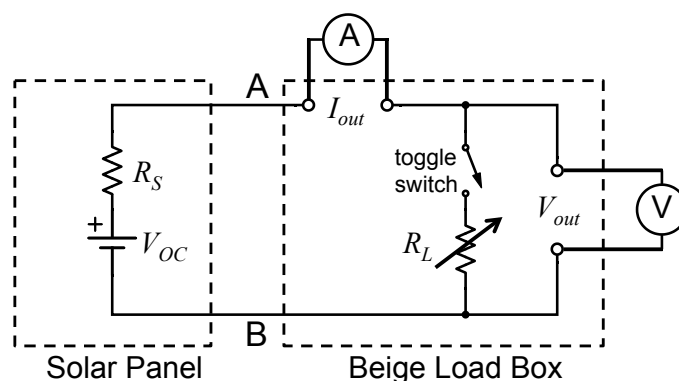


## Experiment A6 Solar Panels I Procedure

Deliverables: **Full Lab Report** (due the week after break), checked lab notebook

### Overview

In this lab, you will measure the power output of a solar panel and use it to calculate its efficiency  $\eta$ . A halogen lamp will be used to simulate the sun in a laboratory setting. The electrical power produced by the solar panel will be dissipated in  $R_L$ . The solar panel is a non-ideal power supply with an internal resistance  $R_S$ . As a result, the output voltage, current, power and efficiency all depend on the load resistance  $R_L$  and light intensity  $E_0$ .



**Figure 1:** The circuit on the left represents the solar panel. Note that the solar panel is a non-ideal power supply with an internal resistance  $R_S$ . It is connected to the load box on the right, which is used to vary the load resistance  $R_L$ . (The arrow indicates that  $R_L$  is a variable resistor.)

### Part I: Efficiency vs. Load

#### Background

The electrical power output by the solar panel will be dissipated via joule heating in a load resistor. You will see that the power output and efficiency of the solar panel depend on the load resistance  $R_L$ , and there is an optimal value of  $R_L$  that yields the most efficient operation. The beige “load box” contains an array of load resistors that can be easily selected by turning a knob, as shown on the right hand side of Fig. 1.

The black “sensor interface box” has two displays that are used to measure the *voltage* output from analog sensors. It also has +3V and +5V DC outputs that can provide power to analog sensors. You will use it to measure the voltage output from the irradiance sensor. The irradiance sensor is an *analog transducer*, and the voltage it outputs is linearly related to the irradiance. There is a document on the A6 webpage that explains how to determine the irradiance in  $\mu\text{W}/\text{cm}^2$  from the voltage output of the sensor.

*Procedure*

1. Measure the dimensions of the solar panel. You will use the dimensions to calculate the area  $A_{panel}$ .
2. Set the toggle switch on the beige load box to “Open”.
3. Plug the red banana cable on the solar panel into the red receptacle A on the end of the load box.
4. Plug the black banana cable on the solar panel into the black receptacle B on the end of the load box. (Refer to Figure 1 for further clarification.)
5. Connect the “ $V$ ” leads of the load box ( $V_{out}$  in Figure 1) to the Keysight Precision DMM using the BNC coaxial cable with banana plug adapters on the end. Set up the Keysight DMM to measure DC voltage.
6. To measure the current, use the orange handheld DMM set to the 200mA range, and connect it to the “ $I$ ” leads on the load box ( $I_{out}$  in Figure 1) using the banana plug cables.
7. Locate the **Irradiance Sensor** (dark blue box). It has twelve different settings that can be chosen by turning the small knob for sensitivity and scaling of the voltage output. Make sure the small knob is set to 9.
8. Connect the Irradiance Sensor leads to the “Sensor Interface Box”: The black wire should be on the top pin (GND), then red on the +5V pin, and yellow or white on the “SIG.” pin. Ignore the loose green wire. (The sensor interface boxes have a pin-out diagram on the bottom left corner.)
9. The sensor interface box should display a voltage that will increase linearly with irradiance. Professor Patrick Dunn has created a document that explains how to determine the irradiance in  $\mu\text{W}/\text{cm}^2$  from the voltage output of the sensor. This document can be found on the lab website along with the handout and score sheet.

**Pro-Tip:** Alignment of the solar panel is important; care should be taken in centering it directly under the lamp for accurate measurements.

10. To measure the effect of resistive loads on output power of the solar panel, center the panel directly beneath the light source.
11. Measure the distance from the light bulb to the solar panel and record it in your lab notebook.
12. The BK Precision AC power supply or “Variac” is used to control the voltage across the lamp  $V_{IN}$ , which ultimately changes its brightness or “irradiance”. (Note that the AC power supply is NOT the same as the DC power supply you used in A4.) You will measure the efficiency of the solar panel as a function of the load resistance  $R_L$  for two different Variac settings, 110V and 90V, which correspond to different irradiances  $E_0$ .
13. Plug the halogen lamp into the variac. Turn on the variac and use it to adjust the irradiance of the lamp. (If the circuit breaker trips and you lose power, ask the TA to help you reset the breaker switch.) Record the variac voltage in your lab notebook.
14. Place the irradiance sensor in the center of the solar panel. Make sure the active area of the sensor is facing upward toward the lamp.

15. As you increase the variac voltage the lamp will get brighter. As the lamp gets brighter, the voltage reading from the irradiance sensor should increase. Record the irradiance sensor voltage when you reach the desired variac setting. Then, set the sensor off to the side.
  16. Flip the toggle to “Closed”.
  17. A “short circuit” occurs when the load  $R_L$  is set to  $0\ \Omega$  (i.e. it is replaced by a wire). Set the load knob to  $0\ \Omega$ , and you should see the output *voltage* drop to nearly zero. The resultant current is known as the “Short circuit current”  $I_{SC}$ . Record the short circuit current in your lab notebook.
  18. An “open circuit” occurs when the load is infinite (i.e.  $R_L$  is removed from the circuit and there is nothing but air between the output terminals). Flip the toggle switch to “Open”, and you should see the output *current* drop to nearly zero. The resultant voltage is known as the “open circuit voltage”  $V_{OC}$ . Record the open circuit voltage in your lab notebook.
  19. Flip the toggle switch back to “Closed”, putting  $R_L$  back into the circuit.
  20. Measure the DC output voltage and current as a function of the resistive load  $R_L$ . Each clockwise click on the knob increases the load resistance  $R_L$  by  $200\ \Omega$ . Record the data in your lab notebook in a table similar to the one shown on the next page. You will use this data to calculate power and efficiency for the deliverables.
- Pro-Tip:** Be careful to keep the solar panel and irradiance sensor in the same position for each successive measurement.
21. Repeat the experiment for the other variac voltage.
  22. When you are all finished, return the lab bench to its initial state.
    - a. Turn off the variac.
    - b. Disconnect all the cables and wires.
    - c. Sanitize the lab bench and equipment.

**Table 1:** A template for the table you should put in your lab notebook.

Load, $R_L$ [ $\Omega$ ]	$I_{out}$ [mA]	$V_{out}$ [V]
0 (short circuit)	$I_{SC} =$	
200		
400		
600		
800		
1000		
1200		
1400		
1600		
1800		
2000		
$\infty$ (open circuit)		$V_{OC} =$

Irradiance Sensor Voltage: \_\_\_\_\_

Irradiance Sensor Setting: \_\_\_\_\_

Variac Voltage: \_\_\_\_\_

## Calculating the Efficiency

The efficiency of the solar panel is the amount of electric power generated divided by the total power from the incident light. That is, you can calculate the efficiency by dividing the power dissipated in the load resistor by the power measured by the Irradiance Sensor times the area of the panel

$$\eta = \frac{I_{out} V_{out}}{E_0 A_{panel}}, \quad (1)$$

where  $I_{out}$  and  $V_{out}$  are the current and voltage through the load resistor,  $A_{panel}$  is the area of the solar panel, and  $E_0$  is the light intensity calculated from the Irradiance Voltage (see the “Irradiance Measurement” document on the lab website).

**Week I Deliverables** – Your results from this week and next are to be compiled in a lab report **no longer than 8 pages**. Please include the following items from this week in your report. (See the score sheet for a breakdown of the points.)

1. A plot of the solar panel output power  $\dot{q}_L = I_{out} V_{out}$  vs. load resistance  $R_L$  for the two different Variac settings. (Recall the Variac controls the brightness or irradiance of the lamp.) Use the ‘-o’ and ‘-\*’ options in Matlab to connect the measured data points with lines. Be sure to include a legend, as well.
2. A plot of the solar panel efficiency  $\eta$  vs. load resistance  $R_L$  for the two different Variac settings. (Recall the Variac controls the brightness or irradiance of the lamp.) Use the ‘-o’ and ‘-\*’ options in Matlab to connect the measured data points with lines. Be sure to include a legend, as well.
3. A table containing the irradiance, maximum power output by the solar panel, the load resistance that yielded the maximum power, and the estimated internal resistance of the solar panel ( $R_s = V_{OC}/I_{SC}$ ) for the two different variac settings. Be sure to include units. Does the solar panel also exhibit impedance matching?

### Suggested Talking Points

- Why does the efficiency depend on the load resistance? Can you come up with an equation that predicts power vs. load resistance? (Hint: The solar panel is a non-ideal power supply with an internal resistance  $R_s$ .)

## Appendix A

### Equipment

- Sensor Interface Box (SIB) w/ 9V power supply
- Light Sensor Box (Irradiance Sensor/Light-to-Frequency Converter) w/ 24" wire lead cable ending in snap connector to SIB input pins
- Load Box
- Solar Panel w/ 24" wire leads ending in male banana connector
- Multi-meter w/ 24" wire leads ending in male banana connector
- BK Precision AC Power Supply
- Halogen lamp Fixture w/ GE Lamp: GE 90w 1900lm M/N 66286 PAR 38
- Scissor lift
- Meter Stick
- 2 Extech handheld digital multimeters
- Keysight precision digital multimeter
- 2 BNC to banana adapters
- Set of banana cables (1 black, 1 red)