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# Introduction

Voltaic Systems has partnered with Young Circuit Designs to develop a lithium-ion / lithium-polymer and LiFePO<sub>4</sub> MPPT solar charge controller. In the same vein as Sparkfun's [Sunny Buddy](#) and Adafruit's Solar Lipoly [Charger](#), it has the ability to efficiently charge a single-cell lithium polymer battery from solar. Beyond that, the TI bq24650 chip gives it more flexibility in both the input MPP voltage range and output battery configurations and chemistries.



Figure 1: Voltaic's Lilon / LiFePO<sub>4</sub> Solar Charger

To get started you'll need a solar panel with an

output voltage greater than that of the battery, so for Voltaic's standard panels which run at 6V, you can charge a single-cell LiPo or LiFePO<sub>4</sub>. With our 18V panels, such as the 9W or 17W, you can charge a 1S, 2S, and 3S LiPo, or 1S, 2S, and 4S LiFePO<sub>4</sub>, or even a 12V lead acid.

## Input Configuration

### Solar Panel Selection

The input voltage maximum to the board is 28V, so as long as the open circuit voltage of panel is below this, it is compatible with this charge controller. When choosing a solar panel, it is important to note:

1. the maximum power point voltage
  - a. this will determine the voltage of the left knob
  - b. it should be slightly higher than the voltage of the battery for reliable operation
2. maximum power output
  - a. power is equal to voltage x current
  - b. the maximum current into the battery without modifications is 2A

### Physical Connectors

There are 3 physical connection options for powering the controller, all of which are connected electrically so make sure not to connect a panel while a micro-USB input is already plugged in. The first and most prominent input is the 5.5x2.1mm barrel jack. To use this with Voltaic's solar panels, you'll need a 3.5x1.1mm to 5.2x1.1mm [adapter](#). Of course, if you choose to use a panel with a different type of connector, you can find the appropriate adapter, or strip the wires and solder on a [screw terminal](#) to the second input. The final input is a

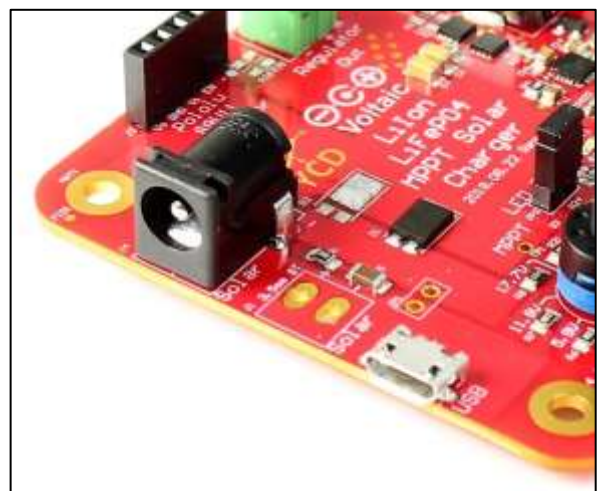


Figure 2: Input connectors

micro-USB, intended for use with a standard 5V source such as from a wall adapter.

## MPP Voltage

Depending on your input supply, whether that's a solar panel or a micro-USB, you'll need to select the correct MPP voltage using the left rotary switch. Make sure both the battery and solar panel are disconnected before adjusting any switch. These switches can be turned by hand, with an additional [knob](#), or with a flathead screwdriver. We have a [blog post](#) written all about choosing the MPP voltage, but it's very simple if using panels from Voltaic. For all the 6V panels, use the 5.9V setting, and for our 18V panels, use 17.7V setting.



Figure 3: MPP Voltage Selection Dial

If using a panel from elsewhere, take a gander at the article and if necessary, solder on a custom resistor (SMD 0805 size) at reference designator R10 'custom' to select an MPP voltage not already on the board – see figure at right.

To figure out what resistor to use for a custom MPP voltage, use the equation found on page 13 of the TI bq24650 [datasheet](#):

$$V_{MPP} = 1.2V * \left(1 + \frac{R3}{R4}\right)$$

where  $R4$  is  $10k\Omega$ , and  $R3$  is the unknown resistor value. For example, if you want to use 15V as your MPP voltage, then you can rearrange the equation to be:

$$R3 = R4 * \left(\frac{V_{MPP}}{1.2V} - 1\right)$$

so that  $R3$  is  $115k\Omega$ , and you'd solder on a resistor of that value onto the R10 pads.

To charge from a standard 5V source such as from a USB port, turn the rotary switch to 4.8V USB. Either a USB-microUSB wire or Voltaic's 5.5x2.1mm [wire](#) can be used.

You'll want to turn the rotary switch to the correct setting before connecting power to the input.

## Output Configuration

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### Compatible Batteries

The TI bq24650 chip at the heart of the board supports charging lithium polymer, lithium iron phosphate, and lead acid battery chemistries. The default options for these include lithium polymer for 1S, 2S and 3S configurations, as well as lithium iron phosphate (LiFePO<sub>4</sub>) for 1S, 2S and 4S configurations. A custom battery voltage can be selected, with similar modifications to choosing a

custom MPP voltage; the only difference being there aren't NP solder pads so an existing resistor must be desoldered first.

The equation (found on page 12 of the datasheet) is:

$$V_{battery} = 2.1V * \left(1 + \frac{R2}{R1}\right)$$

where R1 is 100kΩ. For example, if a 12V lead acid battery were to be charged with this controller, the standard output voltage would be 14.4V. Solving this equation for R2, we get that it should equal 586kΩ. Replacing one of the resistors around the right rotary switch with a 586kΩ resistor will allow that setting to charge a 12V SLA battery – though the 4S LiFePO4 setting will work as well.

**The battery voltage must be less than the voltage of the solar panel, i.e. you cannot charge a 12V lead acid from a 6V panel.**

### Physical Connectors

The top right is a 2mm JST connector, which is common for lithium polymer cells. Keep in mind that this connector has a 2A maximum, and that the polarity of the connector can be different – check the silkscreen! Beneath it are solder pads for a 3.5mm screw terminal – the same as for input.

### Regulated Output

Finally, there is a header for an optional regulated output using a Pololu SgV11x Step-Up/Step-Down Voltage Regulator. Plugging this in will allow for a regulated 3.3V or 5V output at the screw terminal at the top of the board. There is no voltage at the regulated output screw terminal unless a SgV11x regulator is inserted to the female header. The details and features of this setup will be covered in a later [section](#).

## Additional Possibilities

### Power Measurements

The jumper pads at J1 and J2 can be used to measure input and output power, respectively. To use them, cut the trace on the back of the board connecting the through-holes (see bottom figure at right), which will sever the connection either into or out of the board depending – J1 is in, J2 is out. An ammeter and voltmeter can be connected across these points to read current and voltage, which when multiplied together will equal power in/out.

It's important to note that due to the sensitivity of the bq24650 chip to series resistance, the contact resistance out of the



Figure 4: Front and rear view of JP1

board due to inline ammeter measurement could affect charging times, as well as how full the battery is charged to.

## LED Disable

This jumper is for enabling or disabling the LEDs. There are two LEDs on the board that are connected to the STAT1 and STAT2 pins of the bq24650 chip. STAT1 corresponds to the top, red LED and if it is lit, it shows that the battery is charging. STAT2 corresponds to the bottom green LED and if it is lit, it shows that the battery is done charging. These two LEDs consume about 10mA each, which can add up if the board is deployed in low-energy conditions. To disable them, simply remove the jumper short. To limit the current at the expense of LED brightness, change R18 and R19 to a higher value.

Note that the red LED will be on if the input voltage is lower than the MPP voltage setting, even if the battery is not charging. For example, if the MPP voltage is set to 5.9V but plugged into a 5V USB, the red LED will turn on but nothing will charge.

## Charge Disable

You can disable charging at any time by applying a signal (between 2V and 8V) to TP2. If using an Arduino or other digital input, be sure to connect the microcontroller board's ground to the MPPT board's TP5 ground as well.

## Temperature Monitoring



Figure 5: R23 embedded thermistor

There is an embedded NTC 10k thermistor at R23. This will stop the charging process when the temperature is below  $-40^{\circ}\text{C}$  or above  $60^{\circ}\text{C}$ .

**WARNING:** Charging batteries at low temperatures can be hazardous and degrade the life of the battery. Lithium ion and LiFePO<sub>4</sub> batteries should not be charged below  $0^{\circ}\text{C}$ . Lead acid batteries should not be charged below  $-20^{\circ}\text{C}$ .

If you want to use an external thermistor that is put against the battery cells to monitor them, you can desolder R23 (circled at left), and solder the external thermistor leads to TP3 and TP4 (arrows at left). This is similar to the [instructions](#) given by Adafruit on their own charger.

## Pololu SgV11x Regulators

[Pololu](#) offers a family of [regulators](#) that can supply a constant 3.3V or 5V output. While a number of them will work with our header, this guide specifically documents the usage of the [SgV11F3S5](#). All details on its usage are on the link, but also summed up below:

The regulator should be soldered be with straight male header pins. It can then be inserted into the corresponding female header at the top of the board. The correct orientation is so that  $V_{out}$  is on the left side, and the regulator is over the solar charge board – see [figure](#) below.

The operating voltage range of this regulator is between 2V and 16V. It needs 3V to start-up but afterward can regulate up from 2V, though this is below any battery cell voltage that the default board supports. The 16V is likewise higher than any battery cell voltage, but if using custom voltages, please keep this in mind as it will damage the regulator. Also keep in mind that depending on your circuit, LC voltage spikes can occur and go above 16V, so please be [careful](#).

The default output of this regulator is 3.3V but setting the SEL pin high will enable 5V. To do this permanently, you can solder SEL to the small unpopulated pad beside it.

The default state of the EN pin is pulled up to  $V_{IN}$ . It is possible to set a custom enable voltage by creating a voltage divider between  $V_{IN}$  and EN. The regulator is enabled when EN is above 0.8V and is disabled when the voltage at EN is below 0.7V. Say we want a cutoff voltage of 3.0V for a 1-cell lithium-polymer battery. Using the voltage divider equation:

$$EN = V_{IN} * \left( \frac{R25}{R25 + R26} \right)$$

and substituting in the desired values, we find that:

$$3.2857 * R25 = R26$$

Resistor values satisfying this equation should work.

There are other regulators in the family that have built-in potentiometers to adjust for different cut-off voltages, which save you this step.



## Example Usage

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Figure 6: Example setup with panel, cells, and regulated output to microcontroller.

This example setup uses Voltaic System's 3.5W [panel](#) to charge LiFePO<sub>4</sub> cells, which then power a PyCom FiPy through the Pololu regulator mentioned in previous sections.

The board is set at 5.9V MPP on the left dial, and 1S LiFePO<sub>4</sub> 3.7V on the right dial.

Depending on power consumption of the FiPy, this setup could be run independently for long blocks of time as the board maximizes solar power and transfers this power with high efficiency to the battery cells.

## Troubleshooting & FAQs

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My board is pulsing the charge

The board has a termination current of 200mA, which is 1/10 of its maximum programmed current at 2A. For smaller batteries, this termination current is relatively high. This means that the battery will



start to charge at a rate higher than 200mA, but slow to 200mA much faster than a large battery and way before its close to full, terminating the cycle. Then when the battery relaxes and the voltage drops, the charging starts again. This way it cycles on and off.

We've seen this issue with batteries in the 1S LiPo 300mAh range. One possible way to rectify this is to change the maximum charge current by switching out to  $R_{sense}$  to a different value and lowering the termination current.

### Neither LED turns on

Check that the LED jumper short is connected and see that a battery is connected. The LEDs will not turn on if there is an absent battery or if charging is terminated either by temperature or the !EN test point at the bottom left of the board.

### How do I change the maximum current?

The default maximum current is 2A. However, this is modifiable according to the equation found on page 13 of the datasheet:

$$I_{CHARGE} = \frac{40 \text{ mV}}{R_{SR}}$$

The sense resistor at R2 is 20mΩ, but switching it out to 10mΩ will give a 4A max, and so on and so forth. Keep in mind all the maximum currents of the components in the BOM. The bare PCB is designed to charge at up to 6A into the battery with component modifications. Here are some example configurations that are a good starting point for changing charge current (note: PCB is made with 2oz copper, and be sure to validate any change you make with calculations and testing):

1A Battery Charge Current: Change R2 to 40mOhm, L1 to 15uH (consider Eaton DR127-150-R).

(Lowering charge current is helpful for smaller batteries since it also lowers the charge cutoff current to 10% of charge current, e.g. 1A charge current sets a 100mA cutoff threshold).

4A Battery Charge Current: Change R2 to 10mOhm, L1 to 6.8uH (consider Eaton DR127-6R8-R), add a PDS1040 diode at D2, and use a 4A-rated battery connector (not the JST battery connector).

5.7A Battery Charge Current: Change R2 to 7mOhm, L1 to 4.7uH (consider Eaton DR127-4R7-R), add a 10uF 25V X5R cap at C7, add a PDS1040 diode at D2, solder a wire across JP2, and use a 6A-rated battery connector (not the JST battery connector).

# Specifications

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- Minimum voltage in: 4.8V
- Maximum voltage in: 28V
- Maximum current: 2A into the battery
- Temperature range: -40°C to 60°C (see warning above regarding low temperatures)
- Default MPP voltages:
  - 5.9V
  - 11.8V
  - 17.7V
  - 24V
  - 4.8V USB
  - Custom
- Default Battery options:
  - Lithium-Ion / Lithium-polymer
    - 1S 4.2V
    - 2S 8.4V
    - 3S 12.6V
  - Lithium iron phosphate (LiFePO<sub>4</sub>)
    - 1S 3.6V
    - 2S 7.2V
    - 4S 14.4 V
  - 12V lead acid
    - Equivalent to 4S LiFePO<sub>4</sub> 14.4V
- Input connectors:
  - microUSB
  - 3.5mm solder pads, compatible with these [terminals](#) (not included)
  - 5.5x2.1mm barrel jack
- Output connectors:
  - 2mm JST
  - 3.5mm solder pads, compatible with these [terminals](#) (not included)
  - 3.5mm screw terminals (if using [regulator](#))