

SOLAR ARRAY SIMULATOR FOR MICROSATELLITES POWER SYSTEM TESTING

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ABSTRACT

Power systems verification requires the stability of the environmental conditions during the entire testing period, because small variations in irradiance, temperature and solar angle incidence can compromise the test results making difficult the real device performance evaluation. For this reason a traditional photovoltaic module is not a practical power source for laboratory testing, but it is necessary to use instruments that can simulate the I-V characteristic of a solar array. Because of the high cost of these instruments, in the framework of university satellite programs, and the requirement of several devices to simulate each solar array, the design and prototyping of a low-cost system, with the purpose of testing microsatellites power systems, was undertaken at University of Bologna.

1. SYSTEM OVERVIEW

A control board manages the load current modifying the output in accordance with the I-V law generated from a control Personal Computer (PC).

The mathematical model of the I-V curve is processed once per second by the PC considering the solar angle incidence and the temperature effects, simulating the dynamic behavior of the spacecraft. The model creates the curve starting from characteristic values of the cell or array the user needs to simulate.

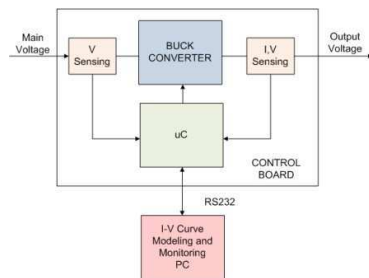


Figure 1 - SAS block diagram

A Labview® graphic tool instantaneously monitors the working point position by reading the load current and voltage values from the control board through a RS232 connection.

2. CONTROL BOARD

2.1. Board hardware

The control board consists of an 8 bit microcontroller(μC) that manages a DC/DC buck converter; it reads the current of the external load and sets the output voltage value picking it up from a look-up table.

A proportional control algorithm inside the μC adjusts the PWM duty cycle to get the value closest to the voltage set point.

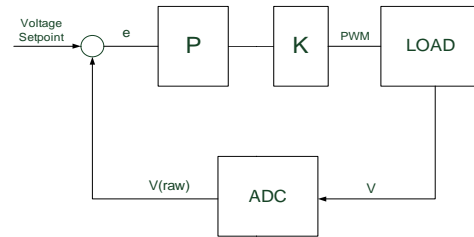


Figure 2 - Control Loop

Due to the low computation resource of the control board it is not practical to perform floating point operations. To fully exploit the μC resources the control algorithm processes only RAW values charging the control PC of all computational tasks. For this reason the error voltage (e) is evaluated in RAW values rather than physical values.

The control board, can simulate a curve with a maximum voltage up to 55V and a current up to 1.2A, input ranges more than enough for microsatellite applications.

The output voltage is sampled with a 10 bits ADC and the μC can control the output voltage with a resolution of 10 bits (1023 step) through its PWM output.

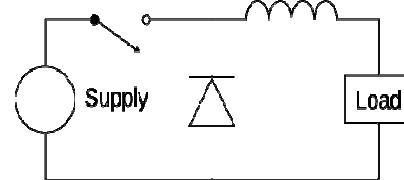


Figure 3 - Buck Converter Topology

The buck converter is used to produce the desired output voltage through the PWM output. Its frequency has been set at 100 KHz so to limit the current through the inductor and limit its size.

The hardware is based on the microcontroller ATmega32, chosen for its performance, the onboard peripheral and the low cost ATMEL JTAG emulator which allows fast in-circuit debug.

The microcontroller has been configured to use an external 16 MHz oscillator which allows to exploit the maximum computation performance to assure a fast tracking of the simulated working point.

2.2. Board software

The board is managed by a program written in C language. It continuously reads the load absorbed current by setting, using an appropriate control loop, the voltage set-point obtained by the look-up table stored into the μC .

The look-up table is an array which the index represents the current values and the value pointed by the index is the correspondent voltage to set.

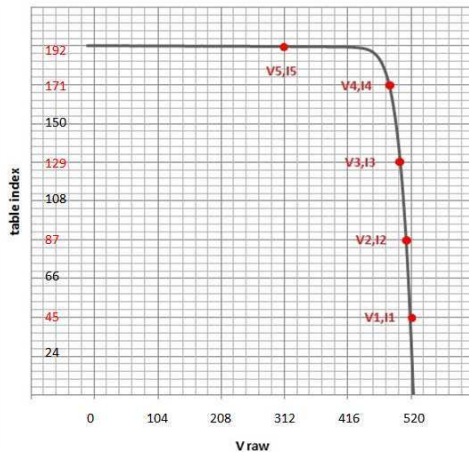


Figure 4 - Voltage RAW values of the characteristic

Table index	V RAW
45	506
60	501
87	492
171	465
192	211

Figure 5 - The look-up table

Figure 4 graphically shows the look-up table where, highlighted in red, are the values shown in Figure 5.

This output voltage is set by a PWM output of the μC which, through the DC/DC converter, regulates the output voltage of the simulator.

A proportional controller compare the voltage found in

the look-up table and the voltage subsequently reads across the load and it will increase or decrease the duty cycle of the PWM in order to change the voltage across the load to a value closest to the voltage read in look-up table.

In order to simulate every condition of the solar panel the onboard software receives once per second the new curve and overwrites the previous one.

The photovoltaic characteristic can be considered as divided in two main parts, with different behaviors: in the first one large variations of the current produce small variations of the output voltage (from I_{mp} to open circuit) and the second one where small variations of the current produce large voltage variations (from I_{mp} to I_{sc}). For this reason, in order to create the curve properly, two different control algorithms were developed.

From 0 to the set-point current (I_{sp}) the voltage is imposed starting from the read current as mentioned above mentioned. From I_{sp} to the short circuit current (I_{sc}) the Solar Array Simulator (SAS) behaves like a current generator, approximating this part of the characteristic to a constant current line. The magnitude of the error is limited at 1% is negligible.

The data about voltage and current read across the load are sent via RS-232 to the PC in order to visualize in real-time the working point position.

The main program loop is executed at a frequency of 533 Hz. The rapid response of the SAS allows to properly assess the power system functioning even in case of rapid changes of the load absorbed current.

3. CONTROL PC

The control PC not only carries out the control task, but also allows the user to monitor the system operations. It carries out the computationally heavy algorithms to reduce the control board work and lets it to operate at maximum speed. The Labview® software is composed by two main parts, one includes the I-V characteristic numerical model and one consists of the monitoring and control algorithm.

3.1. I-V curve modeling

The photovoltaic characteristic is often modeled through the simple photodiode model. This method guarantees acceptable results simulating the mono-junction solar cells behavior as Silicon cells, but represents a coarse model for multi-junction space grade solar cells. In particular, the model has to consider the effect of each dark-current mechanism in a specific junction, and the contribution of each junction to overall device performance. The implemented one uses the simplified diode model to account for electron diffusion, recombination, and tunneling by placing three diodes in parallel each representing an individual mechanism [1]. This method yields an overall expression for current as a function of device voltage. By expanding it with respect the solar cell voltage we obtain:

$$V = Vt * n_{tot} * \log(I / (I_{0GaInP2} \left(\frac{n_{0GaInP2}}{n_{tot}}\right) * I_{0GaInP2} \left(\frac{n_{0GaAs}}{n_{tot}}\right) * I_{0GaInP2} \left(\frac{n_{0Ge}}{n_{tot}}\right))) \quad (1)$$

$$n_{tot} = n_{0GaInP2} + n_{0GaAs} + n_{0Ge} \quad (2)$$

The complete model can be schematized as a series circuit (representing multiple junctions) of parallel circuits (representing multiple dark current mechanisms in each junction), and shunt resistance across the junction and series resistance across the device, as shown in Figure 6.

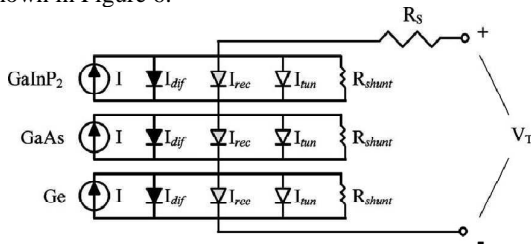


Figure 6- Complete model of a triple junction solar cell

Once the single solar cell has been modeled, its characteristic is translated by angle of incidence, using the cosine law.

Then the curve is translated in temperature exploiting the equation proposed by Jet Propulsion Laboratory (JPL) referred to the ASTM E1036 [2] standard, that keeps the error within 5% [3].

$$V_{oc2} = \frac{V}{(1+\beta)*(T_{ref}-(T+273.15))} \quad (3)$$

$$T_{ref} = 298.15 \text{ K} \quad (4)$$

$$\beta = \frac{V_{oc2}-V_{oc1}}{V_{oc2}*(T_2-T_1)} \quad (5)$$

Now it is possible to configure the system to carry out simulations, by setting the number of series-connected cells and the number of parallel strings. The control PC will compute the input parameters and will send out the RAW values of the look-up table to the control board executing a conversion of physical characteristics.

3.2. Simulator interface

The SAS Management User Interface (MUI) has been designed in order to assist the user during the test campaign operations by means of a virtual instruments for the immediate visual check of the main functioning parameters.

The MUI has been entirely developed in the Labview® 2009 graphical environment in order to exploit the software capability to easy access the source code and add or improve new functionalities for future releases. The MUI offers three control panels for data management, one dedicated to the data input and two for the results visualization, as shown in Figure 7.

Concerning the inputs, three sets of data can be edited by the operator:

- Solar panels array parameters, in terms of number of cells and strings, power characteristics and illumination conditions (both manually or automatically, according to the outputs of the microsatellite orbit simulator),
- Electrical interface parameters, according to the electronic board used to acquire RAW data,
- Output curves aspects.

On the basis of the data settings, the software is able to solve the mathematical model modeling the behavior of the described solar panels array, keeping also into account the corrective coefficients due to the temperature and the direction of the sun. The result of the numerical estimation is shown in the upper panel in form of electrical V-I characteristic of the solar panels array itself (in white in Figure 7).

For graphic and computational easiness, the curve is discretized up to 1024 points, with the capability to introduce numerical simplifications in function of a threshold value on the acceptable gap between consecutive points along the current (y-) axis.

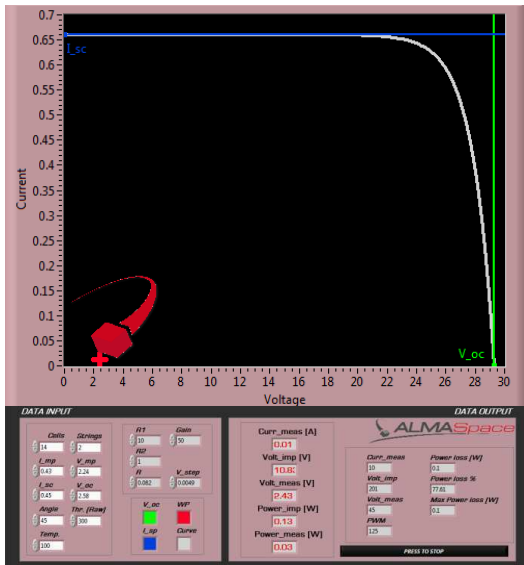


Figure 7. SAS Management User Interface

By means of a standard RS-232 interface, the MUI is able to acquire the RAW measurement data of the actual work point of the SAS, sent at the desired sampling rate by the on board test electronics, and consecutively to convert them in engineering units for a more meaningful visualization. The same data are used to show the work point on the solar panels array characteristic in form, allowing the user to evaluate the performance of the SAS in function of the maximum peak power on the curve.

The gap with respect to the maximum peak power is also shown on the screen and stored in a dedicated text file for successive post-processing operations, together with the other collected data.

4. STATUS OF DEVELOPMENT

The control board development has reached an advanced status of development, freezing the hardware and software of the control board.

The MUI, available in the release 4.3.1, guarantees now the requested stability for a correct working point visualization.

In the next project phase, comprehensive test sessions will be carried out to evaluate the SAS performance in different mission scenarios, and by comparing the results with those obtained through certified instruments.

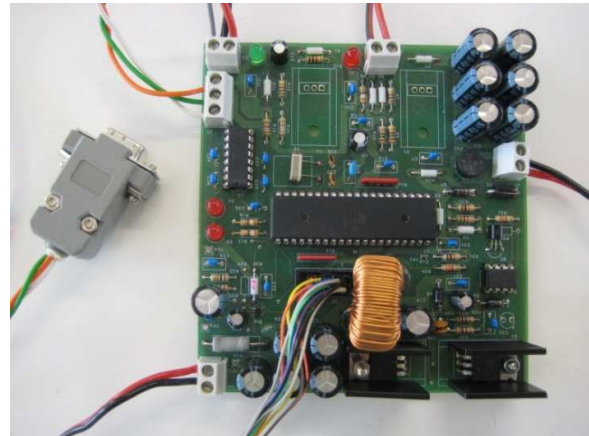


Figure 8 - Control board prototype

5. CONCLUSIONS

The power system test campaign plays a key role in every satellite mission to verify the correct sizing of the system.

The incorrect system design can compromise the spacecraft in orbit operations and this aspect usually justifies the high costs of commercial solar array simulators if compared with a satellite mission costs.

In recent years many university-class spacecraft have been designed, assembled, launched and operated in orbit, but to increase the number of educational missions a cost reduction is necessary.

The solar array simulator presented in this paper is aimed at optimal microsatellites power system testing, thanks to its low-cost nature allowing, in addition, the set-up of clusters of several simulators reproducing the power generated by many solar panels.

6. REFERENCES

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