Experiments with Alternative Energy

Part 1 - Solar Energy

Welcome to this first article on Experiments with Alternative Energy. As an electronic engineer (Cal Poly, Pomona, CA), I've always been interested in renewable energy, so to promote it as a topic for teaching and learning math and science in K-12 schools and colleges, in 2002 I founded my company LearnOnLine, Inc., and created the REEL Power (Renewable Energy Education Lab) project. These experiments are based on that effort.

By John Gavlik, WA6ZOK

Our first lesson is on solar energy and how you can measure DC electricity under various series and parallel wiring configurations, loads, and light sources. Future articles and experiments will address more on solar energy plus wind turbines and fuel cells. I wanted to include experiments on geothermal, biomass, and ocean wave devices, but these are a bit too difficult to perform on a desktop.

We'll begin with the fundamentals of how to set up the "test bed" — the hardware, firmware, and software — along with the data acquisition and data display techniques. The important point to realize is that you will be able to work with either a Parallax BS2 or PICAXE 28X2 microprocessor along with the supplied basic language code for each of them. The code and the component setups are designed to give you a highly detailed insight into how solar panels, wind turbines (three-phase, no less), and fuel cells operate on an electrical basis.

Figure 1. Experimental Test Bed for the Parallax BS2 Processor.

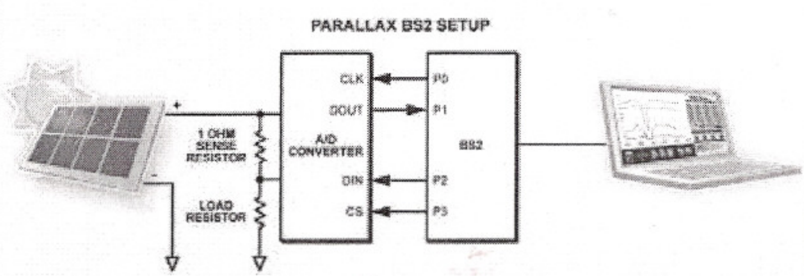
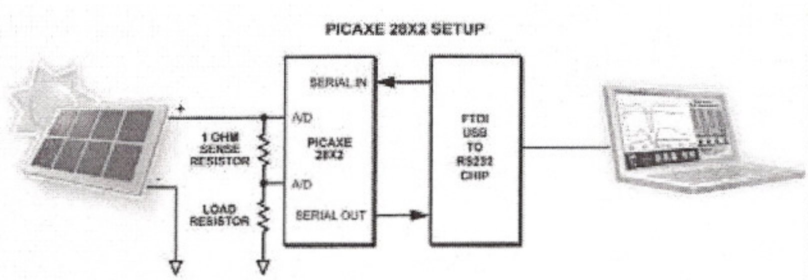


Figure 2. Experimental Test Bed for the PICAXE 28X2 Processor.



In the experiments, I will touch on elements of mechanics, physics, and chemistry to round things out where necessary. However, I will walk a fine line between making things too simple or overly complex in terms of the inner-workings of these devices (read no heavy duty math or cumbersome theory — just the basics like Ohm's Law and first year Algebra). So relax. This is meant to be both fun and informative. If you want to learn more (I hope), there are always schools, online forums, and the web.

One more thing before launching ahead — most of the details for the equipment setups, the firmware, and graphic software, and especially the experimental procedures are found on my website at **www.learnonline.com** under Experimenter Kits. It would be too much of a task to attempt to cover all the necessary material in print form. This and subsequent articles cover just the basics; you can get the full information on the website.

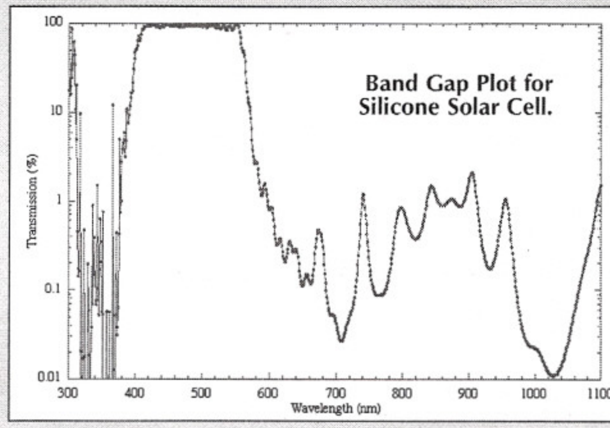
Reference Design

In engineering parlance, there is a term for the experiments presented in these articles. It's called a "reference design" because while a reference design works and does the job it is meant to do, it is not optimized for speed, cost, performance, efficiency, clever extra features, etc. That's why I'm leaving it up to you to take what is offered in terms of hardware, code, and technical approaches to come up with something more personal in terms of what you would like to see the experiments do. I've attempted to make them as complete and open-ended as possible to do this, so I encourage you to put your personal mark on them and then share what you have with me and your fellow experimenters. That's where the fun and satisfaction is anyway — doing it your way and not just following some rote procedure from someone else's design approach — including mine.

Choose Your Processor and Component Setup

The experiments for the Parallax BS2 or PICAXE 28X2 microcontrollers are exactly the same. The only difference is in the Basic language code and components, so pick the one you are most familiar and comfortable with using and let's get started. The general hardware setups are shown in **Figure 1** for the BS2 and **Figure 2** for the PICAXE 28X2. In order to examine the voltage and current output of a solar panel, we need a suitable A/D (analog-to-digital) converter. Since the BS2 doesn't have one, I've chosen a 12-bit model made by Microchip (model MCP3208) that handles the job nicely. The PICAXE 28X2 — one of the newer PICAXE models — has nine 10-bit A/D converters on board so that's not an issue. The PICAXE can be interfaced directly to the computer's serial port; however, I have chosen a USB-to-RS232 converter chip made by FTDI that is nicely packaged by SparkFun on a small PC board. This not only provides good serial communications but the USB connection generates a stable +5 VDC power source for the PICAXE and the A/D converter's reference voltage.

For both setups, you will notice a one ohm "sense resistor" in series with the load resistor. This is to measure current using the voltage drop across it. We'll get into how this is accomplished shortly. Also notice that both setups are connected to a computer for real-time graphic display of voltage, current, power, and load resistance. Seeing these electrical parameters as simply numbers flowing out of the BS2 or PICAXE in debug mode is totally inadequate



Solar PV Materials

Although silicon is the most common type of material used for PV cells thus far, other materials with more promise are also being used, such as:

- Gallium arsenide (GaAs)
- Copper indium gallium (di)selenide (CIGS)
- Cadmium telluride (CdTe)

The choice of PV materials is important since each type of material including silicon has a different "band gap" which means that it absorbs different wavelengths of energy. Think of the term band gap as a typical analog "band pass filter" that allows only certain frequencies to pass through and blocks others, except the frequencies are much higher. The ideal PV solar material would have a nearly "flat" band gap to allow all visible light and possibly other frequencies beyond the visible light spectrum to pass through and generate power.

This is not a formal definition of band gap but the implication is clear enough — materials that absorb more of the sun's energy produce more electrical power. A material or combination of materials that will improve a solar panel's efficiency is where research is focused.

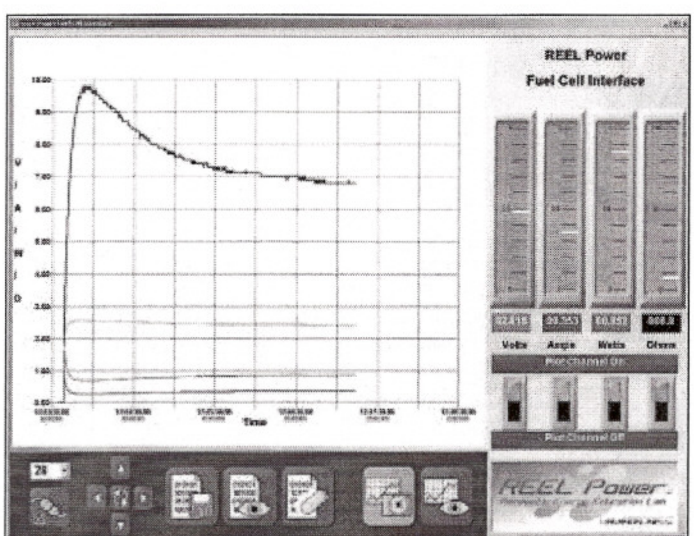
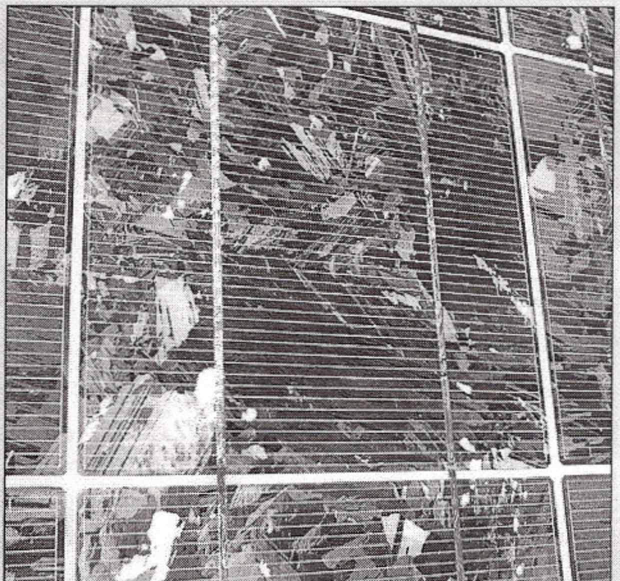


Figure 3. Graphic Software Screen Shot.



Solar Cell.

Solar Cell Characteristics

Regardless of their physical size, common solar cells like those made from silicon produce approximately 1/2 volt. However, the physical size determines the amount of current that can be produced. As such, solar cells need to be wired in series-parallel arrangements to create the necessary voltage and current characteristics.

Solar cells are like magnets. When you break a magnet in half, both halves still have a North and South pole. If you break a solar cell in half, both halves will still produce 1/2 volt. However, the current for each cell will be proportionally equivalent to the break. The same is true for the gauss producing capabilities of a broken magnet.

Figure 5. Suggested Solar Panel.

for a true understanding of how external factors affect the solar panel's output. The graphic software instantly displays how all the electrical parameters react together; a picture is worth 1,000 words (or 1,000 numbers, in this case).

PC Graphic Software

A common element in all the experiments is the graphic software that displays real-time voltage, current, power, and resistance data coming from the BS2 and PICAXE as plots and numeric data on your Windows PC (**Figure 3**).

As you can see, there is a large graphic area where voltage (green), current (blue), power (red), and resistance (black) are plotted. To the right are four vertical gauges that display these same quantities in both bar-graph and numeric form. Below each gauge is a switch that you can click to turn a particular plot ON or OFF in order to eliminate screen clutter.

Below the plot and meter areas (**Figure 4**) are controls to:

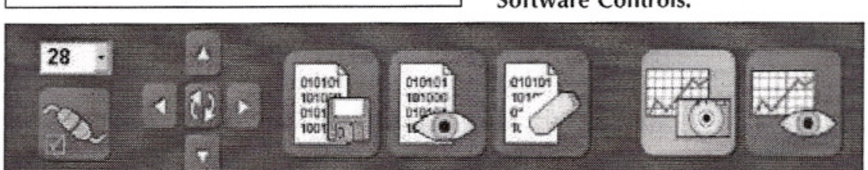
- Select-Connect-Disconnect to the proper com port to receive serial data.
- Horizontal and vertical scale arrow adjustments.
- Clear the plot display area (icon in the center of arrows).
- Start-Stop, Save, View, and Erase logged data in Excel compatible format.
- Capture and View and Save screen snapshots as jpg images.

While the graphic software is a cost item like the micros and other components, at $39 it will do all the experiments for solar, wind, and fuel cells, so one purchase will fill the bill for everything these articles will address both now and in the future.

The Solar Panel

The solar panel chosen for these experiments (**Figure 5**) is both unique and inexpensive for its overall capabilities (about $16 or less). It is really three solar panels in one enclosure, and the three panels can be wired in series and parallel combinations with screw terminals on the back to produce voltages and currents from 1.5 volts @ 300 mA to 4.5 volts at 100 mA. You are

Figure 4. Graphic Software Controls.



Experiment Components

Rather than listing them here, you can find a list of recommended parts on the LearnOnLine website at **www.learnonline.com**. Click on Experimenter Kits.

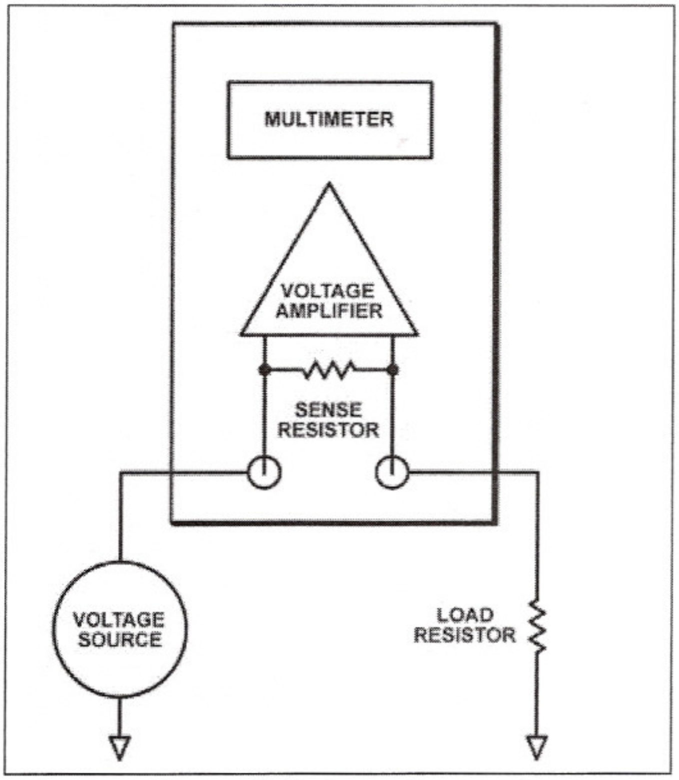


Figure 6. Multimeter Block Diagram for Measuring Current.

Solar Panel History Time Line

1839 Edmund Bacquerel — a French physicist who studied the solar spectrum, magnetism, electricity, and optics — is known for his work in luminescence and phosphorescence. He discovered the photovoltaic effect which is the basic physics behind the solar cell.

1877 Later in the 19th century while investigating this effect, Adams and Day noted an anomaly they thought could be explained by the generation of internal voltages. They made selenium cells that were 1-2% efficient.

1904 Albert Einstein — most known for this Theory of Relativity — published a theoretical explanation of the photovoltaic effect. In 1916, Robert Millikan experimentally proved Einstein's theoretical explanation.

1916 The Czochralski method is the technology used to grow the large crystals required in today's chip industry. The method was named after the Polish scientist Jan Czochralski who discovered it by serendipity after accidentally dipping his quill into a tub of molten metal instead of an inkpot. Accidents are the basis for many scientific discoveries.

1950s The first attempts to commercialize solar panels are begun prompted by prior research during World War II for military applications. Once again, the government is needed to fund basic research into new technology in order to spin off commercial applications.

1958 The first commercial solar panel is used with NASA's Vanguard I satellite. The panel was manufactured by Hoffman Electronics, a major commercial and military electronics firm now essentially out of business.

1980s Solar panels are first used in conventional consumer applications for powering calculators, digital watches, battery chargers, and even small buildings.

1990s More efficient solar panels are developed using materials other than silicon. Mechanical solar tracking devices gain popularity to increase total power output.

2000 to present Solar energy's promise of independent, grid-free power is slowly becoming a reality. High cost and low efficiencies below 25% are still the major issues.

free to use your own solar panels, but make sure they do not go over five volts open circuit or else you will swamp the A/D converter chip or PICAXE microprocessor's A/D inputs and perhaps damage them. Refer to the Experiment Components sidebar for your source.

Measuring Current with Voltage Drop

Current is always measured using the voltage drop across a sense resistor. This is true even in the best multimeters. Once you understand this principle, you will have more appreciation for and understanding of the technique.

When measuring current with a normal multimeter, you must interrupt the circuit by placing the multimeter between the voltage source and the load as shown in **Figure 6**. What you are actually doing is placing a very small [value] sense resistor in series with the load. The multimeter measures the voltage drop across the sense resistor using an A/D converter much like the one we are using for the experiments. Based on Ohm's Law, its internal microprocessor computes the current as follows:

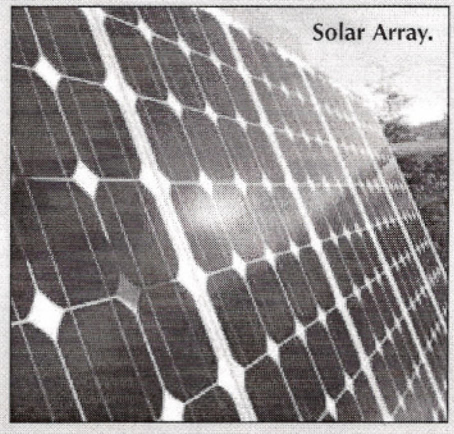
I = V / R
where I = current in amps
V = voltage in volts
R = resistance in ohms

In order to determine the voltage drop, the multimeter senses the voltage at both places on the sense resistor — at the voltage source and at the load. The current is then computed based on the voltage drop across the sense resistor as follows:

I = V / R
where V = Vsource - Vload
R = sense resistor value

In modern multimeters, the sense resistor is typically well below one ohm in order not to add to the load.

Solar Panel Construction



Solar Array.

Individual solar cells are wired together in series-parallel arrangements to create the voltages and currents necessary for the solar panel's application. This requires creating a grid of wires and supporting metallic traces for the interconnections which add to the area and also contribute electrical losses like any wires do in a DC circuit. The wires and traces also block light. Modern solar panels incorporate protective diodes that help prevent heavy current overloads if a portion of the panel is shaded. While effective, the diodes create their own electrical losses in terms of normal voltage drop and generated heat.

Solar cell and solar panel images courtesy ***Wikipedia.com***

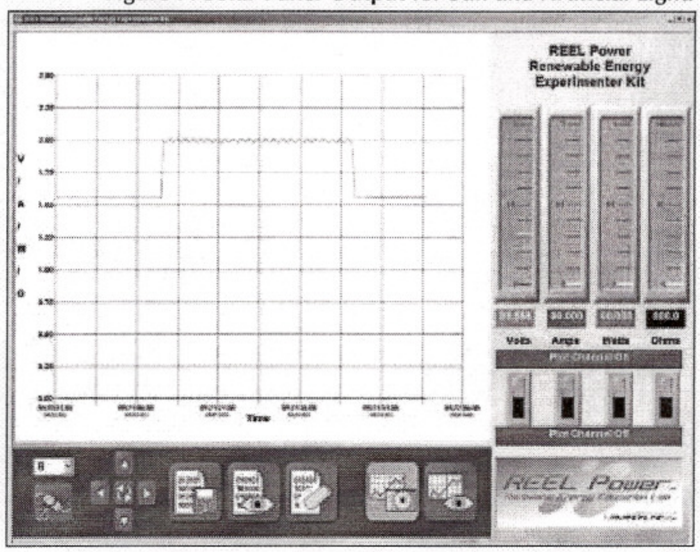
This value is generally 0.01 to 0.05 ohms — 10 to 50 milliohms — hardly anything in terms of adding to the load resistance. However, with such a small sense resistor the voltage drop is also small. To compensate, the multimeter adds a voltage amplifier across the sense resistor to boost the voltage to a measureable quantity for the A/D converter.

The gain of the voltage amplifier is used in calculating the voltage drop and resulting current value. So, if the voltage drop across a 0.01 resistor is one millivolt and the gain of the voltage amplifier is set at 100, the

The Experiments

Now, let's get started on two of the solar panel experiments. You can find complete details on these and the other experiments including background information, equipment setup, and experiment procedures at www.learnonline.com. Just click on the Experimenter Kits menu selection. Then click on the selected experiment for your chosen processor.

Figure 7. Solar Panel Output for Sun and Artificial Light.



Solar Experiment #1: Sunlight versus Artificial Light

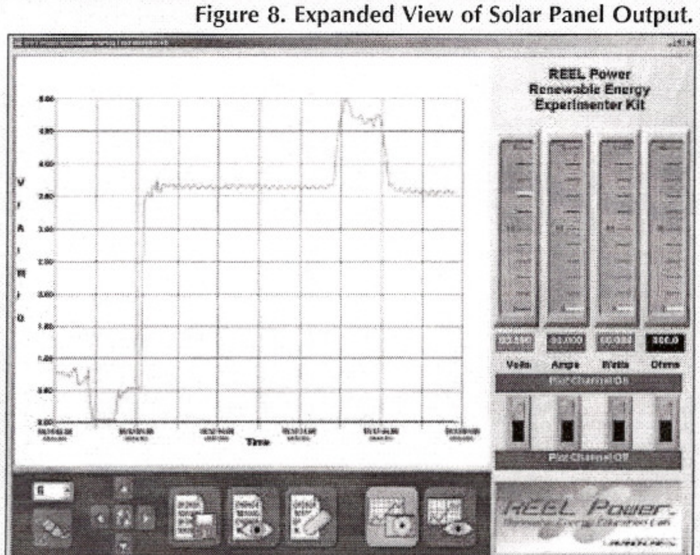
This experiment demonstrates the difference between sunlight and artificial light as it strikes a solar panel. It shows that sunlight provides a constant source of voltage and current while artificial light produces "ripples" due to its AC nature. The ripples are a result of the 60 Hz AC that powers the incandescent light bulbs and fluorescent lights.

Procedure:

Aim the solar panel at an open window with the sun shining (**Figure 7**). Notice the steadiness of the voltage output. Now expose the solar panel to artificial light from an incandescent bulb or overhead fluorescent light. Notice the ripples on the panel's output. This is due to the 60 Hz AC that powers the artificial light. Go back to the window for another look at the steady voltage levels.

Now, expose the solar panel to a higher intensity of artificial light by moving it closer to the light source (**Figure 8**). Note the expected increase in voltage, as well as the increase in ripples. This is a simple experiment, but few people have ever seen artificial light and sunlight measured this way — this may include you, too.

Figure 8. Expanded View of Solar Panel Output.



A/D converter receives a voltage of 100 millivolts that is well within the limits of a good A/D converter.

For our experiments, it was decided to save on the cost and complexity of a voltage amplifier and go, instead, with a one ohm sense resistor. If the actual load resistance is also low (like 10 ohms, or less, as in most of these experiments), there is ample voltage drop across the resistor — especially when applied to a 10- or 12-bit A/D converter which can measure down to 4.88 and 1.22 millivolts, respectively, with a +5 volt reference.

The downside to using a one ohm load resistor is that it adds to the load itself. So, for a 10 ohm load and a one ohm sense resistor, the total load is actually 11 ohms.

Therefore, be aware of the fact that the resistance values displayed on the computer are the "sum" of the one ohm sense resistor plus the actual load resistance.

Conclusions

This first brief look into solar photovoltaic experiments gave you a glimpse into what desktop solar panels are capable of doing and how their performance is measured. Commercial solar panels behave in much the same way which is one of the main points of these experiments; that is, to make the connection between what you learn in model form in order to apply the same techniques to real-world systems.

Next time, we will investigate the effects of tilt angle, heat, and shading on solar panels which will give you even more background information. In the meantime, conserve energy and "stay green." **NV**

Experiment #2: Determining the Maximum Power Point

This experiment demonstrates how solar panels in either series or parallel have a maximum power operating condition known as the Maximum Power Point or MPP. The maximum power point is where the solar panels can deliver the maximum power into a load. MPP is a dynamic condition that varies based on external influences such as light intensity, tilt angle, heat, and either a series or parallel arrangement of the panels. You are shown that the MPP is achieved when the resistance of the solar panels matches the load resistance. You will discover this when you vary the load resistance to produce maximum power with solar panels in series and parallel configurations. Satellites in space must constantly adjust their solar arrays to acquire the MPP, which is why this is such an important concept to understand.

Procedure:

Wire the solar panels in series and adjust the 100 ohm potentiometer from full resistance to a lower resistance until the maximum power is reached. Continue to adjust it for lower resistance to see what happens. Then, rotate it back to the maximum power level. A plot similar to the one in **Figure 9** is displayed. Notice the large dip in voltage, current, and power as the heaver load resistance overwhelms the solar panel's ability to source power.

Next, wire the panels in parallel and repeat the same procedure with the potentiometer. While the voltage is noticeably lower due to the parallel wiring configuration, the voltage does not dip as much and the output current and power remain much steadier under the varying load (**Figure 10**). Thus, solar panels in parallel have a better means to supply more stable power over varying loads as compared to an equivalent series arrangement.

Figure 9. MPP for Solar Panels in Series.

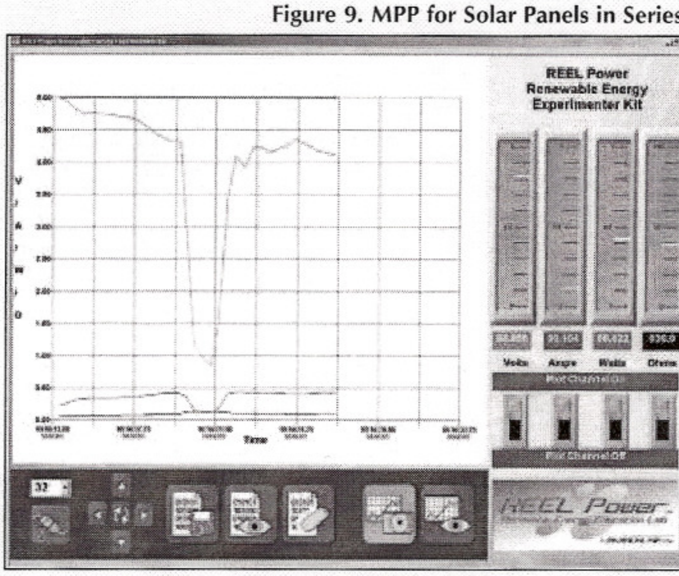


Figure 10. MPP for Solar Panels in Parallel.