PV Cells Test Bench System with Remote Access Trough Internet

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***Abstract*-A test bench system for testing the solar cells is presented. The system allows remote access through Ethernet in order to measure the I-V characteristics at different levels of lighting and the dynamic behaviour of solar cells using light or current pulses. The paper presents two different solutions and emphasizes their advantages allowing high accuracy in the measurement of the PV cell parameters. The paper shows the architecture and elements of a data acquisition system that was developed based on high resolution ADCs. The user interface is implemented in the LabVIEW environment.**

I. INTRODUCTION

The determination of solar cells parameters was, is and will be a domain of interest for researchers. If in the past, in the 70s-80s, it was strictly a lab research domain, lately it has become a research domain with extremely various practical applications. This is due to the expansion of cells and photovoltaic panels in the energetic industry, as well as in the connected ones. The use of "twin" cells, which are cells with almost identical parameters, is indicated in order to create photovoltaic panels. This last aspect implies the necessity to measure and determine the parameters of solar cells. The possibility to measure the photoconversion efficiency by improving the solar cells parameters is another necessity for which solutions can be found by knowing the parameters effect. At the beginning, there was a small variety of solar cells types, but the constraints and the increasingly high requests from the energetic sector led to a sustained growth of solar cells types. The methods and determination of solar cells parameters must be adapted to this evolution of cells types.

Determining the parameters of interest for solar cells implies, alongside the development of methods, the accurate realization of measurements. This desiderate can be achieved by using a measurement system that is performing, rapid and compact. Other aspects that need to be taken into consideration are reliability, flexibility and the costs of the measurement system. Nowadays, several measurement systems are being developed, bearing both advantages and disadvantages [1-4].

The main components of a measurement system for solar cells are:

- The light source – this has to ensure a spectral match as good as possible with the solar spectrum, of course, for reduced costs. In industrial applications, the solar simulators are replaced with halogen lamps, thus an acceptable compromise is made between costs and accuracy [1].
- The module for measuring I-V characteristics – has to permit the measurement in a very short time (seconds), and the number of measurement points has to be large enough to allow a good data processing. Characteristics measurement can be done through various techniques: the use of an electronic load, of a capacitor as a variable load, of a MOSFET or a digital potentiometer [5].
- The mobile system – allows a variation in distance between the solar cell and the light source. Through this variation, the lighting level can be raised from 100 W/m^2 to 2000 W/m^2. The variation in distance can be made using a stepper motor or an actuator.
- The thermostat – permits the realization of measurements for different temperatures of the solar cells.
- The reference cell – is a calibrated solar cell, necessary to measure the lighting level.

II. ARCHITECTURE AND METHODOLOGY OF THE TEST BENCH SYSTEM

The architecture of the test bench system is based on the integration of three parts: the mechanical sub-system, optical sub-system and electronic sub-system. The first one ensures the motorization of the optical sub-system that implements the variation of light flow on the DUT. The quality of implementation is related to the following factors: precision of the positioning system, stabilization of light flow provided by the light source and the data acquisition system. All these aspects were studied and taken into account during the stages of design and implementation of the test bench. The functionality implemented ensured the conditioning process for the PV cell by controlling the position and the voltage applied on the light source. In addition, the signals acquisition was implemented, using ADCs, and the processing of data acquired. The communication part was an important one, and in one of the implementations, the remote access to the test bench through Internet was ensured.

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1. *First Test Bench Implementation*

In the first phase, the solar cells characterization system was developed using a SDK ATmega system and a data acquisition board NI 6215 that together with a personal computer ensured the local control of the test bench. Fig.1 illustrates the structure and the connections that were implemented in the initial bench.

The command of the actuator for positioning the light source towards the solar cell and the lighting activation was achieved by the SDK. A data acquisition board was used to measure the parameters of interest. The command signal for the MOSFET was also generated using the data acquisition board, being a triangular signal (Fig.2). The sample rate and the number of samples were chosen so that they would allow the acquisition of a large enough number of samples on the I-V characteristic of the cell. In Fig.3, the I-V characteristic of a solar cell is presented, measured with the developed system.

The test bench developed for testing and characterization of solar cells is presented in Fig.4. Its structure comprises of the following:

a. Linear actuator – permits the movement of the light source towards/away from the solar cell, in order to obtain a variable lighting level. The lighting variation variant was chosen in order to expose the cell to a radiation with a constant spectrum, even if the lighting uniformity has to suffer. The movement is realized on 50 cm, ensuring a radiation variation of ~2 suns;
b. Light source – contains the source itself formed by a halogen light bulb of 50W with an aluminium reflector assuring a light spot with a high uniformity and the switcher on/off based on a power MOSFET;
c. Device under test, DUT – formed by the monocrystalline silicon solar cell with an area of 15cm^2 under testing (Fig.5 a), 4 photoresistors placed in the corners of the cell (Fig.5 b), a temperature sensor placed in intimate contact with the solar cell with a small thermal inertia, as well as the signal conditioning part;

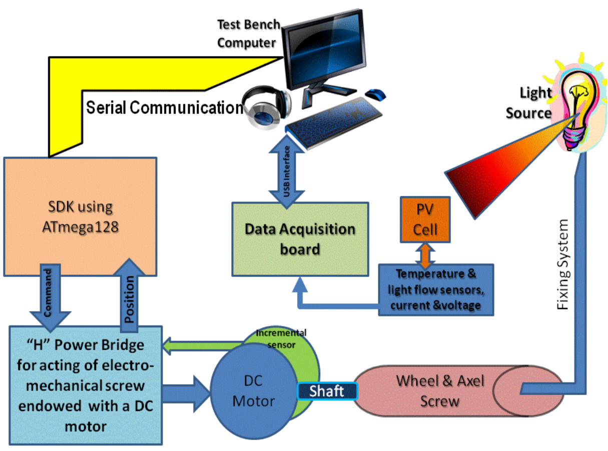

Fig. 1. The block schemata of the characterization and testing system for solar cells. Variant 1

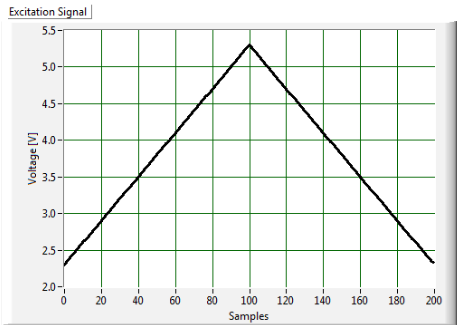

Fig. 2. The excitation signal for the MOSFET

d. The data acquisition board NI USB 6215 is used to measure the I-V characteristics of the solar cells, the signals on the four photoresistors and the signals given by the temperature sensor, and also to generate the command signal of the MOSFET used as electronic load for the solar cell;
e. The power source of 5V DC – used to power the SDK ATmega system;
f. The power source of 12V DC – used to power the linear actuator;
g. SDK ATmega system – used to control the actuator and switch on/off the light source;
h. H bridge driver to command the linear actuator;
i. Embedded server Lantronix – permits the access to SDK ATmega system over the network;
j. Box – used to ensure the lighting of the solar cell only by the light source used and eliminate all other light sources in the lab;
k. 12 V battery – used as a power source for the light source. This ensures a constant voltage of the light source eliminating the fluctuations existent at the power sources DC (10Hz).

To control the system and the measurements, a software application was developed in the graphical programming language LabVIEW. The interface of the application is presented in Fig.6.

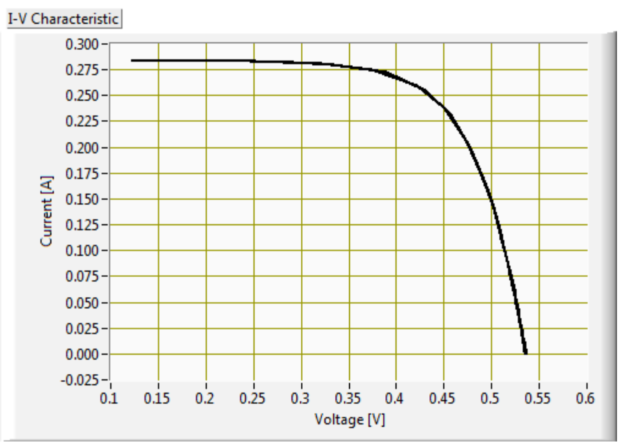

Fig. 3. The I-V characteristic of the solar cell

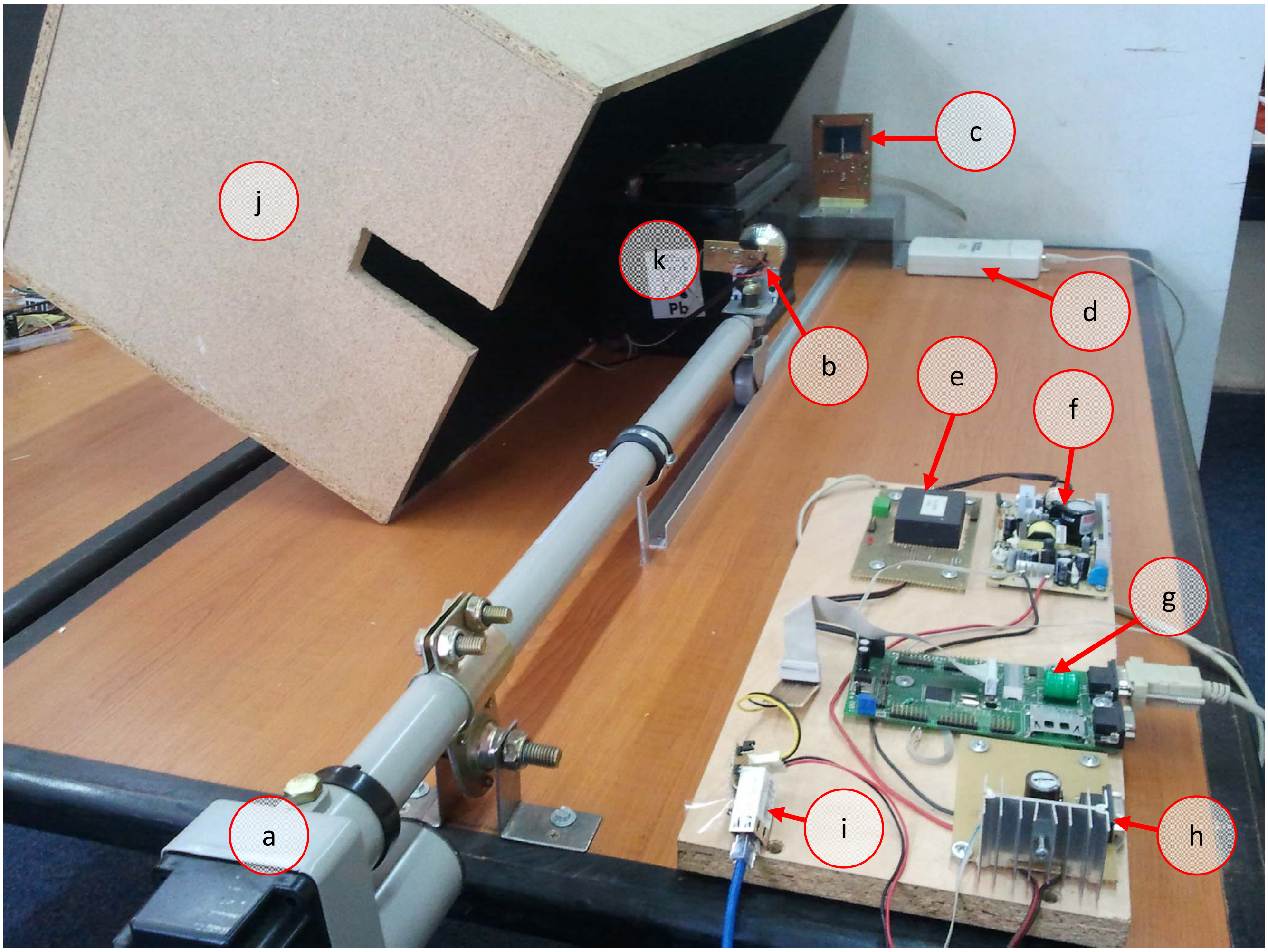

Fig. 4. The test bench system for testing and characterizing the solar cells

The interface is divided in three work zones. The first zone, **System positioning**, is dedicated to control the light source position towards the cell. The communication with SDK ATmega system is realized on the serial port RS232, based on a protocol developed by the authors.

The positioning can be done by two methods: **Light Level Positioning** and **Manual Positioning**. The first method, **Light Level Positioning**, permits the positioning of the light source so that it ensures the desired lighting level for the solar cell. This method is based on a previous calibration of the system using a portable pyranometer - Daystar Solar Meter, that is memorized in a LUT (Look Up Table). The desired position is found by the interpolation of values memorized in the LUT. The second method, **Manual Positioning**, requires

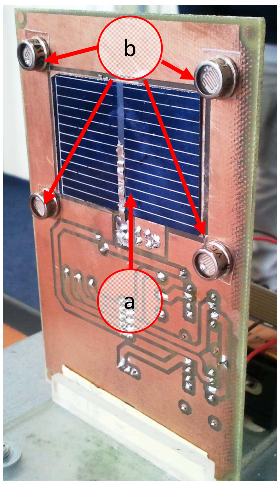

Fig. 5. Device Under Test DUT

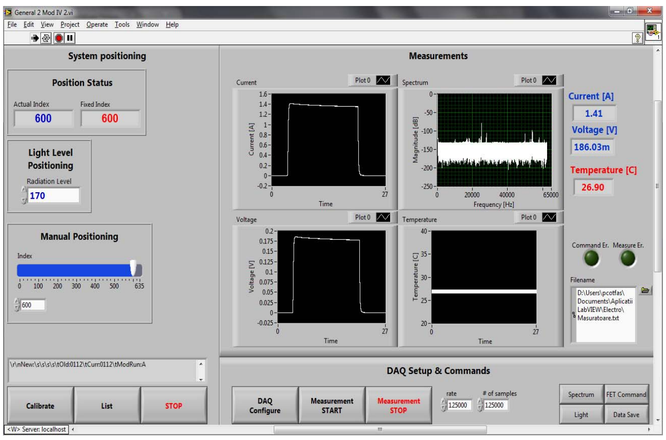

Fig. 6. The interface for measurement and control

the introduction of the actuator's position index using the *Index*. The index domain is between 0 (maximum distance) and 635 (minimum distance). This variation in distance allows a lighting variation in the range of 50-2000 W/m^2.

The actuator's status is presented in the **Position Status** field by the indicator *Actual Index*. The target position of the actuator is presented in the indicator *Fixed Index*.

When the application is started, it is necessary to initialize the system by pressing the *Calibrate* button. The initialization takes the system in the position with the index 0.

The second zone, **DAQ Setup & Commands**, is dedicated to configure the data acquisition board and to send commands for measurement starting. The parameters that can be configured are sample rate and number of samples taken during measurements. For the measurements taken, a spectral analysis can be performed to extract more information (button *Spectrum*). The data obtained can be saved by pressing the *Data Save* button. The application allows studying the dynamic behaviour of the solar cell, either by switching on/off the light source (button *Light*) or by modifying the load applied at the output of the solar cell by short circuit or by passing to the open circuit of the solar cell (by switching on/off the MOSFET using the button *FET Command*). The measurements taken are visualized in the **Measurements** area. Here one can see the current and the voltage evolution on the cell (Current and Voltage graphs respectively). The spectrum of the current signal is presented in the *Spectrum* graph, and the temperature evolution during measurements is given by the *Temperature* graph.

The potential errors appeared on the command part or on the measurements part are visualized by the LEDs *Command Er.* and *Measure Er.* respectively. The file path where data is saved is given in the *Filename* control.

Four photoresistors were used, placed in the corners of the solar cell, in order to obtain the feedback about the lighting level. These photoresistors were previously calibrated using a mobile pyranometer - Daystar Solar Meter. Placing the four photoresistors in the corners of the solar cell facilitates the monitoring and uniformization of the solar cell lighting. A software application was created in order to visualise this uniformity, permitting also the reading of the four resistors' responses (Fig.7)

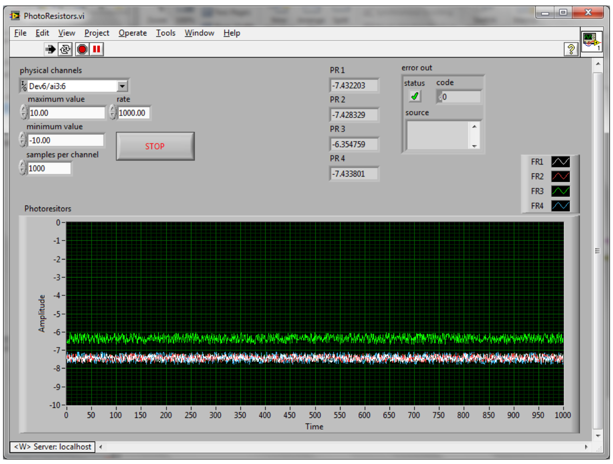

Fig. 7. Lighting measurement using four photoresistors

2. *Second Test Bench Implementation*

In the second phase, the characterizing system of the cells was modified for simplification purposes. The system's structure was modified by replacing the data acquisition board, NI 6215, with the SDK ATmega system to which a module was added formed by two digital synchron converters endowed with programmable amplifiers [6, 7]. In Fig.8, the architecture and the component elements of the test bench conceived are illustrated. In comparison with the first version, this leads to an improvement in performance compared to the first version, ensuring on the one hand the processing performance improvement as it has two independent channels galvanic isolated one from another. On the other hand, an embedded server was added permitting the remote access to the bench, thus making available the testing and characterization of the solar cells to its potential clients that have access to Internet.

The system has overcome the difficulties related to the crosstalk between the analog channels by implementing for the main signals acquired (for current and voltage) of two different data acquisition channels. Each data acquisition channel includes a programmable gain amplifier (PGA) that will adapt the gain factor to the characteristics of the current, respectively the voltage sensor [8]. The analog to digital converter (ADC) assures a high resolution (16 bits, 250KBps) in conversion, thus revealing all the detailed variation of the signals acquired [9]. Both the PGA and the ADC are interconnected with the system coordinator, the microcontroller, by the SPI interface. The PGA and ADC are slave devices under the control of ATmega128 and assure the acquisition and transfer of measured signals via the embedded server to the client. In order to avoid the crosstalk, each data acquisition channel is insulated by two optocouplers on the digital side of the data acquisition channels. The other signals necessary to reveal and control in detail the testing of the PV cell behaviour: temperature of the cell and the instantaneous

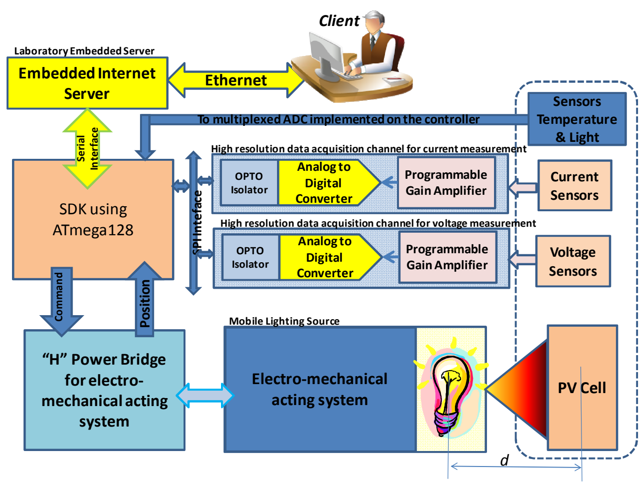

Fig. 8. The block schemata of the characterization and testing system for solar cells. Variant 2

light flow of the four corners are measured by five different channels implemented on the ADC integrated on ATmega128 microcontroller. At the same time, the controller ensures the motorization of the bulb that is used as a light source for the test bench. The "H" power bridge (LMD18200) is controlled by the same SDK that provides two signals: the command signal that defines the sense of movement for the mechanical acting system and the command that switches on/off the voltage on the DC acting motor.

The mechanical actuator is endowed with three positioning sensors: one incremental sensor implemented with a red relay and two movement limitation sensors ensuring the maximum distance that could be taken by the actuator. By using one of the external interrupt inputs of the controller, the increments provided by the actuator are counted and there is a high resolution of the positioning system, respectively of the light source. This distance was defined as "d". Thus, SDK ATmega system permits, on the one hand, to command the acting system at the desired position in order to obtain a preset light flow, and on the other hand, to implement the data acquisition for the temperature and light flow. It is well known that the light flow of the bulb is a parameter that is unstable, due to several factors such as changes in supply voltage, temperature of the bulb etc. For this reason, and in order to have the possibility to improve the accuracy of the measurements, four photoresistors are used as light flow references on the four corners of the PV cell. This solution permits to simultaneously measure the light flow in all four corners of the PV cell, avoiding the errors due to a slight light flow variation of the light source. The microcontroller system dedicated to the signal acquisition and control of positioning system communicates with the client via an embedded server that assures the link to the test bench clients through an Ethernet network. Lantronix provides the embedded server and its firmware allows setting different communication protocols: ARP, UDP/IP, TCP/IP, Telnet, ICMP, SNMP, DHCP, BOOTP, TFTP, AutoIP, SMTP, and HTTP at 10 or 100 KBps. This large variety of protocols facilitates the integration of the test bench into a network. In order to assure the remote control, a set of specific commands seen as telegrams was implemented assuring the settlement of main test bench parameters and the automatic and manual commands for measuring and characterization of PV cells. These telegrams are tunnelled through Ethernet. The facilities offered by this test bench allow the settlement of all test bench parameters: light flow and variation of the light flow on tested PV cell. The lighting test bench characteristic are obtained following the execution of a calibration procedure. This functionality designed for the test bench allows determining the lighting characteristic of the test bench by moving and measuring the light flow with the four photoresistors. The data will be stored on a LUT (Look Up Table) into the SDK local memory. Another function implemented allows sampling all the signals necessary to be acquired from the PV cell and these data will be available at client's request. Different shapes of control signal for the MOSFET that is used as current switch will be provided by the same SDK. Performances reached by the implemented system are the linear resolution for light source positioning of 0.001" (0.0254mm), the added series resistance by on-resistance of the MOSFET and circuit contacts of 20mΩ, the PV cell short circuit current of maximum 1A, and the PV cell open circuit voltage of 0.6V.

Fig.9 shows the developed module for signals acquisition. This assures a programmable amplifier with automatic correction for drift and offset errors, allowing the elimination of all artefacts related to the temperature and low frequency noises. A low pass filter assures the adequate level of signal for ADC. This is an ADC161S626 based on successive approximation register (SAR) with sample&hold facility [9]. The digital interface is a SPI and this is opto-insulated related to the microcontroller. The ATmega128 microcontroller controls all the devices from the card. The maximum speed is 8Mbps and taking into account that two channels are implemented and each one need three bytes for acquired data, the maximum speed obtained with this card is 165 KSPS/channel. The resolution of the ADC is 16 bits.

III. CONCLUSIONS

The test bench system allows testing the solar cell local and remote, via Internet and it is a compact and flexible system.

The test bench system is a work instrument that constructively combines the hardware and the software performances.

The functionality assures both manual and automatic measurements, allowing the user to adapt his strategy at the specific of PV cells tests requirements.

The test bench brings the following advantages: using the LUT obtained in the calibration phase offers a strictly controlled light flow on DUT; by monitoring the light flow during testing any other variation of light flow will be compensated; the uniformity of PV cells lighting is monitored avoiding artefacts due to the light flow variation during measurements; by monitoring the cell temperature it is possible to made the correction of PV parameters; having two insulated signals acquisition channels the crosstalk is

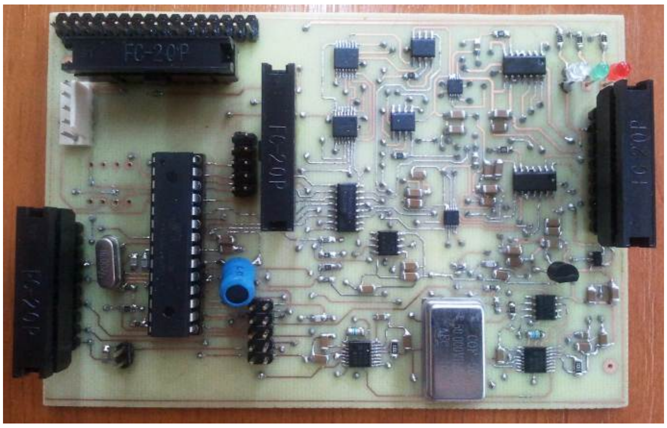

Fig. 9. The module for signals acquisition with ADC and PGA

eliminated; by providing the possibility to customize the measurement gain of the signal amplifier, adapting the characteristics of this test bench at a large variety of PV cells and measuring structures becomes easy; by including an embedded web server, the test bench is ready to be immediately integrated into a network. Finally yet importantly, there is also the advantage of the very low cost of the test bench that makes it suitable for the market.

The software applications allow studying the solar cells using the main tool – I-V characteristics. These characteristics are measured at different levels of lighting. Another study is the dynamic behaviour of light or current pulses.

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REFERENCES

[1] G. Aberle, T. Lauinger, S. Bowden, S. Wegener, G. Betz, "Sunalyzer-a powerful and cost-effective solar cell I-V tester for the photovoltaic community", Photovoltaic Specialists Conference, Conference Record of the Twenty Fifth IEEE, USA, May 1996.

[2] M. G. Guvench, C. Gurcan, K. Durgin, D. MacDonald, "Solar Simulator and I-V Measurement System For Large Area Solar Cell Testing", Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition, 2004.

[3] ***: "Measuring photovoltaic cell I-V characteristics with the model 2420 sourcemeter instrument", Application Note Series, Number 1953.

[4] M. A. Mosalam Shaltouta, M. M. El-Nicklawyb, A. F. Hassanb, U. A. Rahomaa, M. Sabrya, "The temperature dependence of the spectral and effciency behavior of Si solar cell under low concentrated solar radiation", Renewable Energy, vol. 21, pp.445-458, 2000.

[5] D. T. Cotfas, P. A. Cotfas, D. Ursutiu, C. Samoila, "Current-Voltage Characteristic Raising Techniques for Solar Cells. Comparisons and Applications", 12th International Conference on Optimization of electrical and electronic equipment OPTIM 2010, May 20-22, 2010, Brasov, Romania, IEEE Xplore 10.1109/OPTIM.2010.5510373.

[6] A. S. Moraru, M. Romanca, P. Borza, "Distributed Software Architecture and Applications for Remote Laboratories", The 2nd International Workshop on e-learning and Virtual and Remote Laboratories 2008, February 14-15, 2008, Hasso-Plattner-Institute Potsdam, Germany Heft Nr. 21 (2008), ISSN 1613-5652, ISBN 978-3-940793-17-1, pp 21-28.

[7] F. Sandu, M. Romanca, A. Nedelcu, P. Borza, R. Dimova, "Remote and Mobile Control in Domotics", Proceedings of „OPTIM 2008" – 11th International Conference on Optimization of Electrial and Electronic Equipment - Vol. 4, ISBN 978-973-131-031-2, pag. 225-230 / ISBN 1-4244-1545-4, ISBN 978-973-131-028-2, ISSN 1842-0133, IEEE Catalog Number 08EX1996C, Library of the U.S. Congress 2007905111.

[8] *** Texas Instruments Literature Number: SNOSB09A Zero-Drift, Programmable Instrumentation Amplifier with Diagnostics, see at 1.02.2012 on http://www.ti.com/lit/ds/snosb09a/snosb09a.pdf.

[9] *** Texas Instruments Literature Number: SNAS468B analog to digital converters see at 1.02.2012 on http://www.ti.com/lit/ds/snas468b/snas468b.pdf.