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CENTRO NACIONAL DE ENERGÍAS RENOVABLES
NATIONAL RENEWABLE ENERGY CENTRE

Webinars: PHOTOVOLTAIC TECHNOLOGY PROGRAMME

22-25 September 2020

MCAST Malta College of Arts, Science & Technology
MANCHESTER 1824 The University of Manchester
CENER ADItech
MINISTERIO DE CIENCIA E INNOVACIÓN
Ciemat
Gobierno de Navarra Nafarroako Gobernua
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ADItech

SESSION 2. STANDARDS FOR CERTIFICATION AND CHARACTERIZATION OF PV MODULES
- MAX. POWER DETERMINATION

GOBIERNO DE ESPAÑA | VICEPRESIDENCIA CUARTA DEL GOBIERNO | MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA Y EL RETO DEMOGRÁFICO | MINISTERIO DE CIENCIA E INNOVACIÓN

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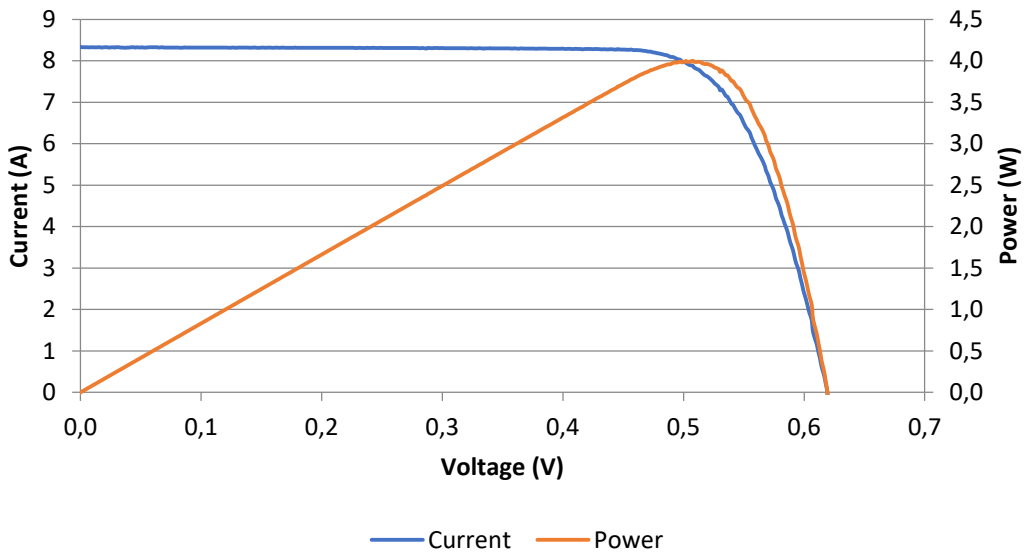
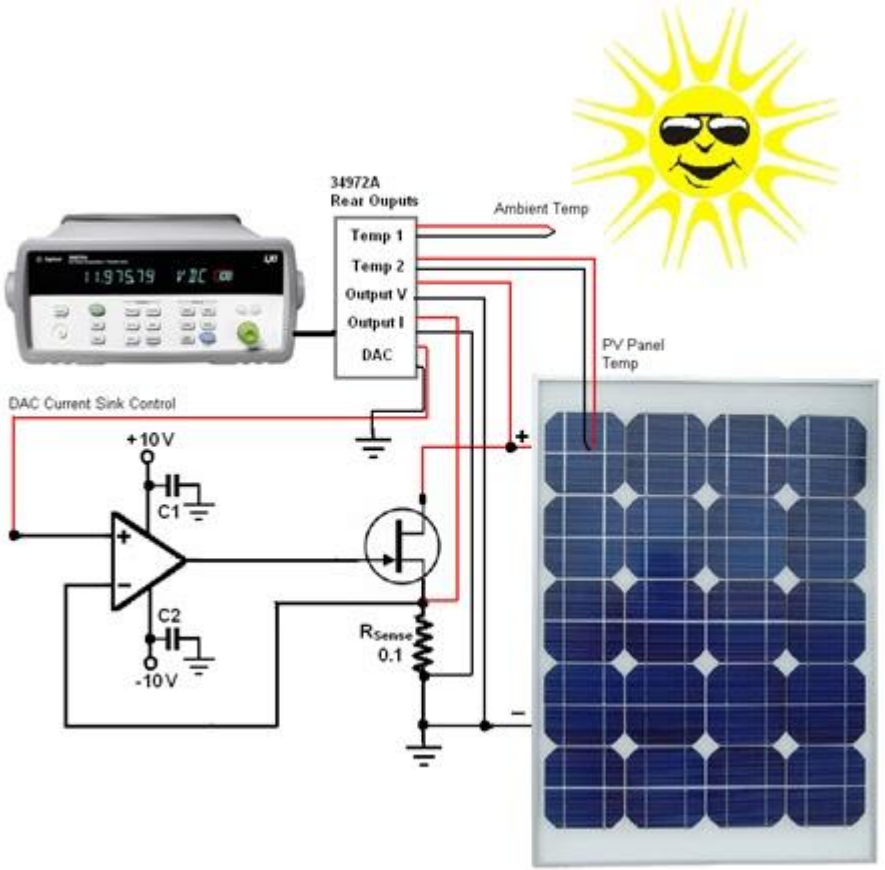
MAX. POWER DETERMINATION

- <u>Maximum power determination test – **IEC 60904-1** – Measurement of PV current-voltage characteristics</u>
  - At STC (Standard Test Conditions) – 25 ºC, 1000 W/m^2, AM1.5G
  - At NMOT – NMOT ºC, 800 W/m^2, AM1.5G
  - At low irradiance – 25 ºC, 200 W/m^2, AM1.5G
  - At different irradiance and temperature conditions – IEC 61853
  - For verification of degradation – Always the same conditions – Increase reproducibility



EQUIPMENT

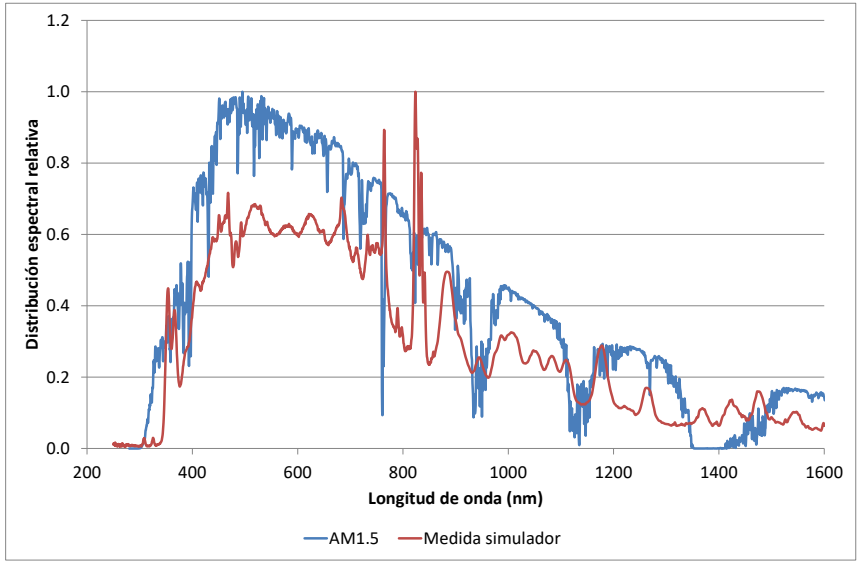
- Equipment
  - Radiant source (natural sunlight or solar simulator)
  - PV reference device
  - Device for measuring I-V curve (electronic load, I-V curve tracer…)
  - Temp. Sensor for DUT and reference device
  - Means for modifying the temperature of the DUT
  - Optical filters for irradiance reduction
  - Solar tracker (outdoor measurements)
  - Spectroradiometer



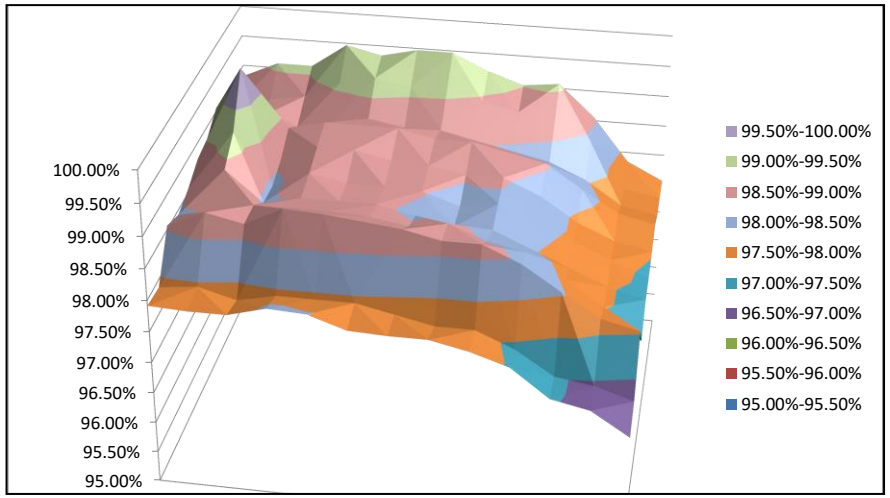
RADIANT SOURCE

- Radiant source: Sun simulator:
  - Steady state or flash
  - Characterization: IEC 60904-9
  - Simulator class (AAA, CBA, …)

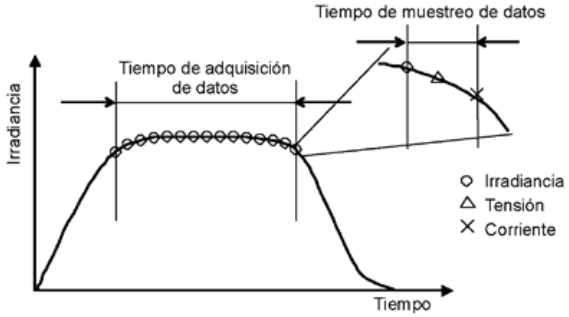
1. Spectral match (A, B, C)



2. Spatial uniformity (A, B, C)

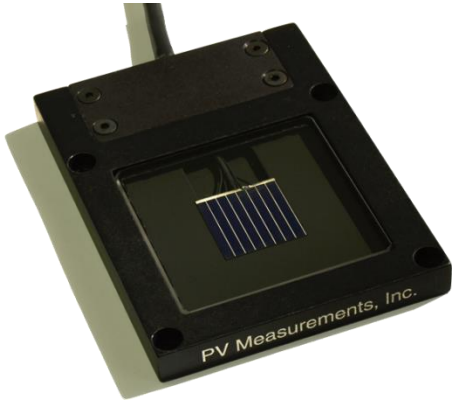


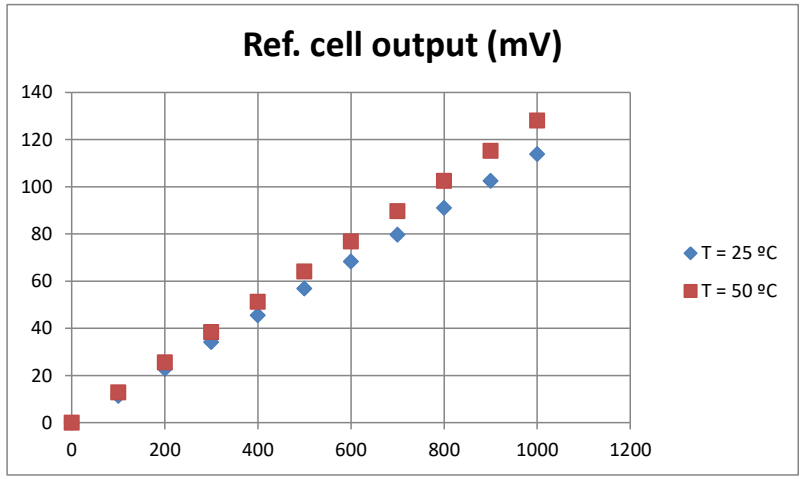
3. Temporal stability (A, B, C)

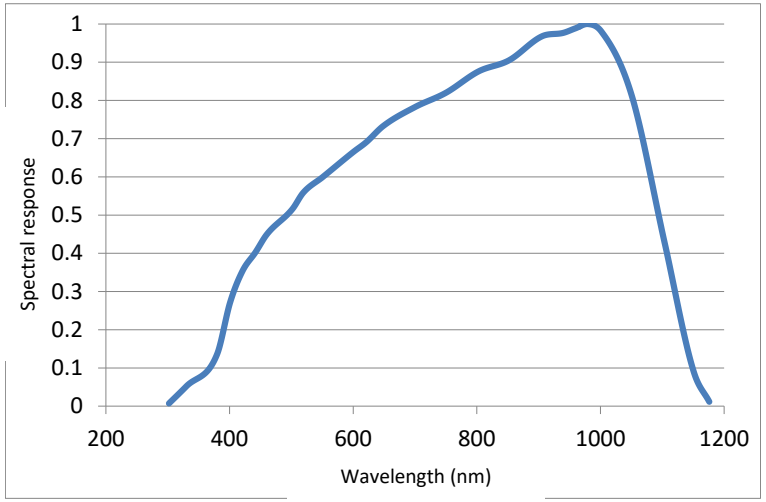


REFERENCE DEVICE

- PV Reference device
  - Requirements defined in IEC 60904-2
  - Sensitivity (output at 1000 W/m2)
  - Must be linear
  - Temperature coefficient
  - Spectral response
  - Spectrally matched to the DUT





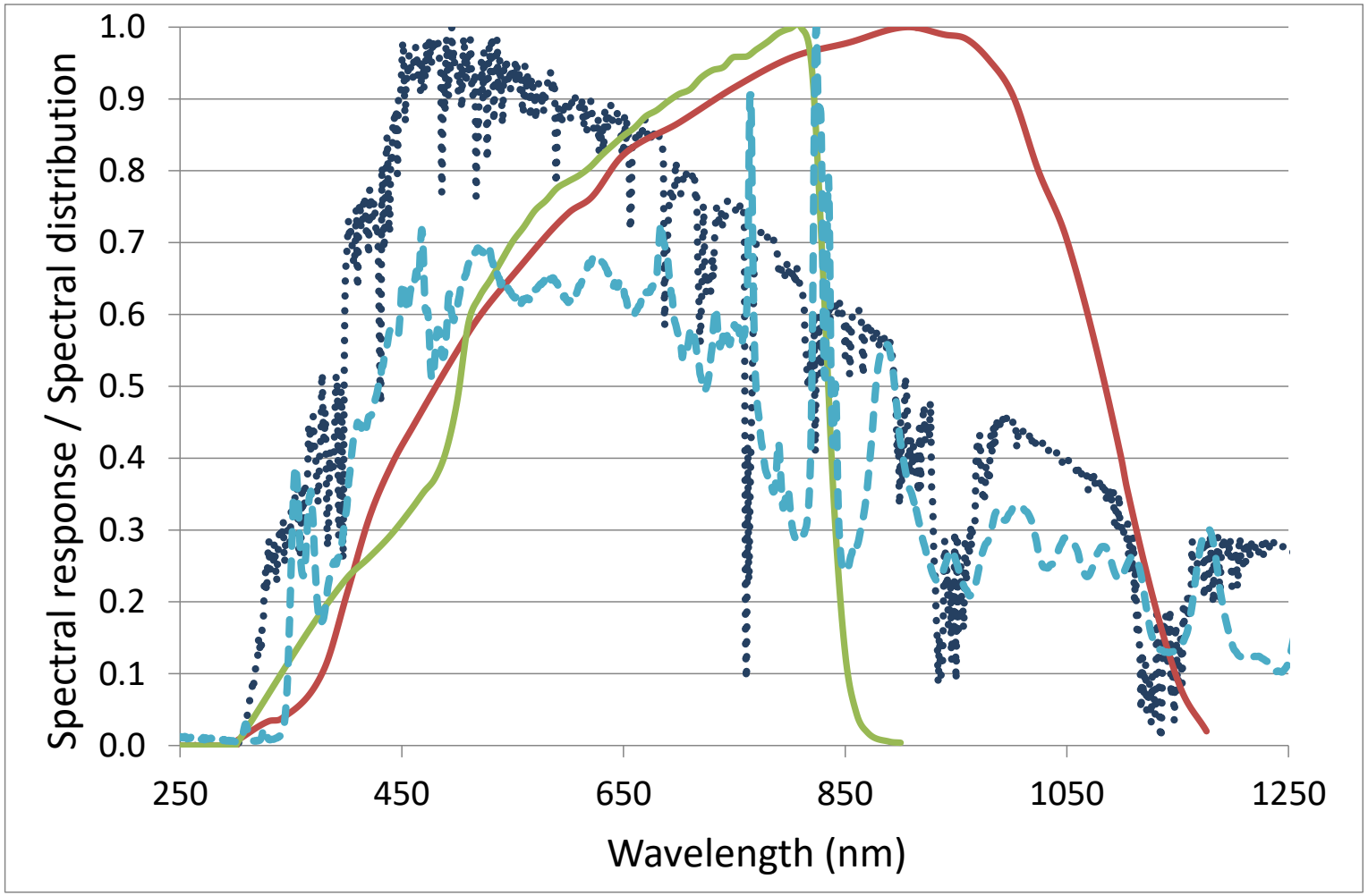


ELECTRONIC LOAD

- Apparatus for measuring an I-V curve
  - Voltage sweep
  - Voltage and current measurement
  - 4 wire measurement

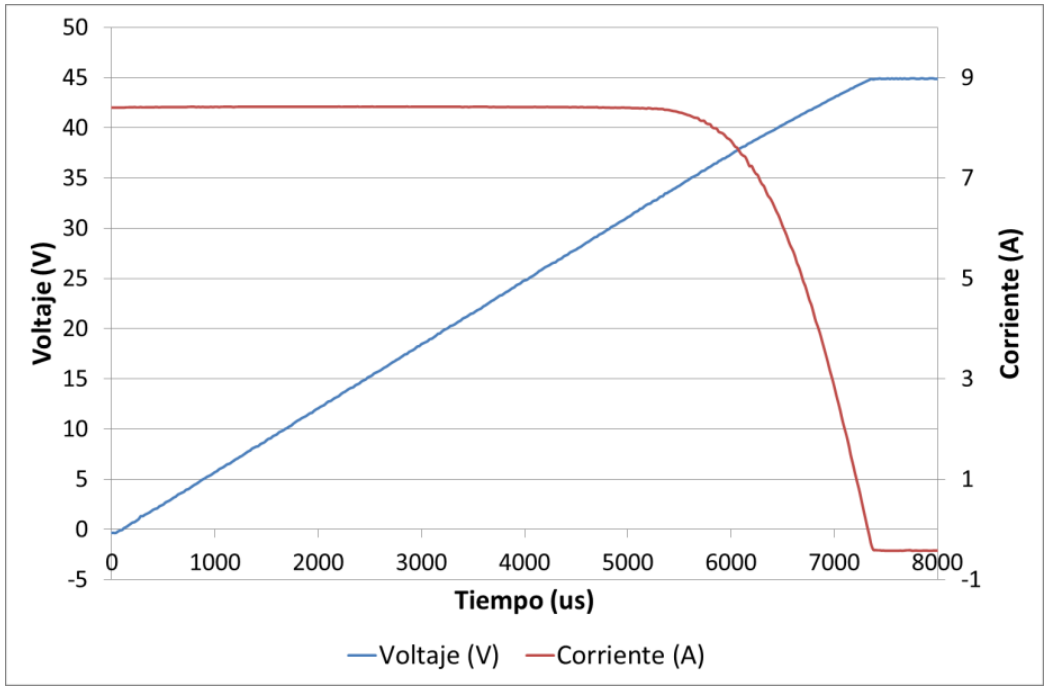
OTHER ASPECTS

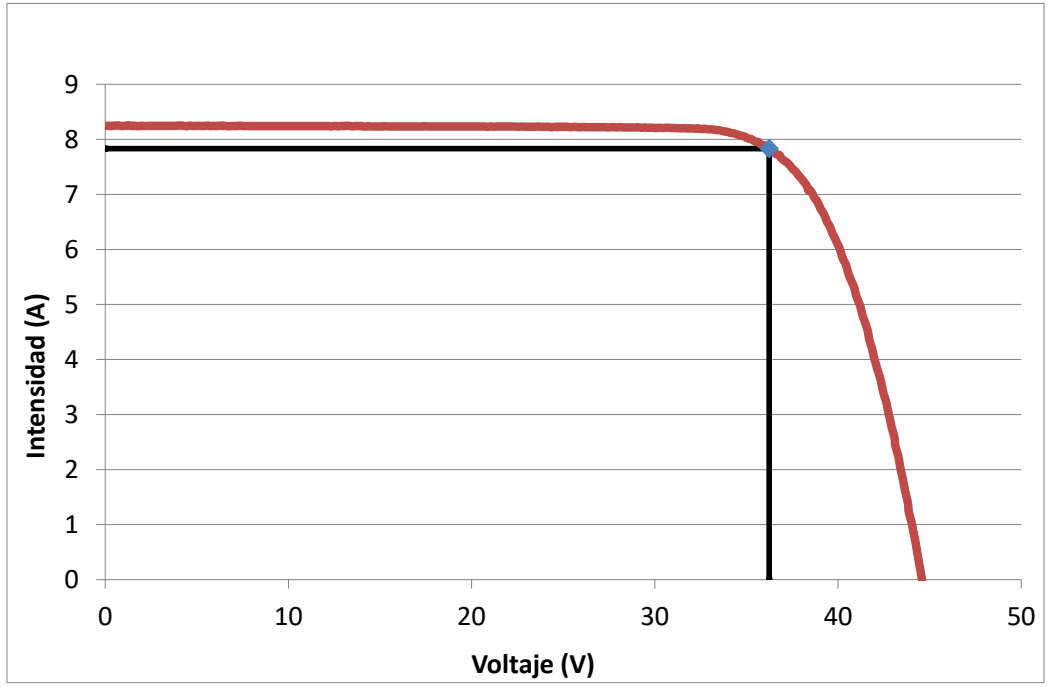
- Incidence angle:
  - Should be normal incidence
- Spectroradiometer:
  - Compute Spectral Mismatch



PROCEDURE

- Procedure: 1) Voltage sweep and V and I measurement



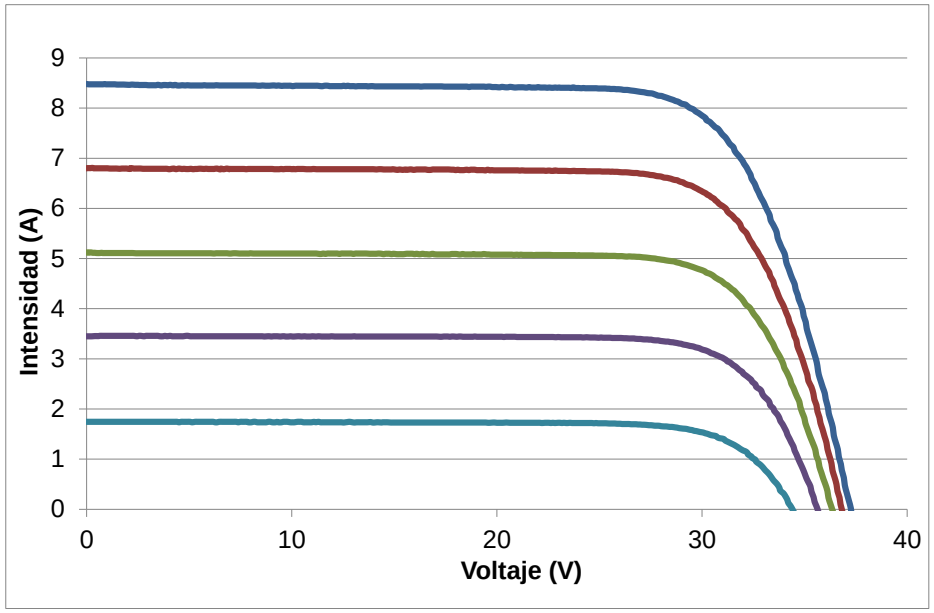


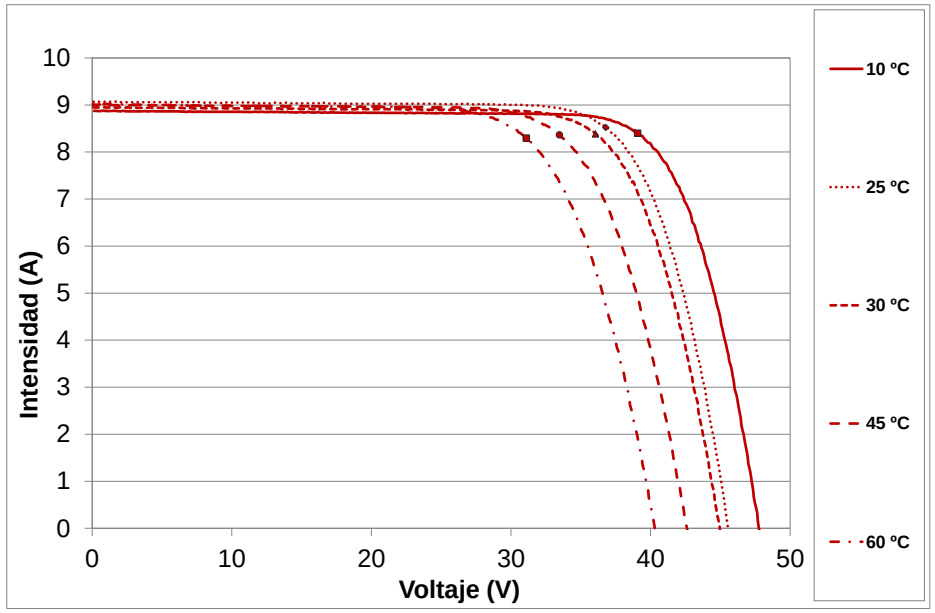
- 2) Temperature and irradiance corrections (IEC 60891):

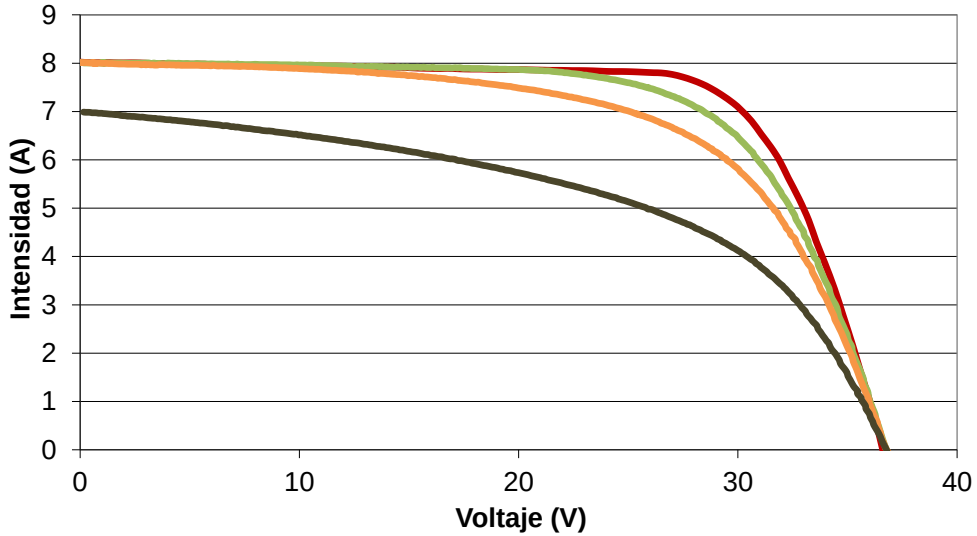
$$I_2 = I_1 + I_{SC} \cdot \left(\frac{G_2}{G_1} - 1 \right) + \alpha \cdot (T_2 - T_1)$$

$$V_2 = V_1 - R_S \cdot (I_2 - I_1) - \kappa \cdot I_2 \cdot (T_2 - T_1) + \beta \cdot (T_2 - T_1)$$

EXAMPLES

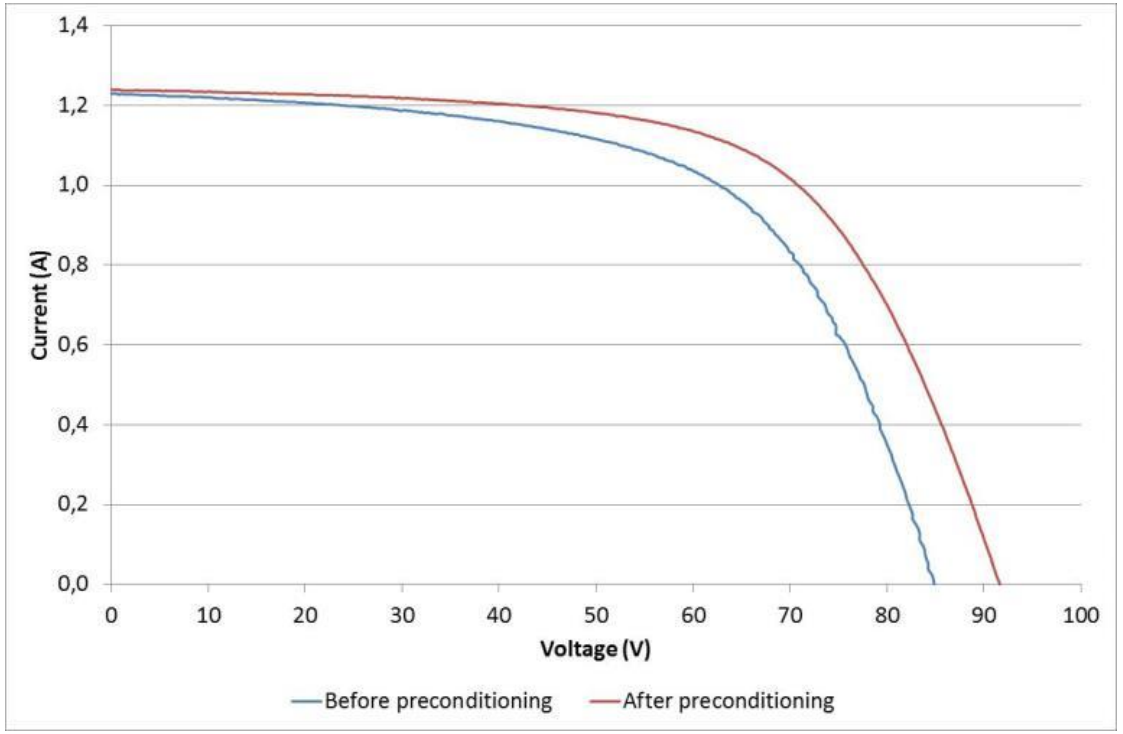

Intensidad (A)
Voltaje (V)
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40

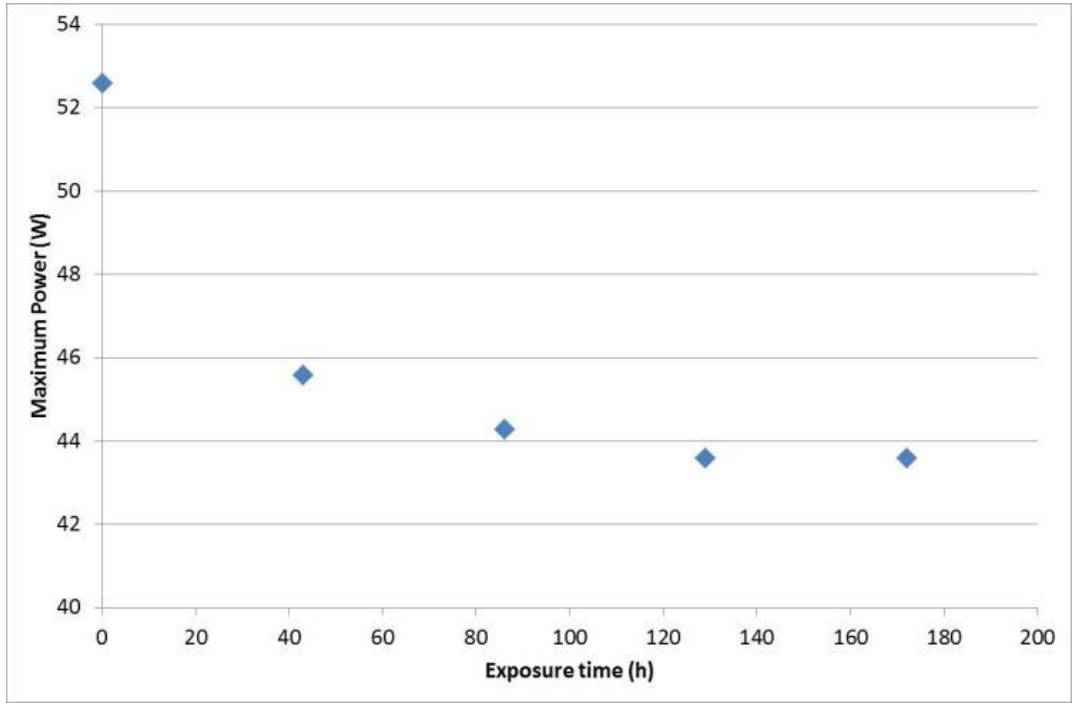

Intensidad (A)
Voltaje (V)
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
10 ºC
25 ºC
30 ºC
45 ºC
60 ºC


Intensidad (A)
Voltaje (V)
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40

THIN FILM MODULES

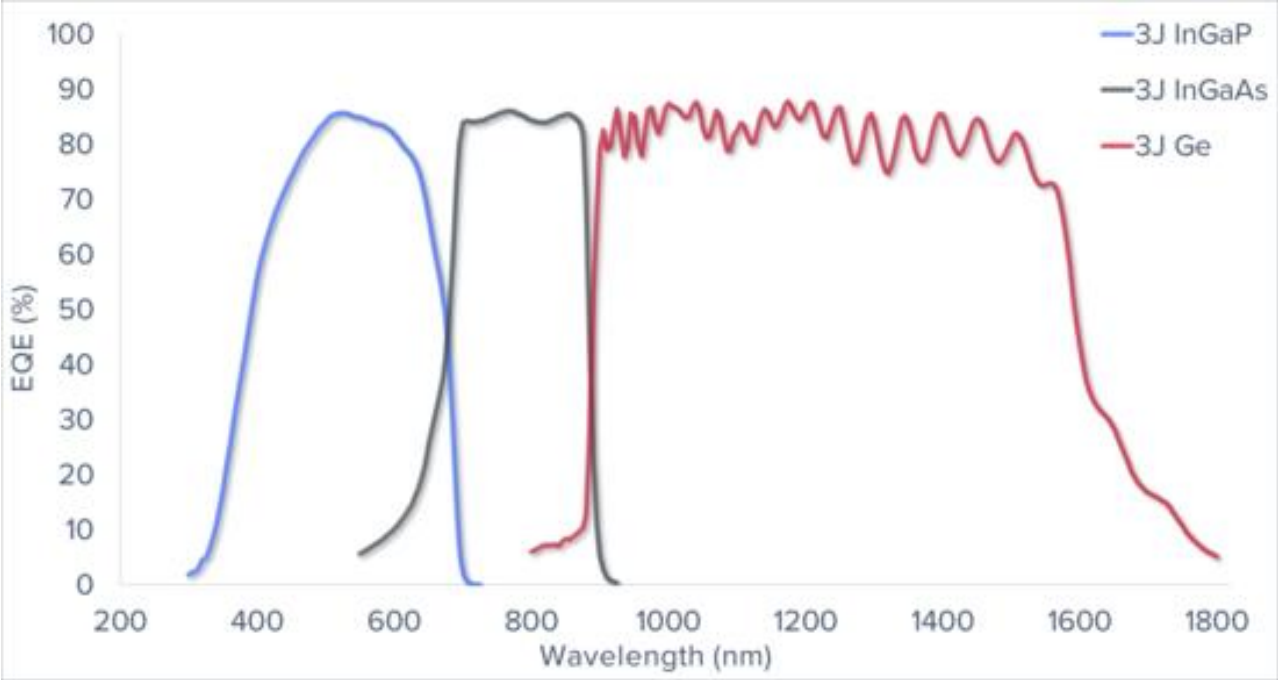
- Thin film I-V curve measurements:
  - Metastable effects due to dark storage (CdTe, CIGS)
  - Staebler-Wronski effect – Seasonal variations (a-Si)
  - Stabilization before measurement
  - PV technology not stable – c-Si reference cell – Spectral corrections

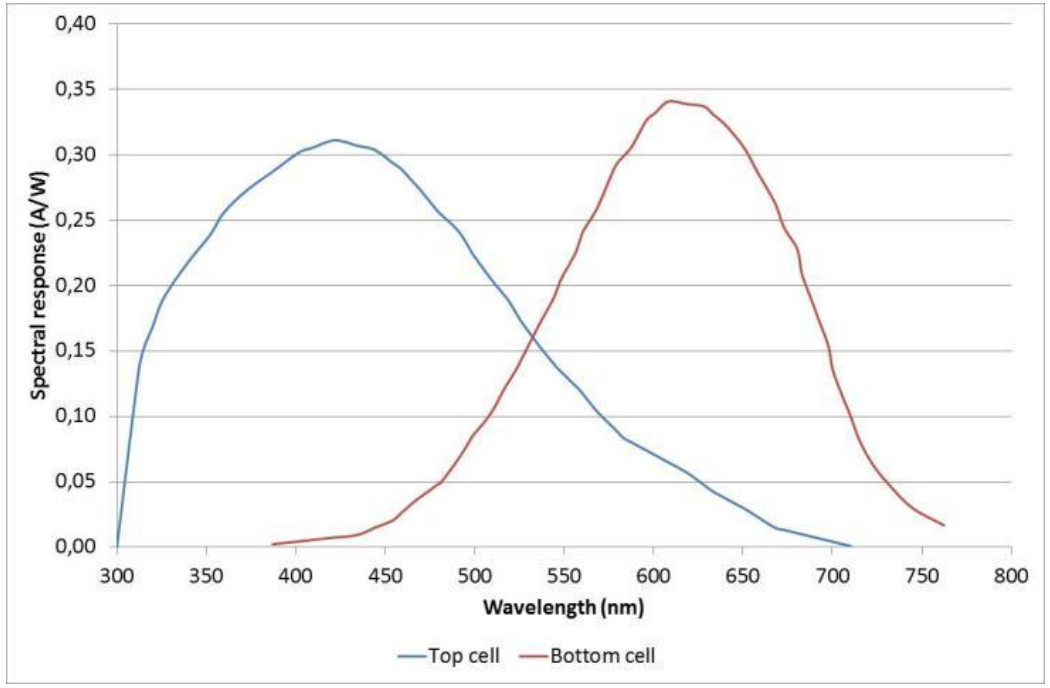




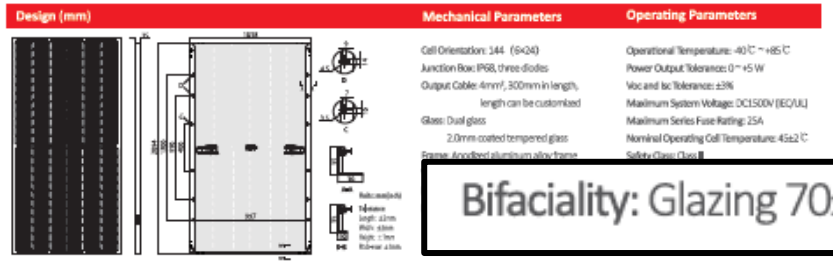
MULTIJUNCTION DEVICES

- Multijunction devices:
  - Junctions are series-connected – one of them limits the current
  - Spectral mismatch in flash simulator measurements

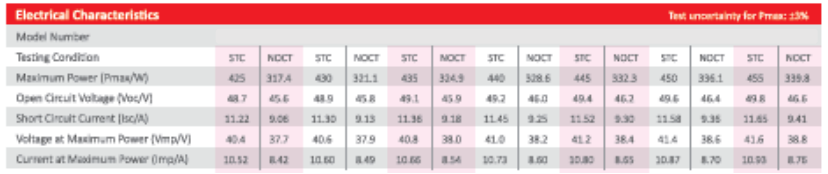




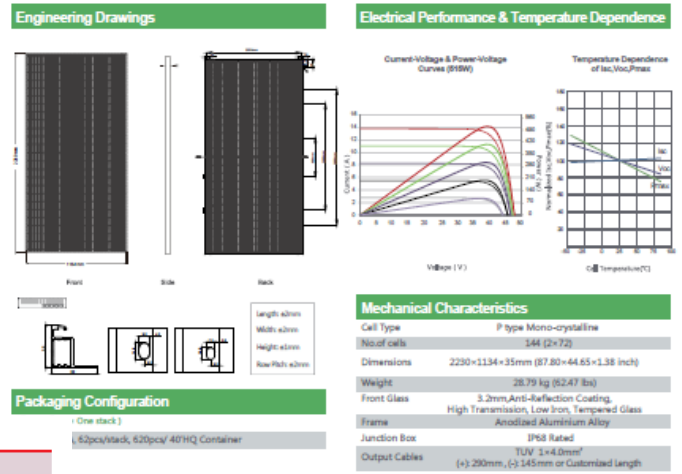
BIFACIAL PV MODULES



Bifaciality: Glazing 70±5%

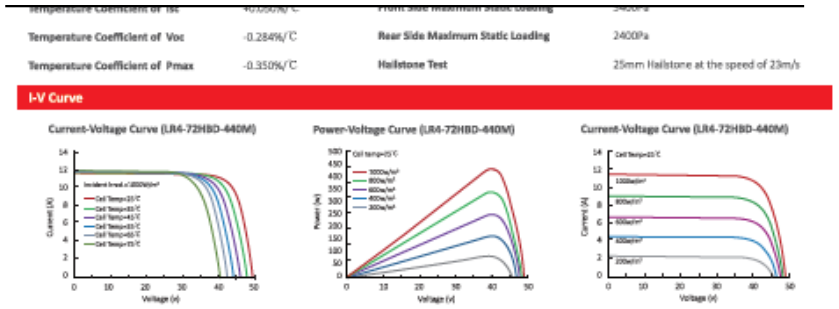


Model Number															
Testing Condition	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax/W)	425	317.4	430	321.1	435	324.9	440	328.6	445	332.3	450	336.1	455	339.8
Open Circuit Voltage (Voc/V)	48.7	45.6	48.9	45.8	49.1	45.9	49.2	46.0	49.4	46.2	49.6	46.4	49.8	46.6
Short Circuit Current (Isc/A)	11.22	9.06	11.30	9.13	11.36	9.18	11.45	9.25	11.52	9.30	11.58	9.35	11.65	9.41
Voltage at Maximum Power (Vmp/V)	40.4	37.7	40.6	37.9	40.8	38.0	41.0	38.2	41.2	38.4	41.4	38.6	41.6	38.8
Current at Maximum Power (Imp/A)	10.52	8.42	10.60	8.49	10.66	8.54	10.73	8.60	10.80	8.65	10.87	8.70	10.93	8.75



Electrical characteristics with different rear side power gain (reference to 445W front)

Pmax /W	Voc/V	Isc /A	Vmp/V	Imp /A	Pmax gain
467	49.4	12.09	41.2	11.34	5%
490	49.4	12.67	41.2	11.88	10%
512	49.5	13.24	41.3	12.42	15%
534	49.5	13.82	41.3	12.96	20%
556	49.5	14.40	41.3	13.50	25%



BIFACIAL OUTPUT-REARSIDE POWER GAIN

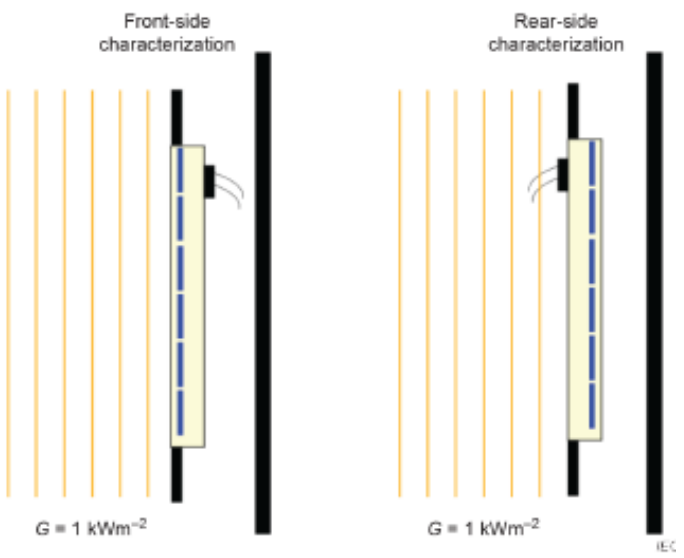
5%	Maximum Power (Pmax)	536Wp	541Wp	546Wp	551Wp	557Wp
	Module Efficiency STC (%)	21.18%	21.38%	21.59%	21.80%	22.01%
15%	Maximum Power (Pmax)	587Wp	592Wp	598Wp	604Wp	610Wp
	Module Efficiency STC (%)	23.19%	23.42%	23.65%	23.87%	24.10%
25%	Maximum Power (Pmax)	638Wp	644Wp	650Wp	656Wp	663Wp
	Module Efficiency STC (%)	25.21%	25.46%	25.70%	25.95%	26.20%

NOCT: Irradiance 800W/m² Ambient Temperature 20°C AM=1.5 Wind Speed 1m/s

* Power measurement tolerance: ± 3%

BIFACIAL MAX. POWER MEAS.

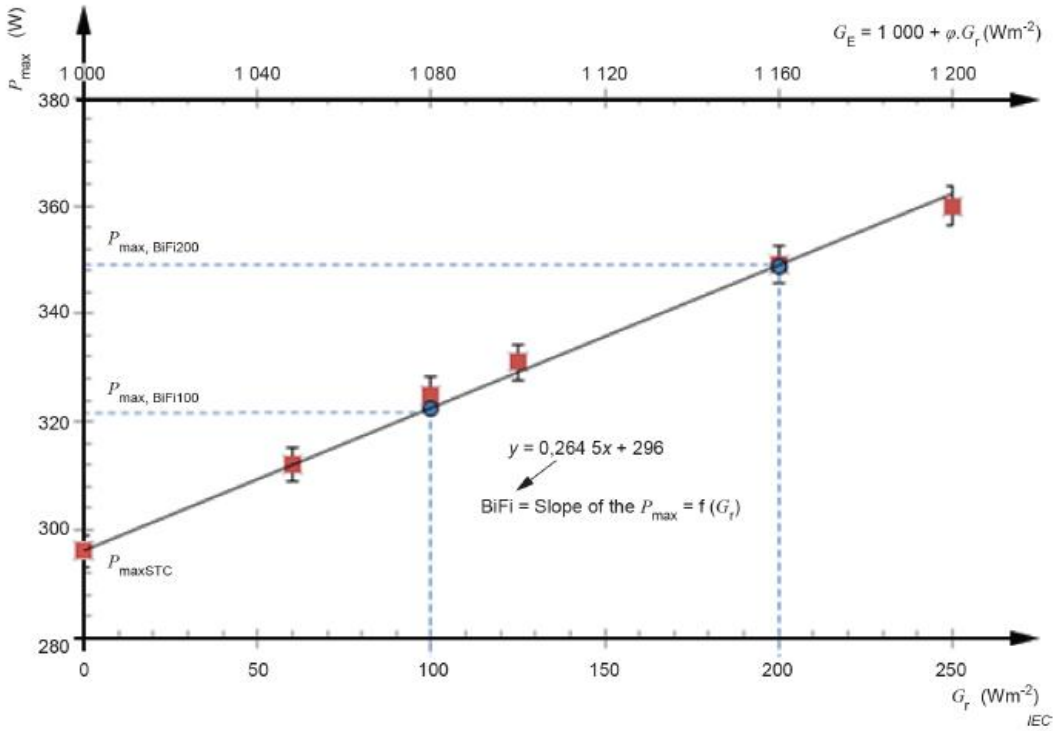
- Defined in IEC 60904-1-2 standard



$$\varphi_{Isc} = \frac{Isc_r}{Isc_f}$$

$$\varphi_{Pmax} = \frac{Pmax_r}{Pmax_f}$$

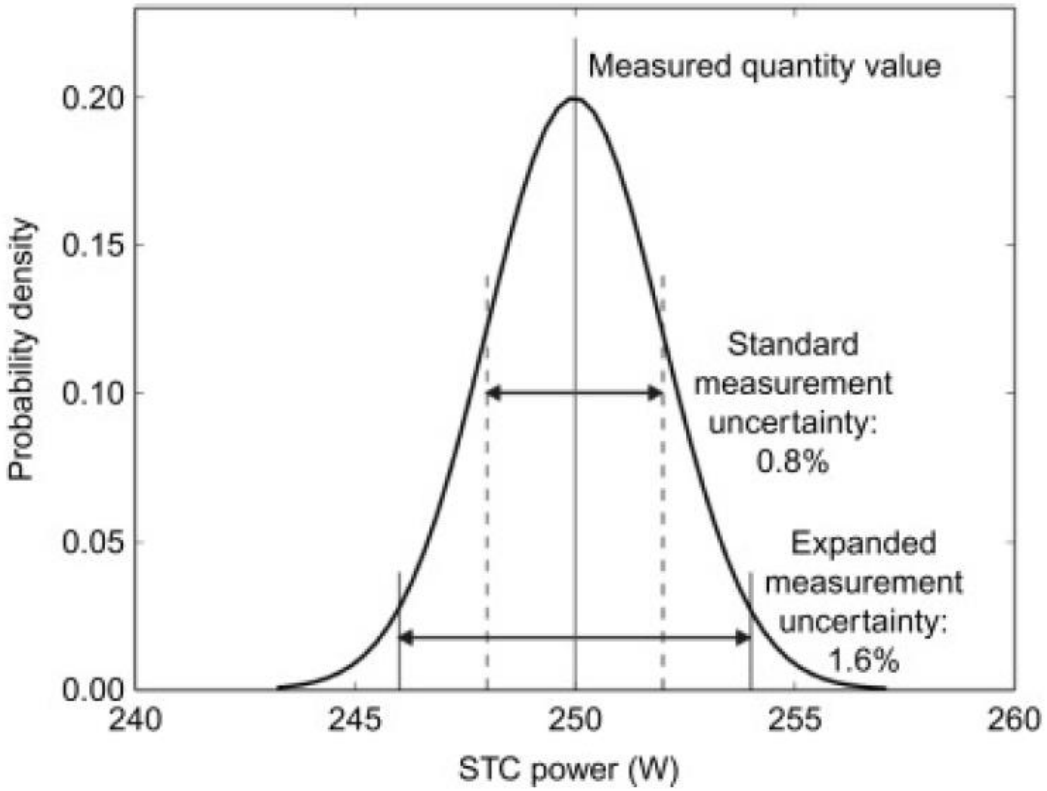
$$\varphi_{Voc} = \frac{Voc_r}{Voc_f}$$



- Bifaciality: φ_{Isc}, φ_{Pmax}, φ_{Voc}
- BiFi: Rear irradiance driven power gain yield
- BNI (Bifacial Nameplate Irradiance): 1000 Wm^{-2} front, 135 Wm^{-2} rear irradiances

UNCERTAINTY - INTRODUCTION

- **Measurement uncertainty:**
  - Parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand.
  - P_{MAX} = 250 W ± **1.6%**
  - IEC Guide 98-3 (GUM)
  - Confidence level: 95%



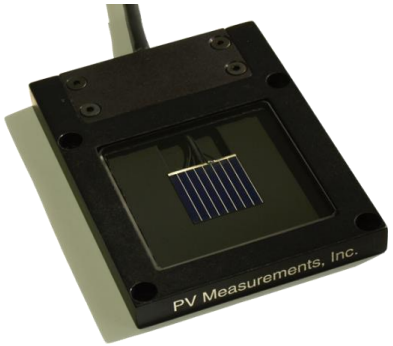
UNCERTAINTY SOURCES

Max. Power

$$P_{MAX} = I_{SC} \cdot V_{OC} \cdot FF$$

Irradiance

- Reference cell
- DAQ
- Temperature
- Uniformity
- Spectral mismatch
- Angular incidence



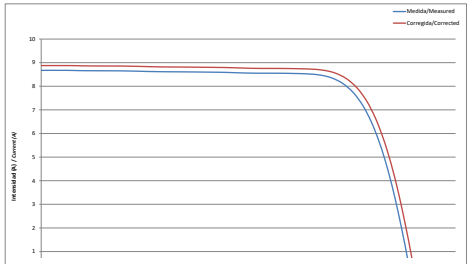
Temperature

- Temp. probe
- DAQ
- T. Uniformity
- Diff. Cell T. – substrate T.

Electrical (V, I) measurements

- I measurement
- V measurement
- Hysteresis (module capacity)

Correction to STC



$$I_2 = I_1 + I_{SC} \cdot \left(\frac{G_2}{G_1} - 1\right) + \alpha \cdot (T_2 - T_1)$$

$$V_2 = V_1 - R_S \cdot (I_2 - I_1) - \kappa \cdot I_2 \cdot (T_2 - T_1) + \beta \cdot (T_2 - T_1)$$

- Corr. method
- Parameters used
- Temp. Coeffs.
- R_S
- k

Other factors

- Calibrations
- Drifts
- Resolutions
- Repeatabilities
- Electrical connections
- Reproducibility
- **THIN FILM:**
  - LID
  - Annealing
  - Dark storage

Muchas Gracias

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