# On-site Measurement Of Limiting Subcell In Multijunction Solar Devices

E.Muñoz-Cerón , J.C.Miñano , P.Benítez , G.Almonacid and M.Buljan

**Abstract.** It is well known that the response of any photovoltaic solar cell is dependent on the spectral characteristics of the incident radiation. This dependency is crucial in the output characteristics of a multijunction (MJ) cell where the spectral composition of the radiation determines the overall photocurrent produced, as either the top or the middle subcell will be limiting its response. The current mismatching between top and middle subcell is translated into energy losses, affecting the yield of the system. For research and commercial purposes it is interesting to measure accurately the incident solar radiation on a MJ cell, in terms of its spectral composition. This measurement will allows us to determine the photocurrent generated in each band of the multijunction device. Nowadays, the only way of measuring the photocurrent generated by each subcell is done with isotype cells or with spectroradiometers but there is no device capable of directly measuring each subcell photocurrent. In this paper it is described a device based on a commercial multijunction solar cell that is capable of measuring the direct irradiance for the top and middle bands thus it offers information of the limiting subcell (top or middle) in outdoors conditions.

**Keywords:** Characterization, Spectral measurement, Multijunction, Limiting subcell

## INTRODUCTION

The output characteristics of a multijunction cell are strongly dependent on the spectral variations of the incident radiation. Commercial cells are usually designed for Air Mass 1.5D, under the ASME standard G173-03, and a cell temperature of 25ºC. At this point, there is a current matching between the top and middle subcell of the MJ cell, meanwhile the bottom one (Ge based) is working in an excess current generation, normally in the range of 30% regarding the top and the middle subcells. As the specifications previously mentioned are constantly varying, either the top or the middle subcell will be limiting the output of the MJ cell at any moment. The ratio of the top over middle subcell photocurrents, $I_T/I_M$ (some authors called it Spectral Matching Ratio [1]), is used as an indicator of which is the limiting subcell.

Nowadays, the photocurrent generated by each subcell in outdoors measurements is calculated with the MJ manufacturer data and with sun spectrum measurements, which are usually done either with isotype based pyrheliometers or with spectroradiometers [2]

There is no device capable of directly measuring each subcell photocurrent in outdoors conditions and thus measuring the current mismatch between the top and middle bands of a MJ cell.

This paper describes a device (Limiting Current Ammeter, LCA) able to measure the limiting subcell in a MJ cell, but in this first prototype it only detects the top and middle band relation, as in the present commercial MJ devices, the bottom subcell will not limit the current generated in the overall output of the MJ cell.

## OPERATIONAL PRINCIPLE

As a first step in the completion of the idea, it has been applied to a MJ cell under 1 sun conditions. This MJ cell plus the LCA, all gathered into a collimator tube, makes this device to become a pyrheliometer, giving the direct irradiance for the top and middle bands (see figure 1).

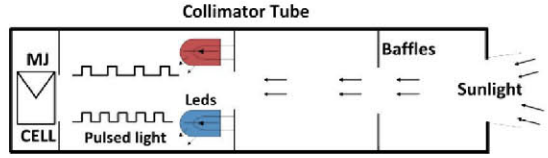


**FIGURE 1.** Outline of the pyrheliometer device.

The proposed device is similar to the ones used to measure the spectral response and the external quantum efficiency of MJ cells [3-5]. Besides the direct sun insolation, the MJ cell is illuminated with a modulated light coming from two set of LEDs whose emitting spectrums are only absorbed by a single subcell (top or middle).

It is important to highlight the range where it is produced the overlapping of the spectral response curves for each subcell, as we will try to avoid these regions when choosing the spectral emission of the

LEDs. In our case, it doesn't matter if the emission of the LED that excites the middle subcell reaches the bottom one as it will only cause an additional overexcitement in this subcell, but it won't interfere in the calculations of the photocurrent for the limiting and non-limiting top-middle subcells.

The MJ cell is biased so the limiting subcell is working in the short-circuit region and additionally, the modulation frequency is different for each LED. The LEDs lights add an AC component in both top and middle subcell photocurrents (see figure 2), but only the AC current of the limiting subcell will show up in the overall current of the MJ cell.

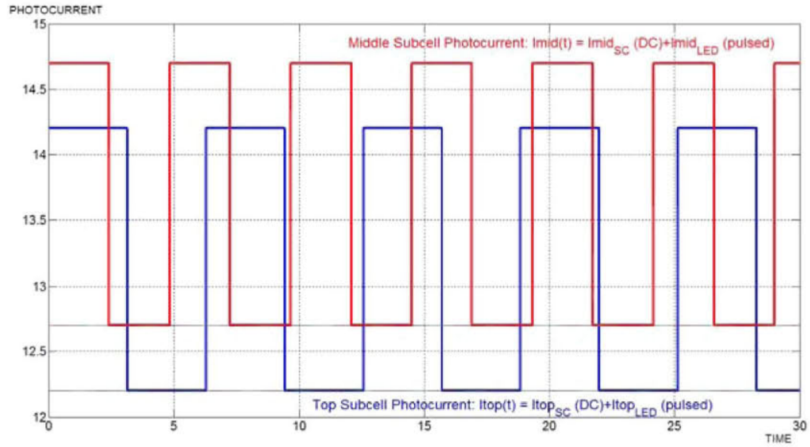


**FIGURE 2.** Photocurrent output characteristics.

A simple lock-in technique is used to detect this AC current and to suppress noise. Once it has been detected, the amplitude of the LED light pulses absorbed by the limiting subcell is increased until the AC output of the overall current is saturated. The amplitude at which saturation is reached gives the value of the difference between the limiting and the non-limiting photocurrents.

## PRELIMINARY RESULTS

Several preliminary experiments were carried out in order to identify possible sources of malfunctions of either the MJ cell or the LCA (see figure 3).

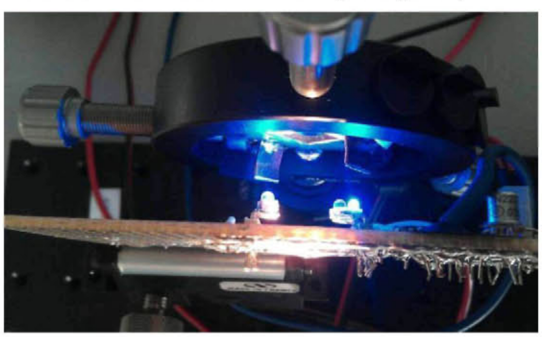

**FIGURE 3.** Initial experiments with the MJ cell and the LCA.

During these experiments, it has been detected a dynamic behavior of the MJ cell. These dynamic output characteristics are related with the inherent capacitance of photovoltaic solar cells, but the MJ cells are more sensible to capacitive effects than the silicon ones [6, 7]. The voltage at which the MJ cell is biased and the frequencies of the modulated light coming from the LEDs are also very related with this dynamic behavior.

The harmonic composition of the modulated light was another issue studied. If the modulation of the emitting light is done with pure sinusoidal waveforms there should not appear any effect, but in the case of using square waveforms, according to Fourier's law, the harmonic components derived from the fundamental frequency may affect the measure of the current as the harmonic components of both LEDs signals could be coupled and the MJ output signal may be deformed or with incongruent information.

Regarding the mechanical design of the collimator tube, two concepts have a mayor influence in the length of the tube and the aperture diameter of the collimator. These are the opening angle and the slope angle.

The choice of these angles determines not only the tracking accuracy of our system, but the quantity of circumsolar radiation and skylight scattering that enter the collimator too. The skylight effect and the circumsolar one have influence on the cell performance because they produce spectral variations in the light received on the surface of the cell [8].

The design of baffles inside the collimator tube is also important because they have the function of shielding the light coming from sources outside the field of view of the receiving area (MJ active area) and rejecting internal reflections that may distort the measure [9].

Additionally, humidity and moisture issues were carefully studied in order to avoid electrical problems or wrong measurements.

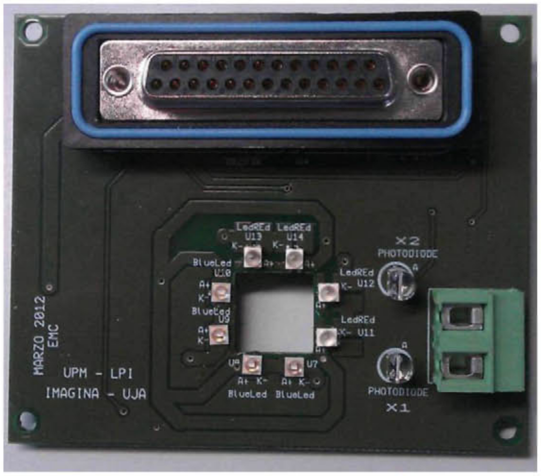


**FIGURE 4.** Prototype of the PCB

Once it has been done some experimental measurement with basic circuits designs it has been proposed a first prototype of PCB, where all the power, control and conditioning of the measured signals was done (see figure 4)

In figure 5 it can be observed the response of a MJ cell where the light applied was filtered to suppress or diminish the amount of radiation in a specific range of the spectrum, thus either the top or the middle subcell photocurrent was limiting the overall output of our device.

The lowest photocurrent measured belongs to the limiting subcell and the next step or value in the waveform shows us the difference in photocurrent generated between the limiting and non-limiting subcell (bottom subcell is not considered in this study). In this figure, the output current is not saturated because both LEDs sets were on, so the highest current level shown in the figure corresponds and depends on the light emission power of the LEDs used.

In figure 5 it is clearly identify that one subcell is limiting the overall output of the MJ but at first glance it gives no information about which is the limiting cell, so in order to identify this issue it has been designed, through software tools, a mathematical protocol of communication between the LEDs response, through their light power emission analysis, and the measurements of the MJ cell output.

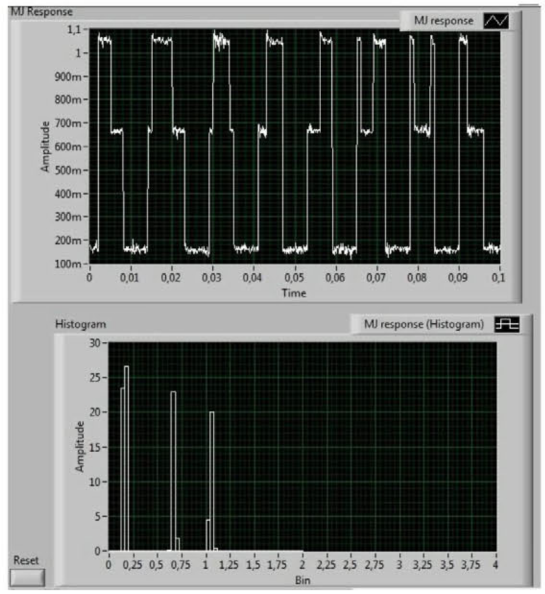


**FIGURE 5.** Screenshot showing the limiting and non-limiting photocurrents.

## CONCLUSIONS

This LCA has the same spectral response as the CPV modules used in photovoltaic plants, so apart from indicating which is the limiting subcell of our device, it could be used to characterize the photocurrent produced by a commercial module.

Another advantage of this device is that although this first prototype was designed for a specific commercial MJ solar cell, it can be rearranged to use solar cells from several manufacturers so this device becomes very versatile and easy to adapt and update to the market requirements. In this field, the next generation of the LCA shown in this paper is focused on measuring the bottom subcell as well as the incorporation of 4-band MJ cells that have been recently come on to the concentrating photovoltaic market.

Another issue to study deeply is that this prototype has been applied to a MJ cell under 1 sun condition. Further designs could be used under a higher concentration factor, but it must be taken under consideration the replacement of the LEDs used as they cannot develop enough light power to visibly excite each subcell of our MJ device. A solution could be done by means of lasers that are more powerful and delimit in a better way the spectral range of their light emission, but this lasers should be used carefully because they may cause nonlinearity problems in the subcells [10, 11].

## ACKNOWLEDGMENTS

This work was partially supported by the Spanish Science and Innovation Ministry and the ERDF within the frame of the project 'Estimación de la energía generada por módulos fotovoltaicos de capa delgada: influencia del espectro' under expedient code ENE2008-05098/ALT.

Additionally, this research has been partially carried out thanks to the College Teacher Training Program (Formación de Profesorado Universitario) of the Spanish Ministry of Education.

Special thanks to Jonathan Leloux, Steve Askins and Rubén Núñez from the IES-UPM. Their help and advice were very valuable in the development of this work.

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