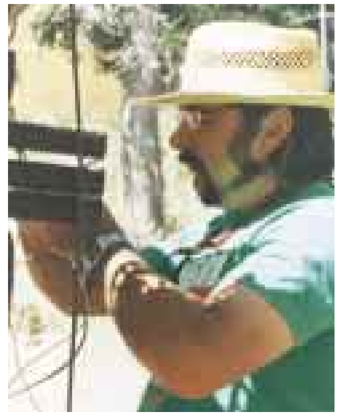
Above: Home Power's "Democracy Rack"



Bob-O Schultze did the wiring & rewiring of the PV modules, and manually rotated the rheostats.

All photos by Michael Hackleman

Richard Perez operated the analog to digital converter and the Mac Powerbook that logged the PV performance data.

PV Performance Tests

Richard Perez and Bob-O Schultze

Ever wonder exactly how much power a PV module makes? Ever wonder how much power a PV still makes after years of exposure to the sun? We have. We placed just about every make module widely available on our "Democracy Rack", out in the sun. Then we measured their electrical output, temperature, and solar insolation. Here is what we found.

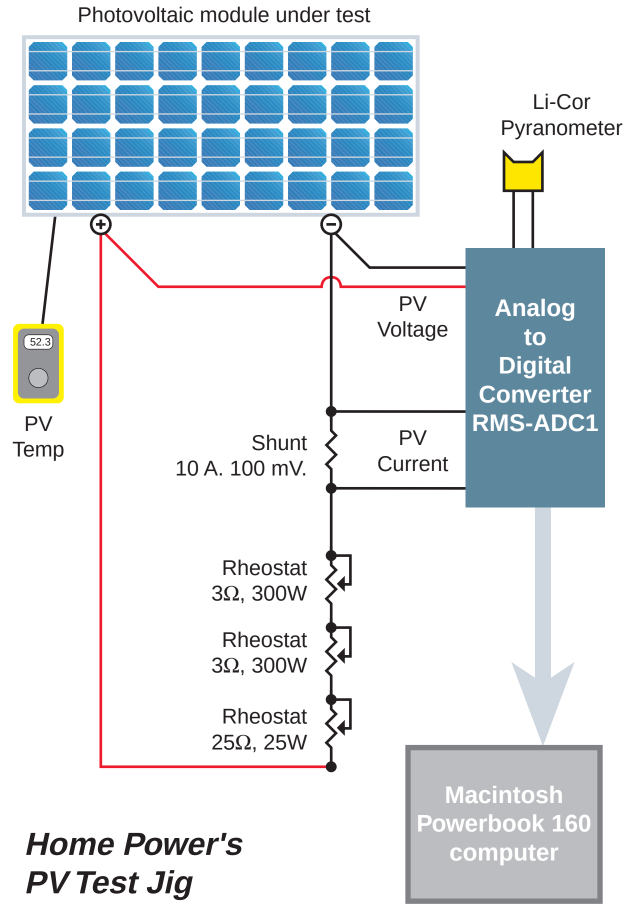
Third in a series…

This is the third time we have published current vs. voltage information and curves for PV modules during the last four years. The first "hot weather" test was published in *Home Power* #24, pages 26–30. The second "cold weather" test was published in *Home Power* #33, pages 17–20. Most of the modules we tested have seen over five years of service in the sun and weather. The youngest module (the BP Solar BP585) has only seen one year's service, while the oldest module (the ARCO 16–1000) has seen over twelve years of sunshine.

The Test Jig & Procedure

The data for these tests was taken and logged on a Macintosh Powerbook 160 computer. We used a Remote Measurements Systems ADC–1 analog to digital converter to make most of the measurements. We set up the ADC–1 to sample and log the PV's voltage, current, and the sun's solar insolation. The analog to digital converter measured and logged each of these three parameters twice a second. The ADC–1 measured module current using a shunt (10 Amperes, 10 milliVolt, 0.1% accuracy). A Fluke 80T-150U temperature probe and Fluke 87 DMM were used to measure both module temperature and air temperature. A Li-Cor 200SB pyranometer measures insolation. This data was taken at Agate Flat, Oregon (42° 01' 02" N. 122° 23' 19" W.) at an altitude of 3,320 feet.

All modules are mounted in the same plane. This assures equal access to sunlight. Their tilt was 30° which is within 0.5° of perpendicular to the sun when we made these tests (20 August 1995). All modules



Home Power's PV Test Jig

were measured with the same instruments in the same places. Ambient air temperature was 31°C. (88°F.) to 35°C (94°F.) with a slight breeze blowing (4 to 7 MPH).

A note on how this data is presented.
Each module tested has two sets of data presented here. Each PV module has a table giving the manufacturer's specifications and our "in the sun" measured data. Each module also has a graph showing the actual current vs. voltage measurements we made.

Here is an explanation of the short-hand terms used in the tables.

- "Isc" is module short circuit current, in Amperes.
- "Voc" is module open circuit voltage, in Volts DC.
- "Pmax" is maximum module power, in Watts.
- "Vpmax" is the voltage which the module develops at its maximum power point, in Volts DC.
- "Ipmax" is the current the module produces at its maximum power point, in Amperes.
- "PV Temp" is the temperature of the module (back side), in degrees centigrade (°C.).
- "Insolation" is solar insolation, in milliWatts per square centimeter.

All of these terms and units are standards used by the entire photovoltaic industry to rate their products. We used manufacturer's ratings at a 25°C. (77°F) module temperature. In the comparison tables that follow:

- Rated value is the maker's performance specifications.
- Measured value. Our measured data.
- Percent of Rated". A comparison of our measured results with the maker's ratings.

The graphs show module current vs. module voltage. In order to better present this information graphically, we limited the voltage axis of the graph to 12 to 18 Volts. We did, however, log all the data from 0.5 Volts to the module's open circuit voltage. If anyone wishes a complete electronic copy of all of the data we took, you can find it on the *Home Power* BBS at 707-822-8640 or send a floppy disk (please specify Mac or IBM) with SASE return mailer to Richard Perez at Home Power.

Most of these modules have had their performance measured by us during the summer of 1991. We reported on their hot weather performance in *Home Power* #24, page 26. What follows here is another hot weather test on the same group of modules. All are now older and we are looking for degradation in module performance over time. *We found no degradation that we could measure in any of these modules.* In fact, some of them actually tested better than they did four years ago!

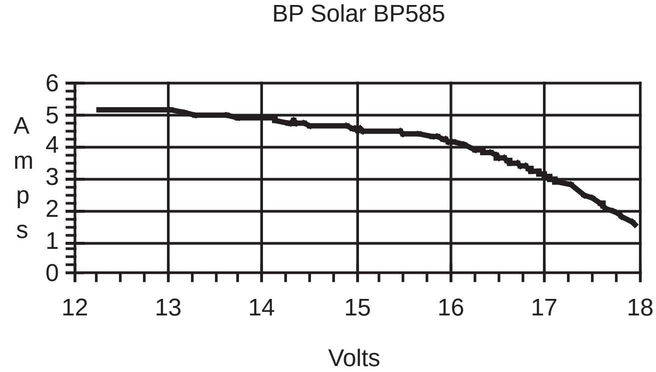
Please note that these are hot weather tests. PV modules are rated at a 25°C (77°F). temperature. The data we took here was from modules whose temperature was from 49°C (120°F) to 55°C (131°F). Heat causes the PV's maximum power to decrease. This is why almost all of the modules do not make as much power as their maker rated at 25°C. All modules are listed alphabetically by manufacturer's name.

BP Solar BP585
This is a one year old PV module that we purchased on the open market. It has 36 series connected, single crystal, PV cells. This module was made in Australia using the patented "laser grooving" technique. We've had this module out in the sun for one year.

Carrizo ARCO 16-2000
This is a 13.5 year old, used, ARCO 16-2000 module we purchased years ago on the open market. It has 33 series connected, single crystal, round PV cells. We've had this module out in the sun for the last 5.5 years. We estimate that this module has spent most of the last 12 years in service. While the potting compound surrounding the cells is extensively browned, the module still delivers good performance. We measured

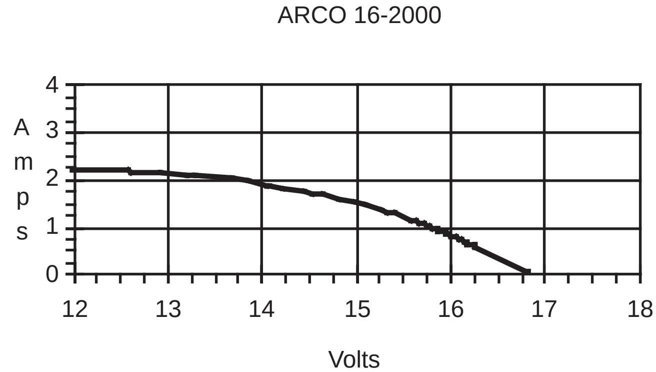
BP Solar BP585 - 1 year in the sun

	Rated Value	Measured Value	Percent of Rated	
Isc	5.00	5.43	108.6%	Amperes
Voc	22.03	18.70	84.9%	Volts
Pmax	85.00	68.78	80.9%	Watts
Vpmax	18.00	14.36	79.8%	Volts
Ipmax	4.72	4.79	101.5%	Amperes
PV Temp	25	51	202.0%	°C.
Insolation	100	106	106.0%	mW/sq. cm.



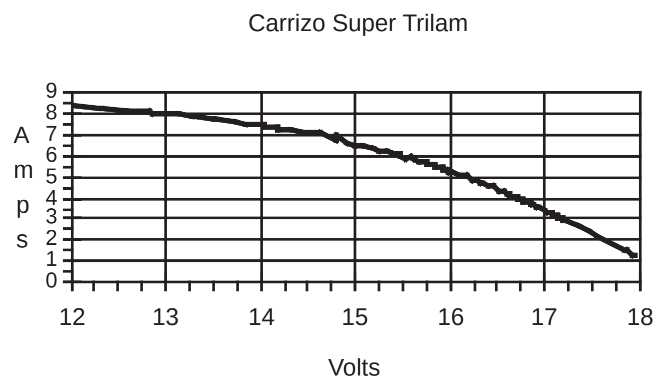
ARCO 16-2000 - 5.5 to 12 years in the sun

	Rated Value	Measured Value	Percent of Rated	
Isc	2.55	2.30	90.2%	Amperes
Voc	20.50	16.84	82.1%	Volts
Pmax	35.00	27.23	77.8%	Watts
Vpmax	15.50	13.22	85.3%	Volts
Ipmax	2.26	2.06	91.2%	Amperes
PV Temp	25	52	208.0%	°C.
Insolation	100	106	106.0%	mW/sq. cm.



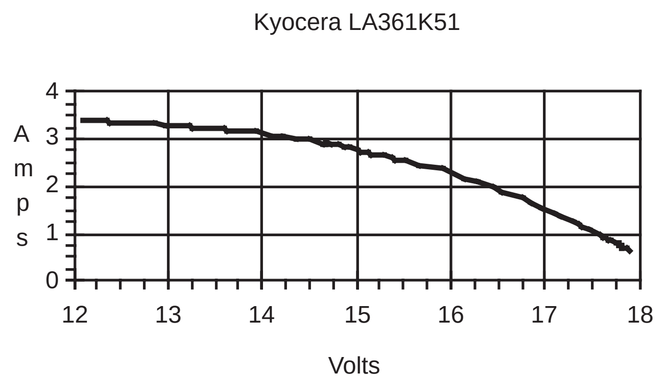
Carrizo Super Gold Trilam - 1 year in the sun

	Rated Value	Measured Value	Percent of Rated	
Isc	7.00	8.67	123.9%	Amperes
Voc	21.00	20.52	97.7%	Volts
Pmax	105.00	103.70	98.8%	Watts
Vpmax	16.60	14.07	84.8%	Volts
Ipmax	6.30	7.37	117.0%	Amperes
PV Temp	25	50	198.0%	°C.
Insolation	100	106	106.0%	mW/sq. cm.



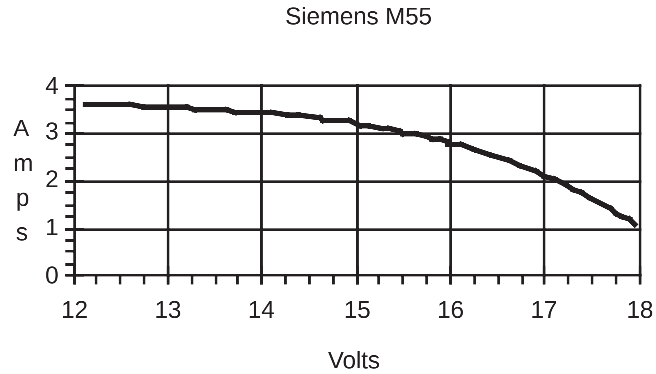
Kyocera LA361K51 - 5.5 years in the sun

	Rated Value	Measured Value	Percent of Rated	
Isc	3.25	3.42	105.2%	Amperes
Voc	21.20	18.46	87.1%	Volts
Pmax	51.00	43.14	84.6%	Watts
Vpmax	16.90	13.96	82.6%	Volts
Ipmax	3.02	3.09	102.3%	Amperes
PV Temp	25	55	220.0%	°C.
Insolation	100	109	109.0%	mW/sq. cm.



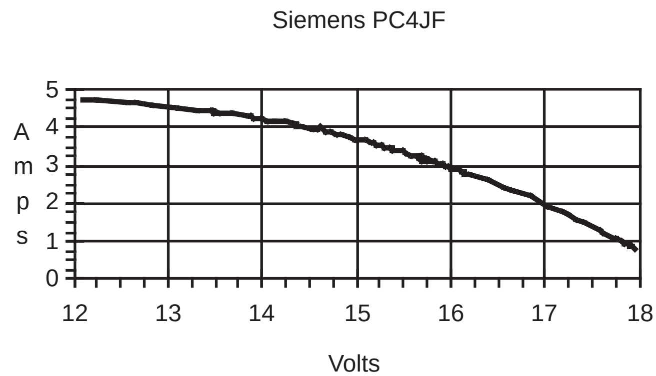
Siemens M55 - 5.5 years in the sun

	Rated Value	Measured Value	Percent of Rated	
Isc	3.35	3.67	109.6%	Amperes
Voc	21.70	18.72	86.3%	Volts
Pmax	53.00	48.02	90.6%	Watts
Vpmax	17.40	14.64	84.1%	Volts
Ipmax	3.05	3.28	107.5%	Amperes
PV Temp	25	54	216.0%	°C.
Insolation	100	109	109.0%	mW/sq. cm.



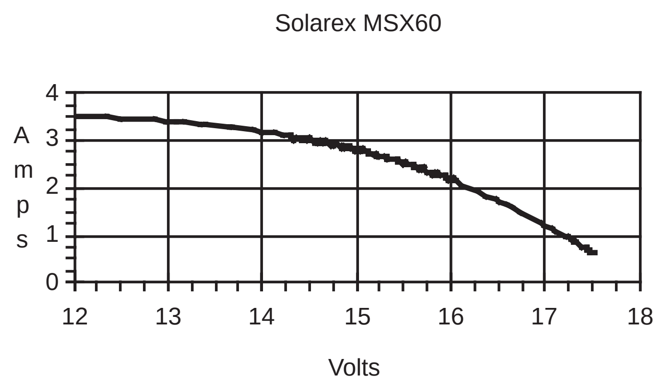
Siemens PC4JF - 2 years in the sun

	Rated Value	Measured Value	Percent of Rated	
Isc	4.80	5.01	104.4%	Amperes
Voc	22.00	18.43	83.8%	Volts
Pmax	75.00	59.05	78.7%	Watts
Vpmax	17.00	13.42	78.9%	Volts
Ipmax	4.40	4.40	100.0%	Amperes
PV Temp	25	49	196.0%	°C.
Insolation	100	109	109.0%	mW/sq. cm.



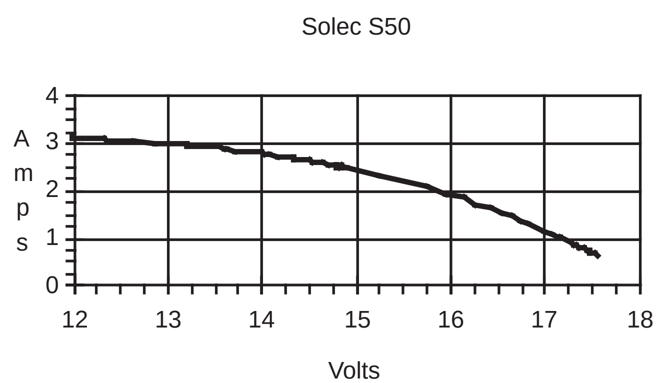
Solarex MSX60 - 5.5 years in the sun

	Rated Value	Measured Value	Percent of Rated	
Isc	3.86	3.94	102.1%	Amperes
Voc	21.10	18.02	85.4%	Volts
Pmax	58.90	44.22	75.1%	Watts
Vpmax	17.10	13.69	80.1%	Volts
Ipmax	3.50	3.23	92.3%	Amperes
PV Temp	25	54	216.0%	°C.
Insolation	100	108	108.0%	mW/sq. cm.



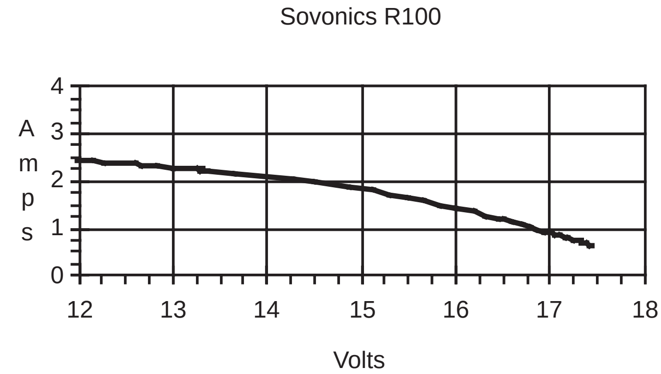
Solec S50 - 4.5 years in the sun

	Rated Value	Measured Value	Percent of Rated	
Isc	3.30	3.35	101.5%	Amperes
Voc	20.30	18.16	89.5%	Volts
Pmax	50.00	38.93	77.9%	Watts
Vpmax	17.00	13.66	80.4%	Volts
Ipmax	3.00	2.85	95.0%	Amperes
PV Temp	25	50	200.0%	°C.
Insolation	100	109	109.0%	mW/sq. cm.



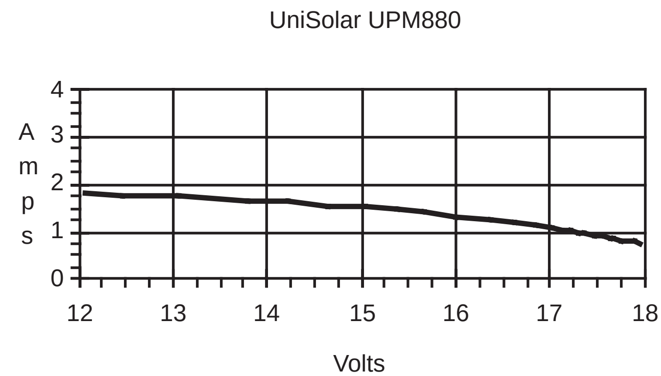
Sovonics R100 - 7.5 years in the sun

	Rated Value	Measured Value	Percent of Rated	
Isc	2.74	3.00	109.5%	Amperes
Voc	25.00	18.27	73.1%	Volts
Pmax	37.00	29.24	79.0%	Watts
Vpmax	17.20	13.23	76.9%	Volts
Ipmax	2.10	2.21	105.2%	Amperes
PV Temp	25	51	204.0%	°C.
Insolation	100	108	108.0%	mW/sq. cm.



UniSolar UPM880 - 2.5 years in the sun

	Rated Value	Measured Value	Percent of Rated	
Isc	1.80	2.03	112.8%	Amperes
Voc	22.00	19.60	89.1%	Volts
Pmax	22.00	22.39	101.8%	Watts
Vpmax	15.60	14.26	91.4%	Volts
Ipmax	1.40	1.57	112.1%	Amperes
PV Temp	25	52	208.0%	°C.
Insolation	100	108	108.0%	mW/sq. cm.



its maximum power at 27.23 watts, up 1.5 watts from the 25.88 watts we measured four years ago. Not bad for a teenaged PV module.

Carrizo Super Gold Trilam (3 @ ARCO M52L)
This module was sent to us by Carrizo for testing. It consists of three used ARCO M52L laminates connected in series. We've had this module in the sun for one year, but these laminates have obviously seen sunshine before. The hot weather performance of this used module is very good, it made 98.8% of its 25°C power rating even though it was at 50°C.

Kyocera LA361K51
We tested a K51 Kyocera module that we purchased new on the open market. This module contains 36 series-connected, square, multicrystal PV cells. We've had this module out in the sun for the last 5.5 years. We measured maximum power at 43.14 watts, up over 3 watts from its test four years ago.

Siemens M55
We tested a M55 Siemens module sent to us new by its maker. This was a current production, single-crystal, PV module. This module contains 36 series-connected square PV cells. We've had this module out in the sun for the last 5.5 years. Hot weather performance is good at 48.02 watts, up about 3 watts from four years ago.

Siemens PC4JF
We tested a PC4JF Siemens module sent to us new by its maker. This was a current production, single-crystal, PV module. This module contains 36 series connected PV cells. We've had this module out in the sun for the last 2 years.

Solarex MSX60
We tested a 5.5 year old, MSX60 Solarex module that we purchased new on the open market. This module contains 36 series-connected square PV cells. We've had this module out in the sun for the last 5.5 years. We measured maximum output power at 44.22 watts, up 0.1 watts from four years ago.

Solec S50
The Solec S50 is a single crystal silicon module using 36 series connected square cells. This module was purchased retail and has been out in the sun for 4.5 years. This is an older model module and was made eight years ago. We measured a maximum power of 38.93 Watts.

Sovonics R-100
This is an amorphous silicon module. We've had this module out in the sun for the last 7.5 years. We measured a maximum power of 29.24 Watts, up 2.4 Watts from our testing four years ago.

Uni-Solar UPM 880

This is a model UPM880 amorphous silicon module sent to us by United Solar. This module has seen sunshine for 2.5 years. Since this module arrived after the last hot weather test, we have no previous hot weather data on it. It is, however, an outstanding hot weather performer producing 22.39 Watts, and that's slightly above its 25°C. rating even though this module was at a temperature of 52°C (126°F). We've heard quite a bit of speculation about performance degradation in amorphous silicon modules. This UPM 880 has seen 2.5 years of service and still makes more than its rated power. And it does it at over 200% of its rated temperature.

Conclusions

The 25°C. temperature rating standard for PV module rating was poorly selected. Out in the sun, these modules are cooking at 50°C (122°F) or more. This causes voltage loss in the cells which in turn lowers the module's power output. If you live in a warm climate, *derate* the maker's 25°C power spec by 15% to 25% to compensate for module heating. A more realistic temperature for rating PV modules would be in the range of 40°C (104°F) to 50°C (122°F) because this is where most modules spend most of their operating lives.

We are very pleased not to have any PV module degradation problems to report. Most of these modules have spent over five years in the sun, yet show no measurable degradation. When PV makers give you a warranty of less than ten percent power loss in ten years or more, they are *really* being conservative. Chances are that all these modules will make 90% of their rated power for twenty years or more.

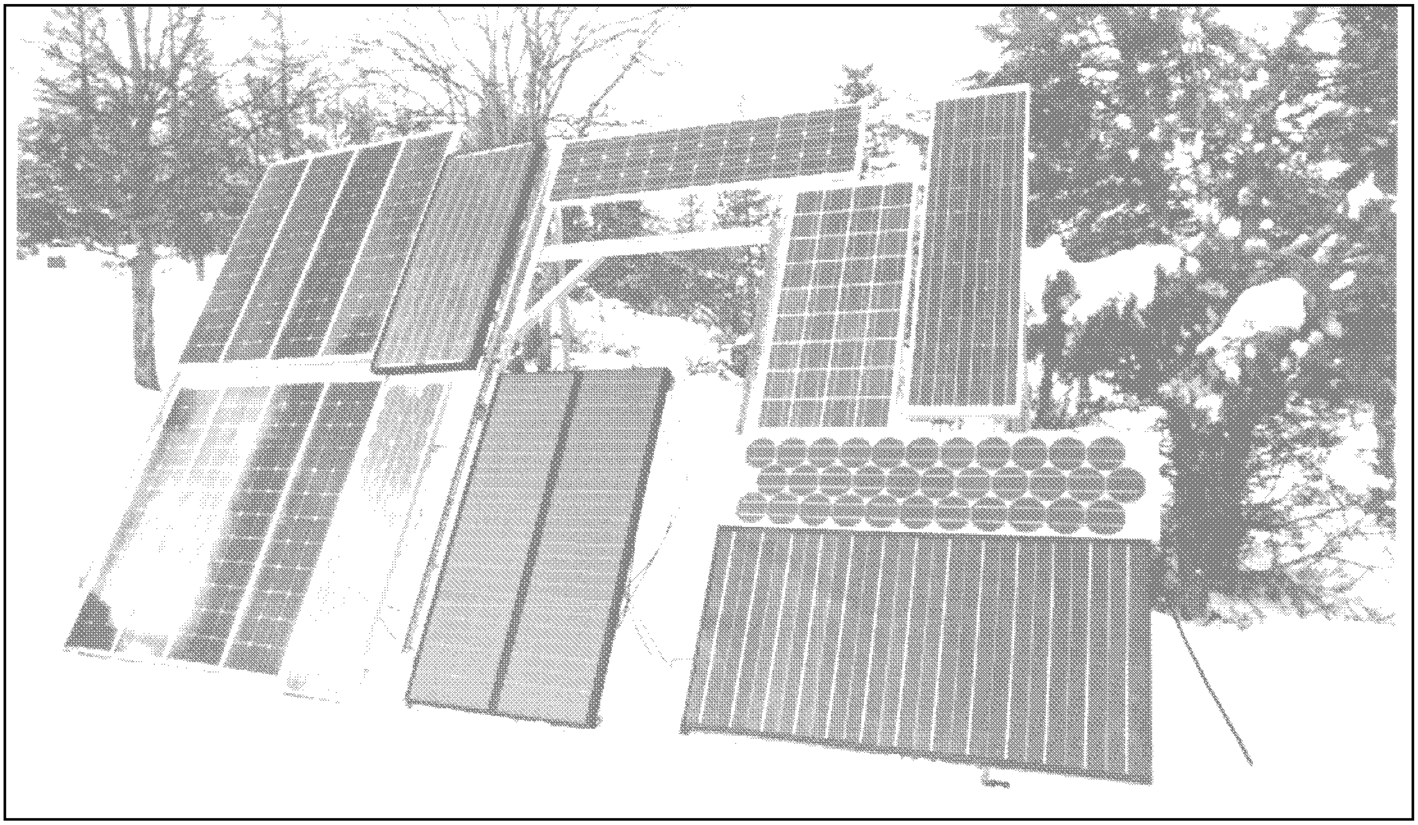
In addition to the electrical data we have presented here, there is another important bit of information. These modules have survived hail, snow, rain, and thermal cycling for over five years here at Agate Flat. This area is considered a tough environment. No failures. All of the modules still keep on working.

We're not finished yet. We are going to continue testing PV modules out in the sun. We are going to do it on cloudy days, on freezing cold days, as well as the hot ones like today. We invite PV manufacturers to send us modules for extended life cycle testing in a real operating environment.

Access

Richard Perez, c/o Home Power, PO Box 520, Ashland, OR 97520 • 916-475-3179.

Bob–O Schultze, Electron Connection, PO Box 203, Hornbrook, CA 96044 • 916-475-3401.



Above: Home Power's "Democracy Rack" where just about every available PV module gets tested in real world conditions.
Photo by Mark Newell.

PV Performance Tests

the Home Power Crew

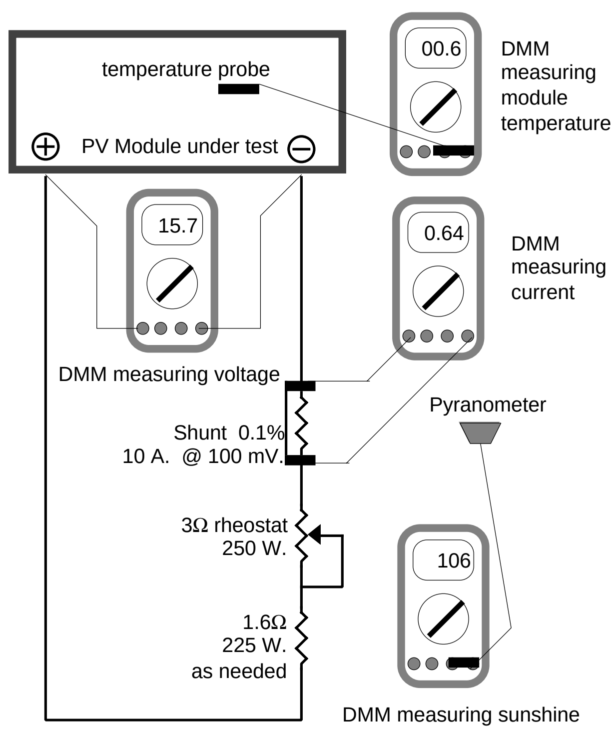
Ever wonder exactly how much power a cold PV module makes? We have. We placed just about every make module widely available on our "Democracy Rack", out in the sun. Then we measured their electrical output, temperature, and solar insolation. Here is what we found.

The Test Jig & Procedure

See Home Power #23, page 20 for a complete rundown of our PV module test jig and procedure. Here's what we do in a nutshell. The diagram to the right shows our basic PB module test jig.

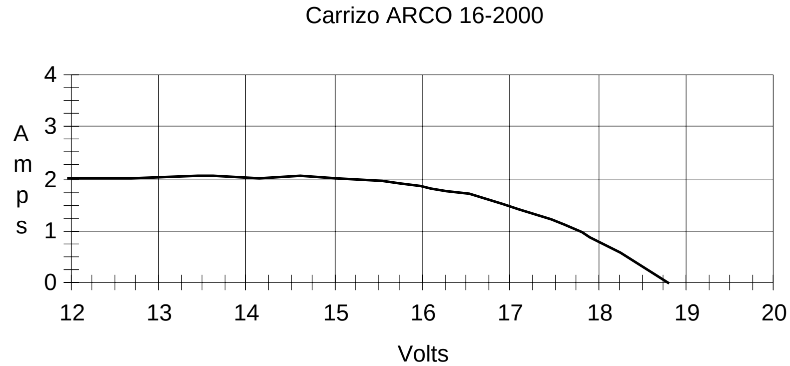
This test jig allows us to take actual data from each module. With four Fluke 87 DMMs we measure the following data: module voltage, module current, module temperature, air

Home Power's PV Test Jig



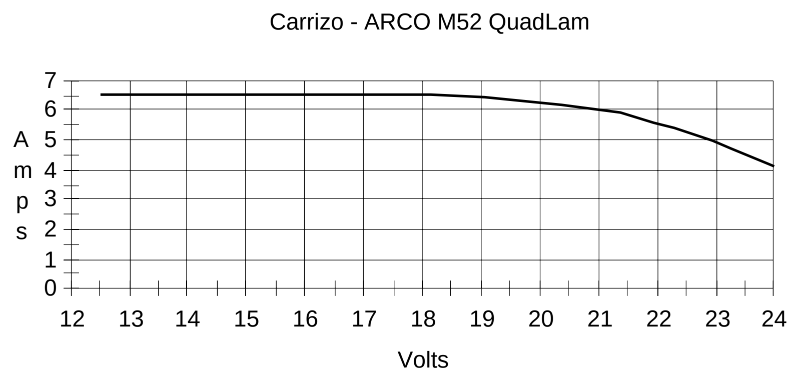
Carrizo ARCO 16-2000

	Rated Value	Measured Value	Percent of Rated	
Isc	2.55	2.07	81.2%	Amperes
Voc	20.50	18.79	91.7%	Volts
Pmax	35.00	30.64	87.5%	Watts
Vpmax	15.50	15.02	96.9%	Volts
Ipmax	2.26	2.04	90.3%	Amperes
PV Temp	25	18	71.6%	°C.
Insolation	100	107	107.0%	mW/sq. cm.



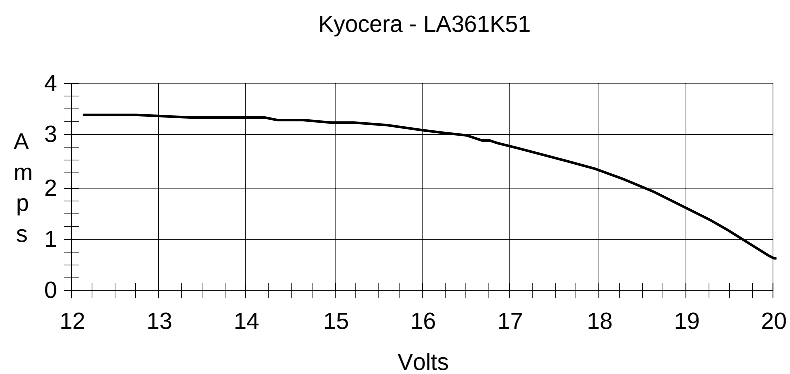
Carrizo - ARCO M52 QuadLam

	Rated Value	Measured Value	Percent of Rated	
Isc	6.00	6.59	109.8%	Amperes
Voc	25.00	27.07	108.3%	Volts
Pmax	105.00	126.82	120.8%	Watts
Vpmax	19.00	21.35	112.4%	Volts
Ipmax	5.50	5.94	108.0%	Amperes
PV Temp	25	23	91.2%	°C.
Insolation	100	106	106.0%	mW/sq. cm.



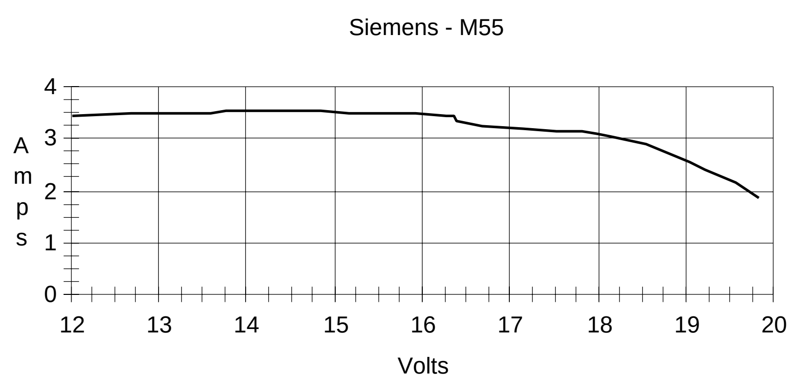
Kyocera - LA361K51

	Rated Value	Measured Value	Percent of Rated	
Isc	3.25	3.42	105.2%	Amperes
Voc	21.20	21.56	101.7%	Volts
Pmax	51.00	50.05	98.1%	Watts
Vpmax	16.90	15.99	94.6%	Volts
Ipmax	3.02	3.13	103.6%	Amperes
PV Temp	25	22	87.6%	°C.
Insolation	100	113	113.0%	mW/sq. cm.



Siemens - M55

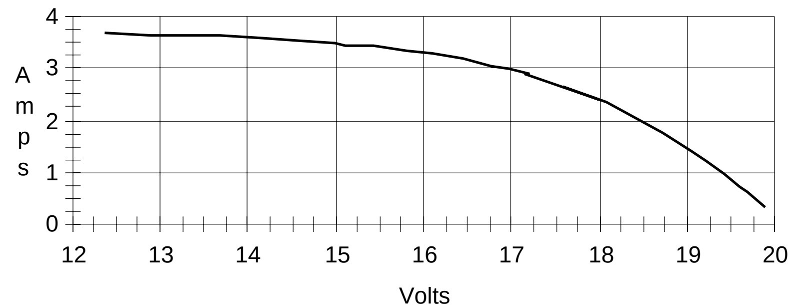
	Rated Value	Measured Value	Percent of Rated	
Isc	3.35	3.44	102.7%	Amperes
Voc	21.70	21.19	97.6%	Volts
Pmax	53.00	56.13	105.9%	Watts
Vpmax	17.40	16.27	93.5%	Volts
Ipmax	3.05	3.45	113.1%	Amperes
PV Temp	25	20	78.0%	°C.
Insolation	100	112	112.0%	mW/sq. cm.



Solarex - MSX-60

	Rated Value	Measured Value	Percent of Rated	
Isc	3.86	3.85	99.7%	Amperes
Voc	21.10	20.11	95.3%	Volts
Pmax	58.90	53.05	90.1%	Watts
Vpmax	17.10	15.79	92.3%	Volts
Ipmax	3.50	3.36	96.0%	Amperes
PV Temp	25	18	73.6%	°C.
Insolation	100	111	111.0%	mW/sq. cm.

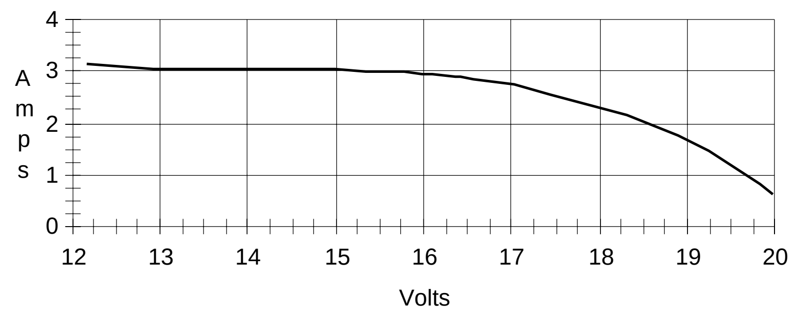
Solarex - MSX-60



Solec S50

	Rated Value	Measured Value	Percent of Rated	
Isc	3.30	3.30	100.0%	Amperes
Voc	20.30	20.46	100.8%	Volts
Pmax	50.00	47.71	95.4%	Watts
Vpmax	17.00	16.34	96.1%	Volts
Ipmax	3.00	2.92	97.3%	Amperes
PV Temp	25	19	76.0%	°C.
Insolation	100	110	110.0%	mW/sq. cm.

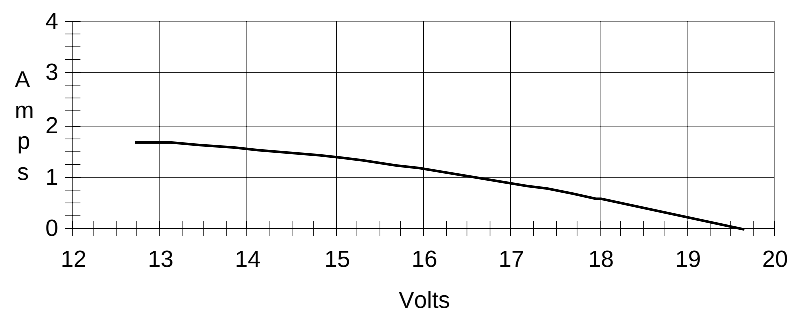
Solec S50



Sovonics R-100

	Rated Value	Measured Value	Percent of Rated	
Isc	2.74	2.52	92.0%	Amperes
Voc	25.00	19.64	78.6%	Volts
Pmax	37.00	21.77	58.8%	Watts
Vpmax	17.20	13.44	78.1%	Volts
Ipmax	2.10	1.62	77.1%	Amperes
PV Temp	25	19	76.0%	°C.
Insolation	100	99	99.0%	mW/sq. cm.

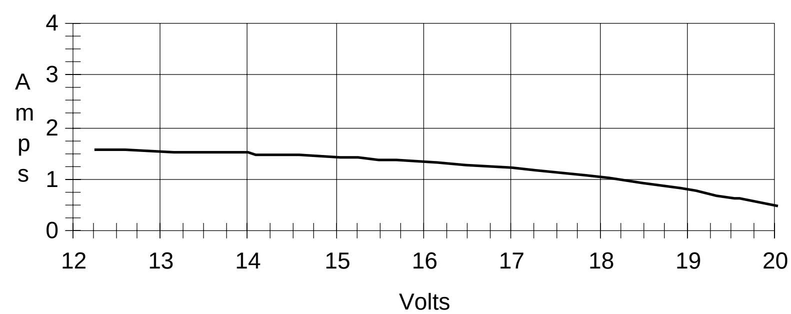
Sovonics R-100



Uni-Solar UPM 880

	Rated Value	Measured Value	Percent of Rated	
Isc	1.80	1.74	96.7%	Amperes
Voc	22.00	21.59	98.1%	Volts
Pmax	22.00	21.81	99.1%	Watts
Vpmax	15.60	15.69	100.6%	Volts
Ipmax	1.40	1.39	99.3%	Amperes
PV Temp	25	19	76.0%	°C.
Insolation	100	111	111.0%	mW/sq. cm.

Uni-Solar UPM 880



temperature, and solar insolation. The DMM measuring voltage is connected directly to the module's terminals. The DMM measuring module current uses a shunt (10 Amp., 100 milliVolt, 0.1% accuracy). A Fluke 80T-150U temperature probe measures both module temperature and air temperature. A Li-Cor 200SB pyranometer measures insolation. This data was taken at Agate Flat, Oregon (42° 01' 02" N. 122° 23' 19" W.) at an altitude of 3,320 feet. The date of this test was 12 January 1993.

All modules are mounted on the same 12 foot by 12 foot rack, i.e. they are in the same plane. This assures equal access to sunlight. All modules were measured with the same instruments in the same places. Ambient air temperature was 0.2°C (32.3°F) to 3.7°C (38.7°F) with a slight breeze blowing. The ground was covered by two to three feet of snow. We froze our butts off getting this data!

The Photovoltaic Players

Most of these modules have had their performance measured by us during the summer of 1991. We reported on their hot weather performance in Home Power #24, page 26. What follows here is winter testing of the same six different brands of modules modules, with two new brands added. All modules are listed alphabetically.

Carrizo ARCO 16-2000

This is a 9.5 year old ARCO 16-2000 module we purchased on the open market. It has 33 series connected, single crystal, round PV cells. We've had this module out in the sun for the last 1.5 years.

Carrizo ARCO M52 "Gold" QuadLam

This is a set of four ARCO M52 laminates wired in series to make a single QuadLam module. This 8.5 year old module was supplied for testing by Mike Elliston of Carrizo Solar. The resulting module of four laminates contains 48 series connected cells and a total cell count of 144. The PV cells used to make these laminates are 3.75 inches square and are single crystal types. We've had this module out in the sun for the last 1.5 years.

Kyocera K51

We tested a K51 Kyocera module that we purchased new on the open market. This module contains 36 series connected square multicrystal PV cells. We've had this module out in the sun for the last 1.5 years.

Siemens M55

We tested a M55 Siemens module sent to us new by its maker. This is a current production, single-crystal, PV module. This module contains 36 series connected square PV cells. We've had this module out in the sun for the last 1.5 years.

Solarex MSX-60

We tested a 1.5 year old, MSX-60 Solarex module that we purchased new on the open market. The performance data of this multicrystal module is printed on its back. This data is the result of flash-testing of this specific module, not a "generic" rating like almost every other module. After flash-testing, a computer prints a label with the data for that specific module. This module contains 36 series connected square PV cells. We've had this module out in the sun for the last 1.5 years.

Solec S50

The Solec S50 is a single crystal silicon module with 36 series connected square cells. This S50 was purchased retail and has been out in the sun for six months. This is an older model module and was made six years ago.

Sovonics R-100

This is an amorphous silicon module supplied by Nick Pietrangelo of Harding Energy Systems. We've had this module out in the sun for the last 3.5 years.

Uni-Solar UPM 880

This is a model UPM-880 amorphous silicon module sent to us by United Solar. This module is brand new and had only seen sunshine for three weeks before this test.

The Data

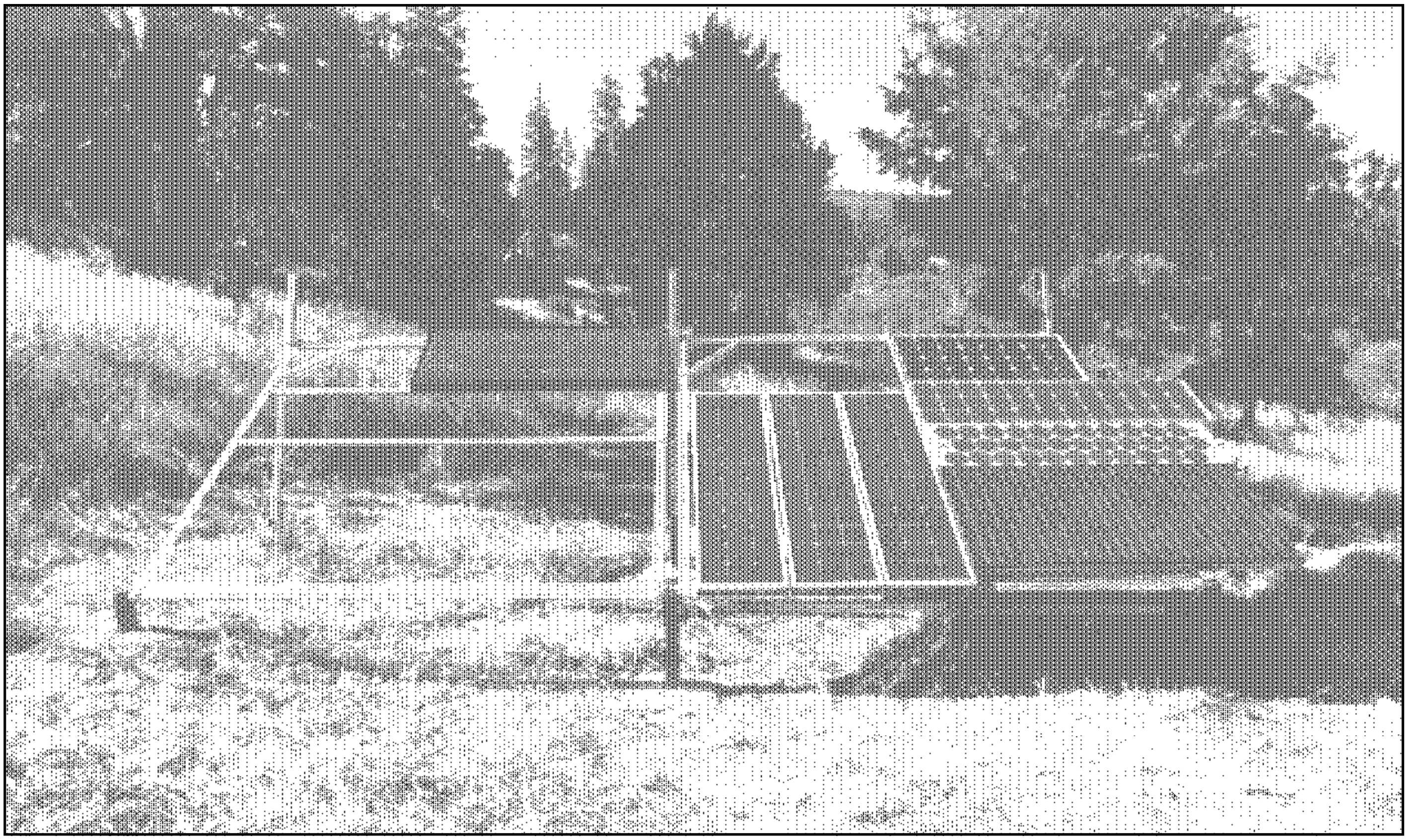
We are content to let the data speak for itself. We used manufacturer's ratings at a 25°C module temperature. In the comparison tables, the maker's performance specification is listed in the column called "Rated Value." Our measured data is in the column labeled "Measured Value." The column called "Percent of Rated" compares our measured results with the maker's ratings. The solar insolation data from the Li-Cor Pyranometer is accurate. At Agate Flat, we often have solar insolation as high as 115 milliWatts per square centimeter.

Conclusions

The modules that have remained on the rack for the last eighteen months show no significant performance degradation. The cold temperature has increased the performance of all the repeat tests. Coming up this summer, another hot weather test of all the modules on Home Power's "Democracy Rack."

Access

Author: Richard Perez. Intrepid PV Testers: Chris Greacen, Mark Newell, Therese Peffer, Richard Perez, and Amanda Potter, c/o Home Power, POB 520, Ashland, OR 97520 • 916-475-3179



Above: the PV test rack, with some of the modules in place. Bob–O Schultze of Electron Connection gets credit for the ultrafine design and metal work on this adjustable six foot by twelve foot rack. When we did the actual testing at noon, the entire rack was covered with panels. Photo by Richard Perez

Home Power measures PV Performance

Richard Perez and Bob–O Schultze

Ever wonder exactly how much power a PV module makes? We have. We placed just about every make module widely available on the same rack, out in the sun. Then we measured their electrical output, temperature, and solar insolation. Here is what we found.

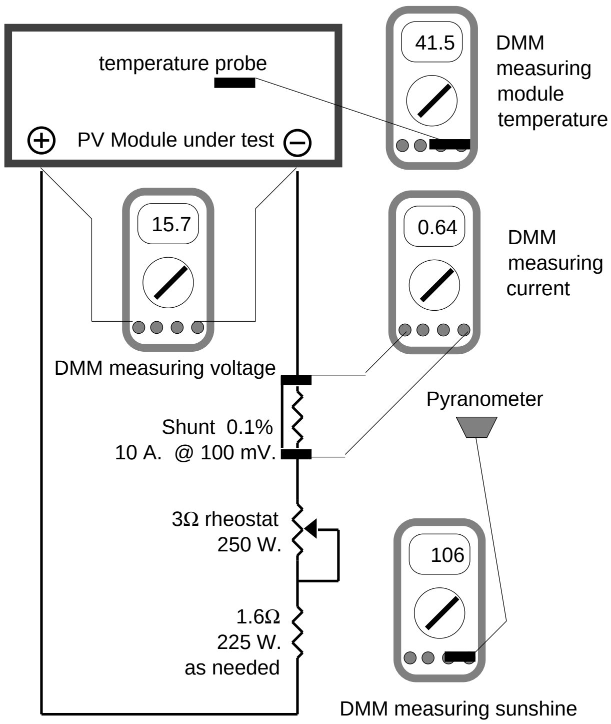
The Test Jig & Procedure

See Home Power #23, page 20 for a complete rundown of our PV module test jig and procedure. Here's what we do in a nutshell. We wire the module into the jig using the instruments shown on the next page.

This test jig allows us to take actual data from each module. With four Fluke 87 DMMs we measure the following data: module voltage, module current, module temperature, air temperature, and solar insolation. The DMM measuring voltage is connected directly to the module's terminals. The DMM measuring module current uses a shunt (10 Amperes, 10 milliVolt, 0.1% accuracy). A Fluke 80T-150U temperature probe is used to measure both module temperature and air temperature. A Li-Cor 200SB pyranometer measures insolation. This data was taken at Agate Flat, Oregon (42° 01' 02" N. 122° 23' 19" W.) at an altitude of 3,300 feet.

All modules are mounted on the same 6 foot by 12 foot rack, i.e. they are in the same plane. This assures equal access to sunlight. All modules were measured with the

Home Power's PV Test Jig



same instruments in the same places. Ambient air temperature was 27.4°C. (81.3°F.) to 31.7°C (89°F.) with a slight breeze blowing.

The Photovoltaic Players

Siemens
We used a brand-new, M55 Siemens module sent to us by its maker. This is a current production, single-crystal, PV module. This module contains 36 series connected square PV cells.

Solarex
We used a brand-new, MSX60 Solarex module sent to us by Dave Katz at Alternative Energy Engineering. The performance data of this multicrystal module is printed on its back. This data is the result of flash-testing of this specific module, not a "generic" rating like almost every other module. After flash-testing, a computer prints a label with the data for that specific module. This module contains 36 series connected square PV cells.

Kyocera
We used a brand-new, K51 Kyocera module provided by Bob–O Schultze at Electron Connection. This module contains 36 series connected square multicrystal PV cells.

Hoxan
We used a brand-new, 4310 Hoxan module provided by Dave Katz at Alternative Energy Engineering. This module contains 32 series connected square single crystal PV cells.

Carrizo
This module is a set of four ARCO M52 laminates wired in series to make a module. This seven year old module was suppled by Mike Elliston of Carizzo Solar. The resulting module of four laminates contains 48 series connected cells and a total cell count of 144 PV cells. The PV cells used to make these laminates are 3.75 inches square and are single crystal types.

Real Goods
This module is a set of four ARCO M52 laminates wired in series to make a module. This seven year old module was suppled by John Schaeffer of Real Goods. The resulting module of four laminates contains 48 series connected cells and a total cell count of 144 PV cells. The PV cells used to make these laminates are 3.75 inches square and are single crystal types.

Photocomm
This module is a set of three ARCO M52 laminates wired in series to make a module. This seven year old module was suppled by Ron Kenedi of Photocomm. The resulting module of three laminates contains 36 series connected cells and a total cell count of 108 PV cells. The PV cells used to make these laminates are 3.75 inches square and are single crystal types.

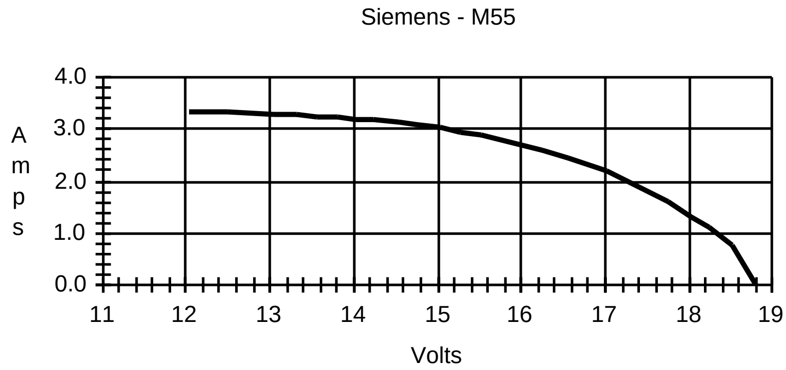
ARCO
This seven year old ARCO 16-2000 module was supplied by Wayne Robertson at Solar Electric Specialties. It has 33 series connected, single crystal, round PV cells.

Sovonics
This is an amorphous silicon module supplied by Nick Pietrangleo of Harding Energy Systems. We've had this Sovonics R-100module out in the sun for the last 2 years.

The Data
We are content to let the data speak for itself. We used manufacturer's ratings at a 25°C. module temperature. In the comparison tables that follow this maker's performance specification is listed in the column called "Rated Value". Our measured data is in the column labeled "Measured Value". The column called "Percent of Rated" compares our measured results with the maker's ratings. The solar insolation data from the Li-Cor Pyranometer is accurate. At Agate Flat we often have solar insolation as high as 110 milliWatts per square centimeter.

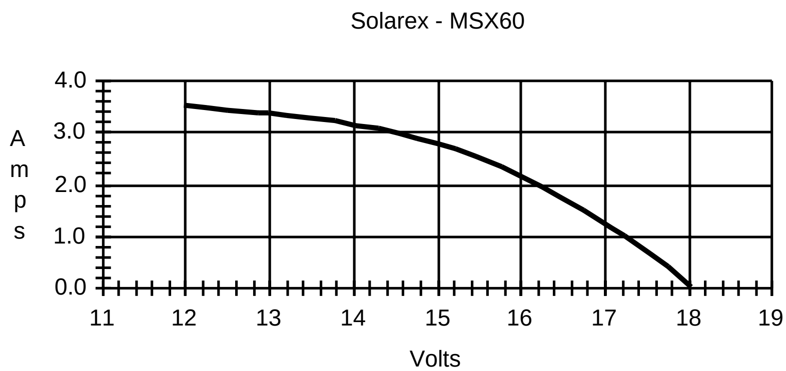
Siemens - M55

	Rated Value	Measured Value	Percent of Rated	
Isc	3.35	3.42	102.1%	Amperes
Voc	21.70	18.79	86.6%	Volts
Pmax	53.00	45.14	85.2%	Watts
Vpmax	17.40	14.76	84.8%	Volts
Ipmax	3.05	3.06	100.3%	Amperes
PV Temp	25.00	50.00	200.0%	°C.
Insolation	100.00	108.90	108.9%	mW/sq. cm.



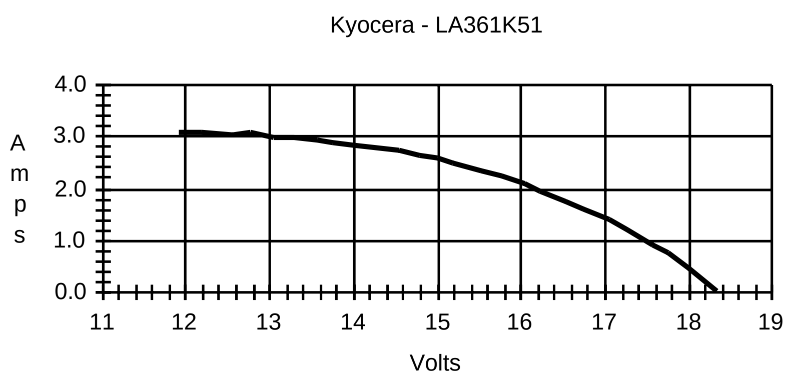
Solarex - MSX60

	Rated Value	Measured Value	Percent of Rated	
Isc	3.86	3.70	95.8%	Amperes
Voc	21.10	18.03	85.5%	Volts
Pmax	58.90	44.13	74.9%	Watts
Vpmax	17.10	13.80	80.7%	Volts
Ipmax	3.50	3.20	91.4%	Amperes
PV Temp	25.00	50.60	202.4%	°C.
Insolation	100.00	108.80	108.8%	mW/sq. cm.



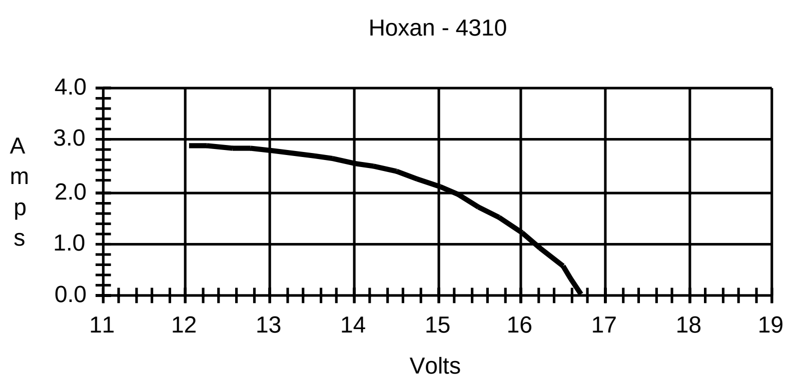
Kyocera - LA361K51

	Rated Value	Measured Value	Percent of Rated	
Isc	3.25	3.15	96.8%	Amperes
Voc	21.20	18.36	86.6%	Volts
Pmax	51.00	39.65	77.7%	Watts
Vpmax	16.90	14.02	83.0%	Volts
Ipmax	3.02	2.83	93.6%	Amperes
PV Temp	25.00	54.50	218.0%	°C.
Insolation	100.00	108.90	108.9%	mW/sq. cm.



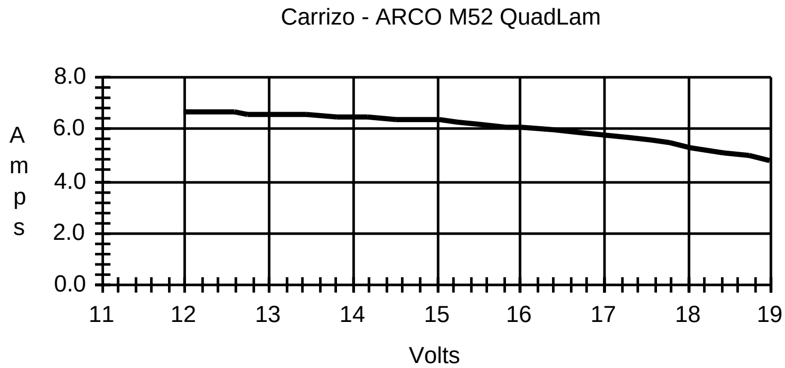
Hoxan - 4310

	Rated Value	Measured Value	Percent of Rated	
Isc	3.30	3.02	91.6%	Amperes
Voc	19.10	16.72	87.5%	Volts
Pmax	44.50	36.10	81.1%	Watts
Vpmax	15.00	13.56	90.4%	Volts
Ipmax	2.97	2.66	89.6%	Amperes
PV Temp	25.00	53.20	212.8%	°C.
Insolation	100.00	108.20	108.2%	mW/sq. cm.



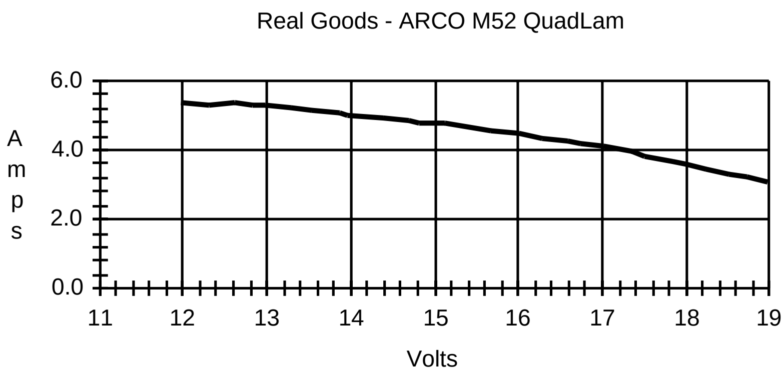
Carrizo - ARCO M52 QuadLam

	Rated Value	Measured Value	Percent of Rated	
Isc	6.00	6.72	112.0%	Amperes
Voc	25.00	24.36	97.4%	Volts
Pmax	105.00	96.94	92.3%	Watts
Vpmax	19.00	16.97	89.3%	Volts
Ipmax	5.50	5.81	105.5%	Amperes
PV Temp	25.00	51.30	205.2%	°C.
Insolation	100.00	107.70	107.7%	mW/sq. cm.



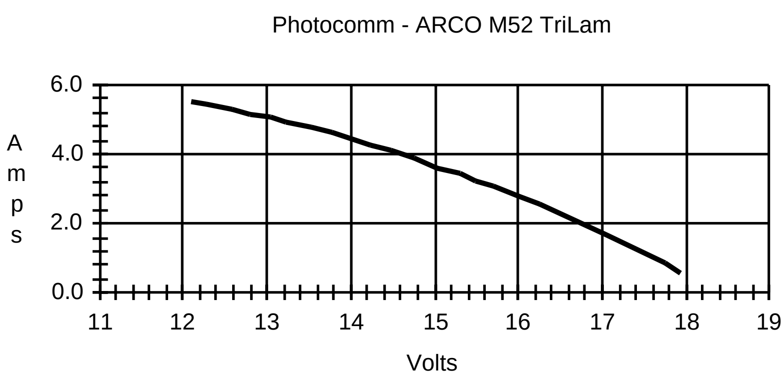
Real Goods - ARCO M52 QuadLam

	Rated Value	Measured Value	Percent of Rated	
Isc	5.50	5.98	108.6%	Amperes
Voc	25.00	23.61	94.4%	Volts
Pmax	100.00	71.39	71.4%	Watts
Vpmax	17.70	15.70	88.7%	Volts
Ipmax	5.60	4.55	81.2%	Amperes
PV Temp	25.00	52.50	210.0%	°C.
Insolation	100.00	106.60	106.6%	mW/sq. cm.



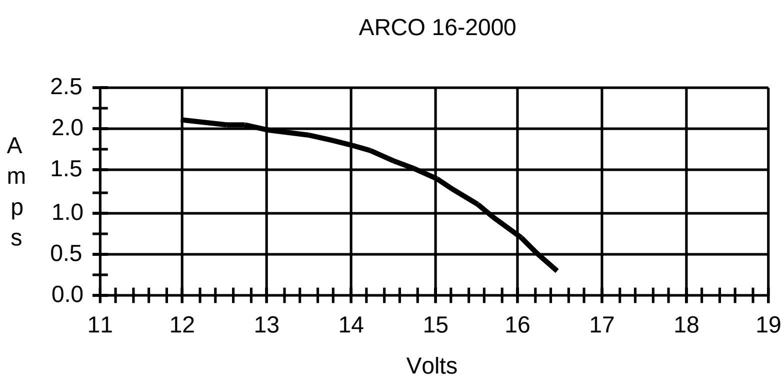
Photocomm - ARCO M52 TriLam

	Rated Value	Measured Value	Percent of Rated	
Isc	7.11	6.39	89.8%	Amperes
Voc	20.10	18.30	91.0%	Volts
Pmax	110.00	66.07	60.1%	Watts
Vpmax	16.50	12.29	74.5%	Volts
Ipmax	6.65	5.38	80.8%	Amperes
PV Temp	25.00	51.30	205.2%	°C.
Insolation	100.00	107.60	107.6%	mW/sq. cm.



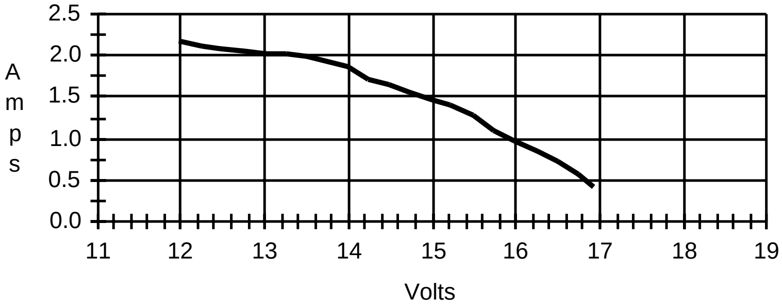
ARCO 16-2000

	Rated Value	Measured Value	Percent of Rated	
Isc	2.55	2.21	86.5%	Amperes
Voc	20.50	16.76	81.8%	Volts
Pmax	35.00	25.88	73.9%	Watts
Vpmax	15.50	13.04	84.1%	Volts
Ipmax	2.26	1.99	87.8%	Amperes
PV Temp	25.00	50.70	202.8%	°C.
Insolation	100.00	106.80	106.8%	mW/sq. cm.



Sovonics R-100

	Rated Value	Measured Value	Percent of Rated	
Isc	2.74	2.74	100.0%	Amperes
Voc	25.00	17.55	70.2%	Volts
Pmax	37.00	26.56	71.8%	Watts
Vpmax	17.20	13.51	78.5%	Volts
Ipmax	2.10	1.97	93.6%	Amperes
PV Temp	25.00	48.90	195.6%	°C.
Insolation	100.00	106.20	106.2%	mW/sq. cm.



Conclusions

The 25°C. rating standard for PV module rating was poorly selected. Out in the sun, these modules are cooking at 50°C. or more. This causes voltage loss in the cells which in turn lowers the module's power output. If you live in a warm climate, then derate the maker's 25°C. power spec by 15% to 25% to compensate for module heating. A more realistic temperature for rating PV modules would be in the range of 40°C. to 50°C. because this is where most modules spend most of their operating lives.

We're not finished yet. We are going to continue testing modules out in the sun. We are going to do it on cloudy days, on freezing cold days, as well as the hot ones like today. We're going to test every module we can get our hands on. We invite you to do the same and send in your data for publication.

Access

Richard Perez, C/O Home Power, POB 130, Hornbrook, CA 96044 • 916-475-3179.

Bob–O Schultze, Electron Connection, POB 203, Hornbrook, CA 96044 • 916-475-3401.

How photovoltaics are tested & rated

Richard Perez

Have you ever wondered how PV modules are rated for power output? How do those magic wattage numbers appear on the back of every module? Well, virtually every module is tested by their manufacturers. This article discusses how PV makers test and rate their modules. And how these power ratings may be different from actual module performance out in the sunshine.

A long and winding road…
This series of articles grew from our PV testing over the last three years. We found differences between the performance ratings printed on modules and their actual performance in the sun. We set out to find out why. This turned out to be a very long journey indeed. We got information from the modules' makers, we talked to the Solar Energy Research Institute (SERI), and we set up module "test jigs" for evaluating modules ourselves.

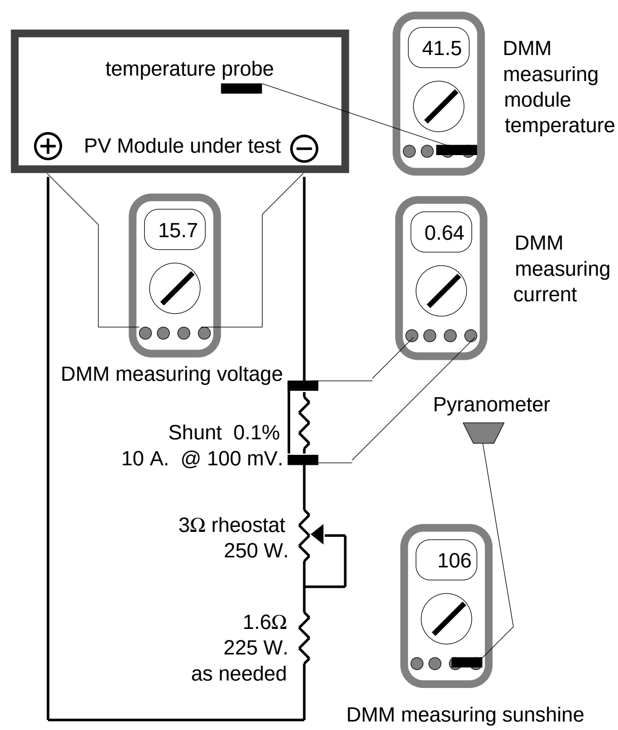
During the next few issues of Home Power, we will be printing the actual performance data of virtually every module, new and used, now available. This article defines the terms, standards and procedures used by PV makers and by us during our "in the sun" PV testing.

The Standards
All measurement depends on standards. Without using clearly defined standards, measurement is meaningless. Rating the power output of a photovoltaic module is done in a highly structured and standardized fashion. Here are the various measurement parameters & a schematic of our test jig.

Voltage
Modules are rated at two voltage levels. The first is called "Open Circuit Voltage (Voc)" and is just that. The voltage output of the module is measured with the module disconnected from any load. The second voltage rating point is called "Voltage at maximum power point (Vmp)" and is the voltage at which the module puts out the most power. All voltage measurements are made at the module's electrical terminals on the module's back. These measurements are made with a highly accurate voltmeter. We use the Fluke 87s with 0.1% accuracy.

Current
Current is also rated at two important levels. The first is called "Short Circuit Current (Isc)" and is the amount of current that the module supplies into a dead short. The second current rating is called "Current at maximum power point (Imp)" and is the number of Amperes delivered by the module at its maximum power point. Current is measured with a shunt in series with one of the PVs' lead. The voltage loss across the shunt provides accurate current measurements. We use 10 Amp., 100 mV. Deltech shunts with an accuracy of 0.1%. We use a Fluke 87 in 4 1/2 digit mode to take these measurements.

Home Power's PV Test Jig



Maximum Power and Maximum Power Point
Power is equal to Amperes times Volts (P=IE, or Watts=Amperes X Volts). Every module has a specific point on its power curve where the product of Amps times Volts yields the greatest Wattage. This is the Maximum Power Point, and the module's wattage output is rated at this point's voltage and current.

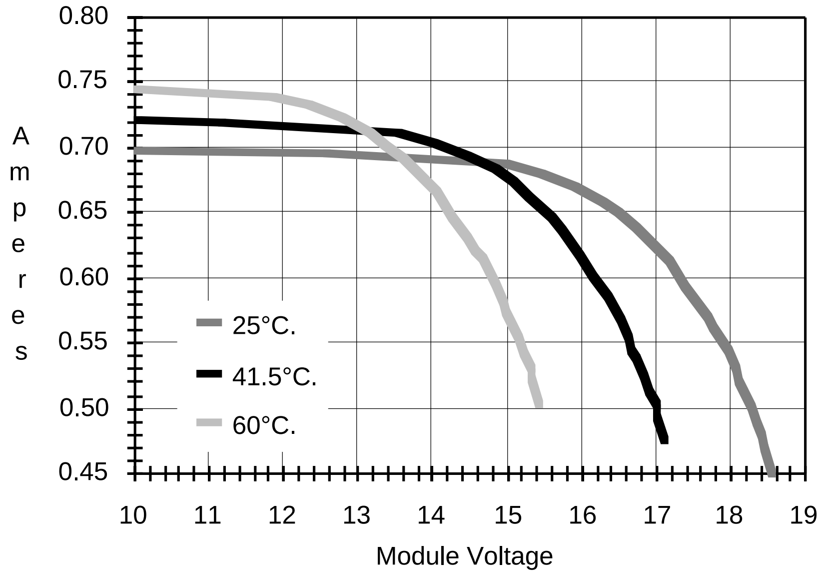
So to find the module's maximum power point we take data over the entire range of voltage and current. Because we have taken the modules voltage and current

Photovoltic Module Test

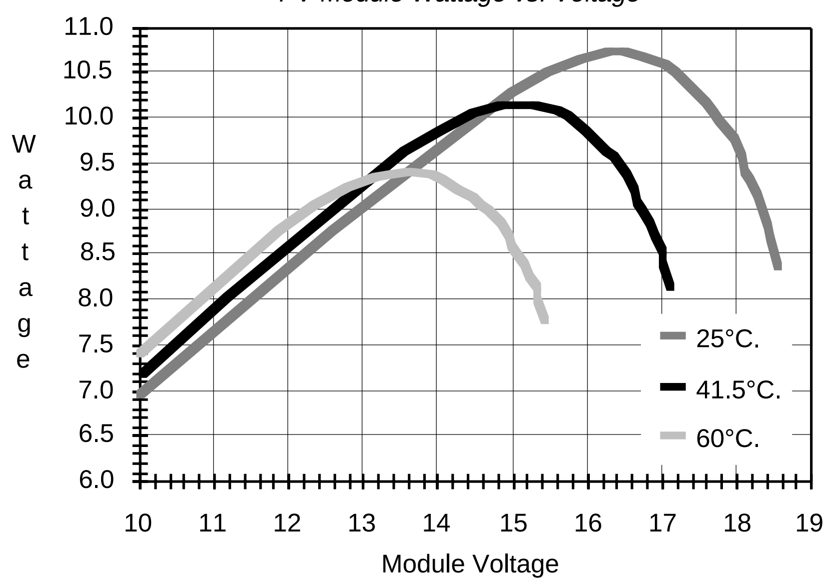
Date	5/27/91	
Time	10:03	AM PST
Air	23.10	°C.
Module	41.50	°C.
Insolation	106.00	mW/cm2
Rated W.	10.80	Watts
Rated A.	0.65	Amps
Rated V.	16.50	Volts

Volts	Amps	Watts
0.14	0.728	0.10
1.03	0.729	0.75
11.16	0.719	8.03
13.55	0.711	9.63
14.03	0.704	9.88
14.48	0.694	10.05
14.85	0.683	10.14
15.07	0.674	10.16
15.30	0.663	10.14
15.61	0.646	10.08
15.73	0.637	10.02
15.96	0.618	9.86
16.16	0.602	9.73
16.26	0.593	9.64
16.35	0.586	9.58
16.53	0.568	9.39
16.63	0.554	9.21
16.66	0.545	9.08
16.74	0.538	9.00
16.84	0.525	8.84
16.92	0.514	8.70
17.00	0.503	8.55
17.01	0.494	8.40
17.12	0.475	8.13

PV Module Current vs. Voltage



PV Module Wattage vs. Voltage



data, we can compute the wattage for each current and voltage data point. By doing this we can easily find the Maximum Power Point in the sea of Current versus Voltage data. The charts and table detail a single test run on a 10.8 Watt multicrystal PV module. All the data appears on the table. The graphs show the data as Volts vs Amps curves and Power vs Voltage curves. We took the data with a module temperature of 41.5°C. (104°F.). The curves of performance at 25°C. and 60°C. where derived from the 41.°C. data.

Effect of Temperature on PV Module Performance

As the temperature of a module increases two things happen. One, the voltage output of each cell decreases, and two, the current output of each cell increases very slightly. The graphs show the effect of temperature on module performance. If the module is at its rated temperature of 25°C., then the module will supply its rated power output. If the module's temperature is increased to 40°C., then its output drops to 94% of rated. If the module's temperature is increased to 60°C., then its output drops to 87% of rated.

This is why we don't see rated output from modules on hot days. The use of 25°C. as a temperature standard at which all other data is taken, leads to less than rated performance in the sun. When modules are doing their work, they have temperatures greater than 25°C. We measure module temperatures as high as 76°C. (169°F.) on very sunny, hot (air temp 38°C. [100°F.]), and windless days. The point here is that, with the exception of cold winter days, the modules are always running at 40°C. or greater. We measure the temperature on the back of the module with a Fluke 80T-150U temperature probe. Air temperature and wind play a big part in the module's operating temperature.

Solar Insolation

Solar insolation is a fancy term for how much sunshine is an object receiving. All modules are rated using a standard solar insolation of 1000 Watts per square meter or also as 100 milliWatts per square centimeter. This standard insolation is rarely seen anywhere on the face of the earth, other than in laboratories. This is because solar radiation is never uniform and stolidly refuses to be consistent. Too many factors affect the amount solar radiation a body receives. Small items like weather, altitude, and reflection all make realistic standardization of sunshine impossible. So we do the best we can and measure the amount of sunshine hitting an object. There are two ways to measure sunshine. One is with a PV module that has been calibrated against a standard radiation of 1000 Watts per square meter. The second instrument is called a pyranometer. We are sending two PV modules to SERI for calibration and future use. Right now we are measuring solar insolation with a Li-Cor 200SB Pyranometer. This pyranometer produces 1 mV. DC per 10 milliWatts per square centimeter with an accuracy ±5%. We measure the pyranometer's output with a Fluke 87 DMM in 4 1/2 digit mode.

Flash Testing Modules

The folks who make the PVs test them under artificial light inside a building. These folks need reproducible lab standards that are not at the mercy of solar insolation and weather. Most manufacturers use what is called "flash testing". This means that the module is exposed to a short (1ms. to 30 ms.), bright (100 mW. per sq. cm.) flash of light from a xenon filled arc lamp. The output spectrum of this lamp is as close to the spectrum of the sun as possible. A computer watches the module's output and gathers the same data as we did above– voltage and current. This data is compared to a reference module located in the flash chamber with the module under test. The reference module has its power output calibrated to solar insolation by SERI or by Sandia National Labs. Flash testing is done at temperatures between 25°C. and 28°C., depending on the particular PV manufacturer. The results of flash testing determine the numbers you see printed on the module's back. Every maker we talked to, flash tests each and every module.

Testing Modules in the Sun

Testing modules in the sun produces different results than testing them with a flash tester. The main difference is caused by temperature. Manufacturers of PVs must test modules in artificial conditions because they mass produce their product. The flash test ratings are not what we will actually see in the sun. This is why we are testing most modules now available and will report on the results.

I think that the makers of PVs could better serve us by rating modules at between 40°C and 50°C. Just making this one change in standards would do much to bring manufacturers' rating into line with actual module performance in the sun. While gathering information for this article, I talked to many PV industry folks. Many of them expressed the same desire- to use standards that more closely reflect actual operating conditions. For example, here is an excerpt from a letter regarding ratings from Mike Elliston of Carrizo Solar.

"Carrizo Solar Corp. purchased the Carrizo Plains solar power plant in January 1990. In June of 1990, we begin taking down the ARCO M52, 4 V laminates from that field.

We devised a laminate rating procedure using the industry standard test conditions of cell temperature of 25°C. and 1000 watts/sq. m. of solar insolation. We have relied on a comparison to a "reference cell". This is a laminate that has been "flashed", i.e. rated under standard conditions by Siemens Solar. We compare the output of this reference cell to the output of a laminate under test.

This method gives us an output rating which is comparable to that of the other manufacturers. How useful is this standard rating? The standard rating is more optimistic than useful. 25° C. is not a typical cell temperature. If it is 25° C. and sunny, look for cell temperatures of 40° C. to 65° C. If it is 35° C. (95°), cell temperatures could reach 75° C. with no wind. The voltage and power drop 0.4% per degree C. A 40 watt (25° C.) module is only producing 33.6 watts at 65° C. and 15 volts sinks to 12.6 volts. Under these conditions this 40 watt, 15 volt rated module would no be able to charge a battery (where 14 volts are required).

What the module buyer needs is more than one 25° C. power curve. He needs 2 or 3 power vs. temperature curves to try and match his location to the appropriate curve. Only with accurate information on his charging system and the power curve for his location can an informed decision be made about modules.

Michael Elliston, Carrizo Solar"

Home Power's PV Testing Program
So we are setting up a large test bed out in the sun. We will test just about every maker's new modules and also the used modules now available. We will run all the modules side-by-side, under the same solar insolation and at the same temperature. We will report extensively on our results in the next issue of HP.

Meanwhile, if you would like to set up your own test jig & take data from your modules, please do. Please send us a copy of your data and we'll include it in the PV survey. The more data we collect about module performance, out in the hot sun, the better we can design, purchase, and/or use our systems.

Access
Author: Richard Perez, C/O Home Power, POB 130, Hornbrook, CA 96044 • 916-475-3179.

Info about PV testing supplied by these organizations:
Keith Emery, Solar Energy Research Institute (SERI), 1617 Cole Blvd., Golden, CO 80401 • 303-231-1032.

Michael Elliston, Carrizo Solar, 1011-C Sawmill Rd. N.W., Albuquerque, NM 87184 • 505-764-0345.

Al Panton, Kyocera America, 8611 Balboa Ave., San Diego, CA 92123 • 619-576-2647.

Ramon Dominguez, Solarex, 1335 Piccard Dr., Rockville, MD 20850 • 301-698-4468.

John Loveless, Siemens Solar, 4650 Adohr Lane, Camarillo, CA 93012 • 805-388-6254.

Joel Davidson, Hoxan America, POB 5089, Culver City, CA 90231 • 213-202-7882.

Instruments to test PV modules.
Pyranometers: LI-COR, Inc., Box 4425, Lincoln, NE 68504 • 402-467-3576.

The model LI-200SB is $200.

Shunts: Deltech, 13065-H Tom White Way, Norwalk, CA 90650 • 213-926-2304. They make a 10 A., 100 mV., 0.1% shunt (MKA-10-100) for measuring current. $12.20

Digital Multimeters and Temperature probes: Flukes are available everywhere, check your phone book or HP ads.

Rheostats and high wattage resistors: Fair Radio Sales, POB 1105, Lima, OH 45802 • 419-223-2196. Fair Radio sells a 1.6Ω, 220 Watt resistor for