# SPECTRAL SENSITIVITY ANALYSES OF TANDEM MODULES USING STANDARD FLASHER AND DYNAMIC LED BACKLIGHT

D. Schär, F. P. Baumgartner
ZHAW Zurich University of Applied Sciences, SoE, Institute of Energy Systems and Fluid Engineering
Technikumstr. 9; CH-8401Winterthur; Switzerland, www.zhaw.ch/~bauf
e-mail: daniel.schaer@zhaw.ch

ABSTRACT: As the solar spectra are changing during the day, seasons and weather conditions, the accurate annual energy rating has to be based not only on the nominal power at Standard Test Conditions STC but also on the sensitivity of power versus spectrum. The aim of the work is to measure the spectral sensitivity of tandem modules within the current/voltage scan. A standard industrial flasher was used to measure amorphous / microcrystalline (a-Si/uc-Si) tandem modules. This system was equipped with a special developed dynamic LED backlight at ZHAW. Test samples were analyzed using different shapes of dynamic backlight superposing the standard flasher STC spectra. The change of the LED backlight in the millisecond regime according to triangular, rectangular and sinusoidal shapes were applied. The analyzes were manly performed on a-Si/uc-Si tandem modules (1.1m x 1.3m). A triangle backlight characteristic was applied, increasing the IR LED light from 0% to 7% of $I_{SC}$ of the crystalline Silicon reference cell. Immediately after that period of 1.25ms, the IR LEDs are turned off and the blue LED decay from again 7% of $I_{SC}$ to 0% remaining on top of the STC spectra. This analysis shows significantly different spectral sensitivity at this specific time of changing from IR to blue. On the one hand the current of the module at maximum power point (MPP) changes proportionally with the IR intensity increase. On the other hand the tandem module's short circuit current shows no significant changes at the same IR intensity variation. The same method of analyzes are applied to a-Si/uc-Si tandem modules operating during 4 months and 34 months respectively, under real outdoor conditions. It is evident that this outdoor degraded modules show only marginal changes of the module current at MPP for the same increase of this dynamic IR LED backlight. Thus, a method together with the setup is presented and confirmed to measure the state of degradation of this kind of tandem module during the flasher period of a few milliseconds. The use of the presented dynamic LED backlight has the potential, in the industrial module production process, to improve the output of a standard STC flash during several milliseconds by providing information about the current matching of top and bottom tandem cells on a module scale.
Keywords: tandem, a-Si/u-Si, micromorph, module, module manufacturing, module tests, spectrum, light soaking, characterization, flasher

## 1 INTRODUCTION

The knowledge of the spectral behavior of tandem modules is important to predict the annual energy output of the module. It could be measured on single junction modules with optical band pass filters and an industrial standard flasher [2]. Since the tandem module has two interdependent layers (Figure 1), the above mentioned equipment is not enough to measure the spectral characteristic of this kind of modules. While saturating the one layer with a backlight, the spectral characteristic of the other layer can be measured [1]. Furthermore, it is possible to determine the saturation type (bottom or top limited) without using the band pass filters. With dynamic control of the backlight during the flash, the spectra can be specifically modified on the two spectrums at 470nm and 850nm. This method has the potential to be integrated in the manufacturer's final nominal power test, without increasing the length of the flasher test period in the line. The saturation type can be determined in the same flash during the I-V scan. The power measurement, short circuit current and open circuit voltage information is still available. Such a measurement method, which is capable of determining the grade of the top or bottom limitation within milliseconds has not been available on the market up until now.
Additionally, with the dynamic change of the backlight a measurement possibility for degradation of the modules was found.

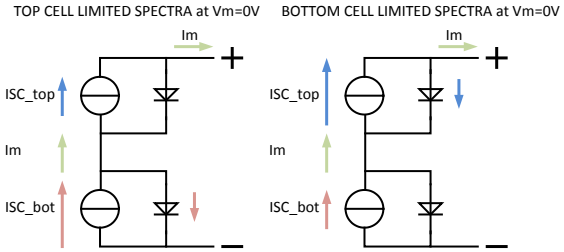


**Figure 1:** electrical equivalent circuit diagrams in the shorting point of the tandem module with top and bottom cell. In the left section the bottom cell receives more IR light but in the right section the top cell receives more blue light. In both cases the total current is also smaller. In this case we can speak of the limitation by the top cell. With ideal STC spectrum a sub cell can limit the total current, to be measured.

## 2 DYNAMIC LED BACKLIGHT MEASUREMENT SETUP

The Swiss Mobile Flasher Bus (SMFB) was constructed in 2009, by integrating a commercial Pasan Flasher into a Mercedes Sprinter bus. The mobile test laboratory SMFB can be performed to measure flasher based nominal power and spectral response of single junction or tandem technology and low irradiance measurements all on module level.[2]

The uncertainty value of the nominal power measurement is about 1% larger than values of the best stationary test labs. However it still enables very accurate

measurements at ambient temperature conditions with the advantage of making more measurements directly on customer's site.[3]

2.1 Spectrum response measurement setup for single junction and tandem modules

The SMFB has been equipped with 15 band pass filters in the range of 400 nm to 1100 nm to measure the spectral response characteristics.[3]

The above listed commercial setup was equipped with a new developed LED back light system with infrared (wavelength 850nm) and blue LED (wavelength 470nm).(Figure 2 and [1]) The developed LED power electronic driver controls the light characteristics within the sub millisecond range independently of each color. Each of the two types of LED is able to generate 7% increase in current in a crystalline cell.

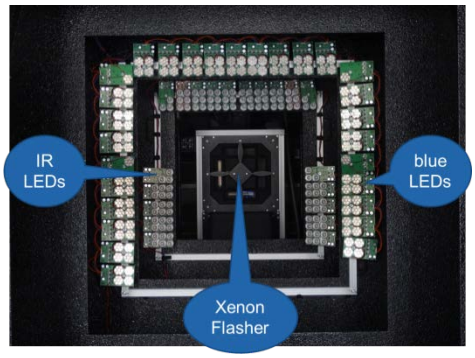


**Figure 2:** The referred measurement device of the Swiss Mobile Flasher Bus with the view toward the Pasan Xenon flasher in the center and the LED backlight on the shading walls. (Description of the setup shown in [1])

2.2 Setup and design of new dynamic LED backlight

The dynamic LED backlight is based on the hardware described above. The technical extension is a microcontroller board, which allows flasher triggered, time precision dynamic LED backlight with different shapes such as sinusoid, rectangular or triangle. The results presented in this paper are based on the triangle shape. Per measurement, just one flash is used compared to the 30 flashes used for the measurement by the band pass filters. In the first part of the 10ms flash, no backlight is turned on, and then in 1.25ms IR backlight is turned on in a triangle shape. At its highest intensity it is turned off and the blue backlight is turned on with highest intensity to go down to zero.(Figure 5) Measurement data could be acquired either with the industrial flasher equipment as electronic load and software or with load resistors and external DAQ data acquisition unit.

## 3 DYNAMIC LED BACKLIGHT MEASUREMENT RESULTS OF TANDEM MODULES

The results are based on 23 tandem modules of the same type with different times of outdoor usage. There are 20 modules measured with an outdoor usage of 34 months, (Figure 7) 2 modules with an outdoor usage of 4 months (Figure 6) and one module with no outdoor usage. The 20 modules are compared in the Figure 8 and Figure 9 – the results are similar. Also the two modules with 4 month of outdoor usage shows the same behaviors. However the results are different from the 34 month modules. Questions to be asked are, whether the module is top limited or bottom limited an how much the results depend on the outdoor usage time as well on the selected electrical measurement point of the module. The biggest difference between ISC and MPP operation is in the module without outdoor usage – in the MPP operation the increase of the current is similar between blue and IR backlights – the module seems neither top nor bottom limited. In the ISC operation the module could be identified as top limited. In the modules, which were exposed to the sun for a longer duration, the difference between the percentage increase of the current through the blue backlight becomes larger (Figure 3 and Figure 4).

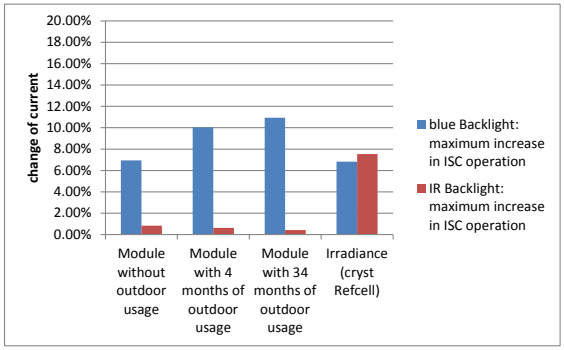


**Figure 3:** ISC operation: increasing percentage of the total current of differently aged tandem modules with increasing of around 7% of blue or IR photons compared to the STC situation, all modules can be referred as top limited

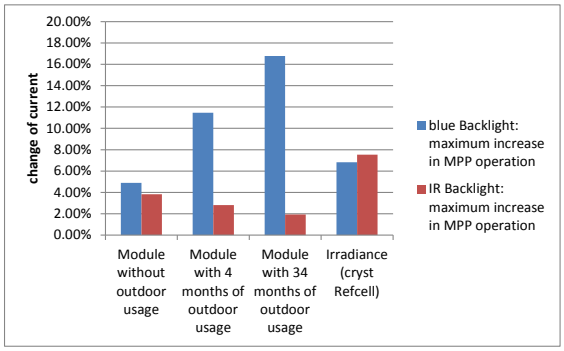


**Figure 4:** MPP operation: With the shown percentage increase of the total current for differently aged tandem modules with increase of around 7% of blue or IR photons compared to the STC situation, the modules can not clearly be designated as top limited in this electrical operating point.

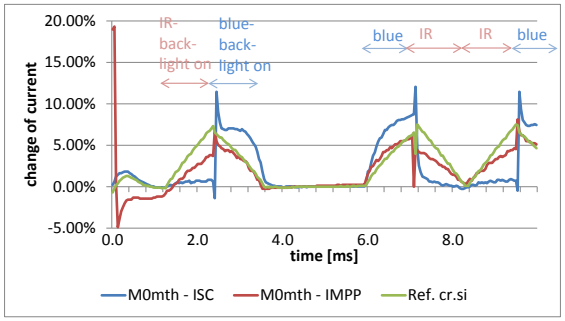


**Figure 5:** module without outdoor usage: Measured additional current to the tandem module STC current using a constant load. In the ISC case, only the increase of blue LED light result in an increase of the total tandem module current, approving the TOP cell (a-Si) limiting condition of this device under test. In the MPP case, the IR and the blue backlight result in an increase of the total tandem module current.

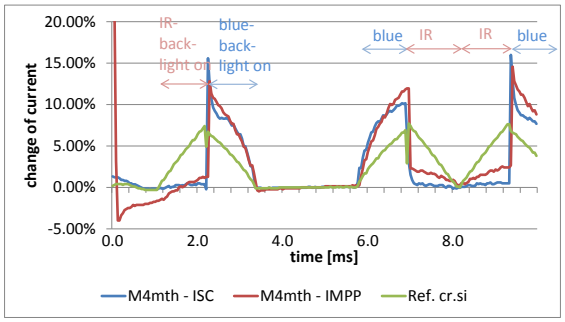


**Figure 6:** module with 4 month of outdoor usage: Measured additional current to the tandem module STC current using a constant load. In the ISC and the MPP case, only the increase of blue LED light result in an significant increase of the total tandem module current, approving the TOP cell (a-Si) limiting condition of this device under test.

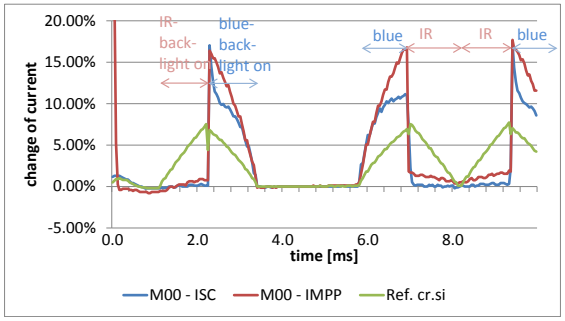


**Figure 7:** module with 34 month of outdoor usage: Measured additional current to the tandem module STC current using a constant load. In the ISC and the MPP case, only the increase of blue LED light result in an significant increase of the total tandem module current, approving the TOP cell (a-Si) limiting condition of this device under test.

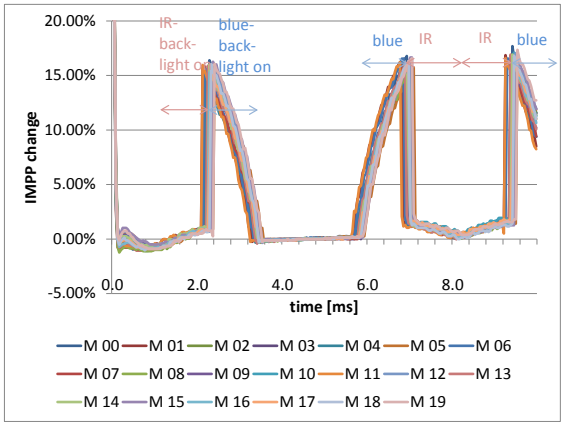


**Figure 8:** ISC operation: reproducibility of the measurement of 20 different modules of the same outdoor usage

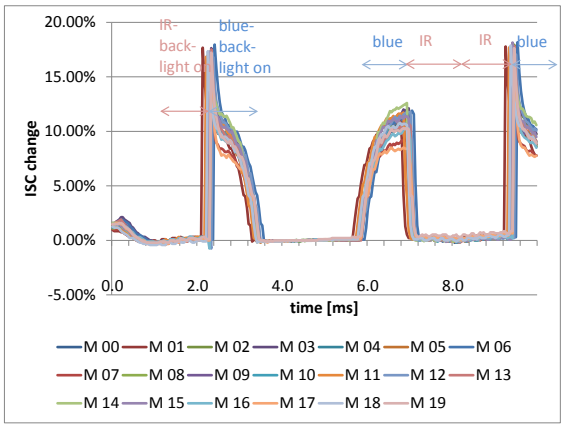


**Figure 9:** MPP operation: reproducibility of the measurement of 20 different modules of the same outdoor usage

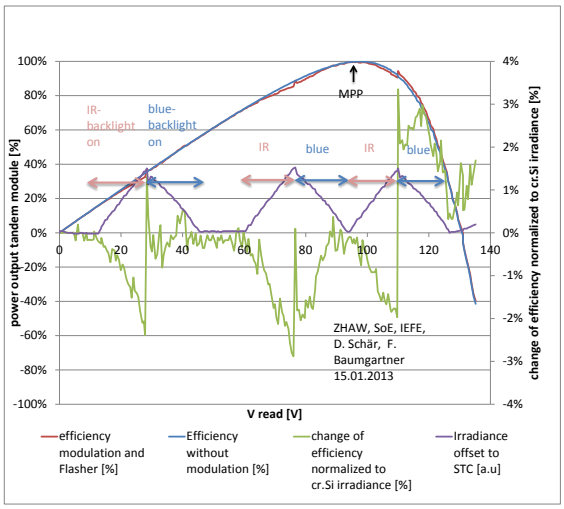


**Figure 10:** Efficiency changes during a standard 10ms flasher pulse IV scan of a a-Si/uc-Si tandem module with three points in time close to Isc close before maximum power and after MPP. The green curve shows the difference to another similar scan without to apply this dynamic backlight. Close to ISC the additional IR LED backlight did not increase the total current of the tandem module resulting in a decrease of efficiency. The total current of the tandem module was increased by blue LED

backlight, approving a TOP cell limiting condition at STC of this device under test. (DUT)

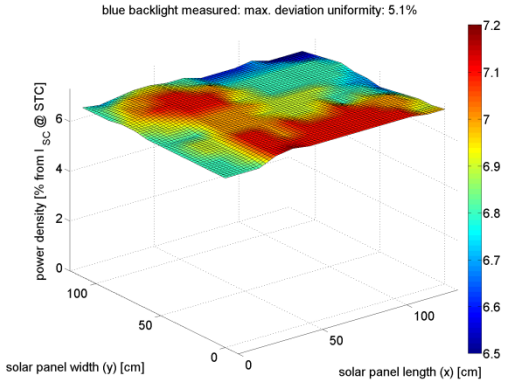


**Figure 11:** improved uniformity of the blue backlight, full potential not yet realized

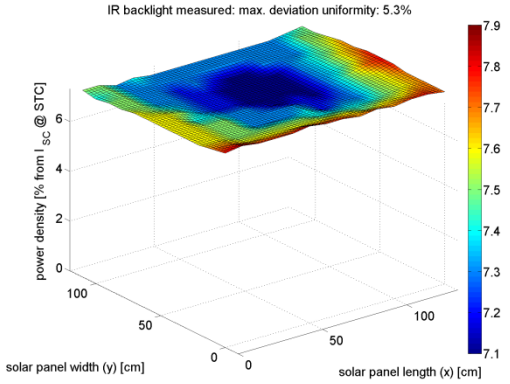


**Figure 12:** improved uniformity of the infrared backlight, without fully realized potential

## 4 CONCLUSION AND OUTLOOK

The industrial Pasan Flasher was equipped with a new designed LED-backlight system, triggered by the flasher light.

The uniformity of about 8.5% described in the publication of 2012 [1] could be improved in measurements to around 5% by orientating each of the LED units individually with a laser based system. (Figure 11 and Figure 12) When the system is installed in a stationary flasher, typically more space is available to install more LED modules for a higher light density and a better uniformity on the module.

By analyzing the final current in the tandem module under test using LED Backlight together with the applied constant STC light the matching of the top and bottom layer was successful demonstrated. This is done, within one flash while simultaneously measuring the maximum power, the short circuit current and the open circuit voltage all at STC.(Fig. 10) The implementation of the LED Backlight system in an existing flasher system was shown without any changes, such as the xenon flasher lamp or the data acquisition of the existing system of the industrial flasher system.

The duration of outdoor operation affects the module current sensitivity due to backlight changes. All modules with the same time of outdoor operation show similar results.

Different sensitivity of the tandem module current relative to the backlight changes were found depending on the applied $I_{SC}$ or MPP operating point. In was found as a measurement result, that for a tandem module analyzed before outdoor exposure, the limitation due to bad current matching is negligible at MPP but not at $I_{SC}$. At this operation point (MPP) the top and bottom current limiting was not observed.

Modules with a short or no time of outdoor operation show an increase of the current change due to additional blue and IR light at MPP. The backlight generates 7% additional current with the blue and also 7% with the IR backlight in the crystalline reference cell and generates 5% additional current through the blue backlight and 4% additional current through the IR backlight in the tandem module at the MPP.

## 5 ACKNOWLEDGMENTS

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