

# Lithium Ion Pack

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This project is an open-source Lithium Ion Battery Pack charger and management system. Over the years, I have used many Lithium Ion cells and struggled over the exact workings of **smart-charging** and **cell balancing**. These terms are thrown around as to create a magic around the lithium ion battery charging process. The schematic, although very intricate can be broken down into **three** major components:

1. The battery charging circuit.
2. The battery balancing and protection circuit.
3. The voltage and current measurement circuit.

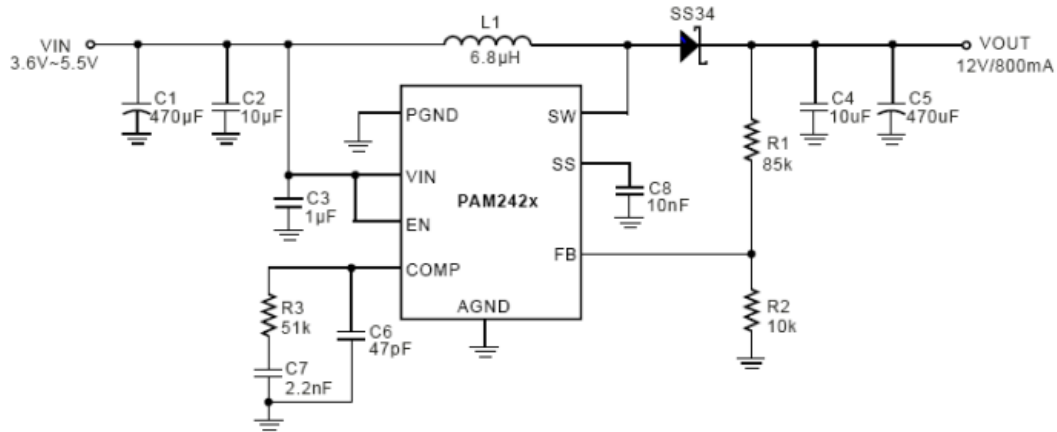
## The Battery Charging Circuit

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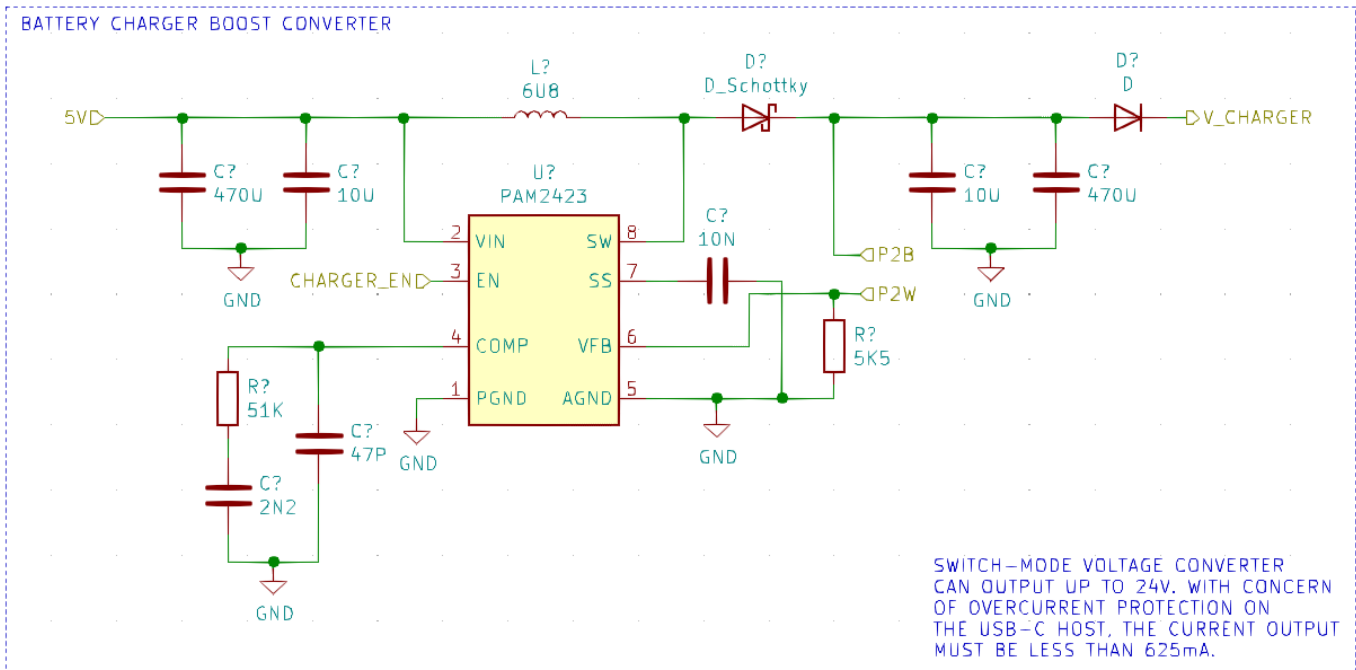
I have used many battery charging Integrated Circuits in the past and have never been able to fully conceive what is going on behind the curtains of the larger devices which charge multiple cells. In fact, the basics *seem* very simple. Constant current until you achieve a specific voltage. Constant voltage until you stop after a certain time, giving the batteries a moment to “top-off”.

This battery pack is able to charge via a USB-C type port, which is a standard USB2.0 port used for Virtual Communications over USB. Since it's a standard USB2.0 connector inside of USB-C, only 5V is input to the device. The included Boost converter then steps-up the voltage through the [PAM2423](#) DC-DC step-up voltage regulator. While this step-up regulator is capable of producing output voltages of up to 24V, the circuit is controlled by the feedback resistor network.

## Typical Applications Circuit



Since the resistor network can be controlled by a resistor network, I propose controlling the output voltage through the use of a digital potentiometer, [MCP4351](#). This device is essentially a digitally controlled resistor divider through SPI communications.



When calculating the possible output voltages using only the resistor divider network, the following equation dictates the output voltage (*datasheet, pg. 6*):

$$V_{out} = \left( \frac{R_1}{R_2} + 1 \right) * 1.262 \quad (1)$$

The MCP4351 has a total different number of 257 different positions or “taps” that the potentiometer can place the “wiper”. The resistor divider network’s is calculated as follows (*datasheet, pg. 43*):

$$R_{aw} = \frac{100 * 10^3 * n}{256} + 75$$

$$R_{wb} = \frac{100 * 10^3 * (257 - n)}{256} + 75$$

$$R_{aw}(0) = 75\Omega$$

$$R_{wb}(0) = 10.465k\Omega$$

$$R_{aw}(257) = 10.465k\Omega$$

$$R_{wb}(257) = 75\Omega$$

Therefore, the the output voltage of the converter can be expressed as an quadratic with an asymptote, where  $R_1 = R_{aw}$  and  $R_2 = R_{wb}$ :

$$V_{out}(n) = (100 * 10^3 * \frac{n}{257 - n} + 1) * 1.262V$$

$$V_{out}(0) = 1.262V$$

$$V_{out}(257) = \infty$$

Obviously, this equation poses a serious issue, infinity is not possible when the maximum allowed output voltage of the switching regulator is 24V. In order to combat this issue, only half of the wiper will be used. Since the wiper position at instruction 000h for  $R_{wb}$  is 0 Ohms, only the bottom half of the resistor divider in the MCP4351 and a static 5.5kOhm resistor will be used as follows:

$$V_{out}(n) = (\frac{100 * 10^3}{256} * \frac{n}{5.5 * 10^3} + 1) * 1.262V$$

$$V_{out}(0) = 1.262V$$

$$V_{out}(257) = 24.30V$$

Creating the resistor divider this way with a fixed resistor on the bottom half of the feedback network creates a linear equation, which allows for more granularity. In fact, the minimum granularity between each LSB sent to the digital potentiometer is:

$$V_{out}(1) - V_{out}(0) = 1.352V - 1.262V = 89.63mV$$

The resistor feeding the battery cells is 5 Ohms, which dictates current steps into the battery pack per change in voltage:

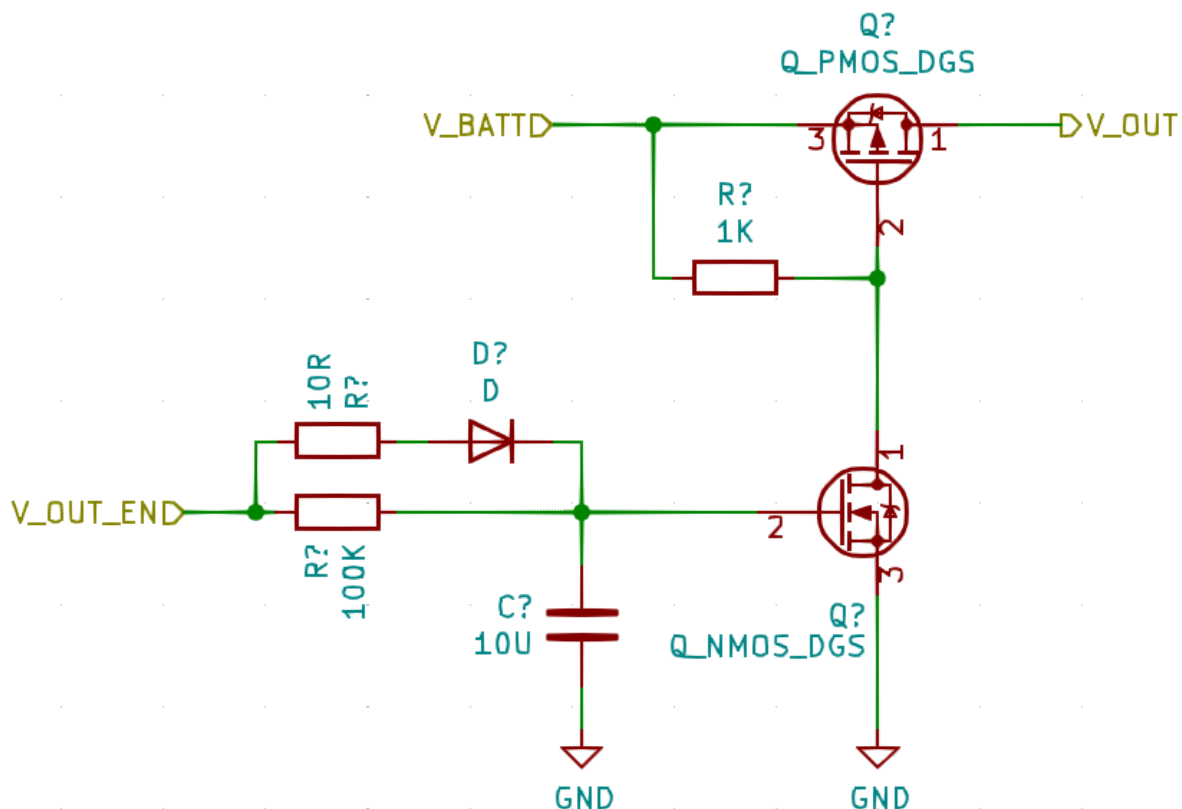
$$I_{charge} = \frac{89.63V}{5\Omega} = 17.93mA \quad (6)$$

This makes the current granularity small enough to manage on a larger scale and easier to manage from the current regulation PID controller. One thing to note in this setup is that due to the maximum wattage of the resistor of 5W, the device is only capable of sourcing up to 1 Amp into the battery pack. Which results in the following number of maximum voltage steps to the voltage regulator:

$$n_{volts} = \frac{I_{chg} * R_{chg}}{89.63mV} = \frac{1A * 5\Omega}{89.63mV} = 55.8 \text{ steps truncated} = 55 \text{ steps} \quad (7)$$

## The Battery Balancing and Protection Circuit

While most IC's use a standard common drain N-Channel MOSFET pair to protect the battery pack, I am going with an easier approach to battery protection, with a P-Channel MOSFET. The gate is held high with a pull-up resistor until the device monitors an overcurrent/over-discharge condition. Otherwise the circuit features a soft-start turn-on with the help of a slow RC circuit with a fast discharge diode. Similar to that of a unstable 555 timer circuit.



When the signal to the N-Channel MOSFET is sent, it slowly charges the gate capacitor through the 100 kiloOhm capacitor. The RC time constant is 1 second. In the event of a fault - overcurrent, overdischarge or undervoltage - the capacitor quickly discharges through the 10 Ohm resistor through the diode. Once the forward voltage of diode is reached, the capacitor continues to discharge through the 100K resistor until completely discharged. This feature allows a rapid turn-off circuit and a slow turn-on circuit in the case of a close-onto-fault scenario.

#### TODO:

- ☐ Continue editing this document
- ☐ Assemble and build prototype
- ☐ Revise design after basic testing
- ☐ Verify programming and charging operation
- ☐ Cycle battery discharge/charging