ALTERNATIVE ENERGY SYSTEMS

PART II

Understanding solar panel structure and performance,

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The following article is part II of a three-part series about alternative energy systems. In Part 1 (November 1997, page 98), the authors discussed their quest for energy independence and their early experiences with solar power. Part III, which focuses on wind power, will appear in the January 1998 issue.

Solar panels are becoming more popular among motorhomers. Having a better understanding of the different types of solar panels and how they work will help coach owners to make purchasing decisions and to obtain the maximum efficiency from a solar electric system.

Solar cell composition. Solar cells are PN junction photodiodes. To under stand the term PN junction, one must first understand some aspects of semi conductors. Under certain conditions, semiconductors can act like conductors or insulators. Semiconductors are made from crystals. Silicon, the main component of sand, makes up about 28 per cent of the Earth's crust and is the most widely used crystal for semiconductors. Because of intrinsic positive and negative attributes, cadmium telluride or gallium arsenide can be used as alternative crystals in the manufacture of solar panels. Gallium arsenide panels are employed for satellite and other space applications.

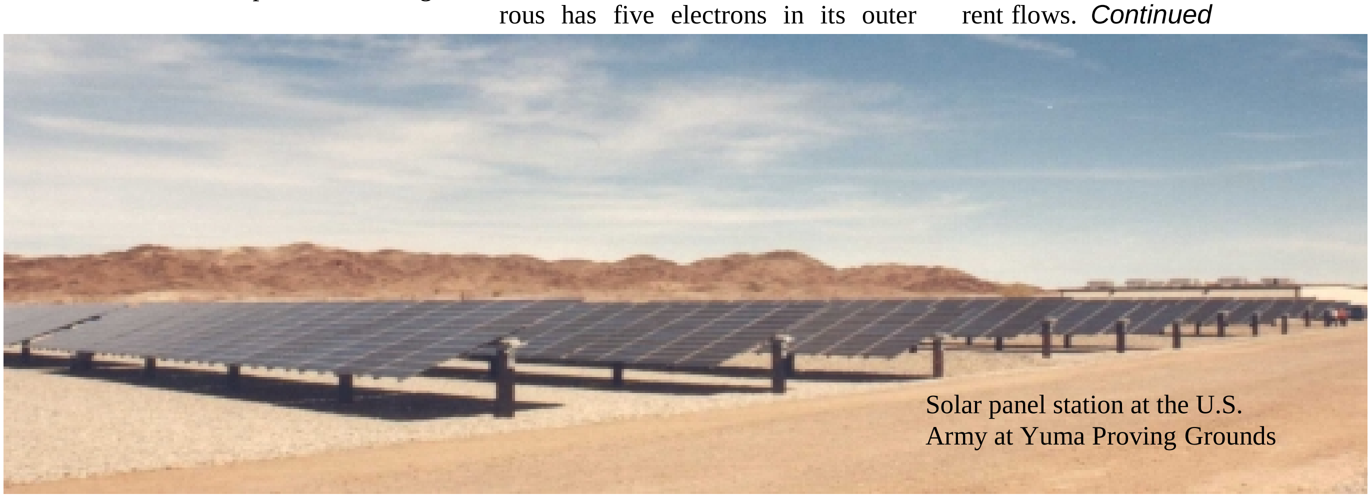
Silicon crystals are created by heating silicon to the melting point. Pure silicon, although inexpensive, is inert and not very useful. To create positive and negative crystals, a small amount of either boron or phosphorous is added to the liquid silicon. This process is called "doping." From this liquid, crystals are grown and cut into wafers. Those wafers with boron are P-type (positive) silicon, and those with phosphorus are N-type (negative) silicon.

The silicon atom has four electrons in its outer shell. In the crystalline form, adjacent silicon atoms share these four electrons. Boron has only three electrons in its outer shell. Having one less electron creates a hole in the P-type silicon crystal. A neighboring electron can jump into this hole. This creates a hole elsewhere, so the hole appears to move. Phosphorous has five electrons in its outer shell. This extra electron can move freely in the silicon crystal. Both holes and electrons can conduct electrical current.

When a P-type crystal and an N-type crystal are layered together, a PN junction is created. All PN junctions are light sensitive to varying degrees. When illuminated, a PN junction photodiode (solar cell) may be either photovoltaic, meaning it is the source of current, or photoconductive, meaning it carries the current.

Solar panels are photovoltaic. A photovoltaic cell is capable of producing a voltage when exposed to radiant energy especially light. As a renewable power source, solar panels have no moving parts and no chemical reactions that could create undesirable end products.

One way to understand how a solar panel works is to think of it as a pump. A particle of light, the photon, is the fuel for the pump. The photon strikes the photovoltaic material, exciting the outer electrons on the silicon atoms. As the electrons jump the PN junction, a voltage potential is created and current flows. *Continued*



Solar panel station at the U.S. Army at Yuma Proving Grounds

The electrons flow from the negative terminal of the solar panel, through the batteries and then back to the positive terminal of the panel.

Types and performance. There are two main types of solar cells: rigid crystalline cells and thin film flexible amorphous cells. Rigid crystalline cells may be a single crystal thick, and are used in solar panels manufactured by Siemens. Another version of the rigid crystalline cell is the polycrystalline type used in solar panels produced by companies such as Kyocera and Solarex.

As mentioned, the second type of solar cell is the thin film flexible amorphous type. Generally, the amorphous type is less expensive, because less photovoltaic material is required. One source stated that the amorphous type uses only 1 percent of the photovoltaic material as a similarly sized crystalline-type panel does. Amorphous panels are subject to a 15 to 30 percent degradation of output, which usually occurs within the first three to six months of use. The rate of degradation is dependent on the amount of exposure to sunlight. The rigid crystalline panels have an efficiency of approximately 13 per-cent and the amorphous type approximately 6 percent. The life expectancy of the crystalline type ranges anywhere from 10 to 30 years. The life expectancy of the amorphous type has not yet been determined.

Some solar panel sales literature implies that the panels have an almost indefinite life. However, even though the photovoltaic material itself does not degrade or deplete, the packaging components are subject to degradation, which affects the panel's output. The packaging refers to all other components, including grid wires, electrical collectors, other electrical connections, and the glass cover. Solar panels are heated by sunlight during the day and then become cooler at night. The resulting expansion and contraction of the various components leads to a gradual deterioration and diminished output over the years. Also, blowing sand can scratch the glass cover, and that can impede the light and decrease energy output.

So, although the photovoltaic material may last forever, the solar panel itself has a definite life expectancy. It's not unusual for a solar panel to be under warranty for 10 years. Siemens recently extended the warranty on its panels to 25 years. The warranty applies to panels of 45 watts or more (SM or SP models) purchased after March 1, 1997. The warranty, which is transferable to subsequent owners, guarantees that the panel will retain 80 percent of its rated capacity for the warranty period.

Light and temperature factors. Various sales claims are made for solar panel performance in low light conditions. Figure 1 shows the typical power response to various light levels, expressed as watts per meter squared (W/M2).

The consumer should be aware that panel performance is most dependent upon engineering design. Panels can be engineered for optimal performance in low light, direct light, or ranges in between. Panels used in space can achieve greater efficiency ratings, because they are designed for bright light conditions and use a light-focusing cover. Such panels require a two-axis positioner to remain perpendicular to the sun at all times. Low light performance is not a factor.

Solar panel output voltage is related to operating temperature. Manufacturers' specifications are often shown for industry standard conditions at a cell temperature of 25 degrees Celsius, but a more common condition in practice is a cell temperature of 47 degrees Celsius. It is important that the panel(s) be able to provide more than 14.6 volts at operating temperatures. Don't forget to allow for line losses between the solar panels and the batteries.

Solar panel cells are wired in series, each producing approximately 0.5 volt. The size of each cell determines the amperage. Panels described as self-regulating have 30 cells. Unregulated types have 33 or 36 cells. To work properly, the self-regulated panel(s) must be sized to an appropriate battery bank. Manufacturers usually provide the sizing specifications. Note that the maximum output voltage for a self-regulating panel is 14.5 to 14.6 volts at 25 degrees Celsius. At operating temperatures, the voltage will be less. As the battery approaches a full charge, the amperage supplied by the panel approaches zero, because of the decreasing differential between the solar panel voltage and the battery voltage.

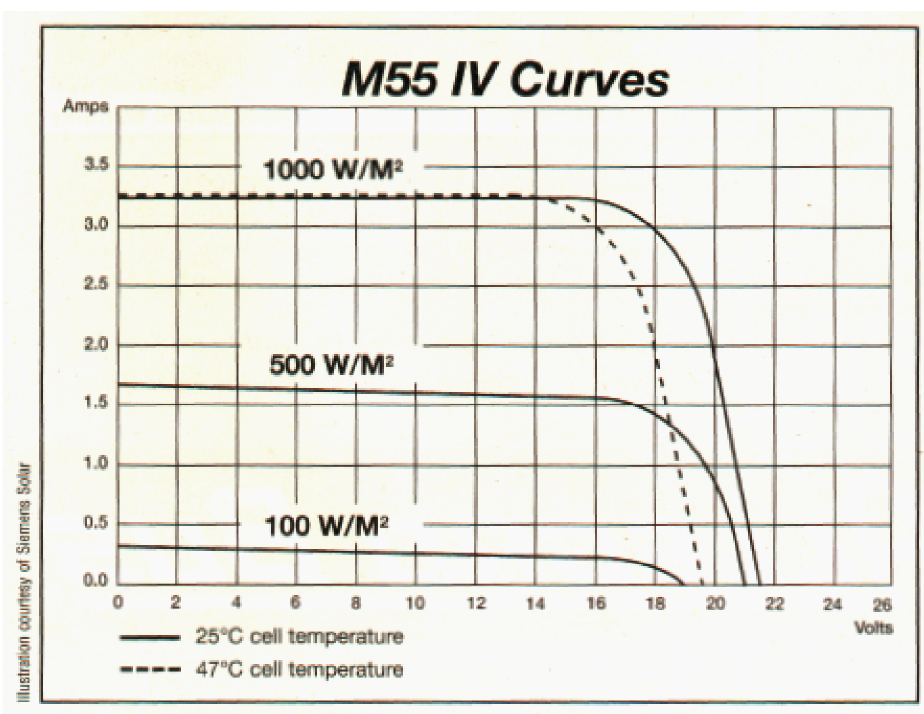


Figure 1. The IV Curve (current versus voltage) demonstrates typical power response to various light levels, measured in watts per square meter, at 25 degrees Celsius cell temperature and 47 degrees Celsius cell temperature. With lower light conditions, the effects of temperature are minimized.

Regulators. Many experts prefer not to use self-regulated panels for serious battery charging, because too many variables exist. The preferred method is to use high-voltage panels with a series relay controller or a shunt-type regulator. A shunt-type regulator uses a blocking diode to direct a one-way flow of current from the solar array to the batteries. When the battery charge set-point voltage has been reached, an internal shunt in the regulator conducts the output of the array back to itself. A series relay regulator simply turns off the flow of cur rent when the battery reaches its charge set-point voltage. When a load is applied and the battery voltage drops, the relay closes and current is allowed to flow. The relay can be internal or external to the regulator.

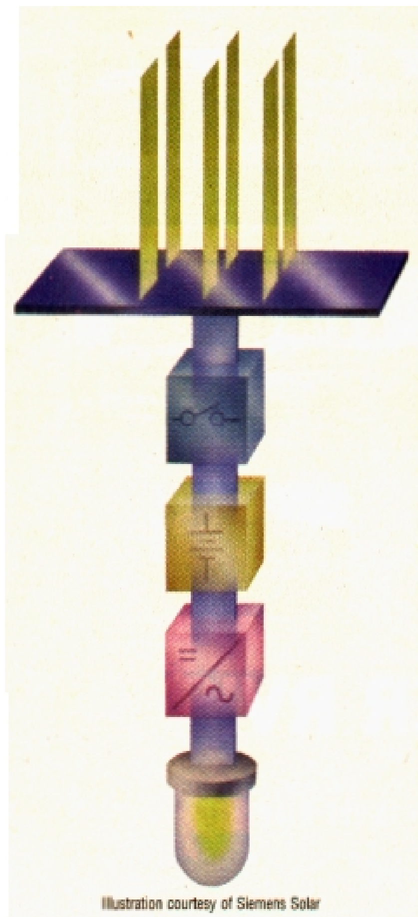
The regulator capacity is determined by the relay capacity, Relays of 20, 30, and 70 amps are available. Either type of regulator may function by turning off at a certain high voltage set point and turning on at some lower voltage set point. Some regulators are capable of three-stage charging, while others are able to charge with partial output, keeping the battery voltage at some intermediate point, or “floating” the batteries.

Shunt regulators tend to run hot as a result of having to dissipate the output of the solar panels. This heat creates some reliability problems. Mechanical relays used in the series relay regulator are subject to failures, because of the repetitive opening and closing of the relay contact points. Our high-output system has a series relay controller with a 70-amp relay, but we have not experienced failures, because we rarely achieve a full charge status; therefore, the relay cycles infrequently. However, if the relay should fail, it is easy and inexpensive to replace.

A phenomenon of reverse current can occur when solar panels are not charging. Reverse current can be caused by nightfall or shade. If caused by shade, this decreases output and also increases heat, which leads to a further decrease in output. To prevent this reverse current, some manufacturers of high-voltage panels incorporate a bypass diode in each panel. One of three methods can prevent reverse flow at night. The first is to use diodes on each panel, as previously mentioned. The second is to use a properly heat-sinked line diode of suitable capacity. The third method is to use a regulator that turns off when the solar panel voltage drops. The regulator may use an internal diode or a relay.

Solar panels equipped with diodes can be wired for 24-volt operation without adding any extra diodes. To accomplish this, create individual series strings of two panels and then parallel these strings to obtain the required current.

Positioning factors. The U.S. Army at Yuma (Arizona) Proving Grounds has installed a 450-kw solar power station equipped with 8,148 Siemens M55 panels, which can supply 7 percent of the facility’s existing peak power demand requirements. In case of a complete grid failure, the solar power station can supply 100 percent of the water plant consumption and emergency power for communications.



This graphic depicts the process wherein light is transformed into usable energy. Sunlight (top vertical lines) lands on the solar panel. The three cubes (from top to bottom) depict the solar panel regulator/controller, the storage battery, and the inverter. The end result is an electrical device powered by solar energy – in this case, a light bulb.

Yuma’s solar panel array is not tilted toward the sun, but it does have east to-west, single-axis tracking. According to Jack Nixon of the Proving Grounds, single-axis tracking increases output by approximately 15 percent, while adding a second axis increases efficiency by only 2 to 4 percent. For Yuma, the cost of two-axis positioning was not worth the small increase in efficiency. Tracking east to west utilizes early morning and late afternoon sun light, which is not available in a stationary array.

For motorhome applications, a two-axis tracking system has been manufactured to position a small array (two to four panels). We have also seen a tracking system fashioned from a manual C Band satellite antenna positioner. However, it is usually more practical and much less expensive to tilt panels perpendicular to the seasonal inclination of the sun and not worry about daily tracking.

Sun spots. The tropic of Cancer and the Tropic of Capricorn are imaginary lines that trace the boundaries of the earth’s tropical zone. The lines mark the farthest limits north (Cancer) or south (Capricorn) of the equator where the sun can appear directly overhead. On March 21 and September 21, the sun is directly over the equator. On June 21, the sun is over the Tropic of Cancer in the Northern Hemisphere. On December 21, it is over the Tropic of Capricorn in the Southern Hemisphere.

The tropics lie 23 degrees, 27 minutes north and south, respectively, from the equator. With this in mind, you can use the date and the latitude of your location to position solar panels perpendicular to the sun for optimal energy output. Use the following for-

Up On The Roof: Installing Solar Panels

Although there are many ways to mount solar panels, a few principles should be followed during any installation.

If you plan to use the solar panels in winter, providing a way to elevate them will increase their efficiency. The mounts must be strong enough in all positions to withstand high winds. For ventilation, there should be at least a 2-inch space between the panels and the roof. Do not wire more than nine panels in parallel. Make sure the size of the downfeed wire is more than adequate to handle maximum amperage output. Also, make sure the controller can handle maximum amperage output. Aluminum structural angles (90 degrees) of 1½-inches or 2 inches by ⅛-inch thick make excellent mounting hardware.

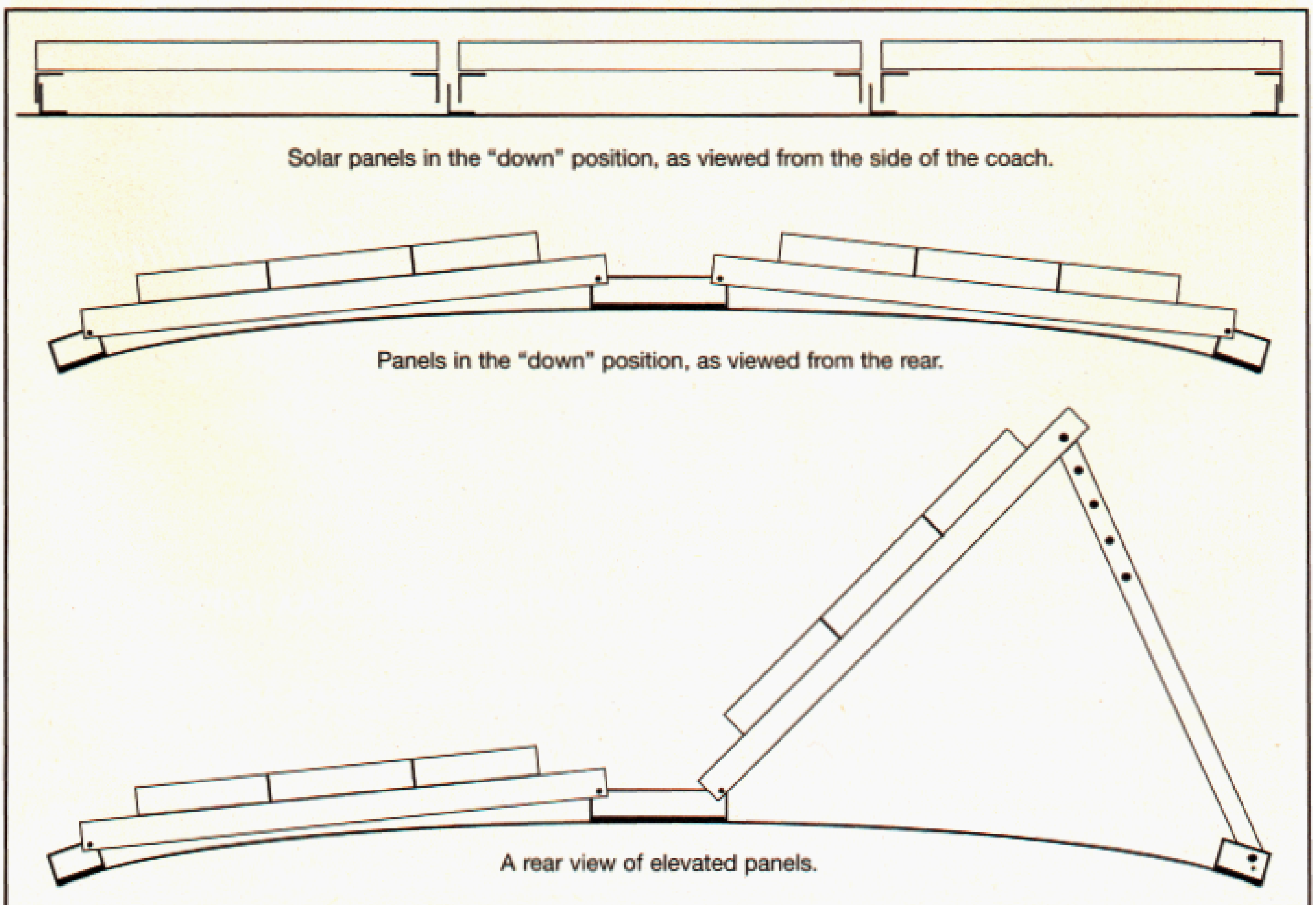
Covering a large area of the roof has a noticeable insulation effect on the coach interior. Mounting bracket(s) that are slightly longer than the panel(s) will facilitate removing bolts to elevate the panels.

Our installation contains 20 Siemens M55 solar panels, each measuring 13 inches wide by 50.9 inches long. The usable part of the roof is approximately 85 inches wide. Eighteen panels cover the roof over the living room area. Three panels are attached together at each end using the aluminum structural angles, and then three groups of three are mounted to each side of the roof, with about a 6-inch space in the center and a ½-inch space on the outboard side.

Attachment holes must be drilled in the panel frame assembly. The outboard roof mounts are 2-inch pieces of the same structural angles. Using silicon and screws, these mounts are attached to the roof rail running the length of the coach. The inboard mounts are approximately 7.5 inches long and extend between the panel groups. Where possible, these mounts are attached to roof cross members. They are siliconed and screwed in place with four to six screws. Holes are drilled off-center in the panel and roof mounts to provide the 2-inch roof clearance.

Nuts and bolts are used to secure the panels to the roof mounts. Stainless-steel nylon locking nuts are used on the inboard side. The nuts are left just loose enough to allow the panels to be elevated. To secure the panels in an elevated position, 1-inch-by-1-inch-by-$\frac{1}{16}$-inch aluminum structural angles are used as struts between the panel and the roof mount. These structural angles are sized to allow maximum elevation. Holes can be drilled down the length of the strut to provide a variety of elevations.

The solar panels are strong enough to bear the weight of an average adult, but care must be taken to avoid scratching the glass. This is particularly important if the panels are dirty. Also, remember that the panels are very slippery when wet.



mulas as a guide. (Any atlas will indicate the latitude of your position.)

Date	Formula
March 21 & September 21	Your latitude + 0 degrees
June 21	Your latitude - 23 ½ degrees
December 21	Your latitude + 23 ½ degrees

Consider the following examples:

In Minot, North Dakota, on July 4, solar panels should be tilted at little more than 24 degrees (48 - 23 1/2). On Labor Day, the panels should be tilted at a little less than 48 degrees (48 + 0).

In Yuma, Arizona, on December 21,the panels should be tilted at 55 degrees (32 + 23 1/2) and on March 21, at 32 degrees (32 + 0).

In Key West, Florida, on June 21, the panels should be nearly flat (24 23 1/2) On December 21, they should be tilted at 47 degrees (24 + 23 1/2).

The earth is tilted 23 ½ degrees on its axis. In the summer, days become longer the farther north you travel, and shorter the farther south you travel. Conversely, in the winter, days become shorter the farther north you travel and longer the farther south you travel. For example, on December 21 in Austin, Texas (at 30 degrees latitude, slightly south of Yuma), there are approximately 10 hours of daylight. In Denver (at 40 degrees latitude), there is approximately 9 hours and 20 minutes of daylight. In Minot (at 48 degrees latitude) there are approximately eight hours of daylight. On June 21, there are approximately 14 hours of daylight in Austin, 15 hours in Denver, and a little more than 16 hours in Minot. Without a solar tracking device, effective solar power production time will be three to four hours less than the total number of daylight hours.

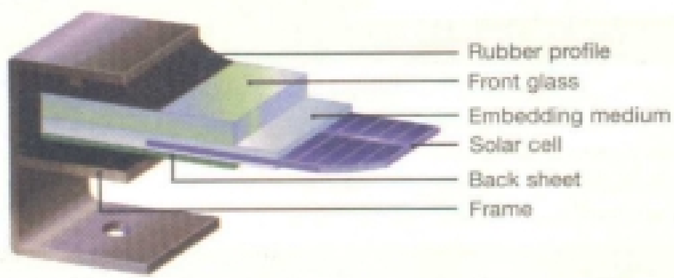
Solar panels are a valuable adjunct to an electrical system and are becoming increasingly popular in the motor-home market. To be effective, the solar array must be sized to the individual application. Seasonal factors will affect the efficiency of any system. Because of the length of daylight hours during winter, it may be difficult to obtain sufficient charging; therefore, an AC generator is still an important part of the charging system.

Building A Solar Panel

Polycrystalline silicon is melted, doped with boron, and then drawn into a single crystalline ingot, which is usually round. The ingot is then squared and sawed into wafers. The surface of each wafer is grooved and etched into a microscopic pyramid shape to create more surface area and improve light absorption. The boron-doped wafers are then doped with phosphorous.

An anti-reflective oxide coating is applied to each wafer, and silver paste is screen-printed onto the front and back of each cell to form electrical circuit contacts. The wafers then undergo a firing process to provide maximum electrical conductivity.

After testing, 30, 33, or 36 solar cells are electrically connected into strings. The strings are arranged in an embedding medium and placed between a special front glass and a multi-layer back sheet. The components are laminated at high temperature to form a protected encapsulation, and the module is then fitted into a torsion-resistant anodized aluminum frame. Depending on the model, diodes and junction boxes may then be installed.



For more information about solar power, you may want to refer to the following sources:

- ***Wiring 12 Volts for Ample Power*** by David Smead and Ruth Ishihara, $20. This book is available from PowerTap Inc., 6315 NW Seaview Ave., Seattle, WA 98107; (800) 541-7789 (phone orders with VISA, MasterCard, Discover), (206) 789-1138.
- A revised edition of *Living on 12 Volts with Ample Power* by Smead and Ishihara will be available in the spring of 1998, also from PoweTap Inc.
- *RV Electrical Systems* by Bill and Jan Moeller, $19.95, plus approximately $4 shipping and handling. This book is available from TAB Books, a Division of McGraw-Hill, P.O. Box 548, Black Lick, OH 43004; (800) 262-4729.
- *Getting Started In Electronics* by Forrest Mims III, $4.99. Radio Shack catalog No. 62-5003; (800) 843-7422.