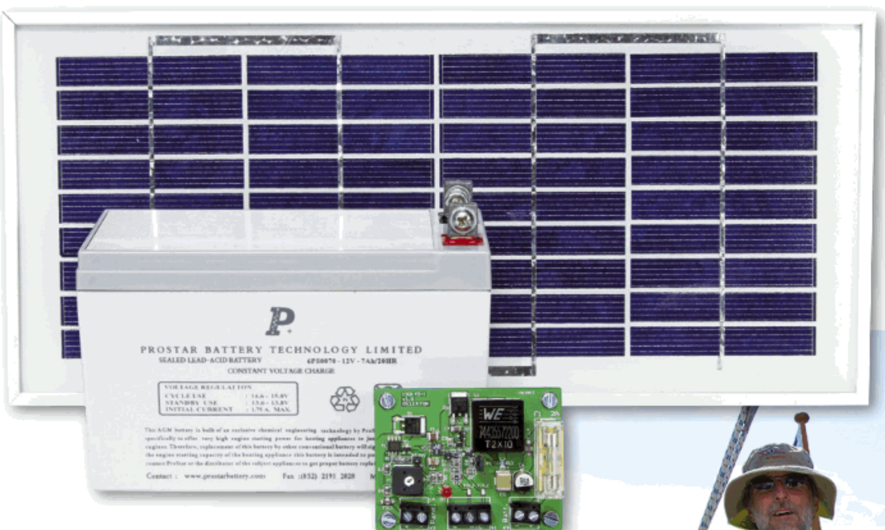
2-amp Maximum Power Tracking Charger

Solar Power To The Max.

Using photovoltaic (PV) panels ("solar panels") is an attractive way to keep batteries charged in boats and recreational vehicles. While RVs have ample space on the roof for panels, boats, sailboats in particular have limited space. You also have to mount the panels so that they face the sun and are not shaded partially as that badly affects their performance. The question thus becomes: How do you extract the maximum power from a PV panel? Find some answers here.



By
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Photovoltaic cells can be modelled as a current source in parallel with a diode. When loaded they exhibit a *V-I* response like the red curve in **Figure 1**. If you calculate and plot the corresponding power, *P*, you quickly see that maximum power for this particular panel is delivered in the 16-volts ballpark (blue curve). This is quite typical for commercial PV panels sold as "12 volts" types. These often exhibit an open-circuit (no load; n/l) voltage of 20–25 V and peak at around 16–17 V in terms of power yield. This point is called the Maximum Power Point or MPP for short. The activity of a circuit or system to adjust itself for MPP electronically and/or mechanically is called Maximum Point Tracking, or MPPT for short.

MPP with a trick

To safely charge a 12-V lead-acid battery, the PV voltage needs to be lowered to 12–14.4 V depending on the charge of the battery. In the past this was often done with a series regulating element, which essentially wastes power. To get maximum power from our panel, we need to use a switching converter to lower the voltage, ideally in a loss-free manner (increasing the current) and regulate it so that we keep the panel voltage at the maximum power point. Doing so will squeeze 10-30% more charge from the same PV panel. MPP optimized chargers exist commercially—they constantly measure the output power and adjust their operation accordingly. Sadly they are quite expensive. There is an easier way, however. The MPP for most panels varies just lightly with light intensity. This design employs exactly that feature. We only need to establish our panel's MPP once—either from the manufacturer or simply by measuring—and then design our charger's behavior to match.

LT3652: battery babysitting

The design uses an LT3652 integrated circuit from Linear Technology [1]. The IC lets us build quite a sophisticated charger with a minimum of external components. You are looking at a three-stage charger capable of accepting voltages up to 32 V and charging a battery at up to 2 amps. The LT3652 fast-charges at 2 amps max. with a *CC/CV* characteristic up to 14.4 V, then switches to 13.5 V float charge. It also adjusts the float charge voltage, based on battery temperature. The graph in **Figure 2** shows battery voltage sampled at 30-second intervals over a period of an hour. Initially a load is connected to the battery and the voltage drops to under 12.5 volts. After about five minutes the load is removed and the battery voltage jumps to 14.4 V. At that point the charge current peaks at 1.8 A. After just over 20 minutes, the battery is fully charged, the charge current drops below 200 mA and float charging is maintained at just over 13.5 V.

The circuit

Looking at the schematic in **Figure 3**, the solar panel's + and – cables are connected to input terminal block K2. With no help, reverse voltage blocking diode D1's forward drop easily wastes approximately 1.2 watts at 2 amps hence it requires bypassing with a P-channel MOSFET, T1. When the LT3652 (IC1) charges, it pulls its CHRG output (pin 4) low, causing T1 to conduct hard and effectively short D1. Preset P1 is the part of the voltage divider that allows the MPP to be set for your panel. Adjust it so that the VIN_REG pin of the LT3652 sees a voltage of 2.7 V at the desired V_{MPP}. When the output voltage

Features

- For 12-V (nominal) solar panel ($V_{(n/l)}$ 20–25 V)
- 2 A max. charging current
- Efficiency 87–90%
- Adjustable for individual PV MPP voltage
- 12-V Gel / Non-Gel battery type selector
- LT3652 switching regulator especially for battery charging
- Thermal and RFI optimized PCB
- FAULT and CHARGE LED indicators
- No microcontroller
- External NTC for temperature monitoring

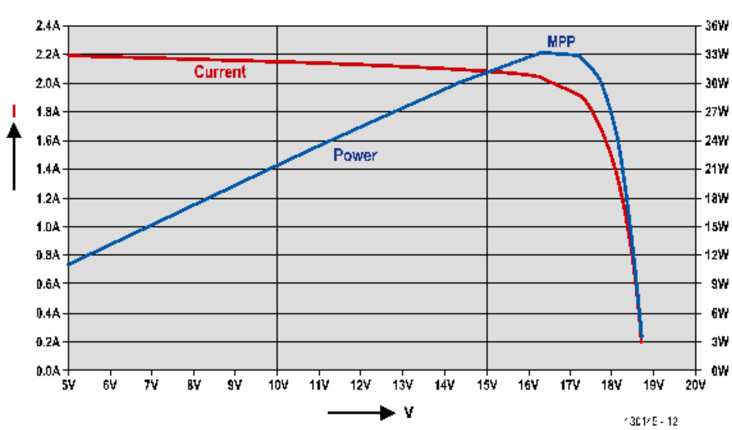


Figure 1. Graphing the voltage-current response of a solar panel is a simple method to find that "sweet spot" called MPP (maximum power point).

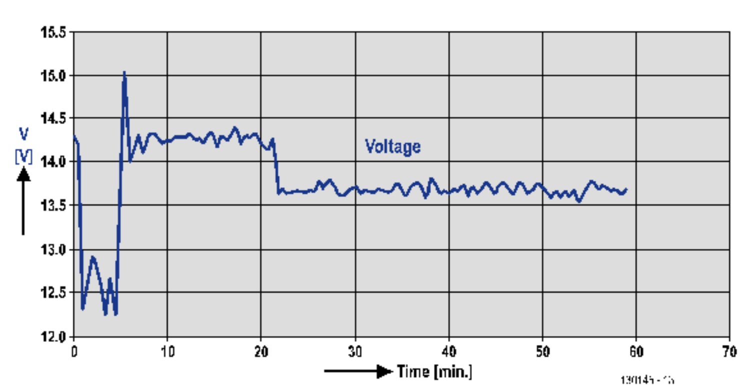
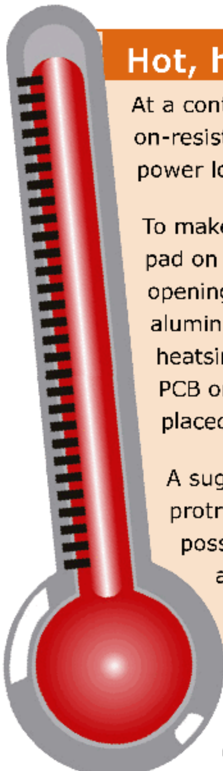


Figure 2. Voltage graph for a 12-V lead-acid RV battery recorded over a period of 60 minutes covering loading, full charging and float charging.



Hot, hot, hot

At a continuous 2 A output current the circuit and even the whole PCB gets hot. The effective on-resistance of the switch transistor in the LT3652 is 0.175 Ω which causes a large part of the power loss of the circuit.

To make sure the integrated circuit has enough cooling it has an exposed pad. Vias in the pad on the PCB conduct the extra heat to the copper plane on the bottom side. Here a larger opening in the solder mask makes it possible to add extra cooling. One way is to place a small aluminum bar between PCB and the aluminum case. The case then acts as an additional heatsink for IC1. Without it we measured the temperature of IC1 at just shy of 75 °C, with the PCB on our table @ room temperature. The junction of IC1 will be even hotter. If the PCB is placed inside a case at higher surrounding temperatures then more cooling is a must.

A suggested size of the aluminum bar is 5 by 10 mm. The thickness depends on the protruding through-hole components at the bottom side. Keep these lead ends as short as possible and make sure the little aluminum bar doesn't form a short circuit to connections alongside of it (especially the solder pad of TP2), and the TH components don't make contact with the aluminum case. Use thermal glue to fix the little bar to the PCB or thermal compound between it and the PCB, and glue in the corners.

drops, because too much current is drawn, the LT3652 responds by reducing its output current, thus servoing the voltage—i.e. striving to maintain it stable at V_{MPP}.

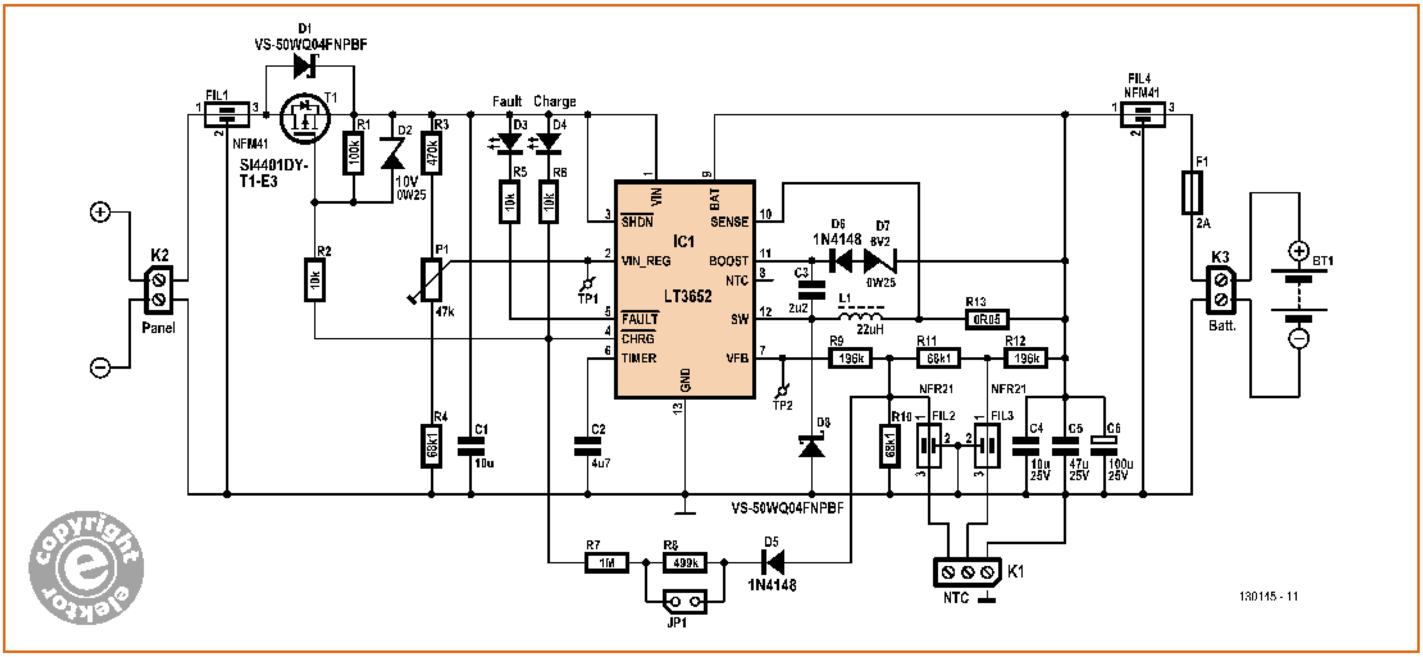
The 13.5-V float charge voltage is determined by the divider formed by R9, R10, R11, R12 and the NTC (negative temperature resistor) connected to K1. The NTC is the variable element—the hotter it gets, the lower its resistance. For a typical lead-acid battery, the float charge varies from 14.6 V at −10 °C to 13.2 V at 40 °C. The NTC takes care of that, keeping the battery fully charged, without overcharging. In case no temperature com-

Sunny Considerations @ Elektor Labs

Senior Designer Ton Giesberts of Elektor Labs kind of grilled the MPP Charger in terms of design philosophy and theoretical (claimed) performance. Among his concerns are core losses in L1. Using a fixed switching frequency of 1 MHz losses are higher with a larger core. However, efficiency measurements gave satisfactory results.

Ton used a solar panel simulator to test the circuit. There are many ways to do this—the simplest one is a beefy current source driving a large number of power diodes connected in series. The voltage across the diodes mimics that supplied by a real solar panel. A more intelligent and compact circuit was set up though with a number of 1N4148 diodes in series and the voltage across them amplified to make a series regulator to reduce the dissipated power at no-load conditions.

Usually the datasheet of a solar panel specifies the open circuit voltage, short-circuit current and the maximum power point voltage and current at 1000 W/m^2 irradiance. The n/l voltage can be set with P1. What Linear Technology call power tracking is in fact regulation of the charger's output power to maintain the user adjusted input voltage at (too) high loads. Reformulating, the output current is reduced if the solar panel is not able to deliver the necessary power. If the output power is less than the solar panel can deliver the input voltage rises above the set maximum power point level. This makes you wonder if this is really power tracking—after all, what happens to the maximum power point voltage of the panel if the irradiation is much lower (or higher) than the level specified in the datasheet?



pensation is needed, simply substitute a 22-kΩ 1% fixed resistor for the NTC.

For a proper V_{float} *vs.* temperature curve a 22-kΩ NTC with a *B* of 3380 is needed. Those are very hard to find, so consider using two 10-kΩ Murata type NTSD0XH103FE1B0 NTCs in series, plus a 2-kΩ 1% resistor.

Figure 3. Schematic of the Maximum Power Point Charger. At the heart of the circuit sits an LT3652 switcher IC from Linear Technology. Note the ferrite beads (FILx) at critical points in the circuit—they serve to keep RFI to a minimum.

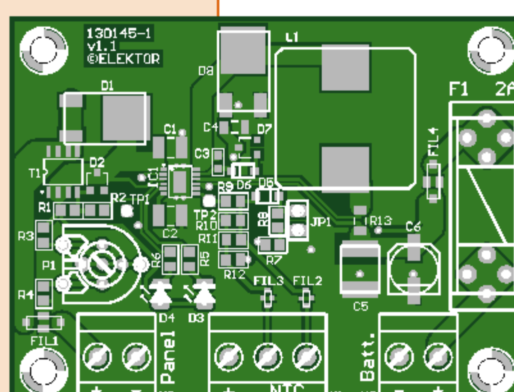


Figure 4. The circuit board designed by Elektor Labs takes into account compactness, high current, RFI you can expect from an SMPSU, and thermal issues. Properly built and encased the charger should emit a minimum of radio interference.

Component List

Resistors
R1 = 100kΩ 5 % 0.125W, SMD 0805
R2,R5,R6 = 10kΩ 5% 0.125W, SMD 0805
R3 = 470 kΩ, 1% 0.1W, SMD 0805
R4,R10,R11 = 68.1kΩ 1%, 0.125W, SMD 0805
R7 = 1MΩ 5% 0.125W, SMD 0805
R8 = 499kΩ, 1%, 0.125W, SMD 0805
R9,R12 = 196kΩ 1% 0.125W, SMD 0805
R13 = 0.05Ω 1%, 1W, SMD 1206
P1 = 47kΩ 20% 0.15W, trimpot, top adjust

Capacitors
C1 = 10µF 50V, +80%/–20%, SMD 1210, Y5V
C2 = 4.7µF 25V, 10%, SMD 1210, X7R
C3 = 2.2µF 25V, 10%, SMD 0603, X5R
C4 = 10µF 25V, 10%, SMD 1206, X5R
C5 = 47µF 25V 20%, SMD 2220, X7R
C6 = 100µF 25V 20%, Radial Can SMD

Inductor/Filters
FIL1,FIL4 = NFM41PC204F1H3L (Murata)
FIL2,FIL3 = NFR21GD4702202L (Murata)
L1 = 22µH 11A, 20%, 14.6mΩ (Würth Elektronik 74435572200)

Semiconductors
D1,D8 = VS-50WQ04FNPBF, SMD D-PAK
D2 = BZX84-B10,215, SMD SOT-23
D3 = LED, red, 3mm, through hole
D4 = LED, green, 3mm, through hole
D5,D6 = 1N4148, SMD SOD-123F
D7 = BZX84-B6V2, SMD SOT-23
IC1 = LT3652EMSE#PBF, SMD 12MSOP
T1 = SI4401DY-T1-E3, SMD SO-8

Miscellaneous
F1 = 2A antisurge (T), 5x20mm, with PCB mount holder and cap JP1 = 2-pin pinheader, 0.1'' pitch
JP1 = jumper, 0.1''
K1 = 3-way PCB screw terminal block, 5mm pitch
K2,K3 = 2-way PCB terminal block, 5mm pitch
TP1,TP2 = solder pin
Case: Teko 2/A.1, aluminum, size 57.5x72x28mm
PCB # 130145-1 v1.1 [1]

Figure 5.
Less than perfect in appearance, sure, but the author's own charger does a good job on his sailboat.

Table 1. Measured Performance @ E-Labs (with 22 kΩ resistor for NTC)

V_{in}[V]	I_{in}[A]	V_{out} [V]	I_{out} [A]	P_{in}[W]	P_{out}[W]	Efficiency (%)
16	1.004	9.8	1.466	16.064	14.469	90.07
16	1.004	10.77	1.35	16.064	14.54	90.51
16	1.002	11.60	1.25	16.032	14.5	90.44
16.97	0.903	13.95	1.00	15.323	13.95	91.03
18.3	0.64	13.97	0.75	11.712	10.478	89.46
18.95	0.4	13.99	0.47	7.58	6.617	87.30

When the LT3652 is charging and assuming jumper JP1 is fitted, R10 is paralleled with R7, effectively setting the voltage at 14.4V. With jumper JP1 not in place, the maximum charge voltage is 14.1 V as required by some batteries, mostly of the gel variety. Check the manufacturer's specifications.
The LT3652 has a fixed switching frequency of 1 MHz, making it an extremely effective jamming transmitter. The prototype managed to block all VHF FM broadcast reception in our boat! The finished charger is much quieter because of a better PCB, shielding and Murata RFI filters (FILx) on the input, output and NTC connections.

The PCB

Since this is a switcher, PCB layout is critical. The PCB design produced by Elektor Labs [2] (**Figure 4**) follows the guidelines in the LT3652 datasheet and also uses "fat" traces whenever necessary. The LT3652 has an exposed pad that needs to be soldered to the PCB, and that area is connected to the reverse side of the PCB for cooling, via a cluster of vias, see also the considerations in the **inset** "Hot, hot". The PCB has to be mounted in such a way that its underside is in thermal contact with the metal enclosure. In the author's charger (**Figure 5**) the PCB is mounted on plastic standoffs, with an aluminum slab directly underneath the PCB. Note that the LT3652 has a built in thermometer that will lower the charge current in case of overheating.
Need more power? Just add panels, have one charger per panel and parallel the outputs!

Notes on efficiency

Losses in this circuit are caused by several factors. Some are within our control; others, not—or not easily. We have the loss caused by R_{DSon} in T1—in this case, around 40 mW, little we can do about that. Likewise, the forward drop of the LT3652 and the loss in D8—both are difficult to control let alone avoid.
Happily there are two factors well within our tech governance. One is the resistive losses in L1—the inductor chosen here is good for a whopping 11 amps and that might seem overkill. A much smaller 2.1-A inductor would work just fine, but then it has a series resistance of 170 mΩ—compare that to the 14.6 mΩ of the 11-A inductor. So the smaller inductor, if chosen, would dissipate close to 0.7 watts at 2 amps where the larger one only dissipates 46 mW. The other factor is resistive losses in C4, C5, C6—yes, the output capacitor(s). They should be selected for high current-carrying capacity and low ESR.

Happy Sailing — RV'ing — Chilling — Outdoor'ing!

(130145)

Other measurements

Jumper (JP1) not fitted:

- charging stops at 14 V (14.35 V if PCB hot);
- Charging resumes when voltage drops to 13.9 V;
- After switch-on, with pure resistive load on output: 2 V at output (0.3 A) until voltage rises to 9.5 V (0.28 A at 9.0 V), then voltage and current rise to 9.8 V; 1.44 A.

Jumper JP1 fitted:

- charging stops at 14.2 V (14.56 V if PCB hot);
- charging resumes when voltage drops to 13.9 V;
- After switch-on, with pure resistive load on output: 2 V at output (0.3 A) until voltage rises to 9.7 V (0.28 A at 8.6 V), then voltage and current rise to 9.88 V; 1.43 A.

Web Links

[1] www.linear.com/product/LT3652
[2] www.elektor-magazine.com/130145