

# Current – Voltage (I-V) Measurements in Small Photovoltaic Solar Panels

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**Overview:** The field performance of photovoltaic “solar” panels can be characterized by measuring the relationship between panel voltage, current, and power output under differing environmental conditions and panel orientation. The system described here (Figure 1) incorporates simple circuitry to step the panel through a variable load in order to “exercise” the panel over a range of current and voltage conditions thereby determining the characteristic current-voltage (I-V) response of the panel. The low power measuring circuit runs from a small 9-volt battery or any 9-12 VDC source. The operator interface is a LabVIEW vi running on a laptop PC, using an inexpensive National Instruments USB-6009 data acquisition system.

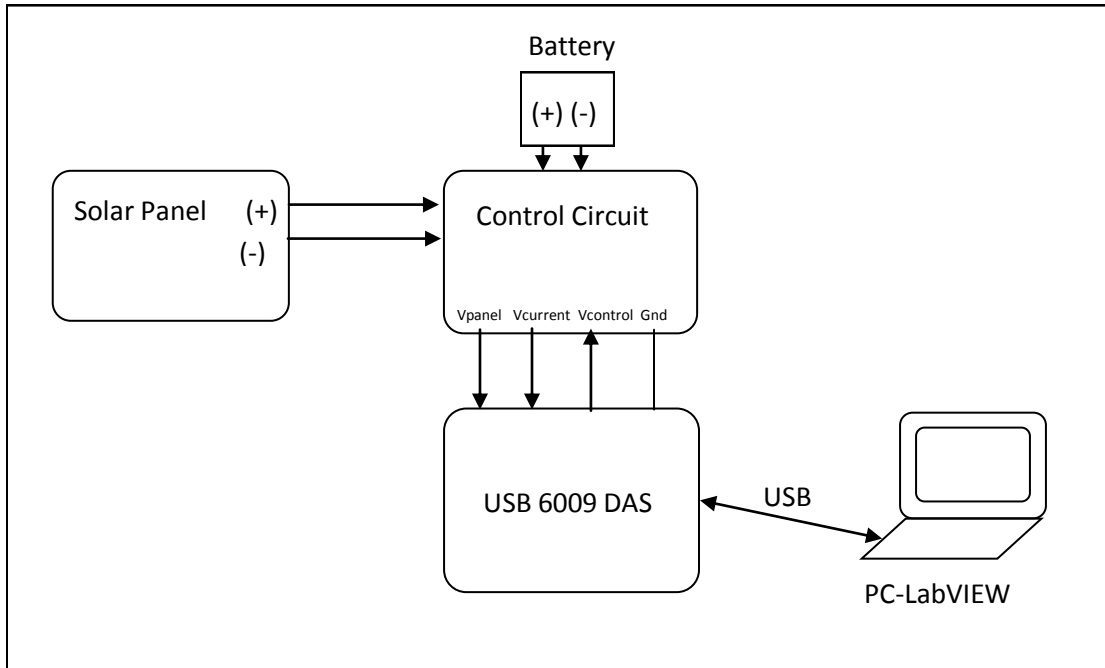


Figure 1. Block diagram overview of the Solar Panel I-V Measurement System

**System Description:** The three major portions of the system are the operator interface consisting of a LabVIEW vi running on a laptop PC; a small data acquisition system (DAS); and an electronic circuit which programs current delivered from the solar panel under test. Each of these subsystems will be described in some more detail.

**Operator Interface:** The LabVIEW screen (Figure 2) consists of setup controls, graphs of measured current and voltage data, and two graphs showing the I-V relationship and the power – voltage relationship. The data are measured and graphed in real time. At the conclusion of the measurement the operator is given the option to save the data set.

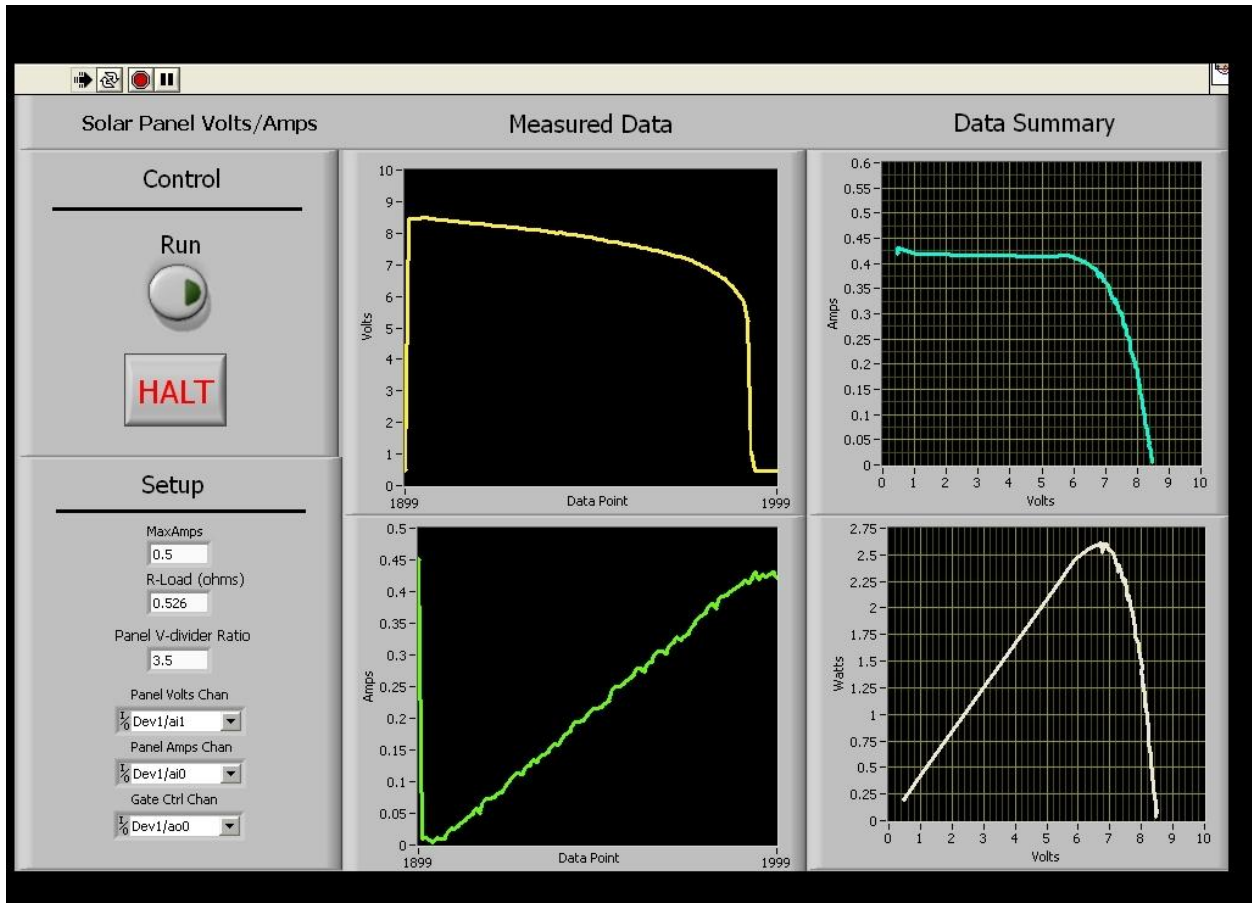


Figure 2. Labview program front panel.

Setup Options: There are six setup options on the LabVIEW front panel.

Max Amps: Enter the maximum current to be drawn from the panel.

R-Sense (ohms): *Normally not changed from default.* This is the actual measured value of the current-sense resistor (R4 figure 3). This is not changed unless you replace the current sense resistor.

Panel V-divider ratio: *Normally not changed from default.* The actual panel voltage is divided down by two resistors (R5, R6) in a voltage divider configuration. The ratio in this option is the ratio between the actual panel voltage and the voltage presented to the DAS. The ratio does not change unless you change the resistors.

Panel Volts Channel: DAS input for panel volts. Dev may change, but channel is always ai1.

Panel Amps Channel: DAS input for panel amps. Dev may change, but channel is always ai0.

Gate Control Chan: DAS analog output for panel current control. Dev may change but the channel is always ao0.

Once the connections are made from the solar panel to the control circuit and to the DAS, the LabVIEW vi is started. Click the Run button to begin a measurement. A full measurement will take about 4-5 seconds. During the measurement the current and voltage values will be graphed as the measurements proceed. At the conclusion of the measurements the derived I-V and power graphs are drawn. At this point a user prompt appears with the option to save the data set just measured. You can then browse to an appropriate location such as a USB flash drive and enter a file name. The data are saved as text data which can be later imported into Excel or some other program for further analysis.

**Data Acquisition System:** The DAS is a relatively inexpensive National Instruments product USB-6009. The analog inputs are +/-10 volt, 14-bit resolution. The analog outputs are 0-5 volts, 12-bit resolution. The DAS connects to the laptop with a USB cable, and connects to the control circuit with four wires as explained later in the control circuit description. The DAS derives its power from the laptop USB connection and does not require external power.

**Control Circuit:** The control circuit (Figure 3) is used to control the current drawn from the solar panel, and to condition the current and voltage signals produced during the measurements. The circuit draws about 8 milliamps and can be powered by a 9-volt battery or by any DC voltage typically in the 9 to 12 volt range. Referring to Figure 3 there are three connectors for the circuit. The J1 connector is from the USB-6009 DAS. In J1, in addition to the ground connection there are two analog outputs from the circuit (panel voltage and panel current) plus the analog control voltage from the DAS to the circuit. The J2 connector is on a screw terminal strip and connects to the solar panel. The positive (+) and negative (-) terminals are labeled, and the polarity of the solar panel must be observed. Connector J3 is the battery power for the circuit.

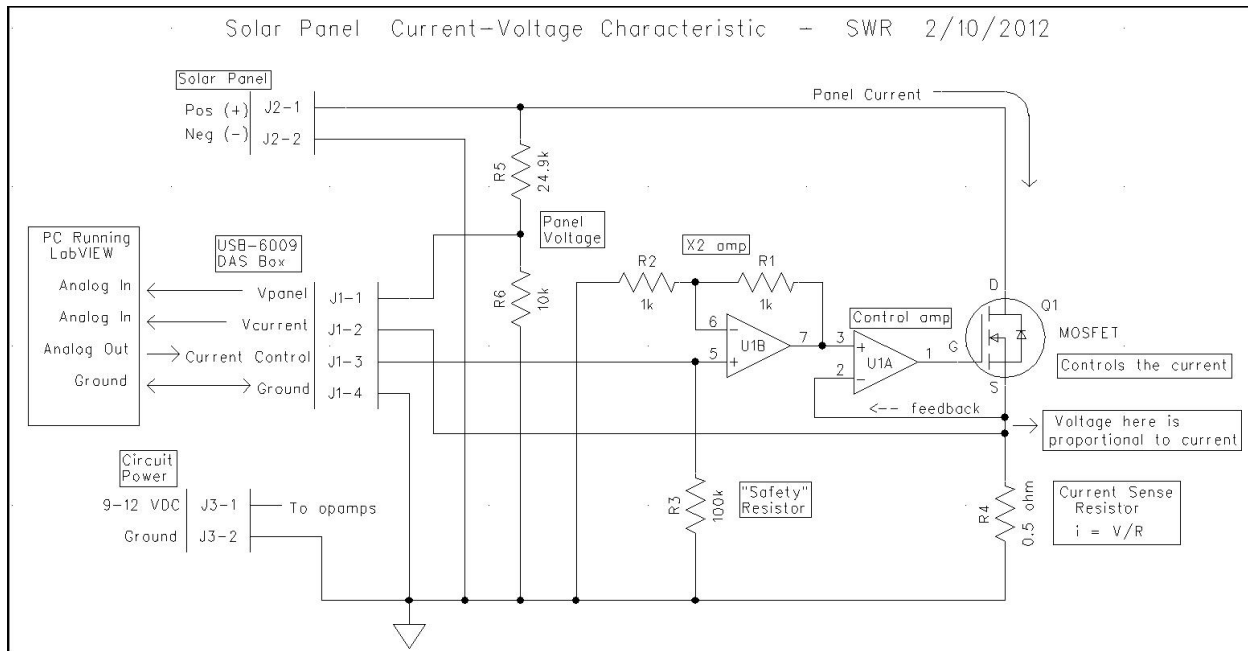


Figure 3. Control/measurement circuit.

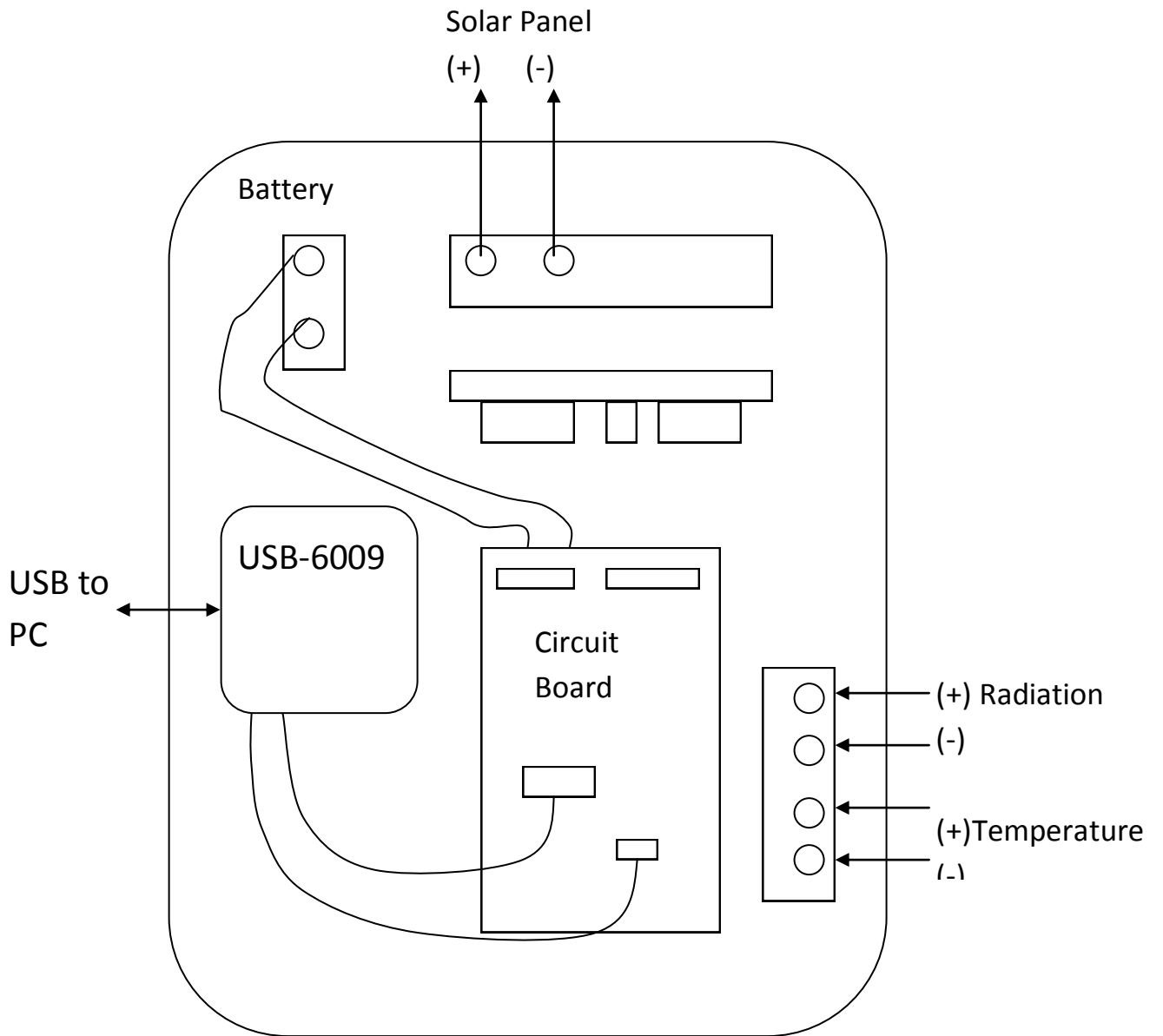
The circuit is relatively simple and uses two operational amplifiers (opamps). Both amplifiers are contained in the 8-pin package on the circuit board. A control voltage from the DAS on J1-3 is presented to opamp U1B pin 5. This opamp multiplies the control voltage by two as configured by the two resistors R1 and R2. Resistor R3 is not required but is included just to make sure a zero voltage is presented to the opamp when the J1 cable is disconnected.

The voltage from U1B is fed to the non-inverting input (pin 3) of the current-control amplifier U1A. Notice that while U1B is configured as an ordinary non-inverting opamp with a gain of 2, in U1A there is no typical feedback resistor network. However, there *is* feedback being provided to the pin 2 inverting input. The feedback is the voltage produced as the solar panel current flows through the *current-sense* resistor R4. The more current the panel produces the greater is the feedback voltage produced at the current sense resistor ( $V = I \cdot R$ ). U1A thus controls the panel current by continuously comparing the control voltage *set point* at pin 3 with the feedback voltage from the sense resistor. U1A produces a voltage output as needed to make the two inputs equal. The resulting output voltage is connected to at the gate terminal (G) of the MOSFET transistor. The voltage present at the gate terminal controls how much current passes through the MOSFET; the higher the gate voltage the higher the current which the MOSFET allows to pass through. The MOSFET thus serves as a software-controlled variable load to the panel.

The LabVIEW vi proceeds by incrementing the current control voltage at J1-3 over 100 steps from 0 to the maximum current as entered on the vi front panel. At each step the program sends the new control voltage and pauses for 10 milliseconds while the control circuit establishes the

new steady-state current. Then the solar panel voltage and current are measured, graphed and stored in an array. This process repeats until all 100 steps have been accomplished thus completing the full current-voltage (I-V) response of the solar panel.

# Running the system



Connection diagram for solar panel test set.

Make the following connections:

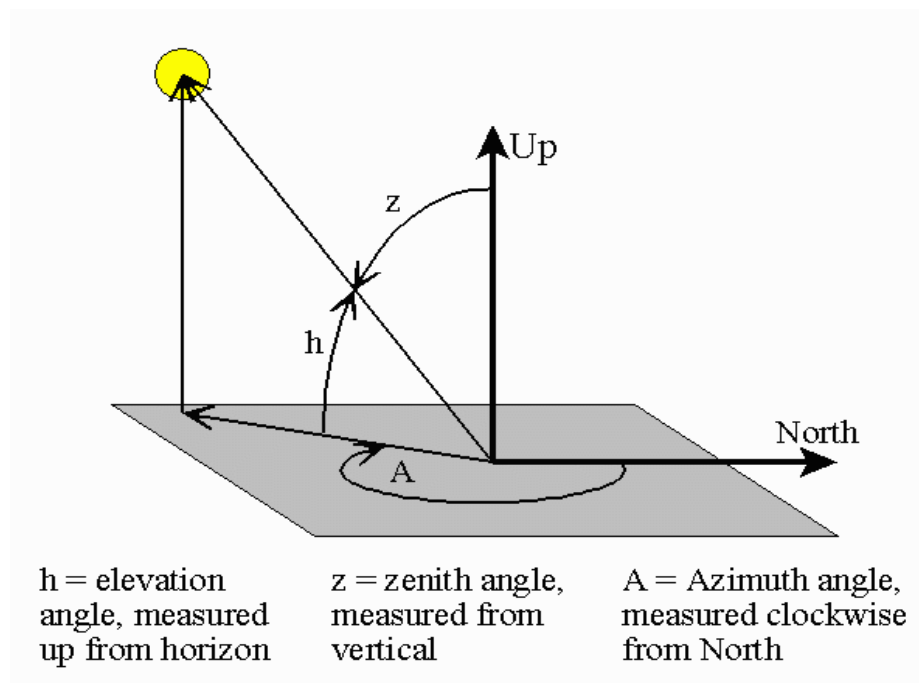
1. At the upper terminal strip connect the solar panel. Be sure to get the **correct polarity**.
2. At the right-hand side of the circuit board are the input connections for the panel temperature measured by a thermistor, and for solar radiation measured by a pyranometer. Connect these two cables again making sure the (+) and (-) polarity is correct.
3. Connect the USB-6009 data acquisition system to the laptop PC with a USB cable.
4. Check the voltage on the 9-volt battery with a multimeter. The battery should show at least 8 volts. Replace the battery if it is below 8 volts. Connect battery cable. The green LED on the circuit board should light up.

### Operating the solar test set

1. Make the connections as shown on the Connection diagram.
2. Set up the solar panel as desired (azimuth and zenith angle).
3. Start the LabVIEW Solar vi and click the “Run” button.
4. The measurement will take about 5 seconds to complete. Click “No” to the data save question.
5. Depending on the panel you have, and the orientation, you will probably need to enter different values in the “Max Amps” and the “Max Volts” boxes located in the Setup section. On the Measured Data graphs observe the maximum amps and volts achieved from step 3 above. Then enter new “Max Amps” and “Max Volts” values in the boxes which are slightly greater than the observed max values from the run in step 3. For example, if you got 0.33 amps and 8 volts initially, you would enter 0.4 amps for Max Amps and 9 volts for Max Volts.
6. With the new entered values, make a new measurement by clicking the Run button. You should now have amps and volts graphs which occupy most of the graph space.
7. If the data look ‘good’, click “Yes” to the save data question. A dialog box will open where you can browse to a location, often the desktop, and enter a file name for your data. Additional measurements will be appended to this file as you work through the experiment.
8. Summary data is shown in the two graphs on the right side of the vi front panel. The top graph shows the current/voltage relationship, and the lower graph shows panel power as a function of panel voltage.
9. At the top of the vi are shown the incident radiation ( $\text{watts} \cdot \text{meter}^{-2}$ ) and panel temperature ( $^{\circ}\text{C}$ ).

## Possible problems

1. If you get an error while running the vi it may be because the correct Device is not selected in the Data Channels section. Reselect the Device with the pulldown menu in each channel box. Note that the **channel number** will be the same, only the device number may be incorrect.
2. **DO NOT** alter the values shown in the Hardware section. These values show the resistance of the current-sense resistor (R-Sense) which is used to calculate the panel amps, and the voltage divider ratio (V-div) which divides the actual panel voltage down to the range where it can be measured by the data acquisition system. These two parameters do not change unless the electronic components have been changed. If you inadvertently change the values in the hardware section, exit and restart the vi.



Angle definitions for panel orientation to the sun.



## Appendix

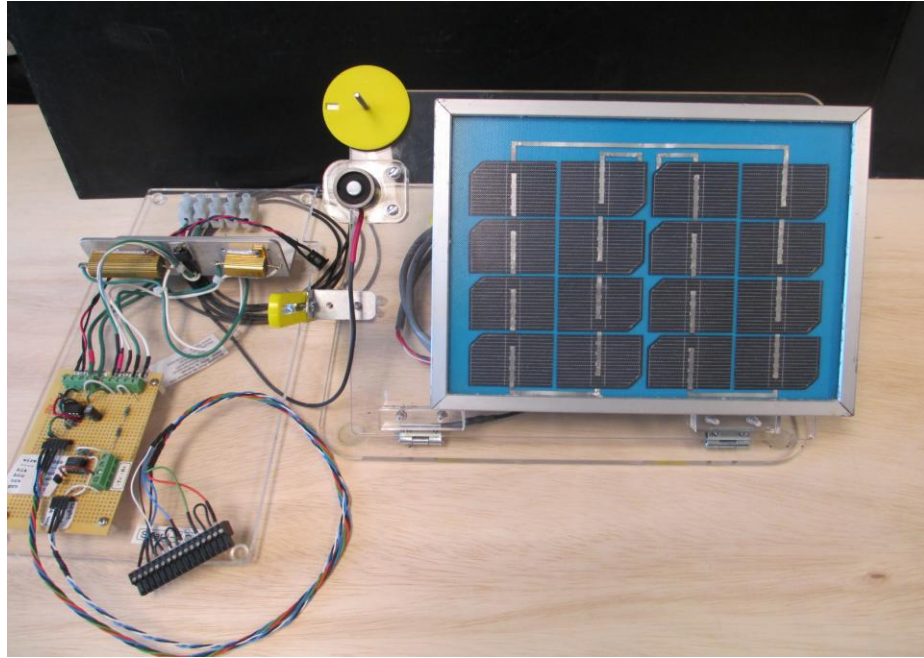


Figure A1. Full test set showing the mini panel, Li-Cor pyranometer yellow “normal incidence” indicator, and measurement/control circuitry.

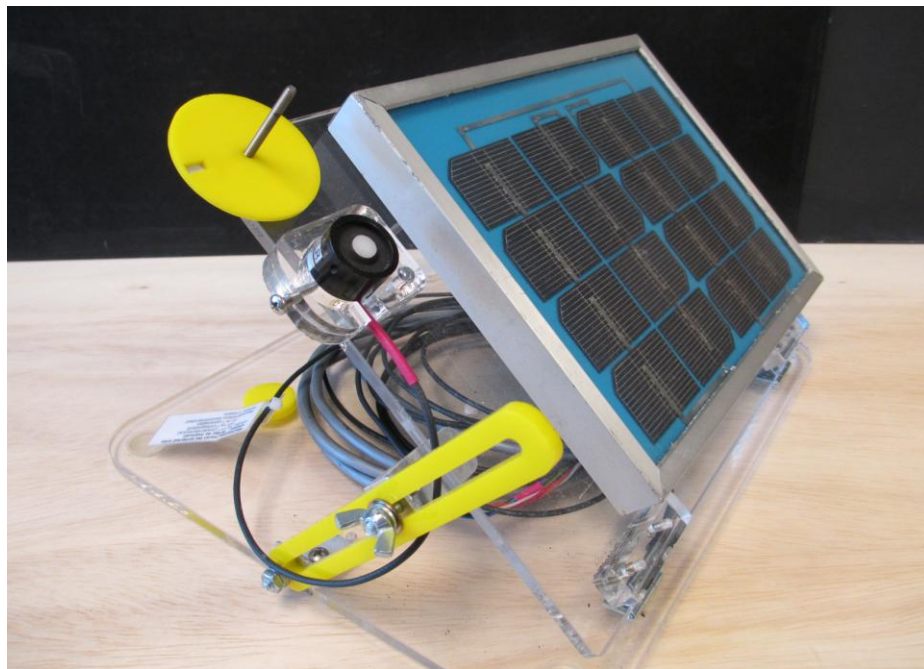


Figure A2. View showing detail of angle adjustment, pyranometer, and normal-incidence indicator

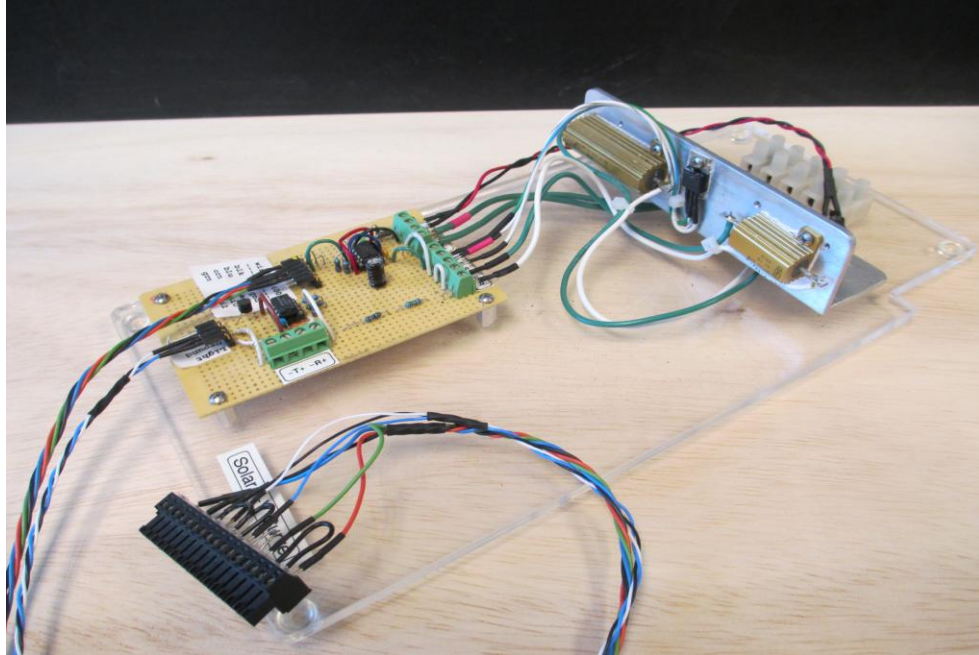


Figure A3. Showing the measurement/control board, and the two current sense resistors. Depending on the panel being tested one or the other sense resistor will be used. The component between the two resistors is the power MOSFET which serves as the software-controllable variable load for the panel (details in the text). The black multi-wire connector plugs into a National Instruments USB-6009 data acquisition system and is controlled by the accompanying LabVIEW vi as described in the text. The 4-wire green connector accepts the signal cables for panel temperature and pyranometer signal.

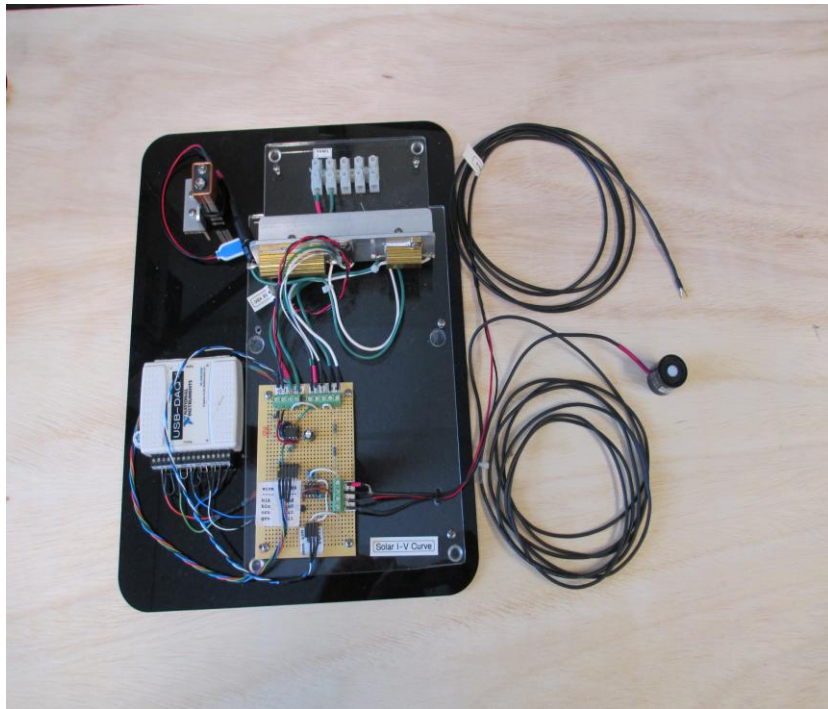


Figure A4. Signal conditioning circuitry and sensors. At the right of the photo are the thermistor (upper cable) and the pyranometer (lower cable). Center bottom is the signal conditioning circuitry. To the left is the USB-6009 data acquisition system. At the upper left is the 9-volt battery. In the center is the aluminum heat sink containing the two gold colored current sense resistors and the power MOSFET which is the load for the panel. At the top is the set of terminals for connecting the solar panel.

## Rarely Asked Questions

- Q1: Why does opamp U1B multiply the current-control voltage by 2?
- A1: The maximum analog output from the USB-6009 is 5 volts. A 5 volt control voltage corresponds to a 10 amp current passing through the sense resistor R4. If the 10 amps were as high as we ever wanted to measure we wouldn't need to do the multiplication. But some panels produce more than 10 amps. In order to be able to demand higher currents from a panel we need a higher control voltage. Multiplying by 2 gives us a max control voltage of 10 volts, increasing our current demand capability to 20 amps.
- Q2: My 9-volt battery is running low and measures only 7.5 volts. Does this have any effect on how the circuit operates?
- A2: Yes it does have an effect. This question also relates to question 1 above. Remember that the outputs from opamps cannot exceed the supply *rails* (the voltage you supply to the circuit). If the circuit battery is down to 7.5 volts that means the opamps' maximum output will be limited to 7.5 volts. In fact, even with a fresh 9-volt battery the control voltage would be limited to the 9 volts of the battery, corresponding to a maximum current draw from the panel of 18 amps. If you need the full 20 amps from a panel you should use a 12-volt source to power the circuit.
- Q3: What exactly are the two voltage-divider resistors R5 and R6 for? I want to know the panel voltage; can't I just measure it directly?
- A3: If you have a multimeter then yes, you can just clip the multimeter leads to the panel and directly measure the voltage. But we are using a data acquisition system, and the DAS is limited to analog inputs in the -10 to +10 volt range. Some solar panels produce 20-30 volts, or more. In order to accommodate these higher voltages we need to reduce (divide down) the voltage going into the DAS to a range we can measure. The software can then compensate for the voltage reduction by multiplying by the voltage divider ratio shown on the vi front panel. The ratio =  $(R5+R6)/R6$ . See figure 3.
- Q4: I'm curious about the sense resistor R4. What does it do exactly? And, is there something special about the 0.5 ohm value, or would some other resistor value work also?
- A4: The *sense resistor* gives us a way to measure the current produced by the solar panel. Note that the DAS can measure only voltage, not current. The current produced by the panel flows through R4. As it does so a voltage drop  $V$  occurs across R4. We measure the

V directly and we know the R. Therefore the panel current can be calculated from Ohm's Law ( $I = V/R$ ). The resistance of R4 should be small, but not too small. If it is too small the voltage drop across it will also be small and may be hard to measure. So then you can make the resistance bigger, but not too big. If it is too big then too much voltage is dropped across the resistor and this would affect how much current can be delivered by the panel. In our case here a 0.5 ohm resistor means a 20 amp current would produce 10 volts at the current sense resistor ( $20 \times 0.5 = 10$  volts). 10 volts is the max voltage the DAS can measure. If we needed to measure higher current we would need a smaller resistor. In summary, it's a compromise. The size of the current sense resistor should be as small as possible while still giving you an easily measurable voltage drop, based on the panel current you expect.

Q5: R3, the "Safety" resistor. It doesn't seem like it's really needed. Why is it there?

A5: You're right, it's not really required. It is just there to prevent current from flowing from the solar panel if the DAS cable is disconnected. The gate terminal G on the MOSFET is a very high impedance input. This means that if the G terminal is left unconnected (floating) its voltage might float up high enough to turn on the MOSFET and panel current would then flow. To guard against this we add R3 which makes the G terminal stay at ground when the DAS is not connected. Just a safety precaution. Well... not "just". It's a safety precaution.