Experiments with Solar Panels

For the PicAxe 28X2 Processor

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.

PicAxe 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**
- **Resistor Color Codes**
- **Reprogramming the FTDI chip – very important!!**
- **Computing Current with Voltage Drop**
- **REEL Power Software Installation and Operation**
- **Safety Precautions**

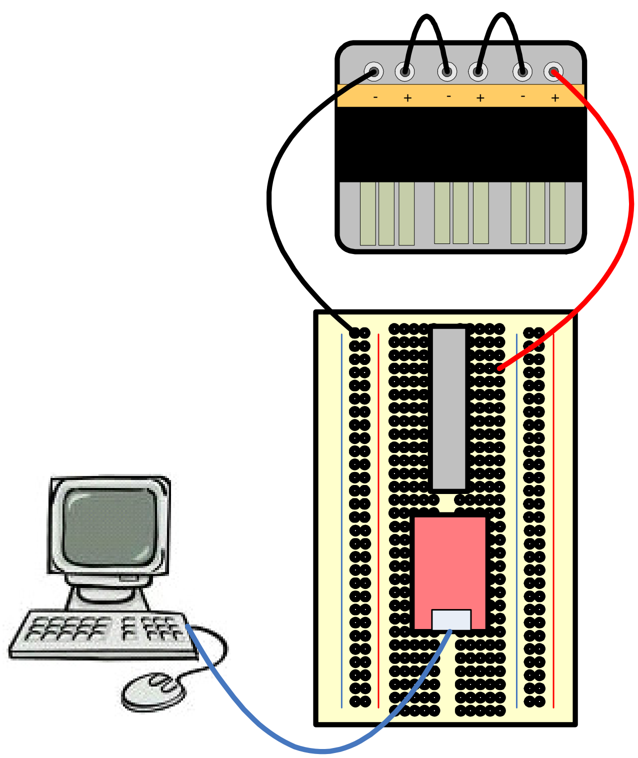
Equipment

Qty	Description
1	Solar Panel
1	Solderless Breadboard (Radio Shack Model: 276WBU301)
1	PicAxe 28X2 microprocessor chip
1	SparkFun USB to Serial Board (BOB-00718)
1	USB cable
1	10K resistors
1	1 ohm resistor
1	100 ohm potentiometer
10	Solid hookup wires (Radio Shack Model: 276-173)
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)

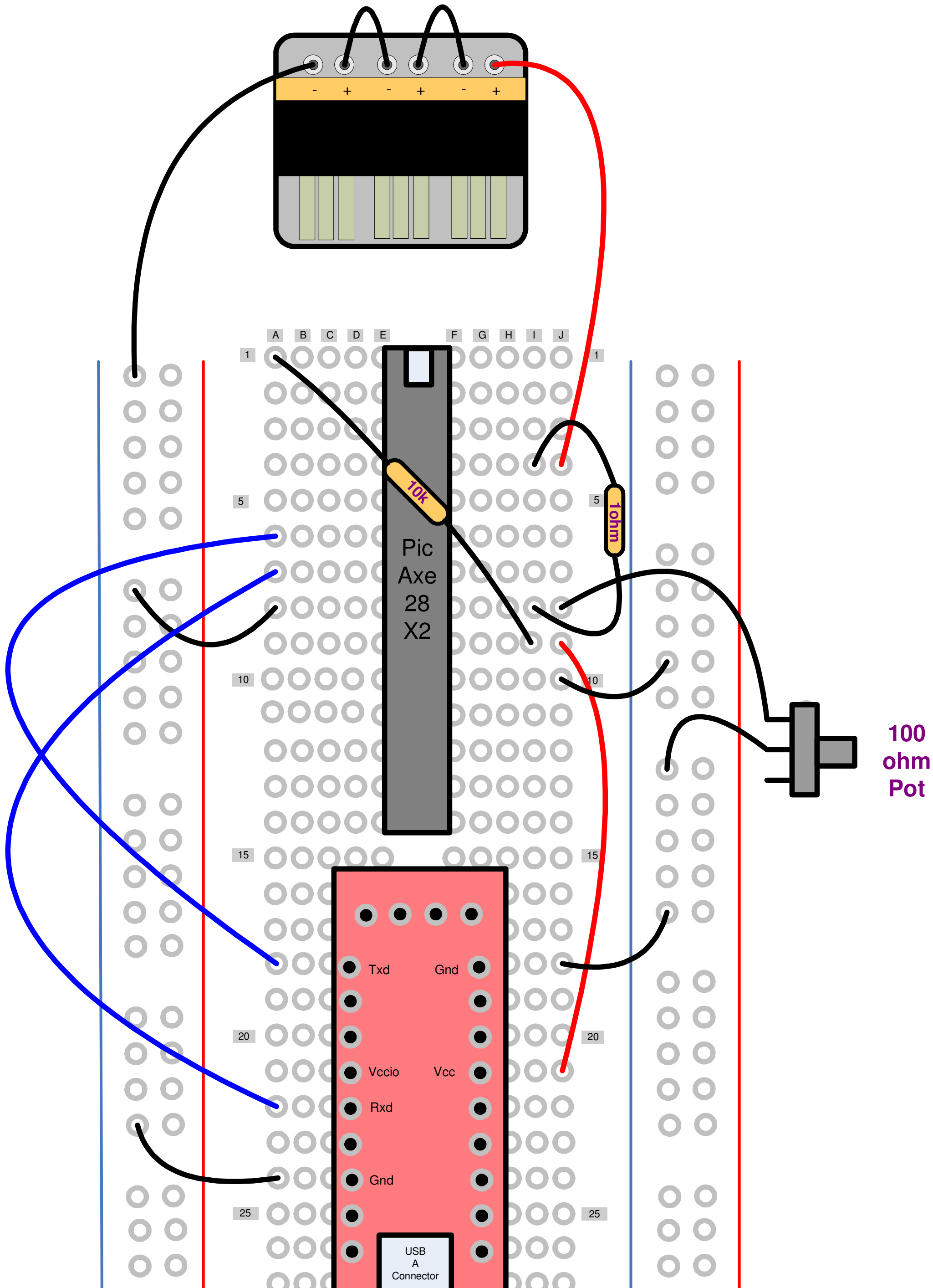
General Hardware Hookup

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

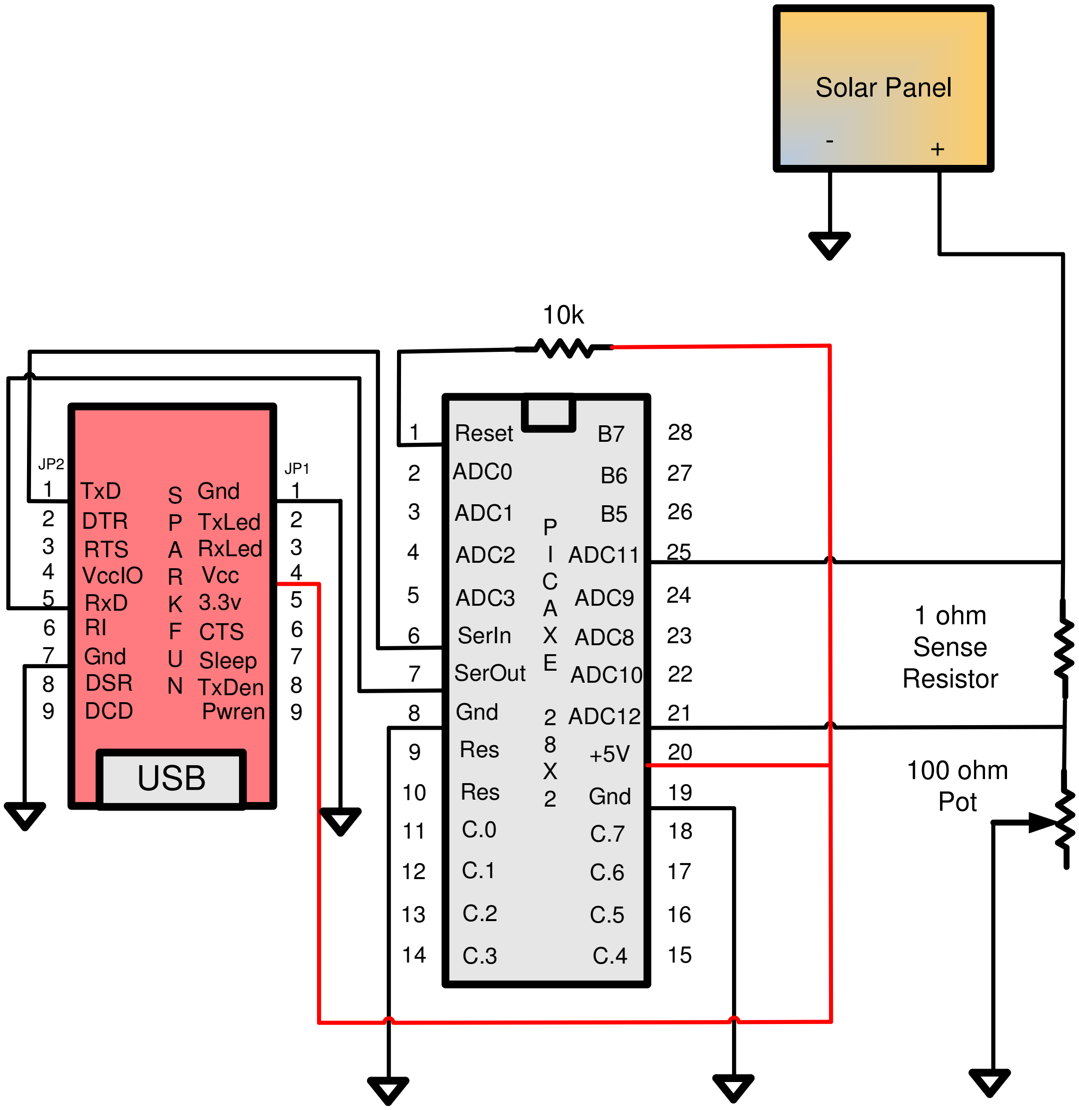
Note: Your setup will NOT WORK unless the FTDI chip on the SparkFun USB to Serial Board is reprogrammed. See PicAxe Background Information for details



Jumper Board Hookup



Schematic



Solar Panel
-
+
10k
JP2
1
2
3
4
5
6
7
8
9
TxD
DTR
RTS
VccIO
RxD
RI
Gnd
DSR
DCD
SPARKFUN
Gnd
TxLed
RxLed
Vcc
3.3v
CTS
Sleep
TxDen
Pwren
JP1
USB
1 Reset
2 ADC0
3 ADC1
4 ADC2
5 ADC3
6 SerIn
7 SerOut
8 Gnd
9 Res
10 Res
11 C.0
12 C.1
13 C.2
14 C.3
PICAXE 28X2
B7 28
B6 27
B5 26
ADC11 25
ADC9 24
ADC8 23
ADC10 22
ADC12 21
+5V 20
Gnd 19
C.7 18
C.6 17
C.5 16
C.4 15
1 ohm
Sense
Resistor
100 ohm
Pot

Code File

Download the following file to the BASIC Stamp:

PicAxe_Solar.bas

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.

Note: Your setup will NOT WORK unless the FTDI chip on the SparkFun USB to Serial Board is reprogrammed. See PicAxe Background Information for details

Code Algorithm

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

The Main loop looks like this…

```
'-------------------------------------------------------------------------------
'
'       Main Routine
'
'--------------------------------------------------------------------------------
Solar_Exp:
        gosub     Get_Average_Voltage          'get average solar panel voltage and
                                               'voltage drop across 1 ohm sense resistor

        IF voltage < oneOhmDrop THEN           'test for illegal condition
               GOTO   Solar_Exp
        ENDIF

        current  = voltage - oneOhmDrop        'compute the voltage drop across the 1 ohm
sense resistor
                                               '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
```

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 step).

```
Current = voltage - oneOhmDrop

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

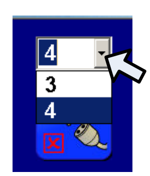
The Plot_It routine computes the checksum for the voltage and current variables and transmits the values to the computer. The process then repeats.

```
GOSUB Plot_It
GOTO  Solar_Exp
```

Procedure

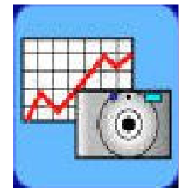
1. Click on the **REEL Power** tm icon to bring up the software menu. Then click on the **Solar Panel Interface** icon.

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 100 ohm pot 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 potentiometer after recording the open circuit voltage.



5. **Measuring Short Circuit Current** - Next, attach a clip lead across the 100 ohm pot leads and note the "short circuit" current. Jot this current reading down for later analysis. Remove the clip lead from the pot.

6. **Series Panels with 10 ohms** - Rotate the potentiometer until a value of 10 ohms is displayed; 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 ohms** –Rotate the potentiometer until a value of 100 ohms is displayed; allow the plot to continue for about 5 seconds then click the screen capture icon to record the voltage, current and power.

8. Rewire the solar panel in parallel as in Figure 1.

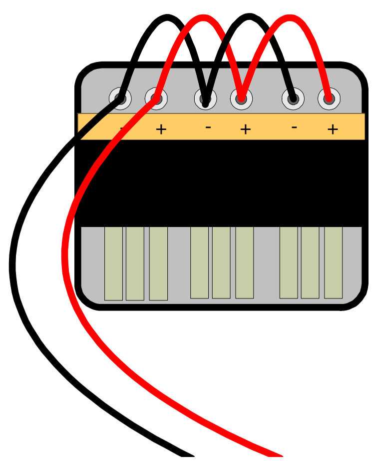


Figure 1 – Solar Panel wired in Parallel

9. **Parallel Panels with 100 ohms** - With the potentiometer set to 100 ohms 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 ohms** – Rotate the potentiometer to 10 ohms; 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 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 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.

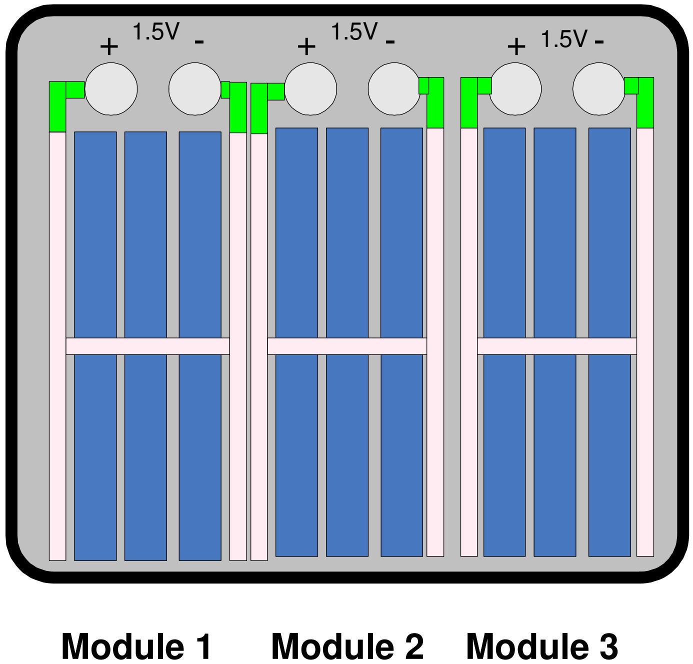
Solar Panel	Ohms	Volts	Amps	Watts
Series	10	01.305	00.121	00.158
Parallel	10	01.492	00.140	00.209

   The parallel arrangement with the same 10 ohm resistance 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.

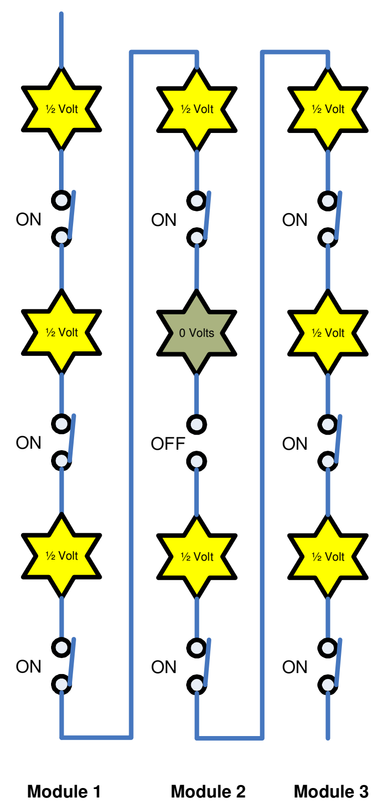


Figure 2 – Weak Solar Cell in Modules in Series