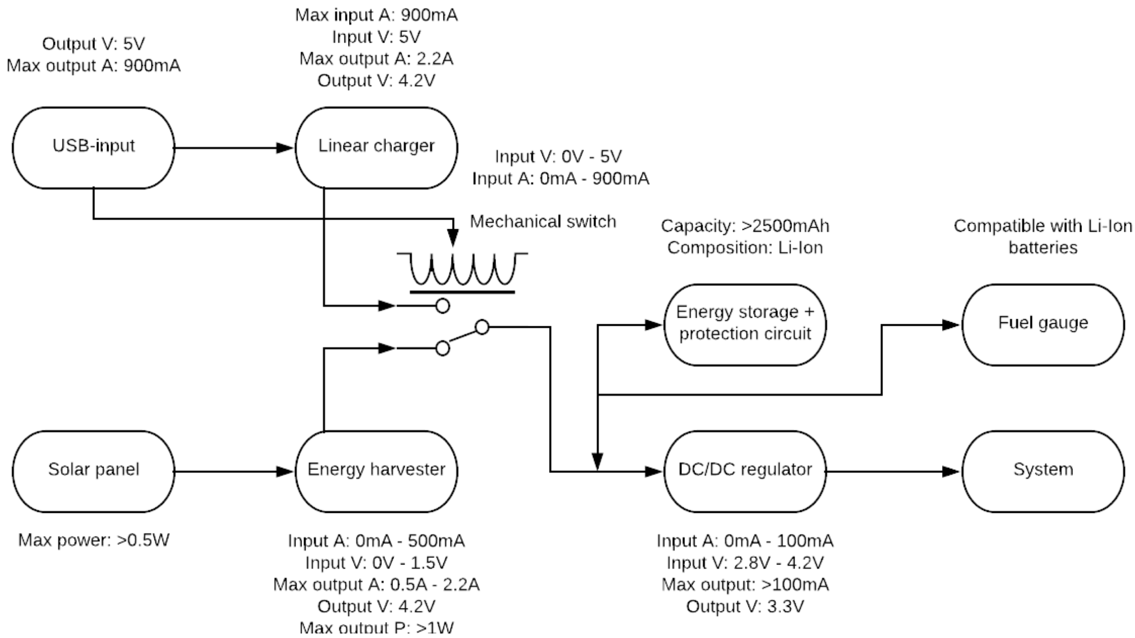
Solar power board

Contents

General description

The design of the power-board used to power nodes with solar energy is explained in this document. The design exists out of 5 stages: solar power input, USB power input, energy storage, a fuel gauge, and a DC/DC regulator to provide suitable power to the node. For clarification, a simplified version of the board is provided below.



The board receives power from USB-input or from the solar panel. Once the node is deployed outside USB input won't be utilized. The USB-input power is used when the node is being charged indoors. Input power goes through an IC (energy harvester or linear charger) to optimize/regulate the power for the rest of the circuit. The power will be used to power the system and to charge the battery. The battery will be used to power the system when there is no other power source available. The fuel gauge measures the state of the battery and can predict how long the battery can last. Before any source is used to power the system (including the battery), it passes the DC/DC regulator. This transforms the input voltage to an output voltage that is suitable for the system that will be powered.

The board has 2 charging options, with a USB connection or using a solar panel. USB charging will happen when the node is plugged into a laptop or pc. This won't happen outside, so the solar panel will not be useful in this situation. When there is a high voltage on the USB-input, the relay will close the connection between the linear charger and the energy storage and open the connection between the solar panel and the energy storage. When the node is plugged out of the laptop or pc the connection between the energy storage and the linear charger opens again, and the connection between the energy storage and the solar power closes again.

The linear charger connected to the USB-input optimizes the charging of the battery. An FTDI chip is connected to the USB-input that functions as a USB to UART interface. The energy harvester connected to the solar panel maximizes the extracted power from the solar panel and regulates the output voltage. The energy storage has a protection circuit that disconnects the battery for charging or discharging in case of a detected fault.

The selected components are:

-USB-input FTDI chip: FT230XQ-R

-Linear charger: MCP73831T-2ACI/OT

- Solar panel: 1W Solar Panel 80X100 or Sparkfun 2W solar panel

-Energy harvester: SPV1040

-Protection circuit: BQ29700

-Energy storage: JA-18650 Li-Ion battery pack (S1P3)

-Fuel gauge: MAX17260DSET

-DC/DC regulator: TPS63031DSK

Solar panel

Power consumption

The decision of what solar panel to use depends on the consumed power. In order to choose a suitable solar panel, the total power consumption and the efficiency must be calculated. Based on these 2 factors the size of the solar panel can be chosen.

$P_{solar\ panel} * \eta_{system} > P_{consumed}$

Harvested energy

The amount of energy that will be harvested by a solar panel is dependent on 3 factors: solar irradiance, panel size, and efficiency.

This site shows how much solar irradiance lands on a city http://solarelectricityhandbook.com/solar-irradiance.html.

This can be used as an estimation of the available energy, keep in mind however that the mountains can obstruct sun which means less energy will be available than stated. Multiply the solar irradiance by the panel size (m2) and the panels efficiency and you have a very rough estimation of the amount of energy that will be harvested. The actual amount will be lower.

Output current

In order to ensure maximum efficiency, make sure the output current of the solar panel is not greater than the maximum charging current of the battery plus the power consumption from the boards. If that is not the case, not all the harvested energy can be used.

Energy harvester

Function

The energy harvester's (SPV1040) task is to extract power from the solar panel. This component is needed because the solar panel's output is unstable. Of course, the output power depends on the amount of sun on the panel, and since this varies a lot throughout the day the output will change a lot. The energy harvester takes the irregular input from the solar panel and stabilizes it, so the output of the energy harvester can be used to charge a battery. Another important feature of this component is MPPT. Not every energy harvester has this feature, but it is an important one. MPPT ensures that the highest possible amount of power is harvested from the solar panel, by dynamically finding the voltage point at which the power harvested is the greatest. The input voltage range of the SPV1040 (0 – 5.5V) may seem too low for the solar panel's output voltages (up to 6V), but after consulting with someone who has more experience in this field, it has been decided this should not be a problem.

Maximum ratings:

Input voltage: 5.5V

Input current: 1.8A

Output voltage: 5.2V

Configuring the output

Below is the schematic of the SPV1040 including passive components:

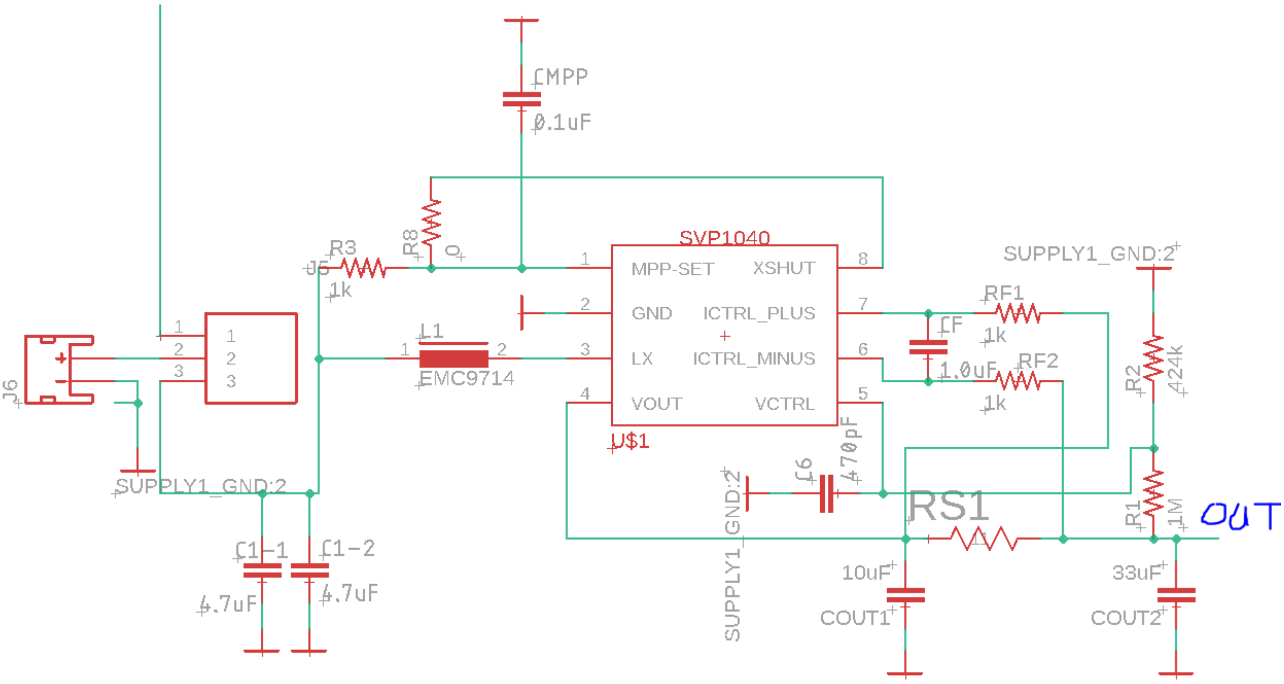


Figure 1 SPV1040 schematic. (jumper pin 1 is an optional bypass)

The output voltage can be set using R1 and R2 using the following formula:

$$\frac{R1}{R2} = \frac{Voutmax}{1.25}$$

Where R1 is 1Mohm.

The maximum output current can be limited with RS1 using the following formula:

$$RS1 = \frac{50mV}{Ioutmax}$$

For more details refer to application note *ST AN3319*.

Rejected alternatives

Several different energy harvesters are available, but the SPV1040 was the best fit. Most energy harvesters were deemed not suitable based on voltage input range or maximum output/input current.
The LTC4010 was deemed not suitable because of the high quiescent current.
The BQ24210 seemed like a good option as well, but it did not have MPPT.
The SVP1050 had a maximum charging current of 70mA, which would mean a lot of energy would be wasted.
BQ25504 had an input voltage range that only allowed a maximum of 3V input, which was way too low.

FT230XQ-R

Function

This chip is used to handle the communication that happens over the USB connection when the board is plugged into a laptop or something similar. It converts the USB signals to UART so the signals can be understood by the boards. This chip is also used to open a switch once the USB input enters sleep mode, so the charging will be terminated when there is barely any current entering the circuit from the USB connection.

MCP738312

Function

The MCP is a linear charger used to charge the battery with the power coming in from the USB port.

Output current

The output current is set with the resistor RProg at the PROG pin. The current value of 2k ohm sets the output current at the maximum current possible, 500mA.

Protection circuit

Function

This circuit has its own battery protection circuit to prevent several faults, such as overcharging, over discharging, overcurrent charging, overcurrent discharging. This protection circuit is suitable with any 3.7V Li-Ion battery. The protection circuit has 2 MOSFET's connected between the negative battery terminal and the ground. As soon as an error is detected one MOSFET will be set open, blocking either charging or discharging of the battery depending on the error. This way the battery can still be discharged when the charging is terminated, and the battery can still be charged when it's discharged all the way. This would not be possible using only one MOSFET and simply disconnecting the battery whenever a fault is detected. The protection IC uses voltage sensing and current sensing to detect faults.

Battery type

This protection circuit only works with Li-Ion battery packs that doesn't have any cells in series.

Overcurrent charging and overcurrent discharging

In the current circuit overcurrent charging and overcurrent discharging are not correctly configured, they are too high. Since the battery that is currently used has a fast charging rating of 1C (2.2A), limiting the charging current is not needed. The SPV1040 regulates the output current and will shut off as soon as the input current rises above 1.8A. Also, research shows overcurrent charging is not dangerous (Tazdin Amietszajew, 2018). The discharge rate of the battery is rated at 0.5C (1.1A). But the absolute maximum rating of the DC/DC converter is 1.1A (which will practically be even less), so there is also no risk of discharging the battery with a current that is too high. If this circuit is changed however, the overcurrent values might have to be configured correctly.

Rejected alternative

The BQ2980 was also considered as protection circuit, however the standard protection values of the BQ2980 weren't as good as the BQ2870's values.

Energy storage

Constraints

The energy storage can be varied without any changes in the circuit, if the following characteristics are the same:

- Battery chemistry: Li-Ion
- Charging voltage: 4.2V
- Battery voltage when fully charged: 4.2V
- Battery voltage when fully discharged: 2.8V

These values are fixed by the protection circuit, so if energy storage with other characteristics are required either select another version of the BQ270x or choose another protection IC.

The maximum charging and discharging current depend on the SPV1040, the protection circuit, and the DC/DC regulator. Refer to the sections of these 2 components to find these currents.

Fuel gauge

Function

The fuel gauge measures the State of Charge (SoC) of the battery. It implements the ModelGauge m5 algorithm to measure the SoC using coulomb counting, voltage sensing, and an internal temperature sensor. What makes this part very suitable for this project are the low operating current (5uA) and the option to use high-side sensing. Most fuel gauges use low side sensing, but this is not possible for our application. The protection circuit already uses low side current sensing, and having 2 current sense resistors on the same net will cause inaccurate measurements. The fuel gauge contains a lot of data concerning the battery's state. This data can all be accessed by connected microcontrollers using I^2C. The fuel gauge also contains an alert pin to alarm a connected microcontroller in case of a problem (1% SoC left, for example). *Important*: when connecting the fuel gauge's sense resistor it is important to do so with a kelvin connection for good accuracy.

Battery type

Li-Ion and LiFePO4 batteries can be used with this fuel gauge. Battery packs with cells that are connected in series will not work with this fuel gauge.

Rejected alternatives

The following fuel gauges were compared to each other: FFG1040UC003X, MAX17043, GG25L, STC3115, MAX1720. The STC3115 was found to be the most efficient. When the protection circuit came into the circuit none of these were suitable anymore, because none of these circuits can use high-side sensing. Also, the energy consumption of all these components is higher than that of the MAX17260.

DC/DC regulator

Function

The DC/DC regulator transforms its input to a suitable power for the 2 boards. It's a buck/boost converter, meaning it can output a voltage that is lower or higher than its input voltage. It is optimized for low power application and has a high efficiency (~90%). The output voltage is fixed at 3.3V which is exactly what the boards need.

Maximum ratings:

Input voltage: 1.8V – 5.5V
Output voltage: Fixed at 3.3V
Average current limit: 1A

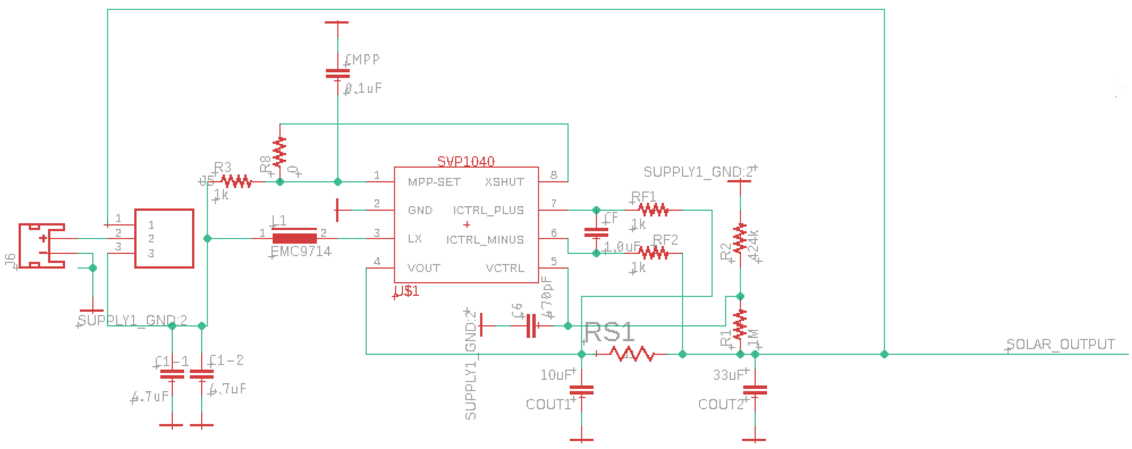
Rejected alternatives

The previously selected DC/DC regulator TPS62737 was only a buck converter, meaning it could only step-down voltages. This causes problems when the input voltage of the regulator drops below 3.3V. This will happen when the solar panel doesn't have much sunlight available, or when the battery is discharged a lot. Also, the efficiency of this regulator is not great at the low currents with which the boards have to be supplied.

Optional connections

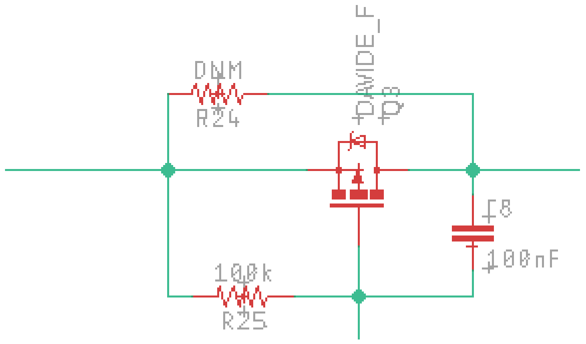
There are a few jumpers and DNM resistors throughout the schematic. Their use is explained below:

Jumper at solar panel connection



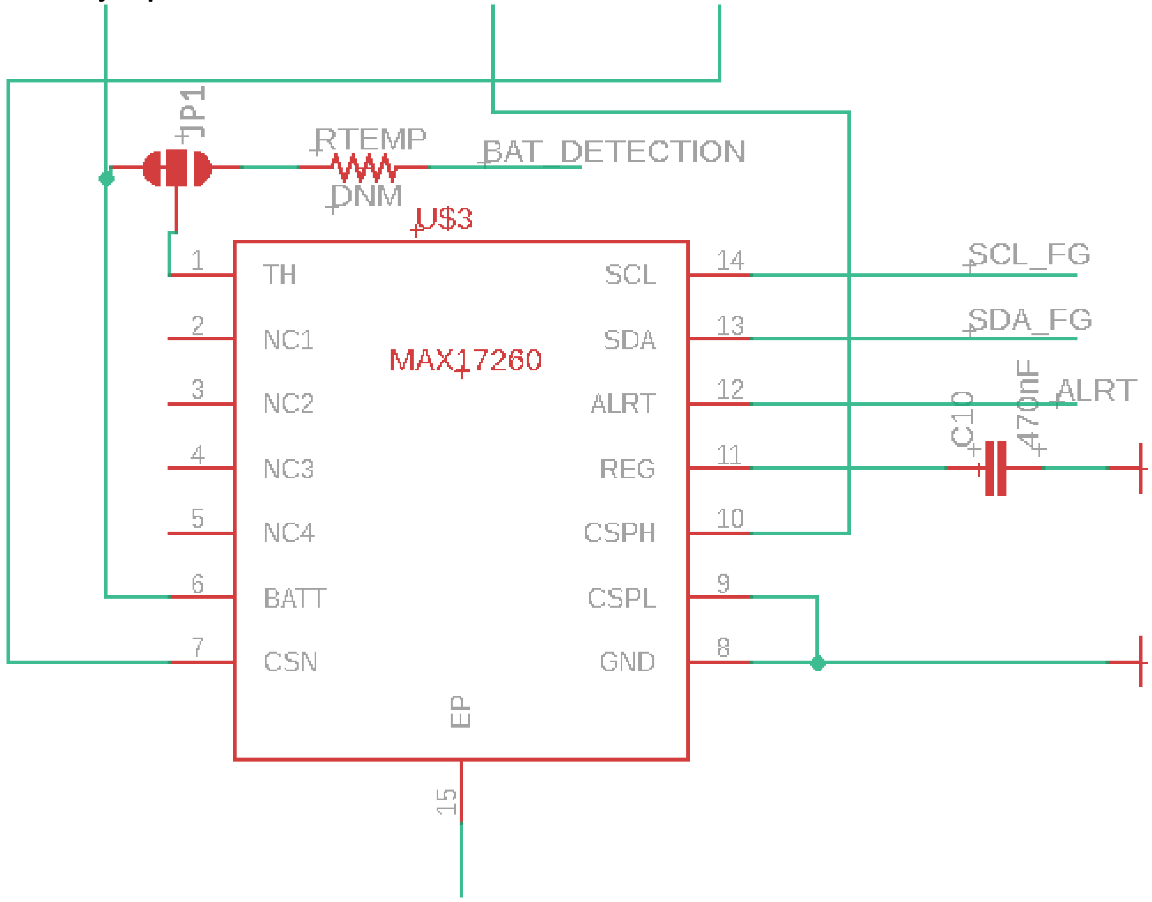
The jumper at the solar panel connection can be used to bypass the energy harvester. This can be done in case energy harvester is not working, but the solar panel still needs to be tested.

R24



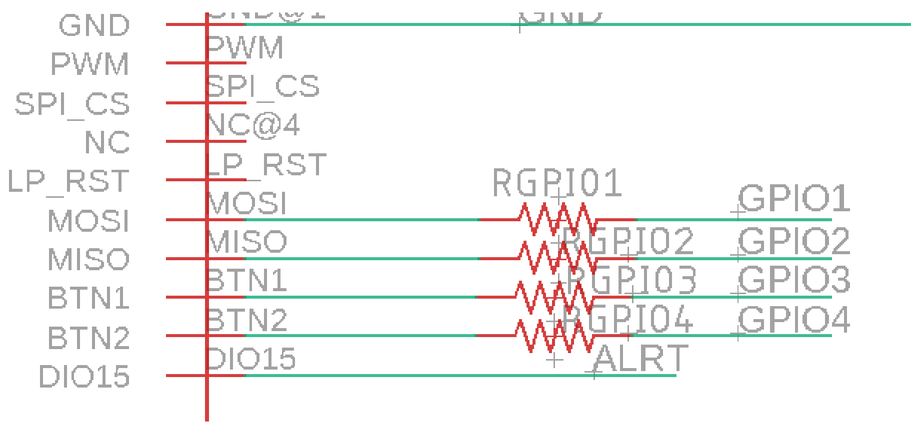
R24 can be mounted to bypass the switch used to cut off the charging power when the USB enters sleep mode.

RTemp and the jumper next to it



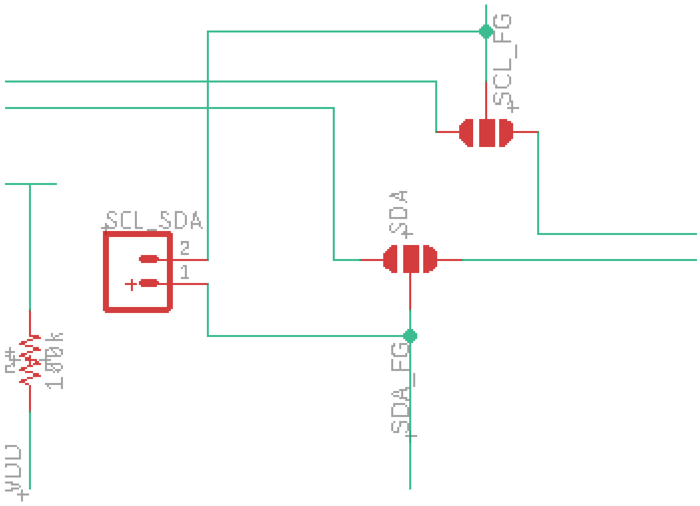
If an external temperature sensor is to be used for the fuel gauge, mount RTemp and cut JP1 on the left side, and short it on the right side. This will also enable battery detection for the fuel gauge.

RGPIO1, RGPIO2, RGPIO3, RGPIO4



These 0 ohm resistors can be placed to enable the use of the corresponding GPIO pin.

SDA jumper



The SDA jumper should be shorted at least one side to allow the board at the shorted side to communicate with the fuel gauge. If both sides of the jumper are open the fuel gauge is useless.

Bibliografia

Tazdin Amietszajew, E. M. (2018). *Understanding the limits of rapid charging using instrumented commercial 18650 high-energy Li-Ion cells.* Coventry: Elsevier.