Capita Selecta

Dramco IoT with a Soft Touch (IWAST)

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Contents

1 Introduction

This project was for the course Capita Selecta where I have been tasked to design a power module for Dramco.
First I quickly summarize what the objective of the power module is. Then I

expand on some of the constraints I had to work with and how they affected some design decisions. Afterwards the actual design is explained.

2 Objective

Design a power module which delivers 3.3V.
The power module contains a battery which can either be charged via solar energy or a USB port. The battery voltage is stepped down to 3.3v and delivered to an external system.
Since the IWAST project is for educational purposes the power module also provides some form of interaction. It contains a fuel gauge which measures the remaining capacity of the battery. The remaining charge value can be obtained via I2C by the motherboard.

3 Constraints

3.1 Space

The module encasing is very small. The overal height is around 17 mm and it has to contain a battery, a pcb, a solar panel and a plexiglass cover. Additionally, the casing is already divided in 3 levels which limits the height of each component. Each level is divided by a ledge on which either the pcb or plexiglass cover rest. This is shown in figure 1.

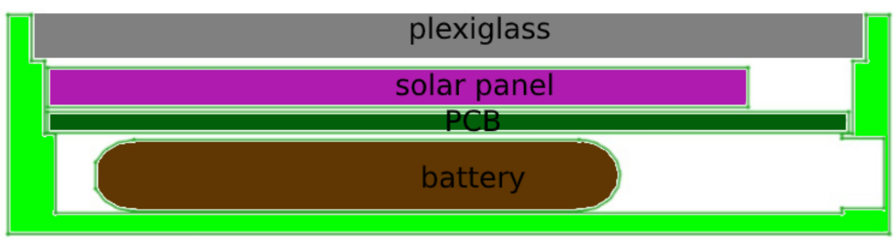


Figure 1: Cross section of the encasing. The PCB rests on the bottom ledge while the plexiglass cover rests on the top ledge.

The hexagon shape limits the size of a potential battery or solar panel. A battery fit in the bottom, for example, can be max 59 mm long and 34 mm wide. Due to the hexagon shape the battery can be wider but then it also needs to be shorter.

3.2 Resulting design decisions

3.2.1 PCB layout

To be able to fit a solar panel between the PCB and the plexiglass the PCB was designed in such a way that the solar panel sits flush with the PCB. All ICs and components are pushed as far to the edges as possible as shown in figure 2. Note that in figure 1 there is a gap between the solar panel and the wall. This is where the micro USB port will fit which, due to its height, limits the overal lenght of a potential solar panel.
By having all components closer to the edges some liberty is gained when choosing a solar panel. Originally, the solar panel size was limited by the length of each side of the hexagon and the distance between the pin header and the back edge. The white box on figure 2 shows this rectangle, which measures approximately 52x34 *mm*. If a shorter solar panel is chosen then the panels can be wider, for example, 40x40 *mm*.
A drawback to having all ICs pushed to the edge is that some traces need to be longer. The solar charger is placed as close as possible to the battery connection while the USB charger is on the opposite side of the PCB. The thought process here is that potential losses due to the longer distance current needs to travel aren't that relevant when charging via USB. Meanwhile, when charging via solar energy, efficiency should be maintained as high as possible. That being said these losses are probably minimal.

Another decisoin I made was to put the USBs charging status LEDs in a somewhat unnatural spot. For both educational purposes and ease of use I would have liked to put the USB charging and standby LEDs as close as possible to the USB port but I had to put them further left and higher up.

3.2.2 Connectors

Both the solar panel and PCB can be connected to the PCB via connectors with a pitch of 1.00 *mm*. Connectors with such small pitch tend to be thinner. At first I looked into connectors with a pitch of 2.54 *mm* but these where around $3-5$ *mm* tall which just wouldn't fit. The footprint used should fit both JST and Molex connectors so there is some liberty in choosing a specific connector.

3.2.3 Casing

I fear that having the solar panel flush with the PCB is a necessity (depending on the solar panel thickness) but, in case there is room to do so, I would lift the solar panel up from the PCB. To this end there are 5 holes in the PCB through which pillars can stick out to support the PCB. These pillars are one with encasing and they are simply created when 3D printing the case. To be able to fit these pillars the battery needs to placed diagonally compared to the solar panel. This leaves the corners free for the pillars as is shown in figure 3.

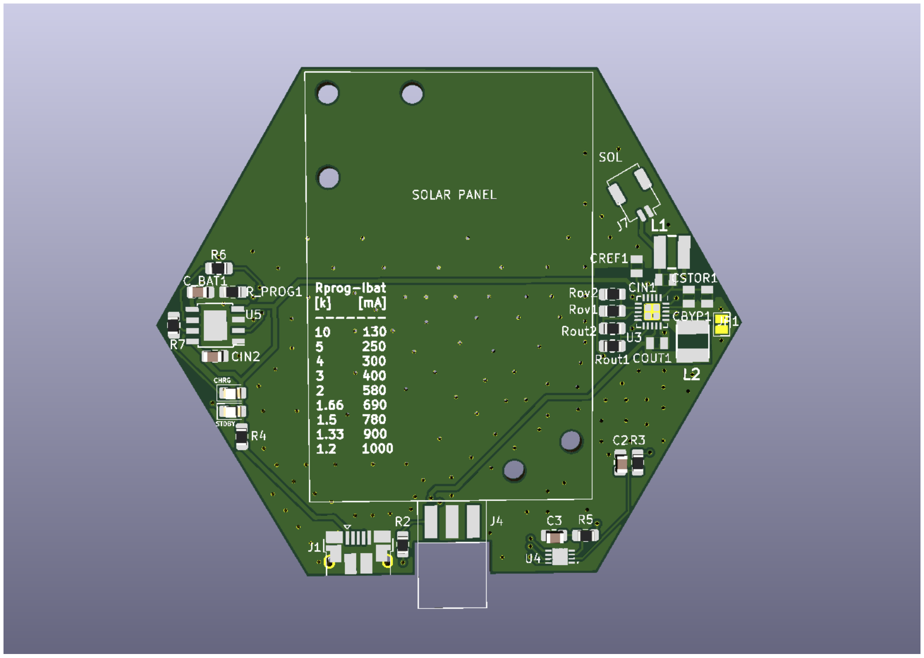


Figure 2: To be able to position the solar panel as low as possible all components are moved to the edges.

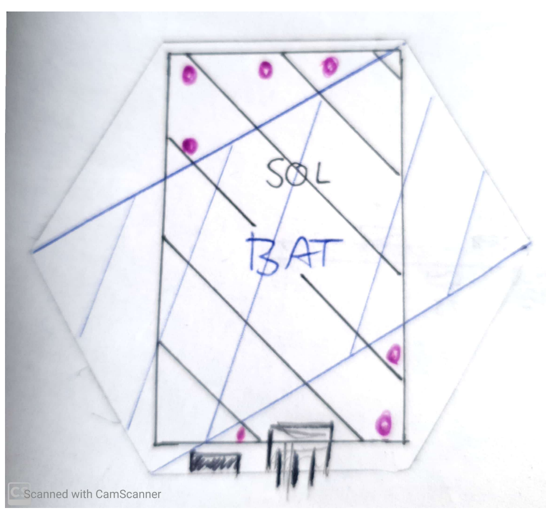


Figure 3: A rough sketch of the battery (BAT) and solar panel (SOL) orientation. The purple dots are where pillars could be constructed.

4 Power Module

4.1 Function

The power module is designed to provide power to an IOT system. It consists of a battery to store this power, a solar panel and usb port to charge this battery and a battery fuel gauge to track the status of the battery.
To this end it uses the:

- BQ25570: solar charger, charges battery and delivers 3.3V;
- TP4056: usb charger, charges battery;
- MAX17043: fuel gauge, monitors battery status and generates interrupt.

Figure 4 shows a general overview. Note that when a USB power source is connected the BQ25570 is disabled. This ensures that the battery is not charged by two systems simultaneously.

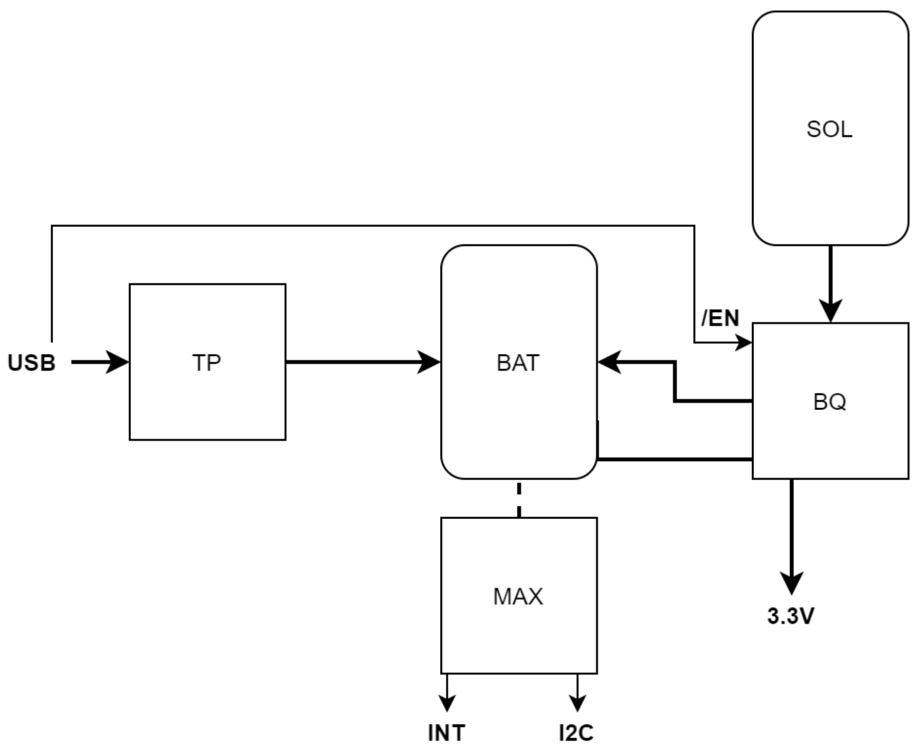


Figure 4: High level overview of the power module. When a USB power source is connected the BQ25570 is dissabled.

4.2 Hardware

4.2.1 Solar Charger

The solar charger used is the BQ25570 by Texas Instruments.
It is marketed as a nano power boost charger and buck converter. It is capable of extracting energy from a solar panel even with voltages as low as 100mV. This energy then charges the connected battery. As a secondary function it provides a buck converter to down step the battery voltage to 3.3V to power a connected system.

Charging
The BQ25570 has a boost converter that serves to extract as much energy as possible from the solar panel. It requires 600mV to get started, after which the solar input voltage can drop to as low as 100mV before the BQ25570 stops charging the battery. The output of the boost converter is stored on VSTOR (CSTOR and CBYP). This energy is then either used to charge the battery or to directly supply the 3.3V for the main circuit.

The inductor L1 is LPS4018-223M by Coilcraft as recommended by Table 3 of the datasheet. It has both a low profile and a low series resistance of 360mOhm. Its inductance value is 22uH, which is what is required by the internal regulation circuitry. The capacitor CIN1 is chosen to have the minimum recommended value of 4.7uF. The capacitor is a low leakage capacitor of type X7R. The internal regulation circuitry regulates to the voltage stored on CREF1. It is a 0.01 uF low-leakage capacitor, as required by the datasheet.
The capacitors used are all low leakage to maintain high efficiency.

The BQ25570 has a built in MPPT that is fixed at 80% of Vin. This should be good enough for most solar panels. It is set to 80% by connecting the VOC_SAMP pin to the VSTOR pin. This MPPT could also be set to 50% by connecting VOC_SAMP to ground or can be connected to the midpoint of an external resistor divider between pin VIN_DC and ground.

Providing Power
The synchronous buck converter serves to step the battery voltage down to 3.3V. VSTOR and VBAT are internally connected as long as the battery voltage is within operating range. If VSTOR is lower than VOUT (3.3V) but higher than the battery under voltage limit then the buck converter operates in pass mode. If VSTOR drops below the set under voltage limit of the battery the buck converter is turned off.

The inductor L2 of the buck converter is of the same type as the one used for the boost converter but has an inductance of 10uH. The capacitor COUT1 is of the same type as CIN1 but has a capacitance of 22uF.

Programming the Output Voltage and Battery Protection
Vout is set to 3.3V by an external resistor divider. To prevent overcharging of the battery VBAT_OV is set to 4.2V. Currently VBAT_OK is unused, if connected, pin VBAT_OK would be low if the voltage of the battery falls below VBAT_OK_PROG. The battery fuel gauge already performs this functionality.

All following values are calculated using the excel sheet 'bq25505/70 Design Help V1.3' provided by TI. Note that all resistors are recommended to sum to 13MOhm.

VOUT is set by ROUT1 and ROUT2 using equation 5 of the data sheet.

$$V_{OUT} = 1.21V \cdot (\frac{R_{OUT2} + R_{OUT1}}{R_{OUT1}}) \tag{1}$$

VBAT_OV is set by ROV2 and ROV1.

$$V_{BAT\_OV} = \frac{3}{2} \cdot 1.21V \cdot (1 + \frac{R_{OV2}}{R_{OV1}}) \tag{2}$$

Swapping Batteries
Hot-plugging a storage element should be avoided. When no input source is attached, the VSTOR node should be discharged to ground before attaching a storage element. This can be done with jumper JP1 which shorts VSTOR to GND.

Enable Pin
The BQ25570 comes with an enable pin (active low) to put the device into shipping mode. This disables the boost charger and buck converter. This pin is connected to the USB charger. This ensures that when the battery is charged via USB the BQ25570 is disabled. This does mean that power module can't be both charged via USB and deliver power to an external system.

4.2.2 USB Charger

The TP4056 is a simple constant-current and constant-voltage linear charger. The charging current depends on the resistor value of R_PROG and is currently set to 2 $k\Omega$. This results in a charging current of 580 mA. Table 1 shows the possible resistor values.
The upper charge stop voltage is $4.2V$.

It comes with a temperature sense input but I've decided to not use it. At first a was trying a system where a 3-pin connector is used for the battery and when a battery without a NTC is plugged in (so a 2-pin connector) the user would have to ground the temperature pin via a jumper. This turned out to be a bit too complex to route and occupied more space than necessary.

The TP4056 also has two output LEDs.

Rprog [$k\Omega$]	Ibat [mA]
10	130
5	250
4	300
3	400
2	580
1.66	690
1.5	780
1.33	900
1.2	1000

Table 1: Rprog current setttings

Charge State	CHRG LED	STDBY LED
charging	on	off
charge termination	off	on
error	off	off
battery absent	pulse	on

Table 2: The TP4056 output LEDs

4.2.3 Battery Fuel Gauge

The MAX17043 is a single cell battery fuel gauge. It periodically measures the battery's voltage (with an accuracy of 1.25 mV) and stores it in an internal register. It also calculates relative state of charge with a proprietary algorithm. This state of charge is also stored internally and is in percentage.
It is recommended that the datasheet of the MAX17043 is read since it contains a lot of in-depth information but a brief overview is presented here.

At power-up the MAX17043 makes an initial guess of what the SOC of the connected battery is assuming that the battery has been in a relaxed state for the previous 30min. If desired, the fuel-gauge calculations can be restarted by writing 4000h to the MODE register. This is useful in case the systems power-up sequence is so noisy that excess error is introduced into the IC's "first guess" of SOC. A possible initial error does, however, fade over time.

The MAX17043 drives the ALRT pin to logic low when SOC falls below a predefined threshold. The /ALRT pin is connected to the INT pin of the connector to the motherboard. To clear the interrupt the motherboard microprocessor needs to clear the ALRT bit of the internal register. SOC being below threshold when this bit is cleared does not generate another interrupt. The SOC threshold is set at address 0Dh of the CONFIG register.
If the first SOC calculation (at power-up) is below the threshold setting, an interrupt is generated. Entering Sleep mode does not clear the interrupt.

The IC can be put in sleep mode by pulling both the SDA and SCL low for atleast 2.5s. Alternatively, Sleep mode can be entered by setting the SLEEP bit in the CONFIG register to logic 1 through I2C communication. If the SLEEP bit is set to logic 1, the only way to exit Sleep mode is to write SLEEP to logic 0 or power-on reset the IC.

Register Summary

ADDRESS (HEX)	REGISTER	DESCRIPTION	READ/ WRITE	DEFAULT (HEX)
02h–03h	VCELL	Reports 12-bit A/D measurement of battery voltage.	R	—
04h–05h	SOC	Reports 16-bit SOC result calculated by ModelGauge algorithm.	R	—
06h–07h	MODE	Sends special commands to the IC.	W	—
08h–09h	VERSION	Returns IC version.	R	—
0Ch–0Dh	CONFIG	Battery compensation. Adjusts IC performance based on application conditions.	R/W	971Ch
FEh–FFh	COMMAND	Sends special commands to the IC.	W	—

Figure 5: The registers of the MAX17043, taken from the datasheet.

The IC measures the voltage at the CELL pin and stores the result in the VCELL register. Measurements are done with a resolution of 1.25 mV. Although only the lower 8 bit contains the measured votlage, all 16 bit need to be read. The 8 highest bit will just read 0. See figure 6

MSB—ADDRESS 02h

2^{11}	2^{10}	2^{9}	2^{8}	2^{7}	2^{6}	2^{5}	2^{4}
MSB							LSB

0: BITS ALWAYS READ LOGIC 0

LSB—ADDRESS 03h

2^{3}	2^{2}	2^{1}	2^{0}	0	0	0	0
MSB							LSB

UNITS: 1.25mV FOR MAX17043
2.50mV FOR MAX17044

Figure 3. VCELL Register Format

Figure 6: VCELL register. The power module uses the MAX17043

The state of charge can be read from the SOC register. this time all 16 bit contain information. Units of % can be directly determined by observing only the high byte of the SOC register. The low byte provides additional resolution in units 1/256%.

The CONFIG register can be used to set the previously mentioned SOC lower threshold, clear interrupts and put the IC to sleep.

ATHD sets the SOC lower threshold. If the state of charge of the battery falls to this level an interrupt is generated. The threshold value is stored in two's-complement form (00000 = 32%, 00001 = 31%, 00010 = 30%, 11111 = 1%). The power-up default value for ATHD is 4% or 1Ch.
The generated interrupt can be cleared by setting bit 5 to 0.

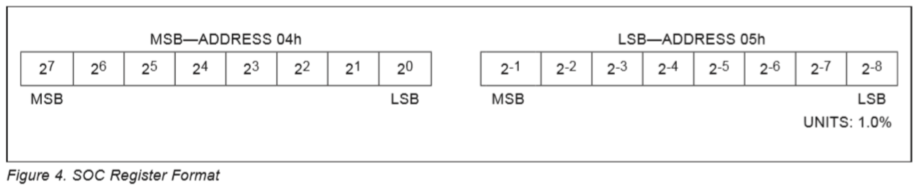


Figure 7: SOC register

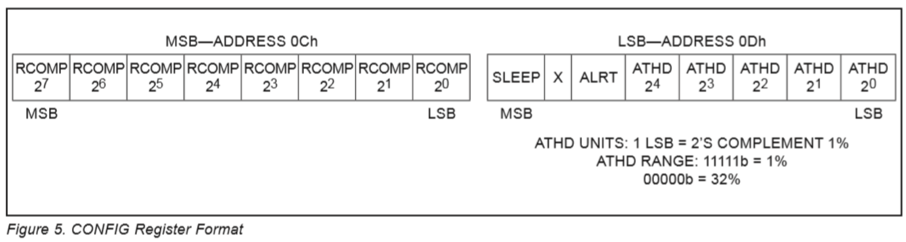


Figure 8: CONFIG register

To put the IC to sleep bit 7 can be set.

The 8 highest bits of the CONFIG register can be adjusted to optimize the IC performance for different lithium chemistries. This does, however, requires contacting Maxim.
For educational purposes the default value probably suffices.

I2C
The datasheet contains 2 pages on the '2-Wire protocol' and although my experience with I2C is limited it seems to me that the only new and useful information it contains is the address of the MAX17043. Figure 5 already shows the register addresses.

$$\text{SALVE ADDRESS:} \quad 0110110 \tag{3}$$

There already exist cpp libraries online, e.g. here and here which can easily be adapted to fit any application. If desired I can also rewrite those libraries to fit the current application.

4.3 Battery Selection

A battery can only be 6mm thick and can be max 6.0x3.5cm.
I found 2 batteries that are small enough to fit below the PCB. Both are from VARTA and are sold on Farnell. At the time of writing the one I would recommend is out of stock but the website predicts that by September they will be back in stock. See table 3. The circuit shown in section 5 assumes the battery that is in stock is used, namely the 660mAh one. If a different battery is chosen

R_PROG needs to be changed. Both batteries come with wires but require a connector to be crimped to them.

Brand	Model	Capacity [mAh]	Dimensions [mm]	Farnell Order code
VARTA	1/LPP 443441 S PCM W	660	41.5x34x4.6	2531266
VARTA	1/LPP 523450 S PCM W	1000	52x34.5x5.3	2531264

Table 3: Battery selection

4.4 Solar Panel Selection

Small solar panels are hard to find but I did find some on AliExpress. Of the table below (table 4) I would recommend the last one since it should fit comfortably on the PCB and provides more power. It does still require wires to be soldered to its terminals.

Brand	Model	Dimensions [mm]	Max power [W]	Link
FRAFLOR	5V30MA53-30	53x30x3	0.15	with wires
ANGUI	NA	52x19xNA	0.16	without wires
ANGUI	NA	39x39xNA	0.25W	without wires

Table 4: Possible Solar Panels

4.5 Connector Selection

The footprints of the connectors used are made so that they can fit both JST connectors and Molex connectors. Table 5 shows a comparison of some connectors.

2 pin

Brand	Model	Pitch [mm]	Height [mm]
JST	SM02B-SRSS-TB	1	2.95
JST	M02B-SHLS-TF	1	1.8
MOLEX	2023960207	1	3.2

Table 5: Connector selection. Connectors with a pitch of 1mm are thinner than connectors with e.g. a pitch of 2.54mm

4.6 Power Delivery

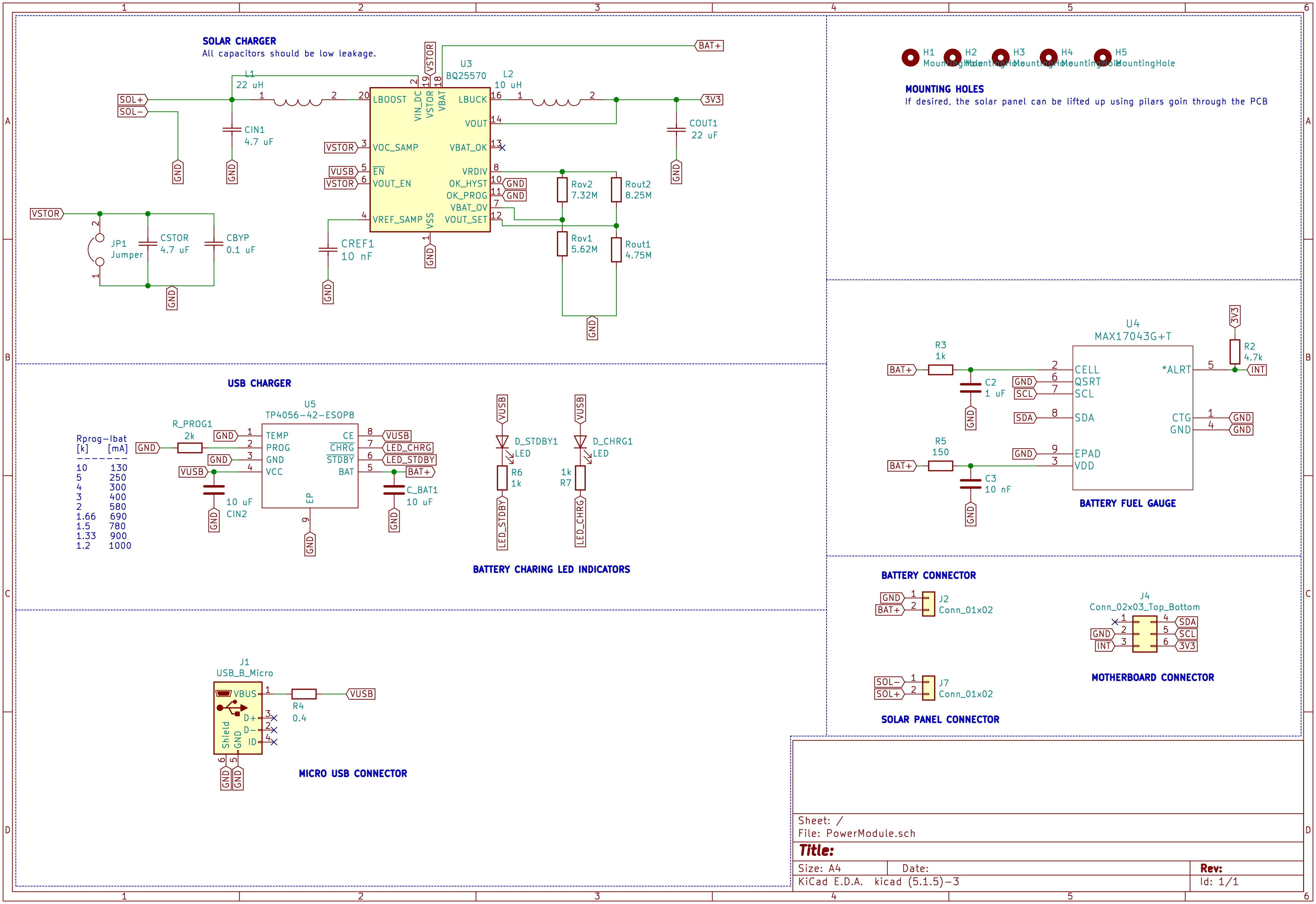
The following calculations are done assuming a required voltage of 3.3V and current of 1mA.
With a battery capacity of 660mAh and a current consumption of 1mA the power module can provide power to the system for up to 660 hours or 27 days.

This is starting with a full battery and assuming the battery does not get charged by solar energy. If there is enough solar power the battery gets bypassed and the 3.3V is taken directly from the solar panel input. Else the solar panel just charges the battery.
Texas instruments provides an Excel file called 'SolarAppDesignExample' which calculates how large a solar panel should be for continuous operation. Some of the values I set are shown in table 6. The Excel file then recommends a minimum battery capacity of 148mAh. Additionally, assuming the solar panel with a max power of 0.25W is chosen, the required size of this panel is at least 10 cm^2.

VOUT	3.3V
IOUT	1mA
operation time	24h/day
operation days	7days/week
max overcast duration	6 days/week
charging days	1 day/week
panel power	16.4mwW/cm^2

Table 6: Some settings of the 'SolarAppDesignExample' Excel file

5 Schematic



SOLAR CHARGER
All capacitors should be low leakage.
L1 22 uH
U3 BQ25570
L2 10 uH
BAT+
SOL+
SOL−
3V3
CIN1 4.7 uF
COUT1 22 uF
LBOOST
VIN_DC
VSTOR
VBAT
LBUCK
VOUT
VOC_SAMP
VBAT_OK
EN
VRDIV
VOUT_EN
OK_HYST
OK_PROG
VBAT_OV
VREF_SAMP
VSS
VOUT_SET
VSTOR
VUSB
GND
Rov2 7.32M
Rout2 8.25M
Rov1 5.62M
Rout1 4.75M
CREF1 10 nF
JP1 Jumper
CSTOR 4.7 uF
CBYP 0.1 uF
MOUNTING HOLES
If desired, the solar panel can be lifted up using pilars goin through the PCB
H1 MountingHole
H2 MountingHole
H3 MountingHole
H4 MountingHole
H5 MountingHole
USB CHARGER
U5 TP4056-42-ESOP8
R_PROG1 2k
TEMP
PROG
GND
VCC
CE
CHRG
STDBY
BAT
EP
LED_CHRG
LED_STDBY
10 uF CIN2
C_BAT1 10 uF
Rprog−Ibat
[k] [mA]
10 130
5 250
4 300
3 400
2 580
1.66 690
1.5 780
1.33 900
1.2 1000
D_STBY1 LED
R6 1k
D_CHRG1 LED
R7 1k
BATTERY CHARING LED INDICATORS
U4 MAX17043G+T
R3 1k
R2 4.7k
C2 1 uF
R5 150
C3 10 nF
CELL
QSRT
SCL
SDA
EPAD
VDD
*ALRT
CTG
GND
INT
BATTERY FUEL GAUGE
BATTERY CONNECTOR
J2 Conn_01x02
J4 Conn_02x03_Top_Bottom
MOTHERBOARD CONNECTOR
J7 Conn_01x02
SOLAR PANEL CONNECTOR
J1 USB_B_Micro
VBUS
D+
D−
ID
Shield
R4 0.4
MICRO USB CONNECTOR
Sheet: /
File: PowerModule.sch
Title:
Size: A4
Date:
Rev:
KiCad E.D.A. kicad (5.1.5)-3
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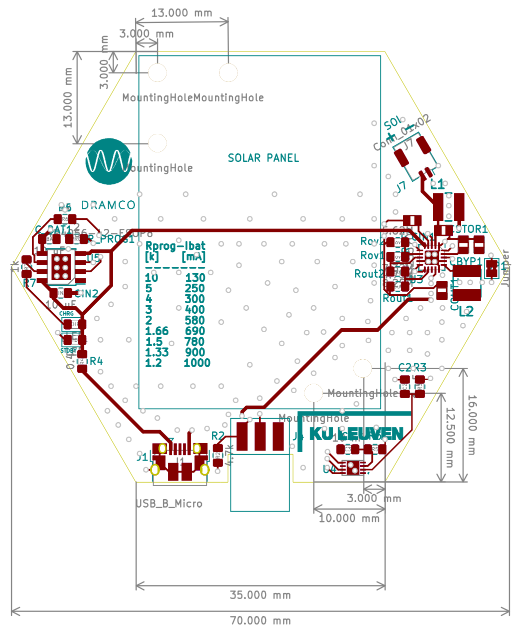
The schematic consists of three ICs and a couple of connectors. Most configurations could be taken directly from the datasheets typical applications. Only the BQ25570 required some calculations specific for the used battery and desired output voltage. As mentioned earlier Texas Instruments provides an excel file to simplify calculations.

In case a different battery is used Rov1 and Rov2 of the solar charger might need to be recalculated to adjust the over voltage protection.
R_PROG1 might need to be changed to accomodate a different charging current.

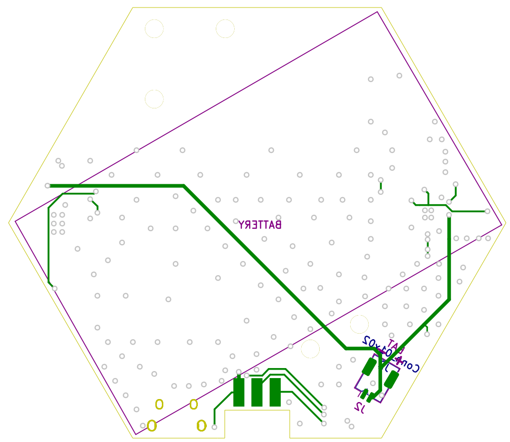
Interesting to note is that VUSB coming from the USB port is connected to the enable pin of the BQ25570. This is based on a suggestion made by one of the engineers of TI. This ensures that the BQ25570 is disabled when charging via USB and prevents charging the battery with two systems simultaneously.

6 PCB

As mentioned earlier all components are placed towards the edges of the PCB. The layout of the BQ25570 was done according to the PCB guidelines found in the documentation. The other ICs didn't come with PCB layout guidelines but are simpler circuits anyway. Following the BQ25570 guidelines resulted in some interesting routing. The return path for the resistor divider network and Cref, for example, is recommended to go to pin 15. This required the usage of quite a number of vias.



13.000 mm
3.000 mm
3.000 mm
13.000 mm
MountingHole
MountingHole
MountingHole
SOLAR PANEL
DRAMCO
Rprog Ibat
[k] [mA]
10 130
5 250
4 300
3 400
2 580
1.66 690
1.5 780
1.33 900
1.2 1000
MountingHole
MountingHole
KU LEUVEN
L1
L2
USB_B_Micro
3.000 mm
10.000 mm
12.500 mm
16.000 mm
35.000 mm
70.000 mm


BATTERY

7 3D View

The 3D view shows how all components fit together. First a battery is placed in the bottom of the housing. The battery should be placed diagonally, as indicated by the markings on the bottom side of the PCB. The battery is then connected to the PCB via the bottom connector. Afterwards, the PCB is placed above the battery on the first ledge.

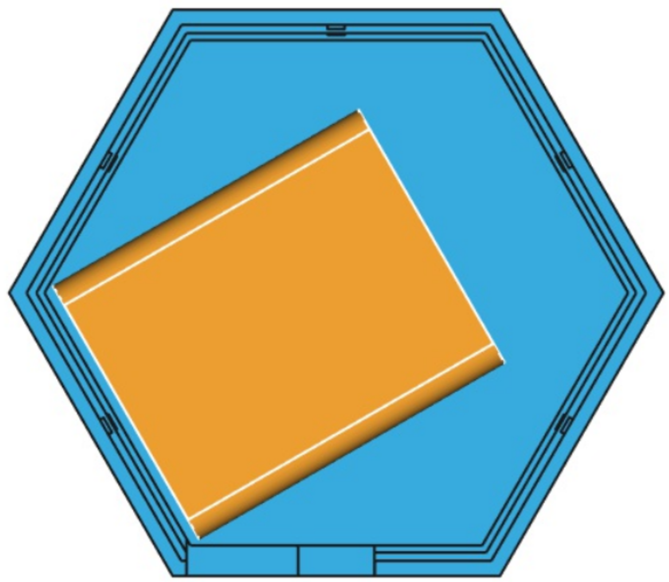


Figure 9: The battery is placed first. The dimensions correspond to those of the 660 mAh battery of table 3

On top of the PCB a solar panel is mounted. Depending on the thickness of the solar panel multiple approaches are possible. These different approaches are a trade-off between making sure no shorts occur and trying to make everything fit. If a thin solar panel is used, some spacing between the PCB and solar panel will ensure that there is no contact possible. The PCB comes with mounting holes through which pillars can stick. These pillars, which are part of the 3D model, then support the PCB. If the height of these pillars is fine-tuned in relation to the thickness of the solar panel the solar panel could be sandwiched between the pillars and the plexiglass cover.

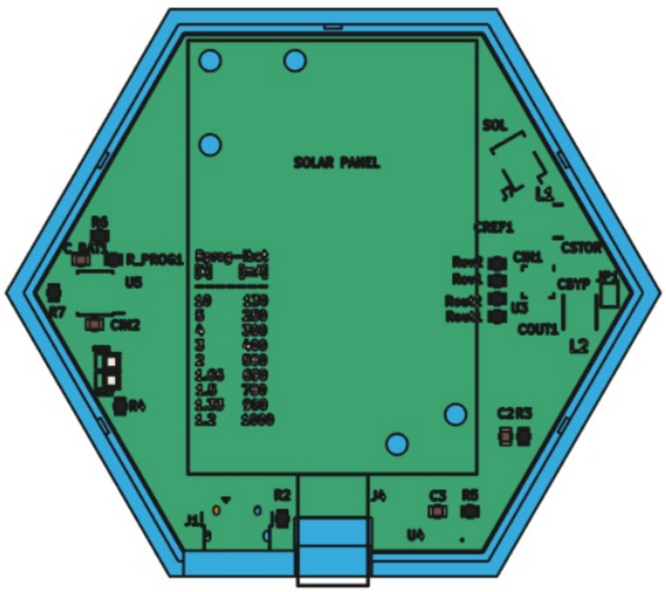


Figure 10: Then the PCB is inserted

Another alternative is simply using double sided tape.

If the solar panel used turns out to be too thick it can be placed as flush as possible to the PCB. This could be done by simply gluing it to the board.

In any case care needs to be taken that there is a way to route the cables of the solar panel to the topside connector.

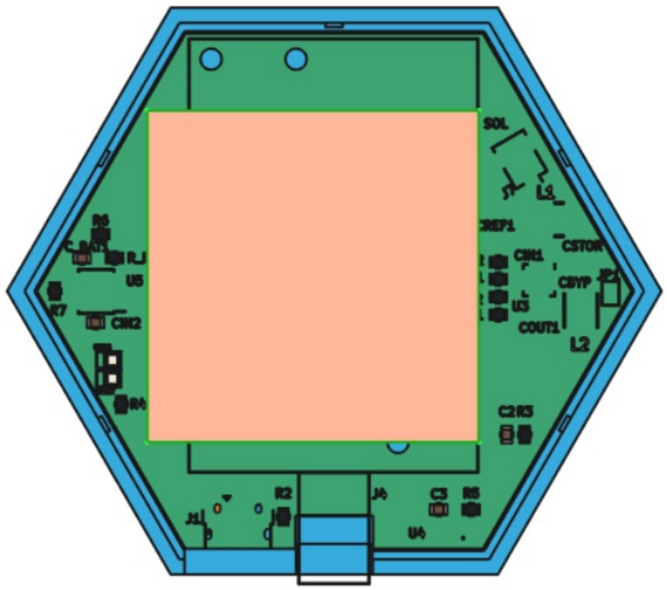


Figure 11: The solar panel is placed on top. The dimensions shown are 39x39mm which corresponds to the 0.25W panel of table 4

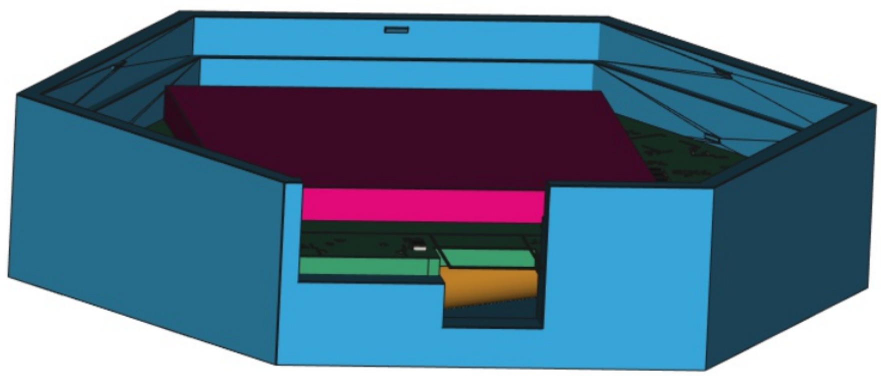


Figure 12: A 3D perspective from the side where the USB and pin header will be.