

1. Dependence of power on the area of the solar cell



Introduction

Solar cells are available in different sizes. With this experiment the dependence of the characteristic values voltage, current and power on the solar cell area should be investigated.



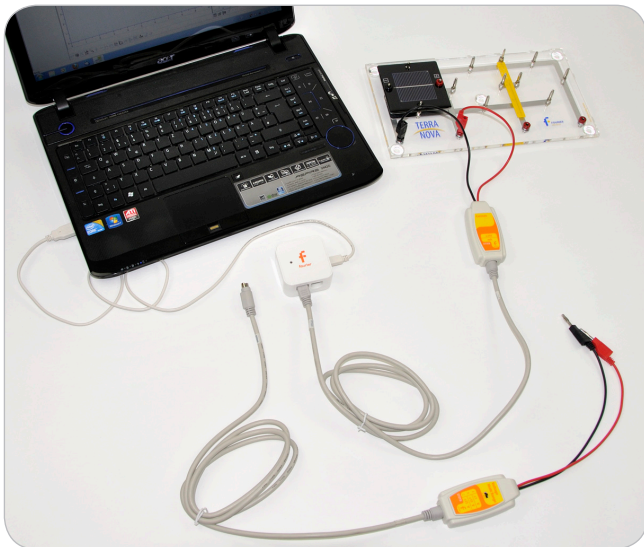
Equipment

1. Main board
2. 1 large solar cell
3. 3 solar cells cover sheets
4. 1 voltage sensor
5. 1 current sensor
6. NOVA LINK




Equipment Setup Procedure

1. Launch MultiLab.
2. Connect the USBLink to the USB port on the computer. The green LED will turn on when the USBLink is successfully connected to the computer.
3. Plug the solar cell onto the main board (left position).
4. For current measurement connect the current sensor parallel to the solar cell and to I/O 1 port of the USBLink.
5. For voltage measurement connect the voltage sensor parallel to the solar cell and to I/O 1 port of the USBLink.
6. Be aware not to connect both sensors at the same time





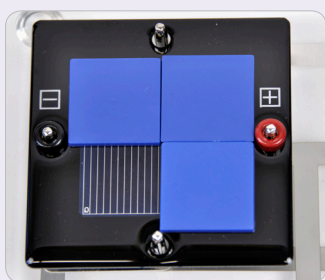
MultiLab Setup


1. Click .
2. Click **Next**.
3. Set **Select rate** to **Manual**.
4. Set **Select recording mode** to **Add**.
5. Click **Next**.
6. Set **by samples** to **50**.
7. Click **Finish**.

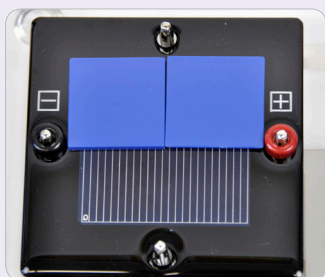


Experimental Procedure

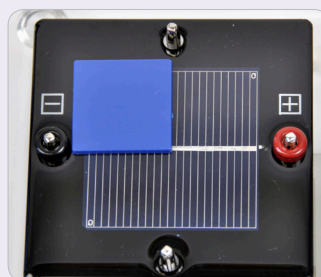
1. Connect the current sensor as described in the equipment setup.
2. Put all 3 covers onto the solar cell.





3. Click .
4. Take one cover away from the solar cell, so that there are two covers left



5. Repeat step 2 to 3 until no cover is on the solar cell.



6. Click .
7. Connect the voltage sensor as described under "Equipment Setup Procedure".
8. Repeat point 1 to 4.
9. Click .



Data Analysis

1. Click f_x .
2. Click **Functions**.
3. Set **Functions** to **Multiply**.
4. Set **G1** and **G2** to voltage and current measurement data.
5. Click **Ok**.
6. Go to **Table > Add manual column**.
7. Set **Column name** to **free active area**.
8. Click **Ok**.
9. Click
10. Add the columns of free active area, the current and voltage measurement and of the calculated power function.
11. Click **Ok**.
12. Click
13. Click y_x .
14. Set **X-axis** to **free active area**.
15. Set **Y-axis** to the measured current and voltage data points.
16. Set the **Graph title** to **"Voltage / Current / Power - Area Dependence"**.
17. Click **Ok**.



Questions

1. How does the voltage V depend on the solar cell active area size?
2. How does the current I depend on the solar cell active area size?
3. What can therefore be conclusion for the power P ?
4. Advanced: Give an explanation for this behavior!
5. Advanced: In the experiment kit only relative small solar cells are included. In practice mostly so called 6-inch solar cells are used. They have a size of 156mm x 156mm. Apply a linear fit to your data and calculate the current and power of a 6-inch solar cell under the conditions of your experiment.

2. Dependence of power on angle of incidence



Introduction

Solar modules are mostly mounted on roofs in a fixed position. During the day, when the sun is “moving” across the sky, the angle of incidence of sunlight changes. In this experiment the dependency of the solar cell power on the angle of incidence should be investigated.



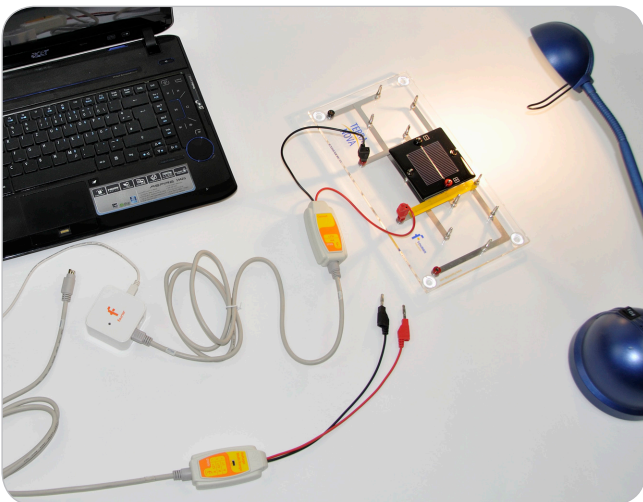
Equipment

1. Main board
2. 1 large solar cell
3. 1 current sensor
4. 1 voltage sensor
5. Desk light or equivalent
(if you do not conduct the experiment in sunlight)
6. NOVA LINK




Equipment Setup Procedure

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. For voltage-measurement connect the voltage sensor to I/O-1 port of the NOVA LINK.
4. For current-measurement connect the current sensor to I/O-1 port of the NOVA LINK.
5. Plug the large solar cell onto the middle position of the main board.





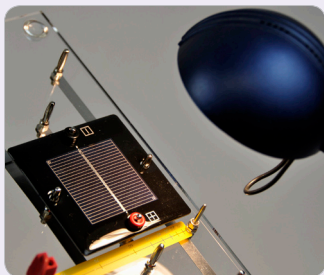
MultiLab Setup

1. Click .
2. Click **Next**.
3. Set **Select rate** to **Manual**.
4. Set **Select recording mode** to **Add**.
5. Click **Next**.
6. Set **by samples** to **50**.
7. Click **Finish**.



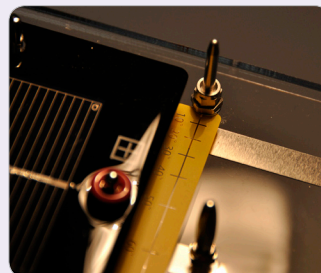
Experimental Procedure




1. Connect the voltage sensor parallel to the solar cell.
2. Align the main board to the sun or the main light source so that the angle between the base unit and the incident light is 90° - this means the angle of incidence is 0° . Use the shadow bar of the main board for alignment: There should be no shadow visible.



3. Click .



4. Change the angle of the main board so that the shadow is parallel to the angle scale and reaches the 10° line.




5. Now change the angle to the values of 20° , 30° , 40° , 50° , 60° , 70° and 75° and for each angle click .
6. Click .
7. Exchange the voltage sensor by the current sensor and repeat step 1 to 4.
8. Click  to save your data.



Data Analysis

1. Click **Table > Add manual column**.
2. Fill in the field for Column title : "**Angle**".
3. Click **Ok**.
4. Click f_x .
5. Click **Functions**.
6. Set **Functions** to **Multiply**.
7. Set **G1** and **G2** to the voltage and current measurement data.
8. Click **Ok**.
9. Click .
10. Add the columns of the current and voltage measurement, of the calculated power function and the column **angle**.
11. Set the name of the table to Overview.
12. Click **Ok**.
13. Fill the column angle with the correct numbers.
14. Click .

Plotting power vs. cosin (alpha)

1. Click f_x .
2. Click **Functions**.
3. In the tab **Functions** select **Cosine**.
4. Set G1 to **angle**.
5. Set B to **0.01745** ($\pi/180^\circ$).
6. Click **Ok**.
7. Click  and add the cosine function as column.
8. Click y_x .
9. Set the **X-axis** to the **Cos function**.
10. Set **Y-axis** to current and **the calculated cosine function**.



Questions

1. How do the current and the voltage depend on the angle of incidence?
2. What is the exact mathematical relation between the power and the cosin function of the angle?
3. Advanced: Explain this behavior geometrically.

3. Series and parallel connection of solar cells (qualitative)



Introduction

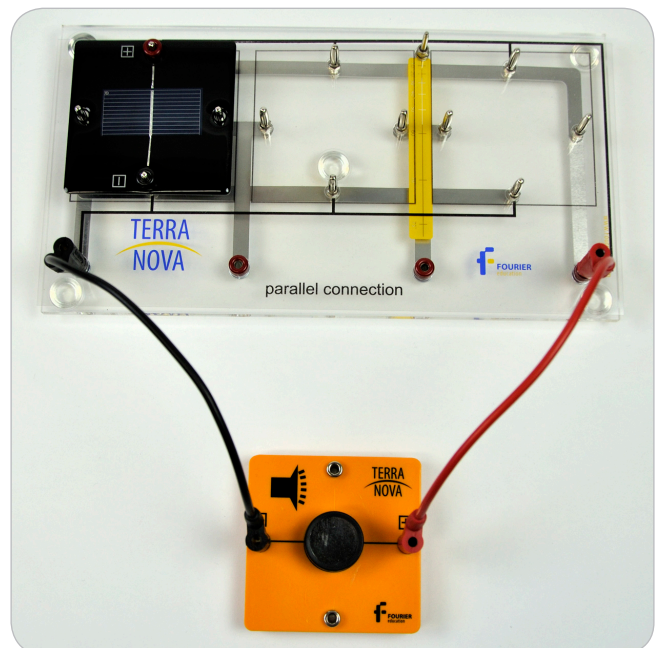
Individual solar cells can only be manufactured up to a size of about 6 inch by 6 inch (156mm x 156mm). Hence, to achieve large photovoltaic power plants it is necessary to connect many solar cells together. But how should solar cells be connected to each other? In this experiment series and parallel connection of solar cells can be compared in a qualitative way.

Also the problem of partly shaded solar modules can be introduced qualitatively.



Equipment

1. Main board
2. 3 small solar cells
3. 1 buzzer module
4. 2 cover sheets
5. 2 cables (not included in the kit)





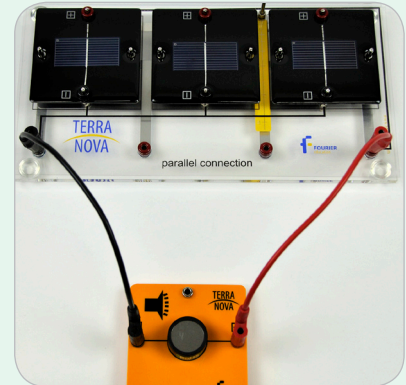
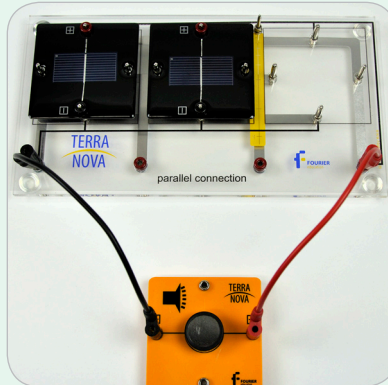
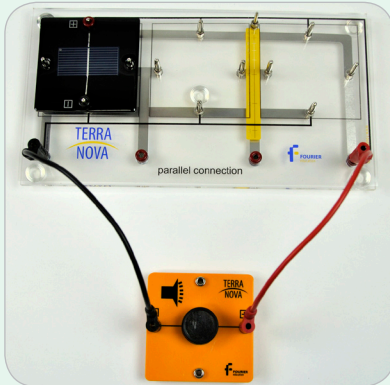
Equipment Setup Procedure



Experimental Procedure

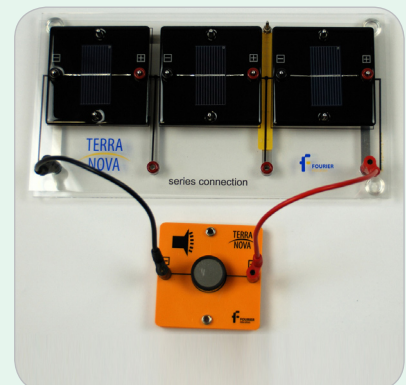
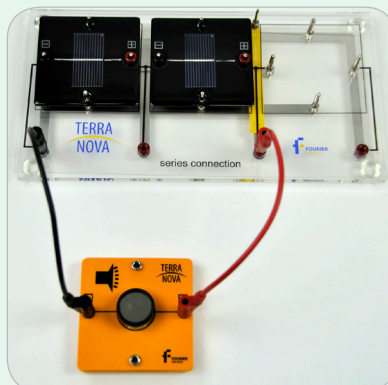
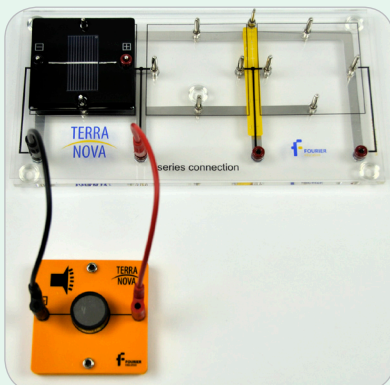
1. Measurement with parallel-connected solar cells

- a) Operate the buzzer with one solar cell, as well as two and three solar cells connected in parallel
- b) You can try different illumination conditions (e.g. sun light, desk lamp, room light)



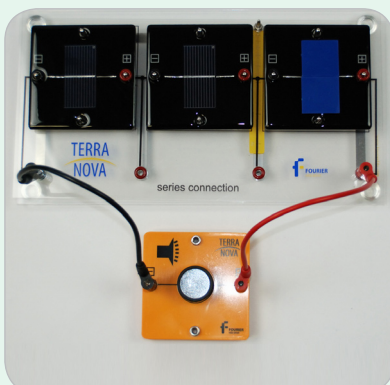
2. Measurement with series-connected solar cells

- a) Operate the buzzer with one solar cell, as well as two and three solar cells connected in series.
- b) You can try different illumination conditions (e.g. sun light, desk lamp, room light).

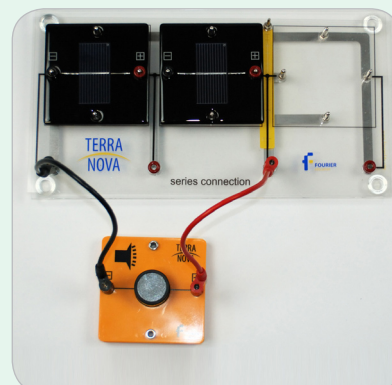


3. Partly shading of solar modules Set up the following circuits and compare the buzzer's sound level:

- a) Three solar cells connected in series to the buzzer with one solar cell completely shaded by the solar cell covers.



- b) Two solar cells connected in series to the buzzer.





Data Analysis

1. The buzzer does not work with parallel connected solar cells.
2. The buzzer only works with at least two solar cells connected in series.
3. Comparing the two circuits:
 - a) The buzzer does not work.
 - b) The buzzer gives a gentle tone.



Questions

1. What behavior of the buzzer do you observe with series connected solar cells?
2. What behavior of the buzzer do you observe with parallel connected solar cells?
3. What could be the reason for this behavior?
4. What is the result of your comparison of the two circuits? What is the conclusion from that?

4. Series and parallel connected solar cells



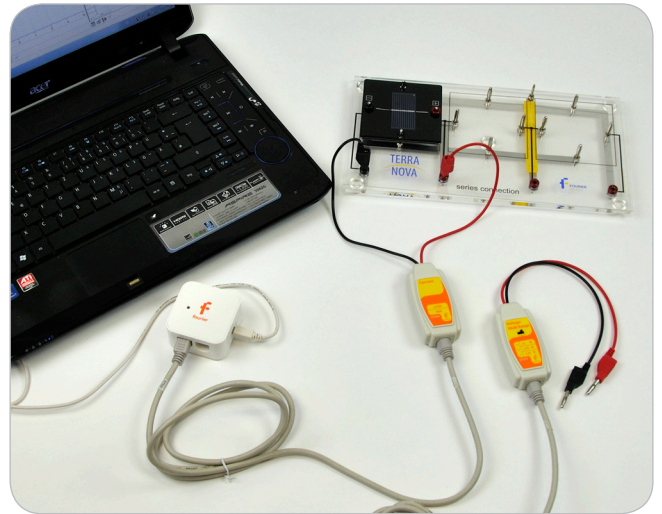
Introduction

In Experiment 1 we have seen that the voltage of a solar cell is around 0,5V and this value cannot be increased by increasing the solar cell area. But such low voltages cannot be used for practical applications. So the question is: How can we achieve higher voltages with solar cells? In this experiment series and parallel connection of solar cells should be compared to determine the best solution for that problem.



Equipment

1. Main board
2. 3 small solar cells
3. 1 voltage sensor
4. 1 current sensor
5. NOVA LINK





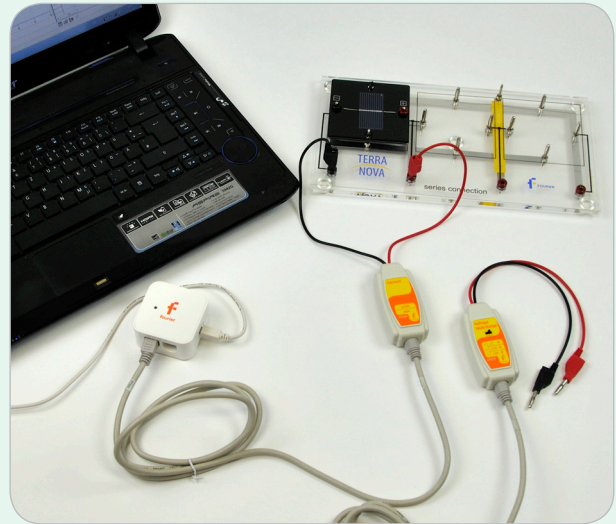
Equipment Setup Procedure

1. Launch MultiLab
2. Connect the NOVA LINK to the USB port on the computer.
The green LED will turn on when the NOVA LINK is successfully connected to the computer

Setup 1:

Measurement with series-connected solar cells

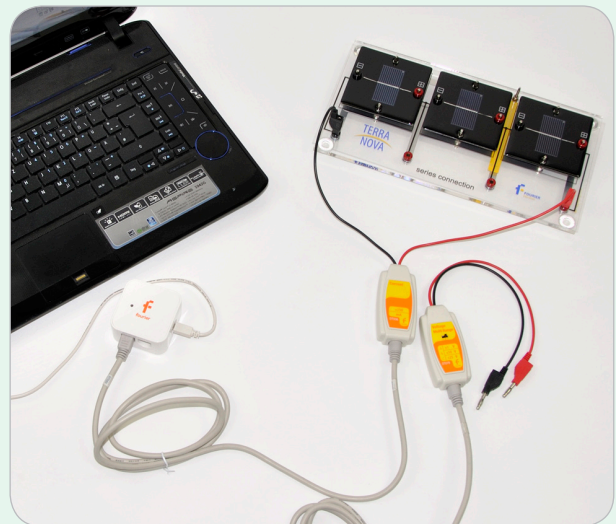
1. Plug 1 small solar cells in series on the main board.
2. Set the voltage sensor to position "B".
3. For voltage measurement connect the voltage sensor to I/O -1 port of the NOVA LINK.
4. For current measurement connect the current sensor to I/O-1 port of the NOVA LINK.
5. Do not connect voltage sensor and current sensor at the same time with the solar cells.
6. Please note that in all pictures only the current sensor is connected – for the voltage measurement it has to be exchanged by the voltage sensor of course.



Setup 2:


Measurement with parallel-connected solar cells

1. Plug 1 small solar cell in parallel on the main board.
2. Set the voltage sensor to position A .
3. For voltage measurement connects the voltage sensor to I/O -1 port of the NOVA LINK.
4. For current measurement connect the current sensor to I/O-1 port of the NOVA LINK.
5. Do not connect voltage sensor and current sensor at the same time with the solar cells.
6. Please note that in all pictures only the current sensor is connected – for the voltage measurement it has to be exchanged by the voltage sensor of course.





MultiLab Setup

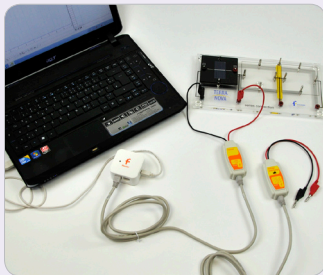
1. Click .
2. Click **Next**.
3. Set **Select rate** to **Manual**.
4. Set **Select recording mode** to **Add**.
5. Click **Next**.
6. Set **by samples** to **50**.
7. Click **Finish**.




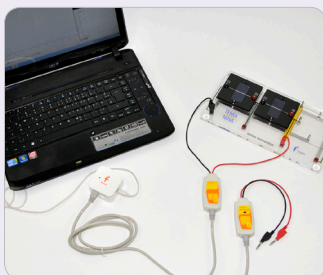
Experimental Procedure


Series connected solar cells (setup 1) - voltage measurement:

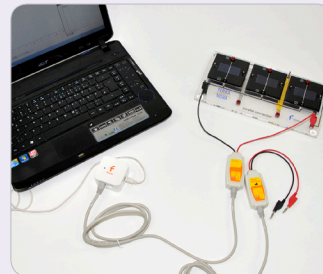
1. Connect the voltage sensor in series to one solar cell






2. Click .
3. Connect the voltage sensor in series to two solar cells








4. Click .
5. Connect the voltage sensor in series to all solar cells



6. Click .
7. Click .
8. Click  to save your data.
9. Disconnect the voltage sensor.

Series connected solar cells (setup 1) - current measurement:

1. Connect the current sensor in series to one solar cell.
2. Click .
3. Connect the current sensor in series to two solar cells.
4. Click .
5. Connect the current sensor in series to all solar cells
6. Click .
7. Click .
8. Click  to save your data.
9. Disconnect the voltage sensor.

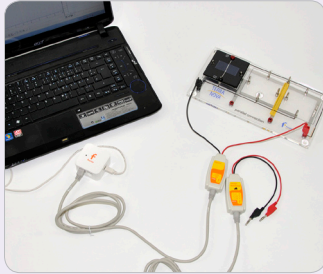
Continue next page...




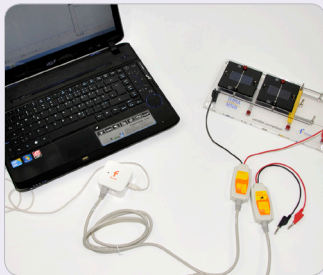
Experimental Procedure


Parallel connected solar cells (setup 2) - voltage measurement:

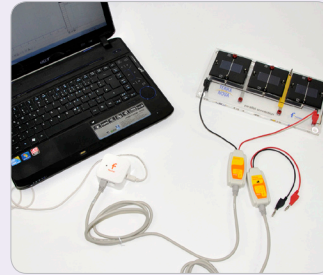
1. Connect the voltage sensor in series to one solar cell





2. Click .
3. Connect the voltage sensor in series to two solar cells








4. Click .
5. Connect the voltage sensor in series to all solar cells











6. Click .
7. Click .
8. Click  to save your data.
9. Disconnect the voltage sensor.

series connected solar cells (setup 1) - current measurement:

1. Connect the current sensor in series to one solar cell.
2. Click .
3. Connect the current sensor in series to two solar cells.
4. Click .
5. Connect the current sensor in series to all solar cells
6. Click .
7. Click .
8. Click  to save your data.
9. Disconnect the current sensor.



Data Analysis

1. Click **Table > Add manual column**.
2. In the field **Column title fill in:** # of solar cells.
3. Click **Ok**.
4. Click .
5. Add all measurement data of the serial connected setup and the new column **# of solar cells** to **current columns**.
6. Write "**Serial Connected Setup**" in the field for the table name.
7. Click **Ok**.
8. Fill the column **# of solar cells** with the correct values according to your measurement (1 to 3).
9. Click .
10. Click .
11. Add all measurement data of the parallel connection and the new column **# of solar cells** to **current columns**.
12. Write "**Parallel Connected Setup**" in the field for the table name.
13. Click **Ok**.
14. Fill the column **# of solar cells** with the correct values according to your measurement (1 to 3).
15. Click .
16. Click .
17. Type "**Comparison of voltage of parallel/serial setup**" in the field for the graph title.
18. Select **# of solar cells** as x-axis.
19. Select the datasets of the voltages for parallel and serial setup in the field for the y-axis .
20. Click **Ok**.
21. Click .
22. Click .
23. Type **Comparison of current of parallel/serial setup** in the field for the graph title.
24. Select **# of solar cells** as x-axis the.
25. Select the datasets of the current for parallel and serial setup in the field for the y-axis.
26. Click .



Questions

1. What behavior of the voltage do you see in graph 1?
2. What behavior of the current do you see in graph 2?
3. How could you explain the behavior of the voltage and current in the parallel setup?
4. How could you explain the behavior of the voltage and current in the serial setup?

5. Dependence of power on illumination



Introduction

Over the day, when the sun is “moving” across the sky, the illumination density on earth is changing. Therefore, also the power of solar cells is changing. In this experiment this relation should be observed.



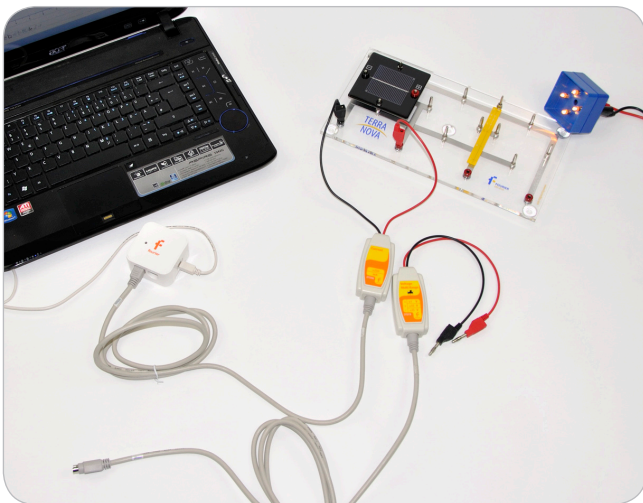
Equipment

1. Main board
2. 1 large solar cell
3. 1 voltage sensor
4. 1 current sensor
5. NOVA LINK
6. Illumination module and power supply (at 12V)




Equipment Setup Procedure

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Plug the solar cell onto the main board.
4. For current measurement connect the current sensor parallel to the solar cell and connect the current sensor to I/O-1 port of the NOVA LINK.
5. For voltage measurement connect the voltage sensor parallel to the solar cell and connect the voltage sensor to I/O-1 port of the NOVA LINK.
6. Be aware not to connect both sensors at the same time.
7. Connect the illumination module to the power supply.





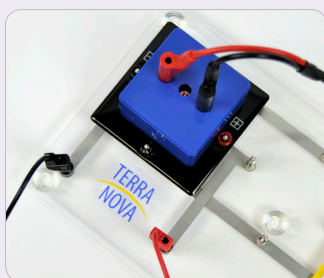
MultiLab Setup





1. Click .
2. Click **Next**.
3. Set **Select rate** to **Manual**.
4. Set **Select recording mode** to **Add**.
5. Click **Next**.
6. Set **by samples** to **50**.
7. Click **Finish**.



Experimental Procedure



1. Connect the current sensor as described in the setup procedure.
2. Screw one bulb into the illumination module (only one should glow) and put it onto the solar cell.



3. Click .
4. Screw one more bulb into the illumination module and put it again onto the solar cell.
5. Repeat step 2 to 3 till all bulbs are screwed into the illumination module.
6. Click .
7. Connect the voltage sensor as described under "Experiment Setup Procedure".
8. Repeat point 9.1 to 9.4.
9. Click .
10. Click  to save your data.



Data Analysis

1. Click f_x .
2. Click **Functions**.
3. Set **Functions** to **Multiply**.
4. Select your voltage and current measurement dataset as **G1** and **G2**, respectively.
5. Click **Ok**.
6. Go to **Table > Add manual column**.
7. Set **Column name** to **# of bulbs**.
8. Click **Ok**.
9. Click .
10. Add the columns: #of bulbs, the current measurement, the voltage measurement and the calculated power function.
11. Click **Ok**.
12. Click .
13. Click Y_x .
14. Set **X-axis** to **# of bulbs**.
15. Set **Y-axis** to the measured current and voltage data points.
16. Set the **Graph title** to **"Voltage/Current/Power - Area Dependence"**.
17. Click **Ok**.



Questions

1. How does the voltage depend on the illumination intensity?
2. How does the current depend on the illumination intensity?
3. From 1 and 2 what can be concluded concerning power?
4. Explain the behavior!

6. IV-characteristics of a solar cell



Introduction

The range of possible loads for a solar cell can vary much. The question is: Does the output power of the solar cell depend on the load? What are practical consequences for such a dependency? These questions can be answered by measuring the current a solar cell is generating in dependence of the voltage that is produced by the solar cell. The according diagram is called IV-characteristics which should be measured in this experiment.



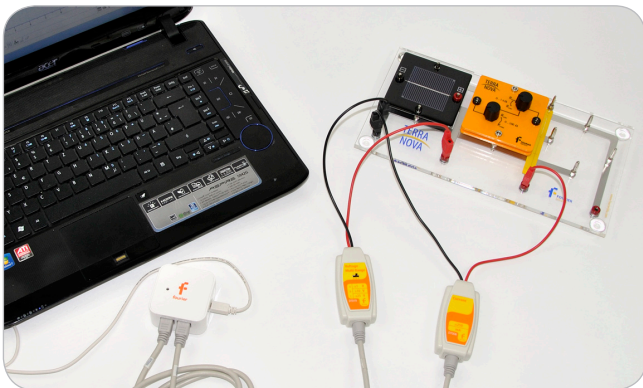
Equipment

1. Main board
2. 1 large solar cell
3. 1 potentiometer module
4. 1 current sensor
5. 1 voltage sensor
6. NOVA LINK




Equipment Setup Procedure

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Connect the current sensor to I/O-1 port of the NOVA LINK.
4. Connect the voltage sensor to I/O-2 port of the NOVA LINK.
5. Plug the large solar cell and the potentiometer module on the main board so that both are connected in series.
6. Connect the voltage sensor parallel to the solar cell (and set the range to A if you have a triple-range sensor).
7. Connect the current sensor in series to the solar cell and the potentiometer module so that the electrical circuit is closed.










MultiLab Setup

1. Click .
2. Click **Next**.
3. Click **X-axis** display properties.
4. Set Select measurement to Voltage.
5. Click **Ok**.
6. Set **Select rate** to **Manual**.
7. Set **Select recording mode** to **Add**.
8. Click **Next**.
9. Set **by samples** to **50**.
10. Click **Finish**.



Experimental Procedure



During the experiment the illumination of the solar cell should stay constant!

1. Set the potentiometer to the lowest resistance (turn both knobs to Rmin).
2. Click .
3. Turn the knob of the 100Ω-potentiometer clockwise in small steps – as more steps as more accurate will the result be.
4. Click .
5. When you reach the maximum position of the potentiometer start turning the knob of the 1kΩ-potentiometer (in quarter turns).
6. Click .
7. Click .
8. Click  to save your data.




Data Analysis

Power Calculation

1. Click f_x .
2. Click **Functions**.
3. Set **Functions** to **Multiply**.
4. Select your voltage and current measurement dataset as **G1** and **G2**, respectively.
5. Click **Ok**.
6. Click .
7. Add the calculated function to **Current columns** (Attention: Do not change the order!).
8. Set the **Table name** to "**Power**".
9. Click **Ok**.
10. Click .



Questions

1. Read the following characteristic values from your measurement using using the first cursor  :

Isc	Uoc	IMPP	UMPP	PMPP	FF

The fill factor (FF) is defined as $FF = U_{oc} \cdot I_{sc} / U_{MPP} \cdot I_{MPP}$.

2. At which working point should a solar cell be used for energy generation and why?
How can this be realized?
3. What would be the optimal load for the solar cell in the experiment?

7. IV-characteristics under varying illumination intensity



Introduction

In Experiment 6 we have seen that a solar cell should always be driven at MPP. Otherwise one can not get the maximal power out of the solar cell. In this experiment the variation of the MPP with illumination intensity should be investigated. This is a very practical question because illumination intensity is varying all over the day for real photovoltaic power plants.



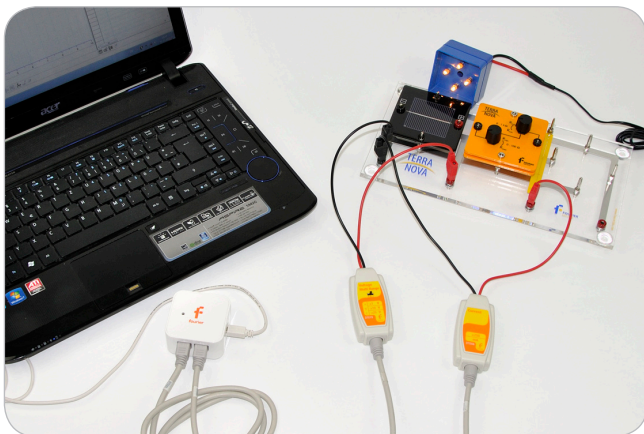
Equipment

1. Main board
2. 1 large solar cell
3. 1 current sensor
4. 1 voltage sensor
5. NOVA LINK
6. 1 potentiometer module
7. Illumination module connected to power supply (9V)




Equipment Setup Procedure

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Connect the current sensor to I/O-1 port of the NOVA LINK.
4. Connect the voltage sensor to I/O-2 port of the NOVA LINK.
5. Plug the large solar cell and the potentiometer module on the main board so that both are connected in series.
6. Connect the voltage sensor parallel to the solar cell (and set the range to a if you have a triple-range sensor).
7. Connect the current sensor in series to the solar cell and the potentiometer module so that the electrical circuit is closed.









MultiLab Setup

1. Click .
2. Click **X – axis display properties**.
3. Set **Select measurement** to **Voltage**.
4. Click **Ok**.
5. Click **Next**.
6. Set **Select rate** to **Manual**.
7. Set **Select recording mode** to **Add**.
8. Click **Next**.
9. Set **by samples** to **50**.
10. Click **Finish**.






Experimental Procedure

1. Unscrew all lamps of the illumination module except for one (only one should glow).
2. Connect the illumination module to the power supply and put it onto the solar cell.
3. Set the potentiometer to the lowest resistance (turn both knobs to Rmin).
4. Click .
5. Turn the knob of the 100 Ω -potentiometer clockwise in small steps – as more steps as more accurate will the result be.
6. Click  after each step.
7. When you reach the maximum position of the potentiometer start turning the knob of the 1k Ω -potentiometer (in quarter turns).
8. Click  after each step.
9. When reaching the maximum position Click .
10. Screw one more bulb into the illumination module and start with 3.






Data Analysis

I-V-curve

1. Click .
2. Set **X-Axis** to **Voltage**.
3. Set **Y-Axis** to all measured currents.
4. Set **Graph title** to “**I-V-Curve**”.
5. Click **Ok**.
6. Find the highest measured current in your data and copy the value to the clipboard.
7. Click  (in plots).
8. Select the first current dataset.
9. Deselect Autoscale.
10. Set Min: to 0 and Max: insert the highest measured current from the clipboard
11. Repeat the last three steps for all current datasets.
12. Click **Ok**.
13. Click .

Power calculation

1. Click .
2. Click **Functions**.
3. Set **Functions** to **Multiply**.
4. Select the first measured voltage and current dataset as **G1** and **G2**, respectively.
5. Click **Ok**.
6. Repeat these steps for the next 3 measurements.
7. Click .
8. Add all calculated functions to Current columns (Attention: Do not change the order!).
9. Set the Table name to Power.
10. Click **ok**.
11. Click .



Questions

1. Describe the differences of the four I-V-characteristics with your own words. Which characteristic values stay constant and which are varying?
2. What is the practical consequence for the fact that the MPP changes with illumination intensity?

8. IV-characteristics of a solar module



Introduction

In practice only solar modules consisting of many individual solar cells connected in series are used (compare experiment 3). Therefore, in this experiment the IV-characteristics of a solar module – not an individual solar cell – should be measured.



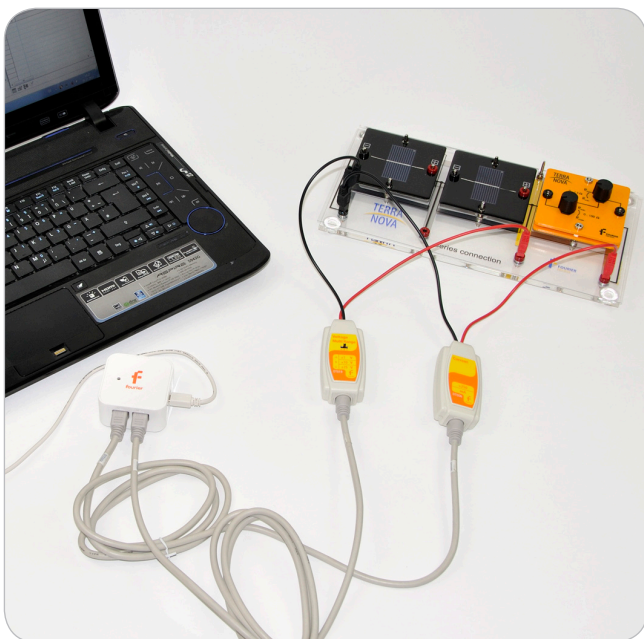
Equipment

1. Main board
2. 2 small solar cell
3. 1 current sensor
4. 1 voltage sensor
5. NOVA LINK
6. 1 potentiometer module




Equipment Setup Procedure

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Connect the current sensor to I/O-1 port of the NOVA LINK.
4. Connect the voltage sensor to I/O-2 port of the NOVA LINK.
5. Plug the 2 small solar cells and the potentiometer module on the main board so that all are connected in series.
6. Connect the voltage sensor parallel to both solar cells (and set the range to B if you have a triple-range sensor).
7. Connect the current sensor in series to the solar cells and the potentiometer module so that the electrical circuit is closed










MultiLab Setup

1. Click .
2. Click **X – axis display properties**.
3. Set **Select measurement** to **Voltage**.
4. Click **Ok**.
5. Click **Next**.
6. Set **Select rate** to **Manual**.
7. Set **Select recording mode** to **Add**.
8. Click **Next**.
9. Set **by samples** to **50**.
10. Click **Finish**.





Experimental Procedure

1. Set the potentiometer to the lowest resistance (turn both knobs to Rmin).
2. Click .
3. Turn the knob of the 100Ω-potentiometer clockwise in small steps – as more steps as more accurate will the result be.
4. After each step click .
5. When you reach the maximum position of the potentiometer start turning the knob of the 1kΩ-potentiometer (in quarter turns).
6. After each step click .
7. When reaching the maximum position Click .
8. Click  to save your data.






Data Analysis

I-V-curve

1. Click .
2. Set X-Axis to Voltage.
3. Select the measured current dataset as **Y-Axis**.
4. Set **Graph title** to “I-V-Curve”.
5. Click Ok.
6. Click .

Power calculation

7. Click .
8. Click **Functions**.
9. Set **Functions** to **Multiply**.
10. Select the first measured voltage and current dataset as **G1** and **G2**, respectively.
11. Click **Ok**.
12. Click .
13. Add all calculated functions to Current columns (Attention: Do not change the order!).
14. Set the Table name to “**Power**”.
15. Click ok.
16. Click .



Questions

1. Fill the table, using the first cursor , with the values from the measurement.

The fill factor (FF) is defined as $FF = U_{oc} \cdot I_{sc} / U_{MPP} \cdot I_{MPP}$.

Isc	Uoc	IMPP	UMPP	PMPP	FF

2. What is the qualitative difference of the IV-curve compared with that of Experiment 6 and why? How do the characteristic values differ especially the fill factor?

9. Partly shaded solar modules



Introduction

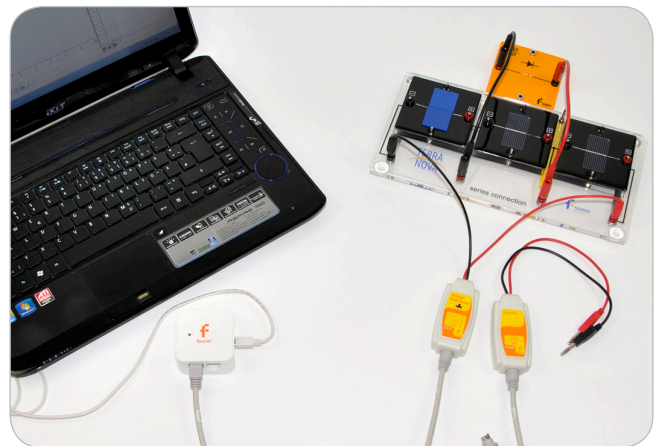
In large PV power plants it often comes to situations where parts of the plant are shaded. This can for example happen if a tree is situated near the PV power plant and during the day it casts a cloud over the solar modules. In this experiment we want to investigate the impact of such a partly shading of solar modules.

Furthermore the concept of so called bypass-diodes is introduced in this experiment.



Equipment

1. Main board
2. 3 small solar cells
3. Diode module
4. 1 current sensor
5. 1 voltage sensor
6. NOVA LINK
7. 4 covers for the solar cells





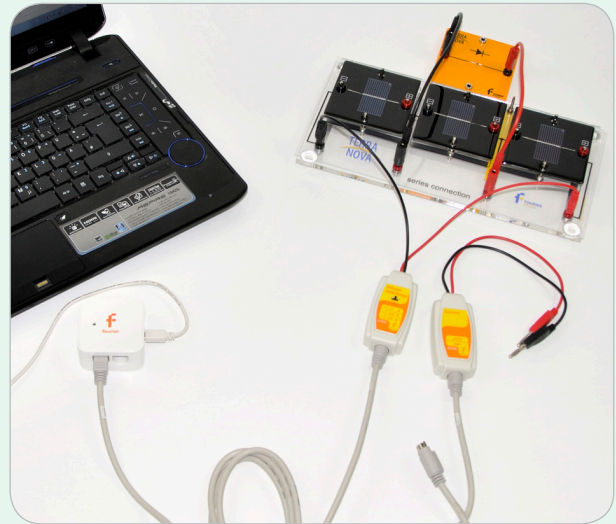
Equipment Setup Procedure

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer.
The green LED will turn on when the NOVA LINK is successfully connected to the computer.

Setup 1:

Measurement with series-connected solar cells

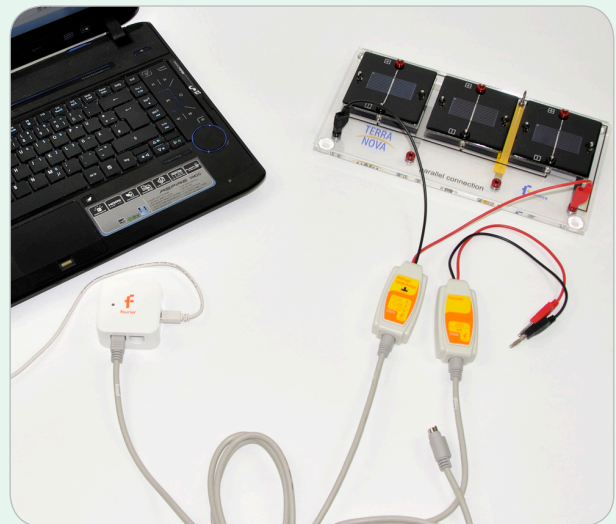
1. Plug 3 small solar cells in series on the main board.
2. Connect the diode parallel to one solar cell.
3. For current-measurements connect the current sensor parallel to all solar cells and connect the current sensor to I/O-1 port of the NOVA LINK.
4. For voltage-measurements connect the voltage sensor parallel to all solar cells and connect the voltage sensor to I/O-1 port of the NOVA LINK.
5. If you have a triple range voltage sensor set it to position B.
6. Do not connect voltage sensor and current sensor at the same time with the solar cells.



Setup 2:


Measurement with parallel-connected solar cells

1. Plug 3 small solar cells parallel on the main board.
2. For current measurements connect the current sensor parallel to all solar cells and connect the current sensor to I/O-1 port of the NOVA LINK.
3. For voltage measurements connect the voltage sensor parallel to all solar cells and connect the voltage sensor to I/O-1 port of the NOVA LINK.
4. If you have a triple range voltage sensor set it to position A.
5. Do not connect voltage sensor and current sensor at the same time with the solar cells.
6. Note that in all pictures only the current sensor is shown! For voltage. measurements it has to be exchanges by the voltage sensor.






MultiLab Setup

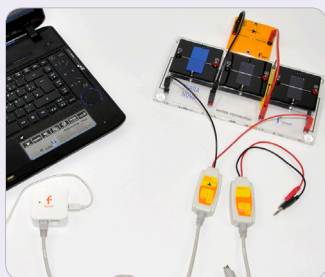
1. Click .
2. Click **Ok**.
3. Click **Next**.
4. Set **Select rate** to **Manual**.
5. Set **Select recording mode** to **Add**.
6. Click **Next**.
7. Set **by samples** to **50**.
8. Click **Finish**.




Experimental Procedure




Procedure for Setup 1










1. Connect the voltage sensor as described in setup 1
2. Click .
3. Shade one of the solar cells where no diode is connected in parallel using the blue covers.



4. Click .
5. Shade the solar cells where the diode is connected in parallel.
















6. Click .
7. Click .
8. Connect the current sensor as described in setup 1.
9. Click .

10. Shade one of the solar cells where no diode is connected in parallel using the blue covers.
11. Click .
12. Shade the solar cells where the diode is connected in parallel.
13. Click .
14. Click .
15. Click  to save your data.
16. Click .
17. Click **Functions**.
18. Set **Functions** to **Multiply**.
19. Select the voltage and current measurement datasets as **G1** and **G2**, respectively.
20. Click **Ok**.
21. Click .
22. Add the columns **Voltage**, **Current** and the **calculated function** to the table.
23. Set the name of the table to series connected solar cells with parallel connected diode.
24. Click **Ok**.
25. Click .
26. Click .
27. Set the graph title to series connected solar cells with parallel connected diode.
28. Select the datasets: current, voltage and the calculated function of the power as Y-axis
29. Click **Ok**.
30. Click .



Experimental Procedure

Procedure for setup 2

1. Connect the voltage sensor as described in setup 2
2. Click .
3. Shade one of the solar cells.
4. Click .
5. Shade two solar cells.
6. Click .
7. Click .
8. Connect the current sensor as described in setup 2.
9. Click .
10. Shade one of the solar cells.
11. Click .
12. Shade two solar cells.
13. Click .
14. Click .
15. Click  to save your data.
16. Click f_x .
17. Click **Functions**.
18. Set **Functions** to **Multiply**.
19. Select the voltage and current measurement datasets as **G1** and **G2**, respectively.
20. Click **Ok**.
21. Click .
22. Add the columns **Voltage**, **Current** and the **calculated function** to the table.
23. Set the name of the table to "**Parallel Connected Solar Cells**".
24. Click **Ok**.
25. Click .
26. Click Y_x .
27. Set the graph title to "**Parallel Connected Solar Cells**".
28. select the datasets: current, voltage and the calculated function of the power as Y-axis
29. Click **Ok**.
30. Click .
31. Click  to save your data.



Data Analysis

I-V-curve

1. Click Y_x .
2. Select the current datasets of the measurement with parallel and series connected solar cells as Y-axis.
3. Click **Ok**.
4. Click Y_x .
5. Select the voltage datasets of the measurement with parallel and series connected solar cells as Y-axis.
6. Click **Ok**.
7. Click Y_x .
8. Select the power datasets of the measurement with parallel and series connected solar cells as Y-axis.
9. 10. Click **Ok**.



Questions

1. What differences in the behavior of the voltage and the current of series connected solar cells do you observe? Compare the two cases: 1. Shaded solar cell has no diode connected in parallel and 2. Shaded solar cell has a diode connected in parallel.
2. What is the reason for your findings?
3. Do the same comparison as in 1 for parallel connected solar cells.
4. What is the overall conclusion?

10. IV-characteristics of partly shaded solar modules



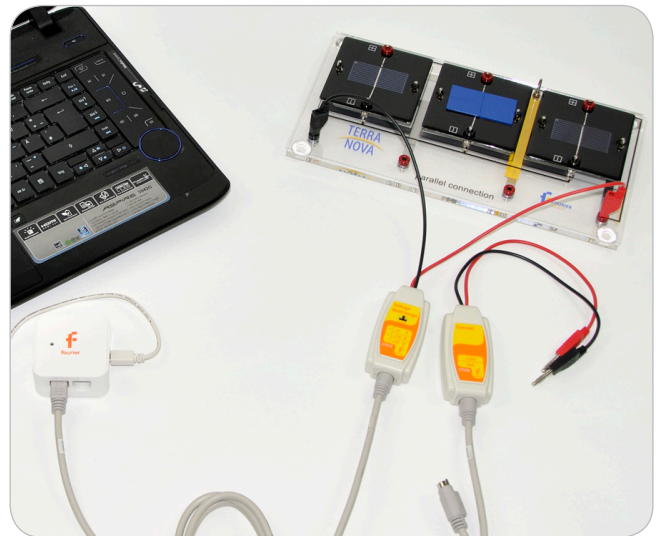
Introduction

A partly shading of solar modules has severe impact on the power of the module (compare experiment 3 and 9). In this experiment this behavior should be investigated in detail. The IV-characteristics of a partly shaded solar module should be investigated.



Equipment

1. Main board
2. 2 small solar cells
3. Diode module
4. 1 cover for the solar cells
5. 1 potentiometer module
6. 1 current sensor
7. 1 voltage sensor
8. NOVA LINK





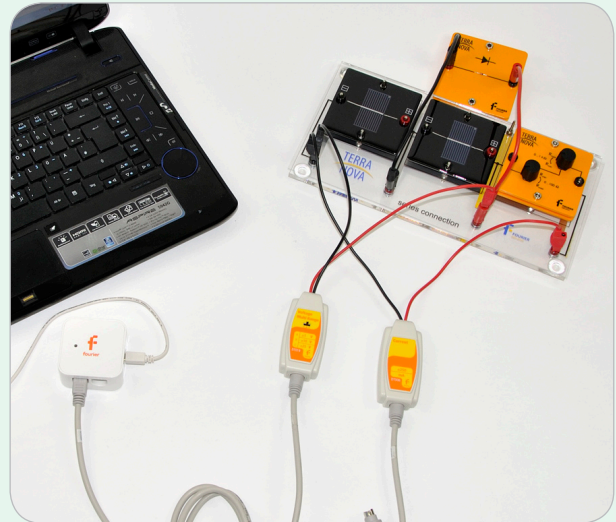
Equipment Setup Procedure

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on. when the NOVA LINK is successfully connected to the computer.
3. Connect the current sensor to I/O-1 port of the NOVA LINK.
4. Connect the voltage sensor to I/O-2 port of the NOVA LINK.

Setup 1:

Measurement of I-V-characteristics of a solar module

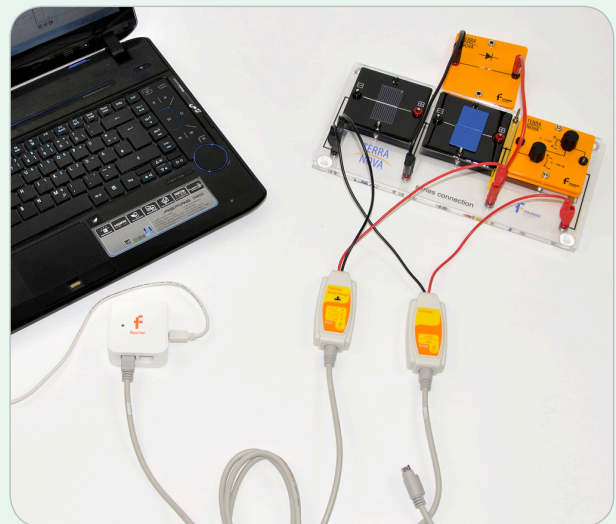
1. Plug 2 small solar cells and the potentiometer in series on the main board.
2. Connect the voltage sensor parallel to the solar cells (and set the range to B if you have a triple-range sensor).
3. connect the current sensor in series to the solar cell and the potentiometer module so that the electrical circuit is closed.



Setup 2:


Measurement of the I-V-characteristics of a partly shaded solar module with bypass-diode

1. Plug 2 small solar cells and the potentiometer in series on the main board.
2. Connect the voltage sensor parallel to the solar cells (and set the range to B if you have a triple-range sensor).
3. Connect the current sensor in series to the solar cell and the potentiometer module so that the electrical circuit is closed.
4. Connect the bypass diode in parallel to one of the solar cells. Put the covers on top of this solar cell.





MultiLab Setup

1. Click .
2. Click **Next**.
3. Set **Select rate** to **Manual**.
4. Set **Select recording mode** to **Add**.
5. Click **Next**.
6. Set **by samples** to **50**.
7. Click **Finish**.










Experimental Procedure











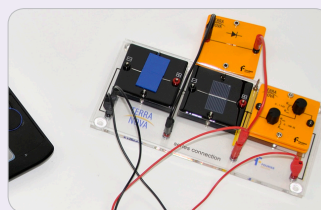
Data Analysis




Procedure for Setup 1

1. Set the potentiometer to the lowest resistance (turn both knobs to Rmin).
2. Click .
3. Turn the knob of the 100 Ω -potentiometer clockwise in small steps – as more steps as more accurate will the result be.
4. After each step click .
5. When you reach the maximum position of the potentiometer start turning the knob of the 1k Ω -potentiometer (in quarter turns).
6. After each step click .
7. When reaching the maximum position click .
8. Click  to save your data.
9. Click .
10. Set **X-Axis** to **Voltage**.
11. Select the measured current dataset as **Y-Axis**.
12. Set **Graph title** to **solar module I-V-curve**.
13. Click Ok.
14. Click .

Procedure for Setup 2

1. Set the potentiometer to the lowest resistance (turn both knobs to Rmin).
2. Click .
3. Turn the knob of the 100 Ω -potentiometer clockwise in small steps – as more steps as more accurate will the result be.
4. After each step click .
5. When you reach the maximum position of the potentiometer start turning the knob of the 1k Ω -potentiometer (in quarter turns).
6. After each step click .
7. When reaching the maximum position click .
8. Click  to save your data.
9. Click .
10. Set the graph title to **"Solar Module with Bypass Diode"**.
11. Set **X-Axis** to **Voltage**.
12. Select the datasets: current and voltage as **Y-axis**.
13. Click **Ok**.
14. Click .
15. Click  to save your data.
16. Take the covers away and put them on the other cell (without bypass diode) and repeat the measurements (steps 1 to 8)



17. Click .
18. Set the graph title to **"Solar Module without Bypass Diode"**
19. Set **X-Axis** to **Voltage**
20. Select the datasets: current and voltage as **Y-axis**
21. Click **Ok**.
22. Click .
23. Click  to save your data.



Questions

1. Compare the three measured IV-curves! Describe the qualitative differences with your own words.
2. What can be concluded for the output power of a partly shaded solar module?