MISPS Solar Position Sensor Development and Field Tests

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Abstract. A solar position sensor integrated within the CPV modules enclosure has been developed and manufactured using several different techniques and substrates. The sensor is made from standard mono-cSi cells which have been laser cut in eight pieces divided in two sectors, providing very large acceptance and high accuracy to an hybrid tracking system, simplifying CPV systems commissioning activities.

INTRODUCTION

This document presents MISPS solar position sensor [1] development and field tests. First, a short introduction on how the sensor works is presented. Then, development work is presented. It has been distinguished between material exploration and electronics improvement. Finally, test results are presented to illustrate how the sensor allows CPVRS trackers to be installed without any precise orientation and within minutes.

MISPS Principle of Operation

MISPS consists in eight monocrystalline silicon cells, cut to cover two sectors around of the desired spot where the optical system should be focused. When the system is out of focus, one or more of the cells is excited. This signal is transduced into a readable analog value and interpreted by the hybrid loop algorithm. Then, a position correction is addressed until the focus is in the proper position. The hybrid algorithm consists in a regular astronomical algorithm which is able to lock on the sun position by reading MISPS output. A closed loop operative tracking is obtained by combining both techniques. MISPS characteristics prevent focusing the tracker on wrong objects like clouds on a bad weather day. [2]

(a) (b)

FIGURE 1. (a) Representation of the eight sectors conforming, outer and inner parts of the MISPS sensor and (b) a picture of the sensor's last revision

All CPVRS systems have MISPS sensors bundled inside to perform sunlight tracking.

Each of the solar cells acts as a light to electrical current transducer. After that, a current to voltage conversion is done by a simple shunt resistor. The voltage resulting from that operation is conditioned properly to be distinguishable from noise and easier to digitalize by using a differential amplifier block.

On current MISPS build, the sensor also performs an analog to digital conversion and is able to send read data by using a CAN bus transceiver.

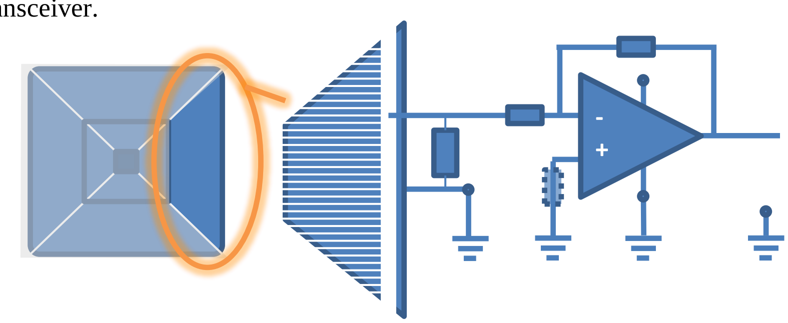


FIGURE 2. Basic schematic for the analog block on one MISPS cell

DEVELOPMENT

Development over MISPS sensor has been focused on improving sensor reliability, assembly, integration, cost and functionality. In order to achieve these objectives, construction of the sensor has changed, material research has been done and electronics design has evolved from first prototypes. Different processes will be summed up in the following sections.

Material Research and Physical Changes on MISPS construction

Different parts of the sensor have been reviewed. Basically:

- Solar cells
- PCB substrates
- Interfaces between solar cells and substrates
- Connectors
- Mechanical assembly to CPVRS
- Coating

Solar Cells

Monocrystalline silicon cells are nowadays a commodity product. So resources have been invested on shaping them rather than searching for a best fit. From test results, cutting technique impacts the performance of the resultant sector rather than the source material.

Mainly, after some preliminary tests trying to slice the cells with a diamond saw (that did not yield good results) the goal was to find a suitable laser cut technique which conserved as much as possible original cell properties after being applied. Combining efforts with one of the providers, and externalizing the responsibility for characterizing the cells after the first tests to them, we obtained cells which had the expected characteristics for their area.

TABLE 1. Characteristics summary for a batch of cells with different bin classes

cell type	class	I_{SC} [A]	V_{OC} [V]	I_M [A]	V_M [V]	P_M [W]	FF [%]	EEF [%]
Outer sector	17	1,3846	0,6172	1,3411	0,4994	0,6698	78,4	17,17
	18	1,3893	0,6178	1,3468	0,5003	0,6737	78,5	17,28
Inner sector	16	0,0307	0,5885	0,0291	0,4802	0,0140	77,4	10,00
	17	0,0320	0,5894	0,0304	0,4807	0,0146	77,4	10,42
	18	0,0344	0,5920	0,0328	0,4818	0,0158	77,5	11,29

PCB Substrates

In order to support the cells and the electronics some kind of PCB substrate had to be used. After preliminary stress tests on the prototype, we concluded standard FR-4 was good enough to withstand conditions on the outer sector area. In order to avoid any radiation derived degradation, all soldermask and silkscreen was removed from exposed side of the sensor. Also, a copper plane with almost no gaps (only the mandatory to bring front contact from cells to the corresponding shunt resistor in the back) was built and finished with a simple tin cover to avoid copper oxidization. Another restriction was applied to the design because of the back contact of the cells; all area under them had to be on the same potential, thus making the electronics design to be fitted in just one PCB side.

Outer MISPS also has PCI-express-like slot in order to save one connector and flash the electronics.

Inner MISPS sector was a whole different concept. Conservative approach was taken at first by using an aluminum based IMS substrate. As it was working correctly, a cost reduction was attempted by trying to change its material for simple FR-4 without any soldermask. This resulted in cells broken (supposedly due to thermal shock, temperature monitoring was not done), so FR-4 central MISPS concept was abandoned.

IMS aluminum PCBs also offer better mechanical properties in order to fix the sensor to the CPVRS assembly.

Cell – Substrate Interface

Last main challenge to solve in MISPS mechanical design, was to find a suitable material in order to connect the cells mechanically and electrically to the substrates.

The obvious approach was to solder them to the PCBs, and it was done that way in some inner MISPS prototypes successfully. On outer MISPS, it resulted in cells breaking in the reflow process because of differences in CTE between the materials. Furthermore, as regular monocrystalline cells were being used, only the area below the bus bar was actually being fixed to the PCB. This resulted in a defective way to spread heat and resulted in some cells broken after radiation exposure.

These two factors combined, leaded the research towards electrically conductive adhesives.

Epoxy based and silver filled adhesives where tried at first. While they seemed to serve well their purpose for attaching bigger MISPS sectors, after days of operation, we detected some inner sectors stopping from generating any signal. Further tests revealed some inner cells where not in electrical contact with the substrate, due to epoxy compound degradation.

At this point, silicone based adhesive with silver filler was tried. This reported good electrical and mechanical contact, but the drawback of a high price per sensor. Other fillers where researched to avoid silver-based solutions. Main restriction was to avoid electrochemical incompatibilities with aluminum in the back of the solar cells. Nickel-based filler reported low enough series resistance (obviously, not as low as silver filler) and adequate properties towards aluminum upon the provider knowledge.

In order to improve manufacturability, adhesive is applied much like solder paste on the PCB, by using stencils.

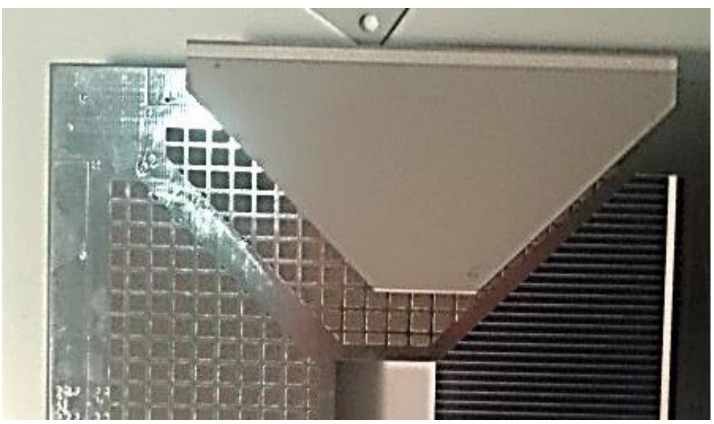


FIGURE 3. Nickel-filled silicone-based adhesive dispensed on a MISPS outer region, open for display

Front contact is done by using a short tinned copper ribbon and is soldered manually in the meantime.

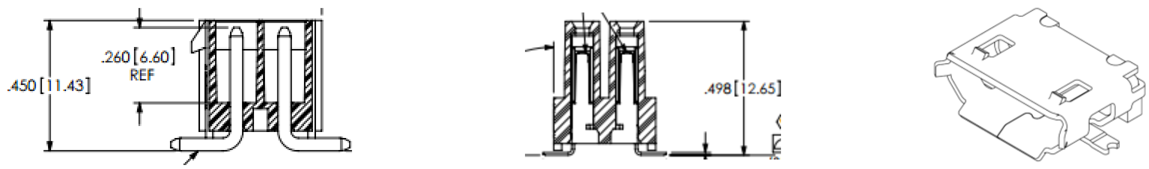
Connectors

Two kinds of connectors are used in the MISPS assembly; connectors between both boards of the sensor and a connector towards the control electronics on the tracker.

Also, in order to improve the device industrialization it is important to use SMD connectors.

Connectors between boards must allow a precise fit, allow some cycles to allow eventual maintenance tasks and offer little series resistance.

With the electronics revision, only CAN bus and power supply must be connected to the outside. So a microUSB connector was used due to its physical characteristics, market availability and cable assemblies reduced price.



(a) (b) (c)

FIGURE 3. (a) Inner and (b) outer MISPS connectors. (c) CAN bus and supply MISPS connector

Mechanical Assembly

MISPS sensor must be perfectly positioned to allow correct system performance. In the CPVRS trackers, this is solved by anchoring the sensor in front of the receivers using a laser cut radiation shield which fits four drills in the MISPS base.

Cabling is routed below riveted metal sheet to avoid any cable degradation during the tracker operation.

Sensor is enclosed in a black metallic riveted prism which prevents light from other lenses and reflections to disturb the sensor performance.

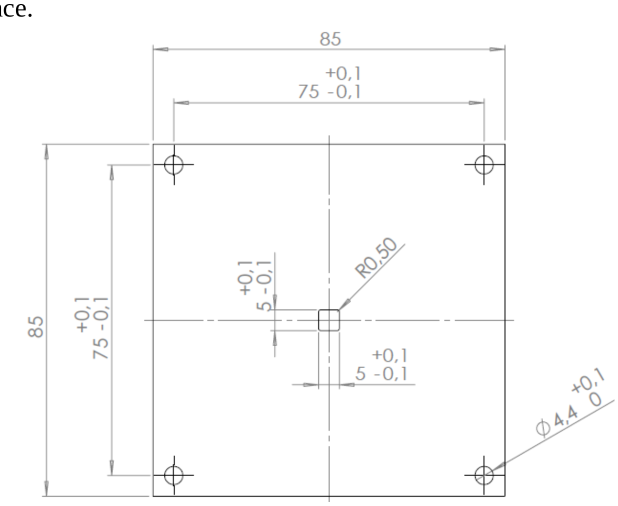


FIGURE 4. Inner MISPS PCB mechanical drawing plane detail

Coating

Coating on solar cells was done with optical silicone tested on receiver assembly process. Due to the current low level of industrialization, placing a coating on the cell provokes problems because it gets damaged after long exposures to concentrated sunlight.

Current approach is to avoid any use of coating, because it should not be necessary for the cells to withstand working conditions.

Electronics design improvements

MISPS sensor functionality consists in some transducers of solar irradiance (solar cells), signal conditioning, analog to digital conversion and data transport.

As little can be done from the electronics point of view in the transducers, other sections have been tackled to improve the sensor performance. Improvements might be categorized into analog or digital areas.

Analogic Block Tuning

Main goal for the analogic part is to condition the signal coming from the cells, making it as independent from the intrinsic characteristics of each cell as possible.

Signal from the cell is shunted in order to convert current to voltage. The objective here was to work as close as possible to I_{SC} in the IV curve but obtaining a decent signal in the tens of mV to be differentiated from noise in the next stage. A resistor value was obtained from testing received test samples under concentrated sunlight.

Once a voltage is obtained, it is immediately passed to a differential amplifier with output ranging in TTL levels (0 to 5 volts). Amplifier gain is crucial on obtaining repeatable results. If the gain is too low, we might obtain very different readings when a cell is illuminated and, if on the contrary, it is too high, noise or some diffuse radiation might be capable of showing a high output under no direct sunlight exposure. Gain values were obtained testing empirically around estimated previous calculations based on cell performance data.

Digital Block Design

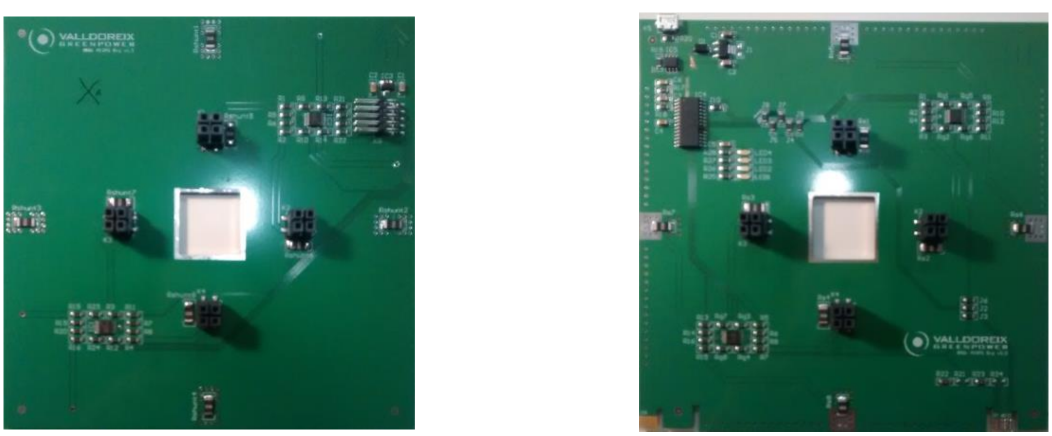
Mission for the digital block is to convert analog signal to a digital stream and pass it to the rest of the system by using CAN bus as the physical layer. In order to decide which microcontroller to use, three restrictions had to be applied: Working temperature range, analog input ports and CAN bus connectivity.

PIC microcontrollers offered all the functionality needed plus at a reduced price and fitted with our background in electronics design.

Due to using a Microchip® processor, a CAN transceiver from the same manufacturer (which was also used in previous electronic designs) was a perfect match to solve the problem.

MISPS has a connector to program the device after being installed in the circuit board, thus making the manufacturing process more modular.

Connection towards the rest of the system, as mentioned before is done through a microUSB connector carrying supply (24 or 5VDC) and CAN data.



(a) (b)

FIGURE 5. (a) Analog only MISPS assembly (b) CAN bus enabled MISPS assembly for comparison

FIELD TESTS

To test MISPS sensor effectiveness, it has been mounted in several machines and their output has been monitored.

Two of the CPVRS installed on the field have a last revision of the MISPS sensor working; these are systems #8 and #10. Another system, numbered as #11 has MISPS feedback deactivated. Also a DNI sensor is recording solar irradiance impacting on the systems.

The following graphic displays system power outputs during the day monitored on the inverters where the trackers are connected. Power differences between systems are negligible for the purpose of this study.

If compared with the DNI curve, curves representing machines #8 and #10 power correlate pretty well with it. Also, it is noticeable that machine #11 is not able to follow the sun precisely well before midday.

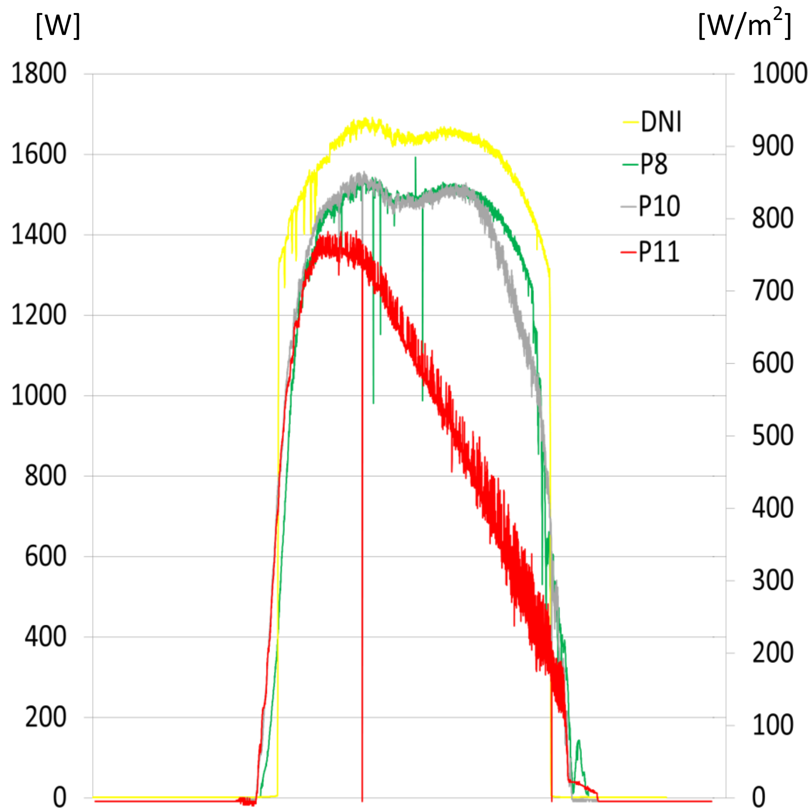


FIGURE 5. Plot showing evolution of DNI, and power on three CPVRS systems during a clear day

Astronomical algorithm is the same on all trackers; furthermore, tracker #11 has been positioned manually with offsets on both axes to meet morning position on the previous day. Trackers #8 and #10 are not manually aligned; MISPS sensor feedback puts them on track early in the morning.

Differences shown in at dawn and sunset between curves are due to inherent shadowing in the facility.

CONCLUSIONS

MISPS sensor allows CPVRS systems to be easy to install by removing the need of calibration, reduces power-on sequence and does not need an accurate nor demanding algorithm to compensate error coming from imprecise axis alignment or mathematical calculations.

Further research may be done trying to test custom silkscreened solar cells if current sensors do not cover working life expectations. Also, a better research on coatings should be done to give the sensor a better finish. Apart from that, MISPS is a product ready to be manufactured and yielding good results already.

REFERENCES

1. R. Pardell "MISPS: Module Integrated Solar Position Sensor for Concentration Photovoltaics" (CPV-8 proceedings).
2. R. Pardell "MISPS: Module Integrated Solar Position Sensor for Concentration Photovoltaics" U.S. Provisional Patent Application. (15 April 2012)