Power Board
User Guide

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Introduction

The power board is composed of an ultralow power energy harvester and battery charger “SPV1050” from STMicroelectronics, a charger management controller “MCP3831”, a fuel gauge “STC3115” also from STMicroelectronics, an ultralow power buck converter from Texas Instruments “TPS62737” and finally an FTDI chip “FT230Q” that is a USB to UART interface.

The aim of this board is to power the system from an energy harvester. Being the most efficient and the most suitable for the application. The energy harvesting source used here is solar energy. The solar panel is used to charge a battery through the charger” SPV1050”. The voltage is then regulated by the TI buck converter “TPS62737” to supply the right power the nodes. The board can also be powered by USB to charge the battery (on startup for instance).

The board is optimized to harvest energy form the solar panel supplying 2.6V ≤ VMP ≤ 9V (VMP: voltage at maximum power point) and charges a battery with 3.1V undervoltage protection threshold and 4.2V end of charge threshold.

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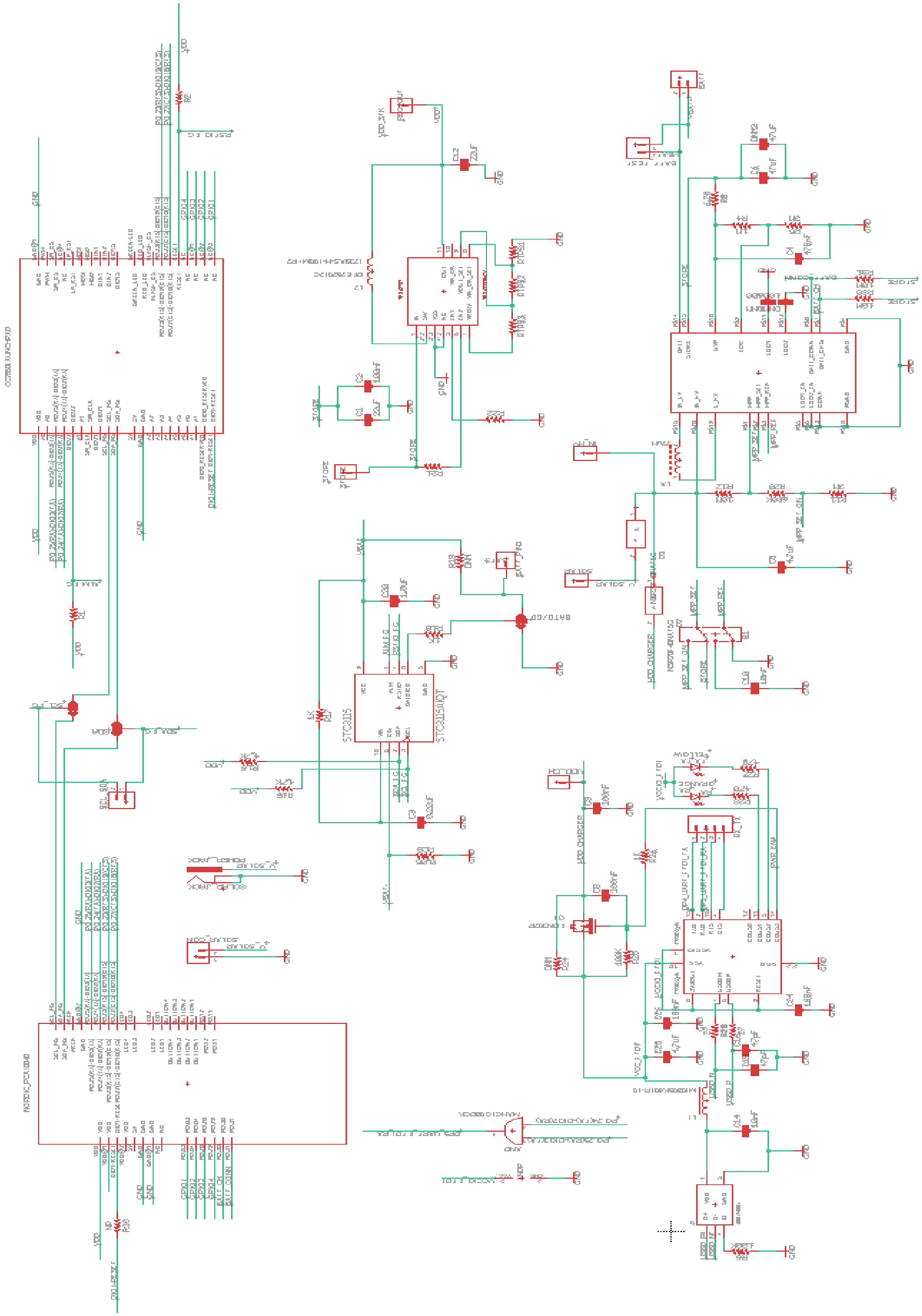
Description

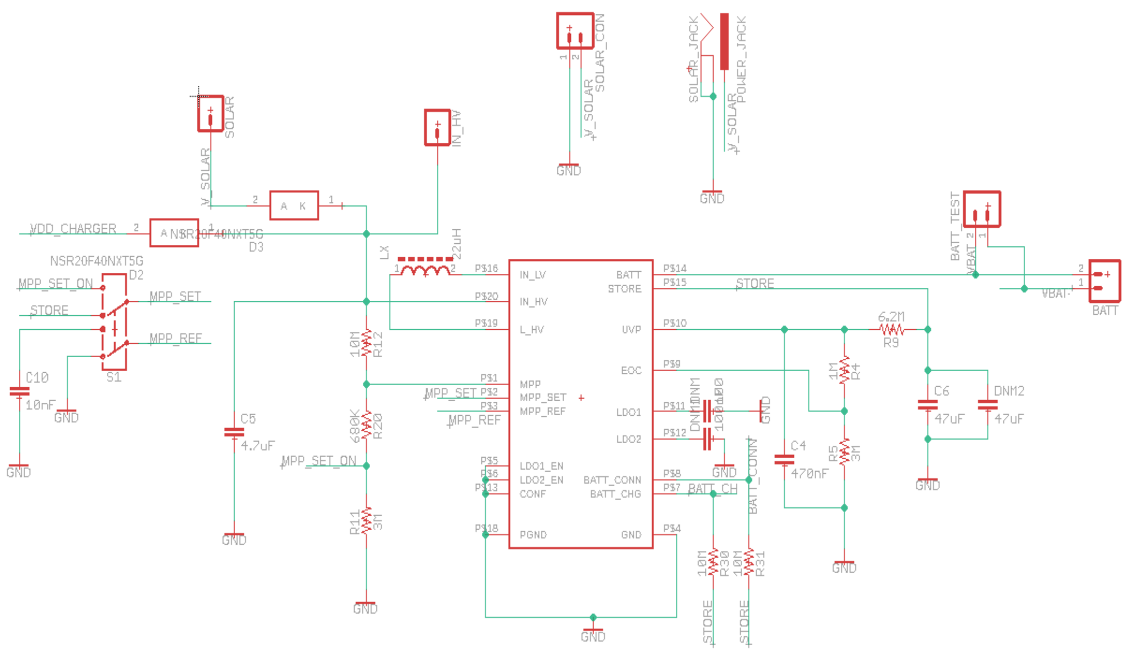
Charger

MaximIntegrated MAX17710, Texas Instruments bq25570 and STMicroelectronics SPV1050 were our last candidates. MAX17710 was the preferred one for it's simple use with a dual input sources (USB and Solar panel) that are both crucial for our application. After realizing that this device cannot support the battery used for the application, bq25570 and SPV1050 became our finalists. Both ICs had very close operating technologies with MPPT technique, the differences where Boosting method used to regulate the power that charges the battery: the TI device used a simple boost converter whereas the SPV1050 had two different configurations: Boost or Buck-Boost depending on the level of the input source. In addition, the SPV1050 has two independent LDOs as outputs, they regulate the power coming from the Battery or the source to the desired value (1.8V or 3.3V). On the other hand, on the output side, the bq25570 has a simple buck regulator. Since we are already using a programmable buck regulator (tps62737) that is more efficient than an LDO regulator, the regulated output of the charger was not important.



Board Schematic

SPV1050



Charger Schematic

The board has a jack connector as well as a screw terminal for the solar panel and a 2mm JST connector for the battery.

The SPV1050 has a DC-DC converter that is configured in buck-boost to regulate the power coming from the source (Solar panel) to charge the battery.

Since the IC has only one High Voltage input source for sources that supply 0.15V ≤ V_{in_HV} ≤ 18V and a low voltage input for sources that supply 0.15V ≤ V_{IN_LV} ≤ V_{EOC} (V_{EOC} : End of charge threshold which is 4.2), the High Voltage input is the one used for the two sources (Solar panel). The question of using one input source without having to manually remove the other is resolved by simply adding two

Schottky barrier diodes, to prevent one source from damaging the other or the board in the worst case.

V_{EOC} and V_{UVP} are set by setting the R4, R5, R9 resistors. V_{EOC} = 4.18V and V_{UVP} = 3.1V

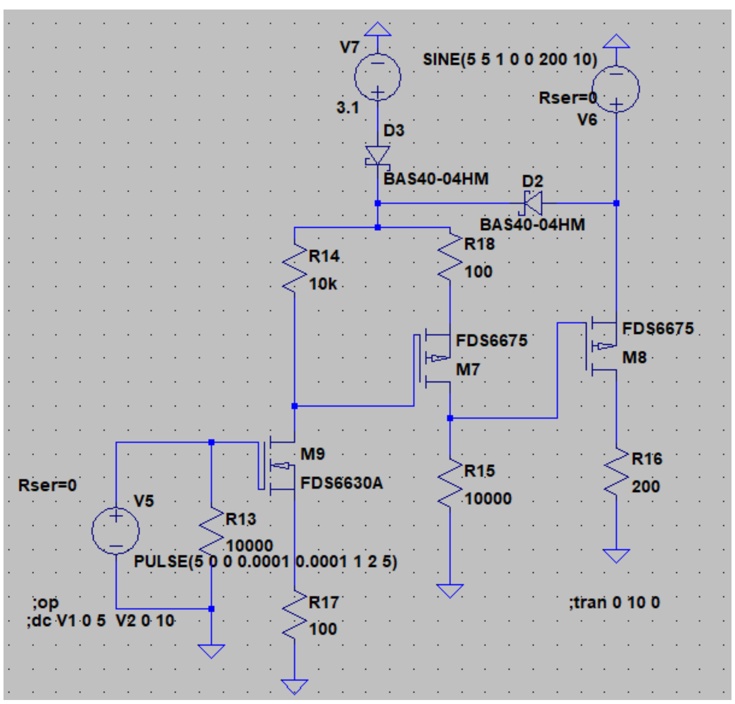
The IC also implements the MPPT (Maximum power point tracking) technique which aims to maximize power extracted from the solar panel.

The SPV1050 IC is equipped with two regulated outputs that are LDO1 and LDO2. It was more suitable for this application in terms of efficiency to use the unregulated output at STORE and regulate this output with the TI-tps62737 buck regulator than to use any of the two LDOs.

Charging from the USB (Ongoing work)

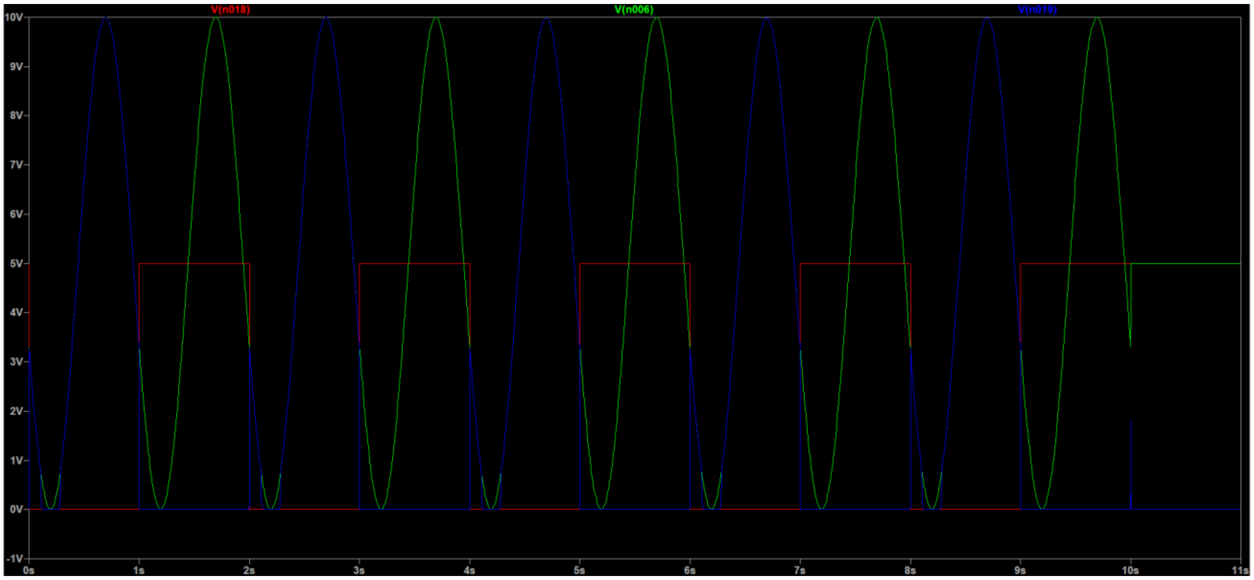
When the USB is the source input the battery should be charged through the MCP3831 charger, therefore the SPV1050 IC has to be disabled and the only way to do so is by preventing the Solar Panel from powering the SPV1050 chip.

Several approaches were tried to disconnect the Solar Panel from the system when the USB is plugged in. The first approach was to switch between the two power sources using discrete components. The circuit was simulated with LTspice.



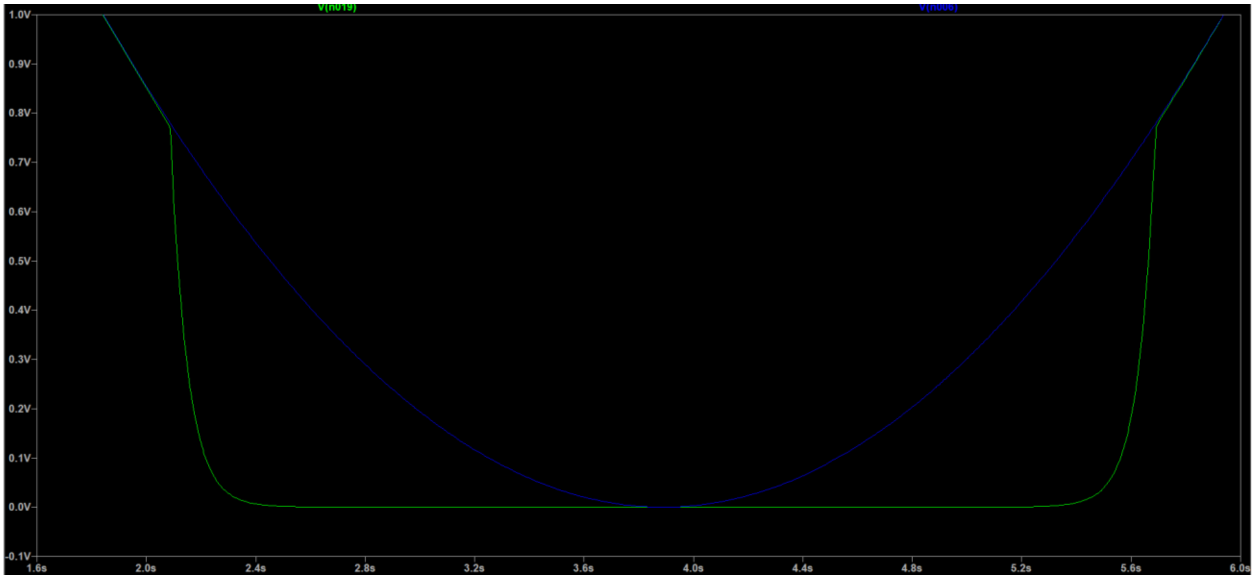
<u>First prototype of the switching circuit</u>

The M9 transistor is an N-channel MOSFET and the M7 and M8 transistors are P-channel MOSFETs. The R16 resistor represents the circuit load which will be the input of the SPV1050 (Solar Panel). The purpose of this circuit, as mentioned before is to for the voltage on R16 to come from the Solar Panel unless the USB is plugged in then the voltage on R16 must be 0.



Simulation of the first prototype of the switching circuit

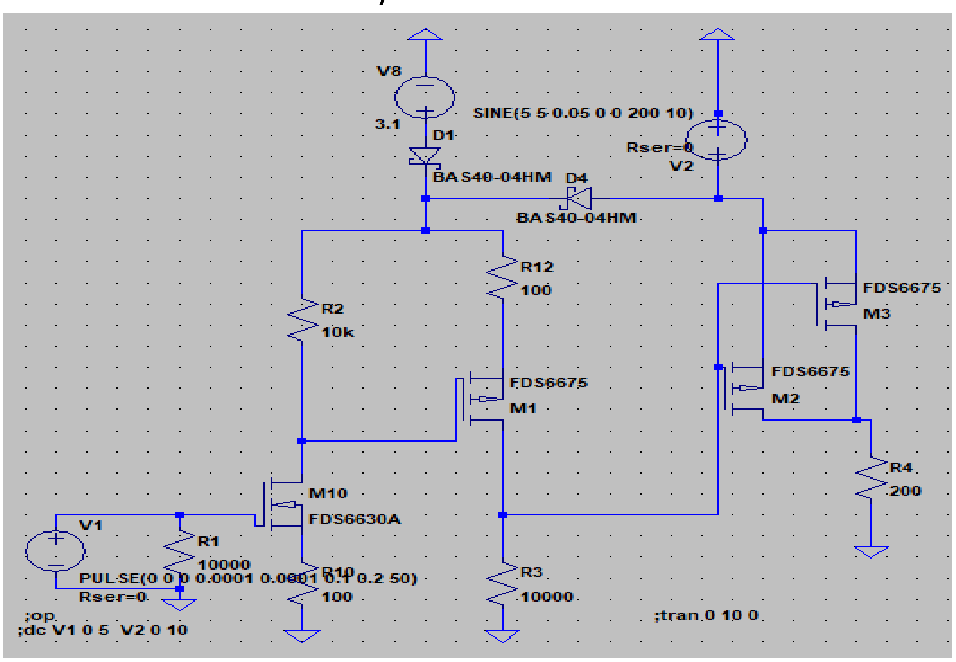
Here the red signal represents the USB signal is a periodic pulse with an amplitude of 5V representing periodic plugging and unplugging the USB. The green Signal was chosen to represent the Solar Panel behavior. The signal is a positive sinusoid with 10V amplitude. Finally, the red signal represents the SPV1050 input voltage. As we see, the circuit behaves like it is supposed to: When the USB is unplugged (red signal is 0V), The blue signal (SPV1050 source input) is equal to the Solar Panel voltage (green signal) while when the red signal (USB) is high (5V) the input of the SPV1050 (blue signal) becomes 0V. Nevertheless, an undesired behavior is noticed when the Solar Panel is providing a low voltage and the USB is not connected; At this point the M6 transistor is not fully open and the blue signal doesn't follow the Solar Panel voltage, instead it decreases rapidly. In this way, When the System is powered by the Solar Panel and its voltage is lower than 0.8V the input of the SPV1050 device is 0V and the battery isn't charging anymore.



Undesired behavior of the first prototype

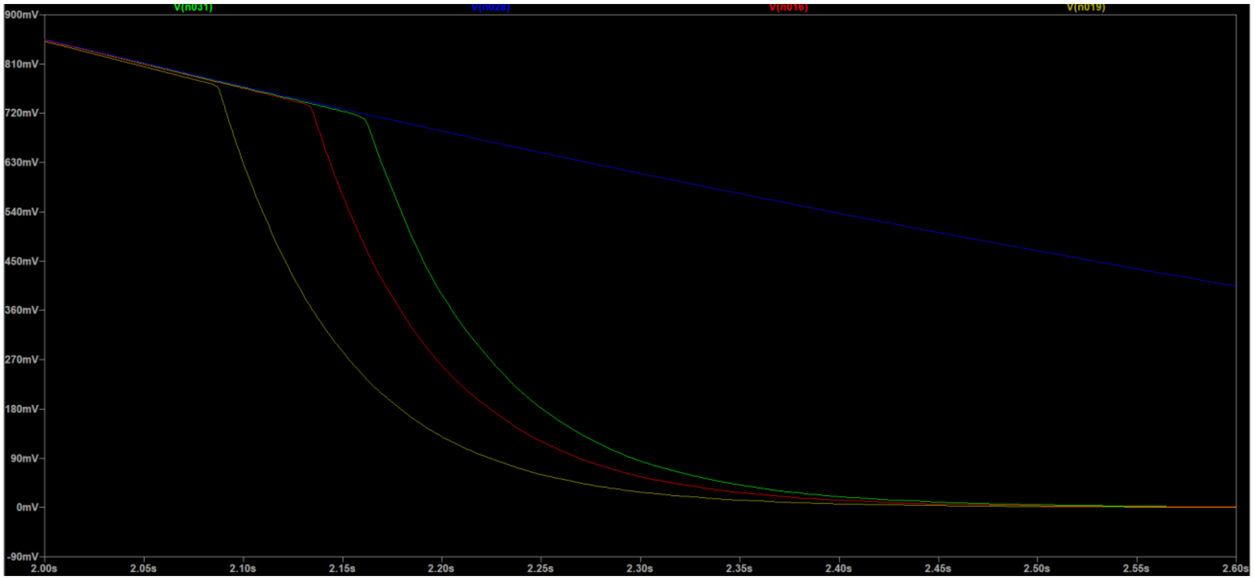
This behavior comes from the fact that at this time, the solar Panel voltage – which is the V_s (Source Voltage) of the M8 transistor- is too low that the V_{GS} threshold of the transistor is not reached.

A way to avoid this behavior was to add another p-channel MOSFET transistor in parallel to reduce the transistors internal resistances (R_{ds}) and let the current flow through the transistors more freely.



Second prototype of the switching circuit

When simulated and compared to the behavior of the first circuit, we see a slight amelioration, but the output still doesn't "follow" the Solar Panel voltage at all times when desired.



<u>Output behavior for different number of parallel transistors</u>

Here we when the Solar Panel signal (blue) is too low and approaching 0V how the circuit behaves: the yellow signal is the output signal of the first prototype, the red signal is the output of the second prototype which has a P-channel MOSFET in parallel with the M2 transistor. Finally, the green signal is the output of the circuit composed by 3 parallel transistors at the output. We clearly see that the parallel transistors ameliorate the behavior of the circuit, but even with 3 parallel transistors, the output drops at 710mV (green signal) instead of 780mV (yellow signal). In this case, even though the SPV1050 starts functioning at 150mV, it will not function until its input reaches 710mV.

A mechanical solution was then approached because of the lack of analog switch ICs that comply with our application (supply voltages, internal resistances factors are not met).

The mechanical solution consists of a simple relay commanded by the USB voltage in a way that it connects the Solar Panel to the SPV1050 IC and disconnects it when the USB is plugged.

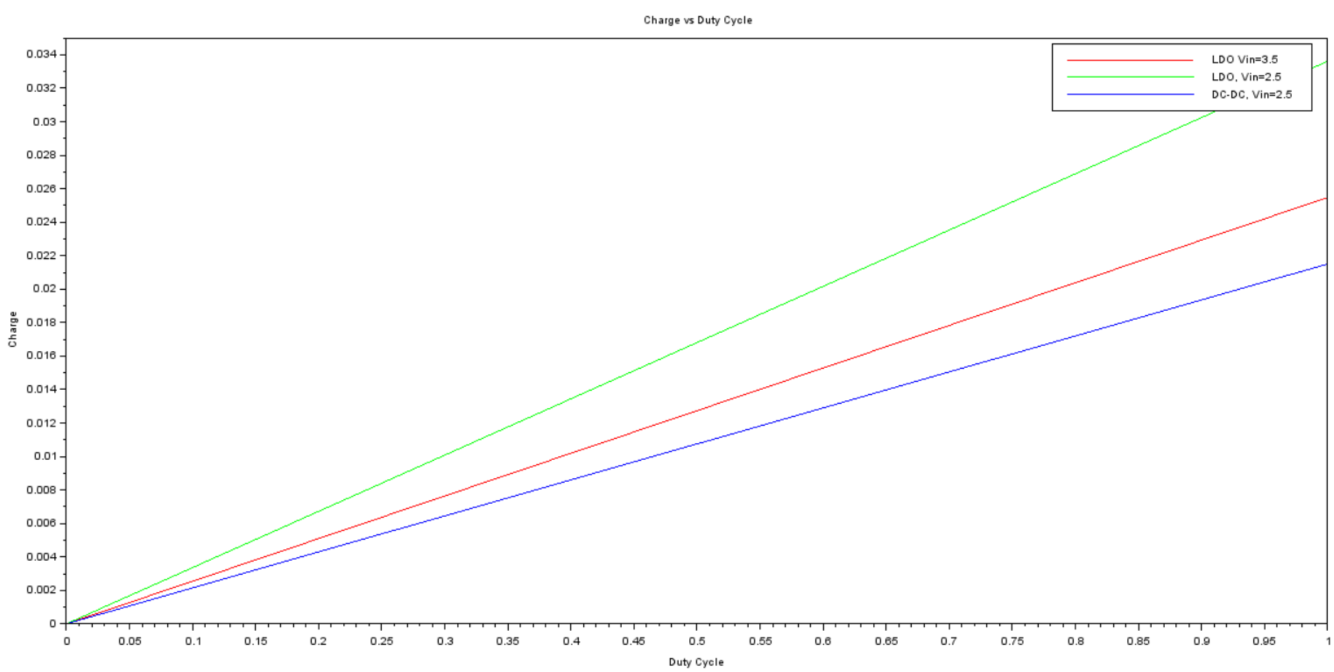
The USB is then connected to the MCP3831 charger to charge the battery.

Buck regulator

As it was mentioned earlier, we had to make the choice of having and external regulator than the one already included in the charger IC for better efficiency.

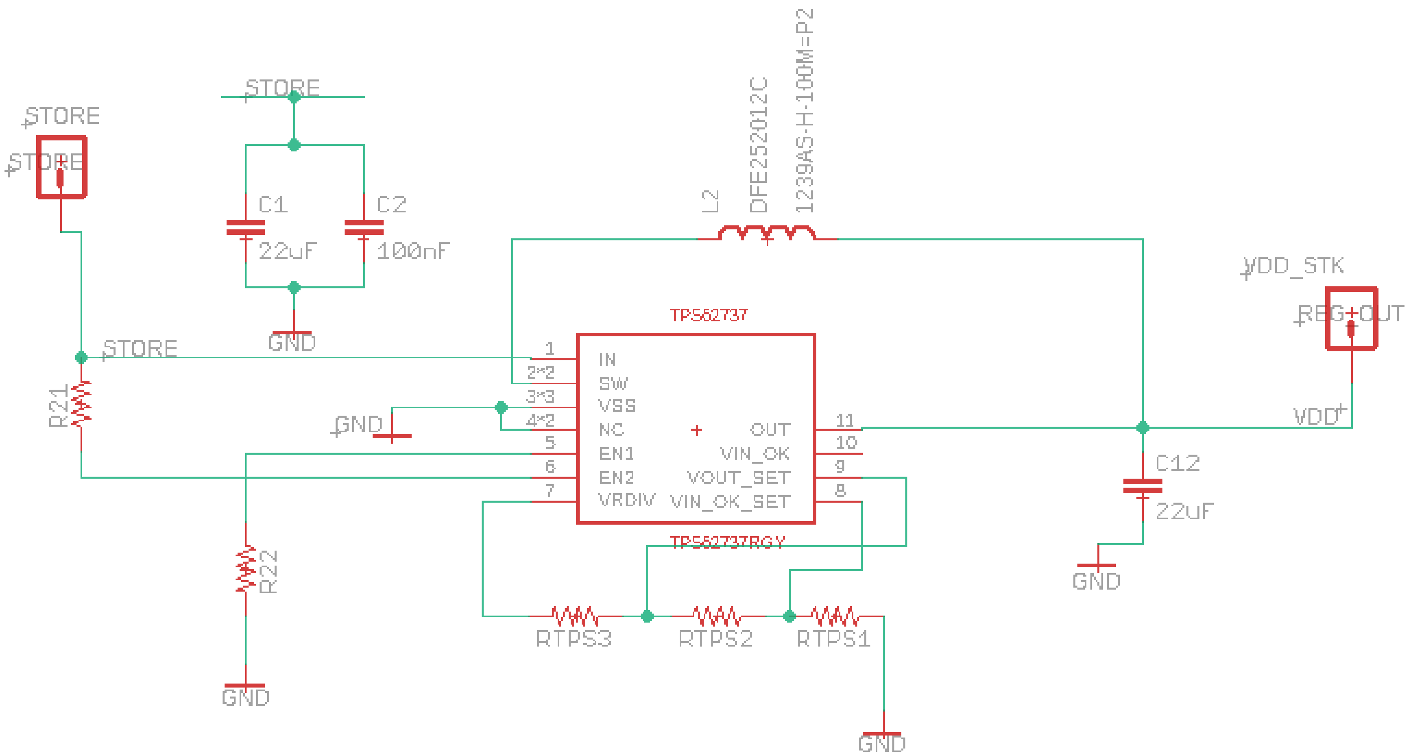
```
clf;
function charge = Q(delta,EfficiencyOn,EfficiencyOff)
    Ion=20*10^(-3);
    Isleep=2*10^(-6);
    IonSupply=Ion*(1/EfficiencyOn);
    IsSupply=Isleep*(1/EfficiencyOff);
    charge = IonSupply*delta+IsSupply*(1-delta);
endfunction
t=linspace(0,1);
//t=[0:0.1:1];
plot(t,Q(t,0.785,0.783),"r");
plot(t,Q(t,0.595,0.593),"g");
plot(t,Q(t,0.93,0.9));
hl=legend(['LDO Vin=3.5';'LDO, Vin=2.5';'DC-DC, Vin=2.5'])
xtitle('Charge vs Duty Cycle','Duty Cycle','Charge')
```

In this following graph representing the charge vs time for I_{active}=20mA and I_{sleep}=2uA we see clearly that an LDO consumes a lot more than a simple DC/DC converter.



<u>Charge vs Duty cycle comparing the LDO and DC/DC converters</u>

TPS62737 is a programmable output voltage ultra-low power buck converter with up to 200 mA output current. The output voltage range is from 1.3V to 5.5V, programmable through the RTPS resistors. Equations on how to calculate the values of those resistors can be found in the TPS6273x datasheet where a spreadsheet is also provided to help size those external resistors.



Buck Regulator Schematic

The device has three functional modes controlled by the enable controls (EN1 and EN2).

EN1 PIN	EN2 PIN	FUNCTIONAL STATE
0	0	Partial standby mode. Buck switching converter is off, but VIN_OK indication is on
0	1	Buck mode and VIN_OK enabled
1	x	Full standby mode. Switching converter and VIN_OK indication is off (ship mode)

Enable Functionality Table

As you can see from the device schematics, it is configured in *Buck mode* where the buck converter operates normally.

The input of the chip is taken from the unregulated output of the SPV1050 charger and its output is the output of the board.

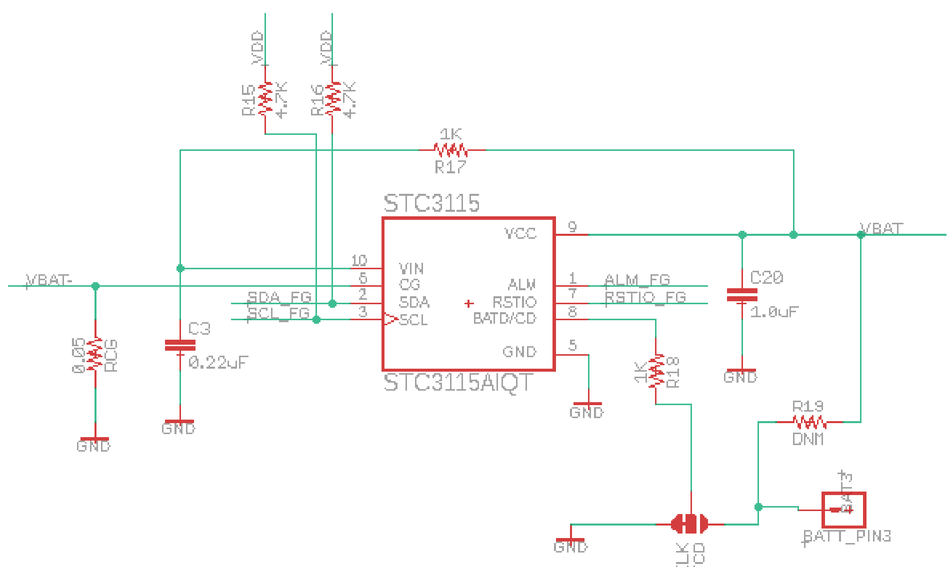
Fuel Gauge

Many fuel gauge devices from different manufacturers where found suitable for our application. In order to choose the most suitable device, we therefore established crucial criteria based on which we compared the different devices to choose from.

Component	**Accuracy**	**Tech.**	I_{active} **(microA)**	I_{sleep} **(microA)**		$I_{shutdown}$ **(microA)**		**Interf. comm.**	**Pack.**	**Cost**	**Availabl.**
FFG1040UC003X	Error=1%	Coulomb-counting (CC)	101	72	-reg can be accessed, read, written to -processor not clocking -mem & reg state is maintained	2.6	-No fuel gauging -mem. & reg. state is not maintained	I^2C	12-UFBGAWLCSP	1.61	Active, Available (Digikey)
MAX17043	+/-12.5mV	Open circuit voltage (OCV)	50-75	1-3	All IC operations are halted	-	-	I^2C	TDFN UCSP	3.05 3.47	Available (mouser)
GG25L (similar to STC3115) STC3115IQT (4.35Vmax batt option 3.8V typ)	0.25-0.5%	OCV + CC	45-100	2	-only OCV is active	1	Occurs when Vcc is lower than the undervoltage	I^2C	CSP (DFN10)	1.74	Available (digikey)

STC3115AIQT (**4.20Vmax batt option 3.7V typ**)							threshold(2.6V)				
MAX17201	+/-12.5mv	OCV + CC	18-35	9-20	-full function + reduced power consumption & activity	0.7-1.5	- activity & reg. & fuel gauge stop -output values are lost	I^2C	TDFN WLP	(01)3.53	Available (farnell)

The result of this comparison was clear that in terms of efficiency, the STC3115 (or GG25L with only difference in packaging) and the MAX17043 were the closest. Finally, the STC3115 was chosen for the quality of the technical information, datasheet and application notes that were available.



Fuel Gauge Schematic

The purpose of the fuel gauge is to have a real measurement of the state of charge of the battery.

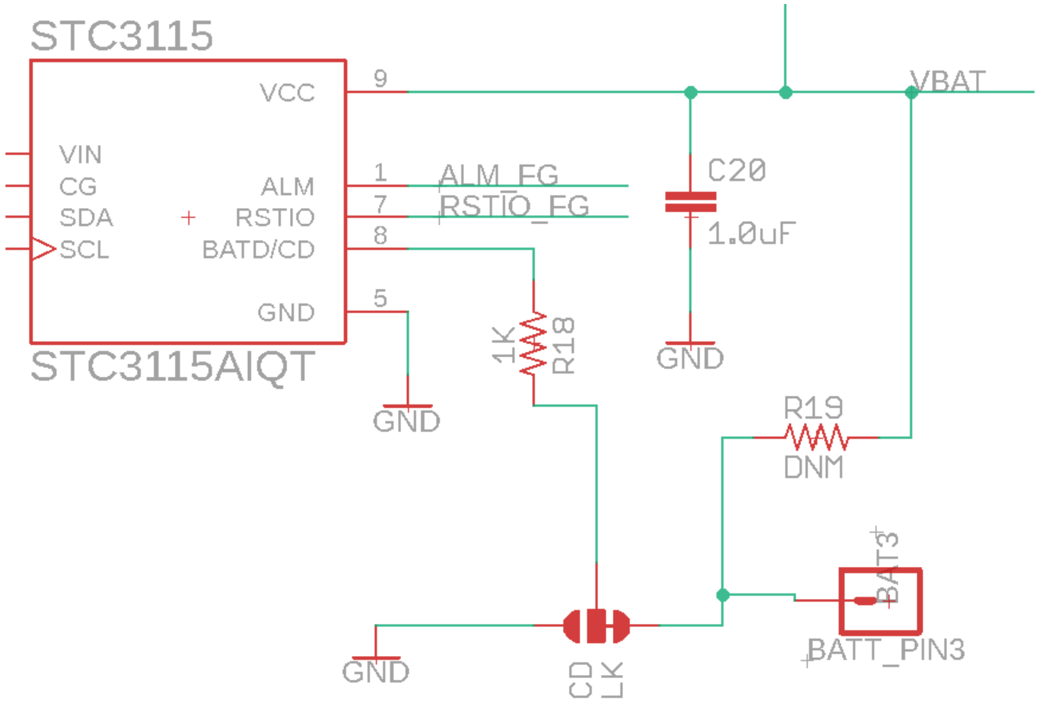
The STC3115 uses OptimGauge™ algorithm which uses two techniques for measuring the state of charge of the battery: Coulomb counting and Open circuit measurement. Coulomb counting is the ''traditional'' technique for estimating the SOC by measuring the current through a sense resistor (RCG). This technology is more accurate and consumes more power than the OCV (open-circuit voltage) measurement. Therefore, the device provides two operating modes.

VMODE	Description
0	Mixed mode, Coulomb counter is active, voltage gas gauge runs in parallel
1	Voltage gas gauge with power saving Coulomb counter is not used. No current sensing.

Operating modes

The mixed mode is the most accurate but the most power consuming whereas on power saving mode, the Coulomb counting is disabled resulting in less accurate measurements but the least power consuming mode.

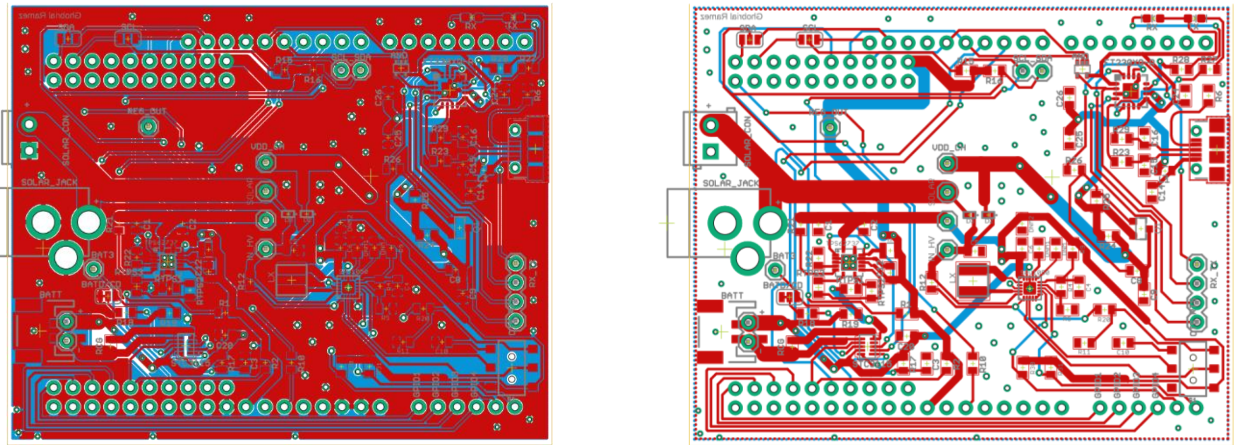
The IC provides I/O pins that are connected to the other boards such as an alarm output to indicate low battery voltage, RSTIO that senses the system reset state and "is used to control the application system reset during the initial OCV (open-circuit voltage) measurement. Finally, the BATD/CD is used to detect battery removal events. This pin is not connected to the other boards but rather to a jumper. The default connection of this jumper is shorting the pin to GND, in a way to disable the BatD feature. If a battery with a thermal resistor is used instead, the third battery pin must be connected to BATT_PIN3, the jumper has to connect the third battery pin and the GND connection has to be cut:



BATD/CD feature enabled using a third battery pin

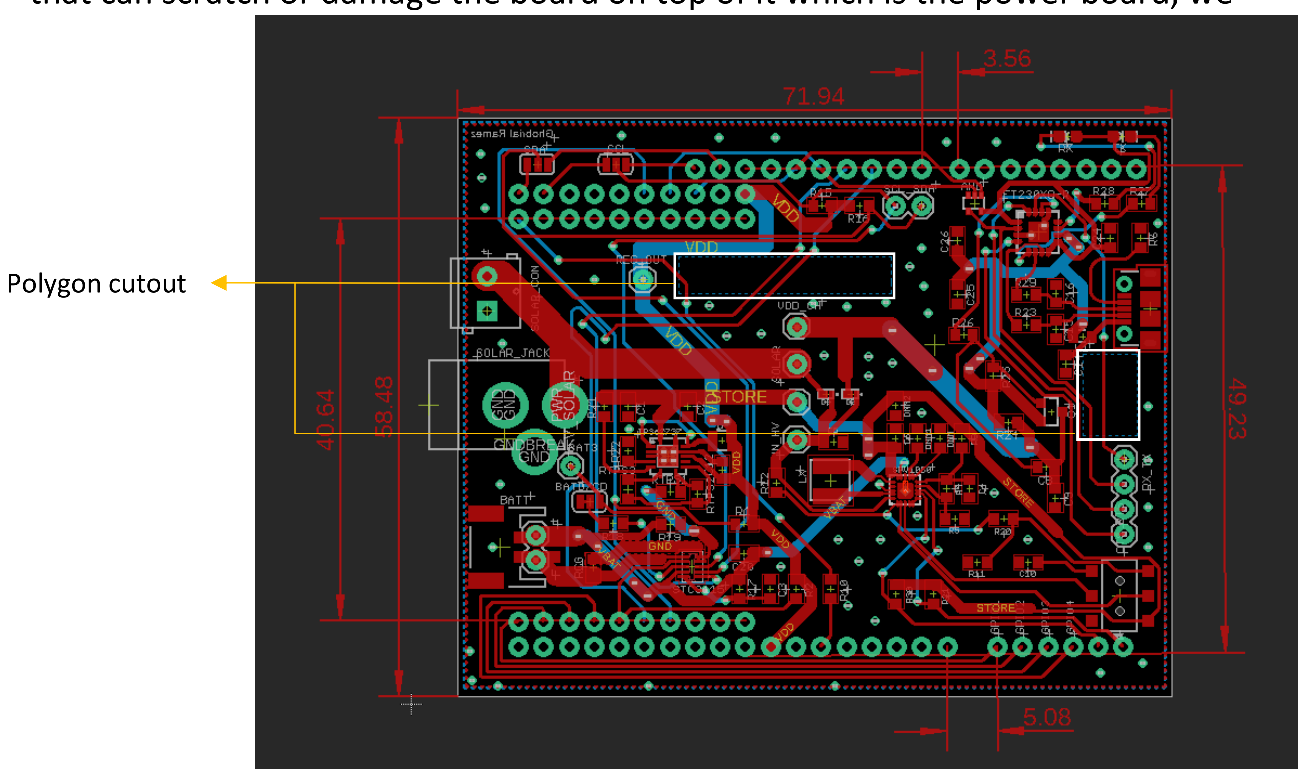
Note: please refer to the Application Note AN4324 for more information about those pins.

Layout



PCB Layout, Top View

The first issue that had to be taken care of is the size of the board and its interaction with the other two boards since the power board will lay in between the two other boards. Then we had to take in account the placement of the pins which will connect the power board with the other two. Since The nRF52832 Nordic board, which will go on the bottom, has male header pins in the middle that can scratch or damage the board on top of it which is the power board, we



had to make sure to leave the corresponding space empty in the power board without having any wires, components but also no planes on its bottom layer. We managed to do so by making a cutout polygone on the bottom layer of the power board. Two ground planes were created (one on the top and one on the bottom layers).