

High-Speed Multi-Channel System for Solar Simulator Irradiance Non-Uniformity Measurement

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Abstract — We present a new tool for the measurement of the non-uniformity of a large-area pulsed solar simulator according to IEC 60904-9. We realized a prototype portable unit that can be controlled via a single USB port of a notebook. The system is composed by several photovoltaic cells and a series of custom designed electronic boards, allowing a high-speed multi-channel sampling of a single pulse. We describe the main components and the design solution, which is using readily available standard electronic and software components, allowing a possible industrialization of the system. Finally we present preliminary results of the prototype unit testing.

Index Terms — solar simulator, IEC 60904-9, non-uniformity.

I. INTRODUCTION

The indoor testing of non-concentrating solar modules requires using either a pulsed or a steady-state solar simulator. The international standard IEC 60904-9 [1] defines the requirements for the performance of a solar simulator in terms of spatial uniformity, temporal stability and spectral match to a reference spectral irradiance.

The compliance to the uniformity requirement of this norm is usually performed by taking multiple measurements of a reference cell in several locations of the test plane area. This procedure is time-consuming and expensive, especially for pulsed simulators where hundreds of flashes are required, thus leading to lamp ageing. In order to simplify this procedure we developed a high-speed multi-channel measurement system which allows performing 96 simultaneous sampling points covering a 204 x 136 cm² area with a single simulator pulse.

II. SYSTEM DESCRIPTION

The system is composed by a receiver, an acquisition system and a Windows-based software. The receiver is made of 96 mc-Si photovoltaic (PV) cells mounted on a custom manufactured frame. The short-circuit current of each PV cell is measured by several electronic boards. These embedded boards have been designed and developed in close collaboration with the Institute of Applied Electronics of SUPSI. A similar system has been previously developed by Herrmann et al. [2] using LABVIEW hardware and software

solution. The development of a custom electronic board enables further affordability and cost reduction.

Each acquisition board is equipped with 12 analogic measurement channels. Up to 10 boards can be interconnected in a daisy-chain configuration, allowing the connection of a maximum of 120 light sensors. It is possible to obtain measurements with a scanning speed of up to a maximum of 100kSample/s for a total of 60'000 samples. This allows the measurement of the non-uniformity of simulators from 1ms to 600ms with a good time resolution. Figure 1 shows the block diagram of the acquisition board.

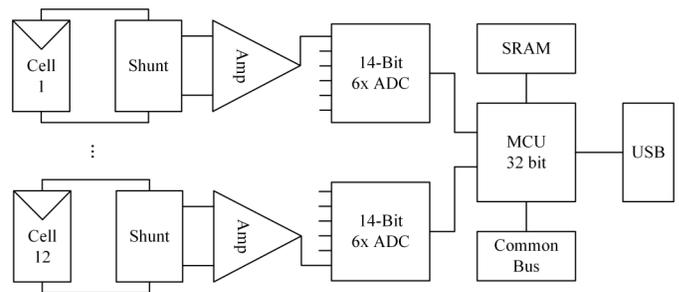


Fig. 1. Block diagram of the acquisition board

The boards are connected with a RS485 communication bus, in a master-slave configuration. The role of each board is selected by a micro-switch that enables to choose the board ID number. The master board is connected to a personal computer (PC) over a USB port. The master board interprets the commands received by the PC and coordinates the slave boards over the communication bus. A schematic of the common bus signals is depicted in figure 2.

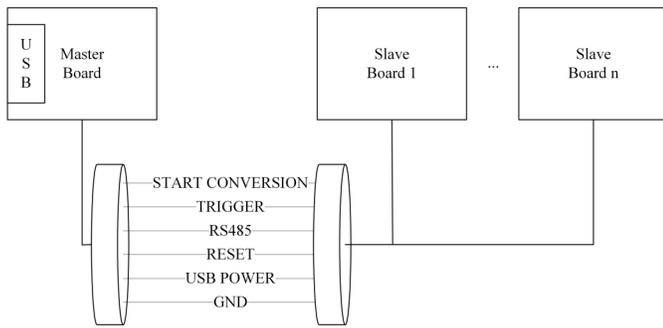


Fig. 2. Common bus signals

The start conversion signal launches simultaneously the acquisition on all the boards before the trigger of the simulator pulse. After the start signal reception, the short-circuit current of the cells is continuously measured by a $10\text{m}\Omega$ shunt resistor. The maximum electric potential at $1200\text{W}/\text{m}^2$ irradiance is 0.1V . This potential is amplified by a factor of 24.696 in order to obtain a voltage range from 0V to 2.5V . This range corresponds to the voltage input range of a 14-bit analog-to-digital converter (ADC). A fixed voltage reference of 0.8V is applied in order to avoid derived currents.

It is also possible to activate an offset voltage reference of 1.25V , enabling a measure range of $\pm 1.25\text{V}$. This is particularly useful for the system calibration.

The digital components of the acquisition board are connected over a SPI bus to an Atmel AVR32, a 32-bit microcontroller (MCU). The digitalized values from the ADC are continuously transferred over an SPI to a SRAM circular memory by the DMA controller of the MCU without wasting precious CPU cycles. The measured values from all the channels are compared with a $1000\text{W}/\text{m}^2$ irradiance value, generating a trigger signal when the simulator pulse is detected. This enables a synchronized stop of the acquisition.

Every board has a crystal oscillator with a 20ppm frequency tolerance at 25°C , which is appropriate in order to guarantee a synchronized multi-board acquisition during the sampling period.

The measurements stored in the acquisition memories are then transferred over the RS485 line to the master board. The complete data are then transferred over USB to the PC software for analysis.

Particular attention was paid to the global power requirements of the electronic system. The analogue part of the board is powered only during the acquisition and it is activated by a digital output of the MCU. The state-of-the-art low power components were chosen so that up to 10 boards could be powered by a single USB port without need for additional supply. This corresponds to a maximal $5\text{V} / 50\text{mA}$ power requirements per board. The power is supplied to the slave board by using the communication bus. The limited power requirements enables the usage of a lightweight

notebook computer and allows to easily transport the system to perform measurements as a service for industry directly at client's simulator.

In addition we selected electronic components with high temperature stability and tolerance. This enables high precision after calibration without affecting the total cost of the system. The assembled acquisition board is shown in figure 3.

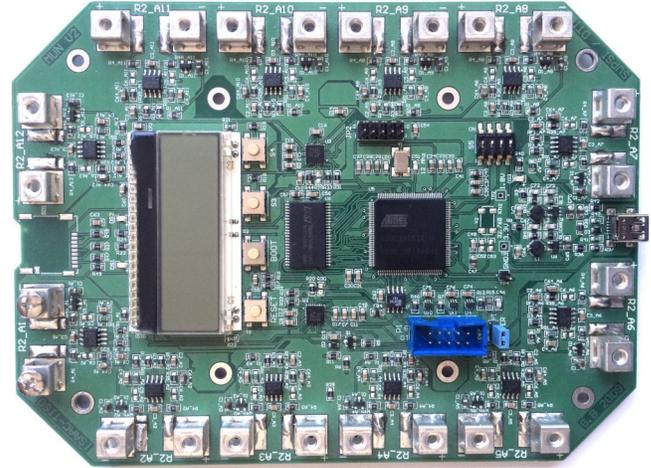


Fig. 3. Assembled data acquisition board for the simultaneous measurement of 12 cells.

After a functional testing of the hardware and firmware acquisition boards with synthetic signals, we assembled a prototype system by using a $204 \times 136\text{cm}^2$ custom module with a total number of 96 mc-Si cells with a 8×12 placement layout. The physical dimension of each cell is $15 \times 15\text{cm}$. The module has an aluminium frame with handle in order to ensure a mechanical protection and easiness of transport.

On the back panel we mounted the shunt resistors. The position is as close as possible to each cell in order to reduce wiring losses. The shunts are then connected to the acquisition board. On the back of the module we also mounted the 8 acquisition board. The only necessary connection is the USB connector, which is used to power the system and for the data communication to the software analysis. A detail of the assembled system is shown in figure 4.

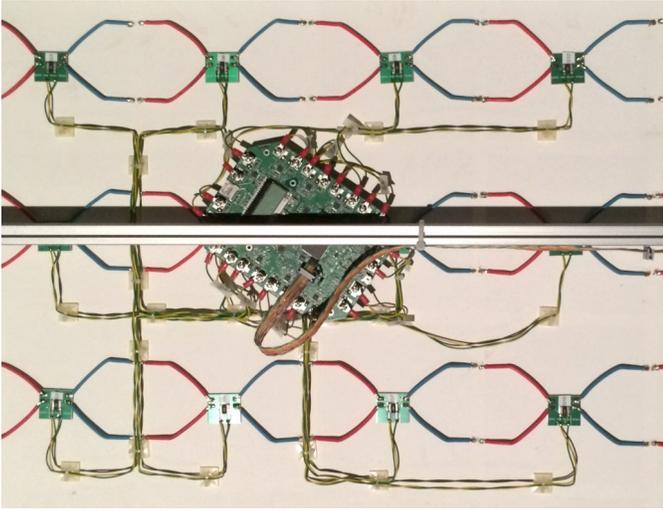


Fig. 4. Detail of assembled system

We developed a Windows C# software interface. This software permits the device calibration and the data acquisition. Using this interface it is possible to define a virtual test surface bigger than the actual sensor module. With a sequence of flashes and different positions for the sensor module, it is therefore possible to aggregate the data in an enlarged virtual test surface.

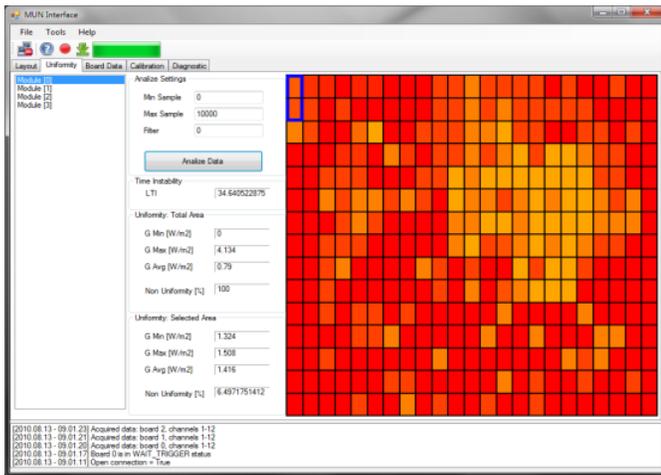


Fig. 5. Software interface for the uniformity measurement equipment

Uniformity and solar simulator classification are calculated according to IEC 60904-9. Data export is available in CSV file format.

III. PRELIMINARY RESULTS

Preliminary tests of the electronic and software components have been performed in laboratory equipment by applying synthetic signals generated by laboratory power supplies.

Then, we performed a functional testing with a pulsed solar simulator (10ms flash duration), verifying the triggering of the acquisition system by the solar simulator pulse.

A. Prototype calibration

Since the application could be used both on pulsed and on steady state solar simulators, we tested the prototype at a wide range of temperatures. After initial degradation of the mc-Si cells we stabilized the module and the electronic boards in a climatic chamber at -10°C . The prototype has been exposed then outdoors in clear-sky conditions. We performed raw measurements of selected measurements channels with temperatures between -1°C and 10°C . Then we stabilized the system at 65°C in the climatic chamber and we performed additional outdoor measurements with temperatures between 57°C and 59°C .

The prototype was then calibrated outdoors in the same temperature range, where the temperature stability was measured within the uncertainty limits listed in Table I below.

TABLE I
EXTENDED STANDARD DEVIATION ON SELECTED CHANNELS
[%] $k=2$

T [$^{\circ}\text{C}$]	Ch. 1	Ch. 2	Ch. 3	Ch. 4	Ch. 5	Ch. 6
57	0.069	0.069	0.071	0.071	0.073	0.087
59	0.068	0.064	0.067	0.069	0.073	0.078

B. Validation

The prototype was then validated indoors, via direct comparison of the measured non-uniformity of a Class AAA pulsed solar simulator, with the known non-uniformity which is measured routinely.

With the traditional measurement method according to IEC 60904-9, a set of 99 equally spaced measurements of total irradiance is performed on a $220 \times 185 \text{cm}^2$, 11×9 matrix: a monitor cell is placed outside the measurement area, and the short-circuit current of a calibrated reference cell is normalized to the total irradiance recorded by the monitor cell. The reference cell is an $11 \times 11 \text{cm}^2$ c-Si cell, fulfilling the geometrical requirements of the cited standard.

The charts in Figure 6 show the results of the validation test: Figure 6a and 6b show the 2D colour maps of the non-uniformity measured with the traditional and with the prototype method respectively. Class A uniformity requirement is between 0.96 and 1.00 normalized total irradiance (i.e. $\pm 2\%$); class B requirement lies between 0.9 and 0.96 (i.e. $\pm 5\%$). Figure 6c and 6d show the total irradiance profile of the two main axes of the target measurement plane: at $x = 0$ and $y = 0$ respectively.

The differences in the two non-uniformity maps are well within 2% and may be further reduced with a more accurate calibration in clear-sky-conditions at controlled temperature.

IV. CONCLUSIONS

We presented a high-speed and low-power uniformity measurement tool for solar simulators, which can simplify and speed-up the current time-consuming non-uniformity determination procedure.

We outlined the main components and design solutions of the system. The choice of standard electronic and software components allows the possibility of an industrialization of the presented solution. The preliminary results show that the system is functioning as expected and presents a good accuracy between the acquisition channels. A comparison to the existing traditional procedure for non-uniformity measurement according to the IEC 60904-9 was also performed, as a preliminary validation of the new measurement tool.

Future works will focus on evaluating the precision, repeatability and as well as the calibration of the system in the outdoor field. The final goal is to integrate the system within the ISO 17025 accreditation.

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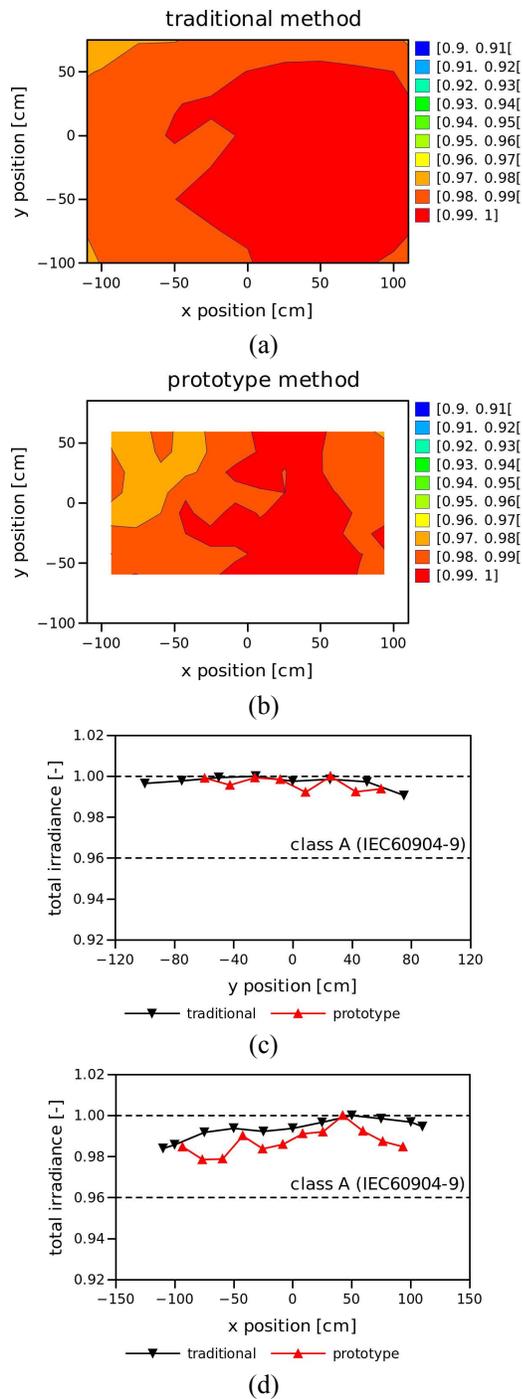


Fig. 6. Prototype validation: comparison between non-uniformity measurements with the traditional method and the new prototype. Non-uniformity colour maps: (a) traditional method; (b) prototype. Profiles of total irradiance at: (c) $x = 0$; and (d) $y = 0$ (the $\pm 2\%$ limits of class A uniformity requirement according to IEC 60904-9 is shown with the dashed line).

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