2. Procurement of Renewable Energy Solar PV Components and Materials

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Remarks:

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Schedule

Workshop Part 2 (1st Workshop)

Date: 25 May 2019 (Sat)

Time: 9:30am – 12:30pm

Test: 15 mins (MC, T/F)

Location:

C.S. Tse Lecture Theatre (LT2),

Ho Sin Hang Campus,

Hong Kong Baptist University

Workshop Part 2 (2nd Workshop)

To be confirmed

Contents

Procurement of Renewable Energy Solar PV Components and Materials

0. Introduction
A. Selection of materials and equipment
   - Essential parameters for PV characterizations
B. Proper design and installation of a RE PV power system
   - Repair and maintenance
C. Demonstration
D. Appendix: Certification and testing for PV panel selection

0. Introduction
Renewable energy feed-in tariff (FiT)

Feed-in Tariff Scheme

- Applicable to electricity generation by solar or wind power systems with a generating capacity of up to 1 MW.

Benefits

- FiT earning
- Renewable energy certificates

0. Introduction
Renewable energy feed-in tariff (FiT)

Types of FiT Rates

Three types of FiT rates will be offered according to the generation capacity of your renewable energy system:

Capacity of the Renewable Energy System	FiT rate (per unit of electricity -kWh)^
≤ 10 kW	HK$ 5
> 10 kW - ≤ 200 kW	HK$ 4
> 200 kW - ≤ 1MW	HK$ 3

^The rates listed above are effective from 1 Oct 2018 onwards and will be reviewed regularly.
Source: CLP

Different groups of people

- FiT earning
- Renewable energy certificates
- Demonstrations and exhibition
- Public image and reputation
- Education
- Environmental protection supporters
- Hobbit

Different groups of people

Demonstrations and exhibition, public image and reputation, Education.

Available solar energy in HK

Month	Sunshine Duration (hours)	Availability (%)	Daily Global Solar Radiation (kWh/m^2)
January	143	42	2.83
February	94.2	29	2.61
March	90.8	24	2.77
April	101.7	27	3.22
May	140.4	34	3.94
June	146.1	36	3.94
July	212	51	4.77
August	188.9	47	4.34
September	172.3	47	4.06
October	193.9	54	3.90
November	180.1	54	3.41
December	172.2	51	3.03
Year	1835.6	42	3.57

Source: HKO global solar radiation (1981-2010) at King's Park

FiT earning

PV efficiency: 12%

Annual energy generation

$= 3.57 \text{ kWh/m}^2 \times 0.12 \times 365$

$= 156 \text{ kWh/m}^2$

Annual FiT earning per m^2

$= 156 \text{ kWh} \times \text{HKD5/kWh}$

= HKD 780

A typical village house of 700 square feet can install ~20 m^2 PV panels.

Annual FiT earning

= HKD 15,600

Basic concepts

What is energy?

- Energy is the ability to do work.

Types of energy:

- Potential energy (勢能)
- Kinetic energy (動能)

Basic concepts

Forms of energy:

- Heat (thermal)
- Light (radiant)
- Motion (kinetic)
- Electrical
- Chemical
- Nuclear energy
- Gravitational

Electricity: an intermediate form of energy.

Common units of power and energy:

[W]

[J, 焦耳] or [kWh, 千瓦·時]

Energy [J] = Power [W] × Time [s]

Concept: Order of magnitude

pico (p)	10^{-12}	0.000 000 000 001
nano (n)	10^{-9}	0.000 000 001
micro (μ)	10^{-6}	0.000 001
milli (m)	10^{-3}	0.001
centi (c)	10^{-2}	0.01
deci (d)	10^{-1}	0.1
	10^{0}	1
deca (da)	10^{1}	10
hecto (h)	10^{2}	100
kilo (k)	$\mathbf{10^{3}}$	**1,000**
Mega (M)	$\mathbf{10^{6}}$	**1,000,000**
Giga (G)	$\mathbf{10^{9}}$	**1,000,000,000**
Tera (T)	10^{12}	1,000,000,000,000

Forms of solar energy for buildings

- Passive Solar
- Photovoltaics
- Solar Thermal

Energy quality: the ability (energy conversion) to convert from one form to another.

Forms of Energy Storage	Energy Quality
Fossil Fuels	High
Electrical	High
Mechanical	High
Thermal	Low

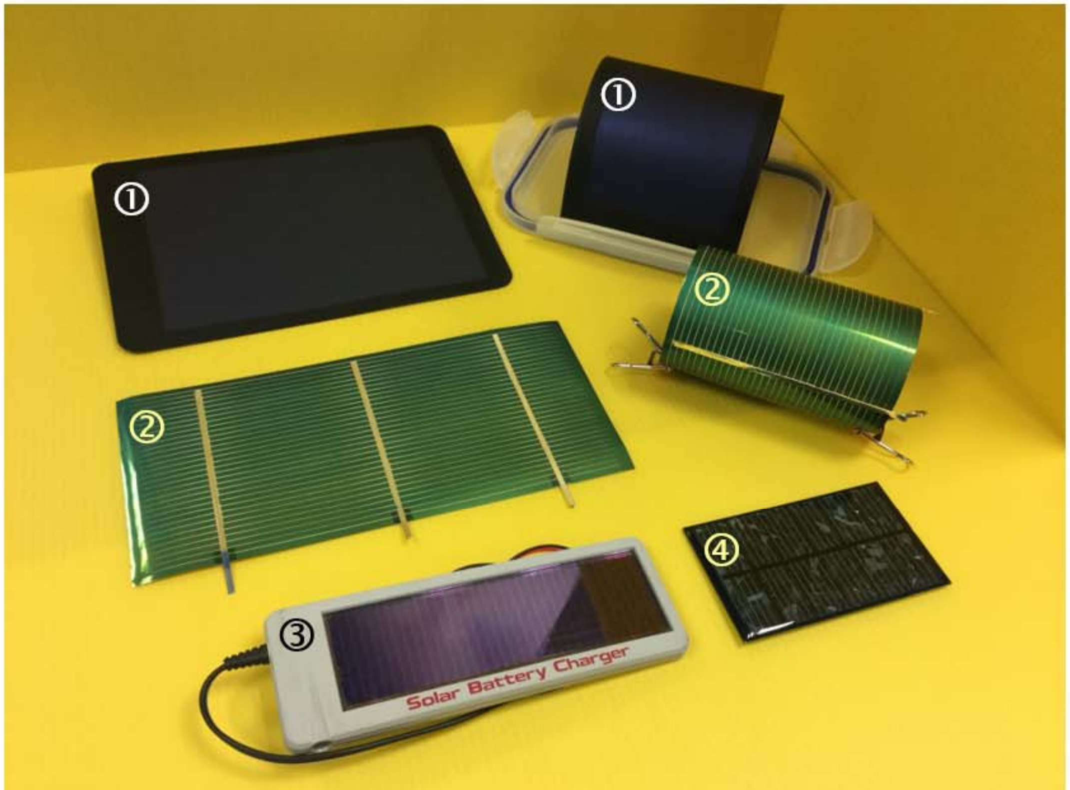
A. Selection of PV materials and equipment

- Commercial available PV
- Background concepts for PV selection
  - PV operation principle
  - PV equipment circuit
  - Shunt resistance
  - PV Colors
- Efficiency, size, purposes, and applications

Common types of solar cells

- Silicon Solar Cells
  - Monocrystalline Silicon
  - Polycrystalline Silicon
- Thin Film Solar Cells (nm to a few μm)
  - Amorphous Silicon (a-Si)
  - Cadmium Telluride (CdTe)
  - Copper Indium Gallium Selenide (CIGS)

Commercial PV cells/panels



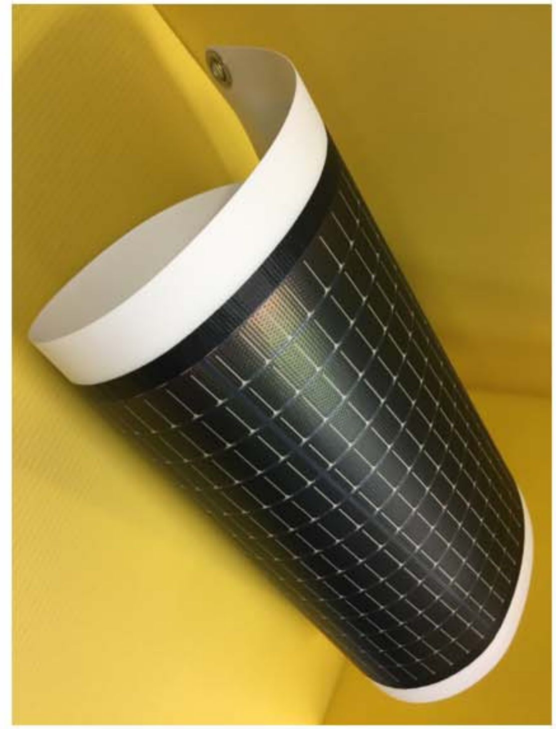
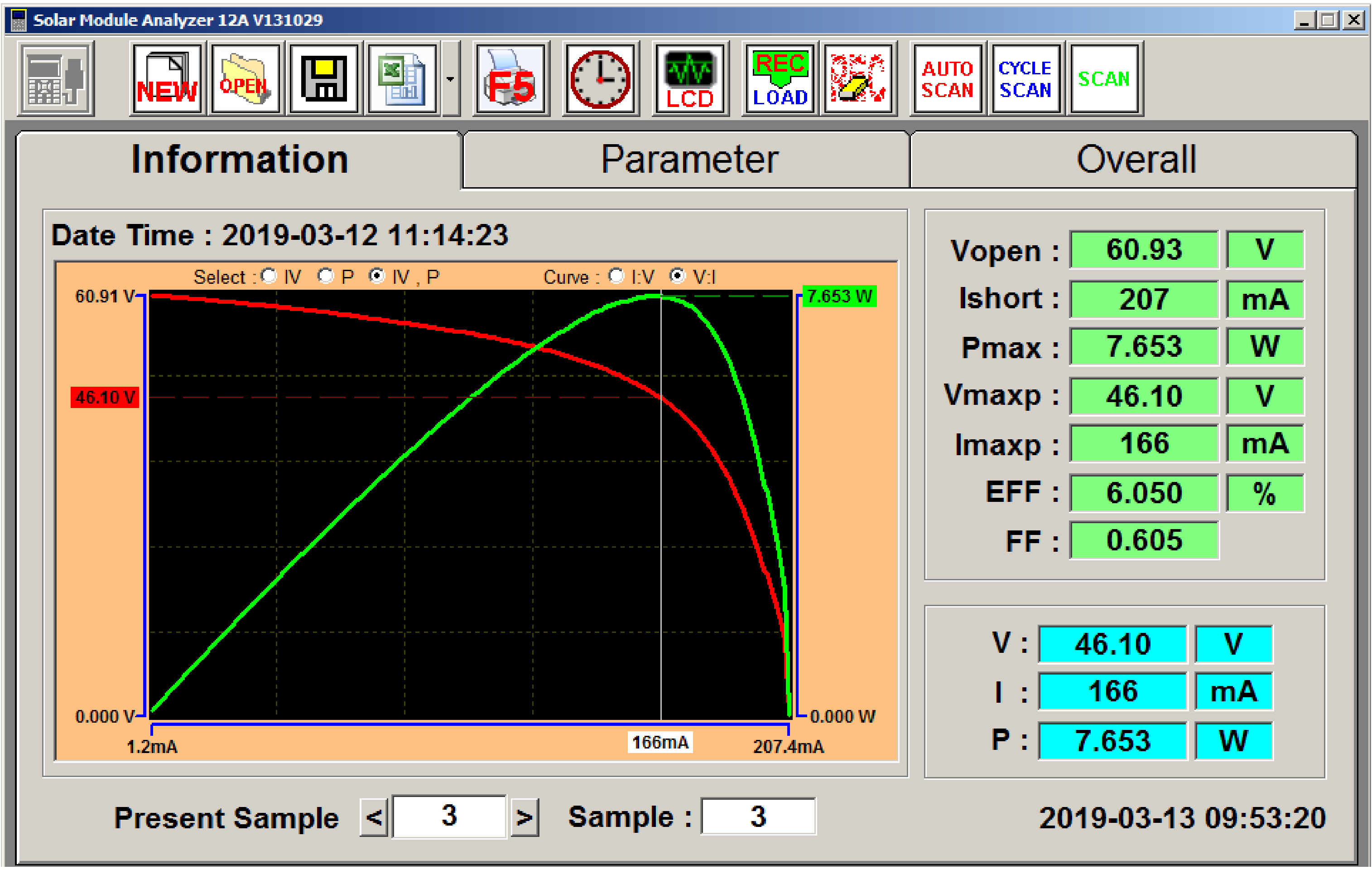


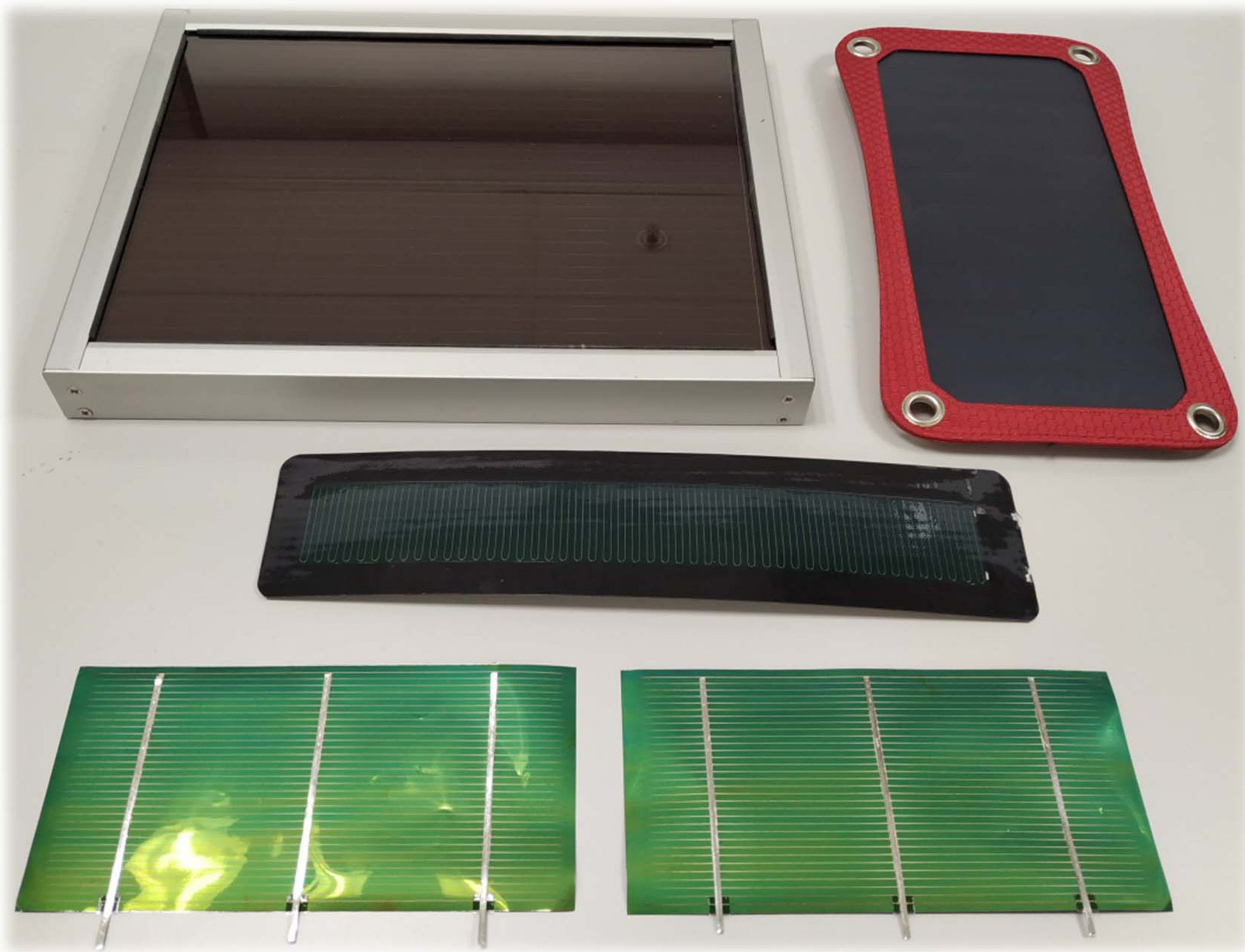
Fig 1. [LEFT] Commercial available solar cells. ① Amorphous silicon thin film, flexible;
② CIGS (Copper Indium Gallium Selenide), flexible; ③ amorphous silicon; and
④ polycrystalline silicon solar cells.
[RIGHT] Rollable solar cell

Amorphous Silicon PV in research

Amorphous Silicon PV in research



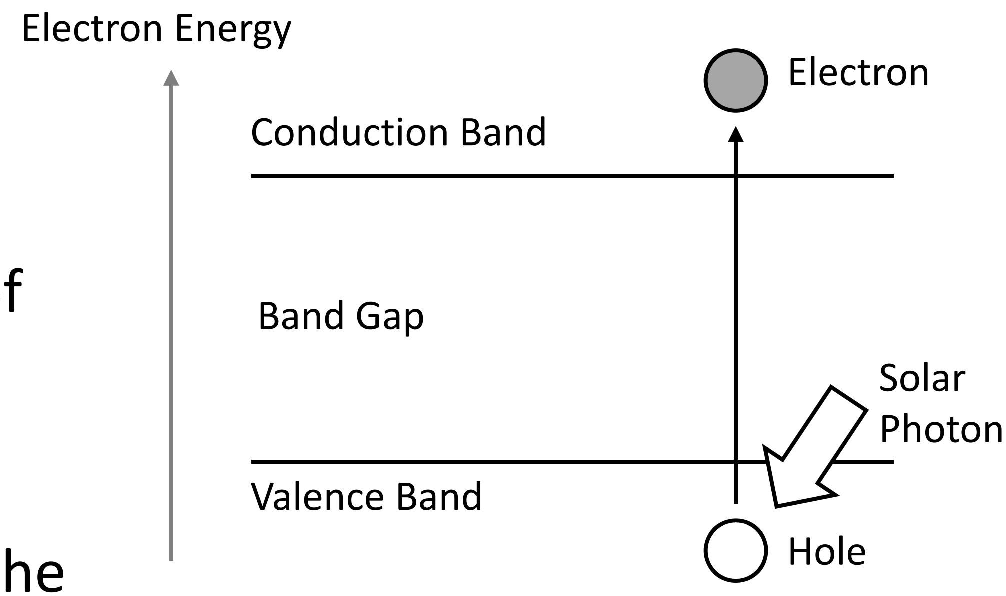
PV Colors



Background concepts: PV operation principle

Basic steps of energy conversion in a PV cell:

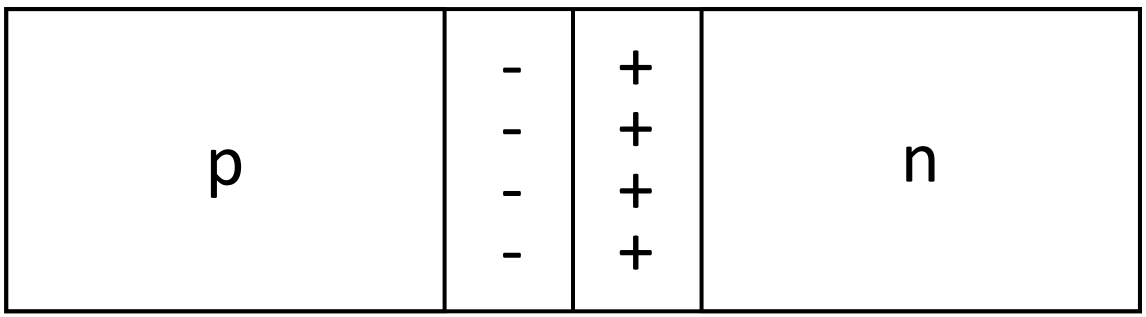
1. absorption of photons (light) and generation of electron-hole pairs,
2. separation of charges (electron-hole pairs in the depletion region), and
3. collection of charge.



Basic steps of energy conversion in a PV cell.

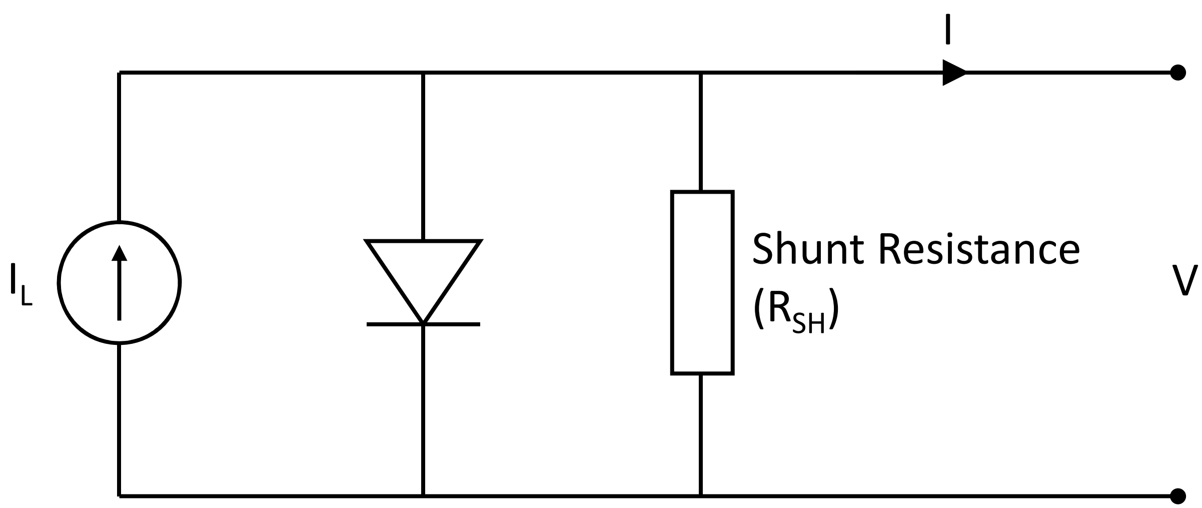
PV operation principle: p-n junction

Electric Field



Depletion Layer

PV equipment circuit



I_L = Light generated current

I = Cell output current

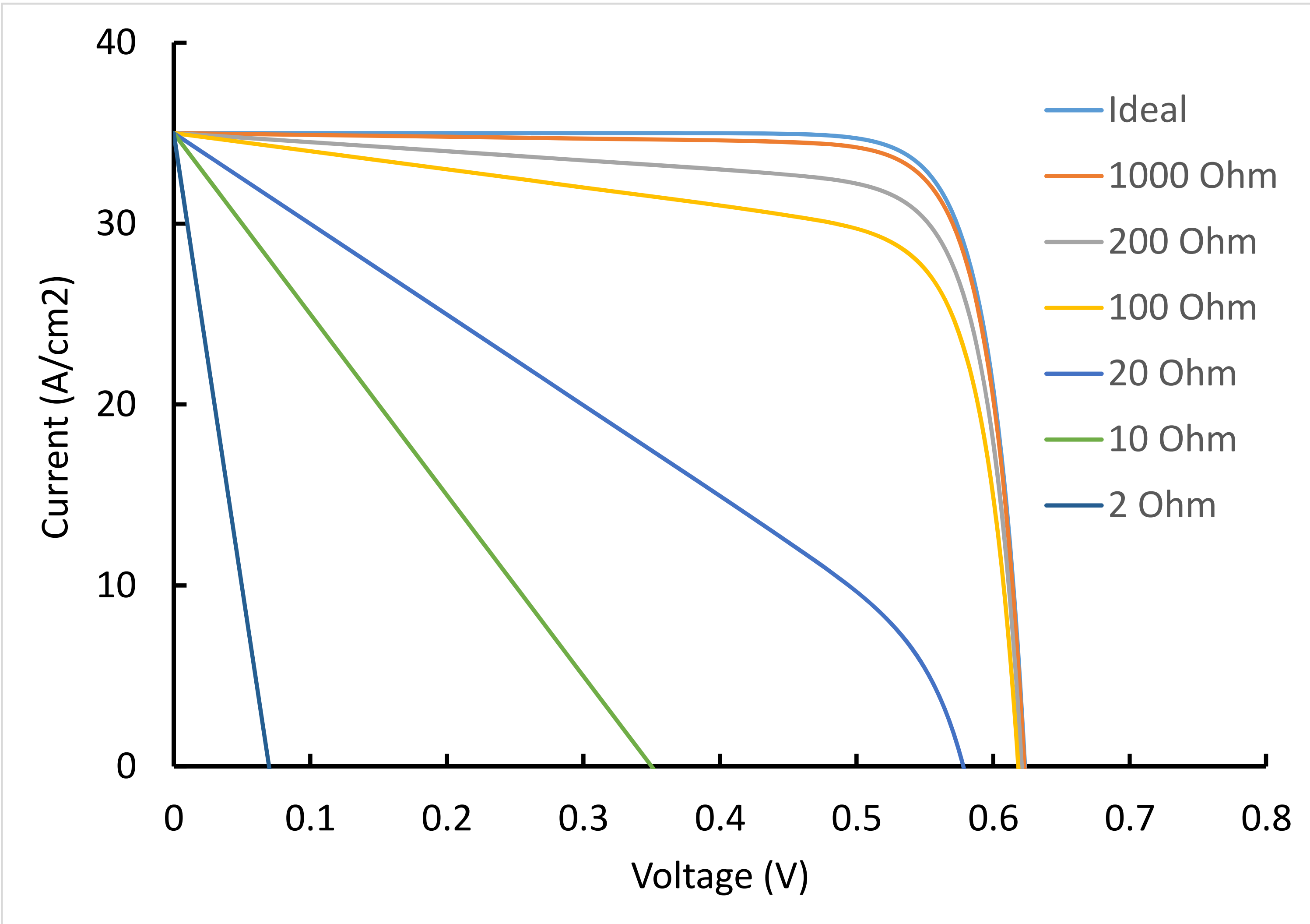
V = Cell output voltage

q, k = Constants

n = Ideality factor

$$I = I_L - I_o \exp\left(\frac{qV}{nkT}\right) - \frac{V}{R_{SH}}$$

Effect of shunt resistance on PV IV curve



Efficiency and PV size

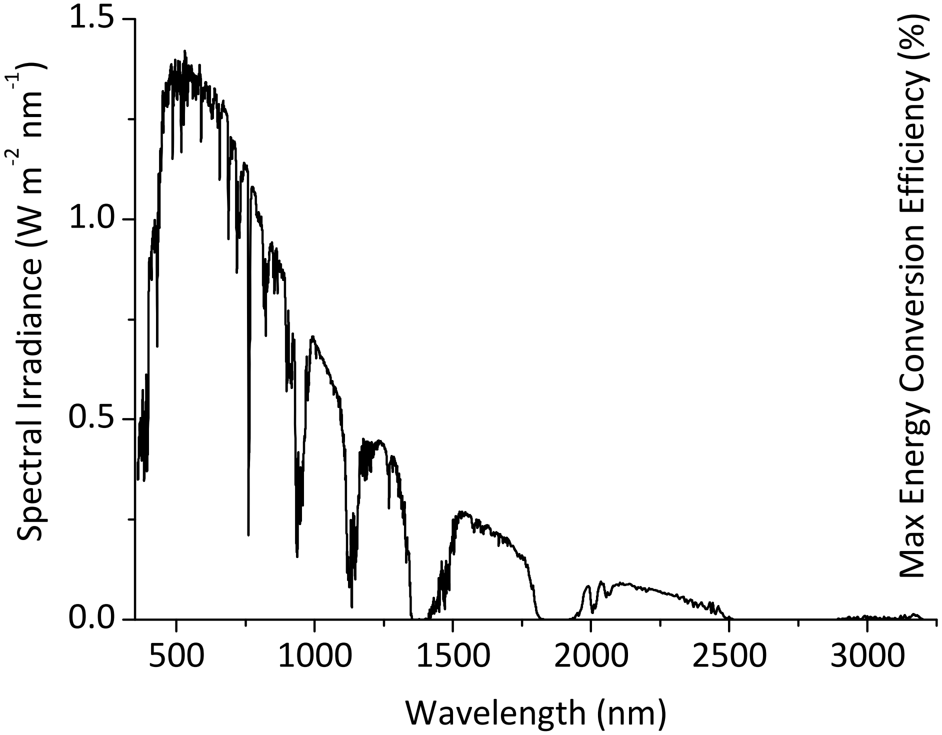
	Efficiency	Required Area for 1 kW power
High Performance HIT (Heterojunction with Intrinsic Thin-layer) Silicon	16-20%	5-6 m^2
Monocrystalline Silicon	11-16%	6-9 m^2
Polycrystalline Silicon	10-15%	7-10 m^2
Thin Film: Copper-Indium Selenide (CIS)	6-11%	9-17 m^2
Cadmium Telluride (CdTe)	6-11%	9-17 m^2
Amorphous Silicon	4-7%	15-26 m^2

Essential parameters for PV characterizations

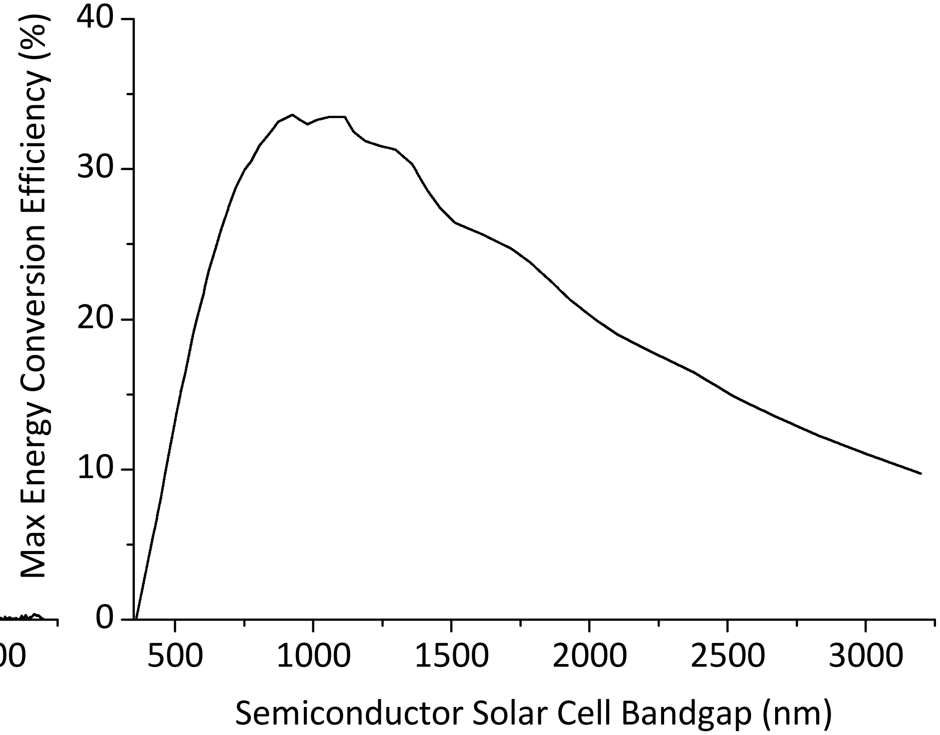
- Concept: Theoretical maximum conversion efficiency
  - IV Curve (電流電壓曲線)
  - Open-circuit voltage and short-circuit current (開路電壓 和 短路電流)
  - Fill factor (填充因子)
  - Operation point / maximum power operation point (最大功率操作點)
  - Energy conversion efficiency (能量轉換效率)

Concept: Theoretical maximum conversion efficiency

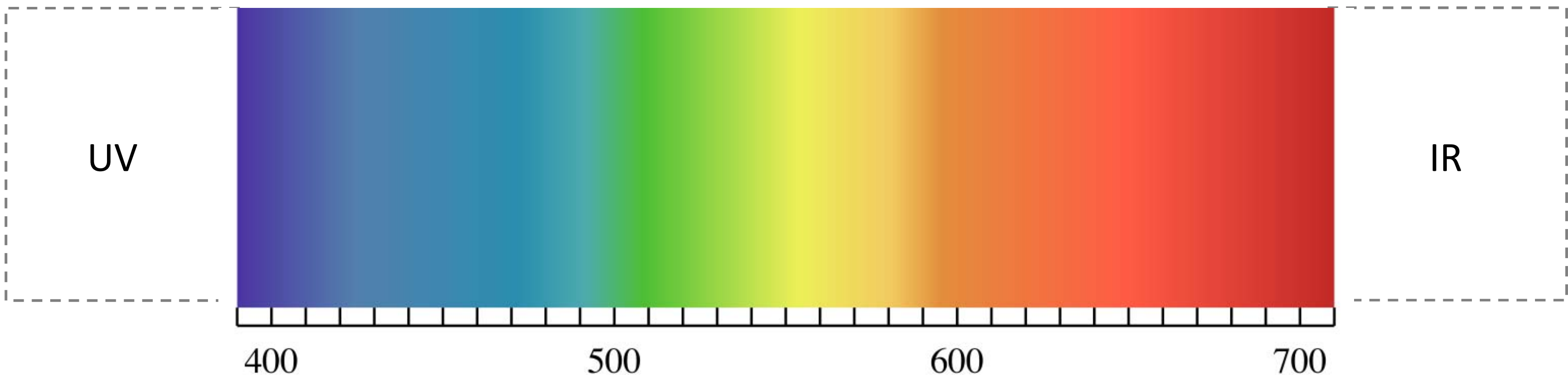
Reference AM1.5 Solar Spectrum



Theoretical maximum efficiency of a single p-n junction PV cell to collect solar power.



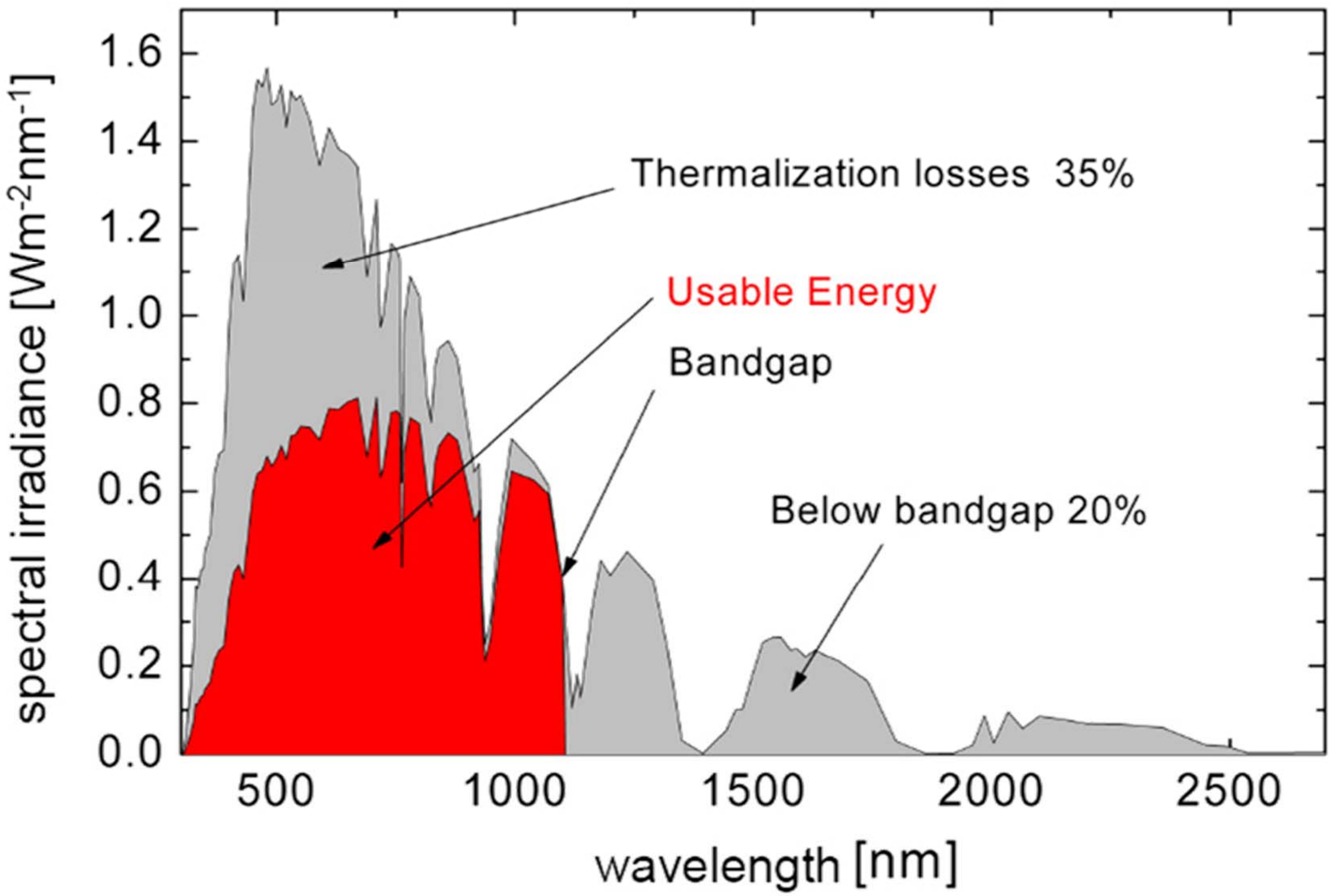
Concept: Electromagnetic spectrum (電磁頻譜)



Visible Spectrum
(Wavelength λ in nm)

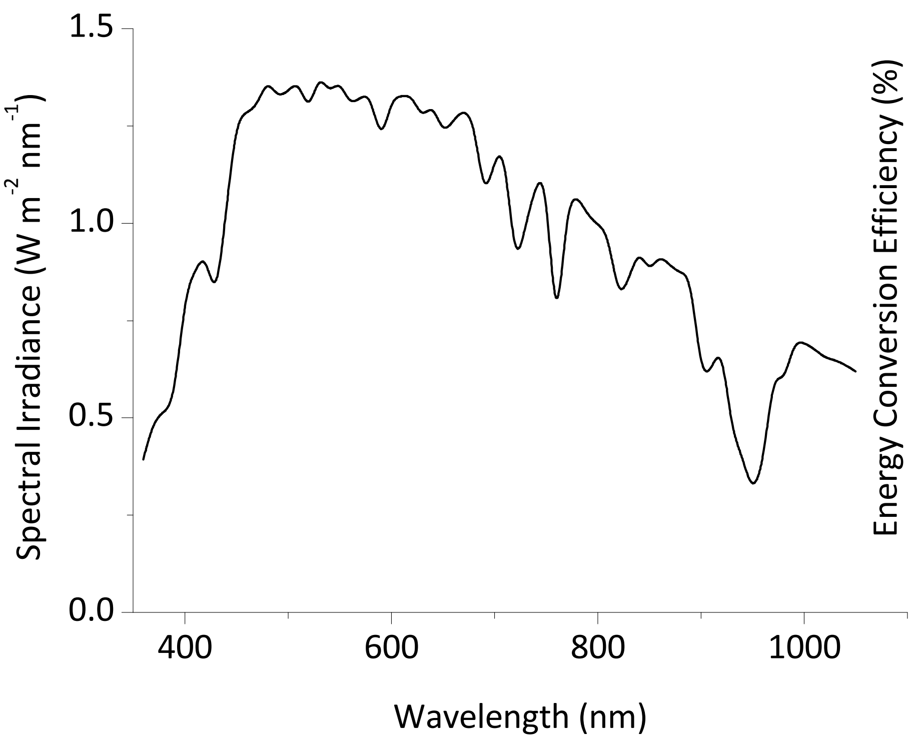
Spatially separation of white light into different colors

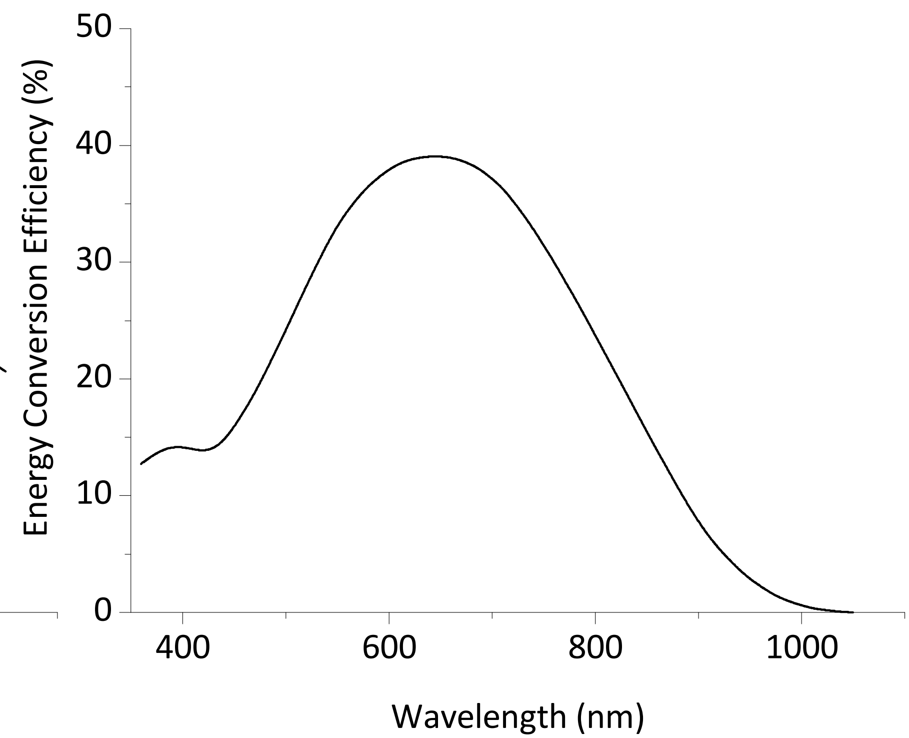
Limits of Si PV efficiency



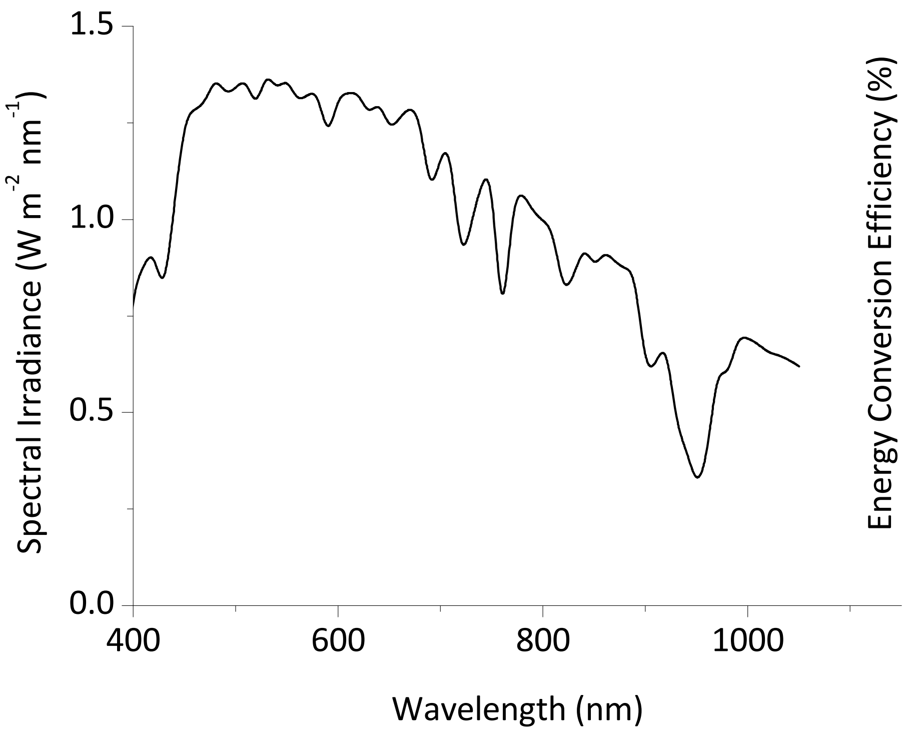
Source: Energies 171-193 (2010); doi:10.3390/en3020171.

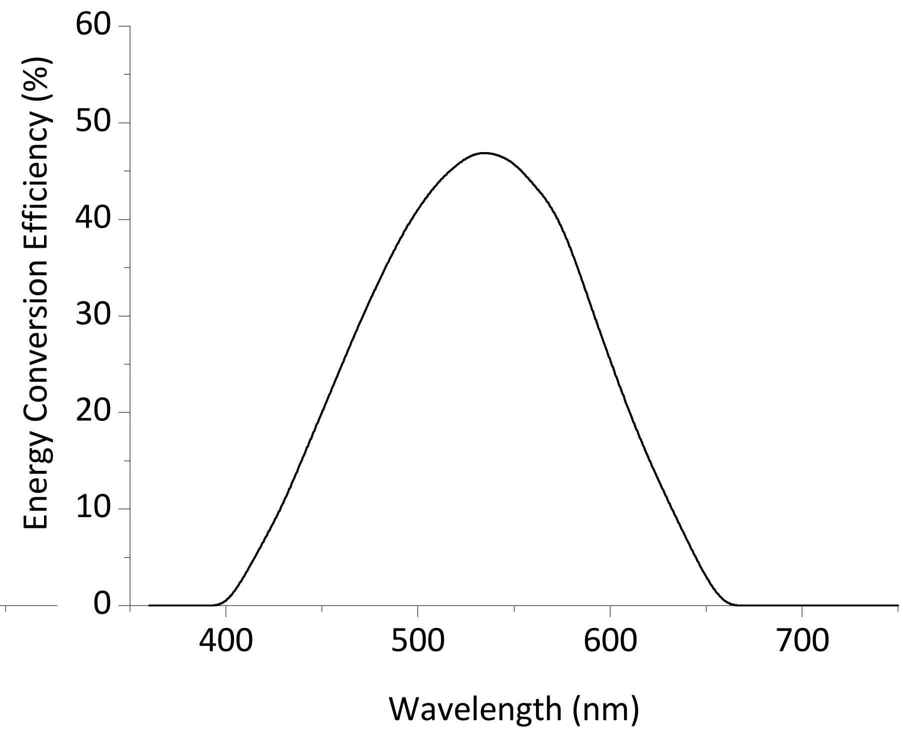
Energy conversion efficiency: Si PV



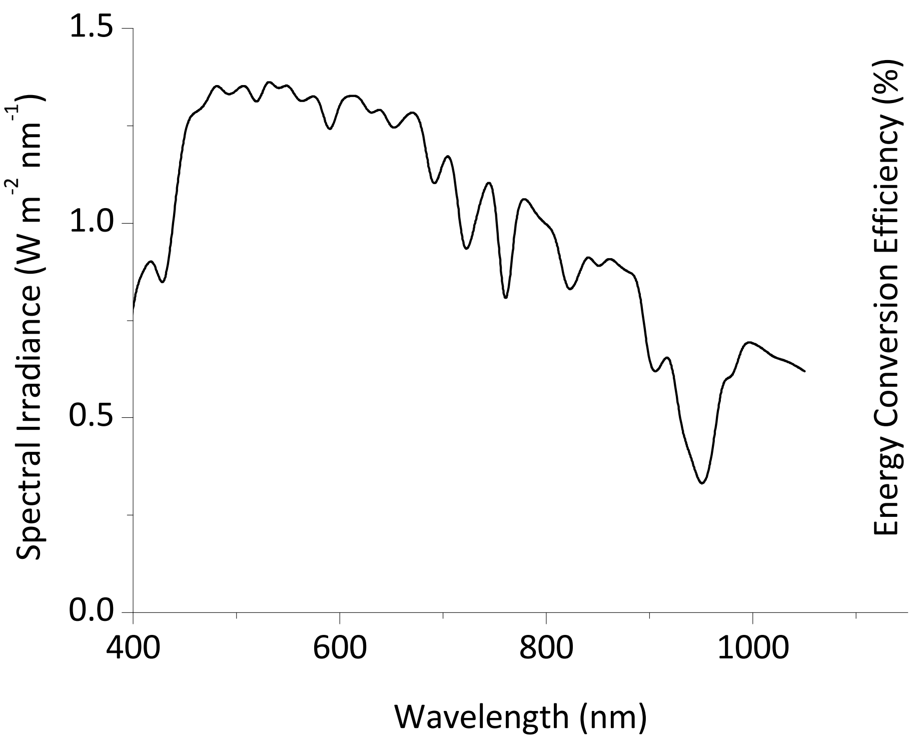


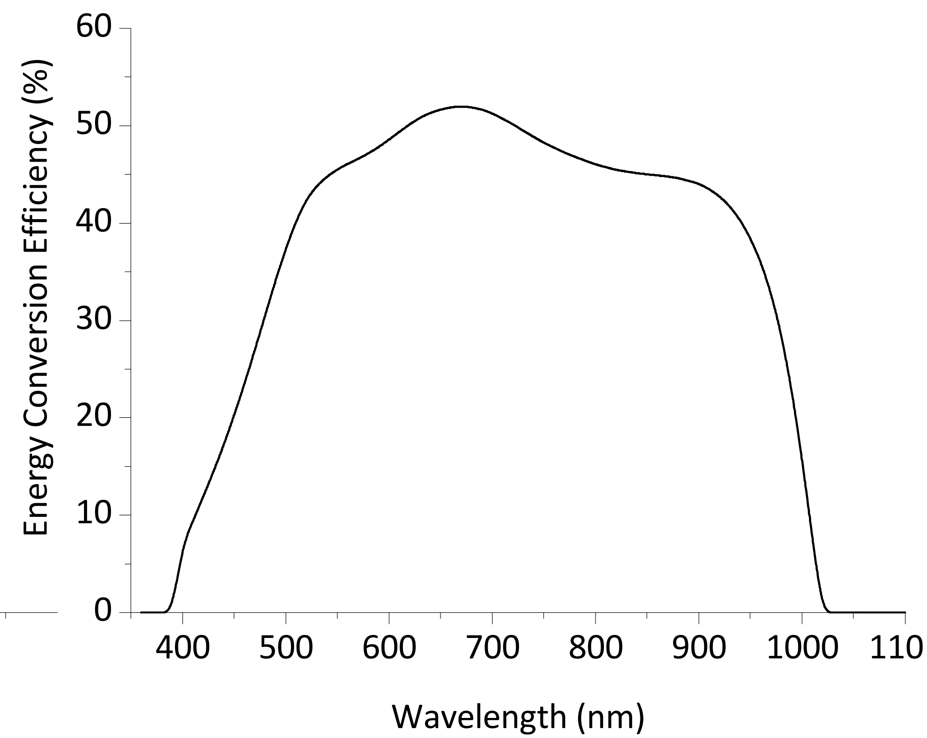
Energy conversion efficiency: a-Si PV



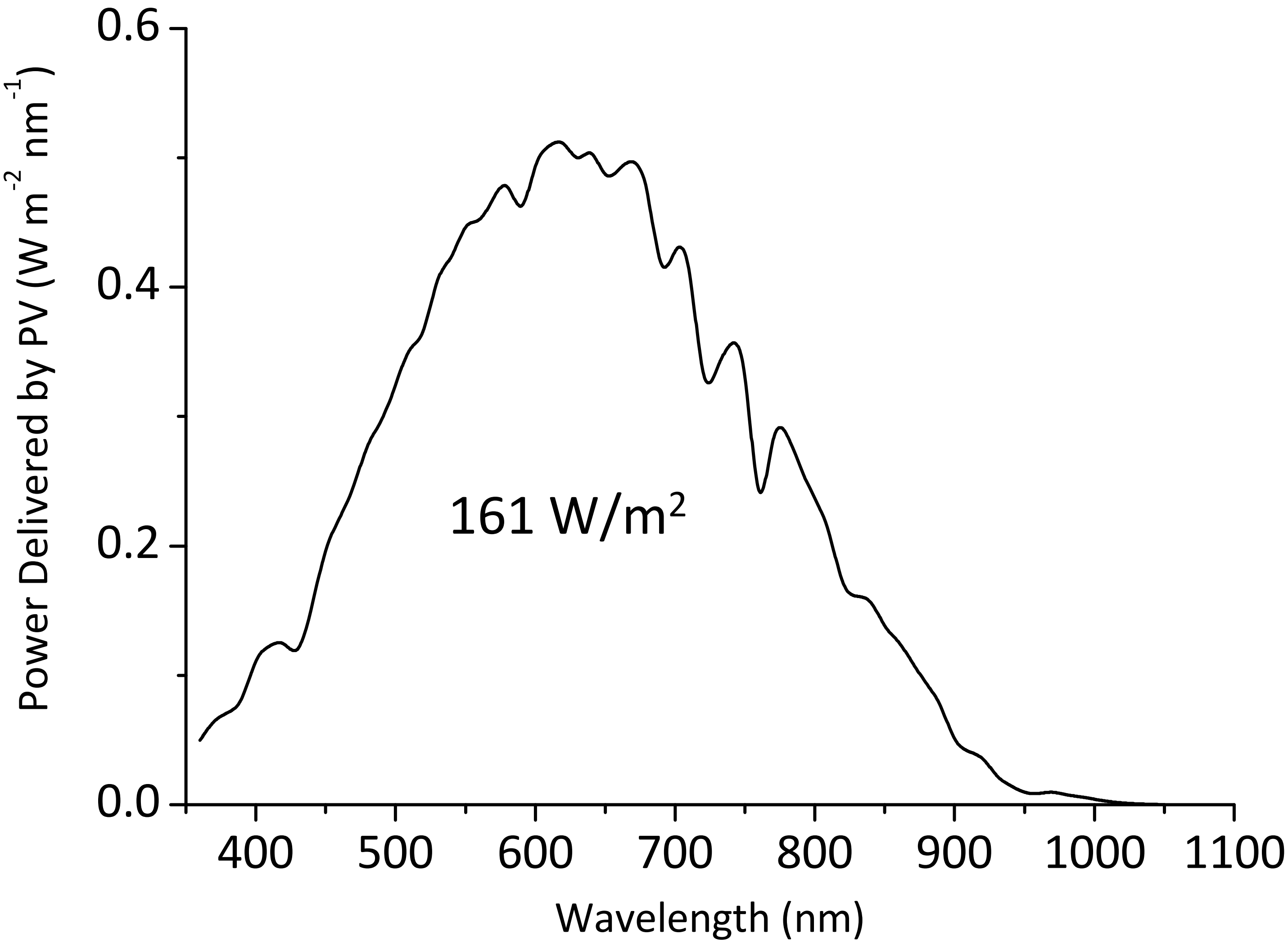


Energy conversion efficiency: CIGS

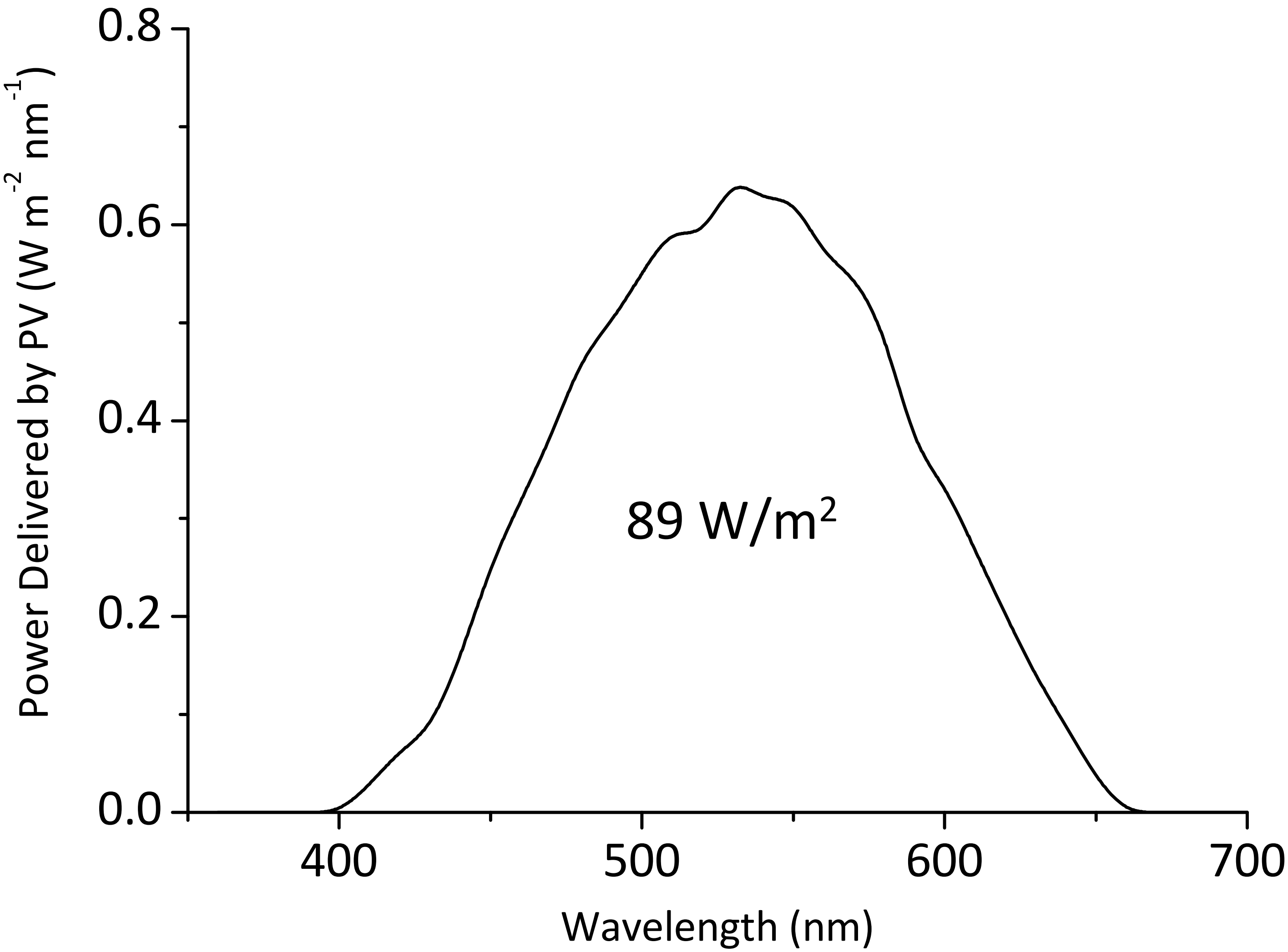




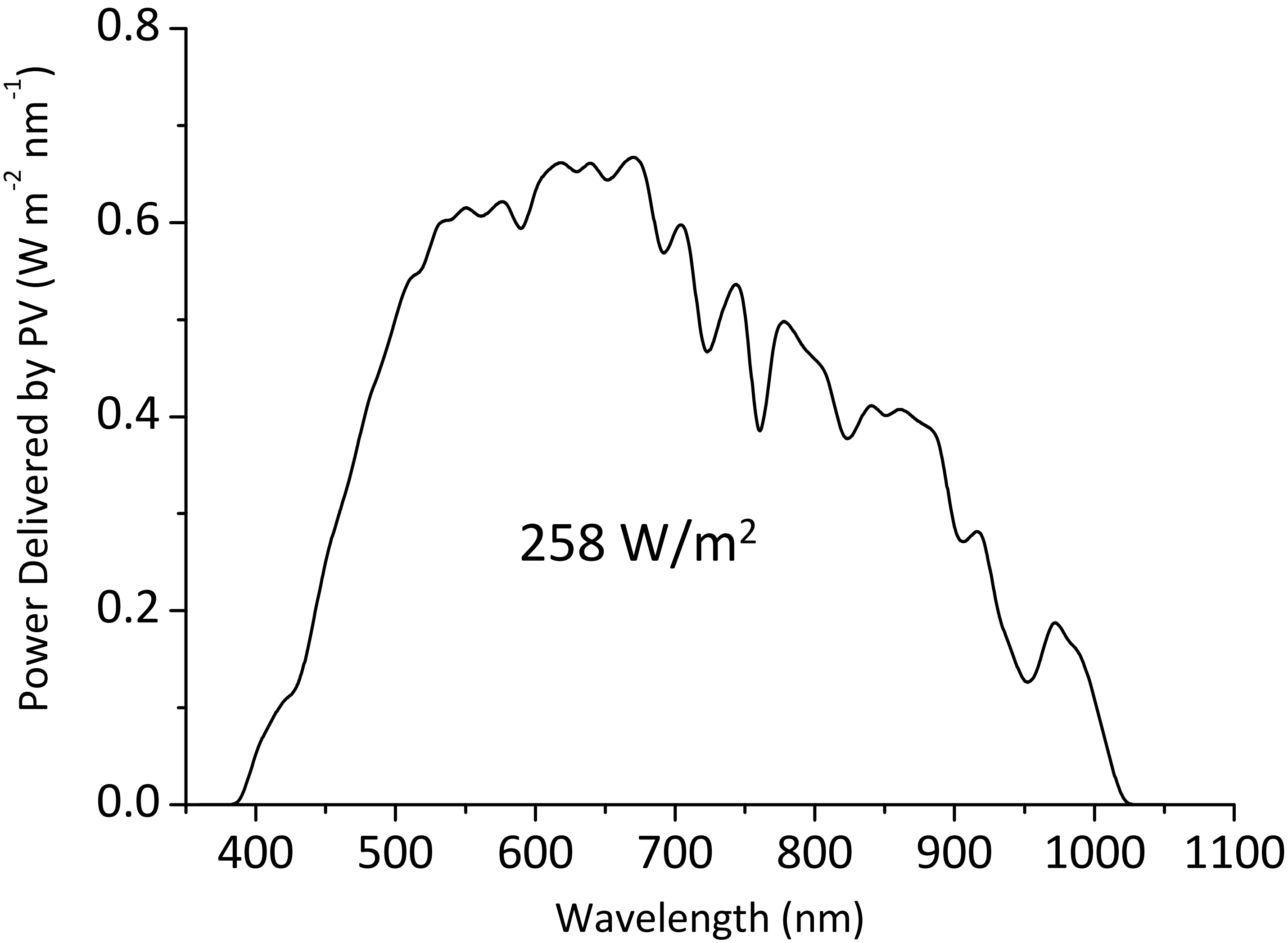
Power delivered by Si PV



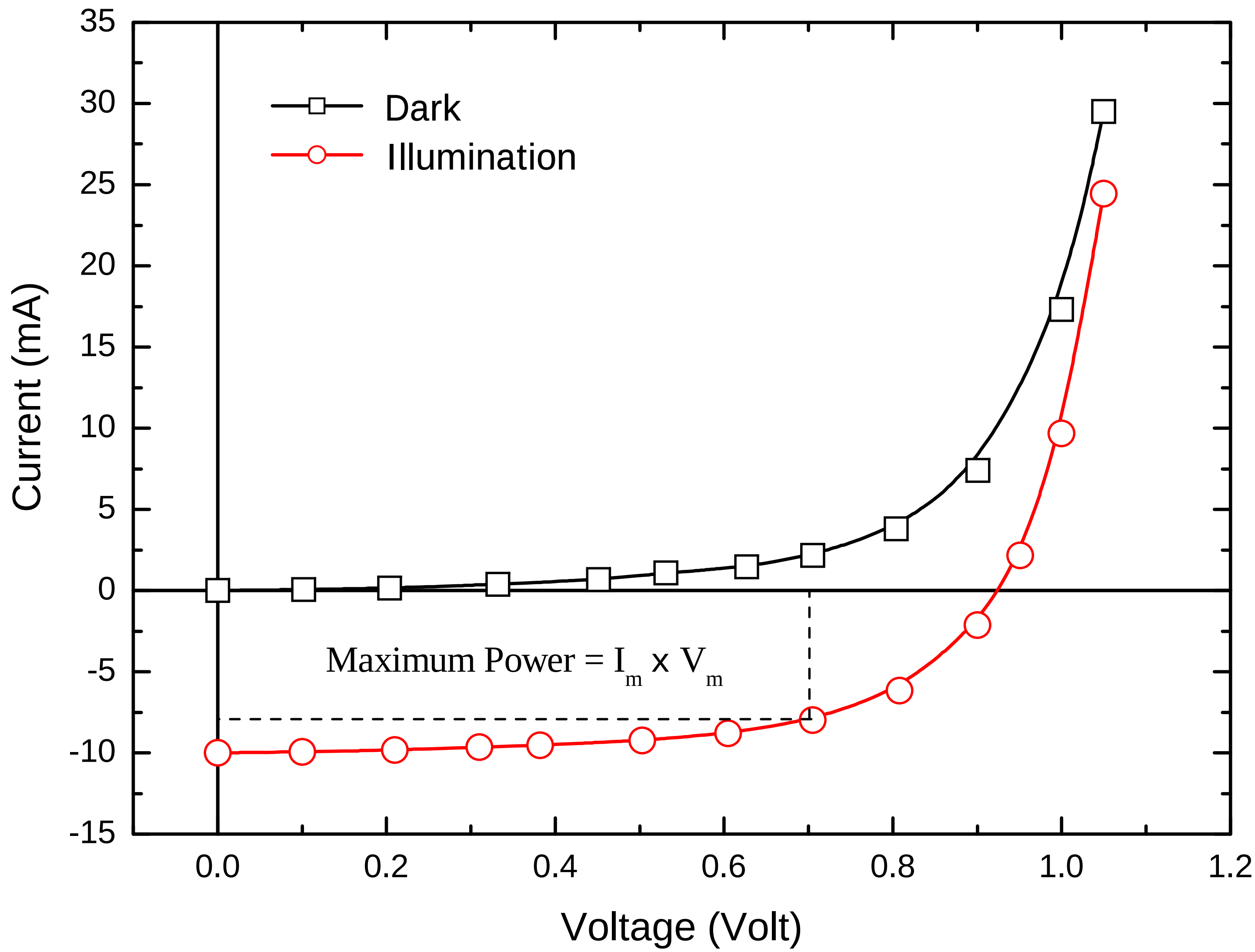
Power delivered by a-Si PV



Power delivered by CIGS PV

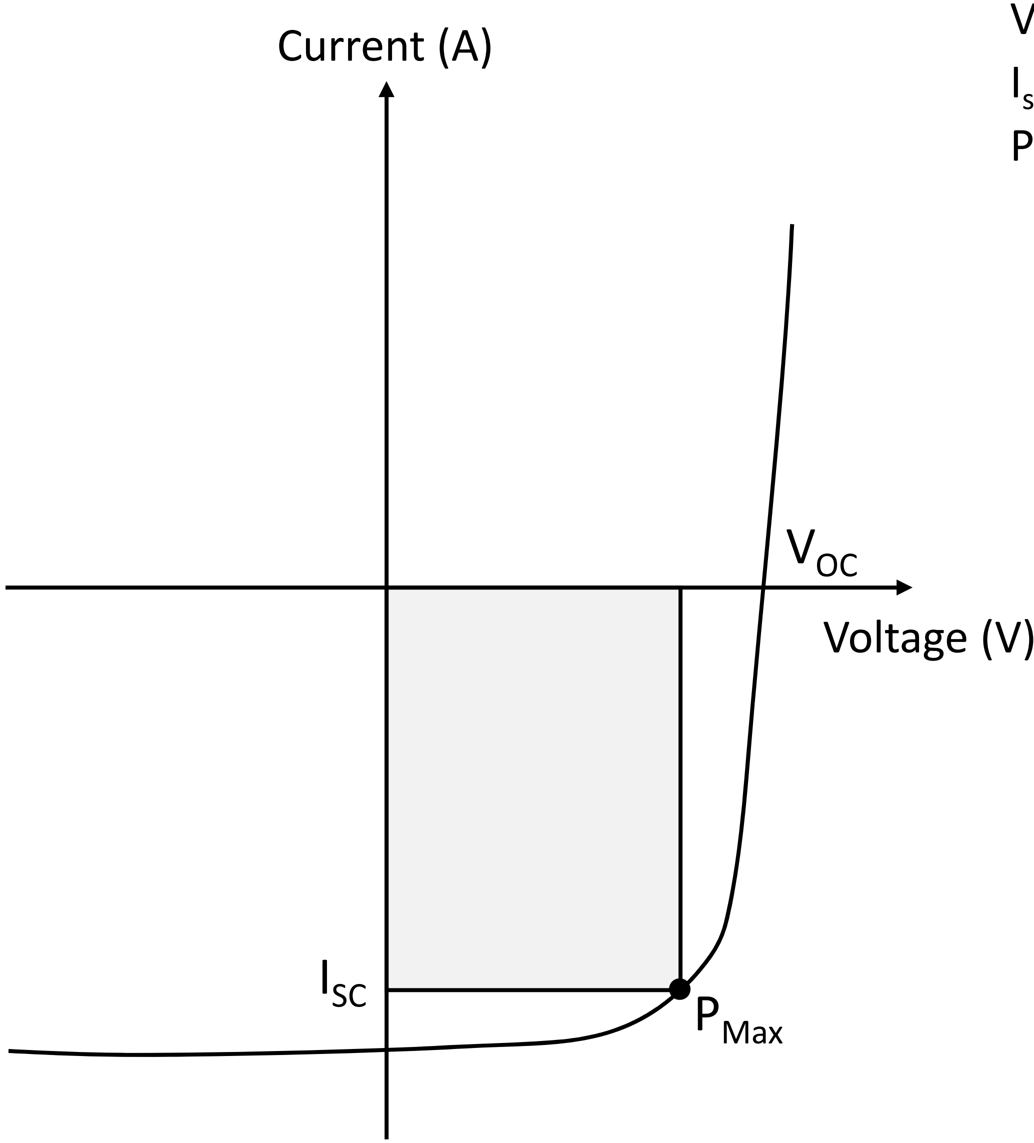


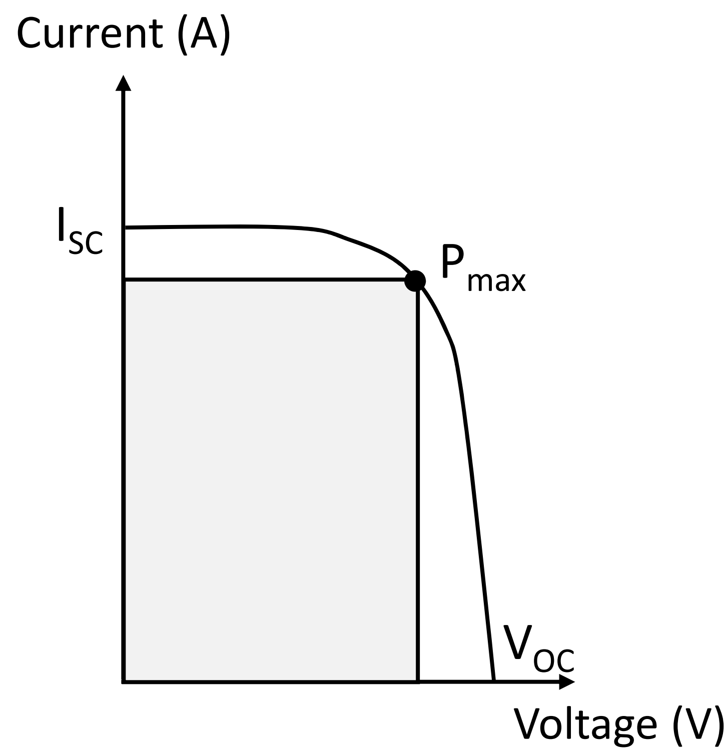
Characterization of PV



I-V Curve

V_{OC}: Open circuit voltage
I_{sc}: Short circuit current
P_{max}: Maximum power





Equations

- Output power:

$$P = IV = I_s V\left(e^{qV/kT} - 1\right) - I_L V$$

- Condition for maximum power: $dP/dV = 0$,

$$V_m = \frac{kT}{q}\ln\left[\frac{1+\left(I_L/I_s\right)}{1+\left(qV_m/kT\right)}\right] \approx V_{oc} - \frac{kT}{q}\ln\left(1+\frac{qV_m}{kT}\right)$$

$$I_m = I_s\left(\frac{qV_m}{kT}\right)\exp\left(\frac{qV_m}{kT}\right) \approx I_L\left(1-\frac{1}{qV_m/kT}\right)$$

Equations

- Maximum output power P_m:

$$P_m = I_m V_m$$
$$\approx I_L \left[V_{oc} - \frac{kT}{q} \ln\left(1 + \frac{qV_m}{kT} \right) - \frac{kT}{q} \right]$$

Conversion Efficiency and Fill Factor

- The power conversion efficiency (η) of a solar cell is given by:

$$\eta = \frac{I_m V_m}{P_{in}} = \frac{I_L \left[V_{oc} - \frac{kT}{q} \ln\left(1 + \frac{qV_m}{kT} \right) - \frac{kT}{q} \right]}{P_{in}}$$

$$= \frac{FF \cdot I_L V_{oc}}{P_{in}}$$

where P_{in} is the incident power and FF is the fill factor defined as:

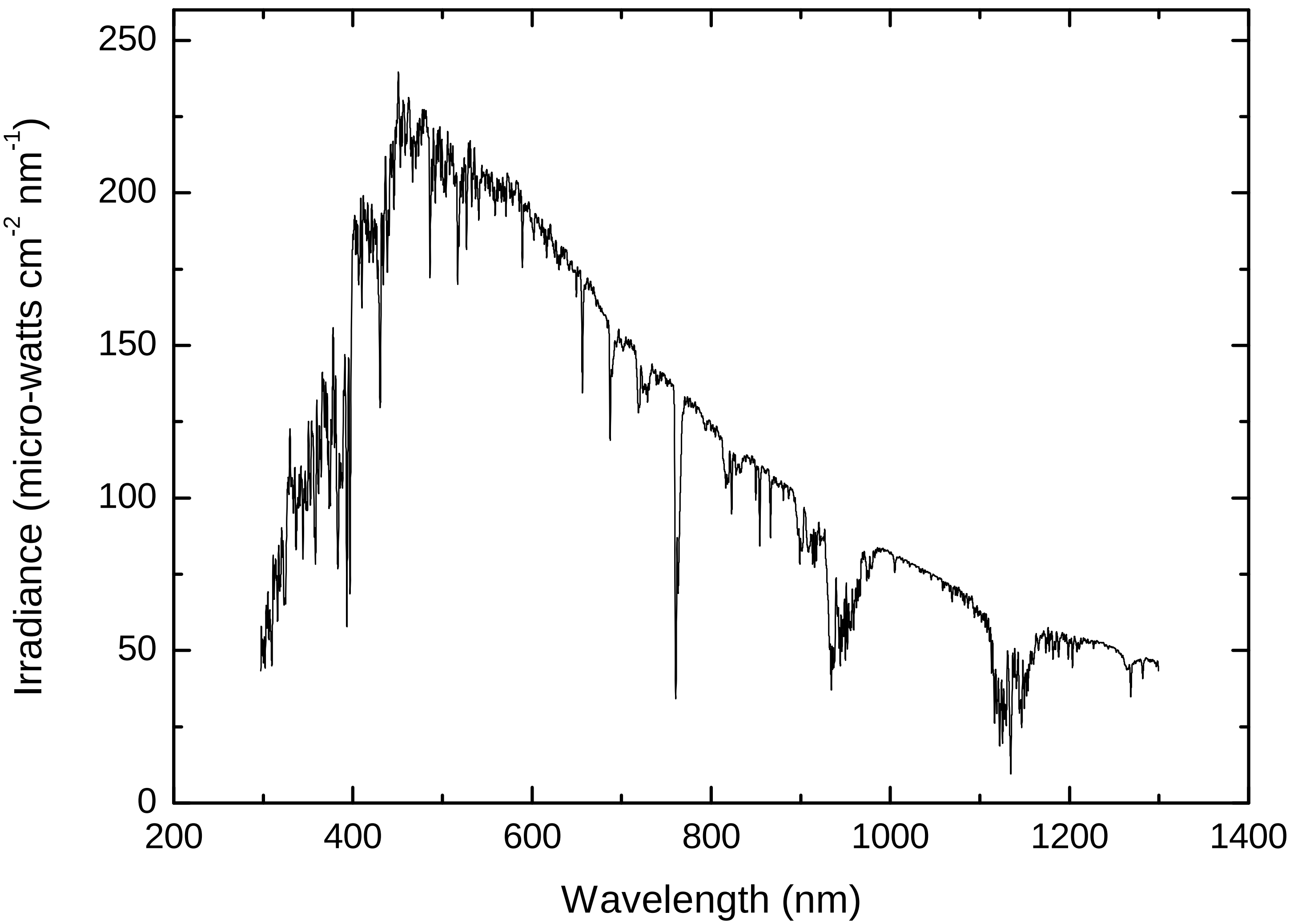
$$FF = \frac{I_m V_m}{I_L V_{oc}}$$

B. Proper design and installation of solar PV panel system

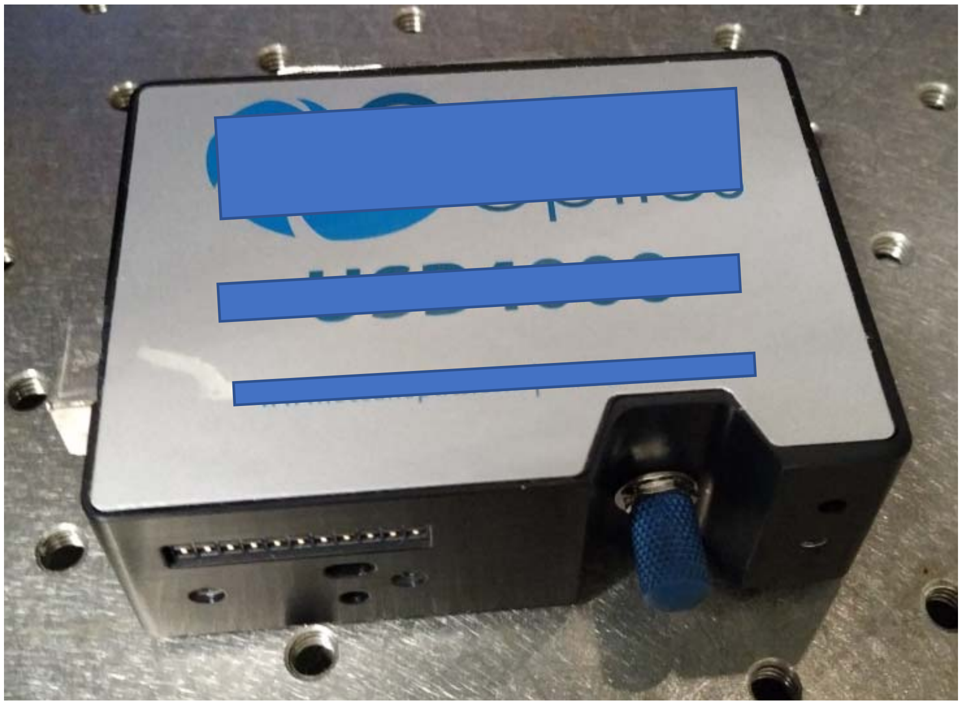
- Properties of sunlight
- Components of PV systems
- Aligning PV
  - The Sun's trajectory
  - Simulation of solar position
- PV System Installation
  - Solar site visits, surveys, and shading analysis
  - Mismatch in PV modules
  - Hot-spot effect, bypass diodes, and shading
  - Lightning effect
  - Price issue

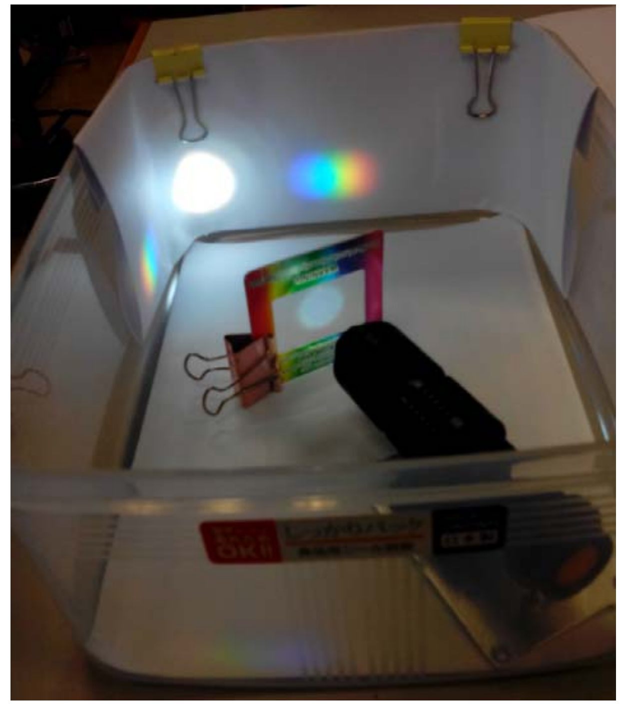
Properties of sunlight: solar spectrum

(1-nm spectral resolution spectrum)



Sunlight spectral analyzing tools





Properties of sunlight: solar irradiance

- Irradiance [Wm^{-2}] at a given temperature [K]:

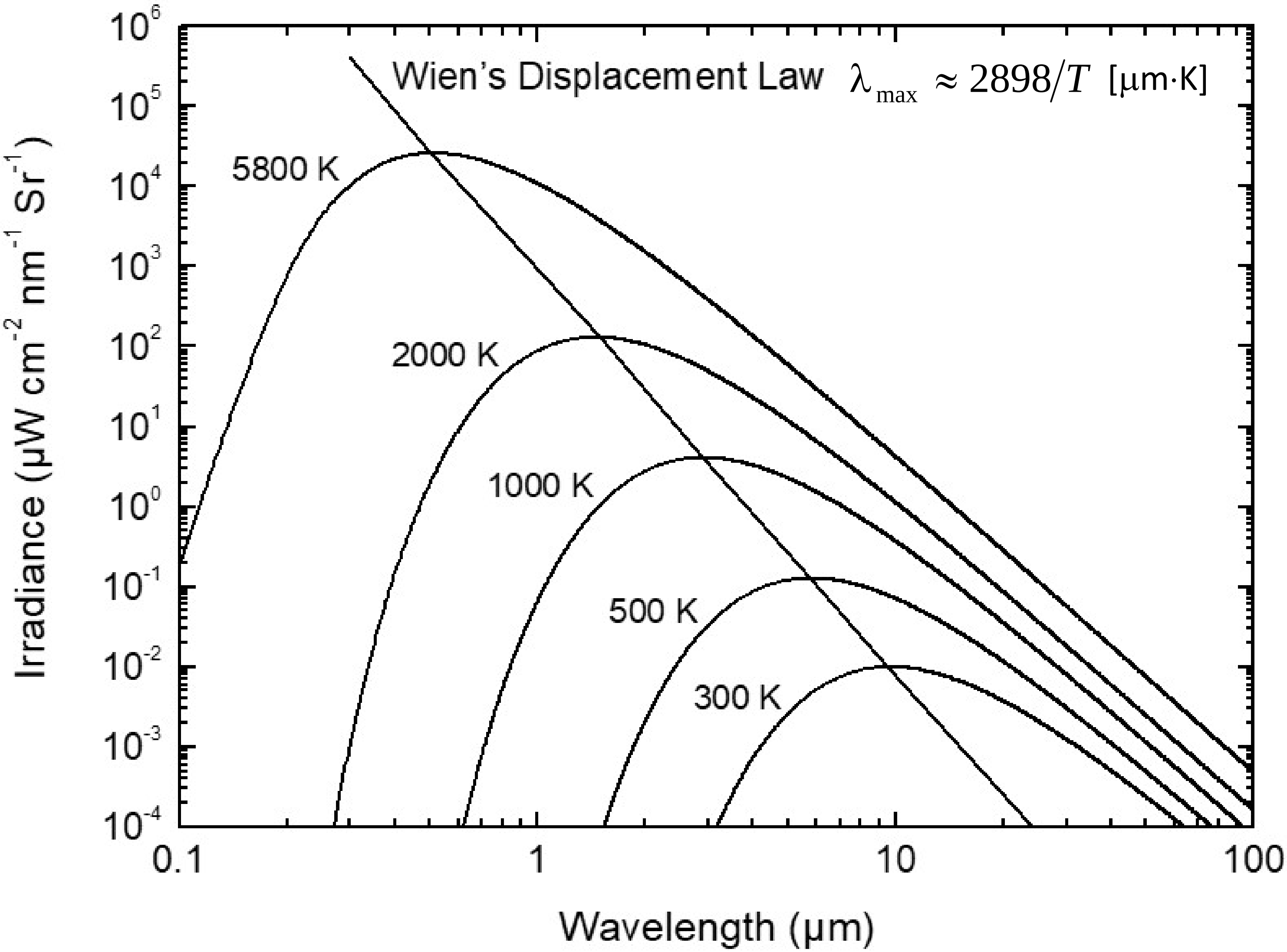
$$E(T) = \sigma T^4$$

where $\sigma = 5.67\times10^{-8}\ Wm^{-2}K^{-4}$.

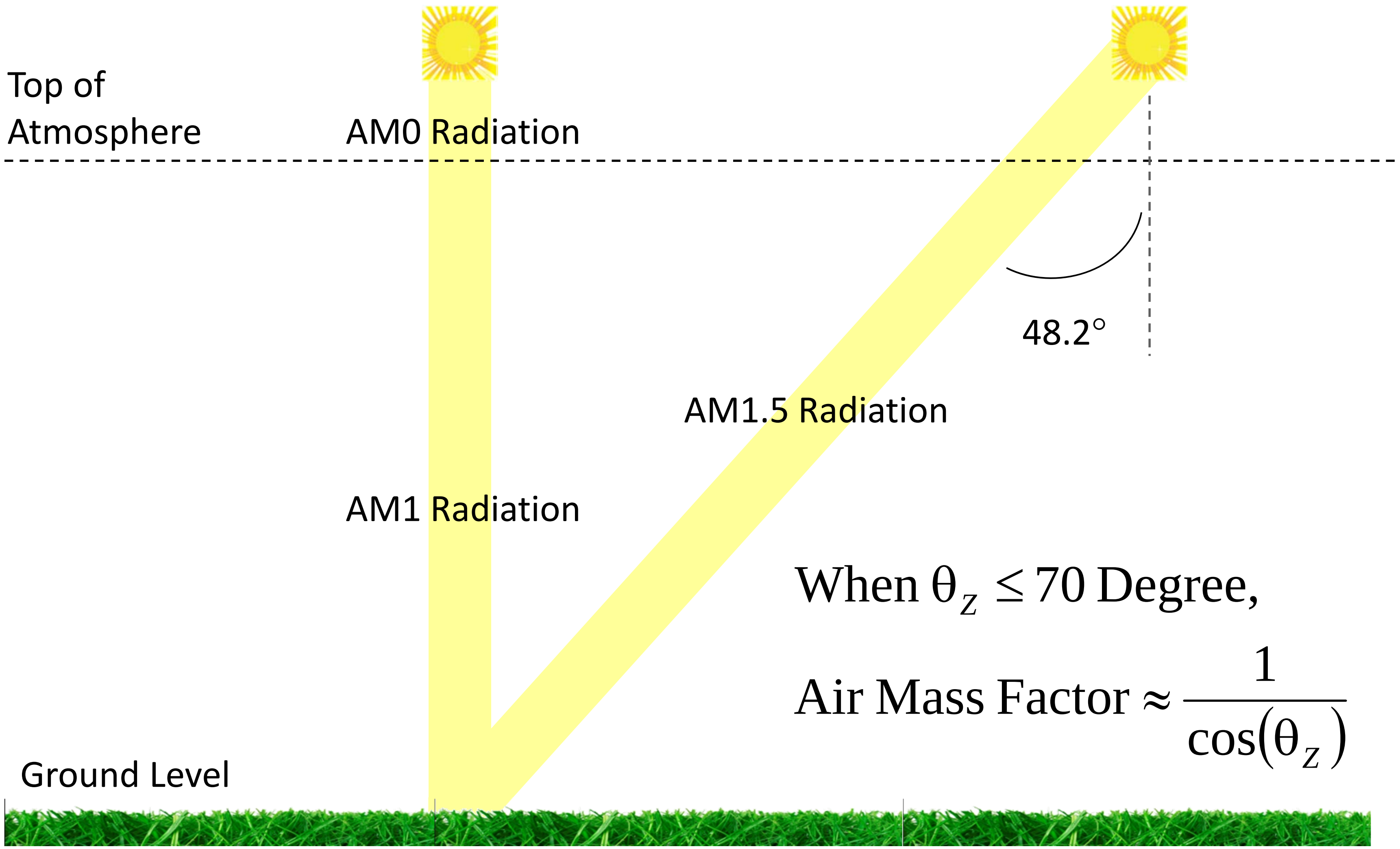
- Wien displacement law (maximum emission wavelength):

$$\lambda_{max} \approx 2898/T \qquad [\mu m\cdot K]$$

Properties of sunlight: Wien displacement law



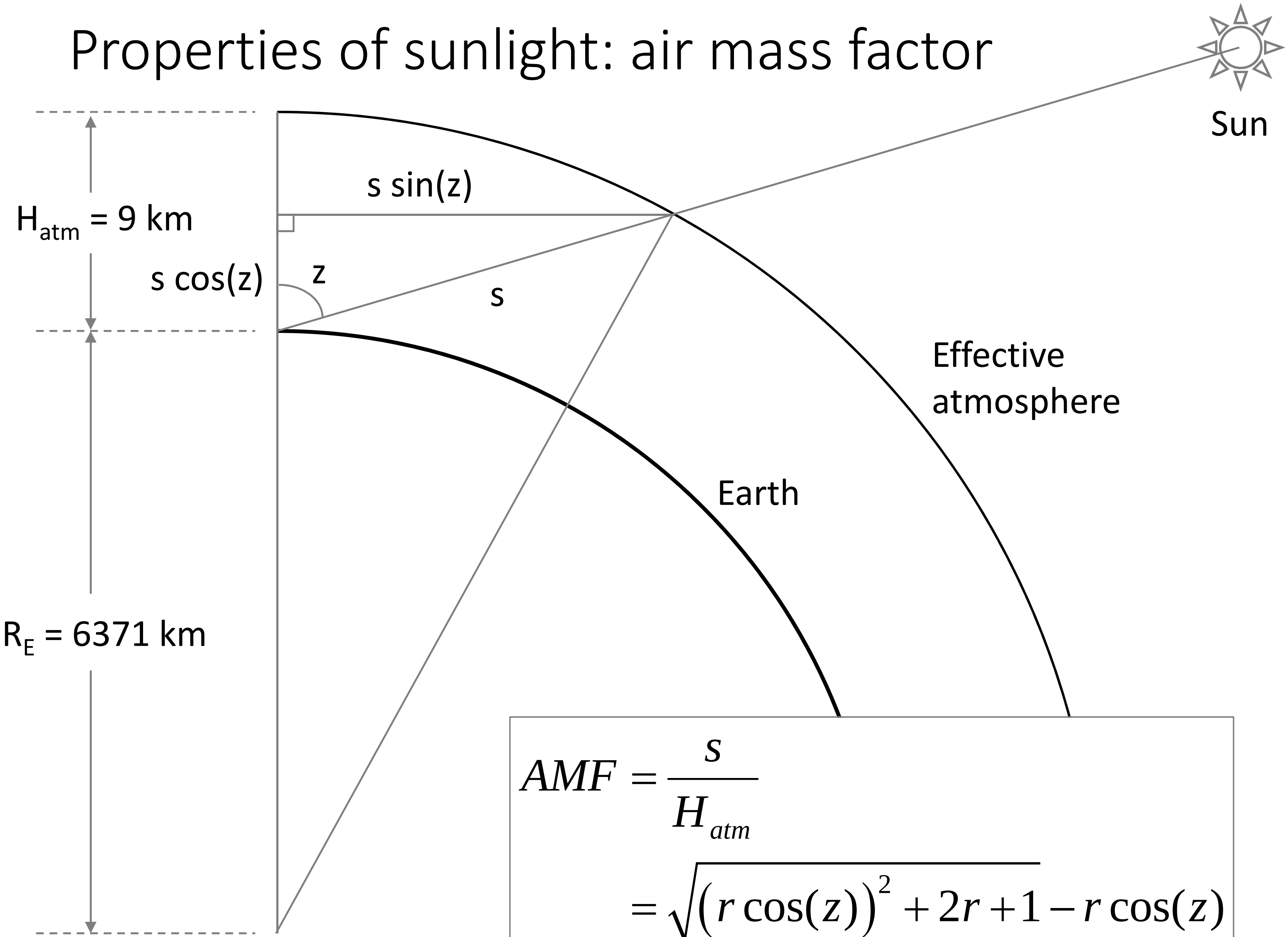
Properties of sunlight: air mass factor (大氣質量因子)



$$\text{When } \theta_Z \le 70 \text{ Degree,}$$

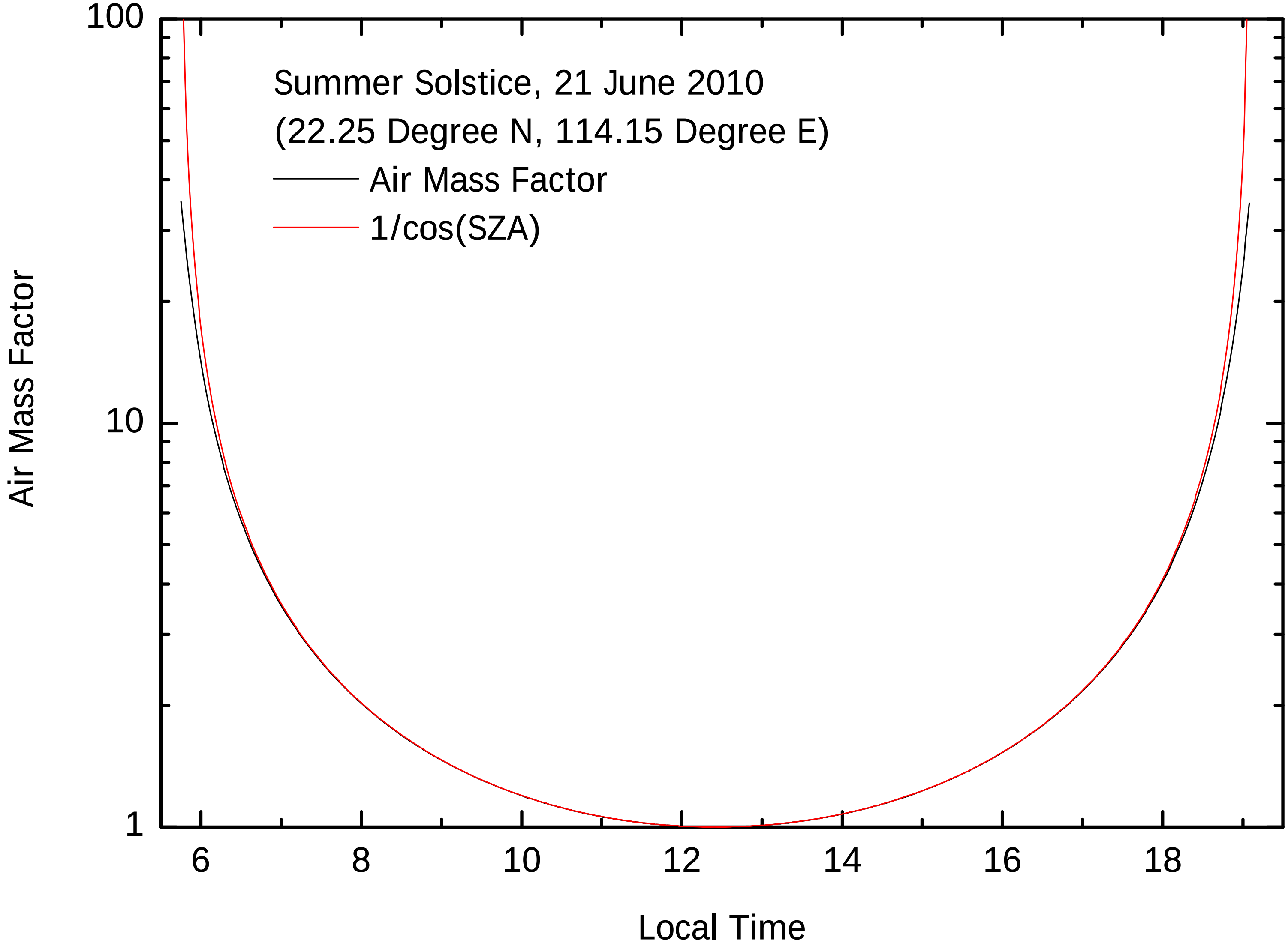
$$\text{Air Mass Factor} \approx \frac{1}{\cos(\theta_Z)}$$

Properties of sunlight: air mass factor

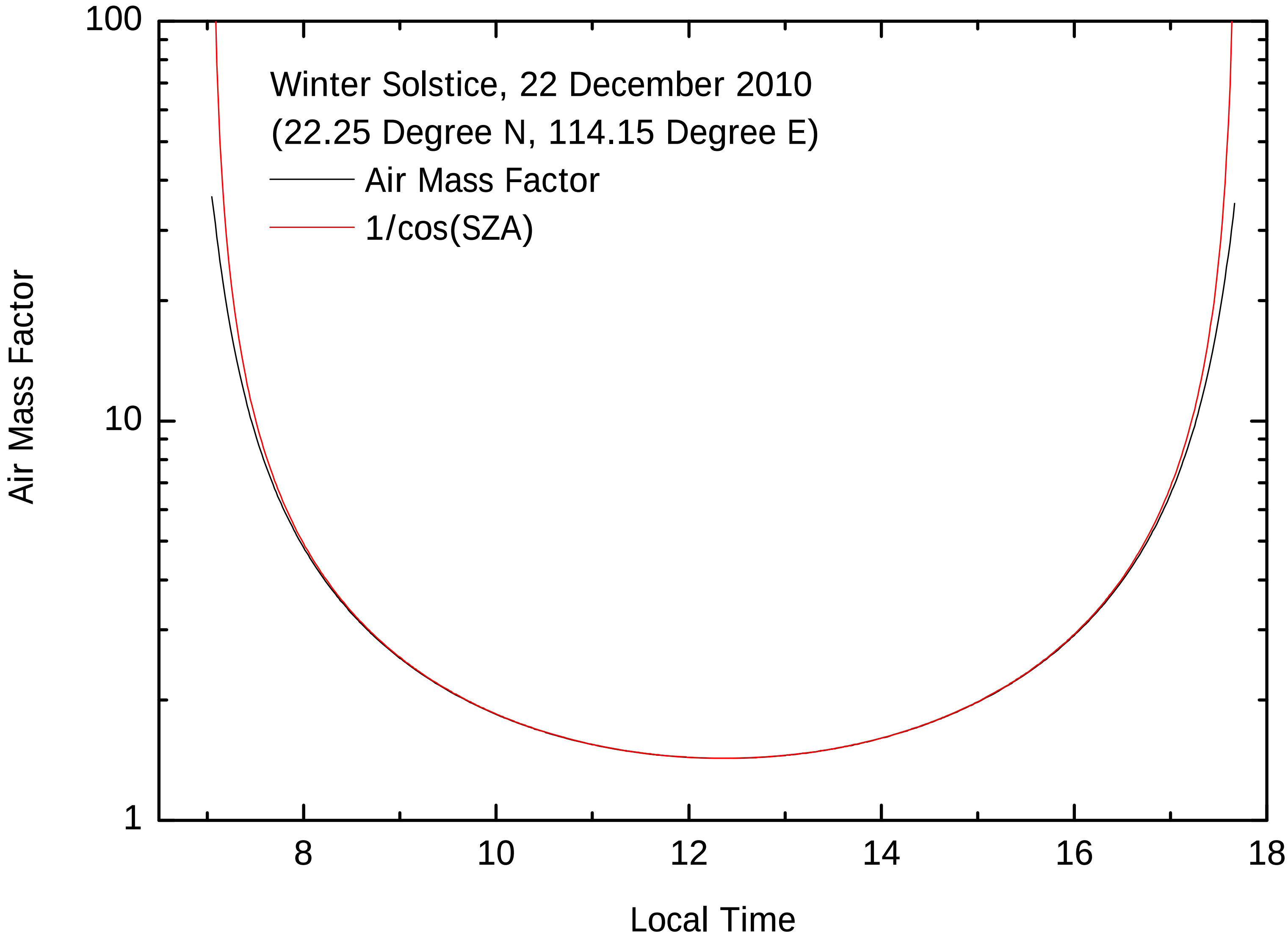


$$AMF = \frac{s}{H_{atm}}$$
$$= \sqrt{\left(r\cos(z)\right)^2 + 2r + 1} - r\cos(z)$$

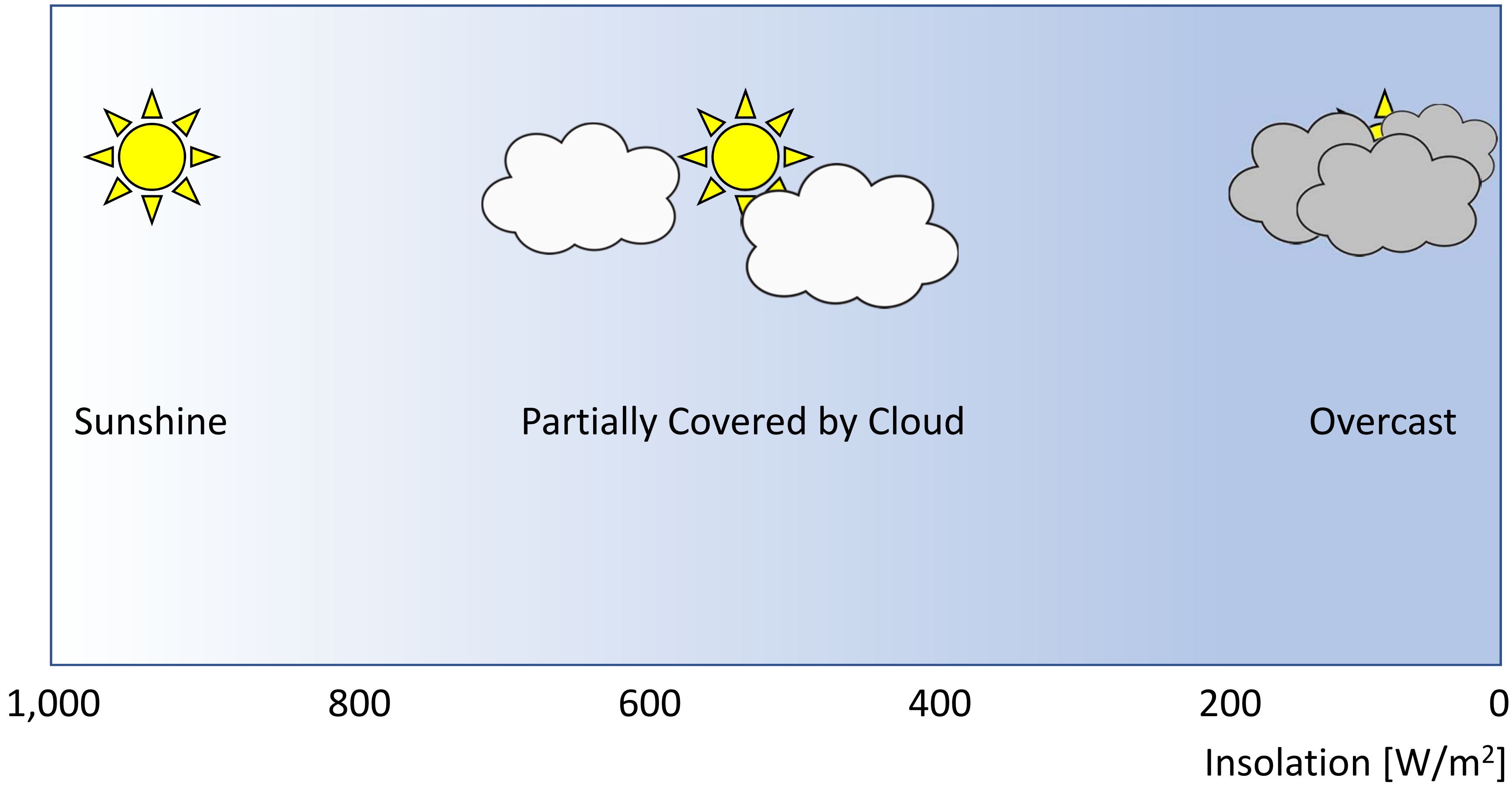
Example: Air mass factor



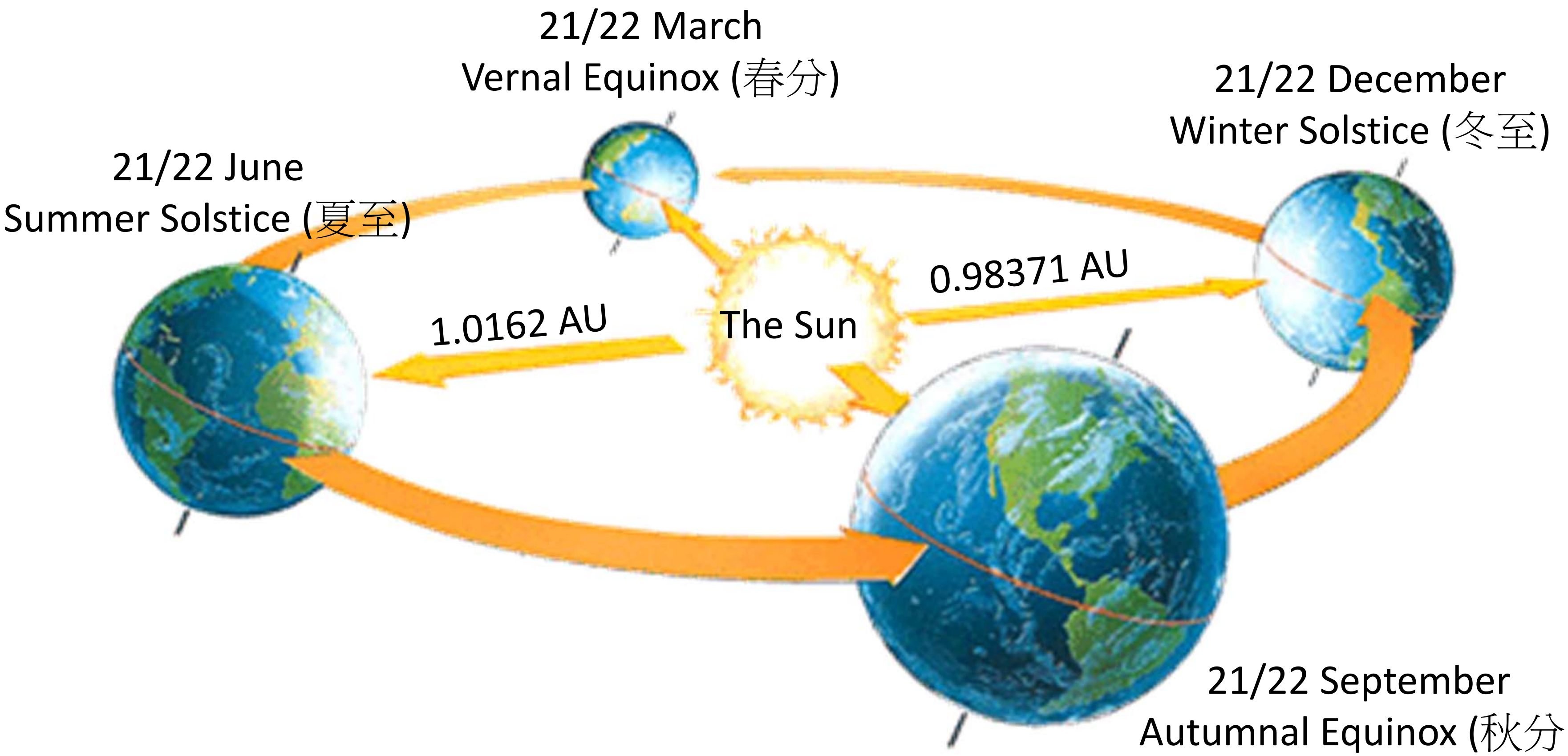
Example: Air mass factor



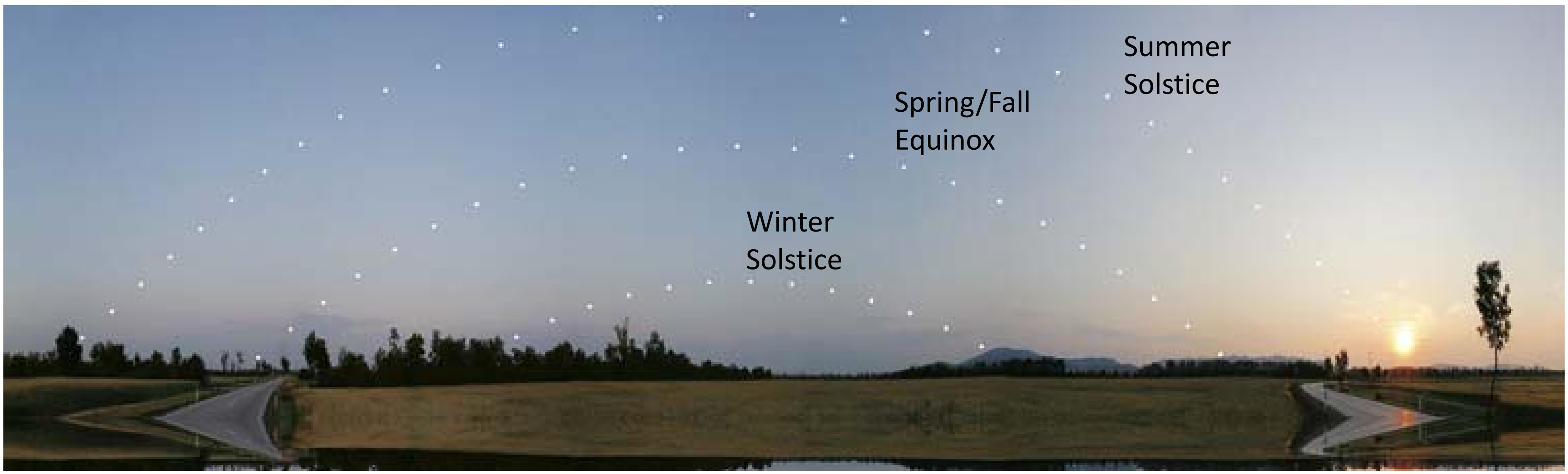
Direct and diffuse sunlight



Properties of sunlight: Earth-Sun geometry



The Sun's trajectory (太陽的軌跡)



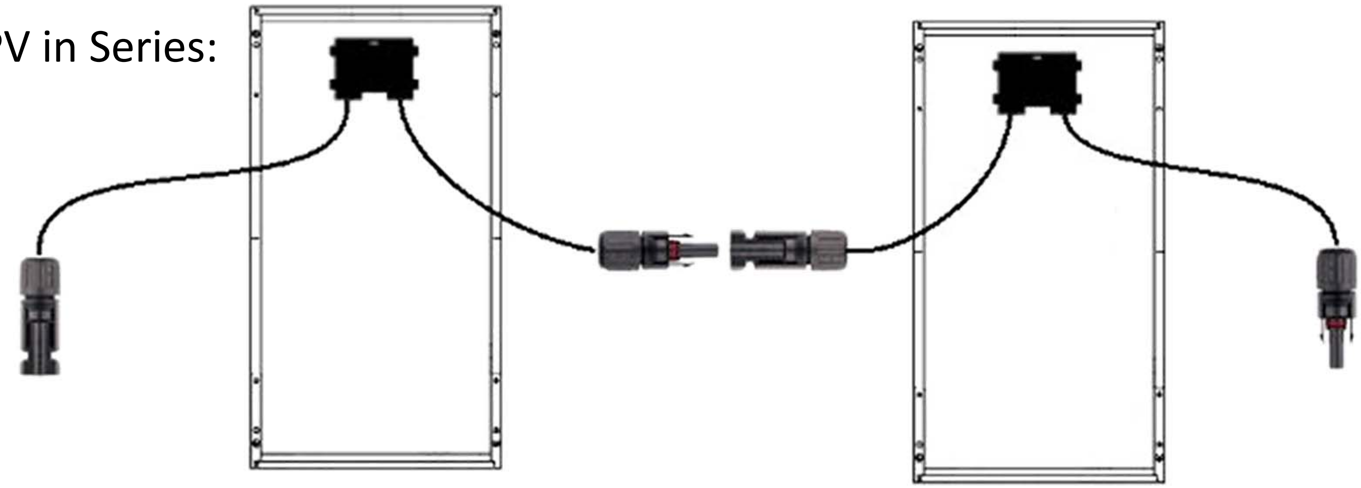
Source: APOD, looking down the Tyrrhenian Sea coast.

Components of PV systems

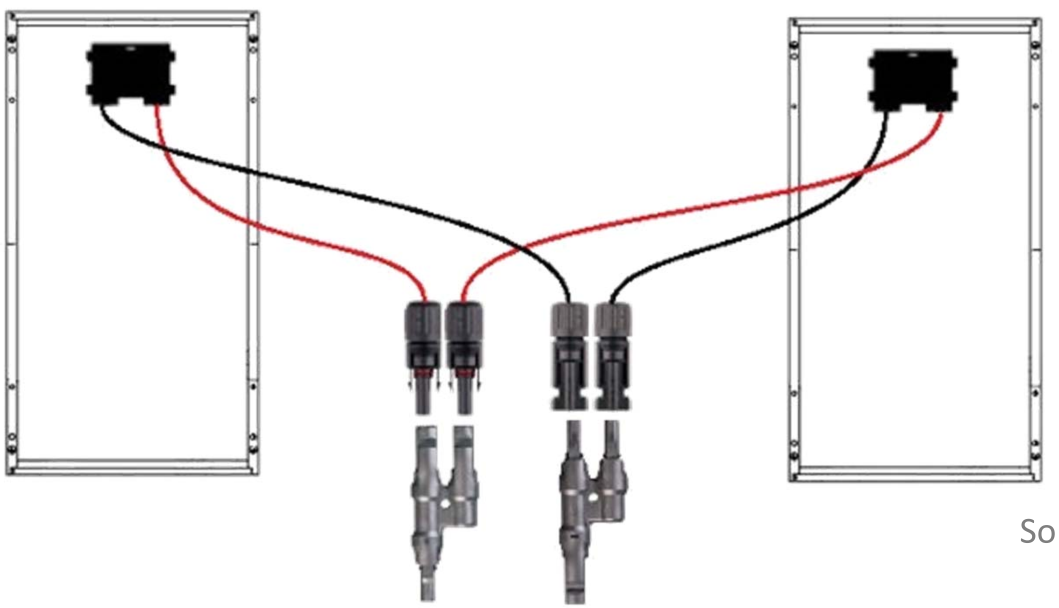
- PV modules/array
- PV cables/wires and standard PV connectors
- Solar charger and PV inverter
- Energy storage (e.g. battery, supercapacitor, power grid)
- Smart energy meters
- Junction boxes, string diodes, PV fuses

Components: Standard PV connectors

PV in Series:



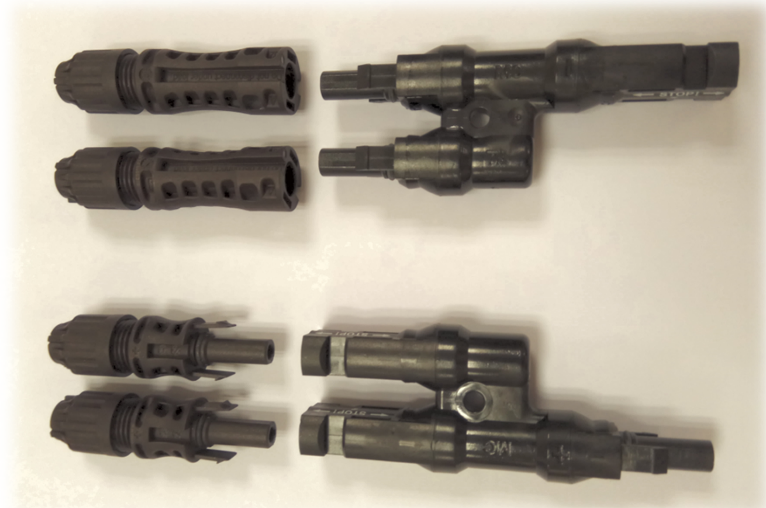
PV in Parallel:



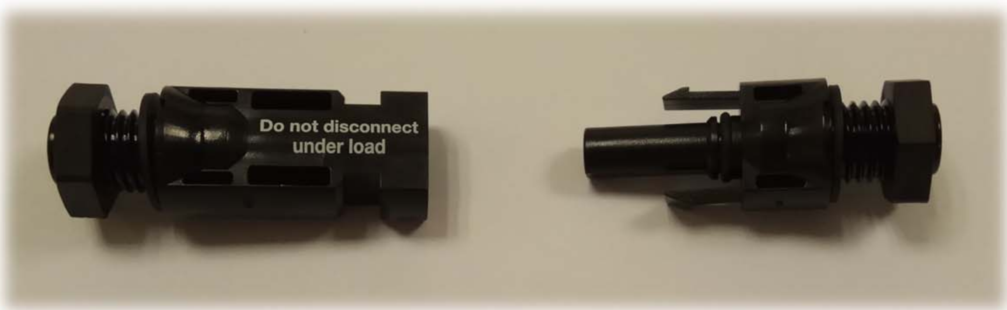
Source: https://www.solar-electric.com/

Components: PV Connectors and cables

MC4 plug connectors



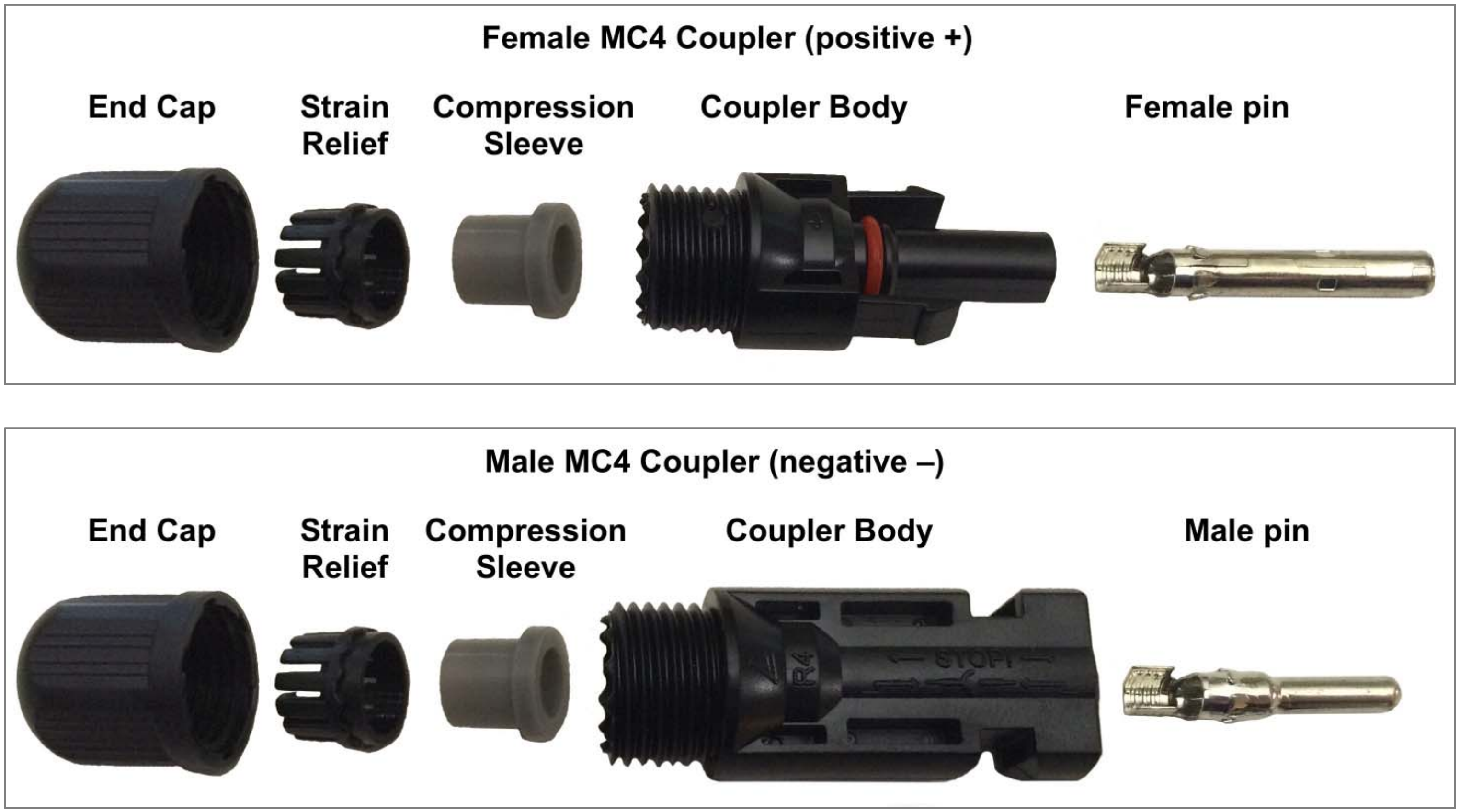
MC4 branch connectors



MC4 panel mounts

Cables

Components: PV Connectors and cables

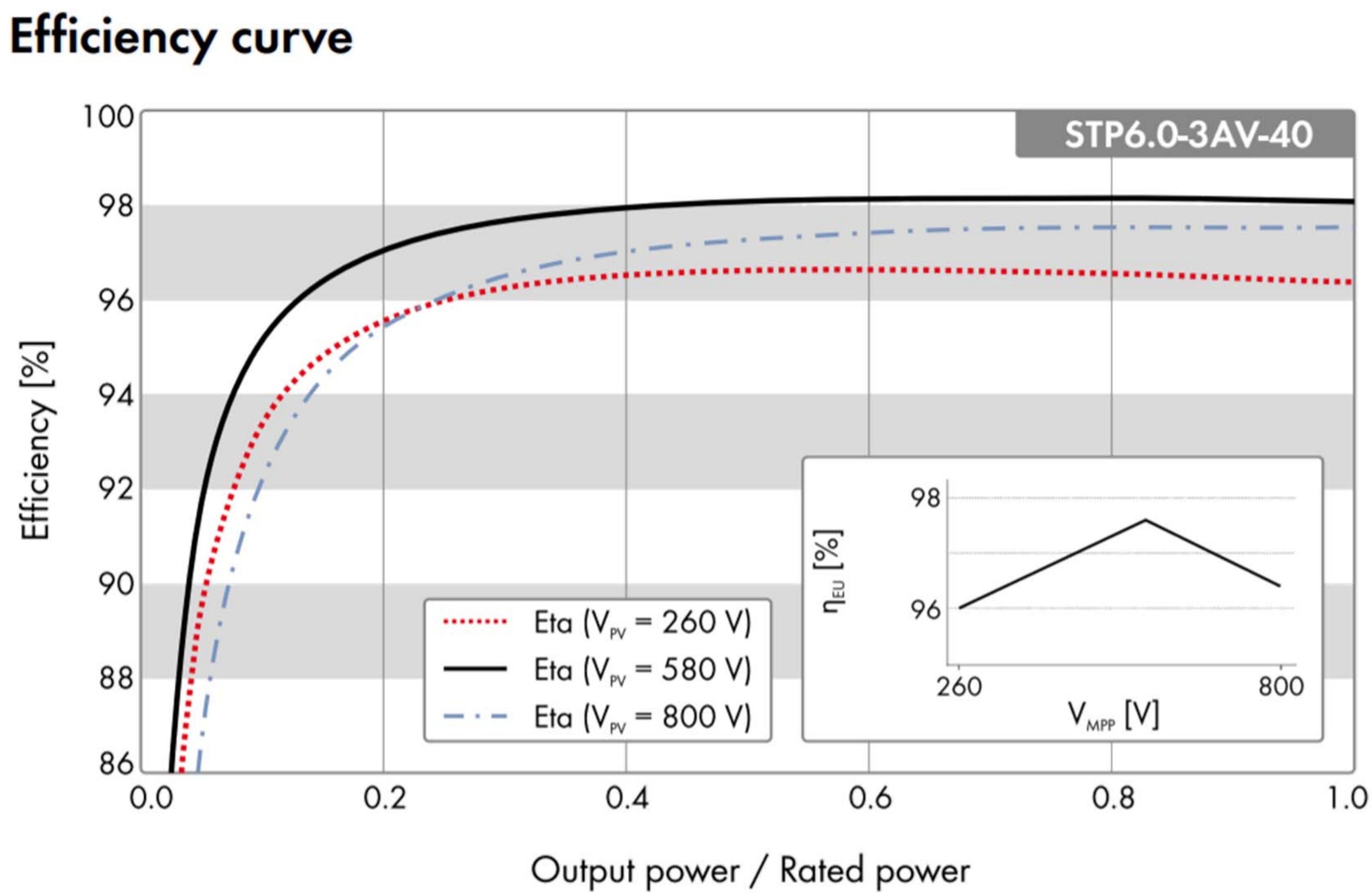


Components: Solar charger and inverter

Is this inverter suitable to PV applications?

PV inverter

Example: SMA Solar Technology (https://www.sma.de/en/)

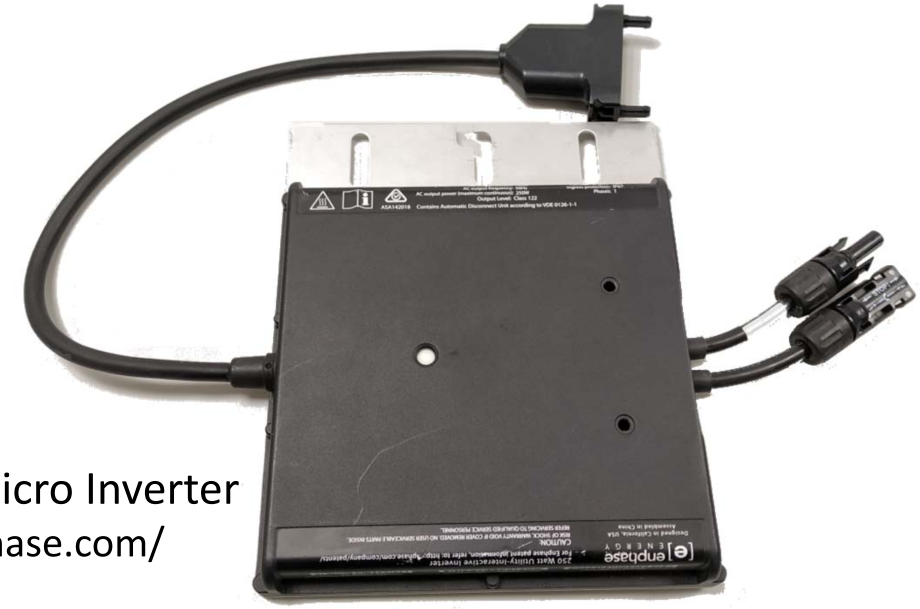


PV inverter

Technical data	Sunny Tripower 3.0	Sunny Tripower 4.0	Sunny Tripower 5.0	Sunny Tripower 6.0
Input (DC)				
Max. PV array power	6000 Wp	8000 Wp	9000 Wp	9000 Wp
Max. input voltage	850 V	850 V	850 V	850 V
MPP voltage range	140 V to 800 V	175 V to 800 V	215 V to 800 V	260 V to 800 V
Rated input voltage	580 V			
Min. input voltage / initial input voltage	125 V / 150 V			
Max. input current input A / input B	12 A / 12 A			
Max. DC short-circuit current input A/input B	18 A / 18 A			
Number of independent MPP inputs / strings per MPP input	2/A: 1; B: 1			
Output (AC)				
Rated power (at 230 V, 50 Hz)	3000 W	4000 W	5000 W	6000 W
Max. apparent power AC	3000 VA	4000 VA	5000 VA	6000 VA
Nominal AC voltage	3/N/PE; 220 V / 380 V 3/N/PE; 230 V / 400 V 3/N/PE; 240 V / 415 V			
AC voltage range	180 V to 280 V			
AC grid frequency / range	50 Hz / 45 Hz to 55 Hz 60 Hz / 55 Hz to 65 Hz			
Rated grid frequency / rated grid voltage	50 Hz / 230 V			
Max. output current	3 x 4.5 A	3 x 5.8 A	3 x 7.6 A	3 x 9.1 A
Power factor at rated power / Displacement power factor, adjustable	1 / 0.8 overexcited to 0.8 underexcited			
Feed-in phases / connection phases	3 / 3			
Efficiency				
Max. efficiency / European efficiency	98.2% / 96.5%	98.2% / 97.1%	98.2% / 97.4%	98.2% / 97.6%

Source: https://files.sma.de/dl/31716/STP30-60-DEN1834-V13web.pdf
Note: Euro Efficiency means operating efficiency over a yearly power distribution corresponding to middle-Europe climate.

PV micro inverter

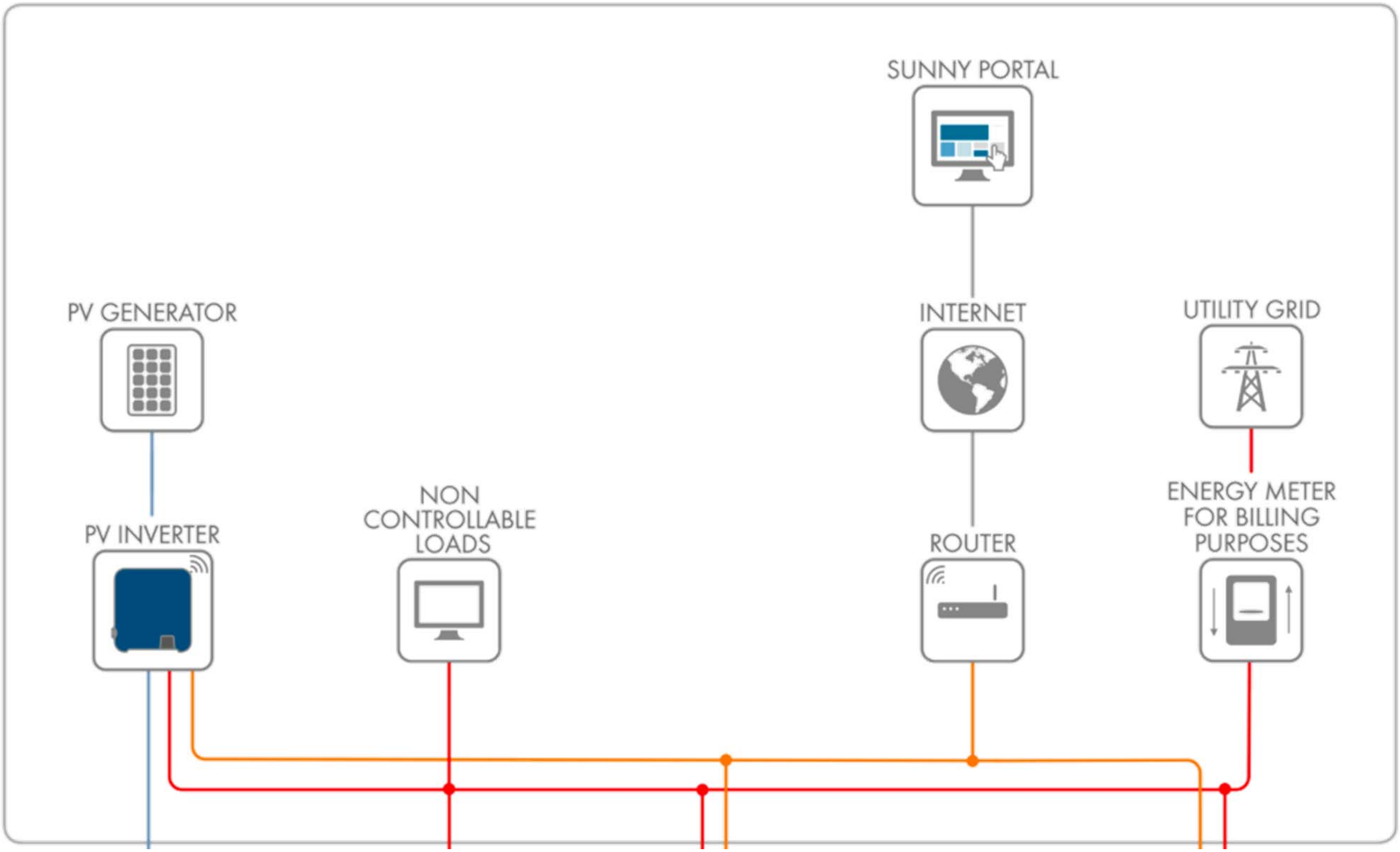


Enphase Micro Inverter
https://enphase.com/

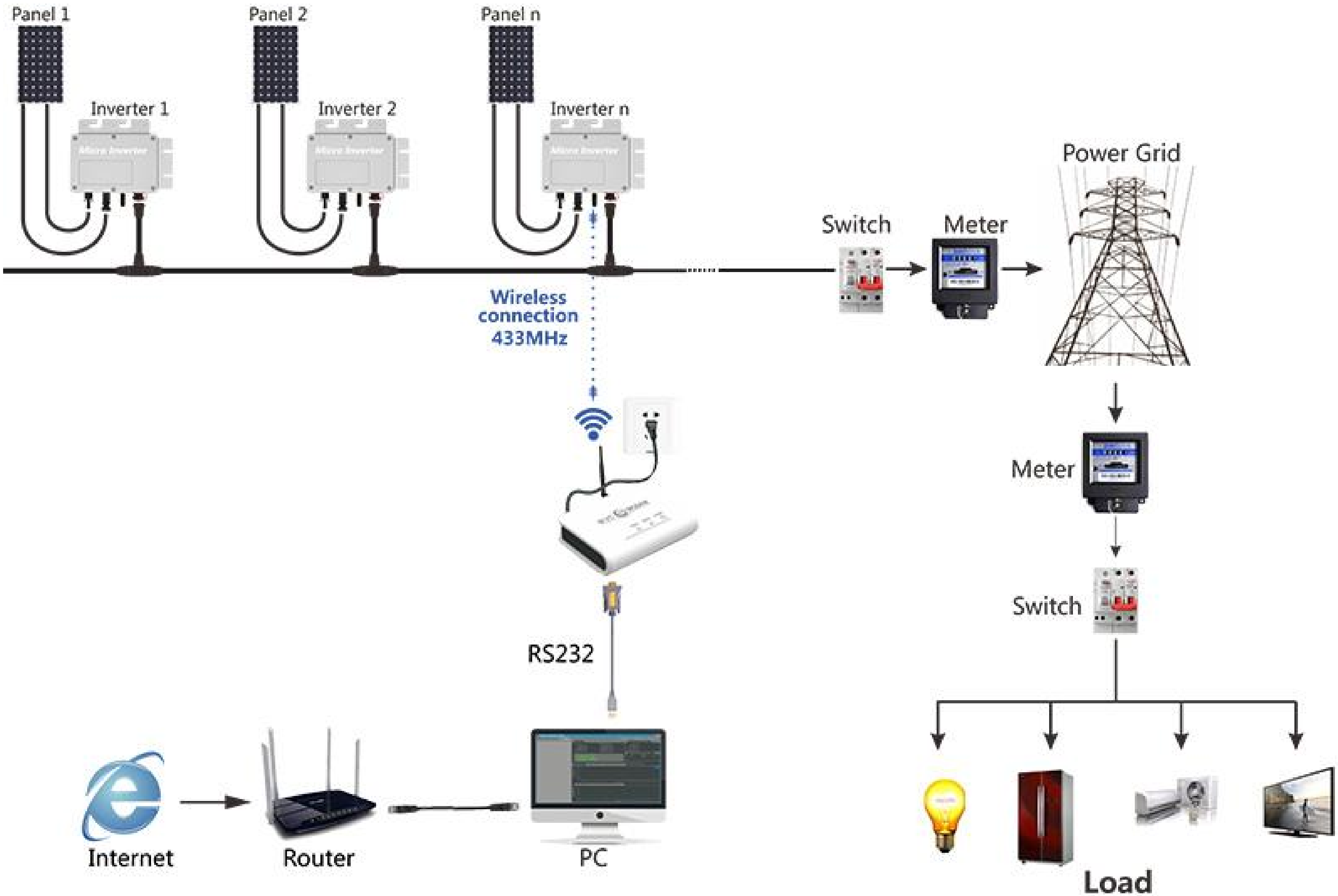
SMA Micro Inverter
https://www.sma.de/en/products/solarinverters/sunny-tripower-30-40-50-60.html

Fenixsolar Micro Inverter
http://www.fenixsolar.com/

PV micro inverter



PV micro inverter



WVC-300 MICRO INVERTER

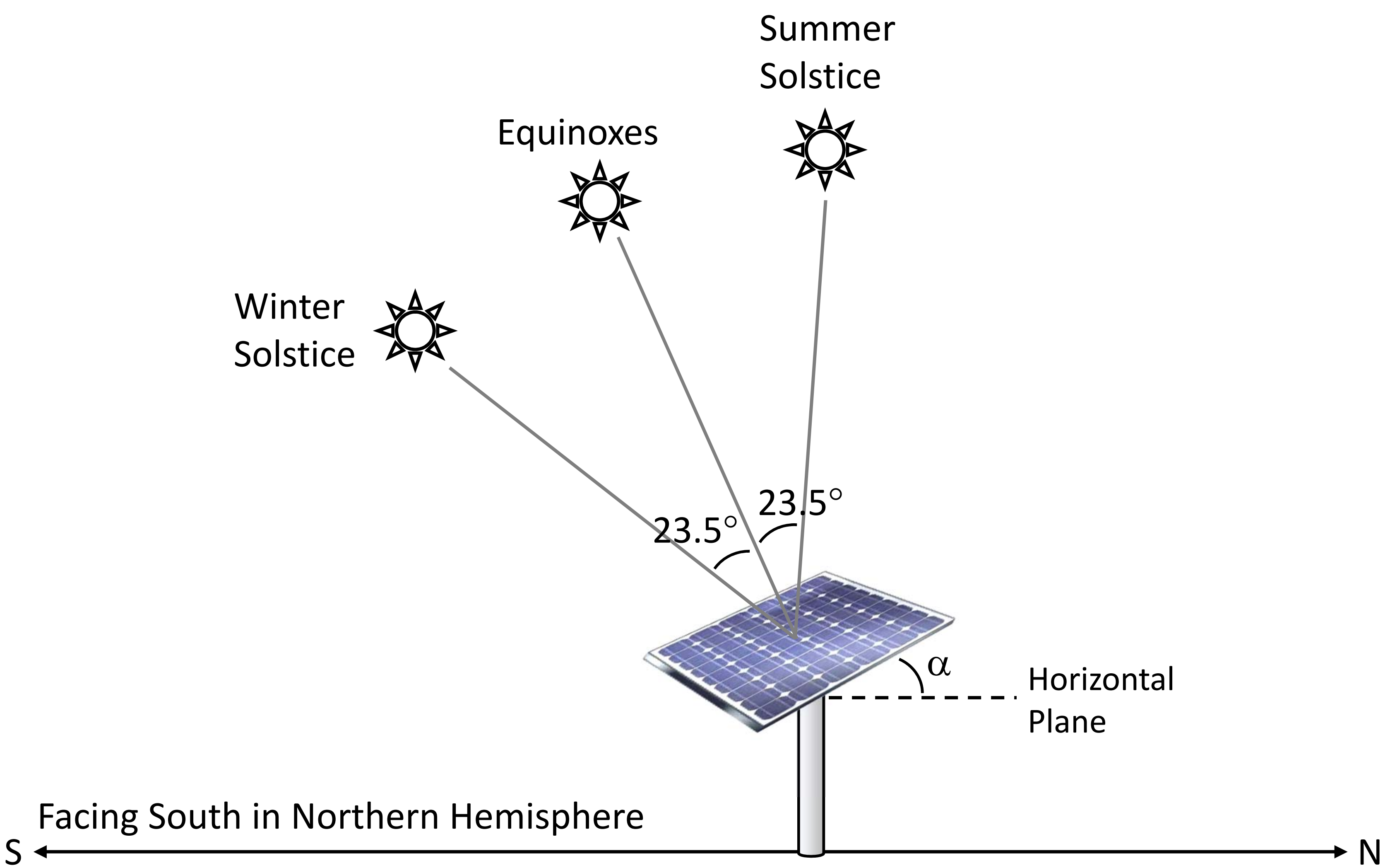
INPUT DATA	WVC-300 (120VAC / 230VAC)
Recommended input power	300Watt
Recommended PV modules	300W / Vmp > 34VDC / Voc < 50VDC
Maximum input DC voltage	50VDC
Peak power tracking voltage	22-50VDC
Operating voltage range	17-50VDC
Min. / Max. Start voltage	22-50VDC
Maximum DC short current	15A
Maximum input current	9.8A

OUTPUT DATA	@120VAC	@230VAC
Peak output power	260Watt	260Watt
Rated output power	250Watt	250Watt
Rated output current	2.08A	0.92A
Rated voltage range*	80-160VAC	180-260VAC
Rated frequency range*	57-62.5Hz	47-52.5Hz
Power factor (cos ϕ)	> 96%	> 96%
Maximum units per branch circuit	15pcs (Single-phase)	30pcs (Single-phase)

OUTPUT EFFICIENCY	@120VAC	@230VAC
Static MPPT efficiency	99.5%	99.5%
Maximum output efficiency	92.3%	94.6%
Average efficiency	91.2%	93.1%
Consumption at night	< 50mW Max	< 70mW Max
THD	< 5%	< 5%

Aligning PV array

for maximum annual solar energy collection



Not to scale illustration

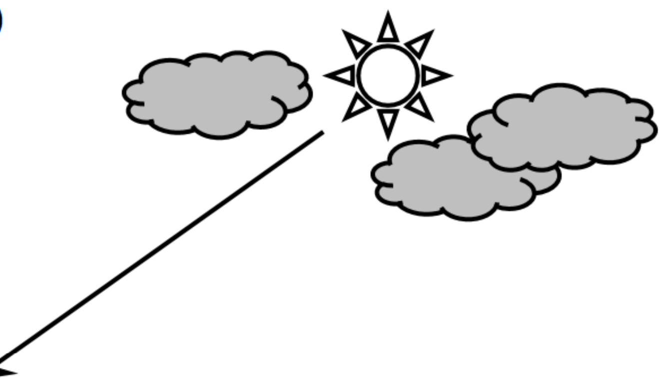
Solar irradiance on tilted PV

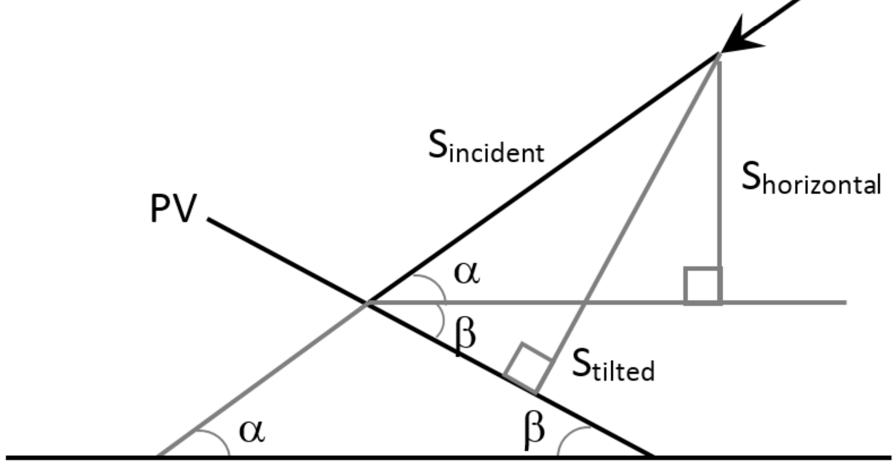
$$S_{horizontal} = S_{incident} \cdot \sin\alpha \qquad (1)$$

$$S_{titled} = S_{incident}\left[\sin\left(\alpha+\beta\right)\right] \qquad (2)$$

Equations (1) and (2) give:

$$S_{titled} = \frac{S_{horizontal} \cdot \sin(\alpha+\beta)}{\sin\alpha}.$$





α = solar elevation angle

β = PV tilt angle

$S_{incident}$ = Incident solar irradiance

S_{tilted} = Solar irradiance on tilted PV

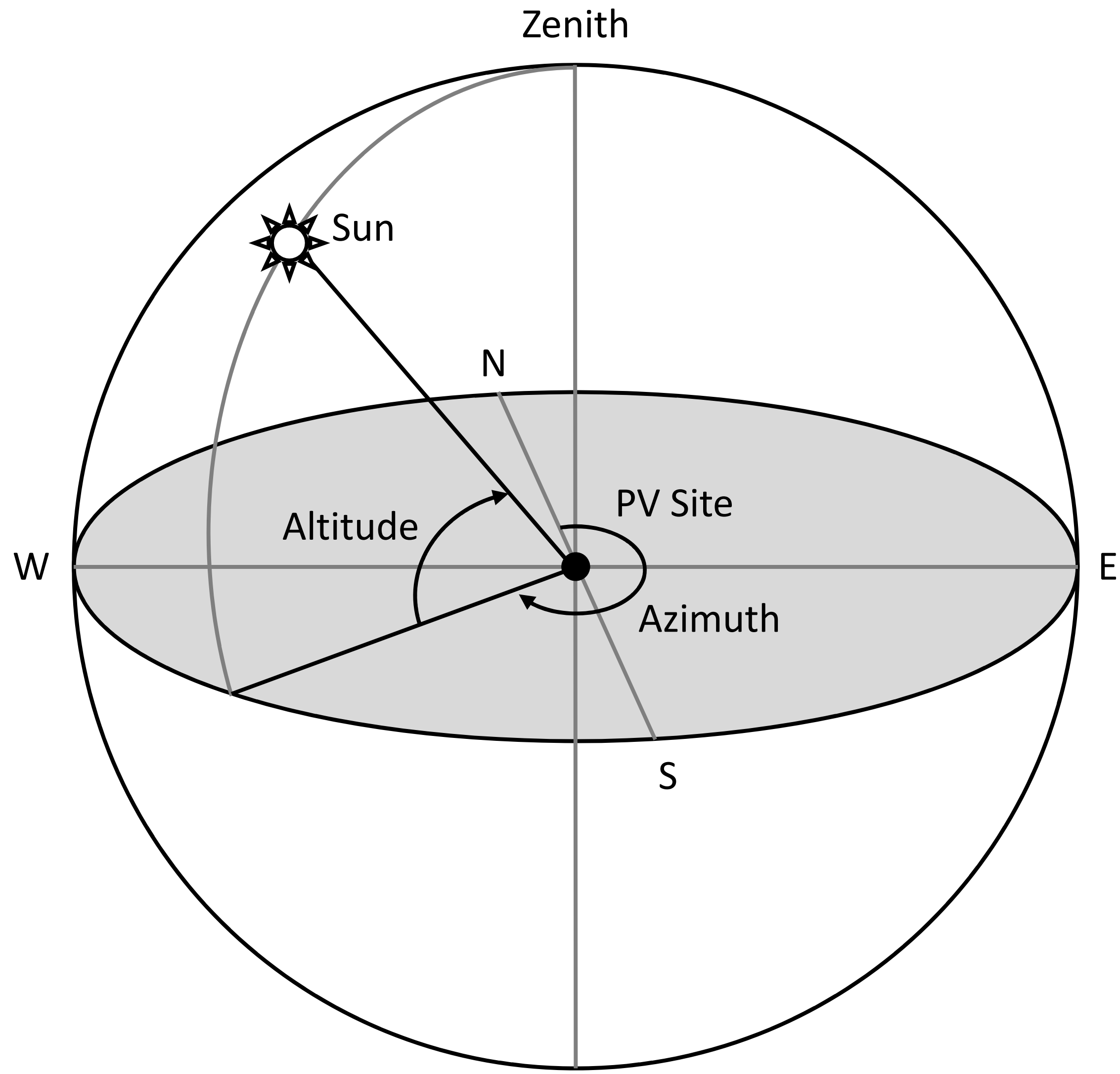
$S_{horizontal}$ = Solar irradiance on horizontal PV

Aligning PV array

Location	Latitude / Longitude	PV Array Alignment Parameters
Hong Kong	22°15' N, 114°10' E	a ≈ 22°
Beijing	39°55' N, 116°23' E	a ≈ 40°
Singapore	01°22' N, 103°45' E	a ≈ 1°
Sydney*	33°55' S, 151°17' E	a ≈ 34°

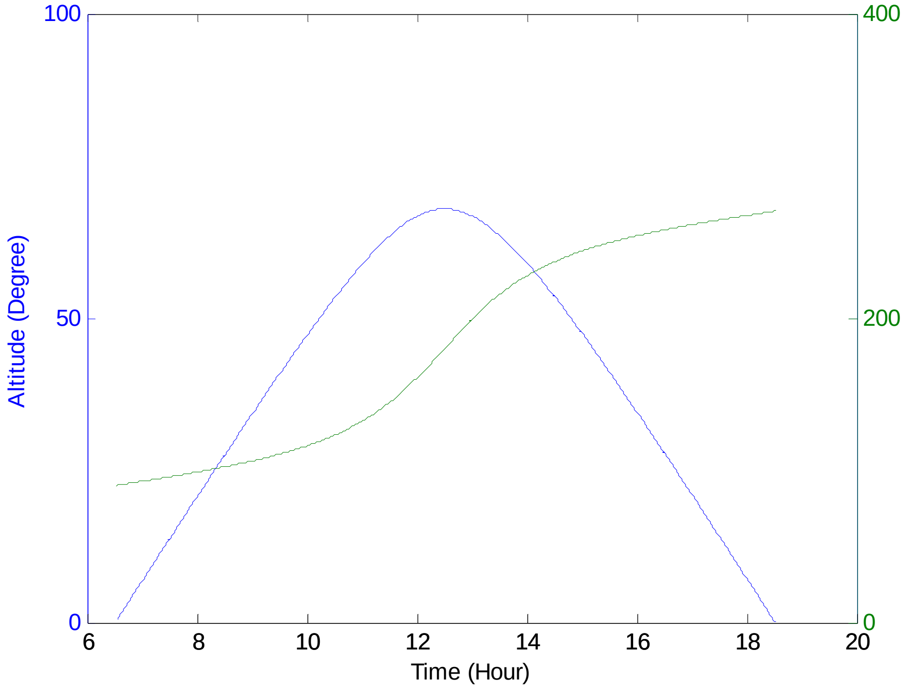
* Facing North

Concept: Altitude and azimuth angles

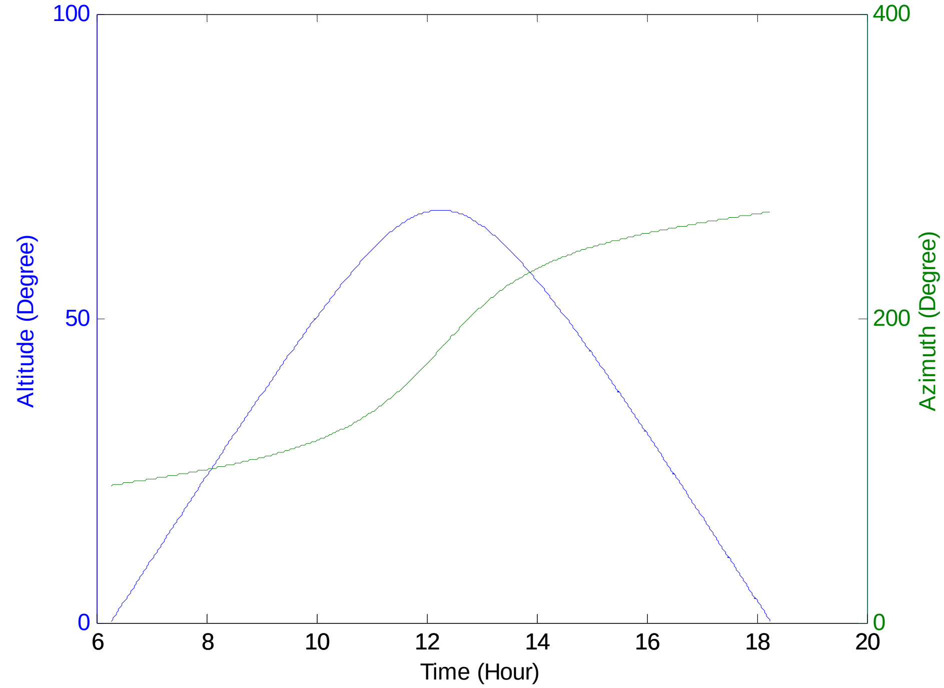


Simulation of solar position

Altitude and azimuth position of the Sun for an observer in Hong Kong (22.25°N, 114.15°E).



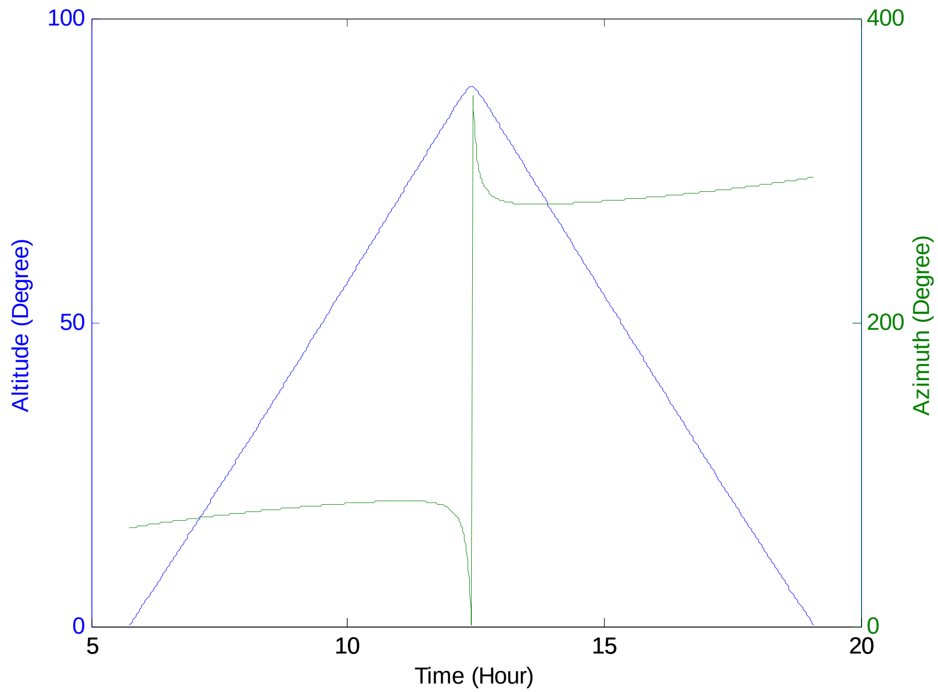
Vernal Equinox, 21 March 2010
Sunrise: 06:31
Sunset: 18:31



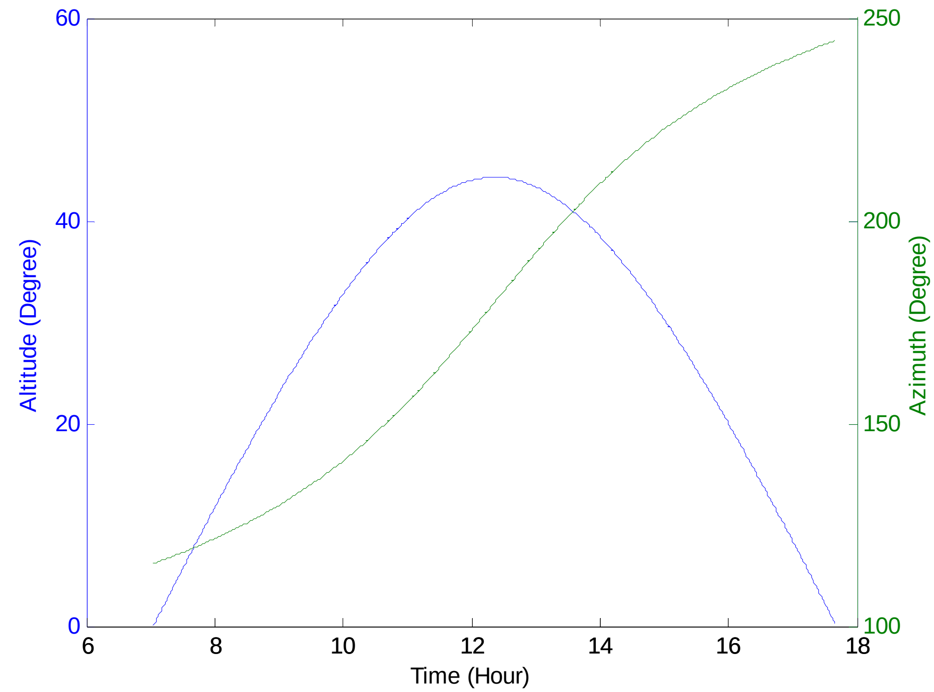
Autumn Equinox, 23 September 2010
Sunrise: 06:16
Sunset: 18:15

Simulation of solar position

Altitude and azimuth position of the Sun for an observer in Hong Kong (22.25°N, 114.15°E).



Summer Solstice, 21 June 2010
Sunrise: 05:45
Sunset: 19:05



Winter Solstice, 22 December 2010
Sunrise: 07:03
Sunset: 17:40

PV system Installation

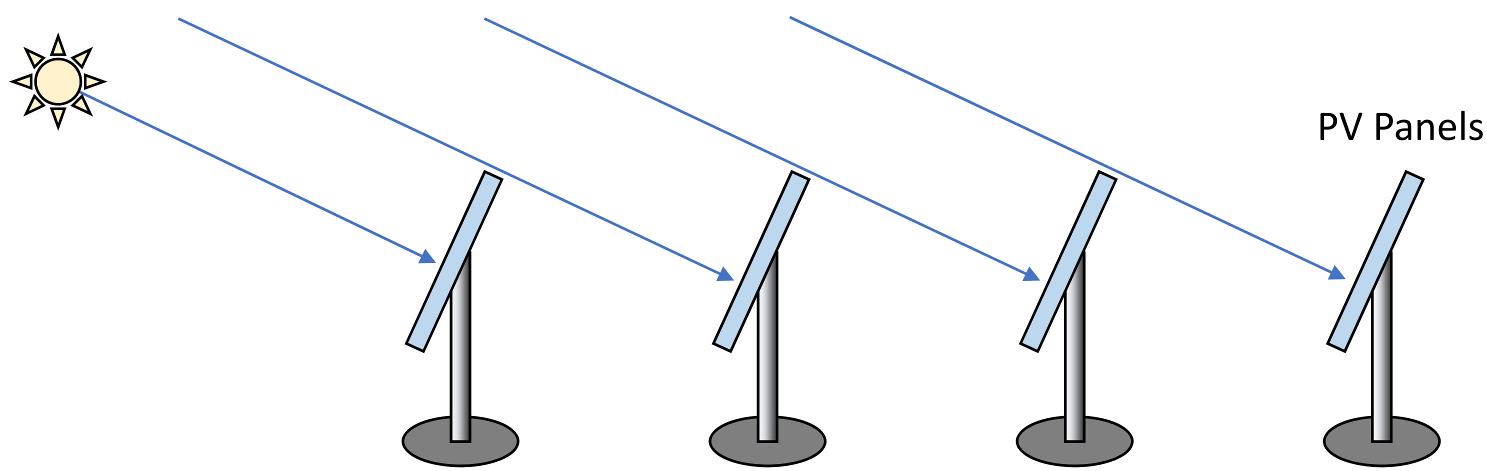
Factors for consideration

- On grid / off grid solar system
  - Battery, supercapacitor
- Efficiency
- PV colors
- Solar site visits, surveys, and shading analysis
  - Checklist for site survey
- Mismatch in PV modules
- Hot-spot effect, shading
  - bypass diodes
- Lightning effect
- PV Power optimizer (DC-DC converter)

Shadow types

- Temporary shading
  - Leaves, bird droppings, dust, snow
- Shading resulted from location and buildings
- Self shading
- Direct shading

Which type of this shading is?

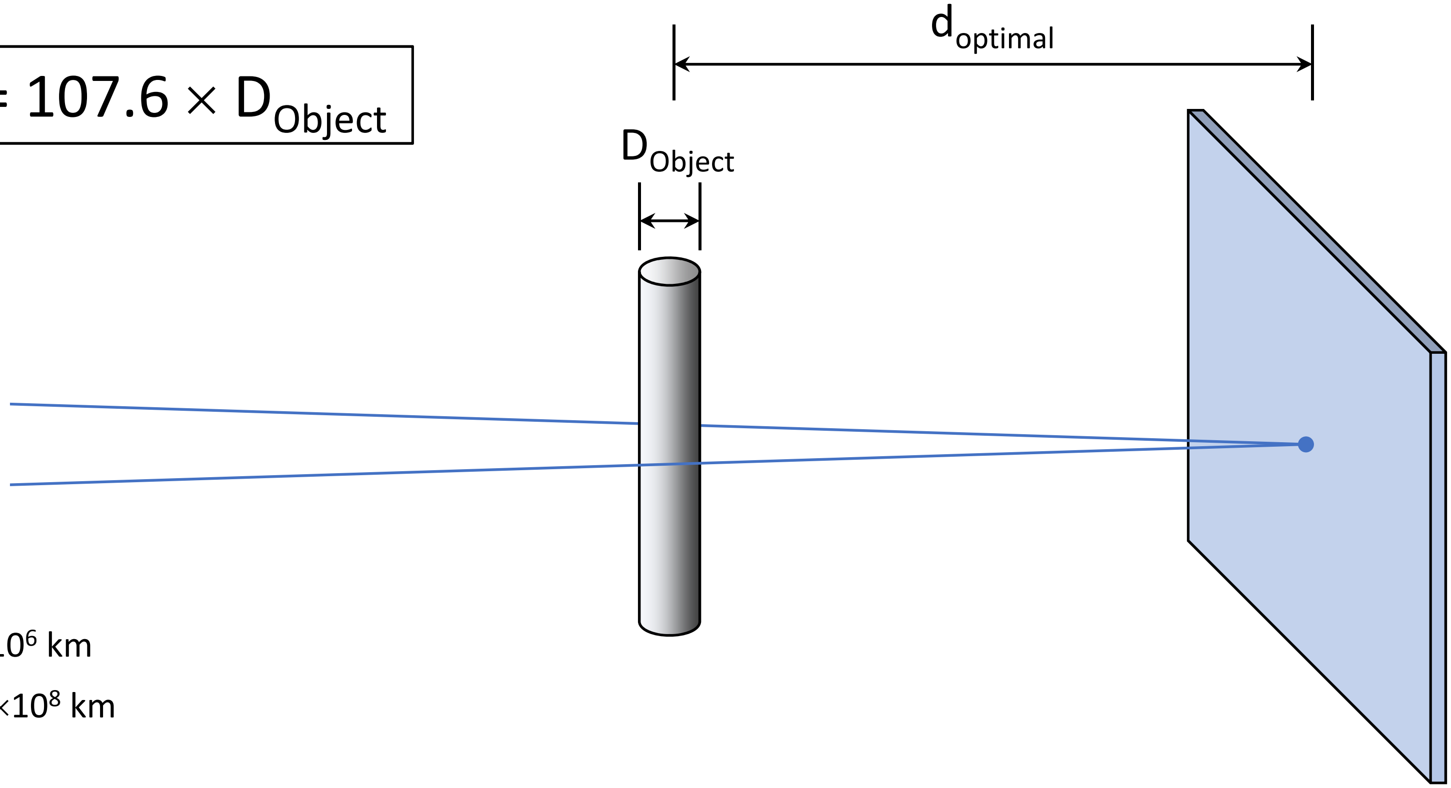


Direct shading

Example: Cable above PV panels.

To find the optimal distance ($d_{optimal}$) between a shading-casting object and PV panel:

$$d_{optimal} = 107.6 \times D_{Object}$$



Remark:

$\varnothing_{SUN} = 1.39 \times 10^6$ km

1AU = 1.496×10^8 km

Solar site visits, surveys, and shading analysis

Traditional method of shading analysis: measure buildings' elevation and azimuth then plot on a sun chart.

Example:

Solar site survey/analysis of shadows using elevation/azimuth

RimstarOrg 34K views

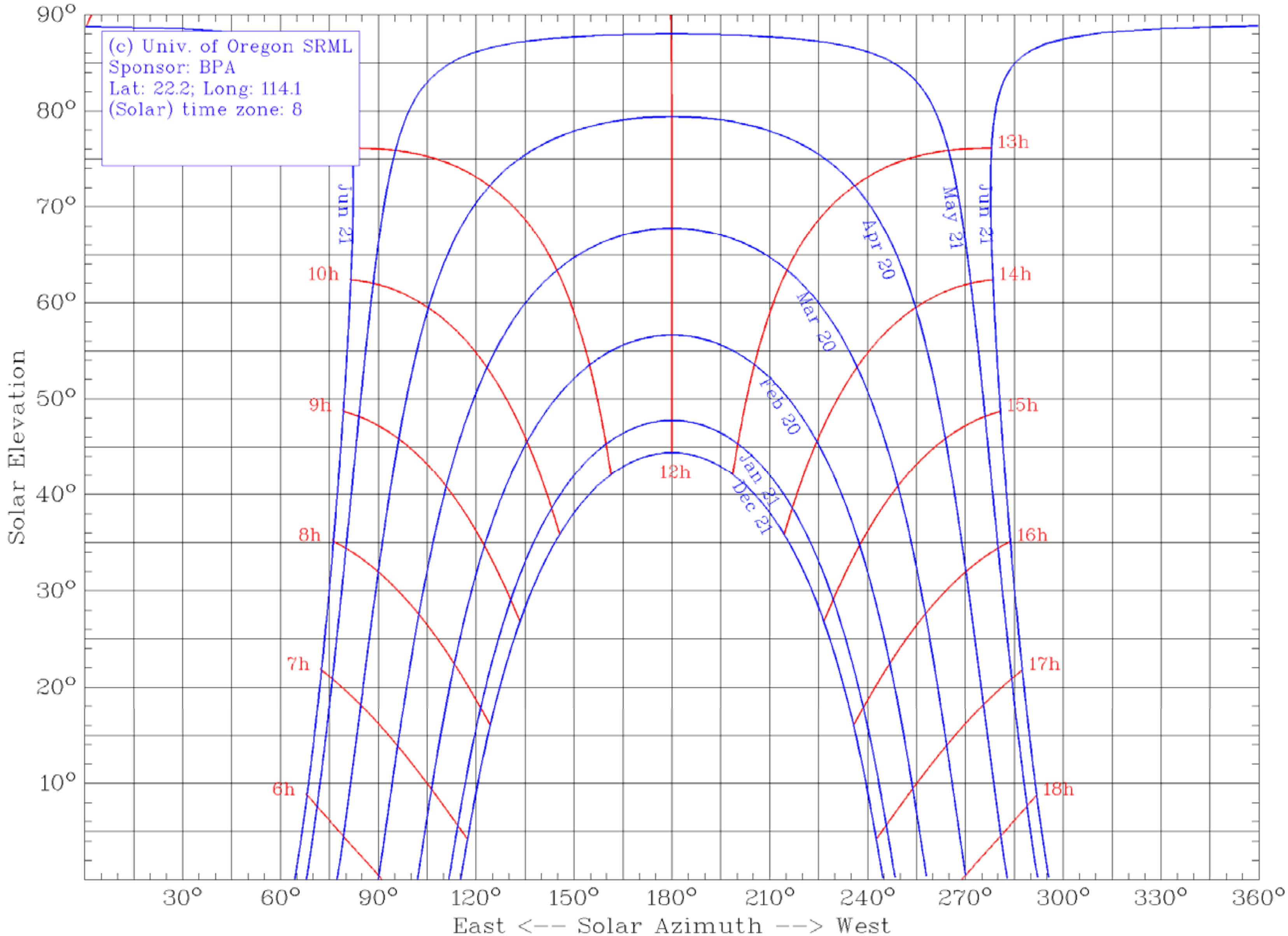
Find where shadows will be year round shading your solar/photovoltaic panels, solar array, solar air heater, solar

Sun chart

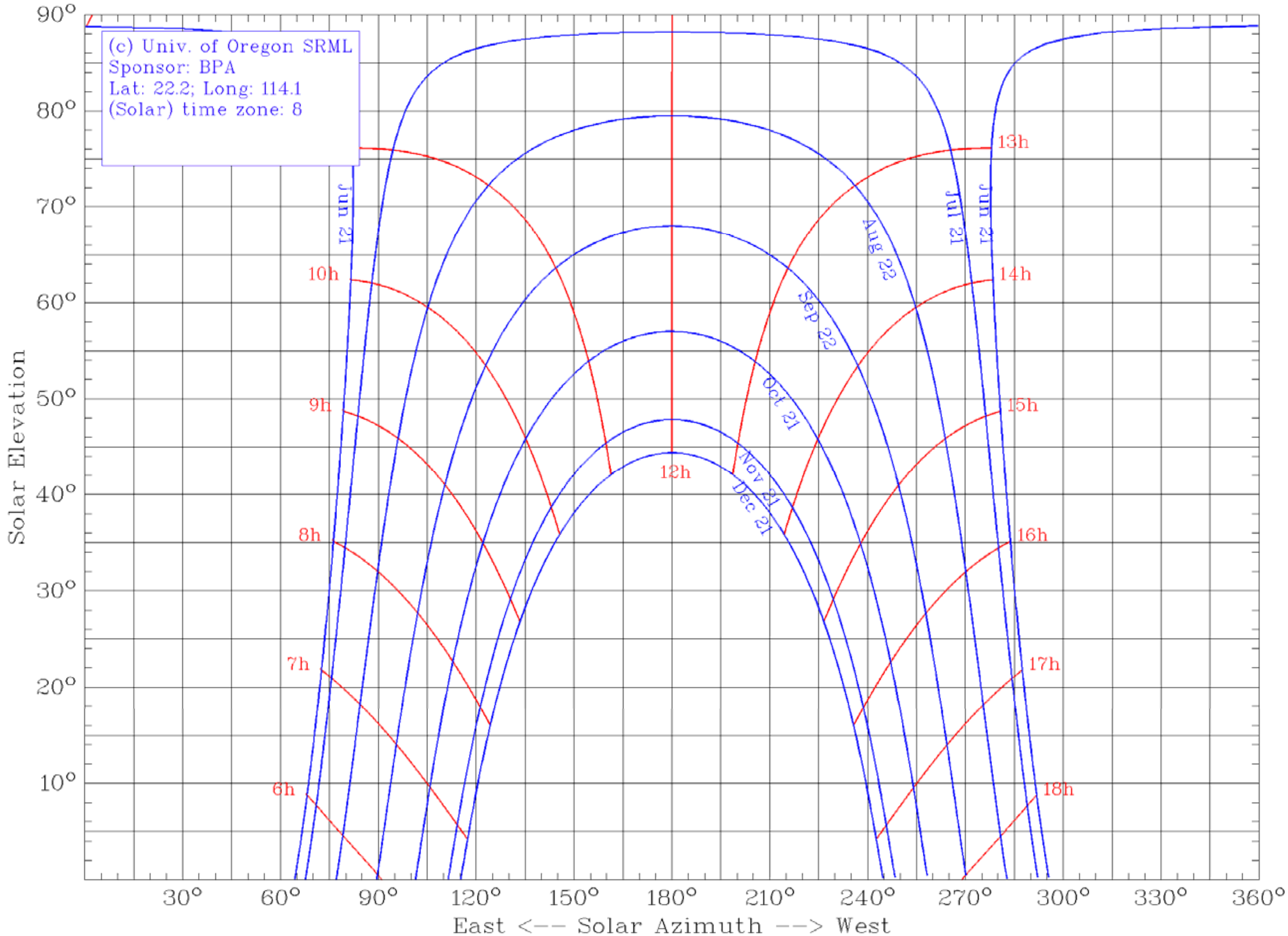
Sun chart is a graph to illustrate the Sun trajectory through the sky throughout the year at a particular geography location.

Online sun chart creator (external link):
http://solardat.uoregon.edu/SunChartProgram.html

Sun chart (between solstices, December to June)

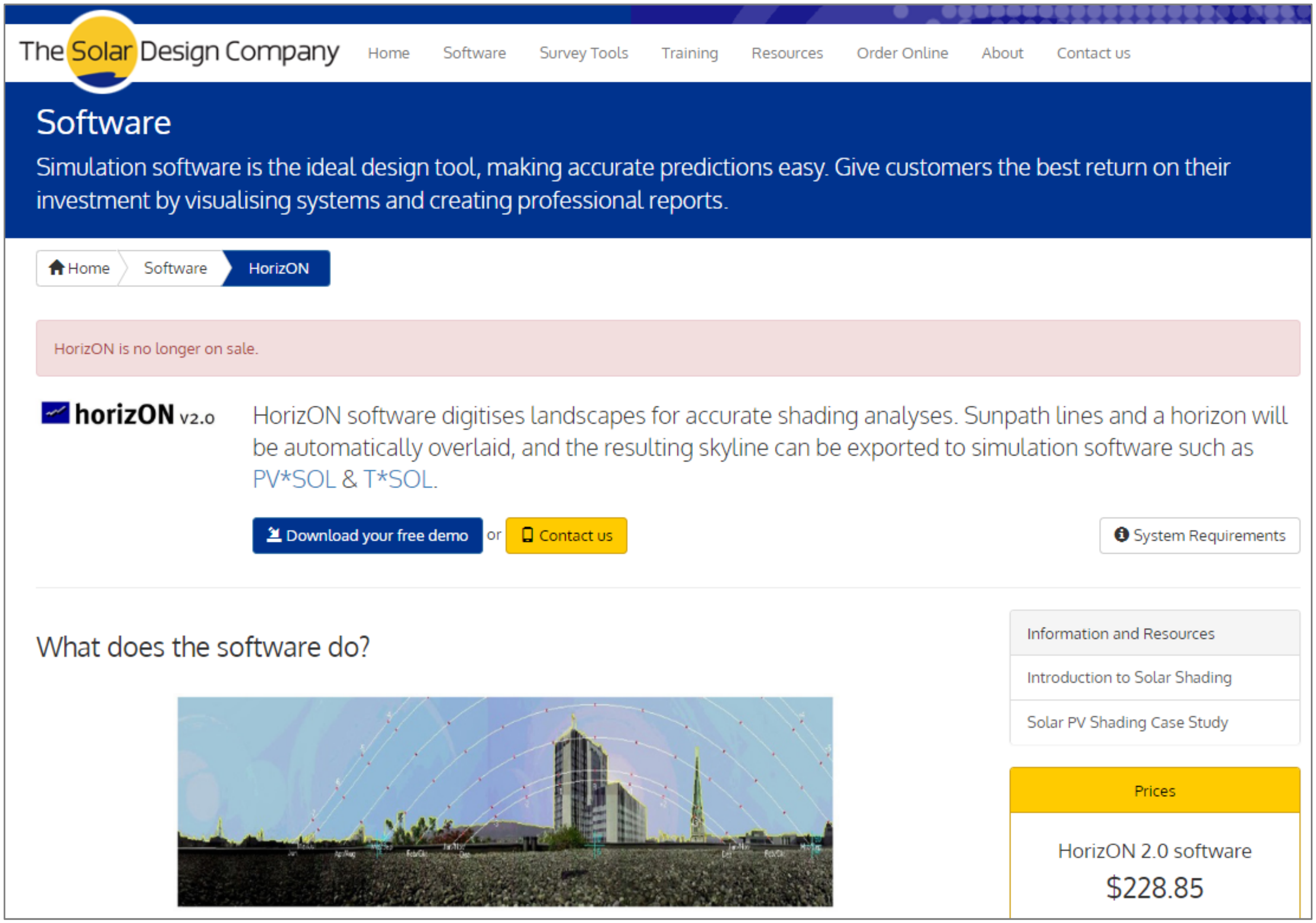


Sun chart (between solstices, June to December)



Shade analysis: Software tool

horizON$_{V2.0}$, Web: https://www.solardesign.co.uk/horizon.php



Shade analysis: Software tool

HORIcatcher, Web: https://meteonorm.com/en/product/horicatcher

Meteonorm

Horicatcher

Horicatcher

Preis	1200 CHF

Order

Horizon analysis in seconds

With the Horicatcher you can digitize the local horizon and shadowing situation efficiently and precisely. Import the horizon into Meteonorm for even more precise results.

The Horicatcher tool within the Meteonorm software calculates the sun's orbit, which is put in relation with the horizon. Meteonorm takes into account the reduced solar energy input, the sunshine duration and sun exposure.

Meteotest also provides individual sunshine exposure analyses with Horicatcher. Ask us for a quote!

Components

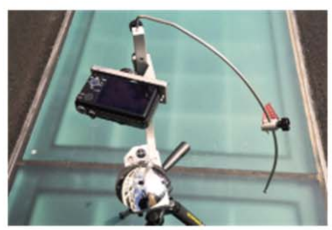
A horizon mirror, the camera and the mounting device are attached to a regular photographic tripod. The built-in circular level allows a precise leveling of the device. The following components are included in the delivery:

Contents

- digital camera
- camera mounting device and horizon mirror
- new: analysis software included in the meteonorm software (Version 7)

More Products

- Meteonorm Software
- Meteonorm Upgrade
- Meteonorm EDU
- Typical years
- Historical time series



Shade analysis: Software tool

Suneye, Web: http://www.solmetric.com/buy210.html

SunEye 210 Shade Tool

Base Price (North America) **$2,195.00**

Options

Add Extension Platform: No

Add Certified Shade Training: No

Add SunEye-210 Hard Case: No

BUY NOW

Description | Features | Ordering Information

Professional Site Evaluation

The patented SunEye-210 is the world-leading shade measurement tool for solar site assessment. This hand-held electronic tool measures the available solar energy by day, month, and year with the press of a button by determining the shading patterns of a particular site.

The SunEye® enables the best solar designs and the highest ROI for solar professionals and their customers. It helps win competitive bids, saves time and money, and gives confidence in performance guarantees.

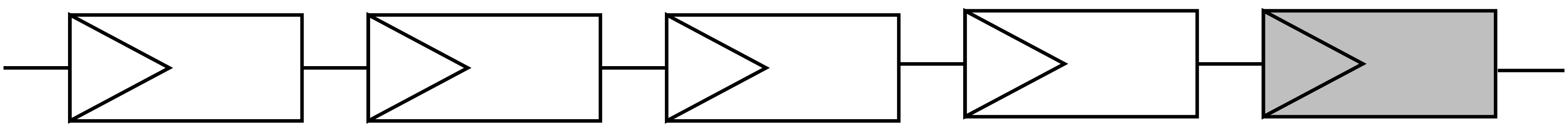
The award-winning SunEye incorporates a calibrated fisheye camera, electronic compass, tilt sensor, and GPS to give immediate measurements in the field. The one-handed operation, rugged enclosure, and outdoor readable display make it a reliable partner in the field.

The Suneye-210 now includes a lifetime license for the PV Designer software, enabling you to import shade measurements, select modules and inverters, layout

Checklist for PV site survey

- Roof area (with orientation information)
- Usable area for PV system
- Chimneys, antenna, satellite dishes
- Nearby buildings (with distance and height information)
- Other objects (such as trees and overhead cables)

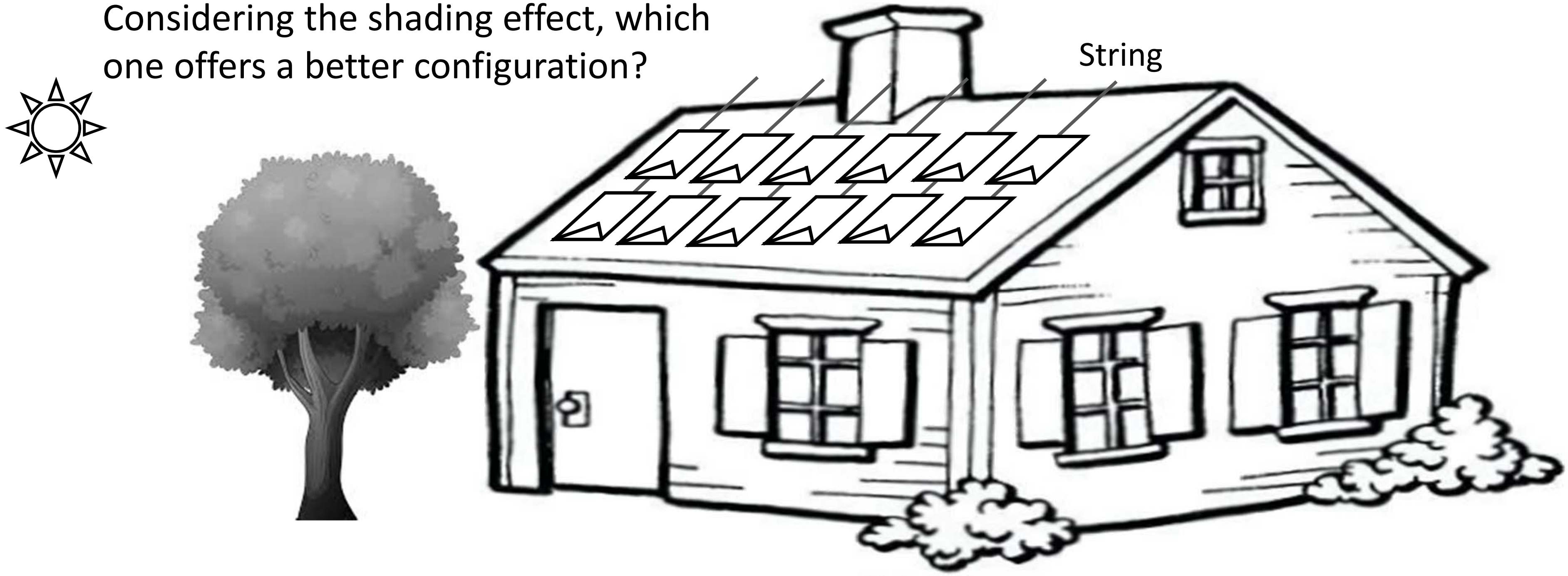
Hot-spot condition

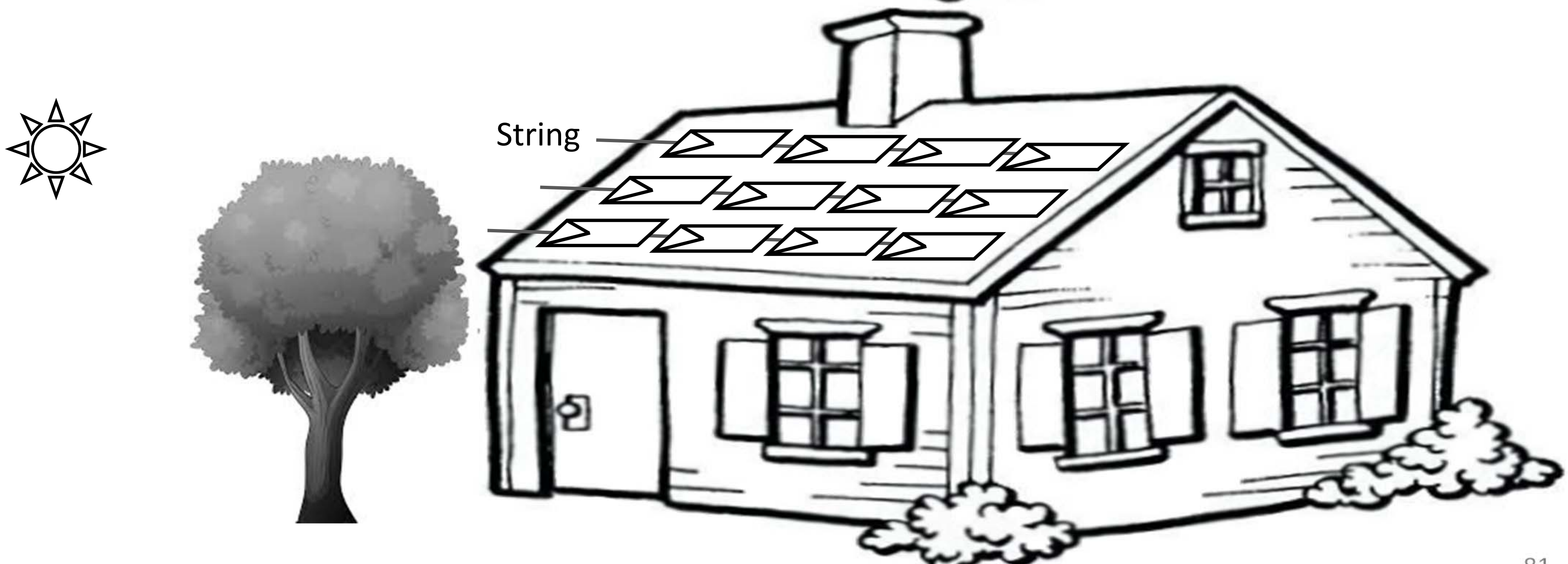


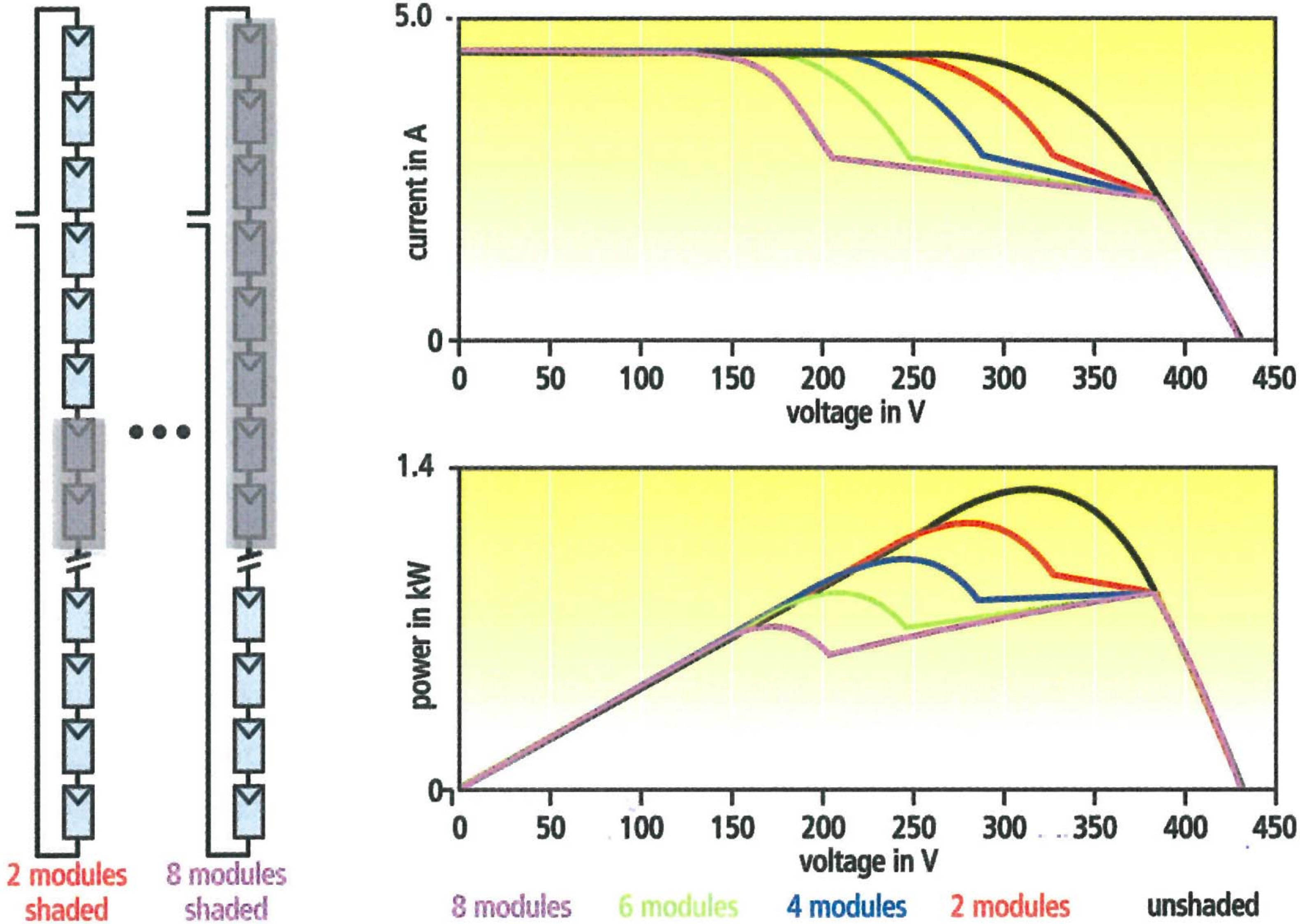
A String of PVs

- Bad PVs cannot generate current, and they will act as a load to dissipate power.
- Severe local overheating may occur $\Rightarrow$ cracking, melting of solder, or encapsulating material.
- Solution: bypass diodes

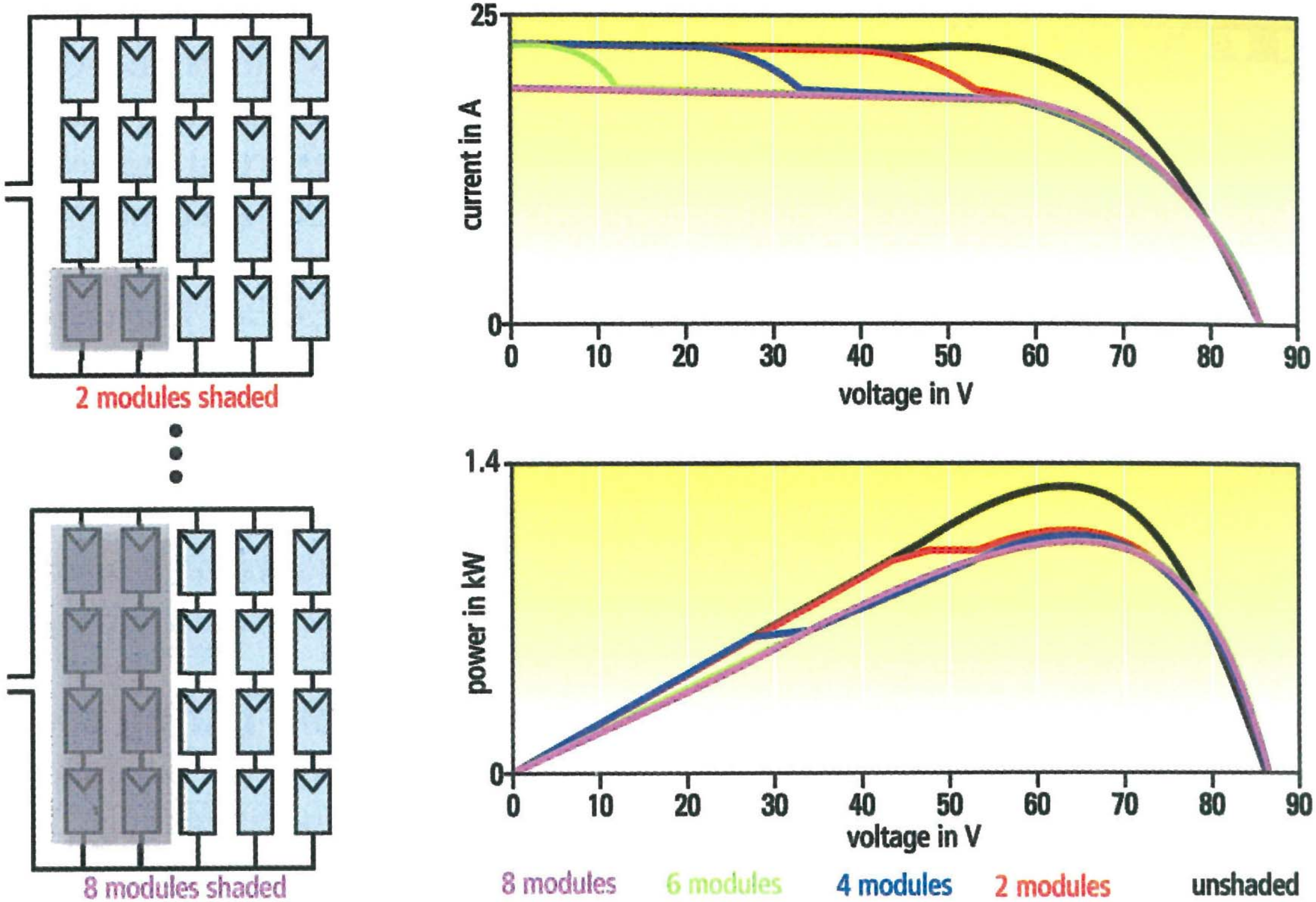
Considering the shading effect, which one offers a better configuration?



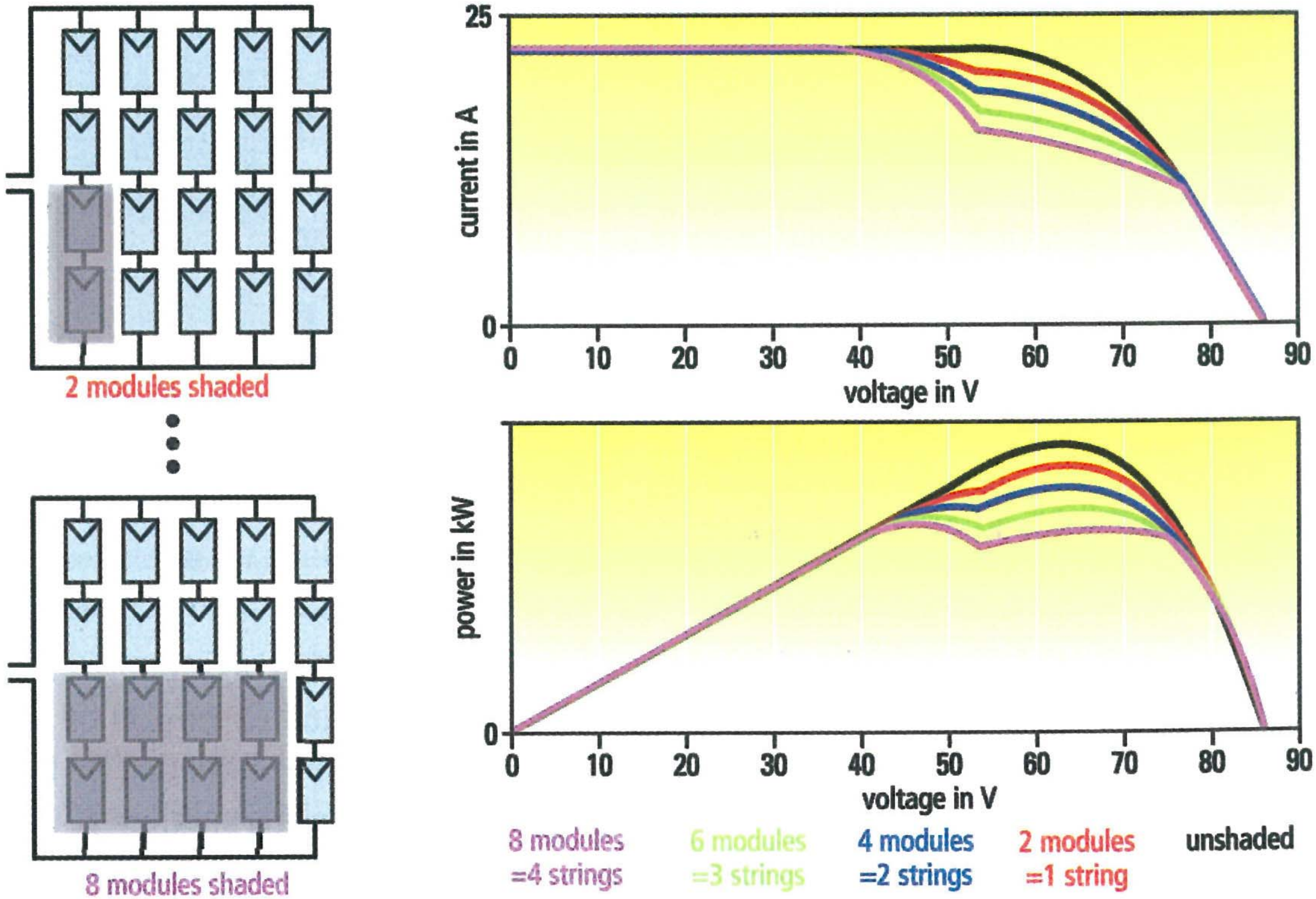




Source: Planning and Installation Photovoltaic Systems, A Guide for Installers, Architects, and Engineers.



Source: Planning and Installation Photovoltaic Systems, A Guide for Installers, Architects, and Engineers.



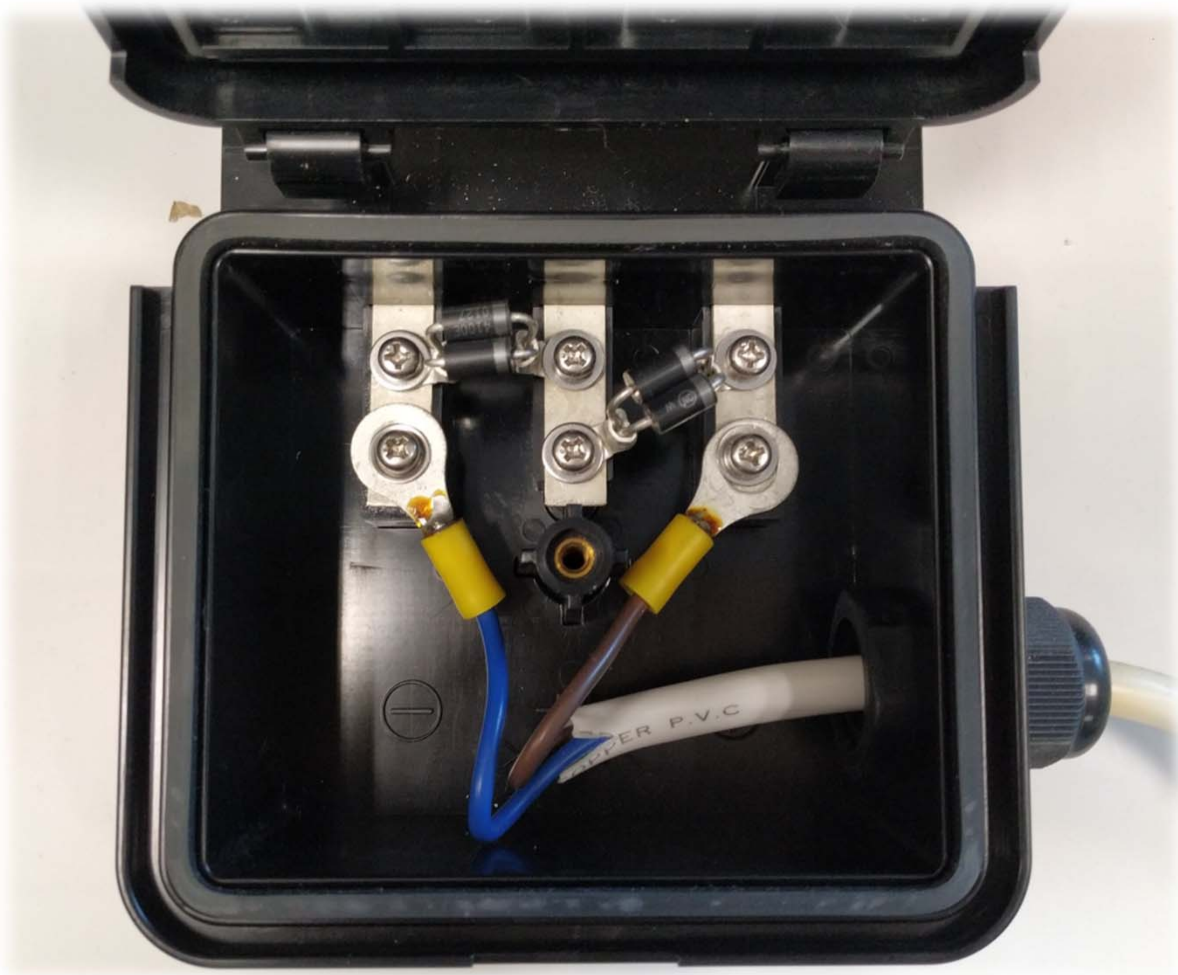
Source: Planning and Installation Photovoltaic Systems, A Guide for Installers, Architects, and Engineers.

Unavoidable shading

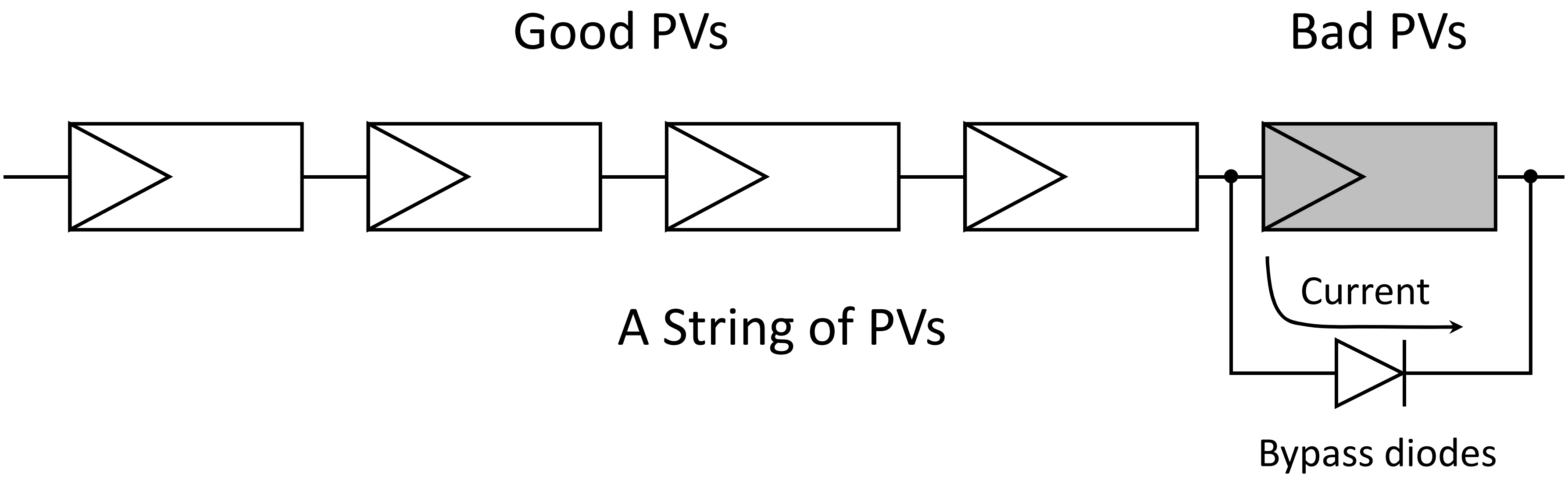
If shading is unavoidable, the favorable condition is to allow the shaded PV modules either

- in the same string, or
- distributed across only a few string.

Bypass diodes

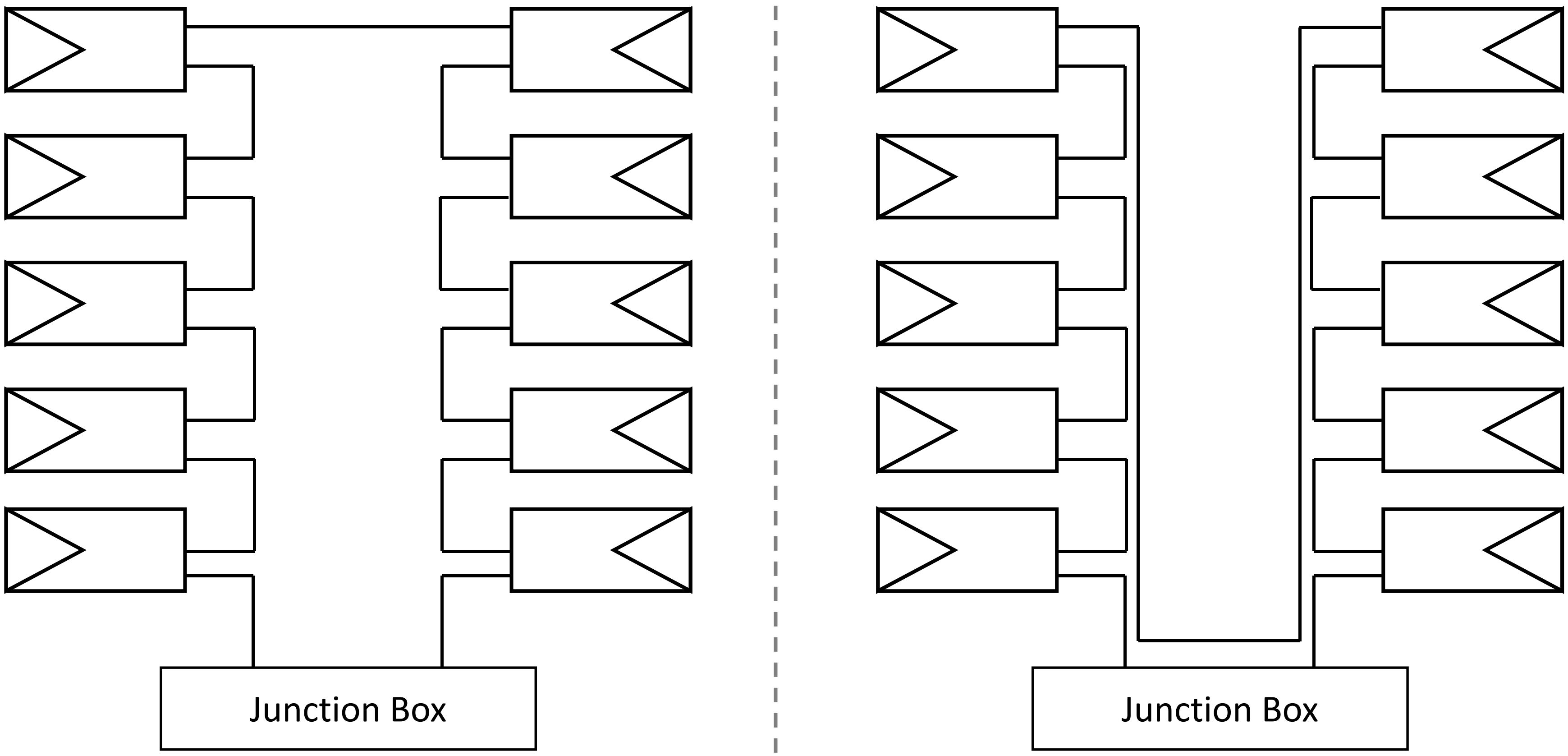


Bypass diodes



Lightning effect

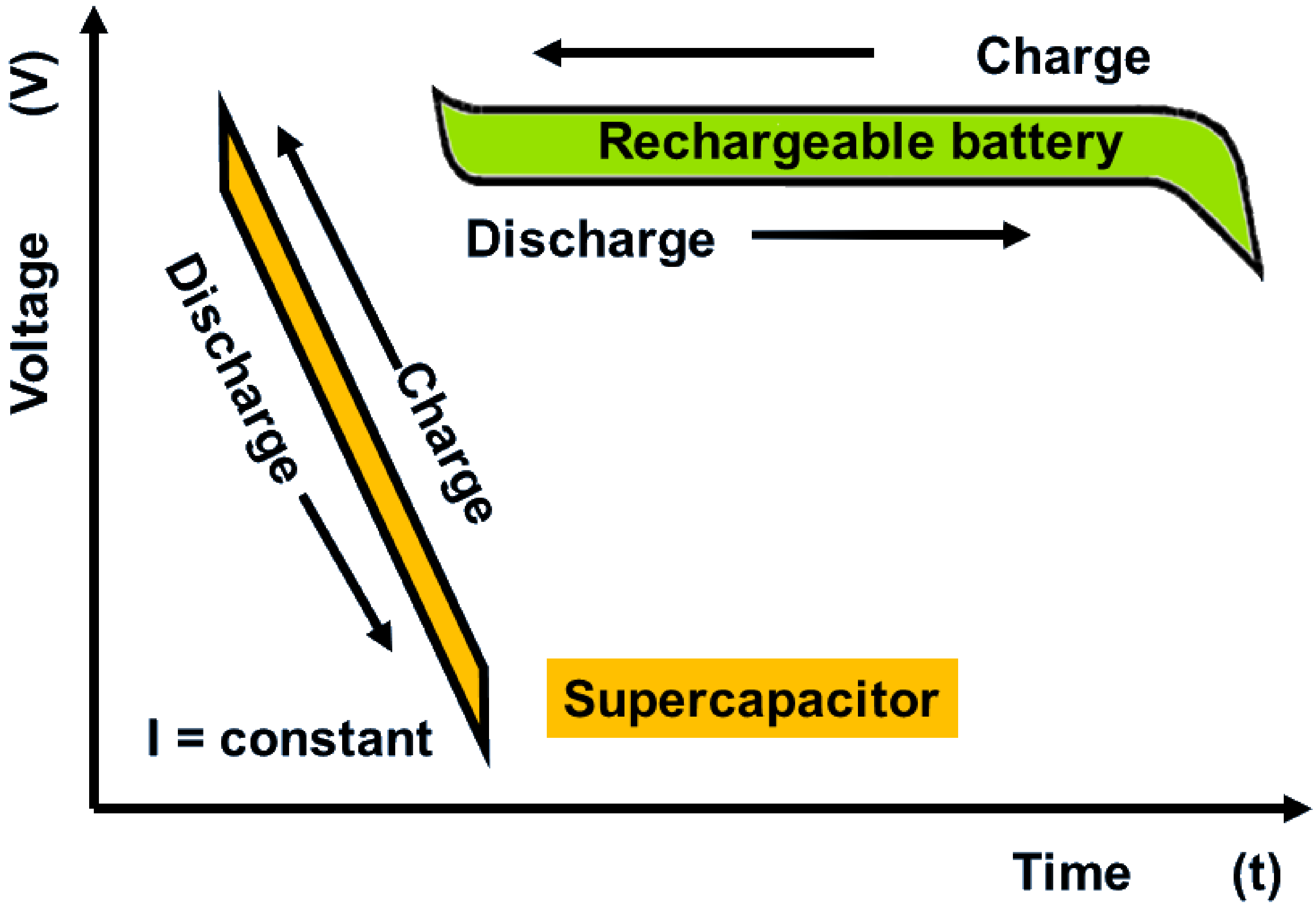
Which one is a better design of connection loop?



The smaller the area of PV array open loop, the lower the induction voltage generated by lightning.

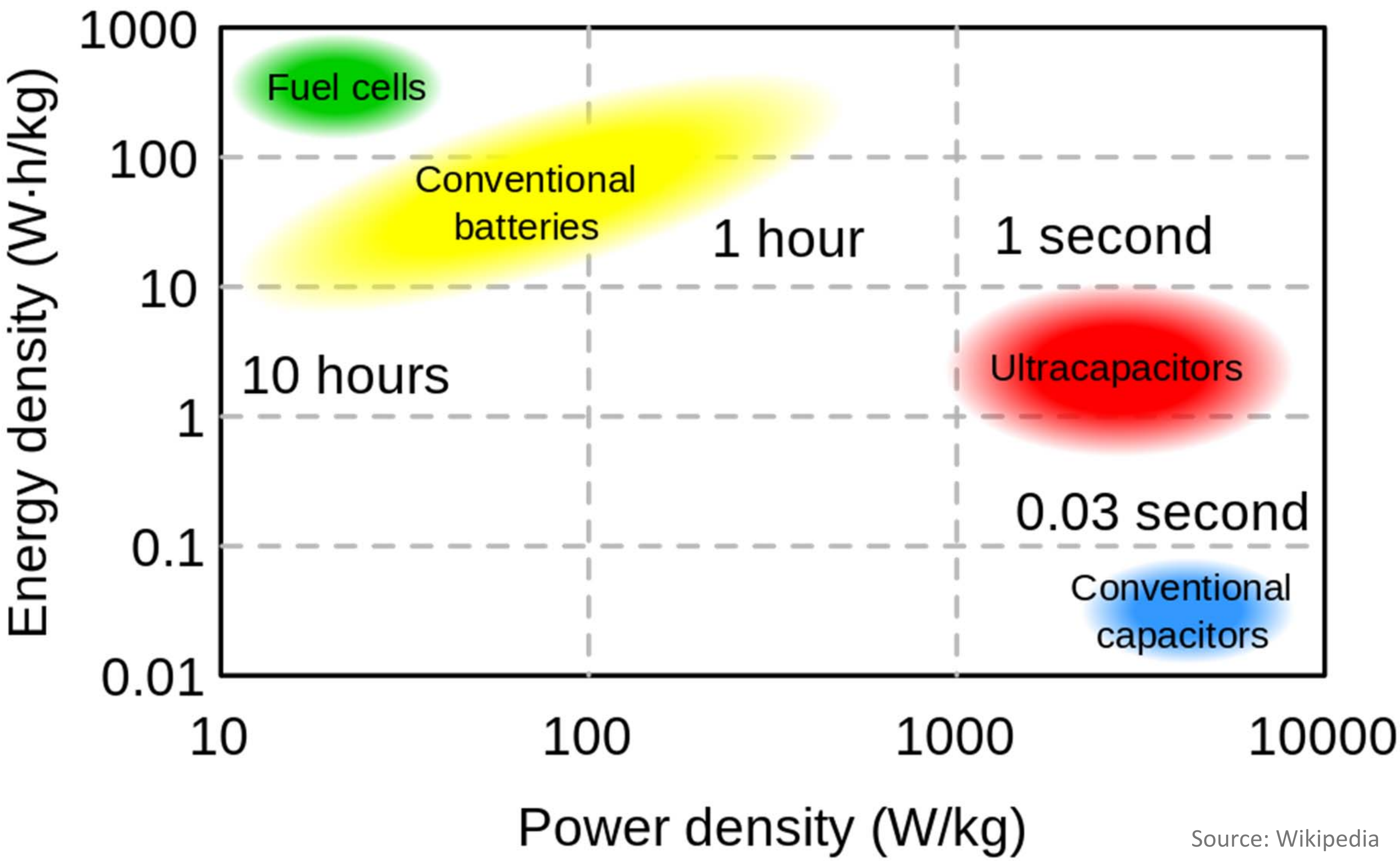
Supercapacitor / Ultracapacitor

- Supercapacitor/Ultracapacitor
  ⇔ Electric Double-Layer Capacitor (EDLC)
  - High value of capacitance
  - Low voltage components



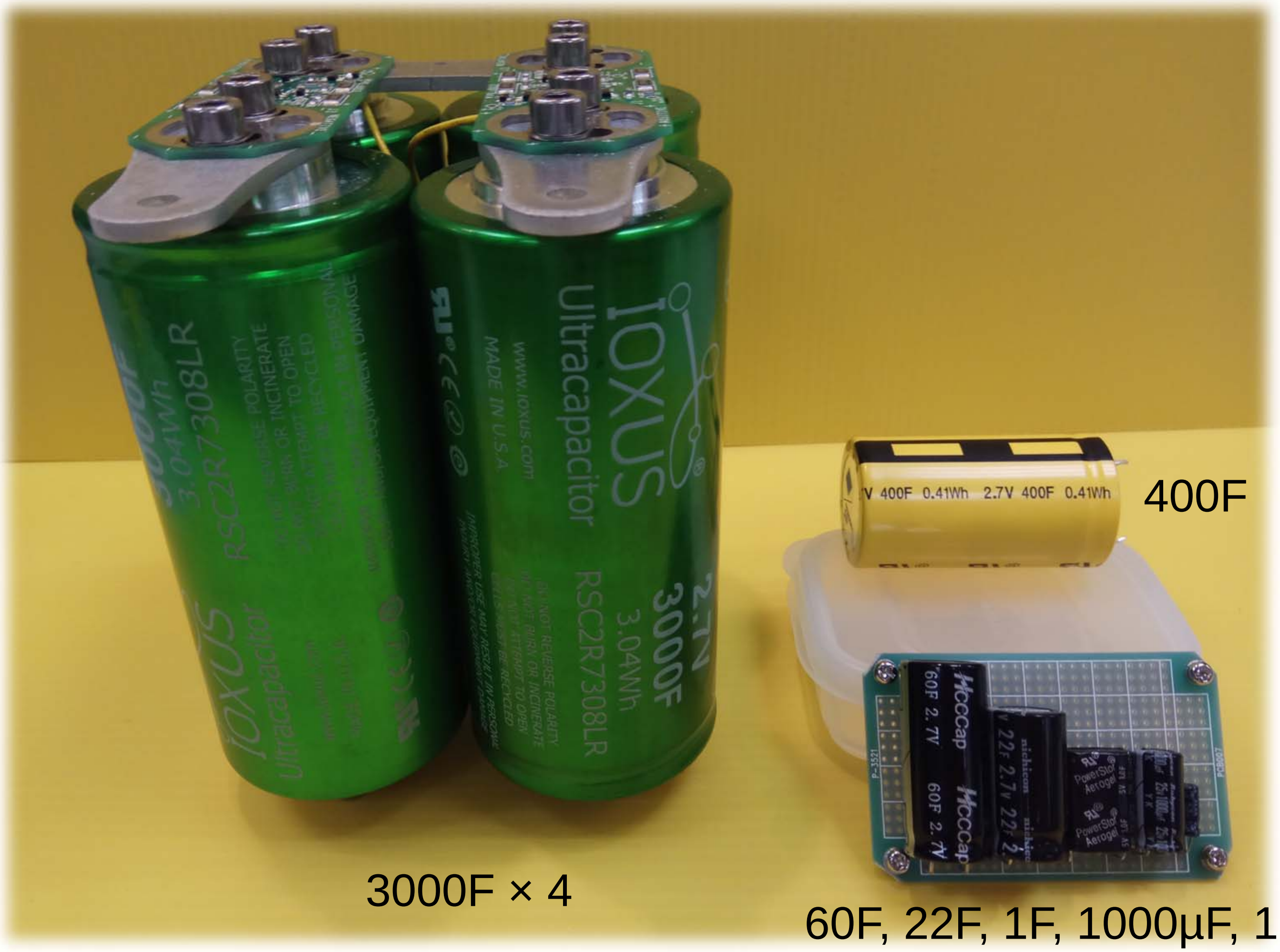
Source: Wikipedia

Energy density vs power density



Source: Wikipedia

Supercapacitor / Ultracapacitor



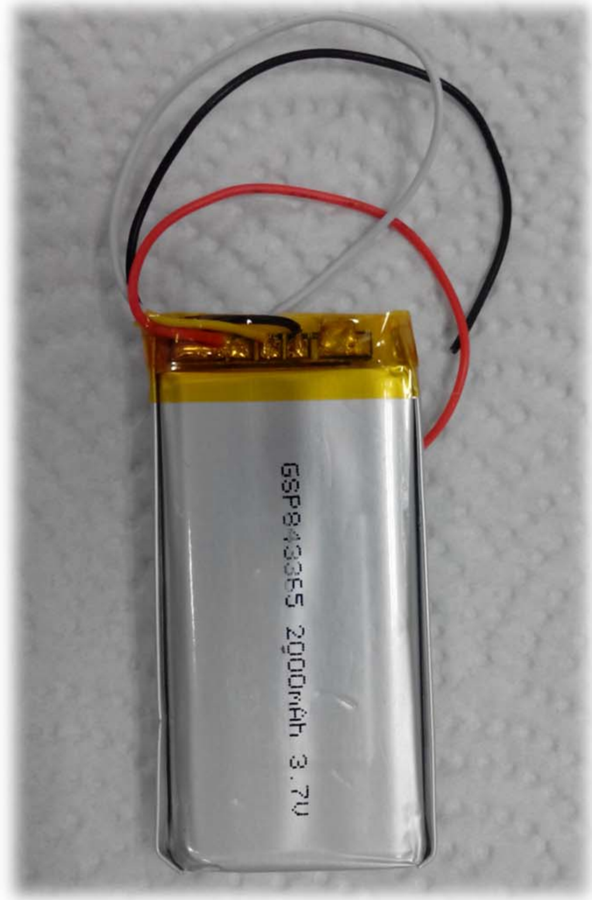
400F

3000F × 4

60F, 22F, 1F, 1000μF, 1μF

Specific energy / energy Density

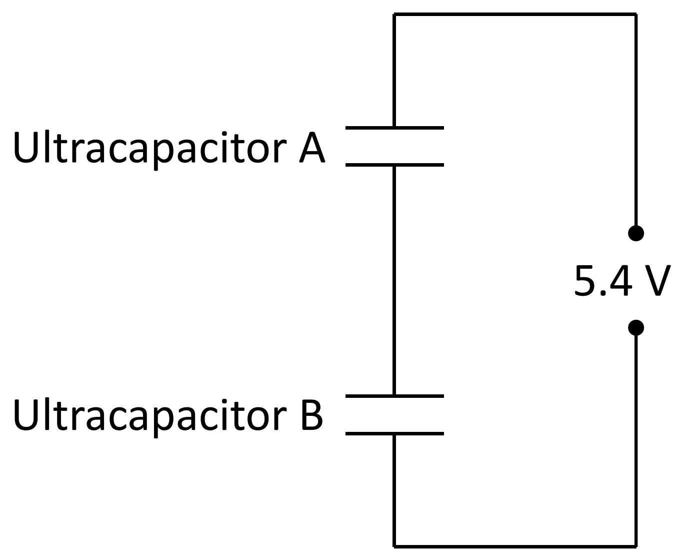
Mass: 507 g, Diameter: 60.5 mm, h = 132.5 mm



Mass: 35 g, Volume: $(32\times60\times8)\ \text{mm}^3$

Example: Charging ultracapacitors in series

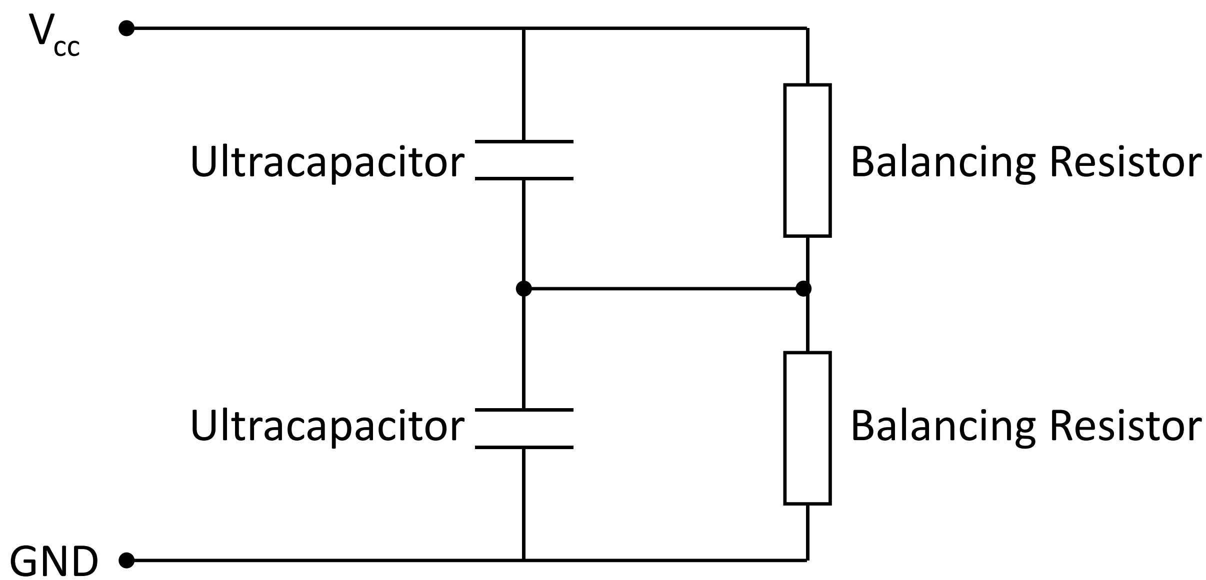
Consider 2 ultracapacitors (10 F, $\pm$10%) connected in series, which are charged by a power supply (supply voltage = 5.4 V). In the worst condition (Ultracapacitor A = 11 F and Ultracapacitor B = 9 F), find the voltages across the ultracapacitors when they are fully charged.



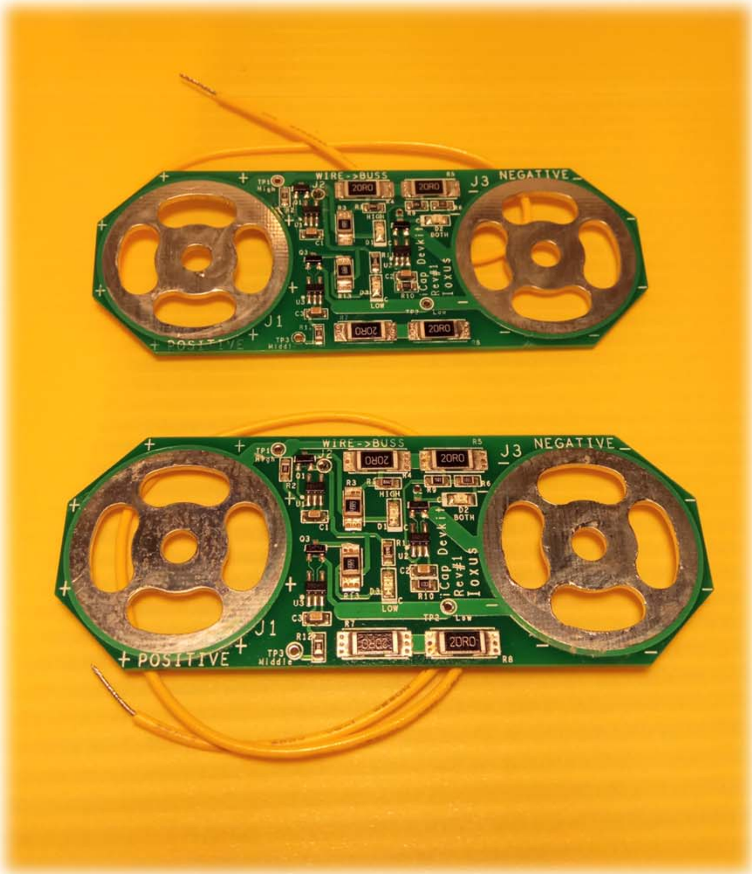
Balancing supercapacitors in series

- To ensure voltage across each supercapacitor is approximately equal.
- Without balancing, it may lead to overvoltage damage.

Simple circuit for balancing ultracapacitors



Commercial product:
Balancing ultracapacitors in series



C. Demonstrations, tools, and equipment

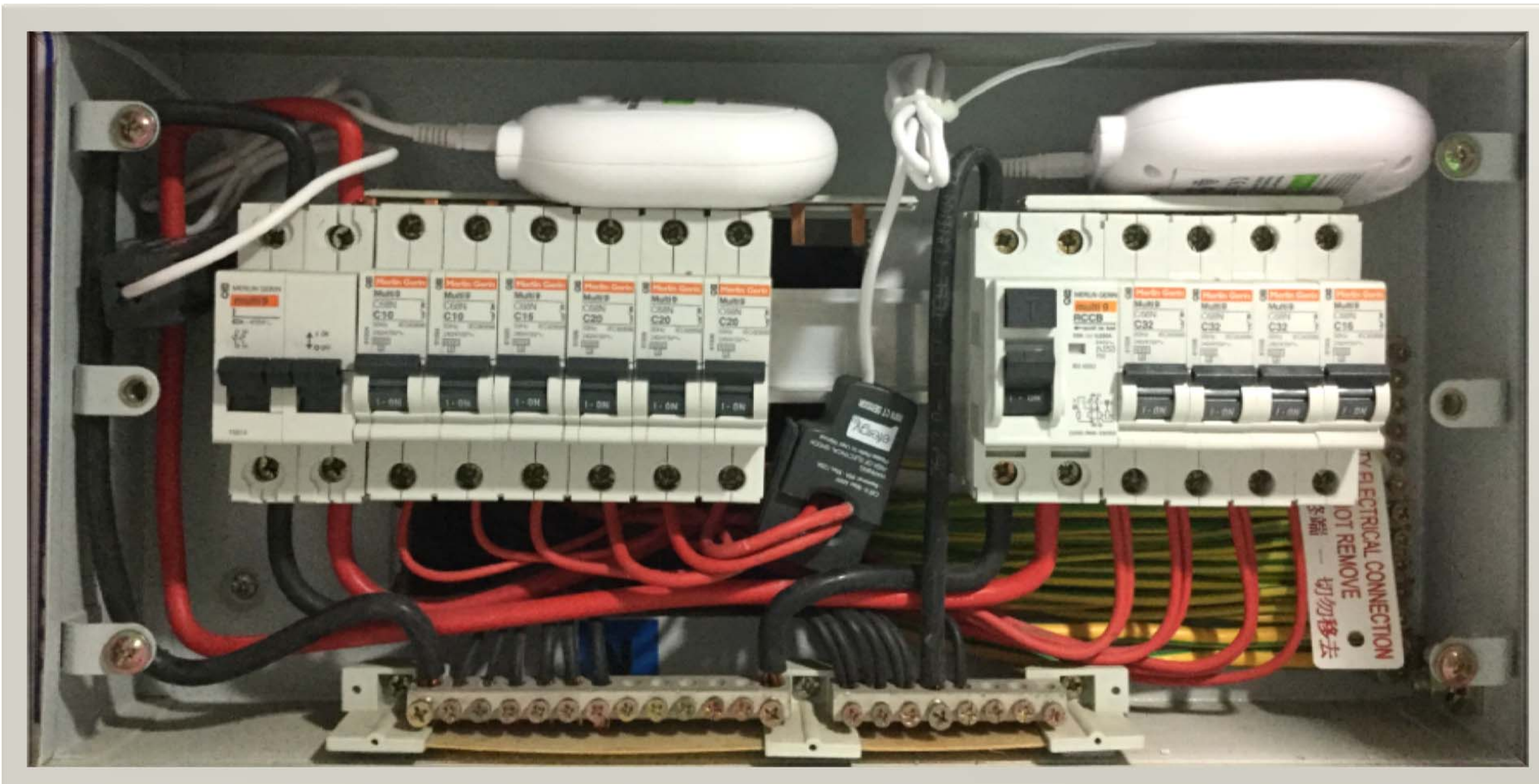
- PV Connectors and tools
- Solar power meter vs Lux meter
- PV inverter
- Current transformer
- Energy/power meter
- IR Camera
- Commercial and DIY PV power analyzers
- I&T enabled PV panels
- Software tool

Solar power meter vs Lux meter

PV connector tools

For disconnecting MC4 Connectors

Current transformer, energy & power meter

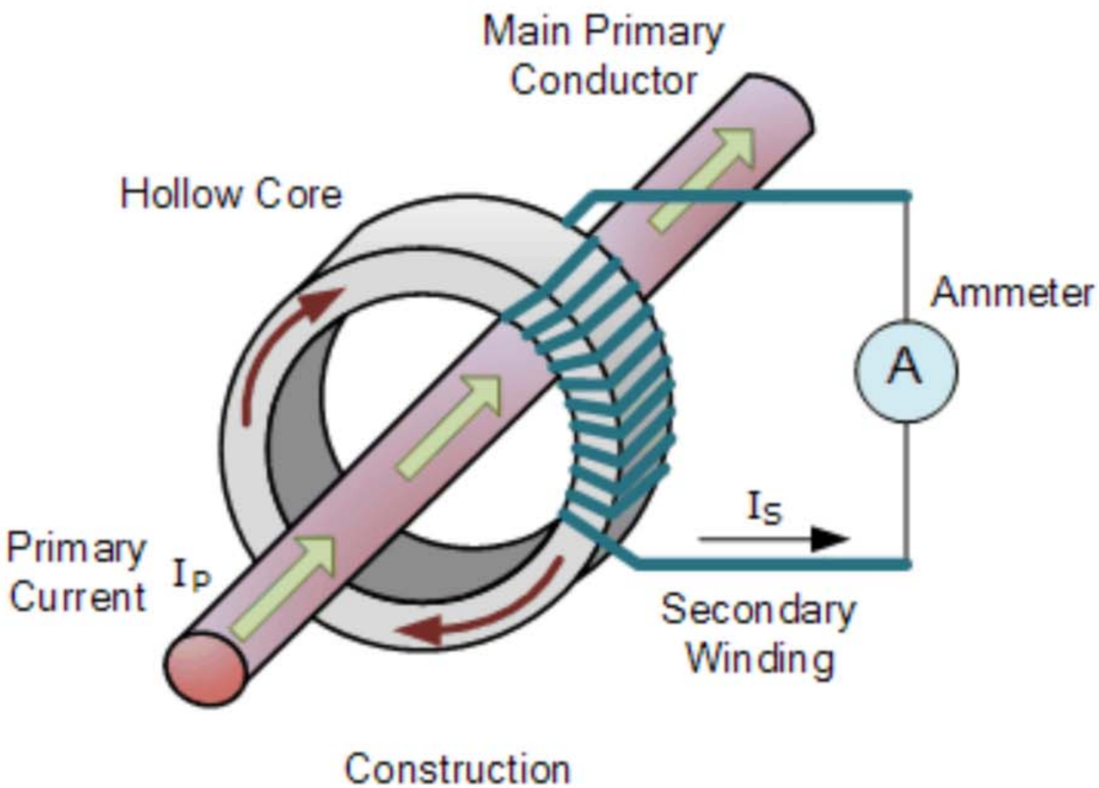


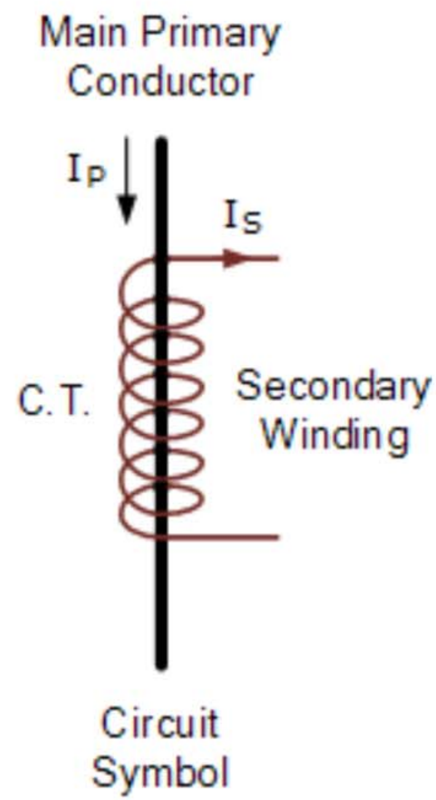
Current transformer, energy & power meter

Wireless Power Meter

Current Transformers

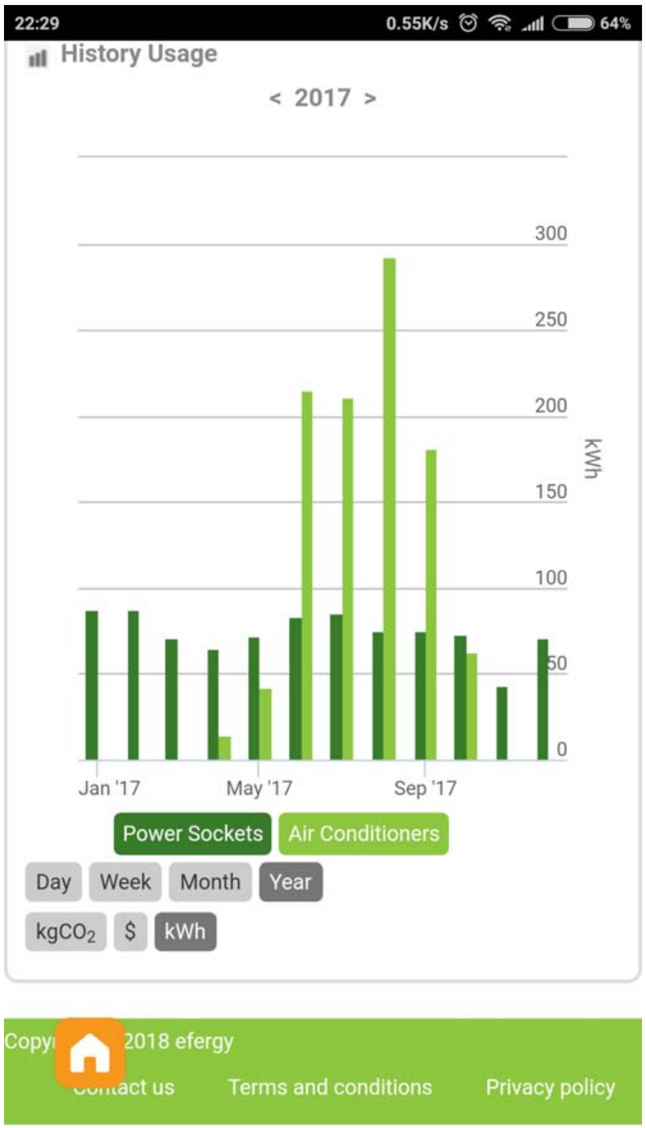
Current transformer: operation principle

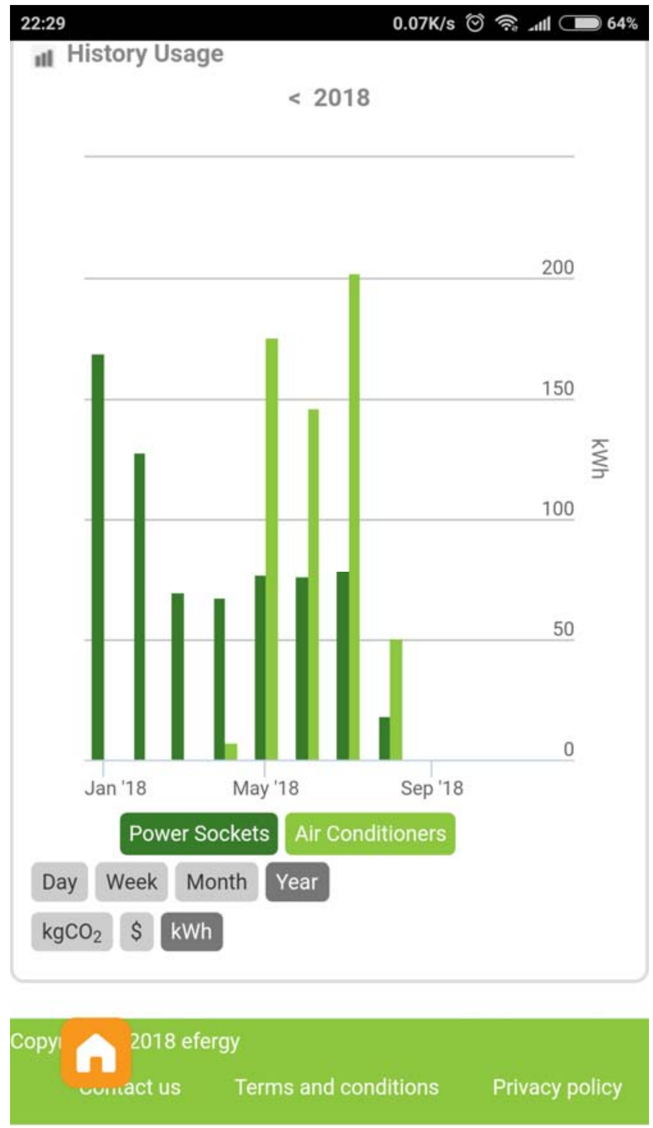




Source: Electronics Tutorials

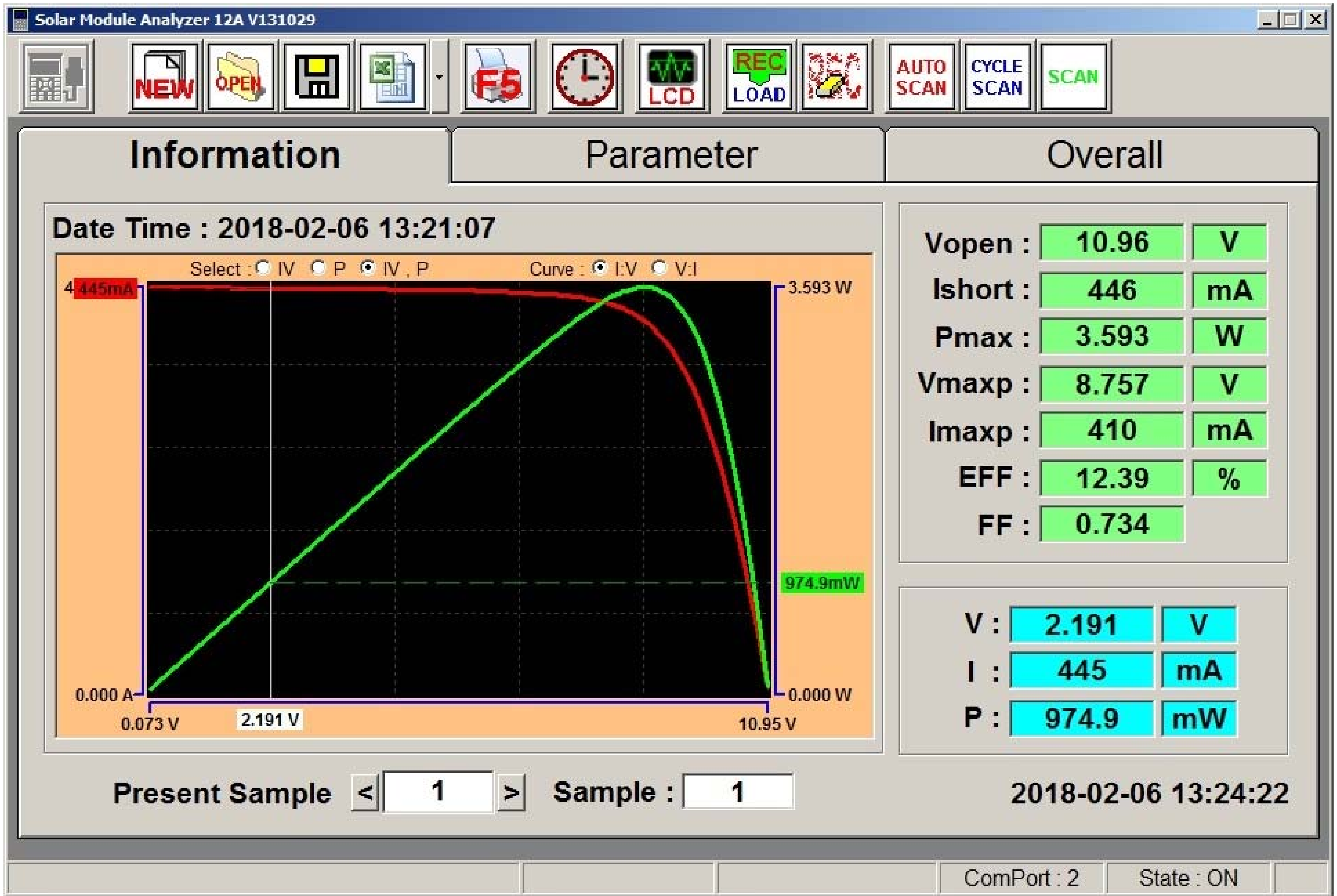
Apps for wireless energy & power meter



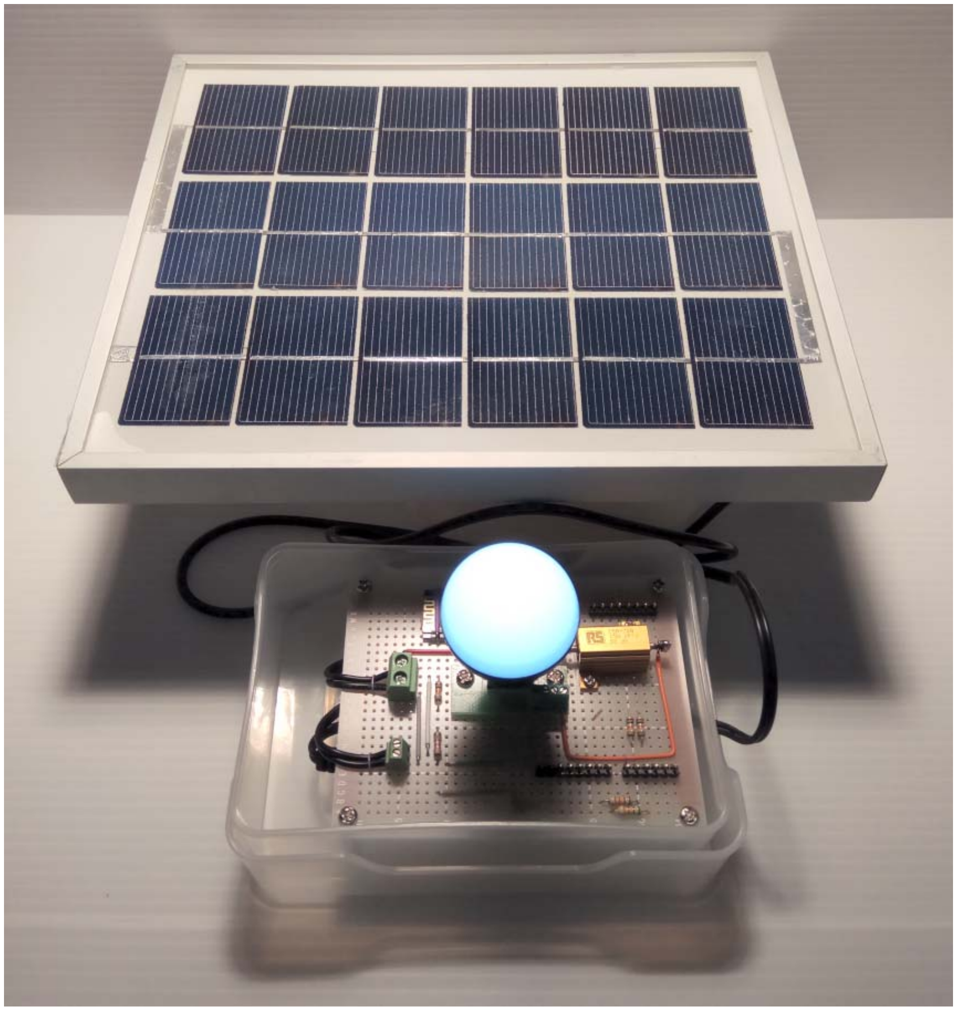


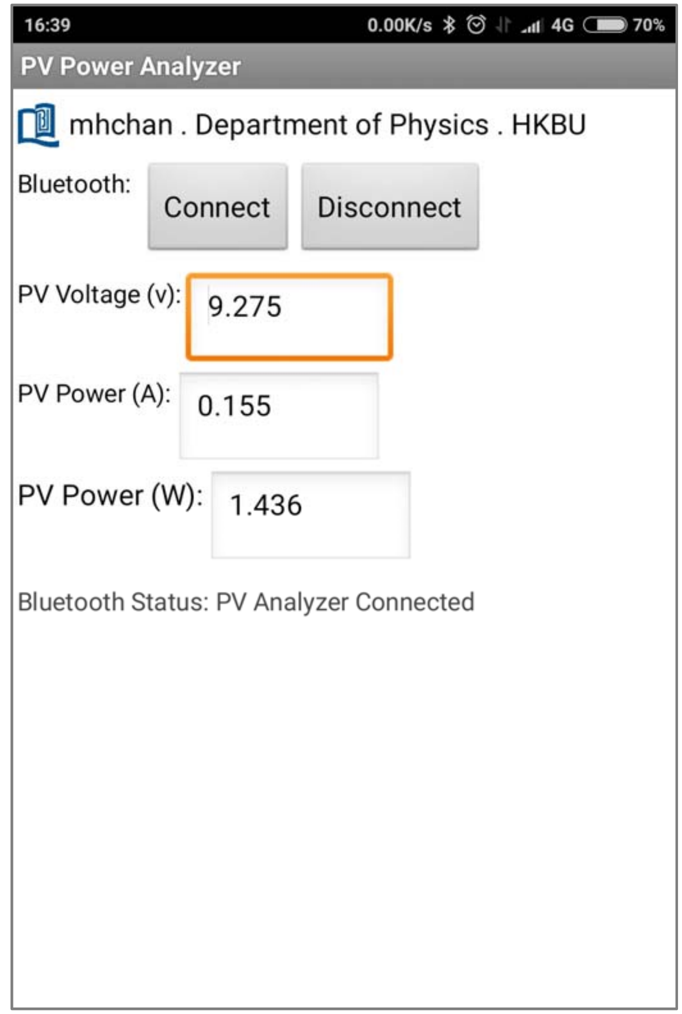
Commercial PV power & IV curve analyzer

Commercial PV power & IV curve analyzer



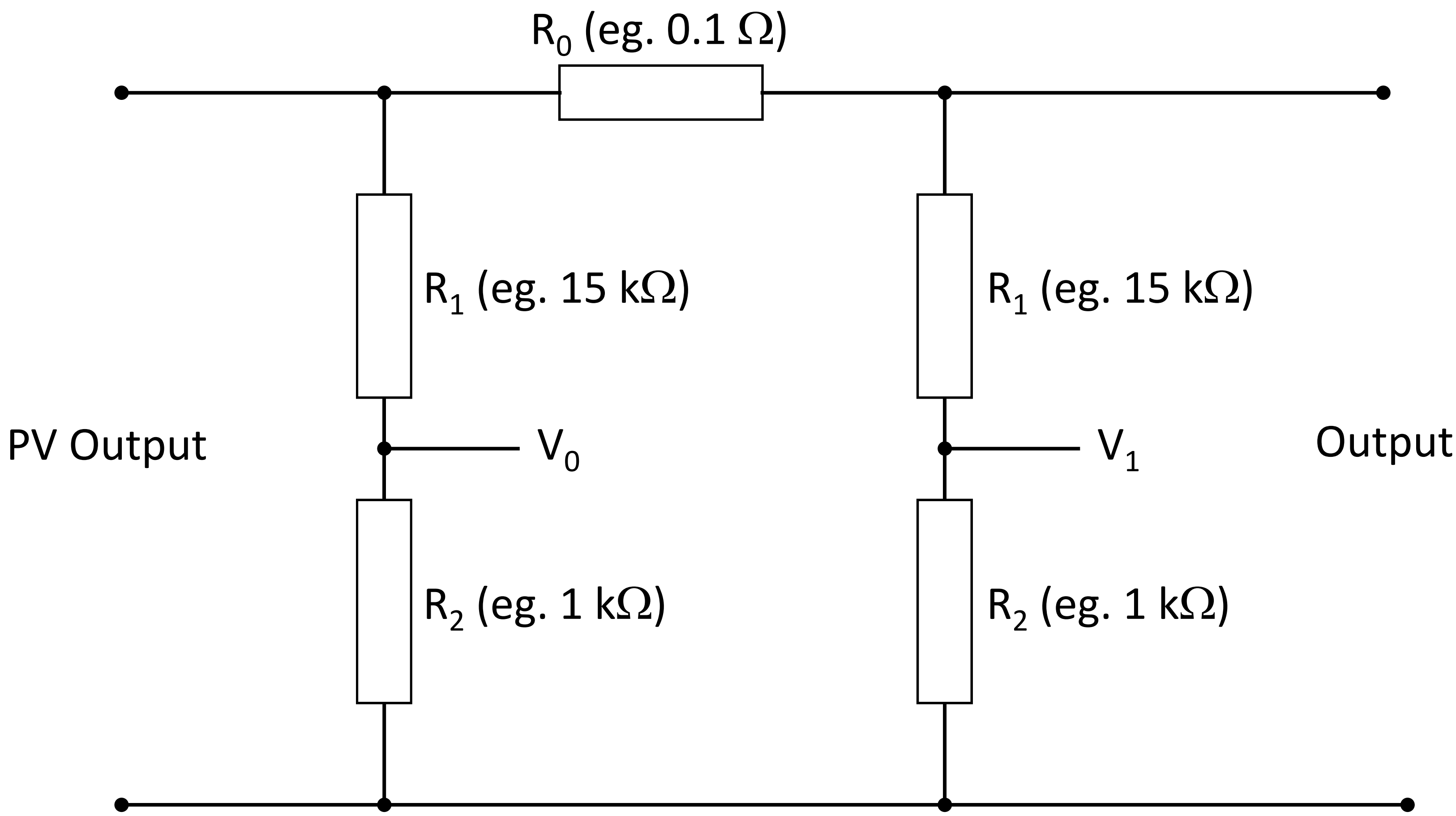
DIY PV power analyzer



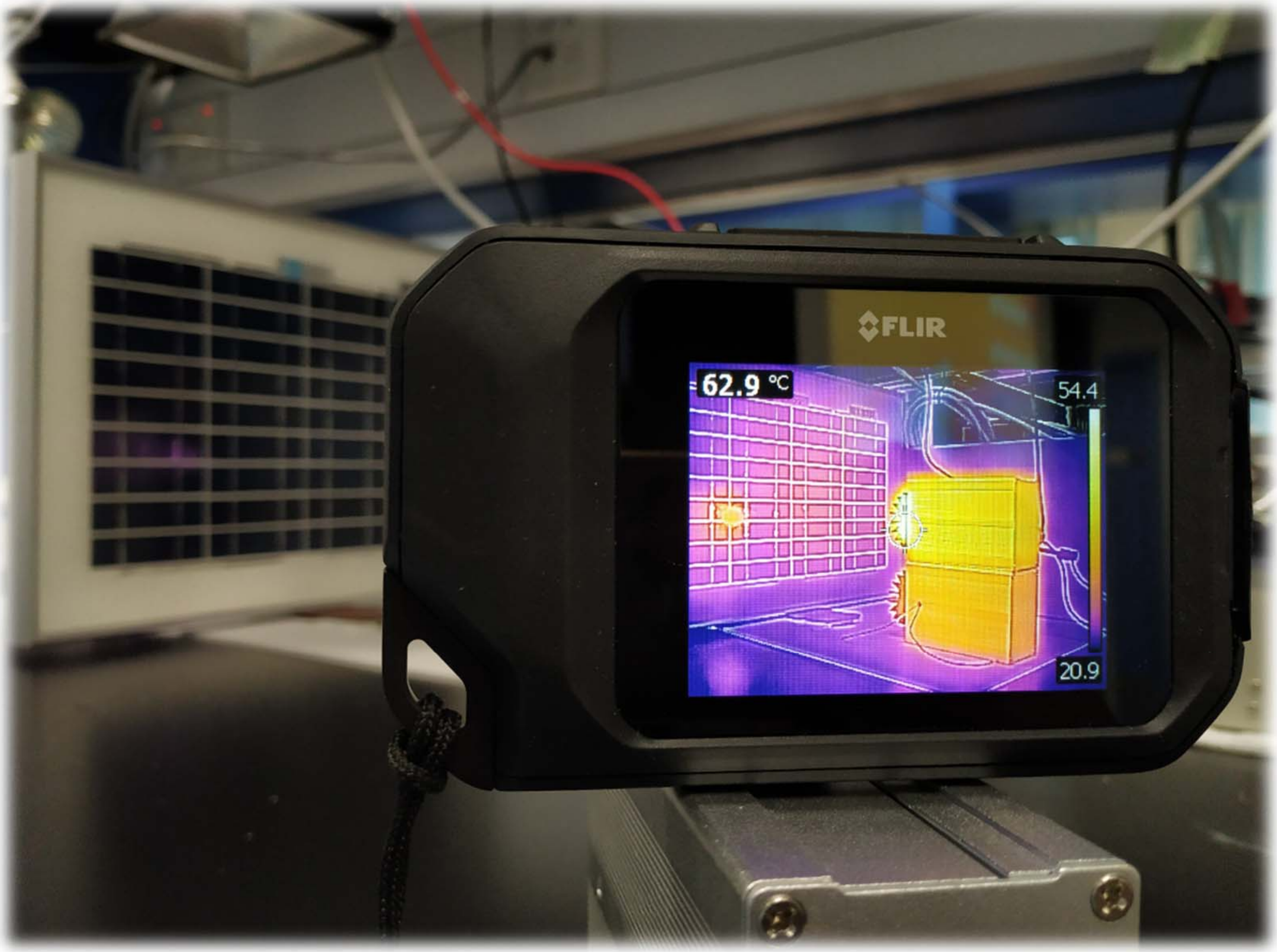


Sample circuit diagram of DIY PV power analyzer

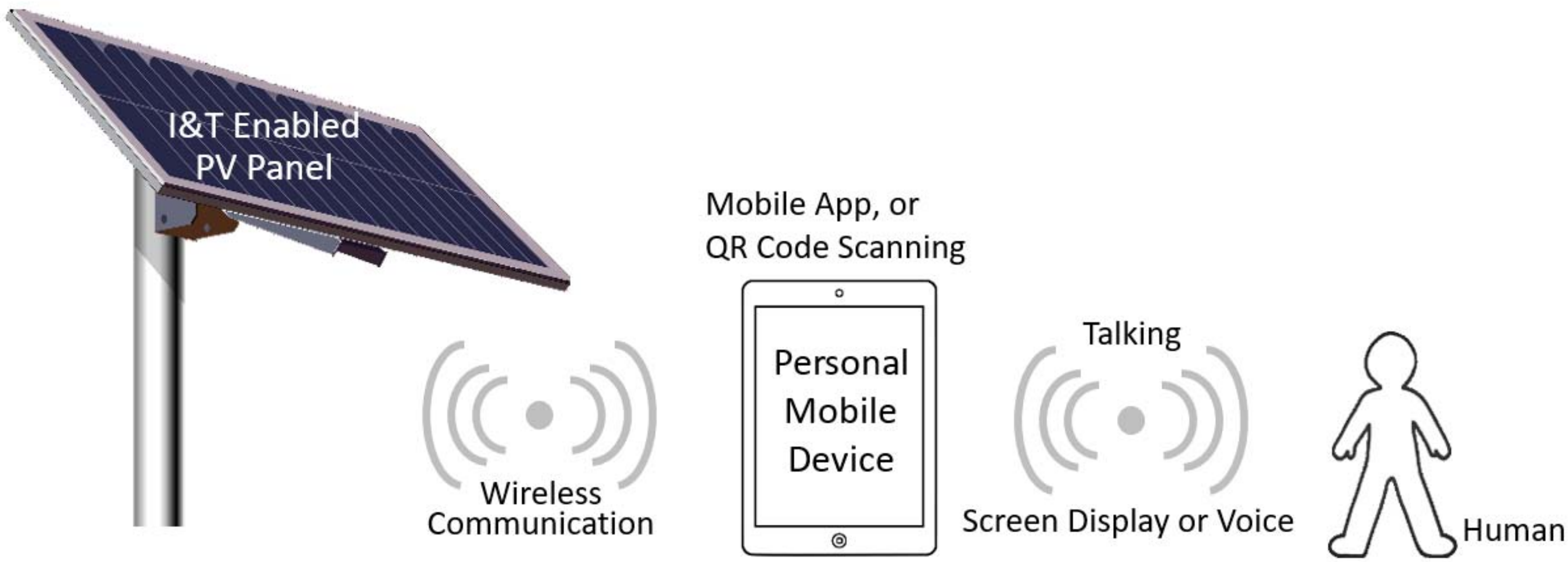
Example:



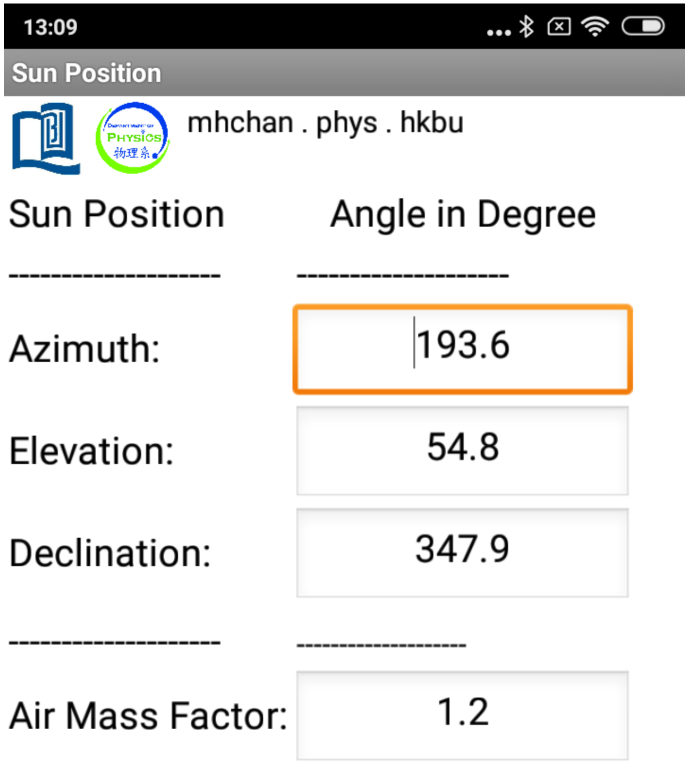
IR Camera



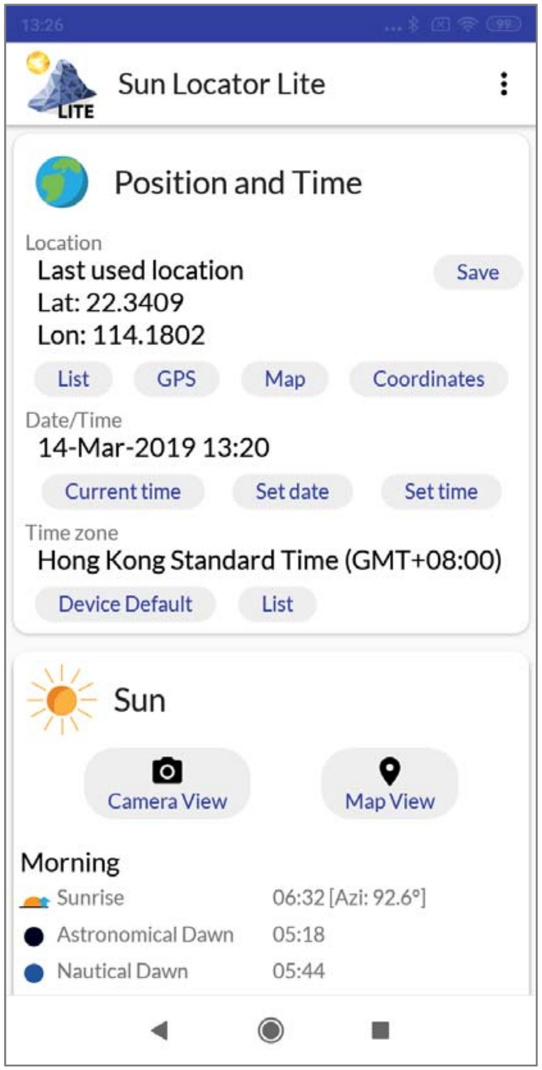
I&T enabled PV panels

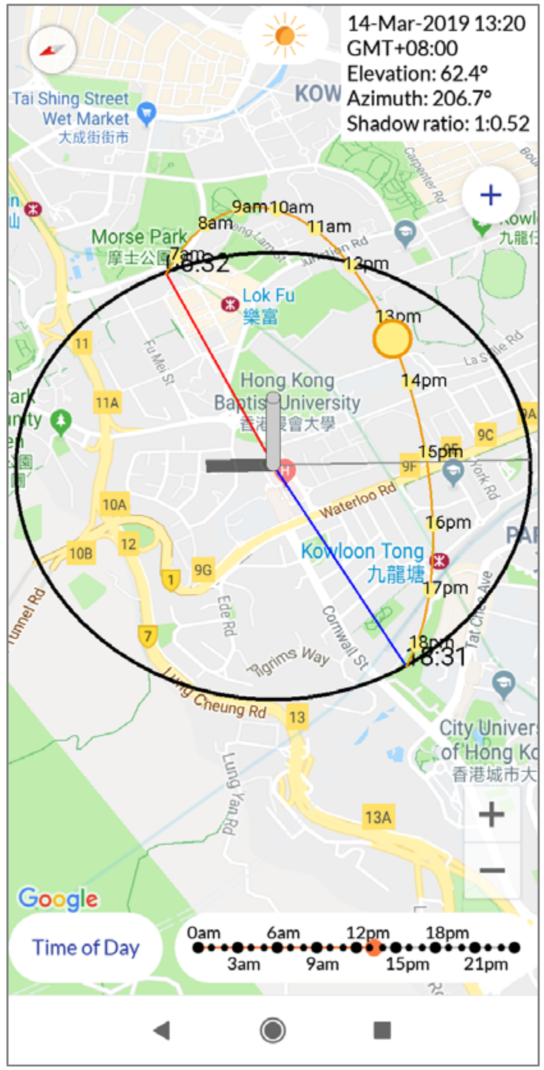


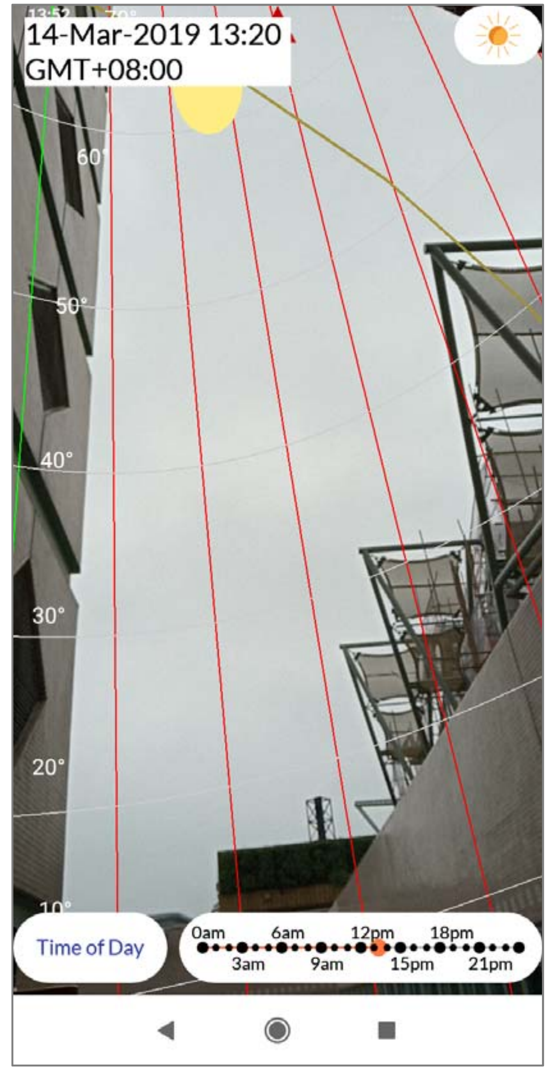
Software tool: Sun position



Sun position: Sun Locator





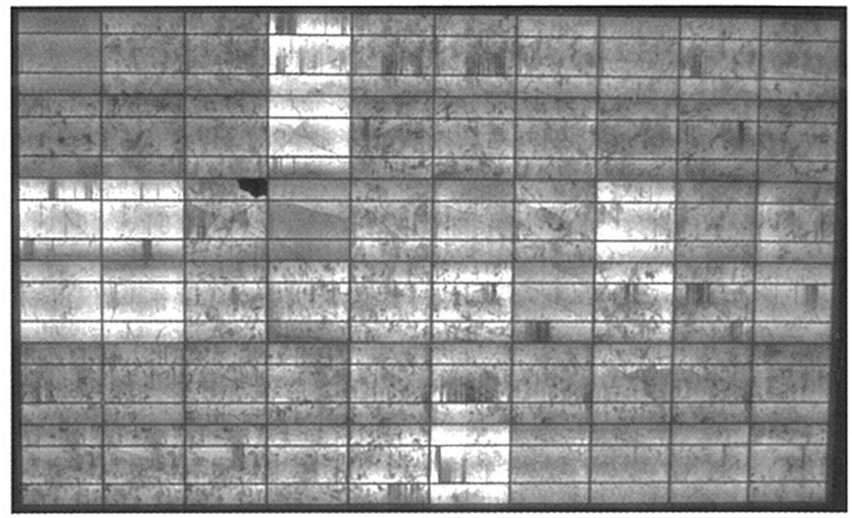


D. Repair and maintenance

- Cleaning
  - PV modules with inclinations greater than 12° are “self-cleaning” (but location dependent)
- Performance monitoring
  - PV output measurements
  - Functional analysis (IV characteristics) and other instruments (e.g., SOLAR300N Solar System Analyzer)
  - Thermography
  - Electroluminescence

Example: Solar system analyzer

Example: Electroluminescence image



Left: perfect PV module. Right: PV module with micro cracks.

Source: Planning and Installation Photovoltaic Systems, A Guide for Installers, Architects, and Engineers.

E. Appendix: Quality Certification

IP code: International Protection Marking (IEC 60529)

International Electrotechnical Commission (IEC)

- Publication and selling IEC International Standards for all electrical, electronic and related technologies.
- IEC Web: http://www.iec.ch/
- IEC Webstore: https://webstore.iec.ch/

IP code

IP code

- International Protection Marking (IEC 60529)
- Degrees of protection provided by enclosures for electrical equipment with a rated voltage not exceeding 72.5 kV.

E. Certification and testing during panel selection

1. IEC 61215-1:2016
   - Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements
2. IEC 61215-1-1:2016
   - Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules
3. IEC 61215-1-2:2016
   - Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules

E. Certification and testing during panel selection

4. IEC 61215-1-3:2016
   - Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules
5. IEC 61215-1-4:2016
   - Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu(In,GA)(S,Se)2 based photovoltaic (PV) modules

E. Certification and testing during panel selection

6. IEC 61215-2:2016
    - Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures

Certification Example

Attribute	Value
Power Rating	60W
Open Circuit Voltage	21.78V
Number of Cells	36
Peak Power	120W
Type	Polycrystalline
Efficiency	17%
Dimensions	1450 x 315 x 3mm
Depth	3mm
Length	1.45m
Maximum Temperature	+80°C
Minimum Temperature	-40°C
Width	315mm
Standards Met	CE, IEC 61215, IEC 61215:1993, IEC 61710 (Salt Mist Corrosion Test), ISO 9001 (2008), TUV
Mounting Style	Surface Mount
Terminal Contact Type	Ring

Scope and object

- IEC requirements for the design qualification and type approval of terrestrial PV modules suitable for long-term operation in general open-air climates.
- Not applicable to PV modules with concentrated sunlight [but it may be utilized for low concentrator modules (1 to 3 suns)].
- Not applicable to PV modules with integrated electronics.

Definitions and abbreviations

- Bins of power classes: *power (typically maximum power) sorting criteria from the PV module manufacturer.*
- Tolerances: *value range of electrical parameters on the label of the PV module as given by the manufacturer.*
- MQT: *Module Quality Test*
- Type approval: *conformity test made on one or more items representative of the production.*

Definitions and abbreviations

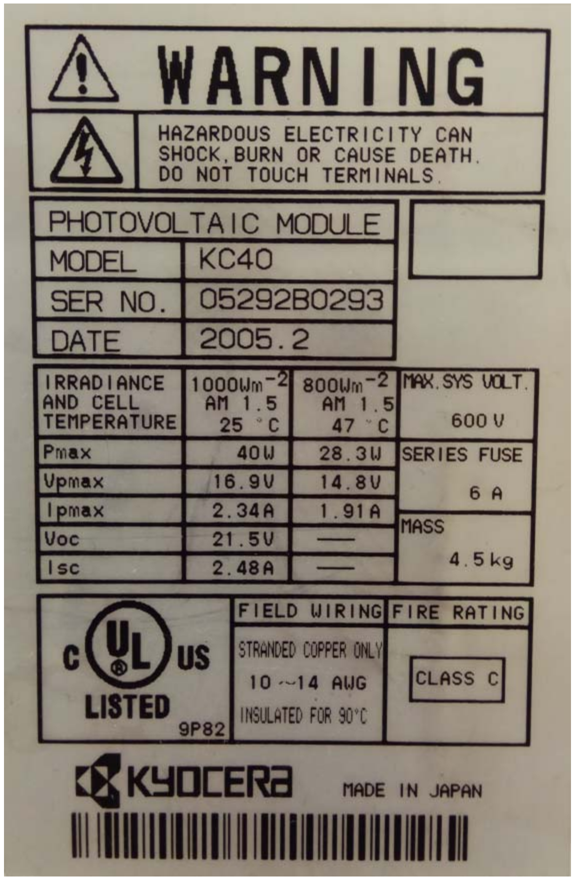
- Reproducibility: closeness of agreement between the results of measurements of the same value of a quantity, when the individual measurements are made under different conditions of measurement.
    - principle of measurement,
    - method of measurement,
    - observer,
    - measuring instruments,
    - reference standards,
    - laboratory,
    - under conditions of use of the instruments.

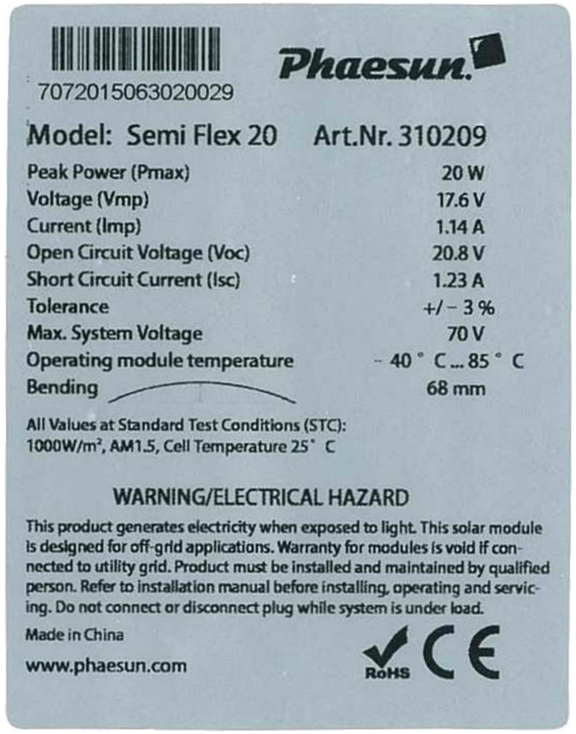
PV name plate

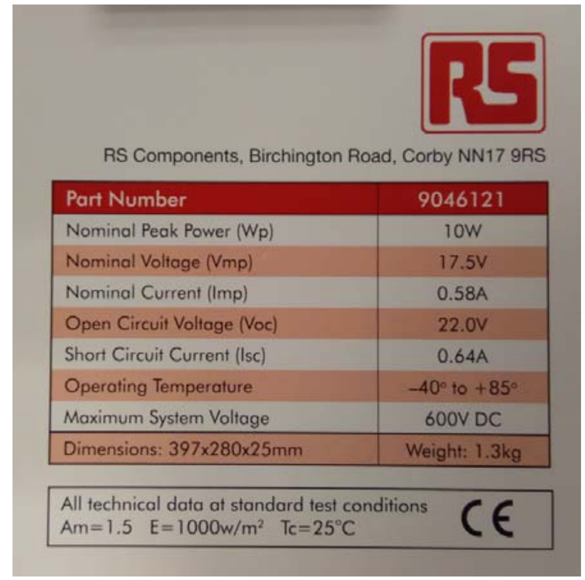
a) name, registered trade name or registered trade mark of manufacturer;
b) type or model number designation;
c) serial number (unless marked on other part of product);
d) date and place of manufacture; alternatively serial number allowing to trace the date and place of manufacture;
e) maximum system voltage;
f) class of protection against electrical shock;
g) voltage at open-circuit or V_{oc} including tolerances;
h) current at short-circuit or I_{sc} including tolerances;
i) module maximum power or P_{max} including tolerances.

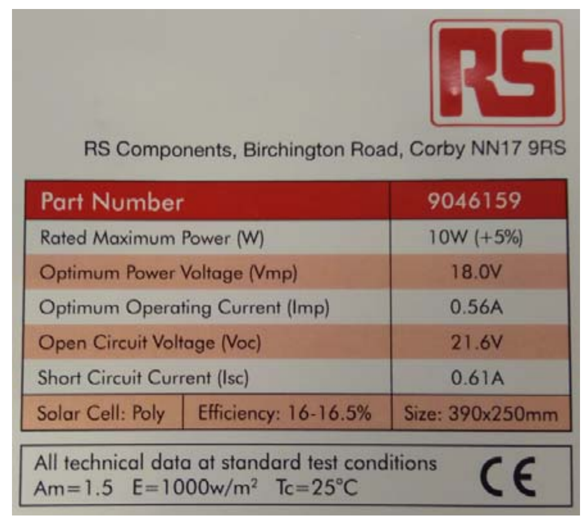
All electrical data shall be shown as relative to standard test conditions (1000 W/m^2, 25°C, AM 1.5)

PV name plate









PV documentation

a) All information required in the PV name plate;

b) reversed current rating in accordance to IEC 61730-2

- e.g. overcurrent protection device type and value;
- maximum series/parallel module configurations is recommended;

c) Manufacturer's stated tolerance for V_{oc}, I_{sc} and maximum power output under standard test conditions;

d) temperature coefficient for voltage at open-circuit;

e) temperature coefficient for maximum power;

f) temperature coefficient for short-circuit current.

PV documentation

g) nominal module operating temperature (NMOT);

h) performance at NMOT (MQT 06.2);

i) performance at low irradiance (MQT 07).

All electrical data shall be shown as relative to standard test conditions (1000 W/m^2, 25°C, AM 1.5).

Electrical documentation

j) minimum cable diameters for modules intended for field wiring;

k) limitations on wiring methods and wire management that apply to the wiring compartment or box;

l) size, type, material and temperature rating of the conductors to be used;

m) type of terminals for field wiring;

n) specific PV connector model/types and manufacturer to which the module connectors shall be mated;

o) the bonding method(s) to be used;

p) type and ratings of bypass diode

q) limitations to the mounting situation (e.g., slope, orientation, mounting means, cooling);

Electrical documentation

r) a statement indicating the fire rating(s) and the applied standard as well as the limitations to that rating (e.g., installation slope, sub structure or other applicable installation information);

s) a statement indicating the design load per each mechanical means for securing the module as evaluated during the static mechanical load test according to MQT 16. The test load and/or the safety factor γm may be noted.

To allow for increased PV output, the following statement shall be specified:

"Under normal conditions, a photovoltaic module is likely to experience conditions that produce more current and/or voltage than reported at standard test conditions. Accordingly, the values of I_{SC} *and* V_{OC} *marked on this module should be multiplied by a factor of 1.25 when determining component voltage ratings, conductor current ratings, and size of controls connected to the PV output."*

Test procedures

- MQT 01: Visual inspection
- MQT 02: Maximum power determination
- MQT 03: Insulation test
- MQT 04: Measurement of temperature coefficients
- MQT 05: Measurement of nominal module operating temperature (NMOT)
- MQT 06: Performance at STC and NMOT
- MQT 07: Performance at low irradiance
- MQT 08: Outdoor exposure test

Test procedures

- MQT 09: Hot-spot endurance test
- MQT 10: UV preconditioning test
- MQT 11: Thermal cycling test
- MQT 12: Humidity-freeze test
- MQT 13: Damp heat test
- MQT 14: Robustness of terminations
- MQT 15: Wet leakage current test
- MQT 16: Static mechanical load test
- MQT 17: Hail test

Test procedures

- MQT 18: Bypass diode testing
- MQT 19: Stabilization

MQT 01: Visual inspection

Purpose: To detect any visual defects in the module.

- Illumination of not less than 1000 lux.
- Make note of and/or photograph the nature and position of any cracks, bubbles or delaminations, etc.

MQT 01: Visual inspection

Example:

Normal PV.

Melting of solder.

MQT 02: Maximum power determination

Purpose: To determine the maximum power of the module.

Apparatus:

- Natural sunlight or solar simulator;
- PV reference device (IEC 60904-2);
- Mount for supporting the test specimen and the reference device in a plane normal to the radiant beam;
- Apparatus for measuring an I-V curve (IEC 60904-1).

MQT 02: Maximum power determination

Purpose: To determine the maximum power of the PV module after stabilization as well as before and after the various environmental stress tests. For determining the power loss from the stress tests, reproducibility is a very important.

Procedure

- Determine the PV I-V characteristic (IEC 60904-1) at 25°C–50°C and irradiance between 700 W/m^2 and 1100 W/m^2 (natural sunlight or solar simulator).
- Effort should be made to ensure that peak power measurements are made under similar operating conditions.

MQT 03: Insulation test

Purpose: To determine whether or not the module is sufficiently well insulated between live parts and accessible parts.

Test condition: Ambient temperature with relative humidity not exceeding 75%.

Apparatus:

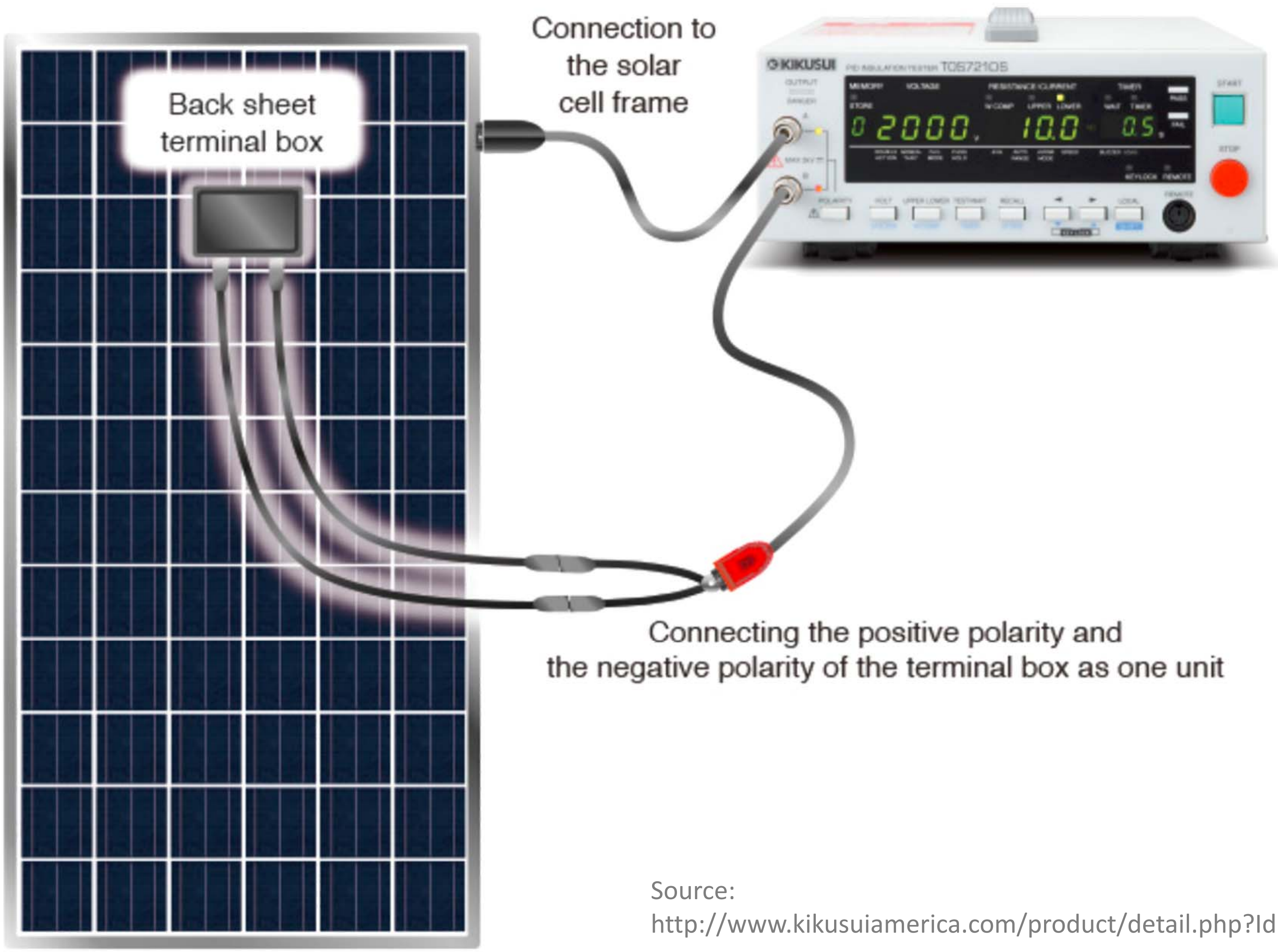
- DC voltage source with current limitation, capable of applying 500 V or 1000 V plus twice the maximum system voltage of the module;
- An instrument to measure the insulation resistance.

MQT 03: Insulation test

Test requirements:

- No dielectric breakdown or surface tracking;
- For modules with an area < 0.1 m^2, the insulation resistance shall not be less than 400 MΩ.
- For modules with an area > 0.1 m^2, the measured insulation resistance times the area of the module shall not be less than 40 $M\Omega \cdot m^2$.

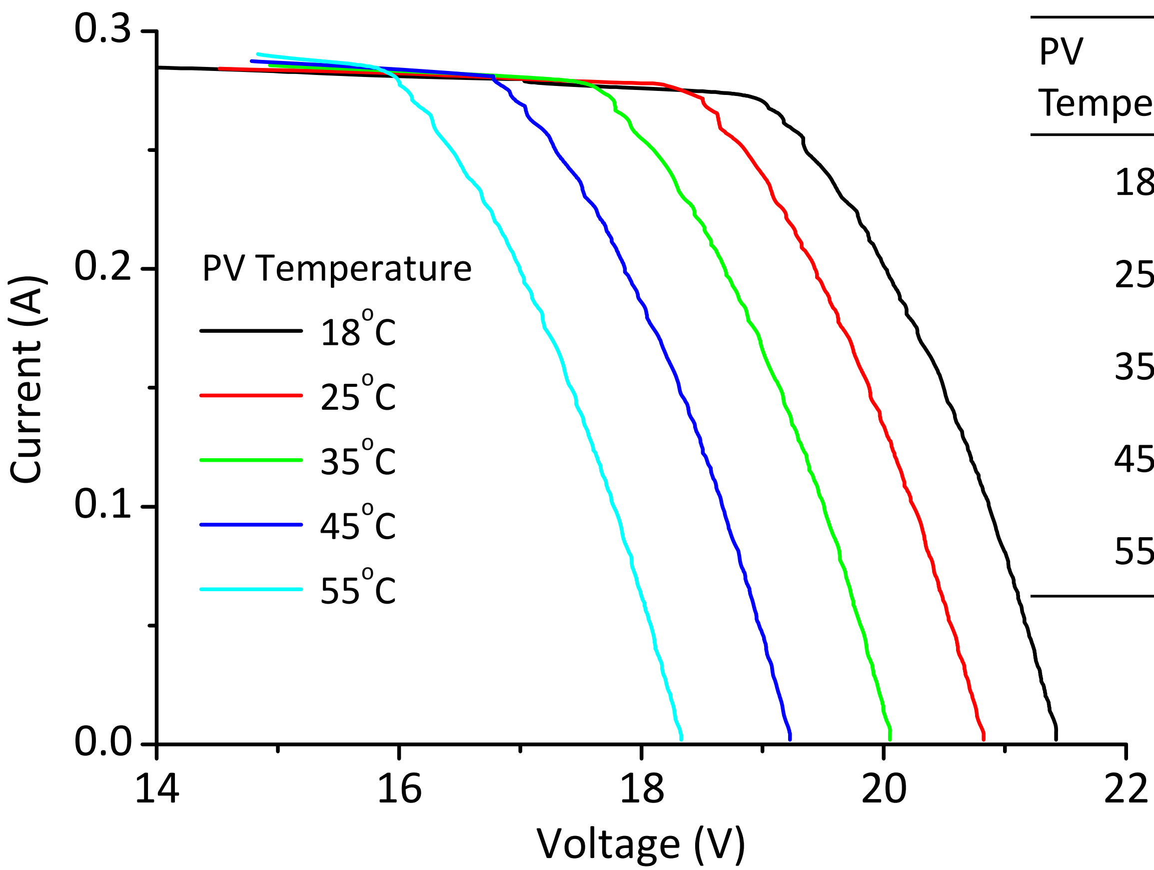
MQT 03: Insulation test



Source:
http://www.kikusuiamerica.com/product/detail.php?IdFamily=0135

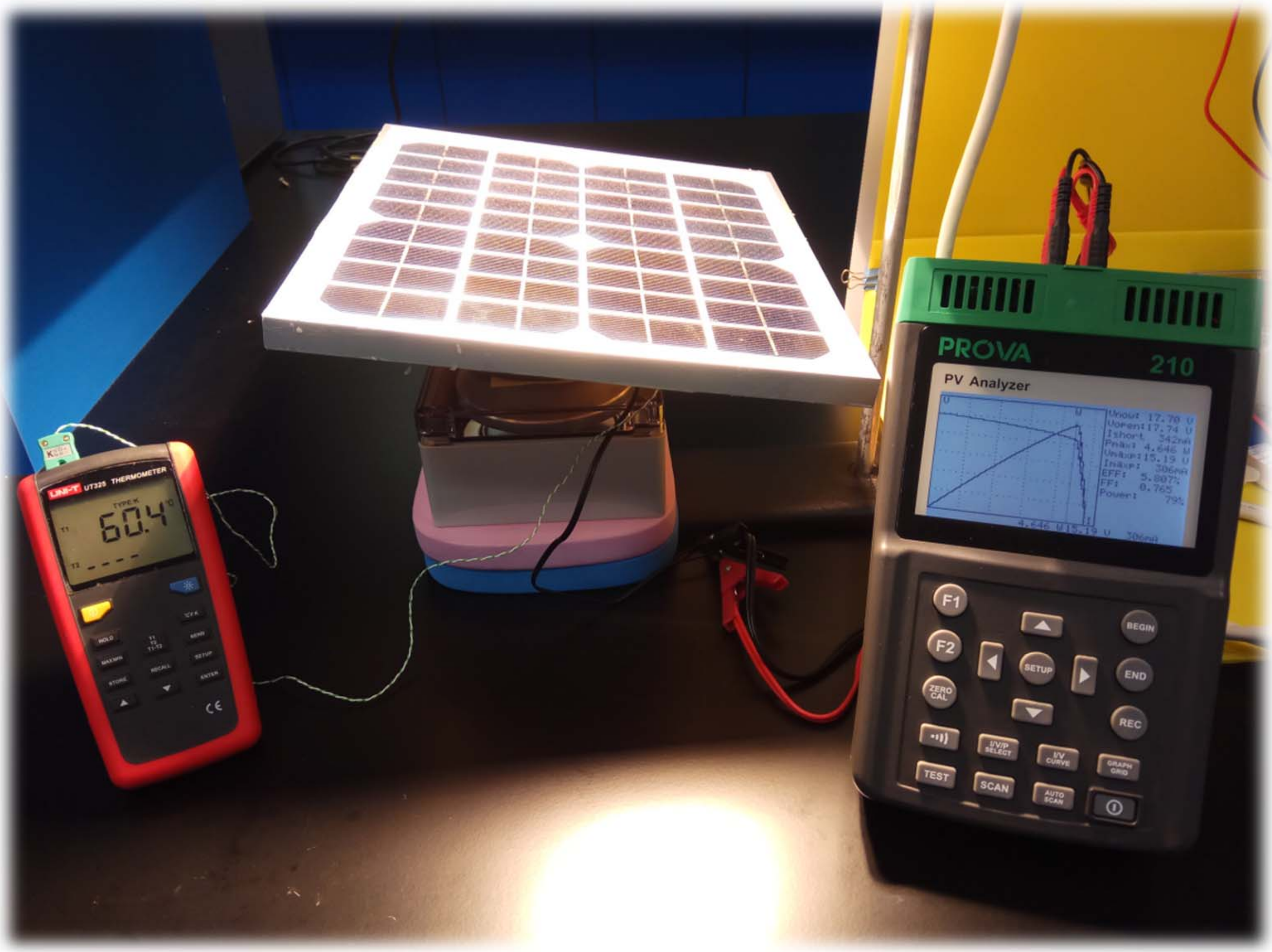
MQT 04: Measurement of temperature coefficients

- Determine the temperature coefficients of current (α), voltage (β) and peak power (δ) from PV module.



PV Temperature	V_{oc} (V)	I_{sc} (A)	P_{max} (W)
18°C	21.45	0.308	5.176
25°C	20.84	0.313	5.065
35°C	20.07	0.315	4.895
45°C	19.23	0.317	4.714
55°C	18.33	0.320	4.533

MQT 04: Measurement of temperature coefficients



Experimental setup for measurement of temperature coefficients.

MQT 05: Measurement of nominal module operating temperature (NMOT)

PV power is temperature dependent. The PV module temperature is primarily affected by the ambient temperature, the solar irradiance, and the wind speed.

MQT 05: Measurement of nominal module operating temperature (NMOT)

NMOT is defined as the equilibrium mean solar cell junction temperature within an open-rack mounted module operating near peak power in the following standard reference environment (SRE):

Tilt angle	(37±5)°C
Total irradiance	800 W/m^2
Ambient temperature	20°C
Wind speed	1 m/s
Electrical load	Operate near maximum point or electronic maximum power point tracker (MPPT)

Test procedure: IEC 61853-2 Spectral responsivity, incidence angle and module operating temperature measurements

MQT 05: Measurement of nominal module operating temperature (NMOT)

Remark:

- NMOT is similar to the former NOCT[#] except that NMOT is measured with the module under maximum power rather than in open circuit.
- Under maximum power conditions (electric) energy is withdrawn from the module, therefore less thermal energy is dissipated throughout the module than under open-circuit conditions.
- NMOT is typically a few degrees lower than the former NOCT.

[#] NOCT: Nominal Operating Cell Temperature

MQT 06: Performance at STC and NMOT

Purpose: To determine how the electrical performance of the module varies with load at

- STC (1000 W/m^2, 25°C PV temperature),
- NMOT (irradiance 800 W/m^2 and 20°C ambient temperature),

with the IEC 60904-3 reference solar spectral irradiance distribution

MQT 06: Performance at STC and NMOT

Procedure:

- Measuring at STC

  Maintain the PV module at (25±2)°C and trace the I-V characteristic at irradiance (1000±100) W/m^2 using natural sunlight or solar simulator.

- Measuring at NMOT

  Heat the PV module uniformly to (NMOT±2)°C and trace the I-V characteristic at irradiance (800±80) W/m^2 using natural sunlight or solar simulator.

MQT 07: Performance at low irradiance

Purpose:

To determine how the electrical performance of PV module varies with load at 25°C and irradiance of 200 W/m^2.

Procedure:

Determine the I-V characteristic of the module at (25±2)°C and an irradiance of (200±20) W/m^2 using natural sunlight or solar simulator.

MQT 08: Outdoor exposure test

Purpose:

To preform preliminary assessment of PV module to withstand exposure to outdoor conditions and to reveal any synergistic degradation effects which may not be detected by laboratory tests.

MQT 08: Outdoor exposure test

Procedure:

- The test PV module(s) shall be positioned normal to the local latitude ($\pm 5°$).
- Attach the resistive load or electronic MPPT to the module and
- mount it outdoors, as recommended by the manufacturer;
- Any hot-spot protective devices recommended by the manufacturer shall be installed before the module is tested.
- Subject the module to an irradiation totalling at least 60 kWh/m^2.

MQT 08: Outdoor exposure test

Requirements

- No evidence of major visual defects (IEC 61215-1).
- Wet leakage current shall meet the same requirements as for the initial measurements.

MQT 09: Hot-spot endurance test

Purpose:

To determine the ability of PV to withstand hot-spot heating effects, e.g. solder melting or deterioration of the encapsulation. This defect could be due to cell faulty, cell mismatch, shadowing or soiling. While absolute temperature and relative power loss are not criteria of this test, the most severe hot-spot conditions are utilized to ensure safety of the design.

MQT 09: Hot-spot endurance test

Apparatus

- Natural sunlight or solar simulator (800 to 1100 W/m^2).
- PV I-V curve tracer
- Equipment for current measurement
- Opaque covers (for test cells shadowing)
- Temperature detector (preferably an IR camera) to measure and record PV temperatures.
- Equipment to record irradiance levels and ambient temperature.

MQT 09: Hot-spot endurance test

Procedure:

- Example: If the bypass diodes are removable, cells with localized shunts can be identified by reverse biasing the cell string and using an IR camera to observe hot spots. If the module circuit is accessible the current flow through the shadowed cell can be monitored directly.

Example of IR image: Hot spot?

MQT 09: Hot-spot endurance test

Requirements

- No evidence of major visual defects (IEC 61215-1)
- Verify that the module shows the electrical characteristics of a functional PV device.
- Insulation resistance shall meet the same requirements as for the initial measurements.
- Wet leakage current shall meet the same requirements as for the initial measurements.
- Any damage resulting from determining the worst case shading shall be noted in the test report.

MQT 10: UV preconditioning test

Purpose: To precondition the PV module with ultraviolet (UV) radiation before the thermal cycle/humidity freeze tests to identify those materials and adhesive bonds that are susceptible to UV degradation.

Procedure:

- UV radiation (250 W/m^2, about five times the natural sunlight level, λ between 280 nm and 400 nm, uniformity $\pm$15% over the test PV module)
- Short-circuit or attach the resistive load to the PV module, and maintain the temperature at (60$\pm$5)°C
- Subject a total UV irradiation of at least 15 kWh/m^2.

MQT 10: UV preconditioning test

Requirements:

- No evidence of major visual defects (IEC 61215-1).
- Wet leakage current shall meet the same requirements as for the initial measurements.

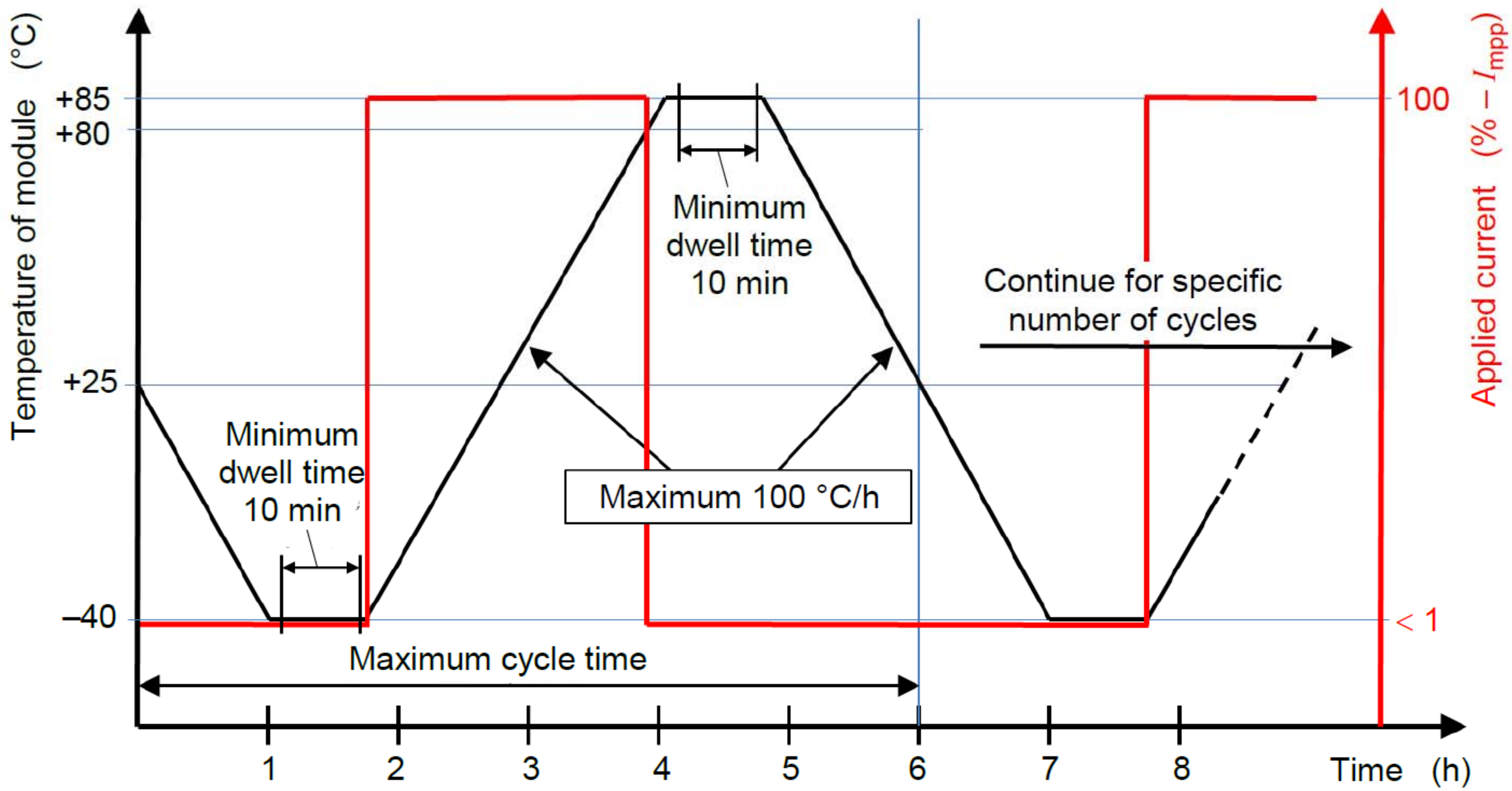
MQT 11: Thermal cycling test

Purpose: To determine the ability of the module to withstand thermal mismatch, fatigue and other stresses caused by repeated changes of temperature.

Procedure:

- Connect the PV positive terminal to the power supply positive terminal and the second terminal accordingly.
- Set the continuous current flow during the heat up cycle.

MQT 11: Thermal cycling test



Source: IEC

MQT 11: Thermal cycling test

Requirements:

- No interruption of current flow during the test
- No evidence of major visual defects (IEC 61215-1).
- Wet leakage current shall meet the same requirements as for the initial measurements.

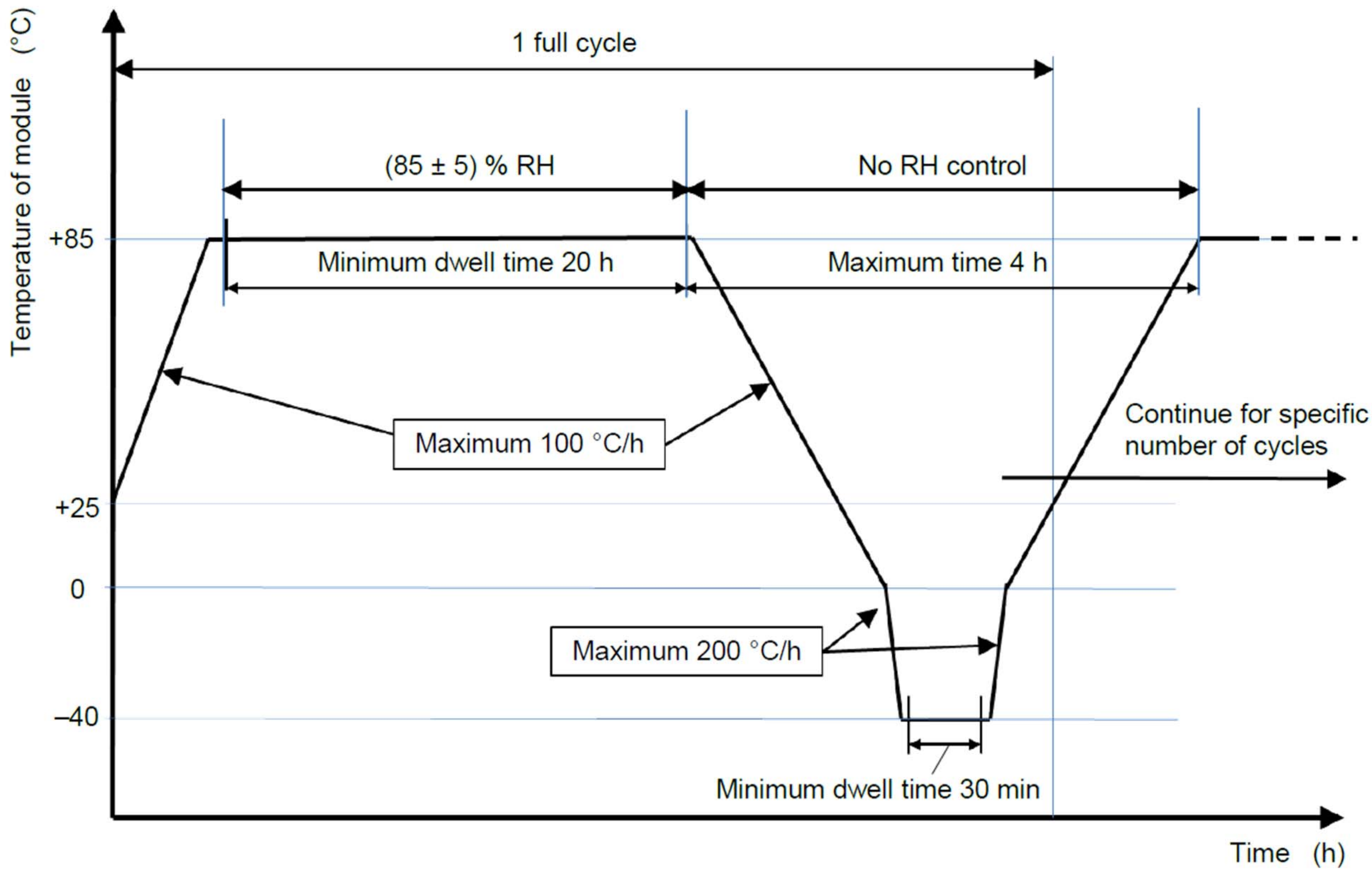
MQT 12: Humidity-freeze test

Purpose: To determine the ability of the module to withstand the effects of high temperature and humidity followed by sub-zero temperatures.

Requirements:

- No interruption of current flow or discontinuity in voltage during the test in one of the parallel circuits
- No evidence of major visual defects (IEC 61215-1)
- Wet leakage current shall meet the same requirements as for the initial measurements

MQT 12: Humidity-freeze test



Source: IEC

MQT 13: Damp heat test

- Purpose: To determine the ability of the module to withstand the effects of long-term penetration of humidity
- Carry out the test in accordance with IEC 60068-2-78:2012

Test temperature: $(85 \pm 2)^{\circ}$

Relative humidity: $(85 \pm 5)\%$

Test duration: ($1000\,^{+48}_{\;\;0}$) hours

MQT 13: Damp heat test

Requirements:

- No evidence of major visual defects (IEC 61215-1).
- Wet leakage current shall meet the same requirements as for the initial measurements.

MQT 14: Robustness of terminations

Purpose: To determine that the terminations, the attachment of the terminations, and the attachment of the cables to the body of the module will withstand stresses that are likely to be applied during normal assembly or handling operations.

MQT 14.1: Retention of junction box on mounting surface

Requirements:

- No evidence of major visual defects (IEC 61215-1).
- Wet leakage current shall meet the same requirements as for the initial measurements.

MQT 14: Robustness of terminations

MQT 14.2: Test of cord anchorage

Requirements:

- No evidence of major visual defects (IEC 61215-1).
- Insulation test shall meet the same requirements as for the initial measurements.
- Wet leakage current shall meet the same requirements as for the initial measurements.
- The displacement of the cable at the outlet of the junction box shall not exceed 2 mm.

MQT 15: Wet leakage current test

Purpose: To evaluate the insulation of the module under wet operating conditions and verify that moisture from rain, fog, dew or molten snow does not enter the active parts of the module circuitry, where it might cause corrosion, a ground fault or a safety hazard.

Requirements:

- For modules with area < 0.1 m^2 the insulation resistance shall not be < 400 $M\Omega$.
- For modules with an area > 0.1 m^2 the measured insulation resistance times the area of the module shall not be < 40 $M\Omega \cdot m^2$.

MQT 16: Static mechanical load test

Purpose: The purpose of this test is to determine the ability of the module to withstand a minimum static load.

Requirements:

- No intermittent open-circuit fault detected during the test.
- No evidence of major visual defects (IEC 61215-1).
- Wet leakage current shall meet the same requirements as for the initial measurements.

MQT 17: Hail test

Purpose: To verify that the module is capable of withstanding the impact of hail.

Requirements

- No evidence of major visual defects (IEC 61215-1).
- Wet leakage current shall meet the same requirements as for the initial measurements.

MQT 18: Bypass diode testing

Purpose: Thermal design and long-term reliability of bypass diode.

MQT 19: Stabilization

Purpose: To ensure electrical (PV power output) stabilization.