AMATEUR RADIO SOLAR POWER
ALTERNATIVE ENERGY EDUCATIONAL MODULE

Created for: Field Day 2021
G. Gibby KX4Z

Outline
1. How solar panels create electrical power
2. Getting the numbers straight: estimating power needs
3. Mechanics of Connections: making the power do what you want
4. Pointing: Keeping the Panel Optimally Efficient
5. RFI: Solar Power Interference Issues

QUIZ

1. How solar panels create electrical power

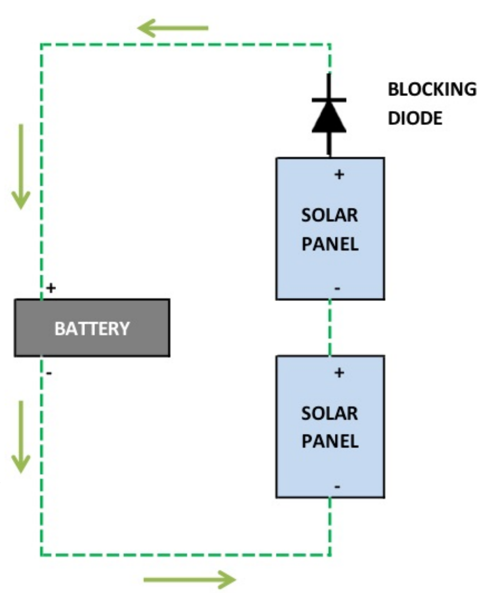
Solar panels are made out of semiconductor DIODES. Normally we use diodes to control the flow of electrical current, allowing it to go in only one direction. In the case of a the most common types of solar cells, a P-N semiconductor junction (diode) absorbs energy from a photon of light, causing the generation of an electron/hole pair; the electron is released from its parent atom by the absorbed energy. This electron then flows out of the cell, through a circuit doing useful work, and comes back to the other connector of the cell to recombine.

The maximum theoretical voltage produced is on the order of 0.5 to 0.6 VDC, and thus doesn't cause the PN junction to conduct. Not much of the current is wasted in internal shunt conduction.

The face of the solar cell is made out of a conductive, but transparent, semiconductor material, with silvered contacts aggregating the current produced.

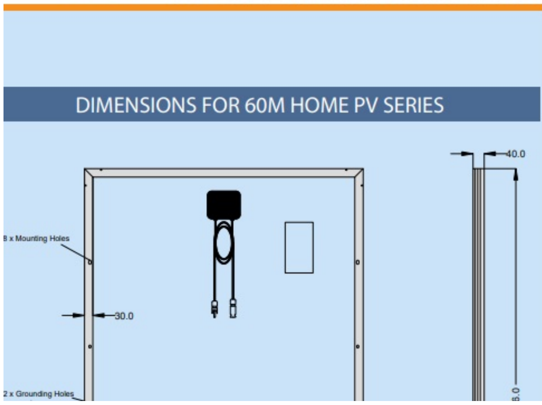
There are many different possible chemistries possible for the solar cell, with different characteristics, advantages and disadvantages.

A typical solar panel has many such solar cells electrically arranged in SERIES to produce a higher voltage. Consumer panels may have an open circuit voltage (no load) of approximately 18 volts (making charging of a 12 volt battery convenient) whereas panels intended for serious power generation usually have 60 or 72 cells in series, and make an open circuit voltage of greater than 30 volts.



The solar panel, being a series of diodes, is also capable of conducting electricity during dark conditions, potentially robbing the charged battery of energy. To avoid this, many panels include a SERIES DIODE to prevent reverse current flow. The accompanying Figure demonstrates the placement of this diode. (REF: https://sinovoltaics.com/learning-center/off-grid/blocking-diode-bypass-diode-solar-panels/)

60-CELL MONOCRYSTALLINE HOME PV



ELECTRICAL DATA (STC)

Peak Rated Power	P_{mpp} (W)	320	315	310	305
Maximum Power Voltage	V_{mpp} (V)	34.10	33.70	33.54	33.60
Maximum Power Current	I_{mpp} (A)	9.37	9.33	9.27	9.07
Open Circuit Voltage	V_{oc} (V)	40.50	40.32	40.13	39.98
Short Circuit Current	Isc (A)	10.20	10.16	10.22	9.67
Module Efficiency *	Eff (%)	19.21	18.92	18.78	18.28
Maximum Series Fuse Rating	MF (A)	20	20	20	20
Power Output Tolerance	[- 3 , + 3] %				

STC - Standard Test Conditions: Irradiation 1000 W/m2 - Air mass AM 1.5 - Cell temperature 25 ºC
* Calculated using maximum power based on full positive output tolerance [-3 , +3] %

Illustration 1: Typical Home Solar Panel Spec: https://documents.unboundsolar.com/media/9434325__black_mono_perc_1621295931.pdf?_ga=2.203867093.43448278.1623843889-763308305.1623843889

The efficiency of solar panels, considering the electrical output versus the solar energy incident to them, is generally less than 25% The theoretical maximum efficiency of a single cell is on the order of 30%. Additional cells can be placed on top of each other to obtain more power from the solar radiation. The incident energy of full sun is approximately 1120 watts per meter-squared at ground level on the Earth. (This is why being in full sun on Field Day can dangerously raise your body temperature over time.)   With a typical efficiency of 20%, that means to produce 200 watts of electrical power requires approximately 1 meter-squared of solar panel.   That works out to about 20 watts per square foot, from an incident energy of about 100 watts per square foot.

Like any power source, solar panels have an equivalent series resistance, and will produce varying amounts of output power, depending on the effective impedance they are driving. You can think of it similarly to matching your transmitter to the impedance of your antenna: maximum power transfer occurs when impedances are matched. As you apply more load (lower impedance) to the output of a solar panel, its voltage DROPS from its "open-circuit" voltage.

Because the VOLTAGE of a solar panel is different from the likely voltage of a battery it needs to charge, or an inverter input it needs to drive, some form of regulation in between is required. This is usually provided by a "Charge Controller."

The earliest charge controllers were inexpensive, inefficient units that simply varied the duty cycle of connection between the solar panel and the battery to get the desired average current flow, wasting the additional voltage in the series resistances of the solar panel, the charge controller, and the battery. The loss of efficiency could be considerable.

More efficient (and more expensive) charge controllers use a dc-to-dc converter system that takes the DC power from the solar panel, uses it to drive an oscillator, and then adjusts the oscillator's output or its usage to develop a desired rectified output. By adjusting the oscillator the system can present the optimal impedance to the solar panel, causing it to adjust the voltage output/current output of the panel to the optimal power producing point. This is called Maximum Power Point Tracking, and can be compared to choosing the optimal gear in a transmission, or adjusting an antenna tuner device for maximum power transfer to an antenna (hence minimum perceived Standing Wave Ratio by the transmitter).

MPPT controllers are usually limited in two ways:

- The maximum open circuit solar panel VOLTAGE to which they can be exposed
- The maximum output current they can produce

For example, a typical MPPT controller might be specified to allow up to 60 volts DC to be applied to its input, and be able to produce a maximum output current (e.g. at nominally 24 volts to charge two 12 volt batteries in series) of 15 Amperes.

NFARC plans to use a very inexpensive simple MPPT controller (see: https://qsl.net/nf4rc/2021/GreeSonicMPPTUserManual.pdf) with the following specifications:

Specification	Value	Comment
Maximum input voltage	60V	Our panel produces a maximum below 40 VDC
Battery Voltage Nominal	12/24	Unit auto-detects the battery voltage
Battery Type	Gell	Unit uses charging voltages appropriate for GELL CELLS, which means that it will NOT do an equalization (higher voltage/current) phase. Boost voltage: 14.5V/29V Float Voltage: 13.7/27.4V
Maximum output current	15A	We rarely see it get above 10A

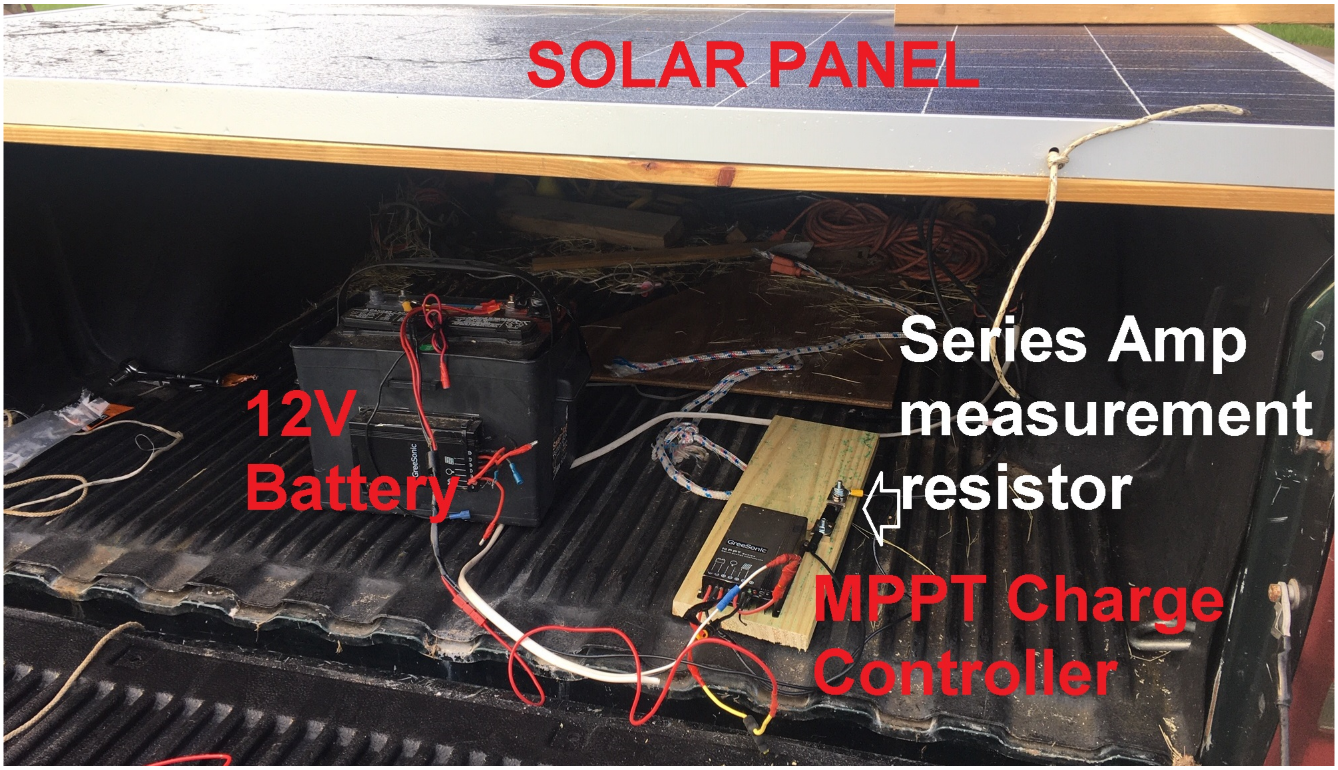


Photo showing simple solar panel / MPPT controller / Battery. This system would reliably produce 10A of charging current with full sun (no clouds in the way). In less than one hour it cold produce enough power to allow 5 or more contacts.

Modest MPPT controllers suitable for charging 12 or 24 volt batteries are now readily avialable:

An example with up to 100V input, 20A output: https://www.amazon.com/Controller-Battery-Regulator-Negative-Temperature/dp/B079ZM9MR6

2. Getting the numbers straight: estimating power needs

Power = Volts x Amps

How much power does a ham radio transmitter use? Typically the "efficiency" is around 50%, so you can estimate the power drawn from the supply at twice the output RF power.

Transceiver	Output RF power	Typical Supply Consumption
VHF/UHF	40W	80W, or about 6-7 Amps @ 13V Power is continuous when transmitting
HF	100W	200+W or about 15-20A @ 13V However, when using SSB-Voice the duty cycle is perhaps 40%

		rather than continuous.
HF - digital	Assume 50 watts	Approximately 10A @ 13V

Since you transmit perhaps 50% of the time, and use relatively little power when receiving, the average power usage is even lower.

Let's estimate the power consumption for 1 hour of digital effort, at 50% transmitting, at 50W output:
Efficiency = 50% implies 100 watts when transmitting. We'll assume 10Amps @ 13V to provide some margin
Operating duty cycle = 50% transmitting implies average current of perhaps 5 Amps @ 13V

Total current-time from a battery source approximately 5 Amp-Hour
Total Energy = watts x time = 5 Amp-hour x 13V = 65 Watt-hours

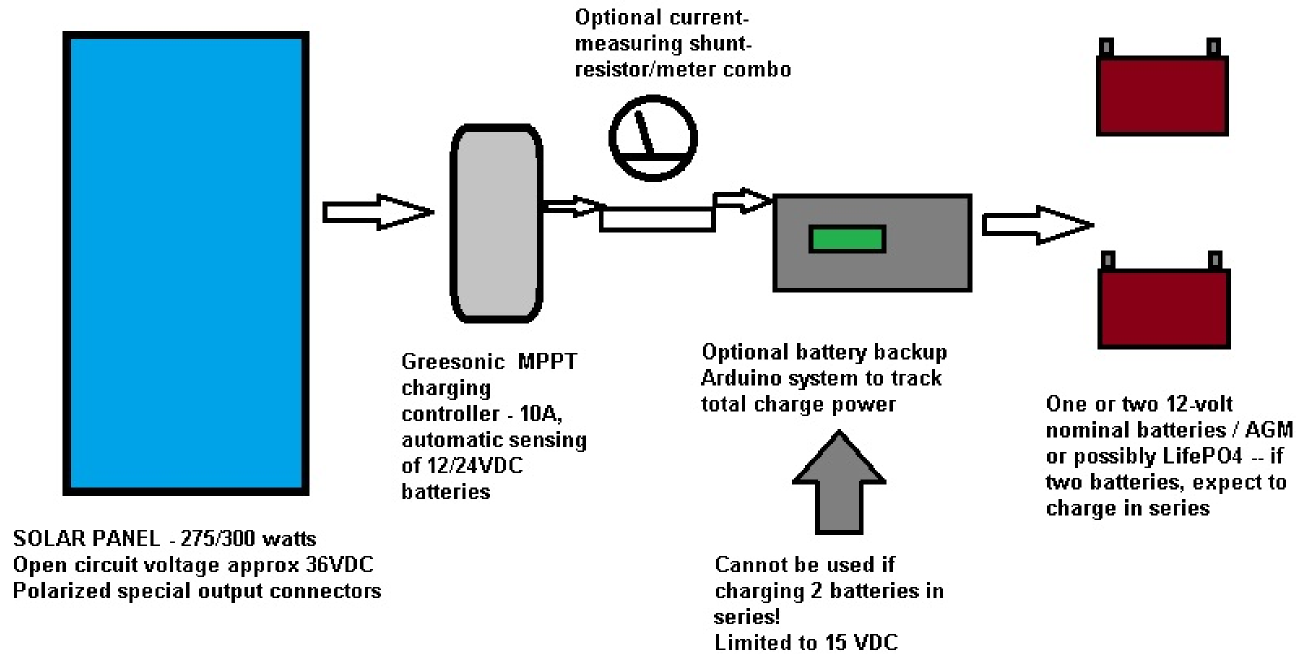
3. Mechanics of Connections: making the power do what you want

Most home Solar Panels with have MC4 connectors. These are polarized connectors designed to prevent miss-connection. Your charge controller should be equipped with matching connectors -- and remember these may have 30, 60 or even 90 volts on them depending on how many panels you have in series.

Some home installations will convert directly to AC right at the panel! A micro-inverter positioned right there will produce AC line voltage to connect to a bus of AC coming out of the panel. Be sure that you know how your home system operates!!

Other home installations may have an "optimizer" dc-to-dc converter mounted on each panel to deal effectively with variable shading of each panel.

Our simple Field Day DC system will take the 30V output of the solar panel, route it to the MPPT controller, and then possibly through a small series resistor used to allow current measuring, and then through Anderson Power Pole connectors to charge a storage battery.



4. Pointing: Keeping the Panel Optimally Efficient

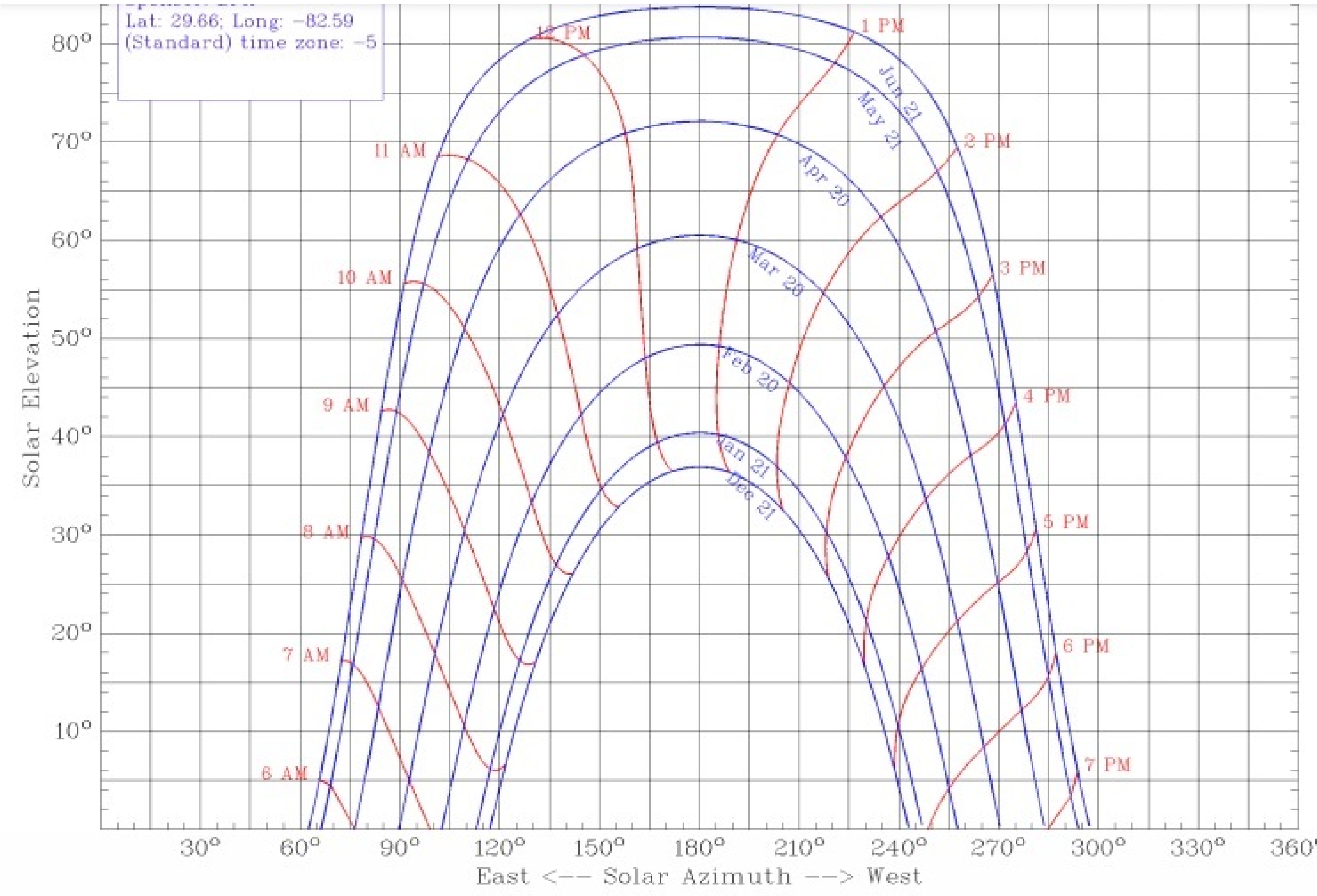
The sun MOVES!! And if your panel isn't pointed STRAIGHT AT the sun, you don't get as much power from it!! Home roof- or ground-mounted systems occasionally have automated pointing controllers (electric utility solar panel farms may have this) but most home systems will be at a fixed angle, which is only maximally efficient at ONE position of the sun.

Here is a chart (from the University of Oregon, http://solardat.uoregon.edu/cgi-bin/SunChart.cgi created for our area, Newberry) that shows the aiming required to point directly at the sun.

It shows that:

Sunrise -- Must point North East almost horizontal.
10 AM -- Point :East at 55 degrees above horizon
Around Noon -- almost straight up
3 PM -- Point West at 55 degrees above horizon

In order to get MAXIMUM power generation from a small solar panel setup, it may be well worth your while to go chock the panel up to point properly at the Sun, a few times each day!



5. RFI: Solar Power Interference Issues

Highly efficient solar panel energy conversion systems use fast-switching transistors, MOSFETs, and IGFETs that spend very little of their time in their "linear operation" region -- for maximum efficiency, the devices switch extremely rapidly from full cutoff to full saturation. That makes them wide band generators of RF energy, much like a spark-gap transmitter, that also has very fast switching on/off of an electrical current.

If you aren't careful, this radio frequency interference can play havoc with your finely adapted sensitive antennas and receivers.

The MPPT controller or inverter appears as if it were a wide-band transmitter. Wiring connected to it of any kind appears to be an "end-fed antenna". If there are two sets of wires, then the device appears to be driving a DIPOLE antenna!!

In order to reduce this impact:

- Reduce the literal area consumed by the wiring -- keep it compact so the "antennas" don't have much "aperture size"

- Position the entire apparatus as far as possible from your sensitive antennas/receivers
- Use common mode filters on as many of the lines as possible. This can be as simple as taking the wires to the solar panel and running them around several turns of an FT-240-43 ferrite toroid. Or you can use a commercial filter, appropriately sized for the application.

Those skills will be important to you in an emergency deployment where someone is utilizing an inverter-generator (another wide-band transmitter!) or solar panel system. Our group has done significant research into how to reduce RFI from these kinds of sources: https://qsl.net/nf4rc/2019/InverterGeneratorSolutions.pdf

QUIZ FOR CREDIT: OPEN BOOK TEST

Name: ____

Your Answer	No.	Question / Choices
	1	What is the typical open circuit voltage of a single solar semiconductor cell? A) 0.5 Volts B) 13.8 Volts C) 0.7 Volts D) 110 Volts
	2	Which of these is a typical number of cells to be put in series to make a solar panel for home power generation? A) 1 B) 10 C) 60 D) 120
	3	Which of these is a typical open circuit voltage of a typical home solar panel? A) 13.8 V B) 35 V C) 110 V D) 600 V
	4	The most efficient type of charge controller is known as? A) Pulse width modulation B) MPPT C) Matched Impedance Monitor D) Zero Loss Controller
	5	The name of the type polarized connectors on the output of typical home solar panels is? A) Anderson Power Pole B) MC4 C) UL514 D) TT30
	6	The typical incident energy from the sun at ground level is A) 1 watt per square foot B) 20 watts per square foot C) 100 watts per square foot D) 1000 watts per square foot
	7	The type of filtering you may need on solar panel systems to reduce radio frequency energy includes A) quasi-differential filtering

		B) magneto-electrical filtering C) common mode filtering D) harmonic filtering
	8	How high is the sun at local solar noontime at Field Day in Alachua County? A) about 50 degrees elevation B) about 60 degrees elevation C) About 70 degrees elevation D) above 80 degrees elevation
	9	If you need 1 hour to make 5 solar-powered contacts, using digital transmissions at 50 watts peak power, roughly how many Amp-hours of power from a 12 volt battery will you consume? A) 1 Amp-Hr B) 5 Amp-Hr C) 50 Amp-Hr D) 100 Amp-Hr