MEASURING THE SPECTRAL DISTRIBUTION OF A FLASH SIMULATOR

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ABSTRACT: At ISE CalLab a spectral mismatch correction is applied to calibration of photovoltaic devices. Therefore, the knowledge of the relative spectral distribution of the solar simulator is mandatory. The spectral distribution of the solar simulator is as important as hard to control properly, especially for flash simulators often used for large modules and production lines. Knowing this spectral distribution allows to calculate the spectral mismatch. The spectral distribution of the solar simulator is the quantity least known in this procedure. For radiometric measurement a guideline exists [1], which excludes the special case of flash lamp measurements. For flash solar simulators it is more difficult to determine the spectral distribution. To measure the spectral distribution of such a flash pulse, single monochromator diode array spectroradiometers (SMDAS) are commonly used. The knowledge of the timing behaviour of SMDAS diode arrays and readout electronics is important for a spectroradiometric measurement of flash pulses. In this paper we discuss these properties in detail.
Keywords: Calibration, Characterization

1 INTRODUCTION

For high volume PV production the accuracy of efficiency measurements has increasing economic impact. With this motivation, at the PV calibration laboratory of Fraunhofer ISE (ISE CalLab) the analysis and reduction of uncertainty components involved in the solar cell and module measurements at Standard Testing Conditions (STC) in test labs as well as in industrial production control is a central topic. A major contribution is the spectral mismatch [2] caused by the differences in the spectral responses of test and reference cell in conjunction with the specific simulator spectrum, which deviates more or less from the standard AM1.5g solar spectrum [3]. The solar simulator classification by the IEC standard [4] gives a guideline for simulator quality. For a traceable qualification of the spectral distribution of a solar simulator a fast (0.6 ms integration time) measurement system with wide wavelength range (280-1700 nm) is used at Fraunhofer ISE. For the measurement of the spectral distribution of a flash lamp over the total duration or precisely timed sections it is necessary to understand the timing of the spectroradiometer measurement. In addition to the usually done and essential investigations for spectroradiometric measurements like stray-light, nonlinearity and thermal effects [5] the timing behavior has to be taken into account for those measurements. A precise trigger and delay control is obligatory.

2 SPECTRORADIOMETRIC MEASUREMENT OF A FLASH PULSE

Solar flash simulators have different temporal behavior. More and more flash simulators with short and steep slopes and highly stable plateaus are available. Usually, the region used for measuring the photovoltaic devices are confined to the part of the pulse with small variation (e.g. ± 1-2 %) of the intensity. The pulse shape of a flash simulator is shown in Fig 1.

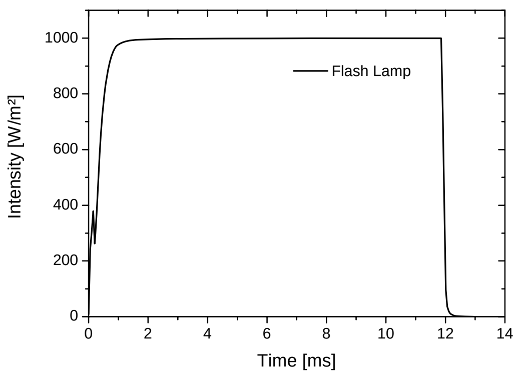


Figure 1: Intensity curve of a flash solar simulator with a pulse length of 12.3 ms and a plateau of about 10 ms (± 1 %).

To measure the spectral distribution of such flash pulses, single monochromator diode array spectroradiometers (SMDAS) are commonly used. SMDAS consist of an input optics, a single grating monochromator and a linear diode array or CCD detector. The SMDAS used here consists of three units with different spectral regions and one diode array sensor per unit. The electronics allows to trigger the SMDAS precisely (within some few µs).

The SMDAS is composed of two NMOS-Si diode arrays (280 - 700 nm, 695 - 1100 nm) with 512 pixel each and a 1 MHz readout electronics as well as one InGaAs diode array (960 - 1700 nm) with 512 pixel and a 0.5 MHz readout electronics.

Due to the sensor architecture the NMOS and the InGaAs-detector are driven completely differently by the electronics.

A second SMDAS considered for comparison consists of a NMOS diode array (280 - 1100 nm) with fix scan time for each pixel, but the option to read variable numbers of pixels. This allows to adjust the scan time for a measurement by reducing the wavelength range or skip several pixels.

2.1 NMOS sensor and electronics

The electronics starts to read out each pixel of the NMOS silicon detector (see Fig. 2) directly after the integration of the signal at each pixel. The multiplexing electronics enforces that the integration on the neighboring pixel stops time-shifted with the readout time of one pixel. In order to get identical integration times for each pixel the integration starts time-shifted as well. That means integration of radiation and readout of different pixels occurs in parallel. If no readout and no integration takes place (e.g. the detector waits for a trigger) the sensor electronics (hold and sample element) can accumulate dark signal (without any radiation). To avoid misleading measurement results the sensor needs to be erased with a readout (scan) and the data will be dumped. This is called a dummy-scan. The integration of signal starts directly after scanning the respective pixel. With the smallest integration time the integration of pixel one ends when the integration of pixel n starts. This leads to a minimum integration time of two times the scanning time for the whole sensor (2 x 0.6 ms = 1.2 ms).

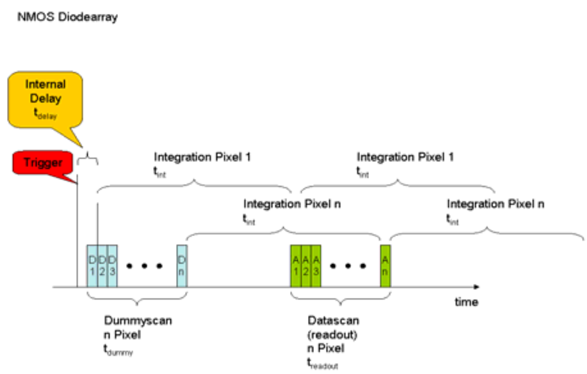


Figure 2: Timing of diode-array readout. The NMOS sensor starts integrating directly after scanning each pixel.

2.2 InGaAs sensor and electronics

At the InGaAs detector (see Fig. 3) the read out starts only after integrating signal from the last pixel of the whole array. Since a dummy-scan is also necessary, there is an internal delay (here 1 ms), while the system is doing the dummy-scan, then integrating signal for the data scan starts.

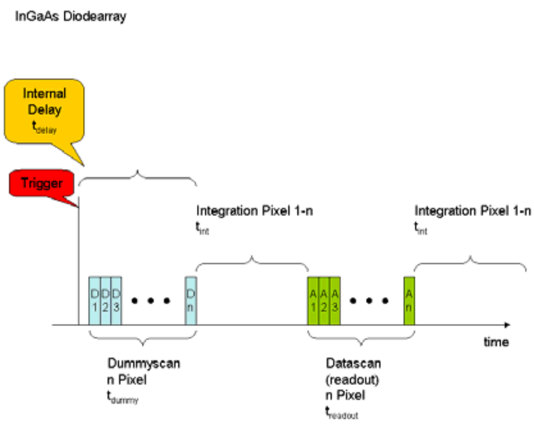


Figure 3: Timing of InGaAs diode-array readout. The InGaAs sensor starts integrating after scanning the whole sensor.

2.3 NMOS flash measurement

Due to the above described timing of the NMOS sensor we can distinguish between three different timing situations for the NMOS diode array measuring a the spectral distribution of a flash lamp (see Fig. 4):

i) one or both slopes of the flash pulse are within the readout time of the diode array
ii) the complete flash pulse (including the slopes) is within the integration time and not affected by the readout
iii) just the complete stable plateau is in the integration and readout time.

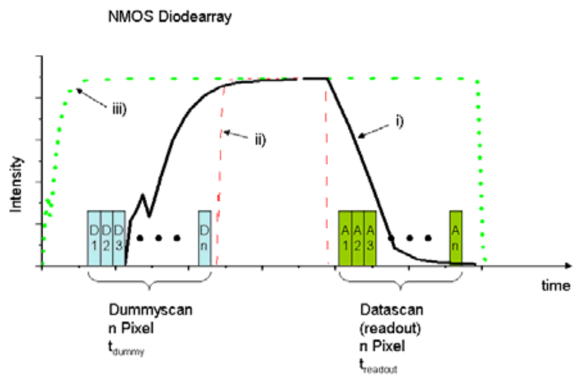
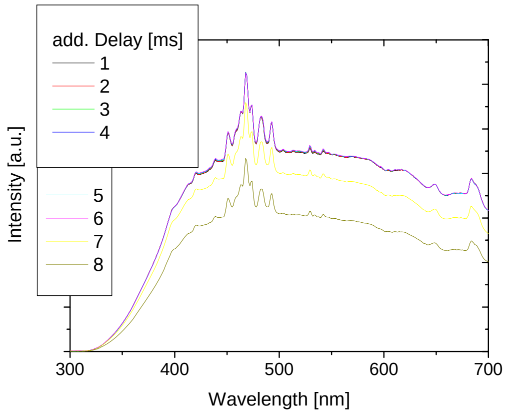
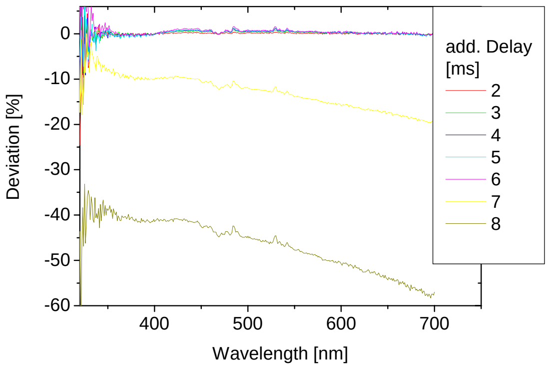


Figure 4: In principle there are 3 different situations for the timing of the measurement: i) the slopes of the flash pulse are within the readout time of the diode array, ii) the complete flash pulse (including the slopes) is within the integration time and not affected by the readout, iii) the complete stable plateau is in the integration and readout time.

The knowledge of the timing of the electronics allows triggering it in the appropriate way. If a slope of the flash pulse coincides with one of the scans (data or dummy) at the NMOS sensor (Fig. 4, situation i)) the relative shape of the measured spectral distribution is strongly affected. To demonstrate possible effects we measured the flash lamp (Fig 1) with different delay times. The falling slope of the flash pulse coincides with the readout sequence of the diode array (situation i) in Fig. 4). Fig. 5 shows the effect for a measurement with 5 ms integration time and 0.6 ms scan time which is fix for the system. With additional delay of more than 7 ms the falling slope is in time with the readout sequence. The relative spectral distribution is strongly affected (Fig. 5 b)). For lower values of the ratio (integration time/scan time) this effect will increase. The temporal dependence of irradiation of the flash lamp was shown in Fig. 1.



a)

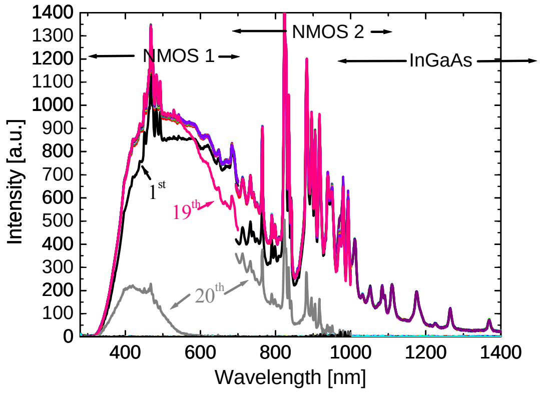


b)

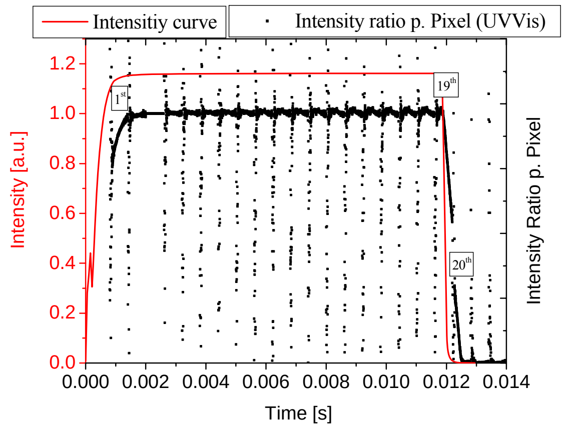
Figure 5: a) Measurement (NMOS) of the flash lamp (Fig 1) with 5 ms integration time and different delay. b) Deviation to the first measurement with delay 1 ms. Starting with 6 ms additional delay it is apparent, that the relative measurement is affected by more than 10 %.

In contrast to the NMOS sensor the complete InGaAs sensor is blind during the readout (Fig. 3). The intensity change during the falling slope does not affect the measured relative spectral distribution, because the integration of all pixels occurs simultaneously.

Measuring 22 successive scans (Fig. 6 a)) with 0.6 ms integration time of the flash lamp (see Fig 1) and calculating the ratio with a dataset from the plateau (third scan) allows to determine the intensity changes at each pixel (Fig 6 b)). At the falling slope the intensity changes are clearly visible and dominate the measurement. The first scan (1^{st}) is affected by the rising slope, the major part is from the stable plateau within a small reproducible band and the 19^{th} and 20^{th} scan are at the step falling slope.



a)



b)

Figure 6: a) Set of 22 successive scans with 0 ms delay of the flash lamp, b) Ratio of all data (280-700 nm) with the third data set (plateau).

Comparing with Fig. 6 b) we directly see the intensity change seen from a silicon solar cell (straight line) and from the NMOS diode array (square dot). Each pixel is delayed to each other with the readout time of one pixel.

Some electronics do not allow triggering the sensor array in order to start a scan. These systems often just allow triggering to receive the dataset of the last/next scan from a permanently scanning and integrating measurement cycle. This has the advantage that no dummy-scan is necessary, but the precision of the measurement time can not be better than ± 1 scan.

Some SMDASs have one detector array from 280 - 1100 nm which will be read out in one scan. With such a system the effects of intensity changes are not obviously like for the two array system with an overlap at 695 - 700 nm (compare Fig 6 a)).

Using the SMDAS with the adjustable scan time we can adapt the measurement in different ways to the present flash profile. To feature the effect of too long integration time in a spectral measurement of a flash lamp, we adjusted the SMDAS in two different ways:

i) $t_{int} \leq t_{pulse}/2$; this gives the real spectral distribution (within certain uncertainties)
ii) $t_{int} = t_{pulse}$; this shifts the readout subsequently to the flash pulse end. So the effective integration times are different for the different pixel.

Measuring with 10.7 ms minimum integration time for a 11 ms flash pulse plateau we see a clear difference in comparison to the measurement with 4.3 ms minimum integration time (Fig 7). The data sets are scaled to the maximum of the 824 nm peak. The effect caused by the intensity change of the falling slope is clearly visible. The red rich class C spectrum shifts to a blue rich class B (according to [4]) (apparent) spectral distribution. The first measurement gives the real spectral distribution within the usual uncertainties, but the second measurement deviates tremendously.

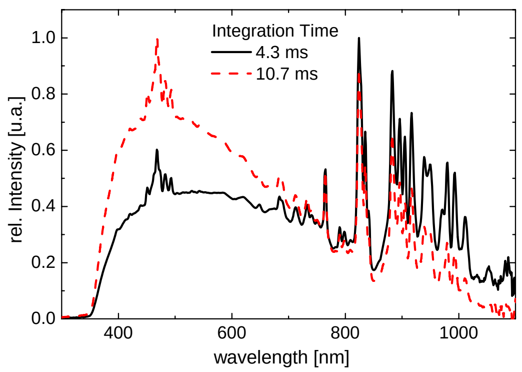


Figure 7: Relative values (scaled) of two different measurement situations for the measurement of the spectral distribution of the flash lamp (Fig. 1). The dashed line shows the effect if the falling slope of the flash pulse coincides with the data scan of the spectroradiometer.

With little adjustment of the trigger delay at the SMDAS we have no change in the measurement result in situation i) in contrast to situation ii) in which it affects the measurement strongly.

3 CONCLUSION

We have shown that for spectroradiometric measurements of flash pulses the timing of the measurement equipment is an essential property to be investigated. Precise triggering and control mechanisms are important to control the measurements. Comparing the values of two successive scans on the flash plateau or the overlap region of two (on the electronic side) identical systems is a comfortable way to ensure correct measurement timing. Otherwise the measurement results can deviate tremendously from the real situation.

4 ACKNOWLEDGEMENT

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