Experiments with Solar Panels

For the Parallax Board of Education and Homework Board

Experiment #5 – Solar Panels in Series and Parallel

A REEL Power tm (Renewable Energy Education Lab) Experiment

Purpose

This experiment demonstrates how solar panels react when placed in series and parallel under load. You are shown that solar panels, like batteries, produce more voltage when placed in series and more current when placed in parallel.

You will come to understand that:

1. Solar panels are rated as “open circuit” voltage and “short circuit” current meaning that the solar panel should operate somewhere between these two limits of external loads. An open circuit (infinite resistance) is really no load while a short circuit (zero resistance) is full load.

2. A “weak” solar cell can affect both the voltage and current outputs of the entire solar panel, especially if it is wired in series.

Background Information

If this is your first experiment or if you just need a refresher on some of the details please refer to the following background information guidelines:

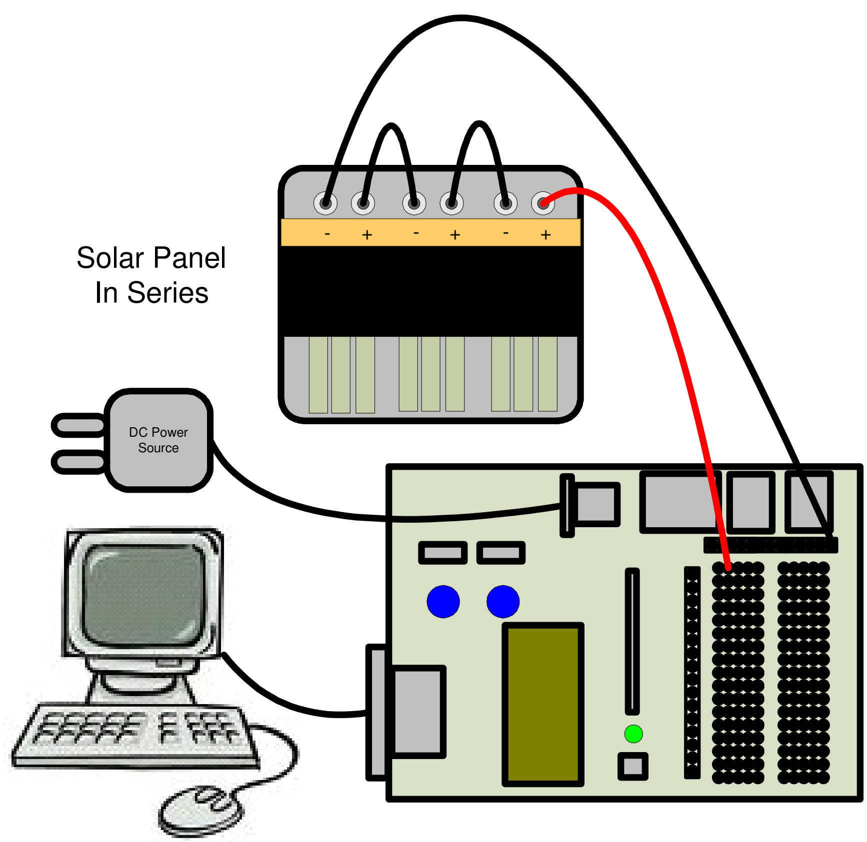
- **Parts Assembly and Wiring Guidelines**
- **Coding Guidelines**
- **A/D Converter Chip Operation**
- **Resistor Color Codes**
- **Computing Current with Voltage Drop**
- **REEL Power Software Installation and Operation**

Equipment

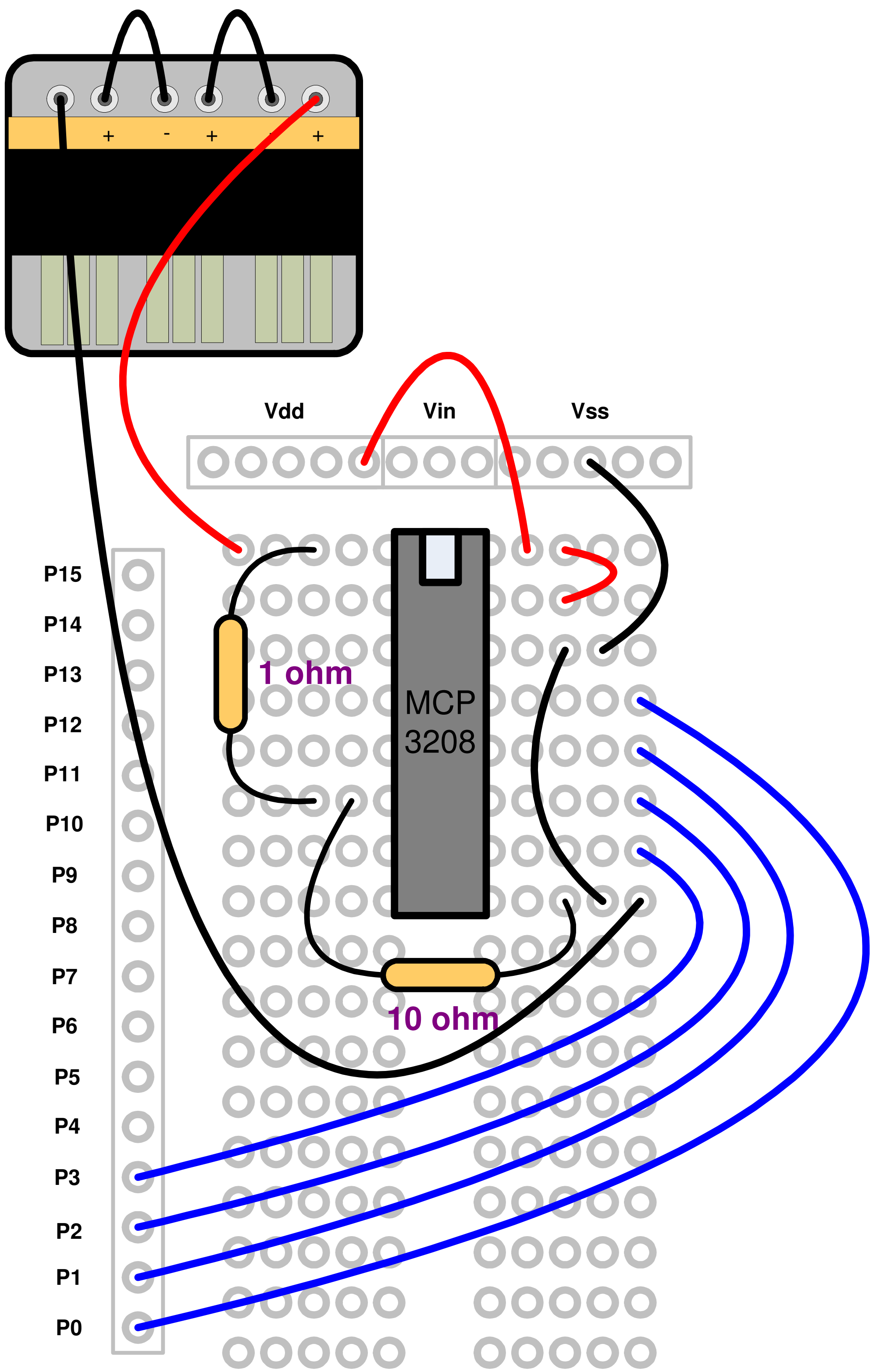
Qty	Description
1	Solar Panel
1	Parallax BOE or Homework Board
1	9-volt battery or +12 volt regulated DC supply
1	MCP3208 - 12-bit A/D converter chip
1	1 ohm sense resistor
1	10 ohm load resistor
1	100 ohm load resistor
10	Solid hookup wires
1	USB or RS232 cable
4	Clip leads
1	Windows PC computer with **REEL Power** tm software (MACs must have Parallel's "Desktop 3.0 for Windows")
1	Printer (optional)

General Hardware Hookup

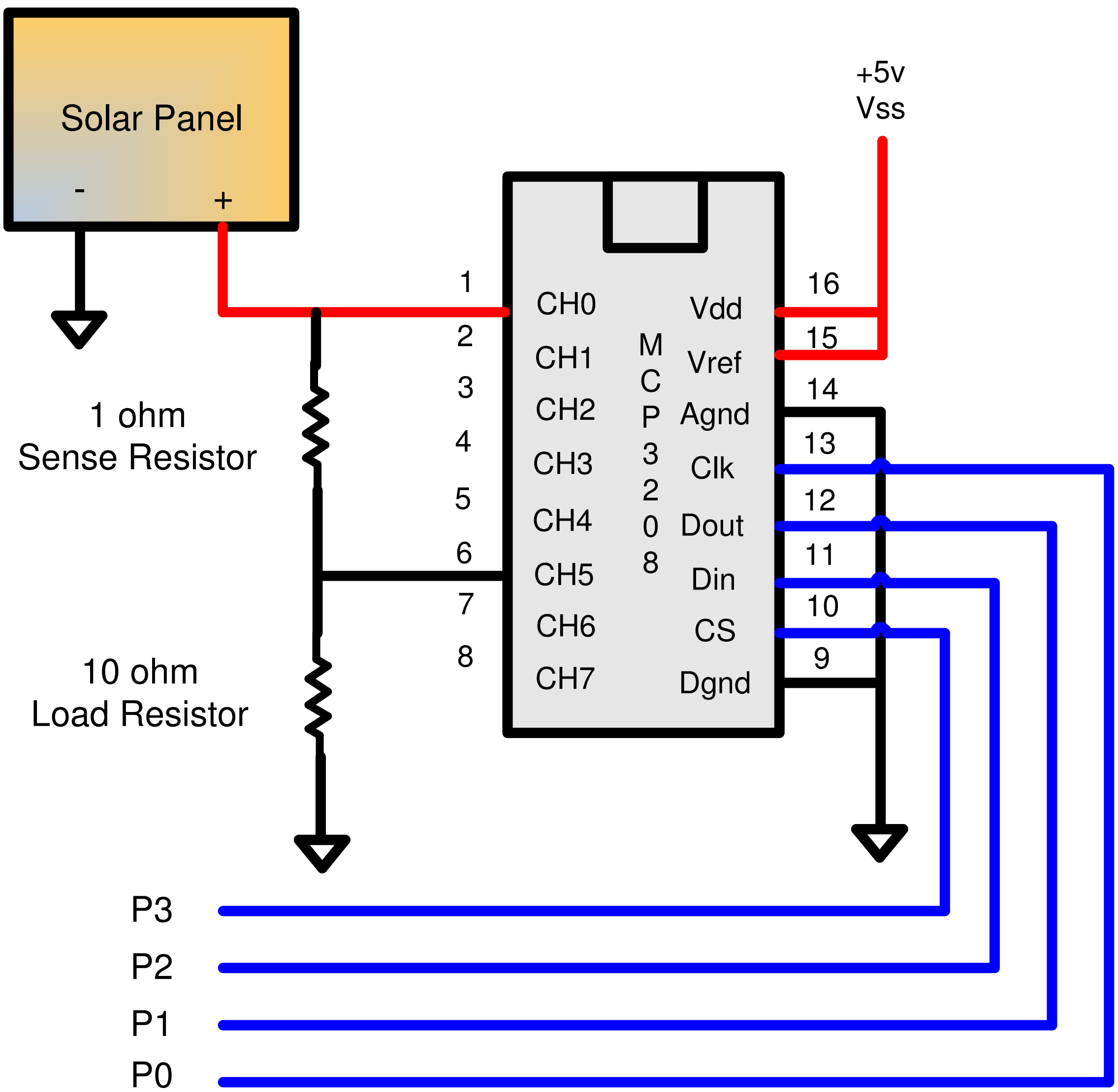
Setup the equipment as shown here, and then examine the **Jumper Board Hookup** (next) for specific details.



Jumper Board Hookup



Schematic



Solar Panel
-
+
+5v
Vss
1 ohm
Sense Resistor
10 ohm
Load Resistor
1
2
3
4
5
6
7
8
CH0
CH1
CH2
CH3
CH4
CH5
CH6
CH7
M
C
P
3
2
0
8
Vdd
Vref
Agnd
Clk
Dout
Din
CS
Dgnd
16
15
14
13
12
11
10
9
P3
P2
P1
P0

Code File

Download the following file to the BASIC Stamp:

Parallax_Solar_Exp.bs2

The code file can be found on the REEL Power CDROM that came with this lesson or on the LearnOnLine website at www.learnonline.com.

Code Algorithm

Here's how the code works. For complete details refer to the above code file.

The Main loop looks like this…

```
'-------------------------------------------------------------------
'   Solar Experiment Algorithm
'-------------------------------------------------------------------
'
' Sample the solar panel input voltage
' Sample the voltage across the 1 ohm sense resistor
' Repeat above xx times (innerLoopLimit x outerLoopLimit)to reduce
voltage ripple from AC lights
' Convert the voltage counts to millivolts

' Test to see if the solar panel voltage > voltage drop across the 1
ohm resistor
'   if so, continue
'   if not,ignore readings and loop back to the top

' Convert the 1 ohm voltage drop to current in milliamps

' Transmit the voltage and current values to the computer
' Repeat
'
'-------------------------------------------------------------------
Solar_Exp:
'acquire solar panel and voltage drop across 1 ohm sense resistor
'and take an average of 64 readings to smooth out ripple
GOSUB   Get_Average_Voltages

'test for catching voltage drop > input voltage
'which can occur when voltage has ripples or changes fast

  IF (voltage < oneOhmDrop) THEN
      GOTO  Solar_Exp
  ENDIF
```

```
'compute the voltage drop across the 1 ohm sense resistor
  current  = (voltage - oneOhmDrop) / 1
'which is automatically now in milliamps by the following:
'
'      I = E / R      where
'                           I = current in milliamps
'                           E = voltage in millivolts
'                           R = resistance in ohms
  GOSUB Plot_It            ' transmit the value to the computer
  GOTO  Solar_Exp          ' repeat
```

The first subroutine acquires 64 readings of the solar panel voltage output and averages the samples in order to acquire a more stable reading.

```
GOSUB Get_Average_Voltages
```

The 64 samples are broken into two loops. The inner loop takes the average of 16 readings while the outer loop takes the average of 4 readings of the inner loop. Altogether, the solar panel voltage and voltage drop across the 1 ohm sense resistor are averaged 64 times. Once done the solar panel voltage and 1 ohm sense resistor voltage drop counts are converted to millivolts.

Since the solar panel voltage and 1 ohm resistor drop voltage are taken at slightly different times (even though they are averaged), a test is made to determine if the solar panel voltage is greater. Otherwise, the resultant subtraction to determine current will be totally incorrect.

```
If    (voltage < oneOhmDrop) THEN
      GOTO  Solar_Exp
ENDIF
```

If the test passes then the current is determined by subtracting the solar panel voltage from the 1 ohm resistor voltage and dividing by 1 ohm (an unnecessary but rigorous step).

```
Current = (voltage - oneOhmDrop) / 1

                         'I = E / R        where
                         'I = current in milliamps
                         'E = voltage difference in millivolts
                         'R = value of 1 ohm sense resistor
```

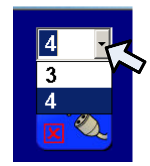
The Plot_It routine computes the checksum for the voltage and current variables and transmits the values to the computer. The process then repeats.

```
GOSUB Plot_It
GOTO  Solar_Exp
```

Procedure

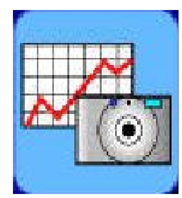
1. Click on the **REEL Power** tm icon to bring up the software menu. Then click on the **Solar Panel Interface** icon.

2. On the graphic display, click on the Connect button at the lower-left of the screen. Verify that the connected icon appears validating the Comm port selection. Make sure to click on the arrow and select the highest comm port number.



3. On the computer adjust the voltage (vertical) scale on the **REEL Power** tm software to 5.00 volts. You may need to readjust it for your solar panel voltage output.

4. **Measuring Open Circuit Voltage** - With the solar panel tilted at an appropriate angle to the light source to capture the maximum light, temporarily remove the 10 ohm resistor from the circuit and note the "open circuit" voltage. Jot this voltage reading down for later analysis or click the screen capture icon to record it. Replace the 10 ohm resistor after recording the open circuit voltage.



5. **Measuring Short Circuit Current** - Next, attach a clip lead across the 10 ohm resistor leads and note the "short circuit" current. Jot this current reading down for later analysis. Remove the clip lead from the resistor.

6. **Series Panels with 10 ohm Resistor** - With the 10 ohm resistor in the circuit allow the plot to continue for about 5 seconds then click the screen capture icon to record the voltage, current and power.

7. **Series Panels with 100 ohm Resistor** – Replace the 10 ohm resistor with a 100 ohm resistor and allow the plot to continue for about 5 seconds then click the screen capture icon to record the voltage, current and power.

8. Take apart the solar panel series wiring and wire it in parallel as in Figure 1. Leave the 100 ohm resistor in place for now.

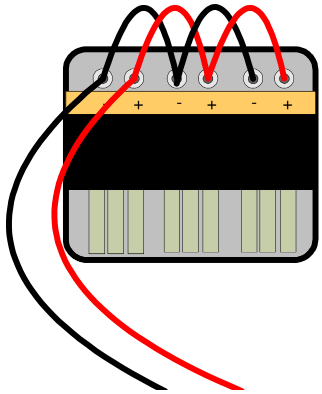


Figure 1 – Solar Panel wired in Parallel

9. **Parallel Panels with 100 ohm Resistor** - With the 100 ohm resistor in the circuit allow the plot to continue for about 5 seconds then click the screen capture icon to record the voltage, current and power.

10. **Parallel Panels with 10 ohm Resistor** - Replace the 100 ohm resistor with a 10 ohm resistor. Allow the plot to continue for about 5 seconds then click the screen capture icon to record the voltage, current and power.

Analysis

1. Refer to your notes or recall the captured images by going to your hard drive at **C:/ REEL Power** and create two tables like the ones below with the captured data. Of course, your numbers will be different; however, the purpose is to compare the readings that you obtained in order to understand why series and parallel wiring configurations along with different resistor loads react as they do.

Solar Panel	Ohms	Volts	Amps	Watts
Series	10	01.305	00.121	00.158
Parallel	10	01.492	00.140	00.209

Solar Panel	Ohms	Volts	Amps	Watts
Series	100	03.076	00.031	00.095
Parallel	100	01.590	00.016	00.025

2. However, before getting into the tables of series and parallel data, first be aware of the theoretical voltage and current limits for the solar panels. These are for the panels used in this experiment; your values may differ.

Parallel	1.5 volts maximum	300 milliamps maximum
Series	4.5 volts maximum	100 milliamps maximum

Compare these values to the parallel and series "open circuit" voltages and "short circuit" currents recorded in Steps 4 and 5. These voltages and current readings should be close to the theoretical voltages – either slightly higher or lower, which accounts for the variations in solar panel materials. However, if they are not close then the solar panels may be internally damaged in some way (which is pointed out shortly).

3. Next, compute the maximum load resistance that can support these limits using Ohms Law.

   $V = I * R$ where V = Voltage in volts
   I = Current in amps
   R = Resistance in ohms

   Substituting to solve for resistance:

   $R = V / I$

4. Compute the "minimum" resistance (the maximum load) that can support the panels in both series and parallel configurations.

   R parallel = 1.5 / 0.300 = 5 ohms (minimum)
   R series = 4.5 / 0.100 = 45 ohms (minimum)

   These values represent the "lowest load resistances" that the solar panels can support. Make sure to use the figures for your particular panels. Anything lower will cause either the voltage or current (or both) to be reduced, since the solar panels cannot support any greater loading.

5. Now look at the data tables in Step 1. As can plainly be seen the first reading with solar panels in series and a 10 ohm resistor load is well below the 45 ohm minimum. As a result the voltage has decreased from a theoretical value of 1.5 volts to 1.305 volts. This is because the solar panel (in series) cannot support the greater load.

Solar Panel	Ohms	Volts	Amps	Watts
Series	10	01.305	00.121	00.158
Parallel	10	01.492	00.140	00.209

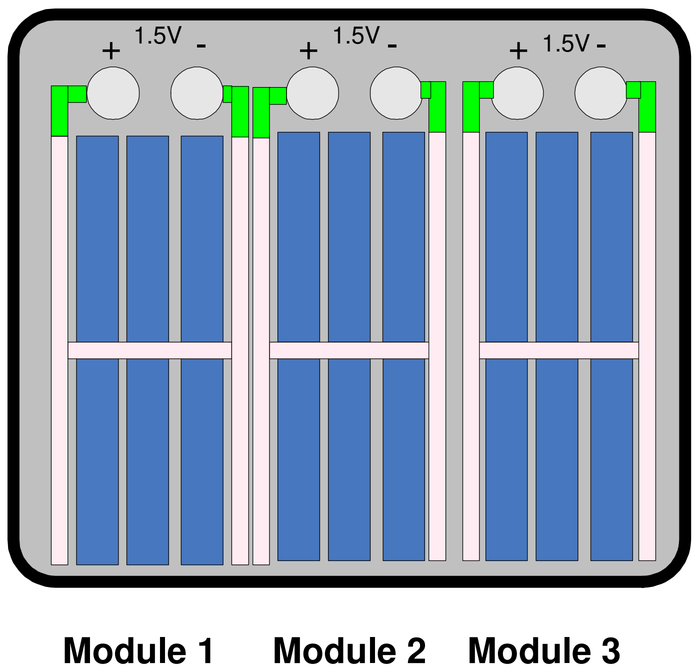
   The parallel arrangement with the same 10 ohm resistor is fine, since this is over four times the calculated minimum value of 45 ohms. Notice that the actual voltage of 1.492 volts is basically the 1.5 volt theoretical maximum voltage for panels in series. This confirms our calculations.

6. Now look at the other data table for the 100 ohm load. Notice that the 100 ohm load for the parallel arrangement is well within limit while the series

load is more than twice the 45 ohm calculated minimum, and the actual voltage of 3.076 volts is well below the 4.5 volt specified voltage.

Solar Panel	Ohms	Volts	Amps	Watts
Series	100	03.076	00.031	00.095
Parallel	100	01.590	00.016	00.025

7. If your readings are similar to this data sample, a possible explanation of the difference between the theoretical and measured data can be due to a "weak" solar cell; that is, one or more solar cells in one of the three solar modules may not be capable of handling the current of the 100 ohm load and would thus cause the lower voltage reading. This is because the internal resistance is too high and can't let enough current flow. In effect the solar modules in series look like Figure 3; and like a bad bulb in a holiday string of lights, a malfunctioning solar cell can, and will, affect the entire output of the series connection.



8. Repeat this experiment with different resistor values – ones that approach the theoretical limits of the series and parallel solar panel configurations. It will give you a better appreciation of why solar panels are rated in open-circuit voltage and short-circuit current as they are.

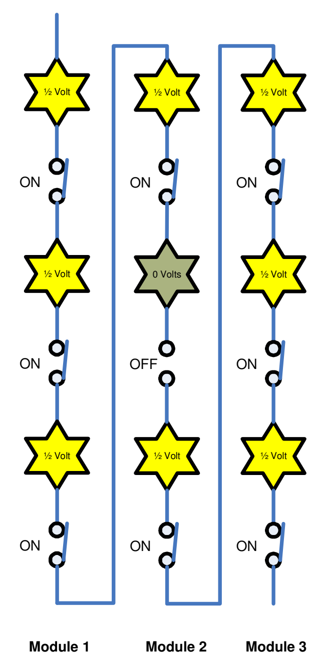


Figure 2 – Weak Solar Cell in Modules in Series