Radiometric Spatial Non-Uniformity of Solar Simulators

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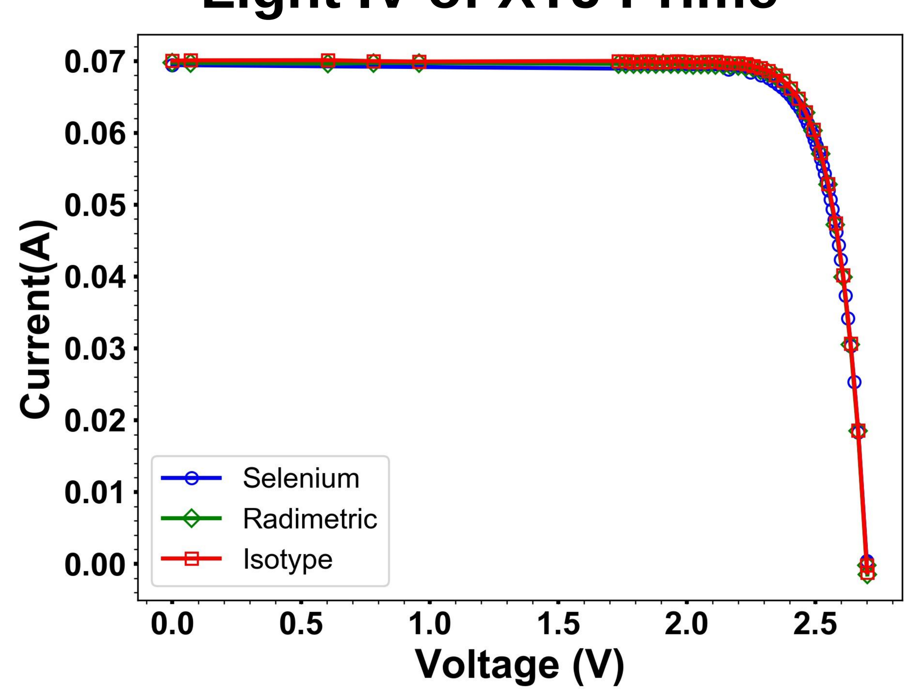
Introduction

- A solar simulator tuned for a given solar cell technology produced discrepant current (Jsc) when measuring a 4cm^2 and 30cm^2 cell size cells due to spectrum and intensity spatial non-uniformity. This presented an significant problem for accurately calibrating and measuring large area solar cells.
- To determine the spectrum and intensity non-uniformity, we performed spatial spectral and intensity characterization of the entire solar simulator beam.
- We applied the technique of radiometric calibration and developed a correction factor to compensate for intensity and spectrum non-uniformity, obtaining accurate large area solar cell Jsc at the air mass zero (AM0) requirement.
- We evaluated a large area solar cell light I-V measurement with and without solar simulator intensity mapping derived correction factor to determine effectiveness.

Light IV of XTJ Prime



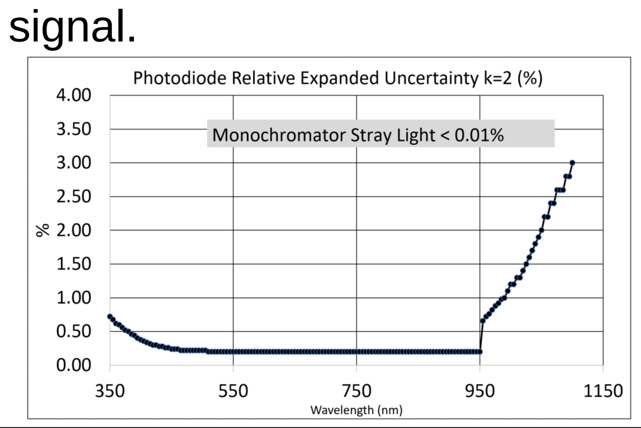
Selenium data corrected for temperature and sun-earth distance. LIV measured by radiometric and isotype solar simulator calibration were taken at 28°C

Technique

Solar Cell Spectral Response Measurement → Solar Simulator Spectrum Measurement → Tune Solar Simulator using Radiometric Calibration Technique → Uniformity Characterization → Develop Correction Factor

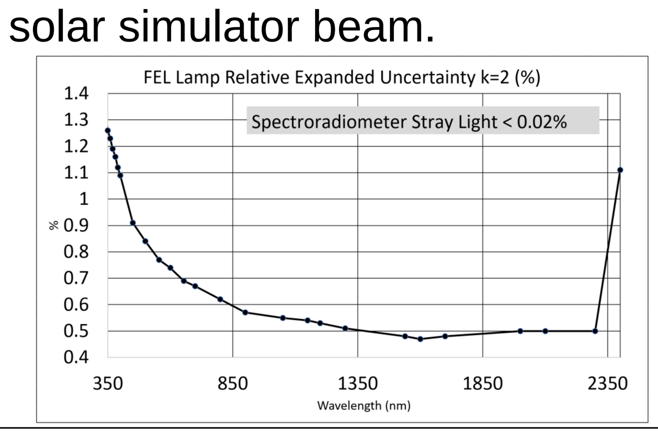
Solar Cell Spectral Response Measurement System

- Spectral response measurement is used to determine the solar cell technology's response to each wavelength of each sub-junction.
- Silicon and InGaAs NIST primary photodiode standards are used for system calibration.
- LED bias lights allow sub-junction light biasing for current limiting junction control.
- The monochromatic beam is mechanically chopped, allowing a lock-in amp to detect the beam signal.

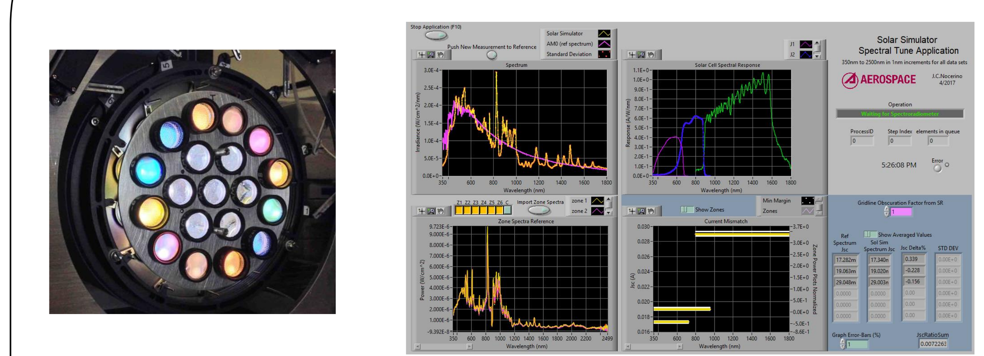


Solar Simulator Spectrum Measurement

- A calibrated spectrometer is used to measure the solar simulator spectrum and intensity.
- The spectroradiometer is calibrated on the day using a NIST FEL primary irradiance standard.
- A 5cm diameter integrating sphere is attached to the spectroradiometer for capturing the solar simulator light input.
- The integrating sphere is attached to a precision control stage for moving across the entire solar simulator beam.

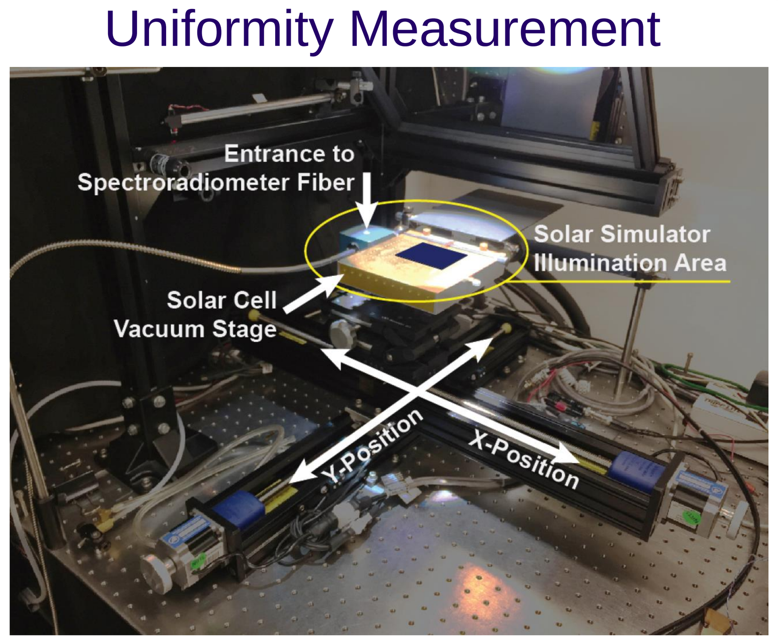


Tune Solar Simulator using Radiometric Calibration Technique



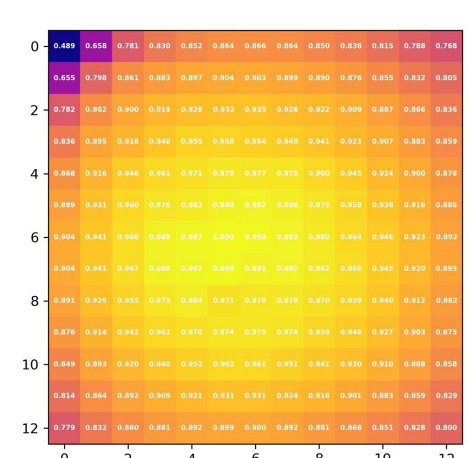
- A modified Spectrolab X25 with six adjustable zones containing color biasing optical filters allows for close matching to the AM0 solar spectrum.
- Aerospace real-time custom software analyzes the solar simulator spectrum, the spectral response for each solar cell junction, the reference AM0 solar spectrum, and the solar cell gridline obscuration factor.
- The optical filters for each zone and overall lamp intensity are adjusted until a close AM0 match is achieved.

Uniformity Measurement



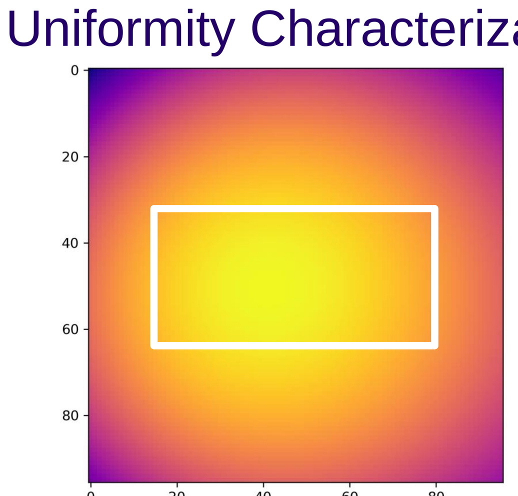
- The temperature controlled test stage area is comprised of a 15cm x 15cm vacuum chuck and a 5cm diameter integrating sphere.
- The test stage and integrating sphere are positioned with a motorized XYZ system.
- The solar simulator illuminates the area with a 25cm diameter beam.
- A 1cm step scan of the entire area, with positing accuracy of 100um, takes approximately 10 minutes, resulting in a spectrum and intensity mapping of the solar simulator beam from 300nm to 2500nm at each position.

Uniformity Characterization



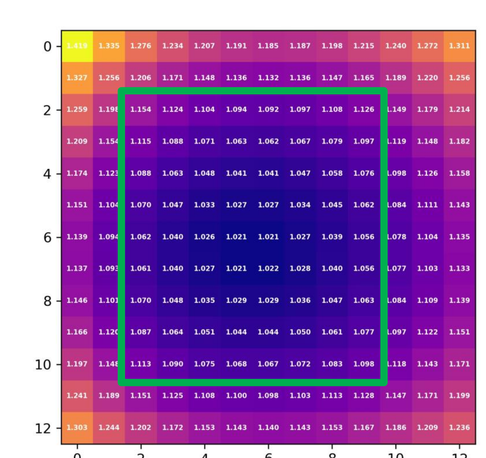
Measured Uniformity Map for J1 QE

- The spectrum of the lamp was measured over a 12cm by 12cm area.
- The J1 quantum efficiency of a ZTJ solar cell was used to calculate the integrated current for each 1x1 cm spot.
- The map was normalized to the area with the maximum current.



Modeled/Interpolated/ Fitted Uniformity Map

- Modeled spatial uniformity derived from fitting the 1cm spaced measurement uniformity map.
- The 1cm map was fit to a 2d polynomial and minimized using the average current over a 1cm area of the more spatially resolved 2d polynomial fit.
- By developing a model that has more finely spaced increments, it allows larger area of where the solar cell can be measured accurately on the solar simulator illumination plane.



Correction Factor

- Utilizing a solar cell of dimensions 4x8 cm, a correction factor needed to measure the performance of the solar cell was calculated.
- The correction factor for each coordinate is mapped, indicating the spatial non-uniformity in spectrum and intensity.
- To reduce significant drop off in solar simulator intensity, the area inside the box is the only valid positions for the 4x8 solar cell measurement

Conclusions

- Aerospace demonstrated, for the first time, an accurately mapped solar simulator spectrum and intensity.
- Determined correction factor to enable accurate large area solar cell ground AM0 measurements using radiometric calibration.
- This technique can potentially be applied to any solar simulator.

Next Steps

- Validate radiometric spatial non-uniformity correction using near-space and space measured solar cells.
- Quantify uncertainty of total system.
- Build correction factor analysis into workstation software.
- Use correction process on pLEDss solar simulator.

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