Solar-powering your Geek Gear

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This article will show you how to solar-power your laptop, PDA, cell phone, portable fridge or almost any other small device. It explains how to choose the right solar panel, how to use (or not use) a voltage regulator and why it might be useful to buffer the energy. It introduces a small and quite simple device to measure power and energy savings and finally some typical applications are discussed.

1 Introduction

1.1 Warning

This project involves currents and voltages that might be considered dangerous. Everything that is discussed here should be used at one’s own risk, connecting devices to anything else than their dedicated chargers could easily break them, void their warranty or cause even worse to happen. There is absolutely no warranty from the author, you have been warned.

1.2 Motivation

Why would someone want to power his devices using a solar-panel? There are a couple of good reasons to do so. First of all, solar power is just a fascinating thing - you put the panel into the sun, plug it in and (hopefully) it is just working - no battery, no power plant necessary. Being independent of power sockets, there are a lot of scenarios where this technology could be used: during camping in the wilderness, lonely on the top of some mountain, in the park or in the garden to name just a few places.

You might also think that it might be possible to save a lot of money using your solar panel. Unfortunately I have to disappoint you for now. At the time of writing this article, you would have to use it *really* long to save money, but as prices for photovoltaics might drop and energy-prices might rise in the next few years this could of course change.

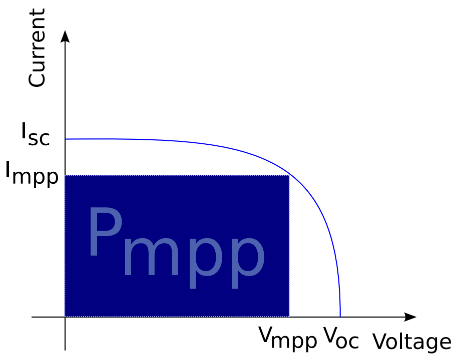
Talking about money, let us consider how much you have to spend. Currently you can buy solar-panels for about 50 EUR (about 60 USD) per 10 Watts. The panel that has been used during research for this project was about 200 EUR for 40 Watts. Depending on what you want to power (see Section 2.2) you will also have to spend money for e.g. voltage regulators, capacitors or plugs.

2 The Solar Panel

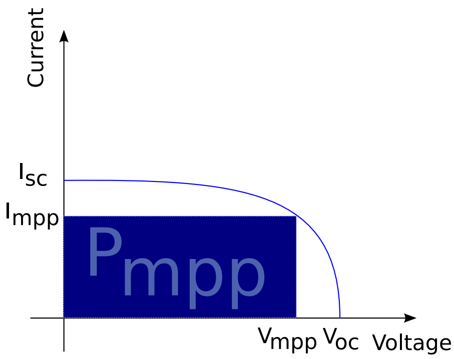
2.1 Characteristics

Solar-panels can be characterized by their short-circuit-current I_{sc}, their open-circuit-voltage V_{oc} and their maximum-power-point (MPP) (V_{mpp}, I_{mpp}). While V_{oc} is almost constant between several lighting-conditions the current I_{sc} is heavily dependent on radiation and cell-temperature (see also [4]).

Figure 1 shows two voltage-current-curves under different lighting-conditions. As illumination increases (decreases) the short-circuit-current I_{sc} and thus the available maximum power P_{mpp} also increases (decreases).



(a) Testing-conditions (1000W/m^2, 25°C)



(b) More typical conditions

Figure 1: Solar-panel under different lighting-conditions

Looking at the figure, it is obvious that you need to include some safety-margin when choosing your panel.

2.2 Deciding what to power

As mentioned before, there are a lot of small devices that can be solar-powered. Some devices are very picky about their input-voltage while others are not. The first thing to do is to have a look at the ratings of the device or its original power-supply. The continuous power of the device should not exceed the power of your panel including some safety-margin (see above). Higher peak power-ratings can possibly be buffered using a capacitor (see section 3.3).

Lower voltages than stated in the rating are often okay while higher voltages should definitely be avoided if you do not want to break your device (or know it very well and you are sure that it will be alright). Devices that are rated below the open-circuit-voltage of the panel should be powered using an adjustable voltage regulator. The regulator will take care of limiting the voltage so that the device will not be damaged. In some cases it may also be necessary to limit the current through the device, see section 4.2 about Nokia phones for a prominent example. Despite of that, the majority of devices will do fine with just a voltage-regulator, see section 3.2 for an efficient wide-range voltage-regulator.

An adjustable laboratory power-supply is a valuable tool to test your devices using different voltages and to measure power consumption. If the device is not working properly under these testing-conditions it is very likely that it will not work using the solar-panel either.

3 Accessories

3.1 Connectors

To give a robust and safe plug-and-play experience special connectors have been chosen for the project. The following requirements had to be satisfied:

1. Connectors should be common for all devices
2. No shorting and no reversal should be possible
3. Connectors should support a current of up to 10A

After some research I came up with the RIA Connect 230/249 Series [6] that are distributed in Germany e.g. by Reichelt[1] [5]. See figure 2 on how these connectors look like.

Figure 2: Connector cord

Having chosen the connectors some useful adapters and tools can be build. Older ThinkPad-Adapters can be build using simple DC plugs[2] with the following specification: $\varnothing_i = 2.5\text{mm}$ (inner diameter), $\varnothing_o = 5.5\text{mm}$ (outer diameter). Newer ThinkPads (20V) have a more complex plug which is harder to obtain, one solution would be to cut it from a cheap replacement power supply. The same applies for cellphone-connectors. 12V Car-Equipment, which includes several chargers and inverters, can be connected using the appropriate sockets. To connect several plugs together, a small distribution board can be built (see figure 3).

Figure 3: Distribution board

3.2 Universal Voltage Regulator

Typical voltage regulators only work with input voltages higher than output voltages (step-down), but there are also step-up-converters that convert lower to higher voltages. For this project, a wide range of output-voltages is required and the panel provides a wide range of input-voltages under load. This is the reason why I have chosen a very special voltage-converter - it is based on the LTC3780 (see [7]), a buck-boost-controller which allows seamless switching between Step-Down (Buck) and Step-Up (Boost) modes. The regulator can be bought as "USW-525" at [3], see Figure 4. It has the following specs and can thus be used for a board range of applications:

- Input-Voltage: 7-25V
- Output-Voltage: 4-25V
- Output-Current: up to 5A
- Efficiency: up to 97%

[1] Reichelt Part-No: AKL 249-02, AKL 230-02
[2] Reichelt Part-No: HS 25-9

Using this regulator, I was able to power older ThinkPads (16V, 4.5A), 12V-car-equipment like chargers and an inverter as well as many other devices.

Figure 4: ELV "USW-525" universal voltage regulator in a case

3.3 Buffering the Energy

Many devices have short peaks of very high energy consumption, see figure 5 for an oscillogram of peak power consumption with a ThinkPad X300 while switching desktops in Fluxbox.

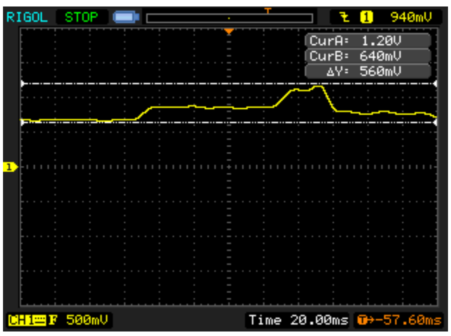


Figure 5: Peak power consumption, $1\text{V} \widehat{=} 1\text{A}$ across a 1Ω-Shunt, $\Delta I = 0.5\text{A} \Rightarrow \Delta P = 10\text{W}$

In case of a laptop this peak-consumption can be buffered using the internal battery while other devices that do not contain a battery might just reset or power off. The solution to this problem is to use a *very* big capacitor to act as a buffer to the solar-panel. Depending on the capacity and the load it might also be able to buffer a temporary shading of the panel (e.g. when someone is walking in front of it).

Figure 6 shows a 1 Farad power capacitor that is usually used for car-HIFI. Please note, that this capacitor can generate *extremely* high currents! Don't ever short it when charged and never try to charge it directly using a high-current source (e.g. a battery)! You should really put a fuse into the cable and isolate the terminals.

Figure 6: Fused powercap

Additional care must be taken that no current can flow backwards from the capacitor to the solar-panel (the same that applies when charging batteries directly with solar-panels). This can be achieved by using a blocking diode between the panel and the capacitor.

3.4 Measuring Power and Energy

Soon after some simple test-setup with the solar-panel and a laptop worked, I wanted to know what power the panel is currently delivering and how much energy I could save in one afternoon.

For this purpose, I built a small device consisting of an Atmel ATmega8 micro-controller, a display, an operational amplifier as well as some other components.

The input voltage is measured directly using a voltage divider and the current is measured using a small shunt of about 10mΩ. A current of 2A will thus cause a voltage-drop of about 20mV at the shunt. This voltage is amplified by the operational amplifier and fed into the analog-digital-converter of the micro-controller. This drop is acceptable - on the other side, if no amplifier had been used but instead a 1Ω-shunt, a current of 2A would cause a voltage-drop of two precious volts.

The software reads out the analog values, converts them to voltage and current values and calculates power ($P = V \cdot I$) as well as energy ($E = \int P\mathrm{d}t$). All values are shown on the display. If input voltage falls below a threshold of about 9V, the device enters shutdown-mode, which means it will write the energy-value to EEPROM and disable further measurements (until it is wakened by the button). This strategy helps to prevent EEPROM corruption when power fails as well as exaggerated EEPROM-writes.

A more detailed description of the device as well as schematics and software can be found at my personal website [1].

4 Applications

4.1 Laptop

Laptops usually have a built-in battery which makes them quite easy to use with solar power. As soon as voltage drops due to higher load or cloudy sky, the laptop can switch to its internal battery and you can continue working. Power consumption of modern laptops is around 10-30 Watts, but while charging its battery and can be *a lot* more (e.g. 60W), so what you need to do is to prevent the machine from charging (as long as you do not have a very large panel that can delivery that additional power).

ThinkPad Laptops can be instructed to not charge the battery by using the `tp_smapi`-interface. The following will set the battery-start-threshold to 10%, so that the battery will not be charged as long as it is above 10%:

```
echo 10 > /sys/devices/platform/\
   smapi/BAT0/start_charge_thresh
```

Apple's iBooks and Powerbooks have a Sense-Pin in their connectors that can be used to prevent battery-charging, please see the technical document at Apple's site for more information [2].

Unfortunately I was unable to find more information about other laptops, so you will need to figure out a way to prevent it from charging the battery. Physically removing the battery is no good option, unless you have a good energy-buffer (see section 3.3) and know that there will be no clouds soon.

One strategy is to apply a voltage that is low enough, so that no "AC connected" will be detected (and thus no charging will take place) but still high enough to entirely power the laptop. Results may of course vary and depend on the implementation of your vendor - I was at least able to verify this procedure with the already mentioned ThinkPad X300.

4.2 Phone

Nokia phones will not charge with a constant voltage if the current that the source can deliver is too high. Reasons why this happens to be so are unknown, but probably the internal charging-circuit has no means of limiting the current flowing to the battery.

Original chargers have their current limited to ≈ 800 mA, so if you want to charge a Nokia phone you will have to limit the current. The phone will test the available current at the begin of the charging-procedure, if it is too high it refuses to charge. The most simple current-limiter-circuit is just a resistor in series to the constant voltage source, see Figure 7. The voltage of the source (e.g. your voltage-regulator) should be set to about 5-6V (see the back of the charger), so according to Ohm's law, a resistor of $R = \frac{U}{I} = \frac{5V}{800mA} \approx 6\Omega$ will do the trick. Experiments showed that 5Ω also worked with several phones.

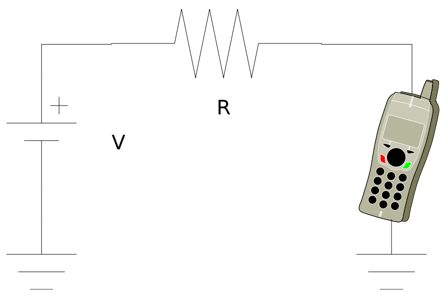


Figure 7: Current-limited charging

4.3 Electrical Fridge

Electrical fridges are quite simple devices, most are rated around 40 Watts (at 12 Volts). You could of course set your voltage regulator to 12V and hope that your solar-panel is strong enough, but those fridges will most likely also work with voltages below 12V (they will not get as cool, though). So if you use a panel that provides about 40 Watts or less you can just try plugging them directly together, the panel will then act as a constant current-source and limit the voltage at the fridge.

5 Conclusions

A rather small solar-panel (40 Watts), combined with some accessories like connectors, adapters, a voltage regulator and a capacitor can be used to have a lot of fun with a variety of small devices. Powering laptops that allow battery management, works great and enables the user to work for hours without the need for power sockets or heavy batteries. Further research should be done on laptops that cannot easily be prevented from charging, however, as charging batteries uses a lot more power.

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