SUNdidactics

SolarEnergyDidactics
SolarEducation
SolarEngineering

innovative Solarsysteme für Schule und Ausbildung
innovative solar- systems for school, college, technical education

- Solardidaktik
- Solarzellen
- Solarmodule
- Photovoltaik- Experimentiergeräte
- Photovoltaik- Gerätentwicklung
- Experimentieranleitungen didaktische Konzepte
- Solarberatung
- Solar- Workshops
- Solar- Fortbildung für Lehrkräfte
- solare Aus- und Weiterbildung
- Solarspielzeuge

- solardidactics
- solar cells
- solar modules
- photovoltaic -experiment -devices
- solar- experiment- manuals
- solar- workshops
- solar consulting
- solar education
- solar training for teachers
- solar toys

SUNdidactics **Wolf- Rüdeger Schanz, Schaperbleek 15, D-31139 Hildesheim, Germany**

Phone: +49(0)5121 86 07 30 Fax: +49(0)3222 370 66 89 Mail: wr.schanz@t-online.de
Mobile: +49(0)175 766 06 07 Web: www.sundidactics.de Mail: info@sundidactics.de

cooperation www.nils-isfh.de

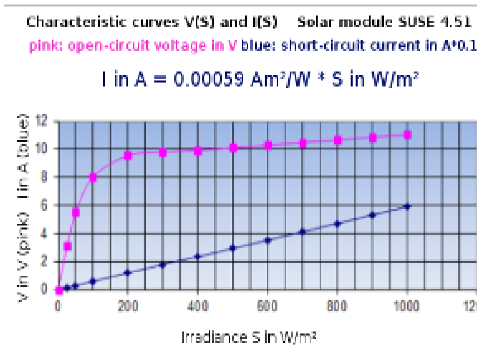
Solar module SUSE 4.51
5 W solar module for PV experiments

18 solar cells in intern series connection V_{oc}=11.0 V, I_{sc}= 0.59 A, P = 5.2 W with S = 1000 W/m², T = 25°C, AM 1.5
Expecially suited for smartphone charging with SUSE 4.17 **11 pages**

The **solar module SUSE 4.51** is a professional and very robust solar module with 18 solar cells in intern series connection behind glass, framed with a stable aluminum frame. On the module's back side an adjustable positioner is mounted, with which the module can be adjusted continuously in an ideal angle towards the position of the sun on the ground or on a table.
Connected to the module's junction box is a 1.5 m long cable with two 4 mm bunch plugs.
With this solar module and the experimentation manual extensive experiments in module technology and solar cells can be conducted. With the additional module SUSE 4.17 smartphones and tablet PCs can be charged with V=5.0 V.

Top: Solar module SUSE 4.51, the multimeter shows the open circuit voltage 11.04 V.

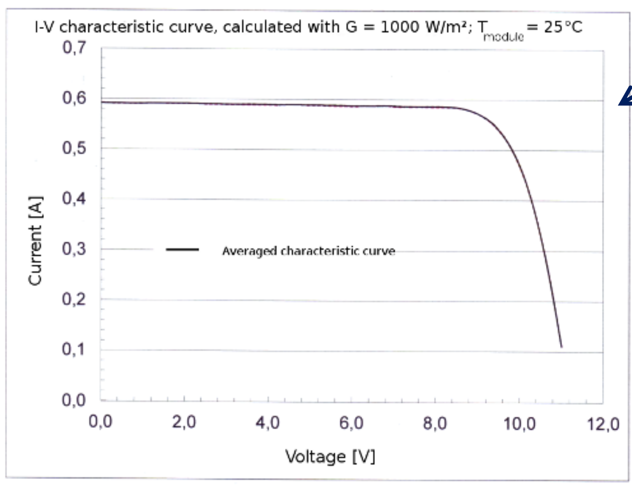
Left: The adjustable table/ground positioner on the back of the solar module



The characteristic curves of the module:
On the left the V_{oc}(S) and I_{sc}(S) curve:
The open-circuit voltage V_{oc} first increases strongly with increasing irradiance S (= light intensity) and then approximates a voltage of 11.0 V.
The short-circuit curent I_{sc} increases with the irradiance in a linear fashion up to a maximum value of 0.59 A.
At the bottom the I(V) characteristic curve

Technical data

with STC S = 1000 W/m², T= 25°C, AM 1.5
Cell type: multicrystalline
Cell dimensions: 52 mm x 31 mm
Cell number: 18
Frame: Aluminum
External dimensions: 240 x 180 mm
Nominal output: 5.2 W
P_{mpp}: 5.2 W
V_{oc}: 11.0 V
I_{sc}: 0.59 A
V_{mpp}: 9.2 V
I_{mpp}: 0.56 A
Fill factor: 79.6 %
Cell efficiency factor: 18.0 %
Module efficiency factor: 12%

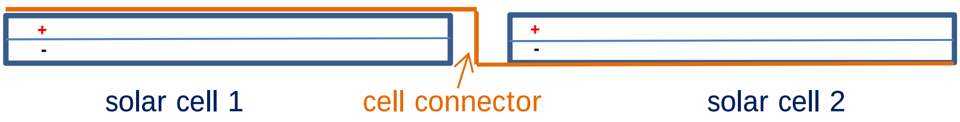


Left: The I-V characteristic curve of the solar modul SUSE 4.51

Bottom: The green indicator LED in the junction box shows operational

2. Technical composition of the solar module:

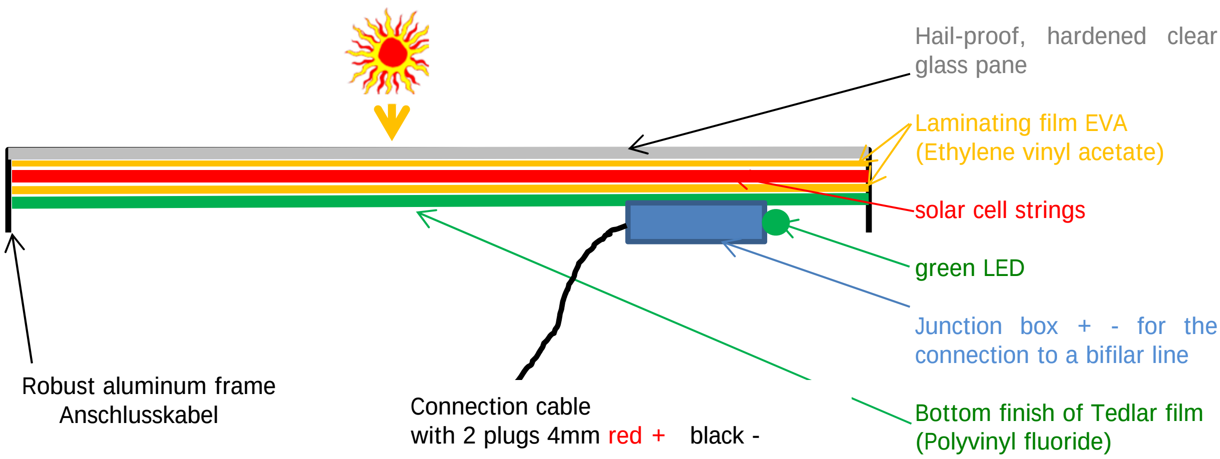
In the module **18 identical solar cells** are **connected in series electrically**, 3 rows with 6 solar cells each. One row is called “string”. The positive pole of the 1st solar cell is the positive pole of the module, the negative pole of the 18th solar cell is the negative pole of the module.
Because the negative pole of a solar cell is on the top surface, the positive pole on the bottom side, 2 solar cells are connected in series like this with cell connectors (tinned Cu tapes):



So the cell connector is soldered on the top side of the 1st cell, run down the 3mm space between both cells and soldered on the lower surface of the 2nd cell. This way all 18 solar cells are connected to each other. At the ends of a string the cell connector is run to the next string.
With this electric **series connection** the **voltages of the solar cells add up**, the total voltage V_{tot} of the module is therefor the 18-fold voltage of one solar cell.
The **current does not change in the series connection**, if the solar cells are equal, otherwise the current of the worst solar cell determines the total current.

The solar cells are embedded in transparent laminating film and laminated to the hail-proof clear glass pane. The back finish is a Tedlar film to which the junction box is glued.

The composition of the solar module in cross section:



Soldered in the junction box of the solar module SUSE 4.51 is a 1.5 m long bifilar connection cable with two 4 mm bunch plugs red (positive) and black (negative), **a green LED** shows operational readiness.

The technical data is used in the **theoretical part of the experiments (part 1)**, for the **practical part of the experiments (part 2)** the open circuit voltage and the short-circuit current are measured with the multimeter and evaluated experimentally. With the continuously adjustable ground/desk positioner the solar module can be positioned exactly towards the sun or the light source.
The experiments only apply to the solar module SUSE 4.51, other modules have different technical data and different measurement values.

3. The experiments A,B,C

can be conducted in sequence or independent from each other

A Solar module SUSE 4.51 as a solar generator for the operation of devices

A1 To the solar module SUSE 4.51 the following devices can be connected directly:

- **LED modules SUSE 4.15** in red, green, yellow, blue, IR, white or **SUSE 4.20**IRRB (12V version).

Connect the LED modules to the solar module with the right polarity.

- **Solar vehicle SUSE 4.5**

To charge the GoldCap energy storage the module cable plugs are plugged into the black-red jack pair at the vehicle with the right polarity. In the experimentation manual of the vehicle SUSE 4.5 you can find further information on how to proceed.

A2 Connection of the DC-DC converter SUSE 4.17 to the solar module SUSE 4.51

The DC-DC converter SUSE 4.17 converts the module voltage to 5V DC, which is applied at the output at a USB socket. The connector cable of SUSE 4.51 is plugged into the input jacks of SUSE 4.17 with the right polarity. To the USB output socket the following devices can be connected:

- **Smartphone for charging** with micro USB socket

Connect the smartphone charging cable with USB plug to the USB socket of SUSE 4.17 and orient the solar module optimally towards the sun.

Powerbank rechargeable battery for charging with micro USB socket Connect the charging cable with USB plug to the USB socket of SUSE 4.17 and orient the solar module optimally towards the sun.

- **Solar radio SUSE 4.36USB**

Plug the USB plug of the radio cable into the USB socket of SUSE 4.17 and orient the solar module optimally towards the sun. The radio can also be operated with the powerbank rechargeable battery in the dark.

During the day the experiments can be conducted perfectly outdoors in the natural sunlight or with clouded sky. Indoors light sources such as halogen spot lights (120 W on pipe stand) or overhead projectors (bright glass plate) can be used.

B Experiments / exercises with the technical data on page 1

All data refer to the standard test conditions (STC), solar irradiation 1000 W/m², temperature 25°C, air mass AM1.5.

For geometric measurements on the module we need a set square/ruler and a folding rule, for the calculations a calculator or calculator app on the smartphone.

B1 Determination of the open circuit voltage of a solar cell

Determine the open circuit voltage V_{oc} of <u>one solar cell</u> in the module with the aid of the technical data and your own calculations:

V_{oc}= ………………V

B2 Determination of the cell efficiency factor

The efficiency factor of a solar cell can be calculated with the technical data:

$$\textbf{Efficiency factor in \%} = \frac{P_E}{P_L} * 100$$

P_E = electric power of all solar cells at the MPP
P_L = Light power on the area of <u>all solar cells</u> (not on 1 m²!!)

Calculate the efficiency factor and compare it to the information in the technical data:

B3 Determination of a solar cell's quality

The short-circuit current I_{sc} per 1 cm² cell area = current density j is a quality feature of solar cells. Calculate this value and compare it to the table.

Evaluate the quality of the solar cells in the module:

Current density j of solar cells

Very good: > 34 mA/cm² Good: 29 - 33 mA/cm² Medium: 25 - 29 mA/cm²
Bad: < 25 mA/cm²
With an irradiance of 1000 W/m² !! Maximum possible theoretical value: 44 mA/cm²

B4 Determination of the solar module's power

At the Maximum Power Point (MPP) the solar module has its maximum power, from the product of voltage and current at the MPP the peak power arises.

Calculate this value and compare it to the technical data about the power:

B5 Determination of the module efficiency factor of the solar module

The sun irradiates the whole module area, but only the entirety of the area of all solar cells produces electric energy. The empty space between the solar cells does not produce any energy. For the module efficiency factor the ratio of the produced electric energy over the incoming radiation power <u>on the whole module area</u> is used.

This value plays a big role in the commercialization of solar modules, because customers look out for a high module efficiency factor.

Calculate the module efficiency factor here and compare it to the manufacturer information:

Active solar cell area in % of the module area:.................................%

Inactive empty space in % of the module area:.................................%

B6 Theoretical exercises on a higher level

1. Explain both characteristic curves on page 1 in your own words!

2. How do open circuit voltage, short-circuit current and power change, if the sun only shines with half the intensity = 500 W/m² (clouded sky)? Explain and give numerical values!

3. How would the I-V characteristic curve change, if the sun only shines with half the intensity = 500 W/m² (clouded sky)? Explain and sketch in the changed course with a pencil!

Exercises B6

C Experiments and measurements with the solar module SUSE 4.51

C1 Measurements of open circuit voltage, short-circuit current, and power

a) The exact adjustment of the solar module towards the sun

We connect the red-black plug pair to a multimeter in the measurement range 10 A DC.

In doing so the short-circuit current is measured. With the ideal adjustment towards the sun or the brightest spot in a clouded sky a maximum measurement value results. By rotating and tilting the module this position can be reached. Note the value for the short-circuit current here:

I_{sc}=……………………………………………A

With the passing of clouds the value can vary severely! With blue, cloudless sky after approx. 10 minutes the module must be readjusted because of the earth rotation!

Measurements of V_{oc} and I_{sc}:

Date:………………………………Weather conditions:……………………………………………

Measurement range voltage: 20 V DC Measurement range current: 10 A DC/indoors 200 mA DC

b) The measurements with optimal adjustment towards the sun

Measurement location	Outdoors with sunshine directed towards the sun or overhead projector	Outdoors with sunshine in the shadows	Outdoors with clouded sky	In illuminated room on the desk
Open circuit voltage V_{oc} in V				
Short-circuit current I_{sc} in A				
Power P in W (V_{oc}*I_{sc}*0.8) Approximate value				

c) The measurements with horizontal position on the ground or desk

Measurement location	Outdoors with sunshine directed towards the sun or overhead projector	Outdoors with sunshine in the shadows	Outdoors with clouded sky	In illuminated room on the desk
Open circuit voltage V_{oc} in V				
Short-circuit current I_{sc} in A				
Power P in W (V_{oc}*I_{sc}*0.8) Approximate value				

Explain and evaluate your results here:

d) Reduced output by covering and shadowing the solar cells of the module

In photovoltaic installations on roofs it often occurs, that single solar cells are covered (e.g. by leaves lying on top or dirt) or shadowed (e.g. by shadows of adjacent trees, chimneys, houses…).

Plan a suitable experiment about this with the module SUSE 4.51 and measure the reduced output.

Record the experiment here and assess the measurement values:

e) Change in output with warming of the solar module

Solar modules on roofs or in ground mounted systems get very hot in summer. Voltage, current, and power of solar cells are temperature dependent, they change their values with warming. In the summer, with intensive solar irradiation, photovoltaic systems on roofs or on free ground indeed produce the highest power, but it decreases significantly, if the solar cells heat. In the summer cell temperatures of 60°- 80°C are possible. In contrast ideal conditions are found in space, there intensive irradiation with very low temperatures (<-50°C) are on hand.

Measurements without temperature measurement on the module

Requirement: Bright sunshine without clouds or irradiation with halogen flood light 120 W, e.g. on basic device SUSE 4.0, or measurement on the plate of an overhead projector
Accessories: 1 multimeter for the measurement of voltage and current, 2 lab wires, calculator or calculator app on smartphone

We place the solar module SUSE 4.51 in the refrigerator or in a dark, cool place in the room for 10 minutes and let it cool down. After the cooling we go into the sunlight, adjust the module towards the sun. For experiments indoors we place the module on an overhead projector, measure V_{oc} and I_{sc} in time lags for 5 minutes and enter the values into the table. In the measurement breaks we calculate P and enter the power into the corresponding column. **We immediately start** with the measurements after the placement of the module.

Time in s	**Open circuit voltage V_{oc} in V**	**Short-circuit current I_{sc} in A**	**Power P $= V_{oc} * I_{sc} * 0.8$**
0			
30			
60			
90			
120			
180			
240			
300			

What do you notice? Explain here:

C2 Determination of the light intensity = irradiance S of the light with the solar module SUSE 4.51

The brightness (intensity) of the light is called irradiance S and is measured in W/m² (Watts per m²).
With the calibrated solar cell used here the light intensity in W/m² can be determined exactly in front of a halogen spot light, on an overhead projector, or outdoors.

1000 W/m² is the intensity of the light radiation of the sun with cloudless sky in the summer and the international standard measurement value for solar cells.

Short-circuit current I_{sc} of the solar cell with an irradiation of 1000 W/m²

I_{SC}= ....0.59...................A = ...590................mA

Measurement of the irradiance S of light (light intensity) in W/m²:

Because the short-circuit current I_{sc} of a solar cell is proportional to the irradiance S, it holds:

$$\frac{0.59\ \text{A}\ (I_{sc})}{1000\ \text{W/m}^2} = \frac{I_{mes}\ \text{in A}}{S_x\ \text{in W/m}^2} \quad \text{or solved for } S_x: \quad \boxed{S_x = \frac{I_{mes}\ (\text{in A}) * 1000\ \text{W/m}^2}{0.59\ \text{A}}}$$

It is: I_{sc} in A the calibrated short-circuit current at 1000 W/m² **= 0.59 A**

I_{mes} in A the measured short-circuit current at the irradiance S_x

S_x in W/m² the measured irradiance of the light radiation

Measurements outdoors and with light sources:

Use a multimeter in the current measurement range of 10 A.
For indoors measurements use the measurement range 200 mA or 20 mA.

Light radiation	**Short-circuit current I_{sc} in A**	**Irradiance S_x in W/m²**
Bright sunshine, measured directly towards the sun		
Bright sunshine, measured in the shadows		
Clouded sky Measured towards the South		
Very gloomy weather		
On the plate of an overhead projector		
40 cm in front of halogen spot lamp 120 W		
Indoors, directed towards the window		

What do you notice? Explain here: