analog circuit is neglected). According to figures xx and xx, on resistance should not exceed 2 Ω, moreover maximal on resistance match between channels is specified as 1.5 Ω in -40 °C – 125 °C temperature range. Temperature drift should not exceed 1 Ω. All these factors taken into account yield in variations of voltage drop across the mux of approx. 0.2 mV. Taking into account sensitivity of the RTDs – 0.26 °C/Ω, connection of multiplexers in that fashion leads to an error of approx. 0.5 °C. In this configuration, all eight RTDs might be interfaced with usage of single ADG708 8:1 multiplexer, current source, analog interface and ADC channel.

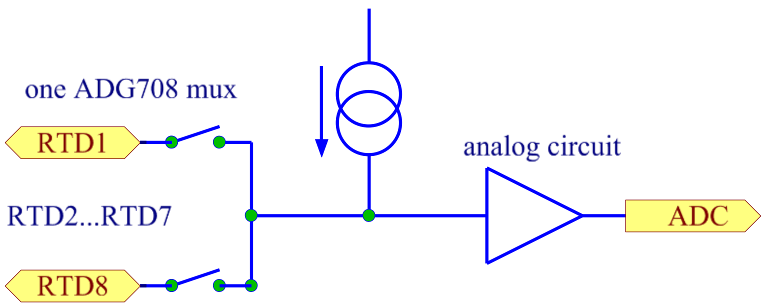



**Figure 6-7 Circuit demands one ADG708 mux, one current source, one analog circuit and one ADC channel for all eight RTDs**

Another approach is so called 3-wire interface. The scheme of connection is presented in the fig. xx. There are two separate channels for high current from current source and small, negligible current flowing into analog circuit. Thanks to this solution, voltage drop across the multiplexer which output is connected to voltage sensing analog circuit is also negligible. The circuit may use two ADG709, differential, 4:1 analog multiplexers or two 8:1 ones (ADG708).

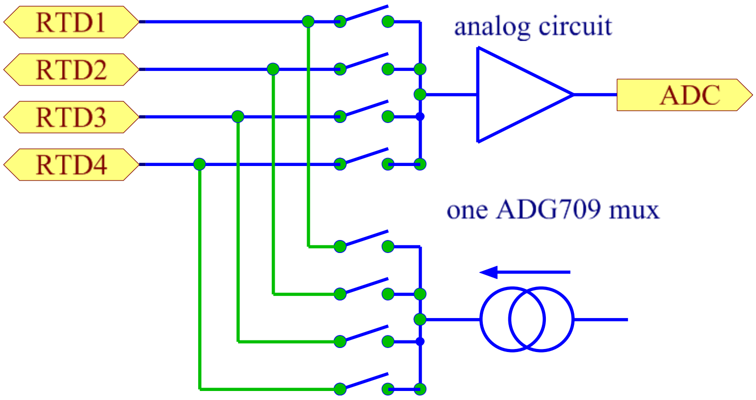



**Figure 6-8 Presented circuit is able to interface four RTDs, hence two, twin circuits are required, as well as two ADC inputs.**

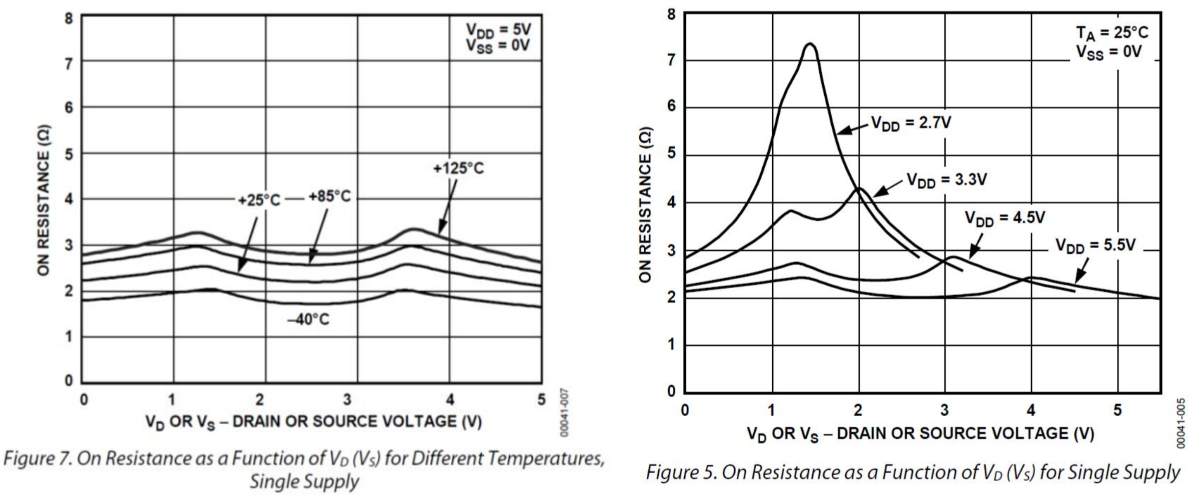



**Figure 6-9 On resistance of ADG708/9 analog multiplexers**[3]

In order to obtain reliable results of measurements as well as redundancy, following, presented in fig. xx, interface is proposed. It consists of two separate, twin interfaces utilizing multiplexing scheme presented in the second approach (fig. xx). On each solar cell there is one RTD, connected to the first interface, and the other one connected to the second, twin interface. It demands two inputs in analog-to-digital converter, but assures redundancy in case of failures.

[3] Figures taken from Analog Devices ADG708/9 datasheet.

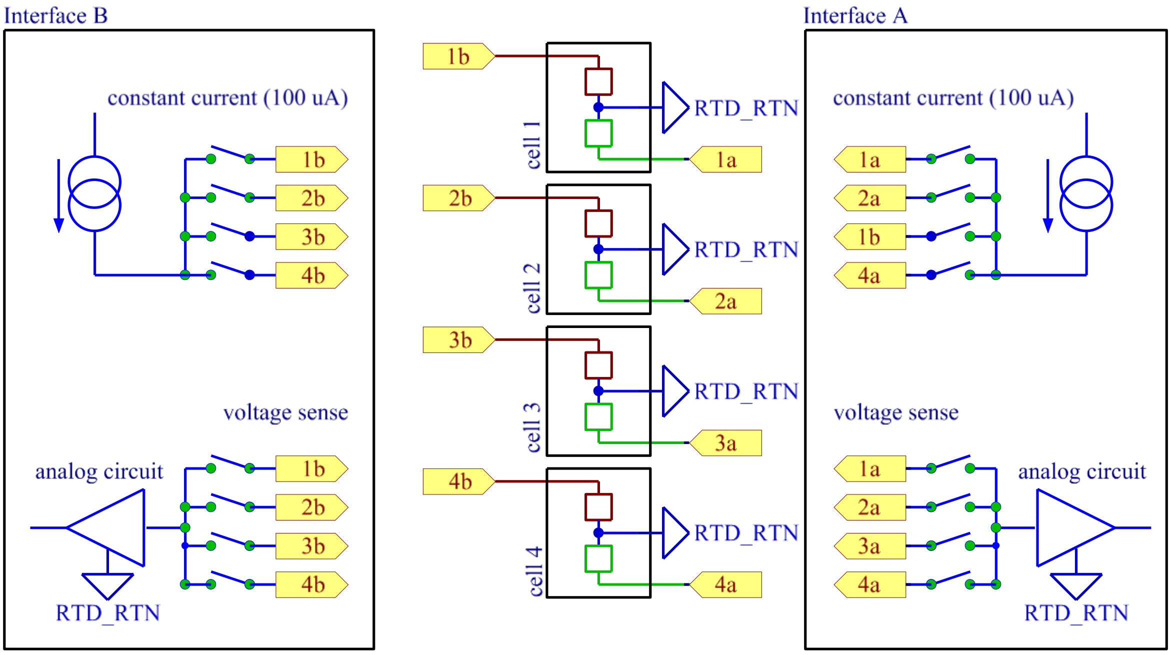
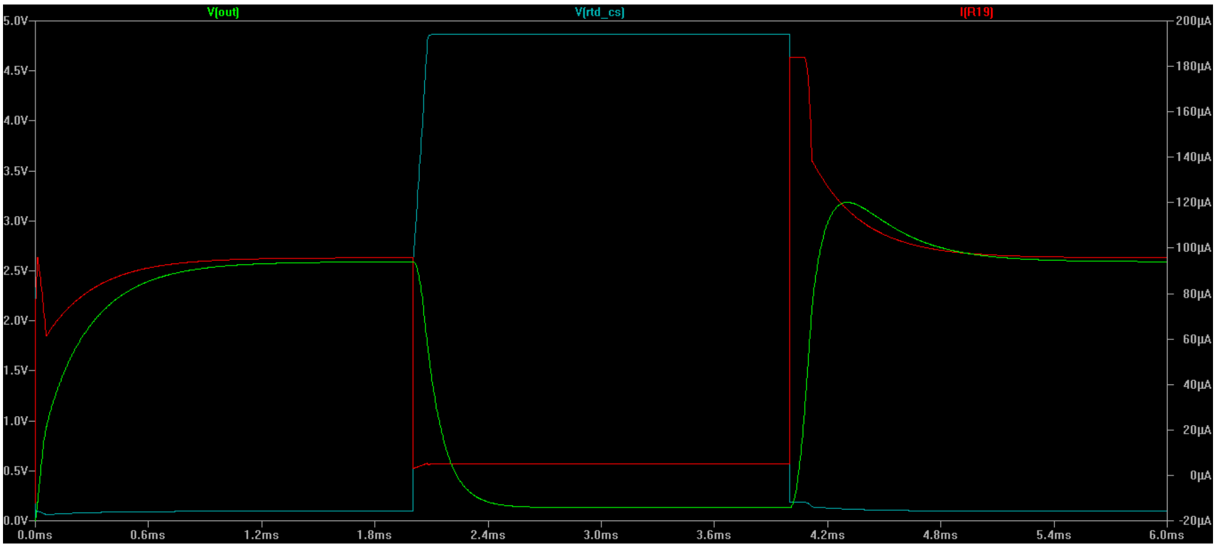



**Figure 6-10 Multiplexing scheme in SunS' temperature sensors**

### 6.3.6 Scenario of measurement, inrush current, transient analysis




TBD

## 6.4 Analog to digital converter

### 6.4.1 Analog Devices AD7714 Signal Conditioning ADC – key parameters

- 24 bit resolution
- 5 V single supply operation

- three fully differential inputs
- built-in PGA 1-128
- external, reference voltage differential input
- REF IN differential voltage max.: 2.5 V
- AIN differential voltage max.: REF IN / GAIN
- AIN/REF IN absolute voltage: max. $AV_{DD} + 30\ mV$
- three-wire serial interface (SPI compatible)
- low noise <150 nV RMS
- small, 24-lead TSSOP package

### 6.4.2 Configuration of analog inputs

AD7714 may be configured in differential inputs mode.

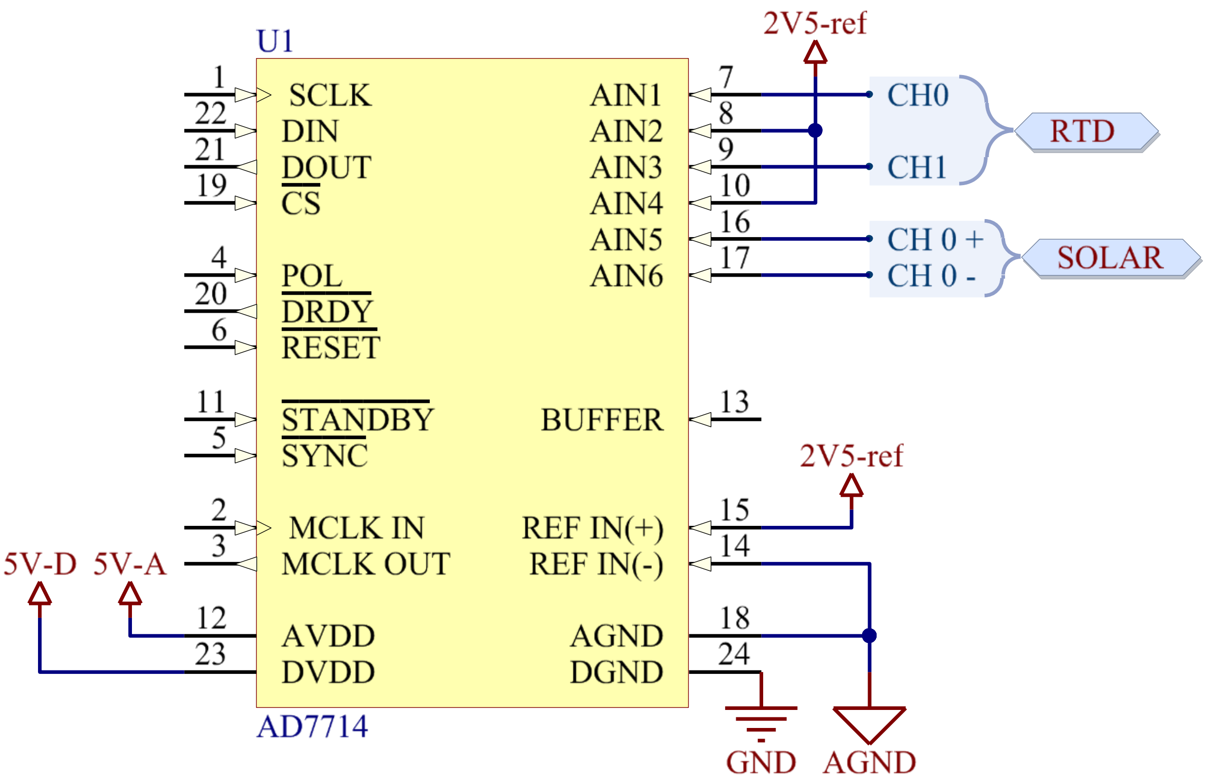



**Figure 6-11 Channels configuration in fully differential mode (please note that schematic does not contain all necessary parts)**

## 6.5 Microcontroller Unit

Microcontroller tasks in SunS are:

- taking measurements (panels exposure, temperatures, telemetry),
- basic angle calculations,
- communication with OBC.

Due to chosen ADC the microcontroller must have following interfaces:

- $I^2C$ bus – satellite bus,
- SPI bus – ADC communication,
- ISP/JTAG for first-time programming and debugging in development phase.

Microcontroller chosen to EPS will be sufficient – to reduce number of different parts it was proposed to use the same processor (ATMEGA164PV-10AQ). More information about selection process can be found in EPS PDR [xx].

# 7 SUN SENSOR ALGORITHM

Preparing the Sun Sensor's algorithms requires the knowledge of the cells' current signal distribution depending on the light direction. The sensor should also take into account the cells' mounting errors and temperature changes, which have big influence on the dark current, being a part of the measured signals.

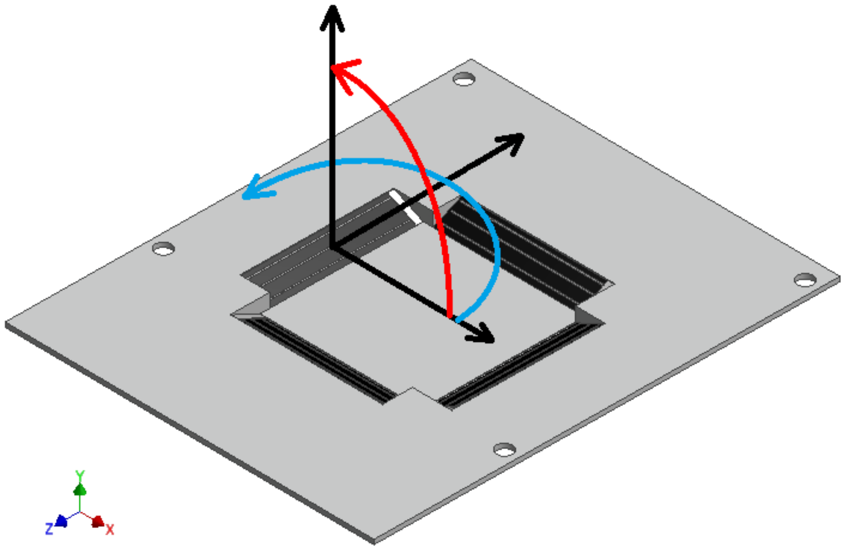



**Figure 7-1 Presentation of considered angles; red - alpha, blue – delta**

Initially the analysis of the theoretical distribution was made. There were considered the first configuration of the sensor's case with taking into account the shadows and different cells mounting angles. The example of the results is showed below. The solar cell's dimensions proportion (width:length) is 1:4.

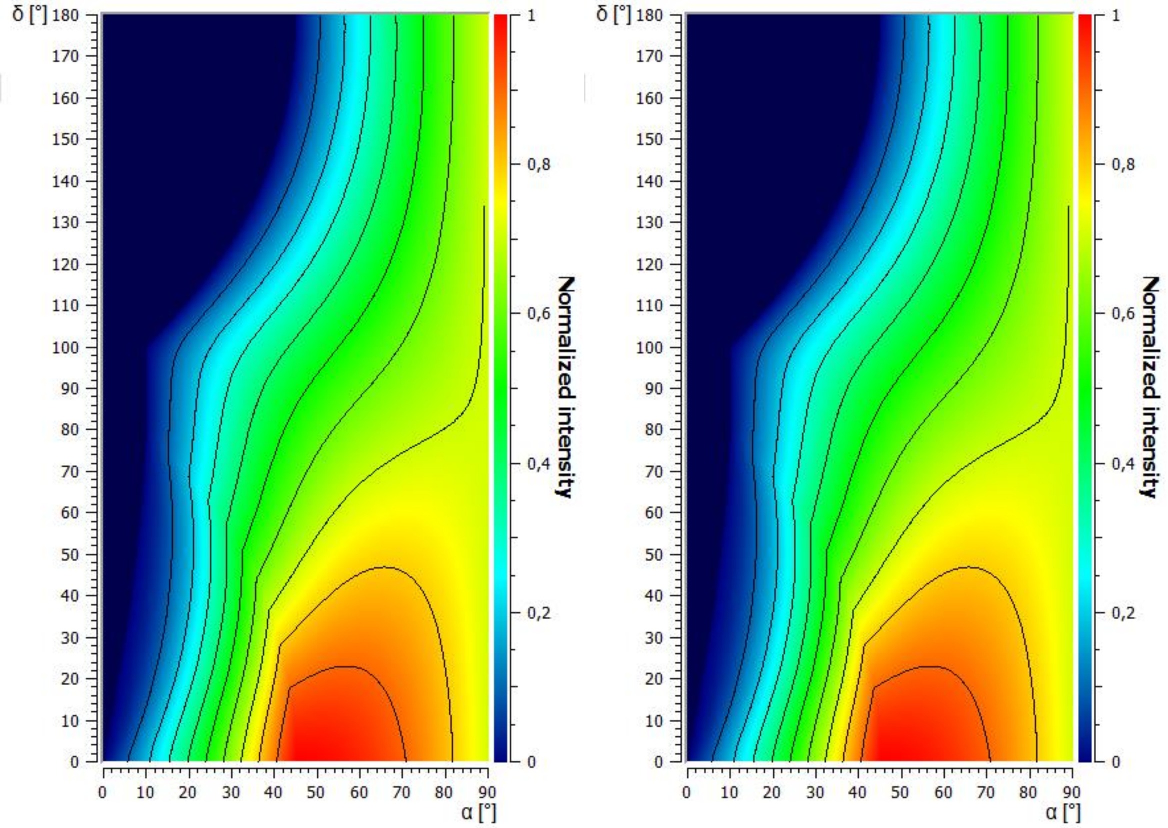



**Figure 7-2 Results for cell's in configuration from Figure 4-1 with the angle: left 45°, right 25°**

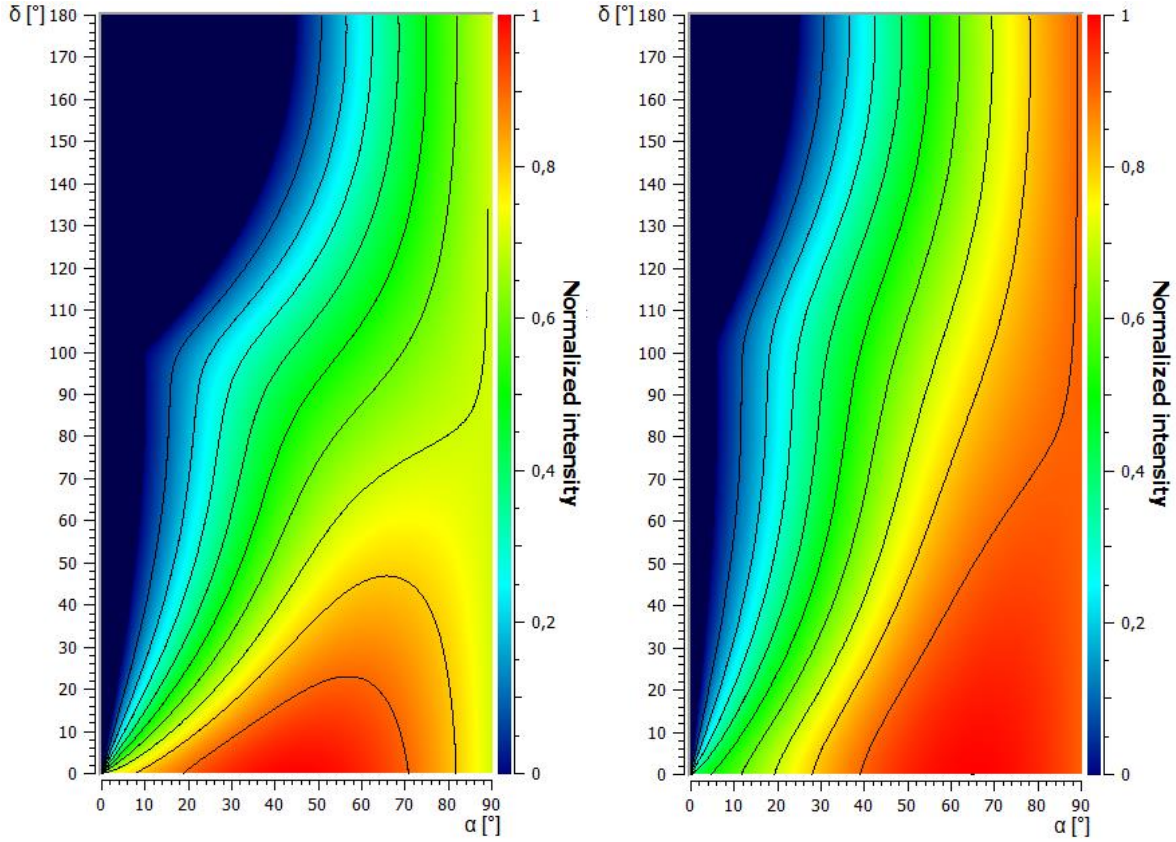


**Figure 7-3 Results for cell's in configuration from Figure 4-2 with the angle: left 45°, right 25°**

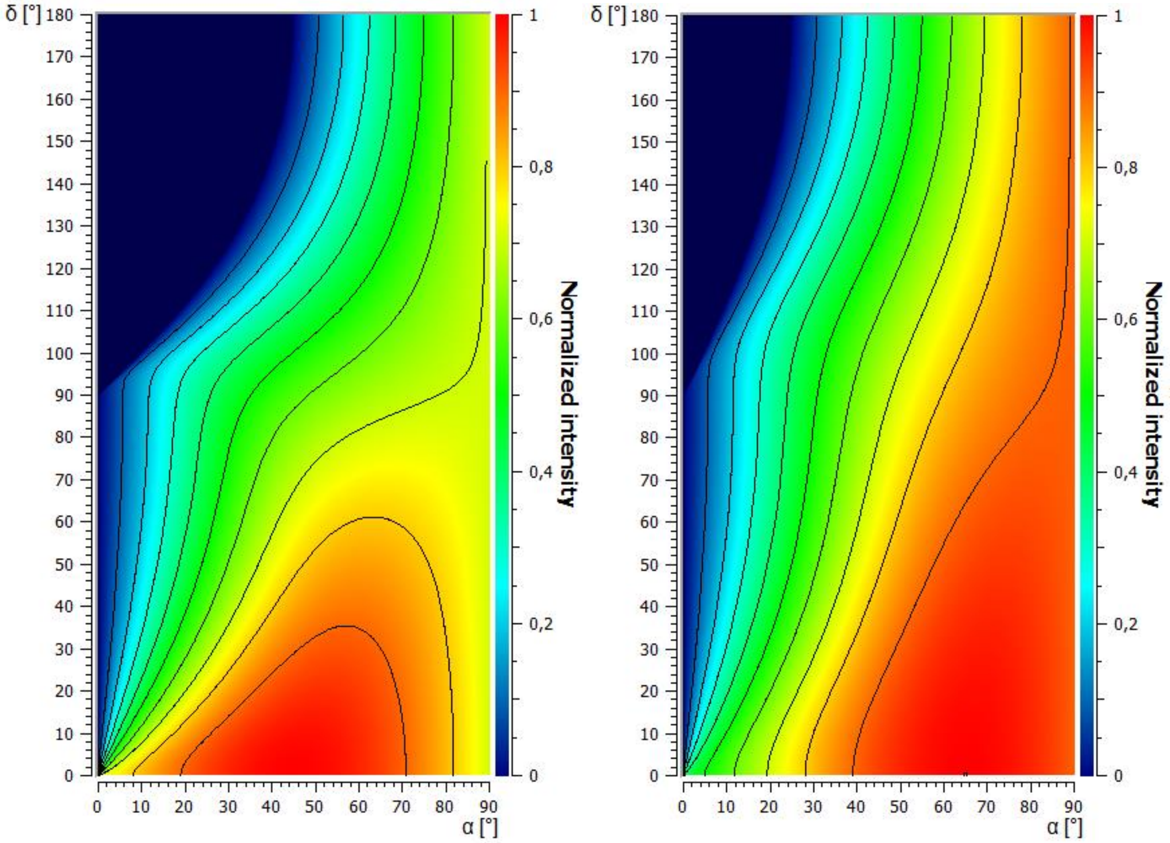



**Figure 7-4 Results for cell's in configuration from Figure 4-3 with the angle: left 45°, right 25°**

With decreasing the cell angle the field of view is widening, but the sensor precision is getting smaller, because the angle derivative of the signal is smaller. The estimated field of view of the sensor depending on the considered angles is 120°-160°.

The similar data tables are expected from the experimental results. We plan to test the sensor on the Test Stand with the sufficient accuracy. There is possible to measure the mounting errors, which can be implemented to the algorithm as a correction parameters. There can also be found the operational differences between used cells and their signal-temperature relations, which must also be placed in the algorithm.

In the case of small differences between the four cells' signals in the sensor's field of view, the table could be placed in the sensor memory as a lookup table. Reading the cells' current signals and comparing with the table values could give as a result the two angles describing the orientation of the sensor with respect to the Sun. Such simple method in the case of 0,1° resolution requires quite big memory and a lot of computing power. This may stand in opposition to the idea of cost effective sensor and may still be relatively slow in action. But when we will be able to achieve only 1° resolution, this solution can be taken into consideration.

The second solution is using the neural network to model the "surface" of the data table with enough precision to find the angles, minimizing significantly the number of processor's operations.

The initial neural network analysis, performed on the 50 neurons with simple model, gave quite good results. The maximum calculation errors on the delta axis are ±1,5°, and on the alpha axis are ±0,3°. The calculation time, simulated on the ATMEGA328P-PU was less than 2ms. The next step is to optimize the model and try to reach the better results.

# 8 THERMAL ANALYSIS

In this phase we decided to hold on with thermal analysis of the sensor to the time we will have more determined the sensor’s case design and cells dimensions.

# 9 PERFORMED TESTS

The first tests had the aim to check the working of the Test Stand, find and solve problems in electronics and software and check whether the Sun Simulator meets our requirements.

We have found some problems with electronic connections and data transfer. It took quite long time to fix them. Also we have made a research of the cells' measured signals, and the influence of the light from different lamps.

Below there is presented the first tested prototype of the Sun Sensor, with four solar cells with the angle 45°, mounted to the test case, and the exemplary data gathered during the three-day tests. The upper figures are the presentation of the current values on the four cells. The fourth cell is significantly saturated in this measurement. The lower figures present the temperatures on the cells, and range from 30°C to 70°C.

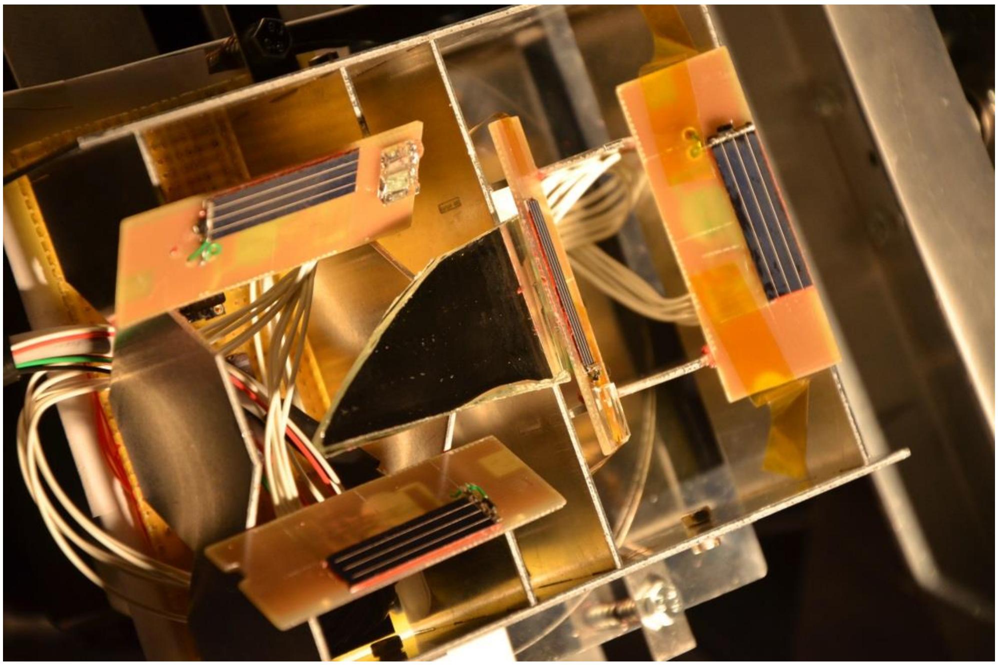


**Figure 9-1 Solar cells mounted to the first Sun Sensor prototype**

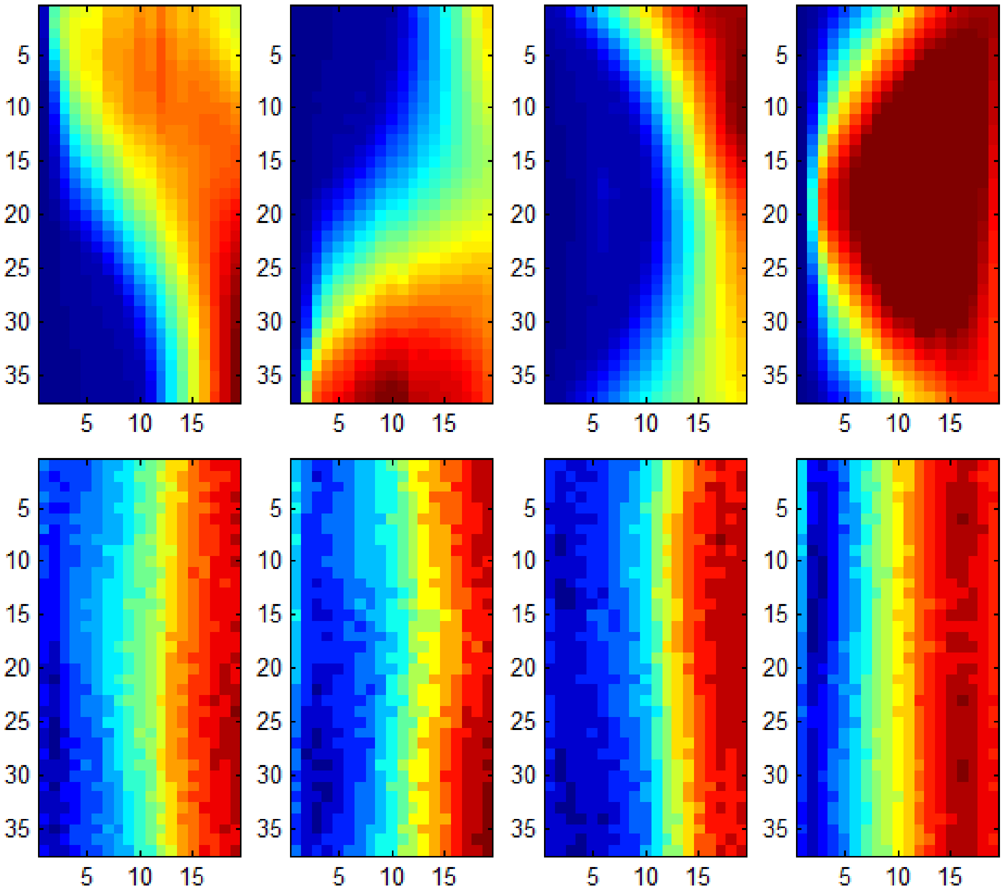



**Figure 9-2 An example of the data gathered in the tests**

The performed tests showed, that the Test Stand is designed properly and can be a platform to test either the Sun Sensor or the photodiodes system (which is a part of the main ADCS).

# 10 ACCURACY EVALUATION

The final accuracy verification will be done in relation to the reference sensor with better accuracy. It will consist of two phases: the test on the ground with Sun Simulator, and the on-orbit test, during the satellite operation. The reference Sun Sensor will be probably the sun sensor delivered by ISIS, with the accuracy better than 0,5°. We may also use the SSoC-D60 or SSoC-A60 from Solar MEMS Technologies with 0.3° accuracy or the Mini Fine Sun Sensor from with the 0.3° accuracy.

# 11 PREDICTED ON-ORBIT OPERATION

During the first phase of the Sun Sensor main operations, the performance will be checked. This phase duration is dependent from the possibilities of communication. Partially the tests will be conducted from the ground. The data prepared for sending to ground station will have to be precisely determined. The data gathered from the Sun Sensor are going to be compared to the data acquired with the reference sensor from the same moment of time and send to Earth in compressed format. If the check phase will end with success, the Sun Sensor might be added to the ADCS instead of the reference sensor, to check the ADCS performance with this sensor.

## 11.1 OPERATION PLAN

We plan to make a few performance tests a day during the beginning of the mission. As it will be possible, all gathered data will be send to Earth. Later, the tests will be performed less rarely, to check the changes in accuracy with the time of the mission. The test session may last about one minute each. The signals, which we would like to check, are the currents and the temperatures on the cells and also the calculated positions of our Sun Sensor and the reference sensor. All the data will then be prepared as a data package. Send to the ground station during the closest communication session. The precise operational plan will be determined during the next phase.

# 12 CONCLUSIONS AND FUTURE WORK

The team has encountered a few problems during the phase B. There is still a lot of work to do. In the close future, when the SunS electronics prototype will be build, we will start the phase of the intense testing the sensor design and algorithms on the Test Stand. Earlier we have to analyze the solar cells' characteristics, to find the most appropriate solution for their kind and size. Also the Sun Sensor's case have to be prepared as a prototype possible to use in the flight version.

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