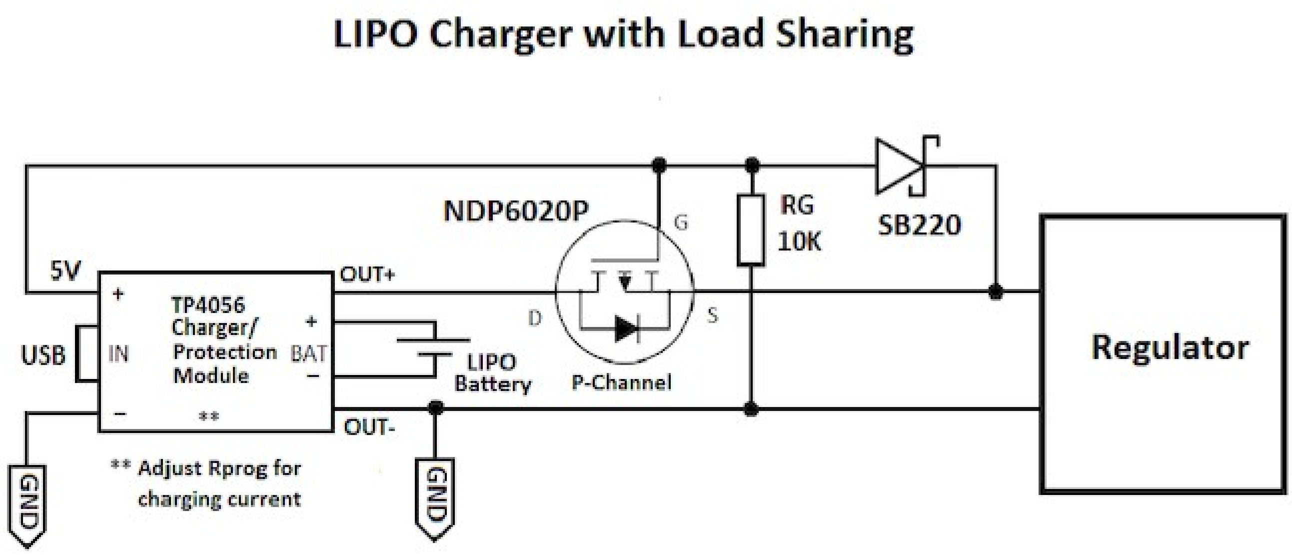
Solar Charger Load Sharing

TLDR: A typical 5V USB-powered LIPO charger should have a "load sharing" circuit added, which allows the input supply to power the load directly rather than going through the charger. The circuit consists of a logic-level P-channel mosfet, a Schottky diode, and a resistor. But such a circuit does not work well when using a solar panel to power the circuit. That's because the input voltage varies with sunlight intensity rather than being fixed at 5V. In the daytime, the circuit acts like a two-diode model, with the second diode being the mosfet's body diode, and this causes a significant Vf voltage drop in the battery line. The mosfet turns on, and the Vf is bypassed, only at night. The Vf drop is reduced if a second Schottky is connected across the mosfet in parallel with the body diode. However, a circuit which uses an opamp to control the mosfet gate produces no voltage drop at all, so the output voltage is never lower than the battery voltage.

There are many inexpensive 5V-powered charger modules available for single-cell lithium batteries. Here's an example which also includes battery protection circuits. It uses the TP4056 charger IC:

However, if such a module is used in a battery backup system which powers a project load, a "load sharing" circuit (also called "power path") should be added so that power for the load will be directly provided by the 5V supply when it is plugged in, rather than powering the load through the charger. The load sharing circuit consists of a logic-level P-channel mosfet, a Schottky diode, and a resistor. Here's an example circuit:



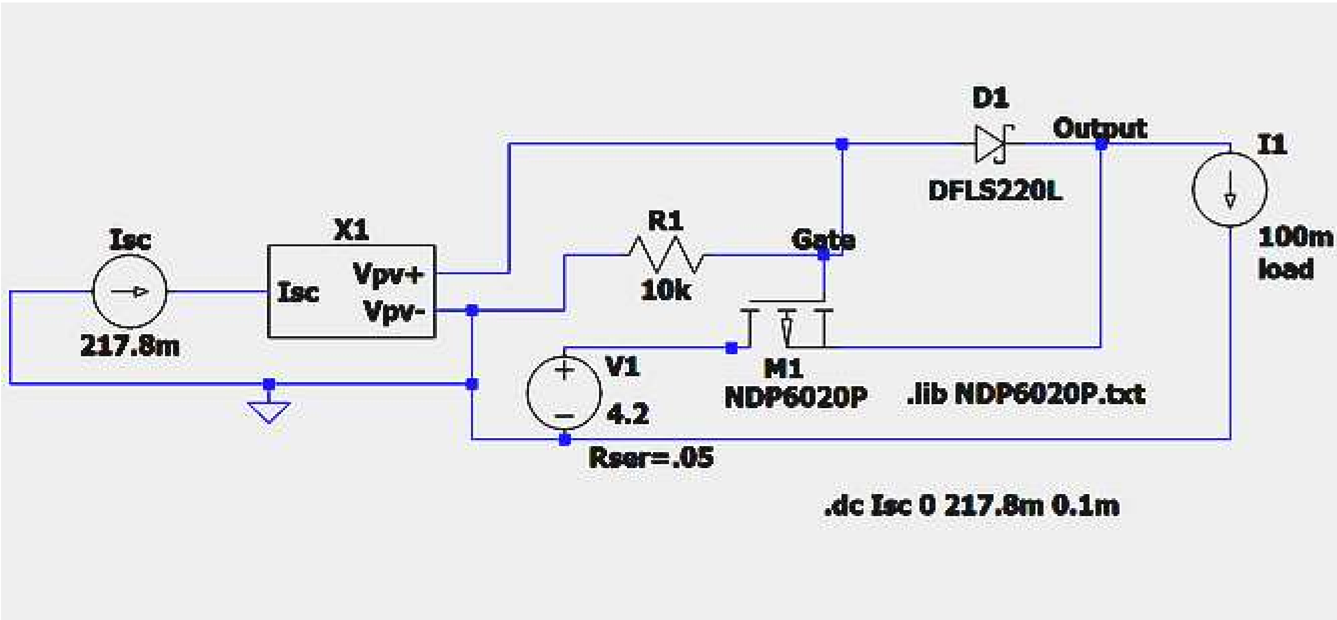
The mosfet takes the place of what would be a second diode in the battery path, and has almost no voltage drop. All of this is explained in a video I contributed to my local Open Source Hardware Group:

https://www.youtube.com/watch?v=T70mBHeIOZA

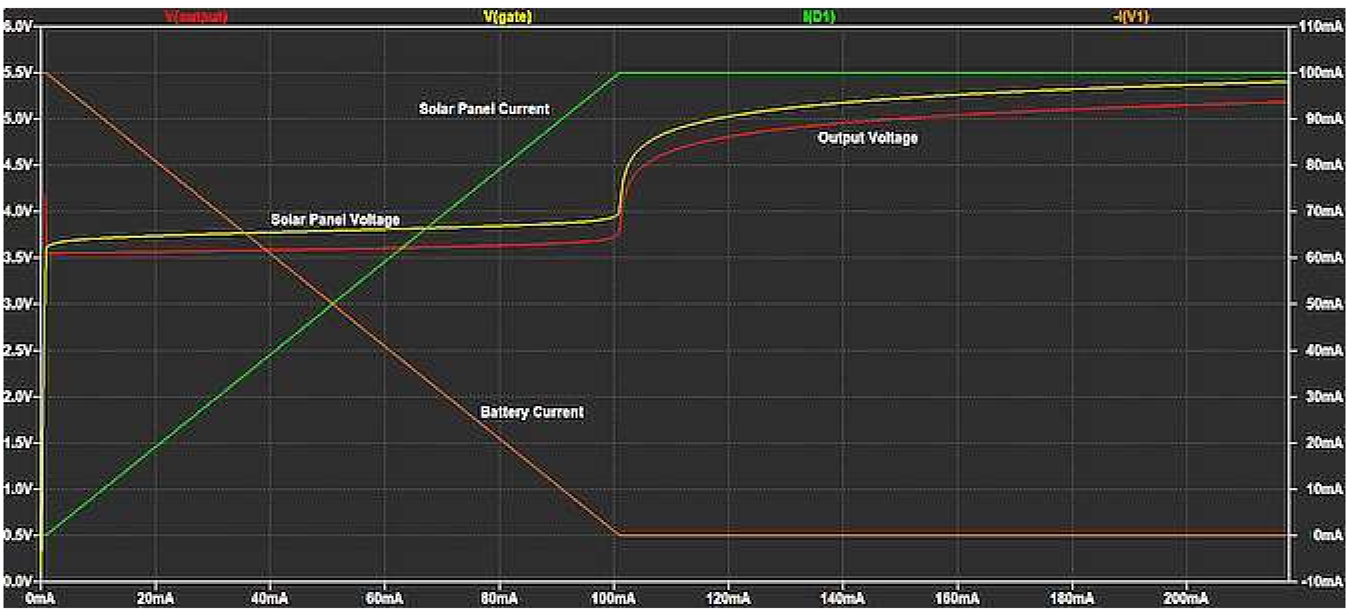
The load sharing circuit works with a standard 5V power input (USB or equivalent) because that power is either connected and supplying 5V with enough current to charge the battery and power the load, or it is completely absent. There's no in-between. The mosfet is either on, with the battery supplying all the load current, or off, with the input power supplying the load and independently charging the batttery if needed..

In the video I suggested that this circuit should not be used with solar power because the input power could wander, and it was unclear what would happen with the mosfet at intermediate supply voltage and current levels. What's presented here is an LTspice simulation of the load sharing portion of the circuit when powered by a 5.5V solar panel. It shows what happens when the input current (Isc), which is proportional to solar illumination, is swept from zero in the dark to the panel's short circuit current in full sunlight. The model for the solar panel ("X1" in the schematic) was obtained from a Youtube video, with adjustments made to match a specific panel available from Digikey.

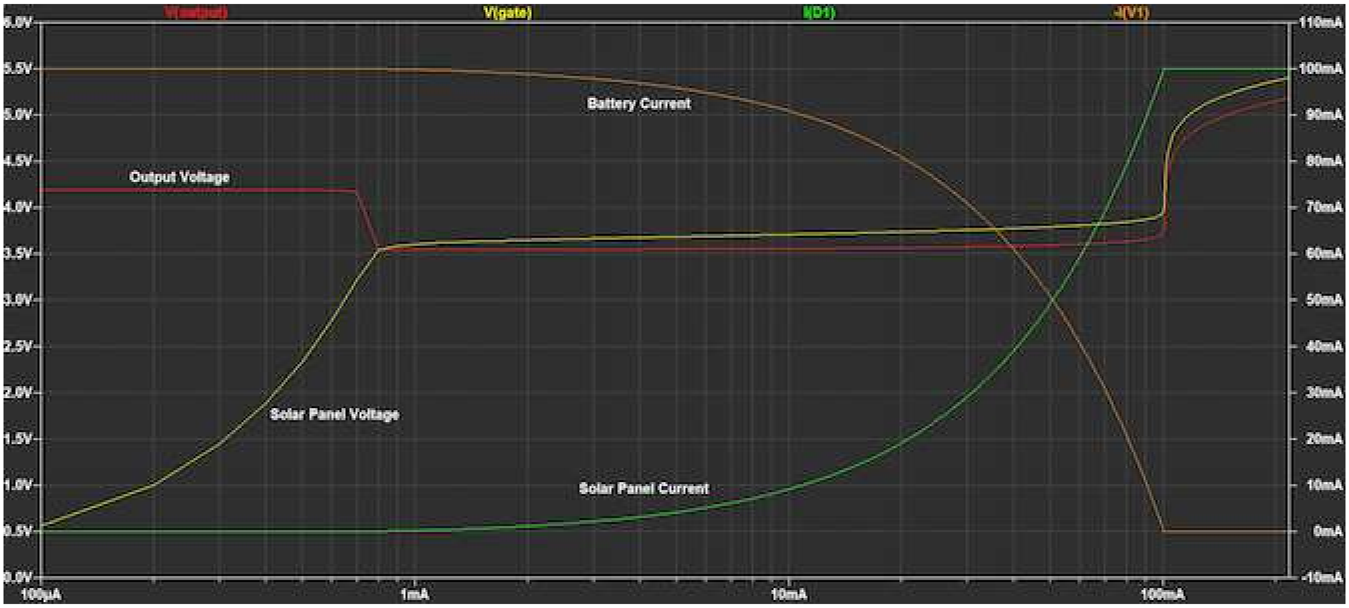
This is the schematic used. The charger is not included because I don't have a simulation available for the TP4056 charger. The battery is assumed to be fully charged at 4.2V, and the load current is fixed at roughly half the maximum short-circuit current of the panel.



And this is the DC sweep simulation with the illumination current on the X axis, and plots of the output voltage, solar panel voltage, battery current, and solar panel current:



Overall, the simulation shows that with increasing illumination the solar panel supplies more and more of the load current, and the battery supplies correspondingly less current. Barely visible at the very far left, when illumination is near zero, the output voltage is 4.2V, which is the battery voltage with the mosfet fully turned on. The entire load current is provided by the battery. But as the solar panel even begins to supply current, the output voltage drops to about 3.5V. That happens because the mosfet switches off, and all of the battery current now passes through the mosfet's body diode. Looking at a logarithmic display of this same simulation, we can see more clearly what happens on the far left:



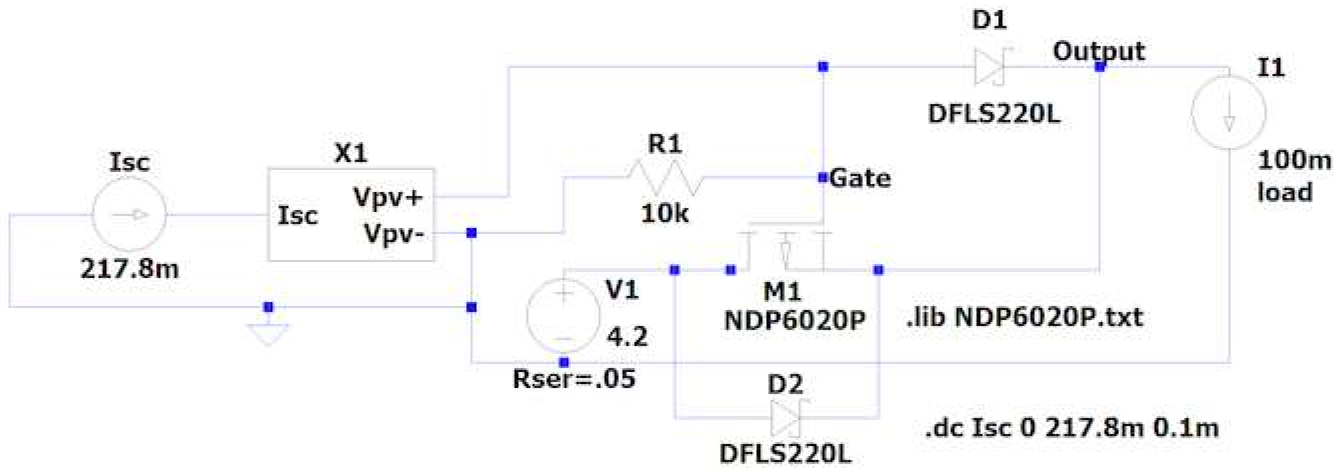
Remember that the solar panel voltage is also the mosfet's gate voltage, and the circuit output voltage is also the mosfet's source voltage. The 10K gate pulldown resistor current briefly delays the rise of the solar panel voltage. But when it gets closer to the output voltage, the Vgs threshold voltage (about 1V) is no longer met, and the mosfet shuts down. Battery current then passes through the body diode, which accounts for the 0.7V drop in output voltage.

This means that when the solar panel is providing any amount of current to the output, the mosfet will be turned off, and any current supplied by the battery will flow through the body diode. We know that must be true because if current is flowing from the panel through the Schottky diode, the diode's anode voltage must be 0.3V higher than its cathode voltage, and that means the mosfet's gate voltage must be 0.3V higher than its source voltage, so the mosfet will be forcefully turned off.

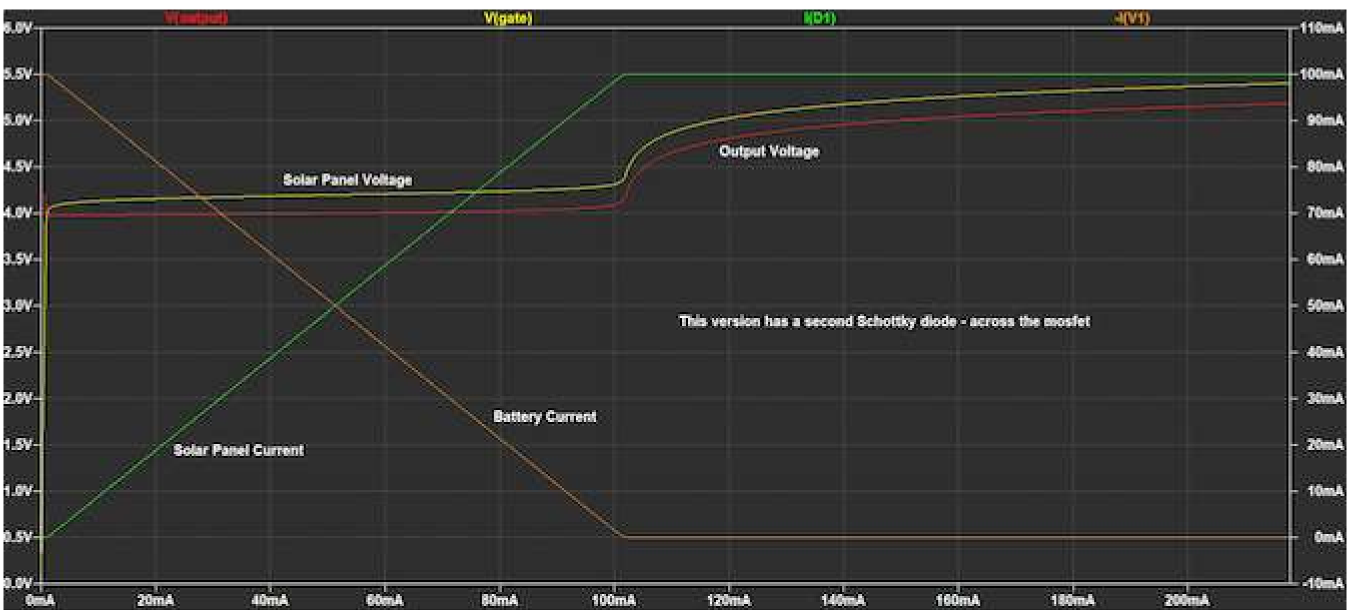
The bottom line is that for solar power this circuit is the same as a two-diode model - except at night. In total darkness, the mosfet turns on, and the diode voltage drop is bypassed. But in daylight, it's just the Schottky and the body diode carrying the current.

<u>Added Diode</u>

If avoiding the night time Vf drop is felt to be important, one should at least make the two-diode operation at all other times as efficient as possible. That can be done by installing another Schottky diode (D2 below) across the mosfet in parallel with the body diode. That effectively replaces the body diode with one which has a much lower Vf, so the output voltage under partial illumination would be almost 1/2 volt higher. Shown below are the schematic and simulation of this version. The only difference is the lower voltage drop under partial illumination. Also, remember that the charger is not included here. One would need to make sure the TP4056 charger works properly with this circuit.



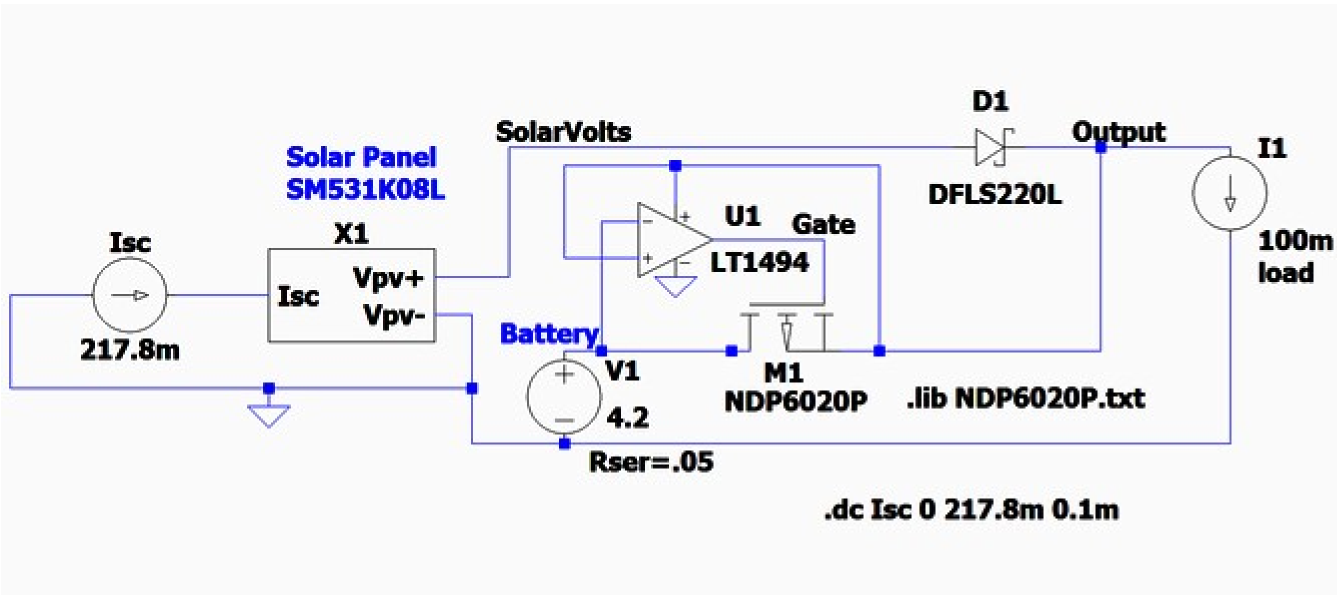
D1
Output
I1
DFLS220L
Isc
X1
R1
Gate
100m
load
Isc
Vpv+
Vpv-
10k
217.8m
V1
M1
NDP6020P
.lib NDP6020P.txt
4.2
Rser=.05
D2
DFLS220L
.dc Isc 0 217.8m 0.1m



V(output)
V(gate)
I(D1)
-I(V1)
Solar Panel Voltage
Output Voltage
This version has a second Schottky diode - across the mosfet
Battery Current
Solar Panel Current

OpAmp Version

The diode voltage drop can be eliminated entirely if an opamp is used to control the mosfet gate. The opamp inputs are connected to the circuit output (non-inverting input) and the battery (inverting input). If output voltage is lower than battery voltage, the opamp drives the gate to ground, which turns on the mosfet. Otherwise the opamp drives the gate high, which turns the mosfet off. Here are the schematic and simulation for this version:



The simulation shows that the output voltage never falls below battery voltage, so battery life will be maximized. Also note that even though the mosfet is wide open on the left half, the circuit behaves like a two-diode model in that the solar panel provides as mush load current as it can, and the battery supplies the rest.

The opamp chosen was the LT1494. It has ultra-low supply current - about 1uA - and the voltage on its inputs can extend to just above the upper rail. That means there's no need for resistor dividers or biasing of any kind that would draw current. The LT1494 is quite expensive at about $5.00, but the MCP6041 at $0.66 should also work (a Spice model for that part that works in LTspice is not available). Both opamps come in DIP packages and in the usual SMD packages.

All of these circuits are simulations only, and have not been physically tested. Also missing even from the simulations is the TP4056 charger. There's no obvious reason why the circuits wouldn't work with the charger in place, but that would need to be confirmed.

Conclusions

The opamp version is clearly the best performer, but would be more complicated to work into an existing TP4056 charger module. A two-Schottky circuit, with or without the mosfet, also works pretty well with a modest Vf drop, and if battery life isn't critical, that might be the best option. The mosfet decision may depend on what's downstream from this circuit. The biggest challenge to the battery would be in the morning when the battery voltage is at its lowest and partial illumination switches off the mosfet and reimposes the Vf drop before it's bright enough to begin charging. The mosfet's contribution during the night doesn't really help if the regulator is linear because the current draw will be the same no matter where the voltage drop occurs. But using a switching regulator would mean that any voltage drop in the battery line at any time of day or night has a real cost in terms of battery life. In that case, even a 0.3V drop will draw down the battery faster.

One can use one of the newer chips that are designed for solar power and have load sharing built in. But most of those are not available in hobbyist-friendly packages, or in convenient modules. So it's good that a proper circuit can be rigged up using readily available parts if that's needed.