

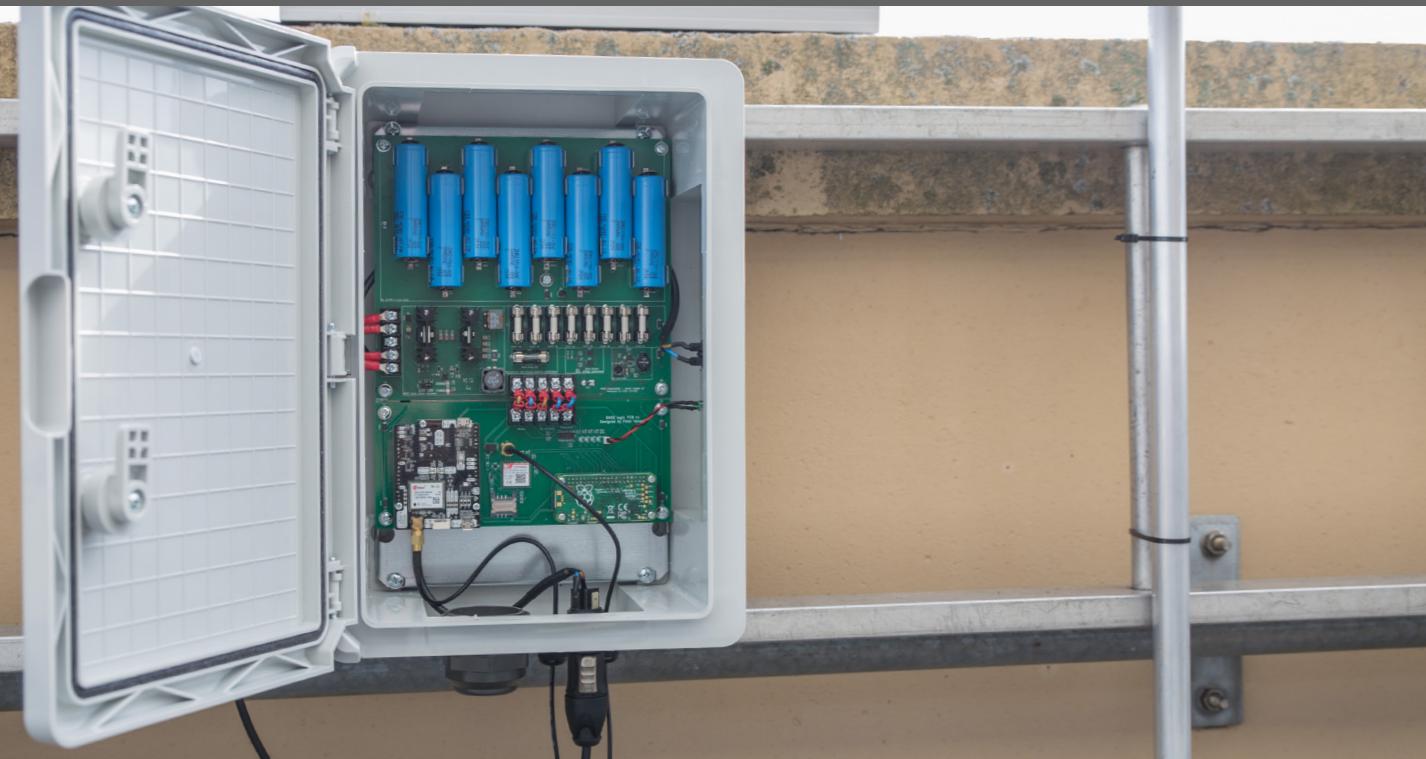
# Lowcost GNSS reference station

Design choices and assembly instruction

Peter Verweij - 1 May 2021 - Version 2



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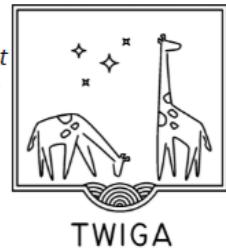
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GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
MPPT	Maximum power point tracking
PCB	Printed Circuit Board
RF	Radio Frequency
SIM	Subscriber Identity Module
SMA	SubMiniature version A (Coaxial RF connector)



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TWIGA

# 1. Introduction

Peter Verweij has designed a BASE and ROVER device for low cost precise positioning during his graduation for the master Integrated Product Design of the faculty Industrial design. In the months after his graduation, a follow up project was carried out to refine the BASE design.

## 1.1. Target

The target of this project is to build a lowcost GNSS reference station.

The proposed system for centimeter accuracy positioning (figure 1.2) is a differential GPS system. It uses dual frequency receivers which can largely eliminate the ionospheric error by comparing the travel speed of two waves with a different wavelength through the ionosphere. A reference (base) station is used to correct for other positioning errors, such as the troposphere. This base station is situated at a known location. By measuring its own known location, the base station can define the current present error.

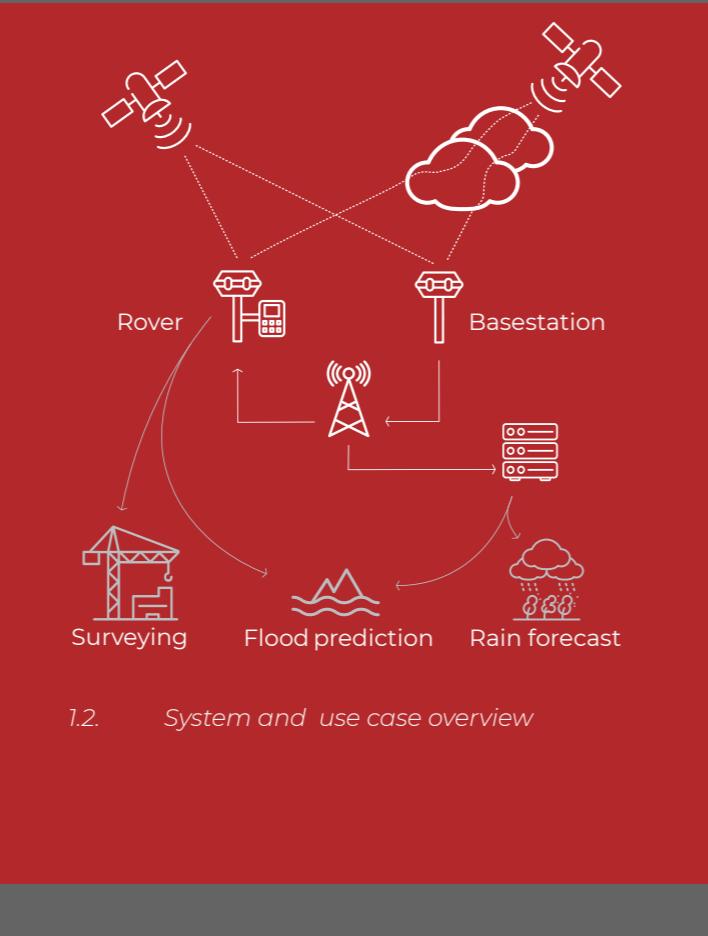
The positioning data is uploaded to a server. From that location the data can be used for surveying and research purposes.

Research towards better rain forecast models, together with affordable survey equipment can improve the ability to predict flooding.

## 1.2. Previous design

The previous GNSS reference station was portable and could easily be transported. However the 3D printing and separate PCB's made the device hard to reproduce. Also the watertightness of the 3D printed parts was questionable.

A similar design should be made which overcomes these issues. Most base stations will be used stationary. Portability is still useful but not the main target of this project anymore.



1.1. BASE2 design

# 2. Design choices

In this chapter the system structure and design choices are noted down.

## 2.1. Basic system description

The newly designed GNSS reference-station consists of an antenna, solarpanel and electronics in a standard water tight electronics case. (figure 2.1) In this case, all power electronics are mounted on one PCB. Logic modules can be plugged in to headers on this PCB. The complete system costs less than 600 euro when build in small quantities.

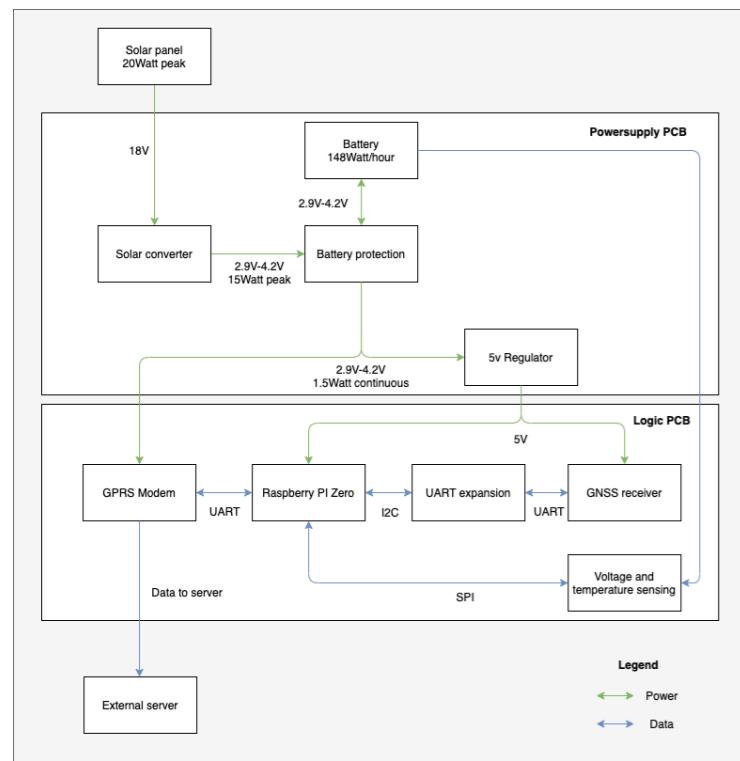
The GNSS reference station may be mounted to the side of a building, a roof or in a separate setup in the field. There is no strictly prescribed method of mounting the system.



2.1. GNSS referencestation

## 2.2. PCB structure and technical information

The PCB consists out of a power section and a logic section (figure 2.2). The full schematic can be found in the PCB folder on Github. Each functional section is shortly described in this paragraph.



2.2. System structure of the GNSS reference station.

### Battery

The battery capacity has been calculated using the off-grid PVgis tool (JRC Photovoltaic Geographical Information System (PVGIS) - European Commission, 2016).

When using a 20Watt solar panel the 148Wh battery should never run out of power in Kumasi, Ghana. However, one should realize that the same system will not be able to run continuously in the winter months in the Netherlands.

Eight 21700 lithium cells are used. It is advised to use the Samsung 50E cell because of their optimization for a high capacity at a low discharge rate.

### Solar converter

The solar converter was designed based on the bq24650 chip from Texas Instruments. The MPPT voltage can be fixed to 18.2V or 12V using the jumper on the board. The charge current is limited to 5A and the temperature range in which the charger will be active is -3°C up to 55°C.

### Battery Protection

The battery protection is based on the BQ29700 chip from Texas instruments. This chip operates two transistors. One which can cut-off charging (at 4.275V) and one which can cut-off discharging (at 2.8v). The chip will also cut-off the power at a current flow of more than 7A.

Beside the protection chip, also fuses are installed which protect each separate cell for over current. These fuses will also blow when a cell is connected in reverse.

It has to be noted that the BQ29700 chip will only enable the battery after the charger (solar panel in this case) has been connected and has charged the battery for a second.

### Raspberry Pi Zero

The Raspberry Pi Zero receives data from the GNSS receiver and sends it to the webserver using the GPRS modem. There is an image available for the Raspberry Pi SD-card in which the hardware is pre-configured. For configuring the mountpoint on the server etc. I refer to the software manual of Andreas Krietemeyer.

### UART expansion

The UART expansion is a SC16IS752IPW chip from NXP. The chip communicates to the raspberry over the I2C protocol.

It has to be noted that the I2C baudrate of the raspberry has to be set to 400Kbits/S instead of the standard 100Kbits/S to properly receive the GNSS receivers signal at 115200baud.

In the Github software manuals folder, the configuration manual for the UART expansion can be found

### Voltage and temperature sensing

Voltages can be read with the analog to digital converter MCP3008 chip.

1. Two leads are connected to the current shunt resistor of the solar converter. This can be used to read the charging current.
2. One lead is connected to the positive pole of the battery (only reliable when charger is off)
3. One lead is connected to the LM35 temperature sensor.

In the Github software manuals folder, the configuration manual for the voltage and temperature sensing can be found

### GNSS receiver

The GNSS receiver is an simpleRTK2B Ardusimple receiver. The right configuration has to be done with Ublox Ucenter software. The configuration file for the receiver can be found in the software manuals folder.

### GPRS Modem

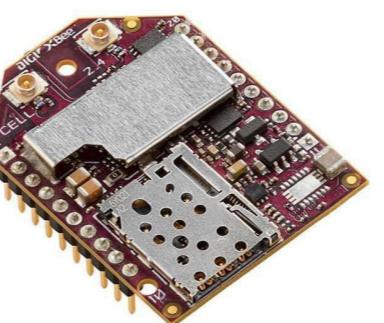
The modem is directly powered from the battery. This is the most efficient while the modem needs high current up to 2A in bursts. The downside of this choice is that the modem will shut down when the battery voltage drops below about 3,4v (dependent on the modem) However, the used batteries have not a lot of capacity left below 3,4V.

In the Github software manuals folder, the configuration manual for the GPRS modem can be found.

The PCB is designed so that a GPRS module can be installed. At this point of time the GPRS modules are by far the cheapest radio chips (€2,-), and the GPRS network is wide spread world wide. However in the Netherlands radio frequencies are valuable, therefore GPRS will be phased out in the future. Network provider KPN will maintain the network atleast until 2025.

To be able to use this device in the future, also an XBEE socket is available. Each XBEE module which can cope with voltages between 3,3V-4,2V is suitable. LTE-M XBEE modules are already available. For example: Digi XBee 3 Cellular LTE-M/NB-IoT - figure 2.3 (€86) or Dragino NB-IoT Bee - figure 2.4 (€33)

Although the XBEE socket is properly prepared (Powersupply available, UART connection and reset pin is connected to raspberry Pi). It has to be noted that the XBEE socket and the modules have not been tested. One should do some testing to be sure that everything works correctly.



2.3. Digi XBee 3 Cellular LTE-M/NB-IoT



2.4. Dragino NB-IoT Bee

### 3. List of tools needed

Before one can start assembling the GNSS reference-station we need to collect the right tools.

#### Wrenches/Spanners



Spanner 5.5  
Spanner 7  
Spanner 13  
Spanner 18



Wrench cap 4.5  
Wrench cap 5.5  
Wrench cap 7



Allen key 2.5  
Allen key 3  
Allen key 6



Small wrench

#### Drills



drill machine



50mm hole saw  
24mm hole saw



20mm drill bit  
15mm drill bit  
8mm drill bit  
5mm metal drill bit  
3mm drill bit

#### Screwdrivers



Torx screw driver T8



Philips head screw driver

#### Electrical wiring tools



Crimping tool



Stripping pliers



Solder iron



Heatgun



Multimeter

#### Other



File



hammer



center punch

# 4. Main unit assembly

This chapter describes all steps to assemble the main unit of the reference station. A component list with shop links can be found in the documentation folder on Github.

## 4.1. (Optional) Solder heatsinks

### Tools to use

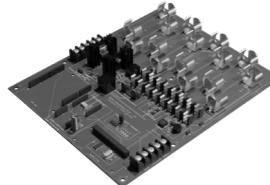


Solder iron

### Materials needed

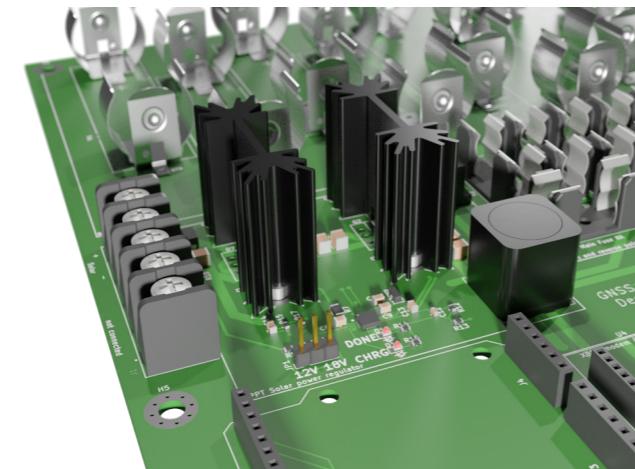
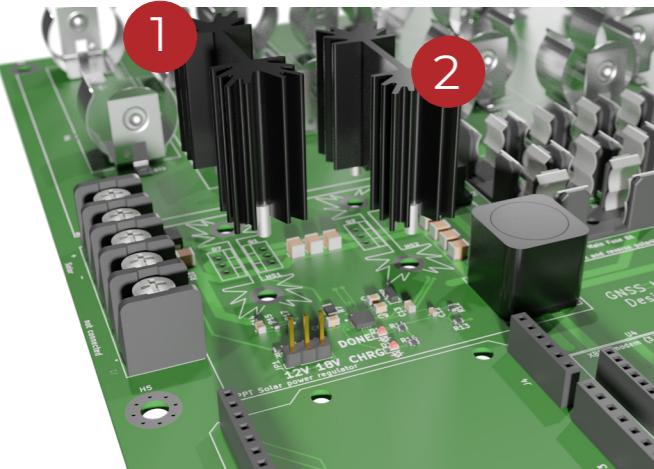


2x 513002B02500G



PCB

### Task



This step is marked as optional - Heatsinks could be ordered pre-mounted. However, the chance is big that the transistors and diode will not be properly aligned with the heatsink during this process. Therefore it is advised to install them yourself.

Solder the heatsinks flat to the board at their designated positions HS1 and HS2. The solder should be applied from the bottom side of the board.

## 4.2. (Optional) Solder solar regulator components

### Tools to use

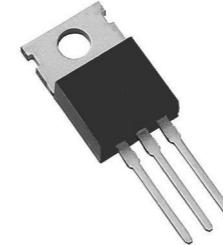


Solder iron

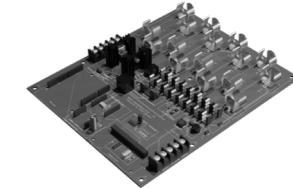
### Materials needed



2x CSD18537NKCS  
(Transistor)

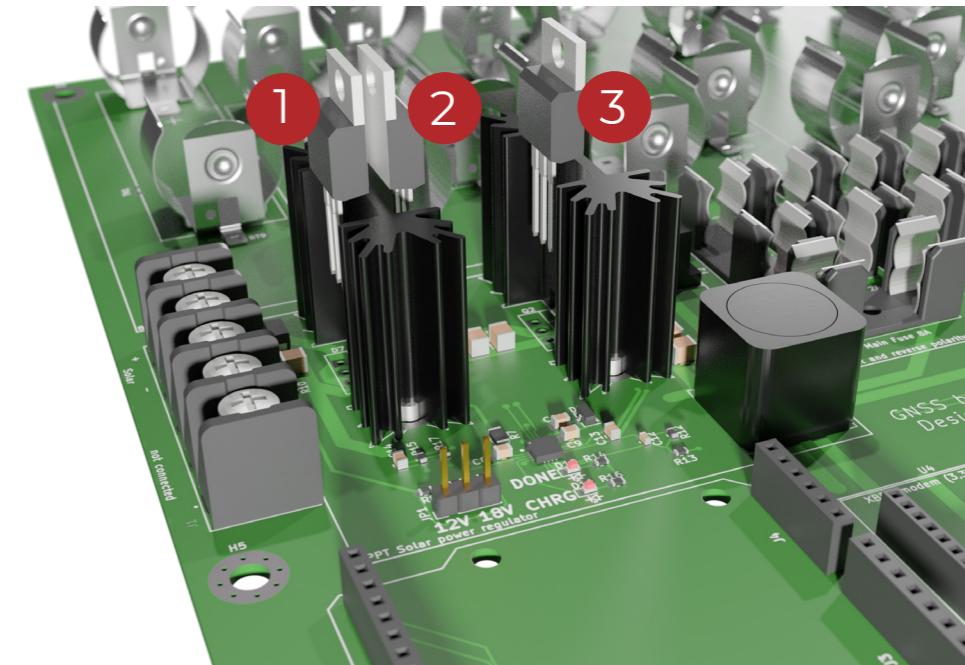


1x SBR10U40CT  
(Diode)



PCB

### Task



This step is marked as optional - Heatsinks could be ordered pre-mounted. However, the chance is big that the transistors and diode will not be properly aligned with the heatsink during this process. Therefore it is advised to install them yourself.

Align the diode (1) and transistors (2&3) to their heatsinks. Then solder the legs from the bottom side of the board to the designated positions. The SBR10U40CT diode to footprint D12 and the CSD18537NKCS transistors to footprint Q1 and Q2.

**Tip:** The bolts of next step "4.3. Heatsink bolts" can potentially be used to align the diode and transistors

#### 4.3. Heatsink bolts

##### Tools to use



Wrench cap 5.5



Small wrench



Allen key 2.5

#### 4.4. PCB spacers

##### Tools to use



Wrench cap 4.5



Wrench

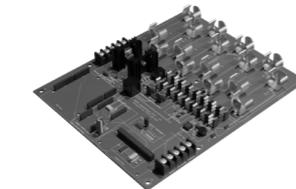
##### Materials needed



2x - m3x12



2x m3 nut



PCB

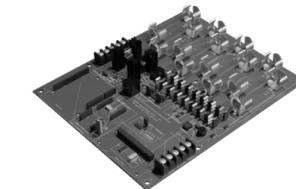
##### Materials needed



7x m2.5 standoff

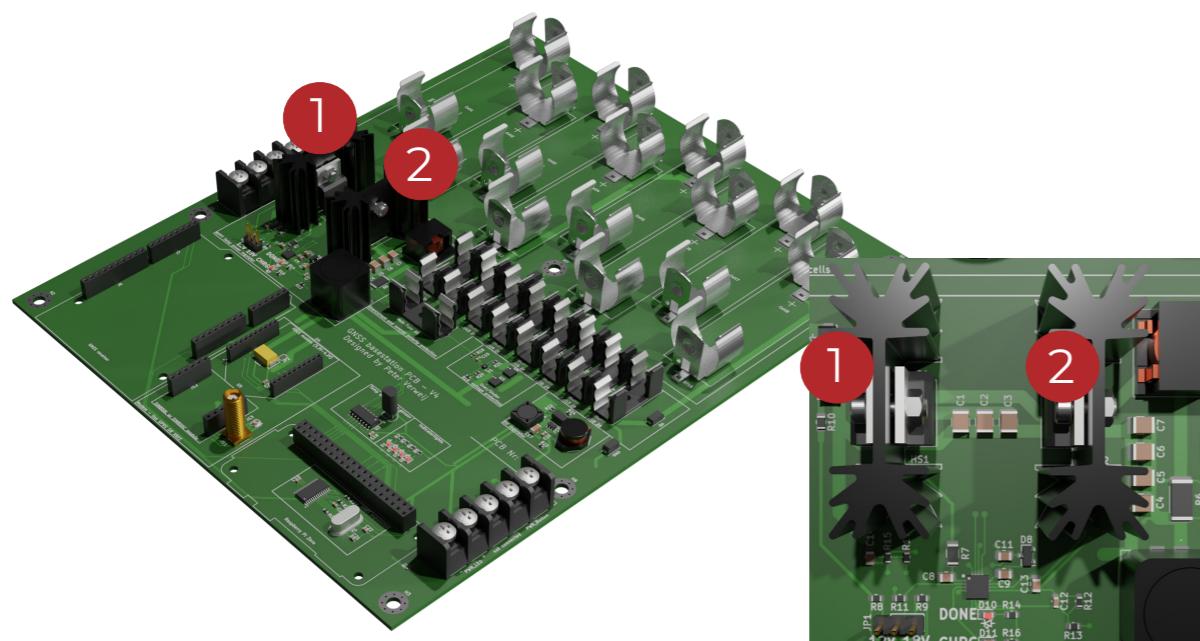


7x m2.5 nut



PCB

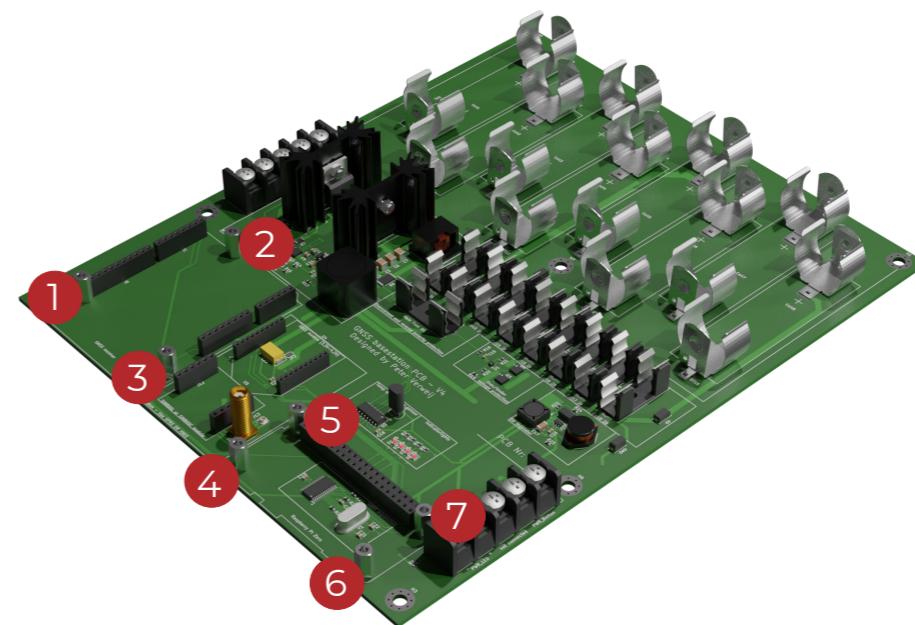
##### Task



The TO220 transistors should be attached to the heatsinks with an m3 bolt.

On heatsink1 both the TO220 transistor and TO220 diode are attached to both sides of the heatsink. On heatsink 2 only the transistor is attached by the bolt.

##### Task



The seven m2.5 standoffs should be mounted to the PCB, the nuts on the backside should be tightened fairly so that the spacers will not turn when a screw is inserted later on.

#### 4.5. Drill holes in backplate

##### Tools to use



5mm metal drill bit



drill machine



center punch



hammer

#### 4.6. Attach spacers to backplate

##### Tools to use



Wrench cap 7



Wrench



Spanner 7

##### Materials needed



Backplate (included with case)

##### Materials needed



7x m4 standoff

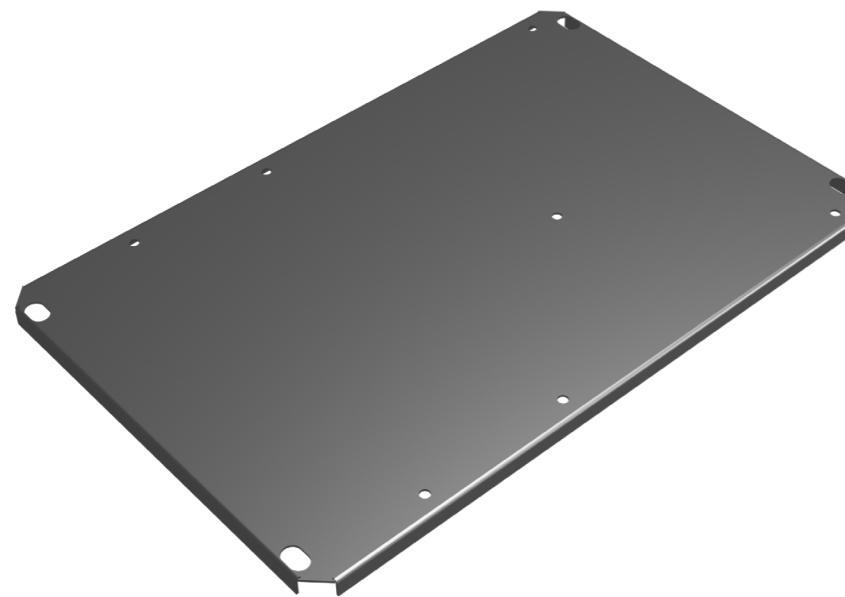


7x m4 nut



Backplate

##### Task

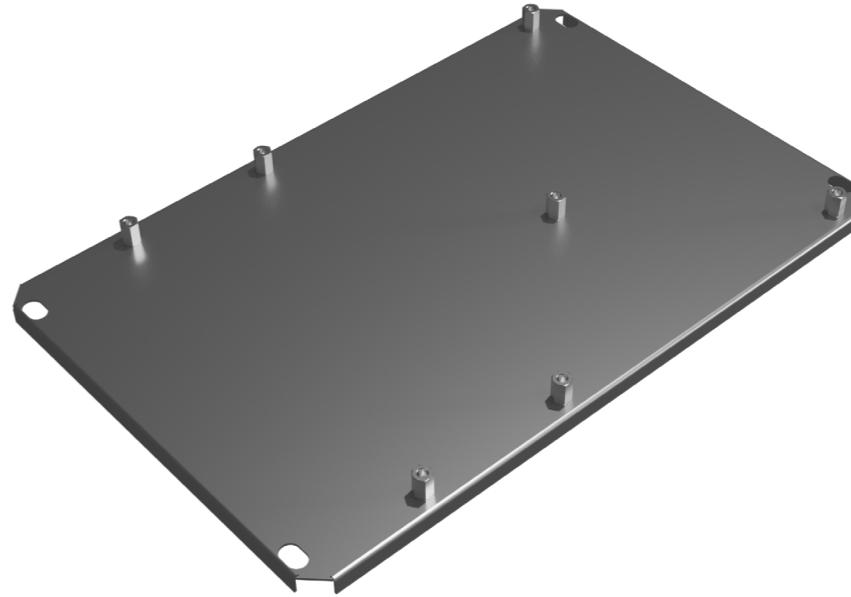


7 holes of 5mm diameter should be drilled in the backplate. The exact pattern can be found in Appendix... The holes are 1mm wider than the m4 spacers which will be placed in the holes. The larger holes are useful while the construction is over-constrained.

**Tip:** When the PCB is in the good position on the backplate, a marker can be used to mark the correct spots on the backplate.

Using a center point to slam a dent will make drilling in the right position easier.

##### Task



Attach the 7 m4 standoffs to the backplate

**Tip:** Use the PCB for the positioning of the spacers before tightening the nuts.

#### 4.7. Mount board onto backplate

##### Tools to use

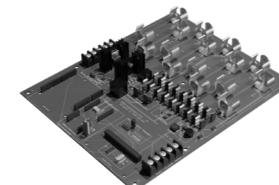


Philips head screw  
driver

##### Materials needed



7x m4 Pan head



PCB



Backplate

#### 4.8. Solder header to Raspberry PI

##### Tools to use



Solder iron

##### Materials needed

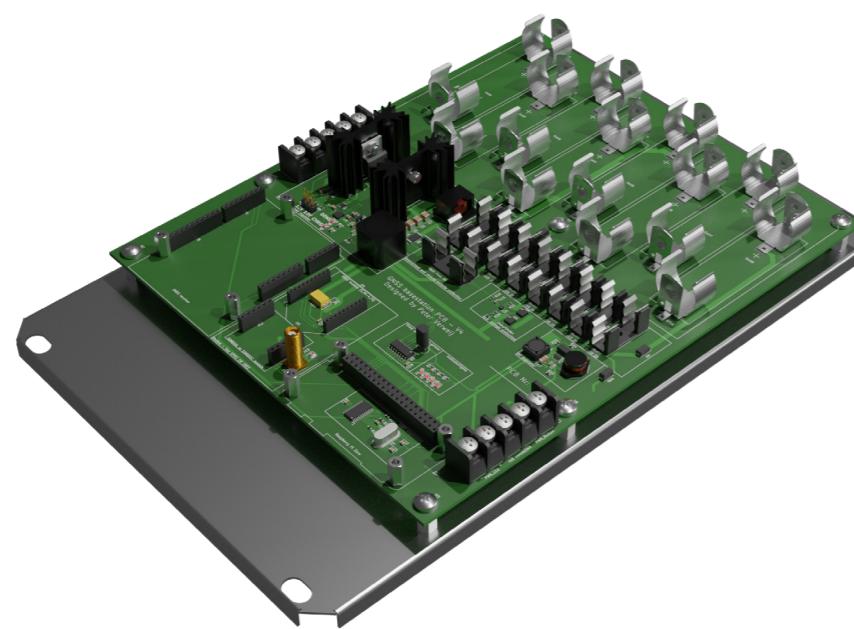


2x20 pinheader



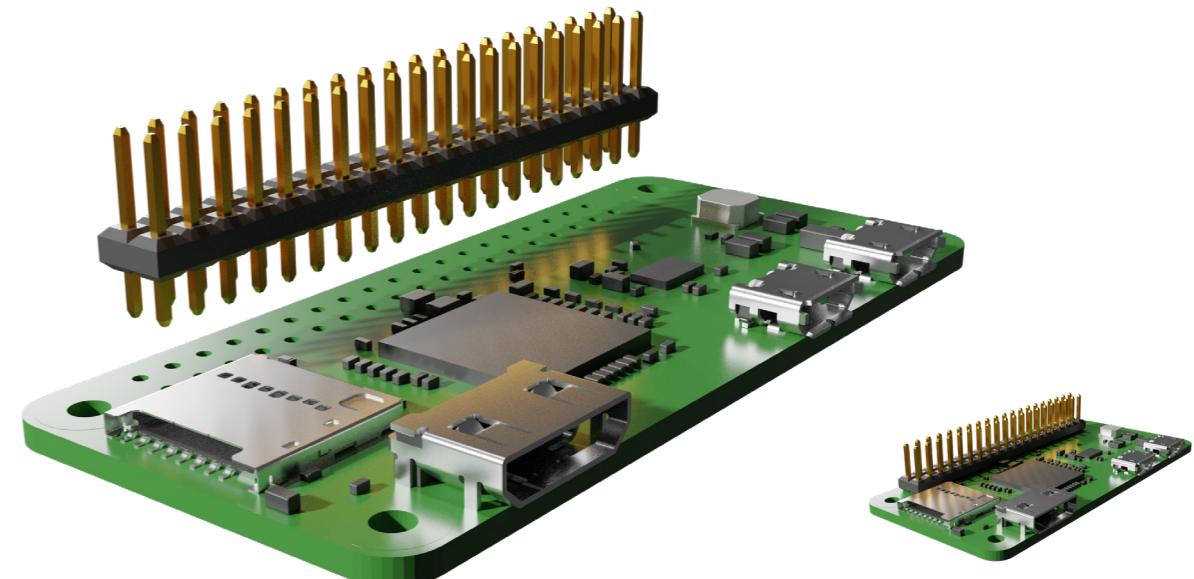
Raspberry PI Zero

##### Task



Screw in the 7 pan head screws to attach the PCB to the backplate.

##### Task



Solder a strip of 2x20 header pins to the upper side of the Raspberry PI Zero.

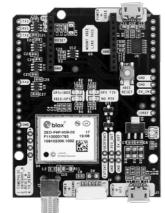
#### 4.9. Solder headers to GNSS receiver

##### Tools to use



Solder iron

##### Materials needed



GNSS receiver



headerpins

#### 4.10. Attach GNSS receiver and Raspberry PI

##### Tools to use



Philips head screw  
driver

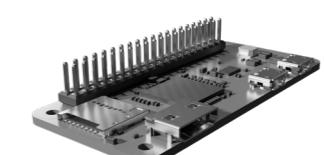
##### Materials needed



7x m2.5 Pan head



GNSS receiver

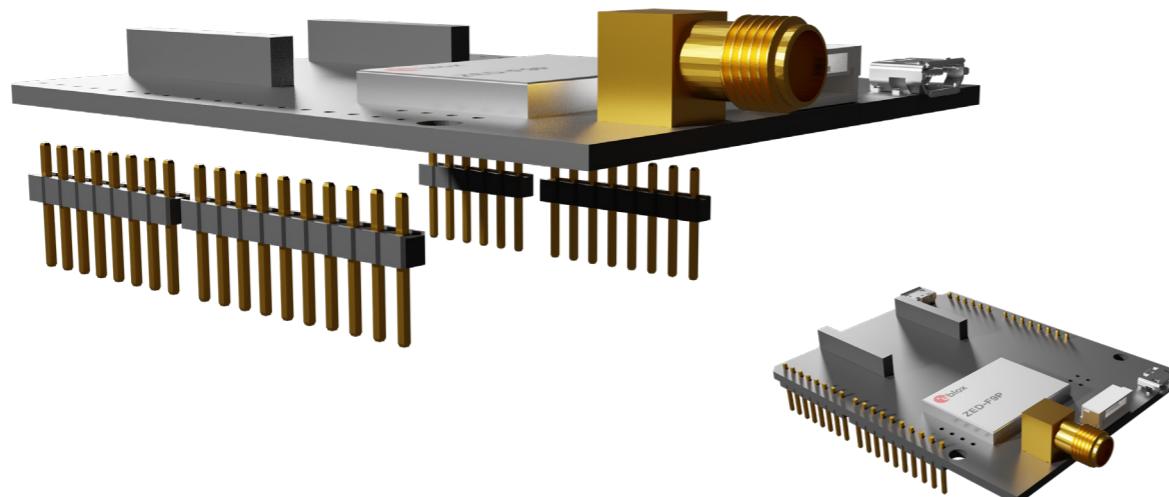


Raspberry PI zero



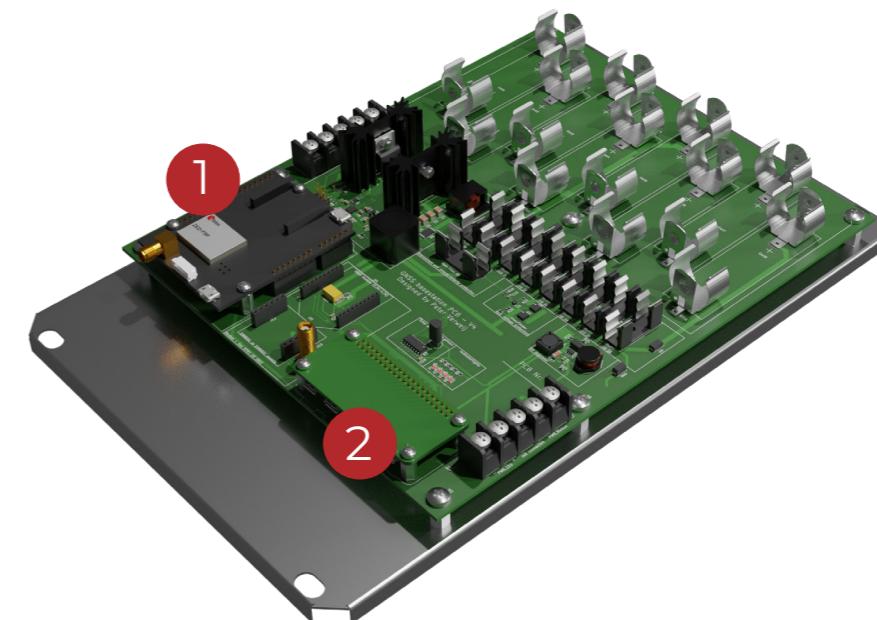
Assembled backplate

##### Task



Cut two strips of 8 header pins, one of 6 pins and one of 10 pins. Solder these headerpins to the lowerside of the GNSS receiver.

##### Task



Attach the GNSS receiver right side up (1) and raspberry PI upside down (2) to their headers. Thereafter they can be fixed with the 7 m2.7 pan head screws.

## 4.11. Solder headers to GNSS receiver

### Tools to use

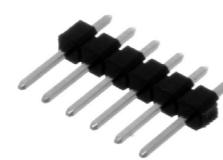


Solder iron

### Materials needed

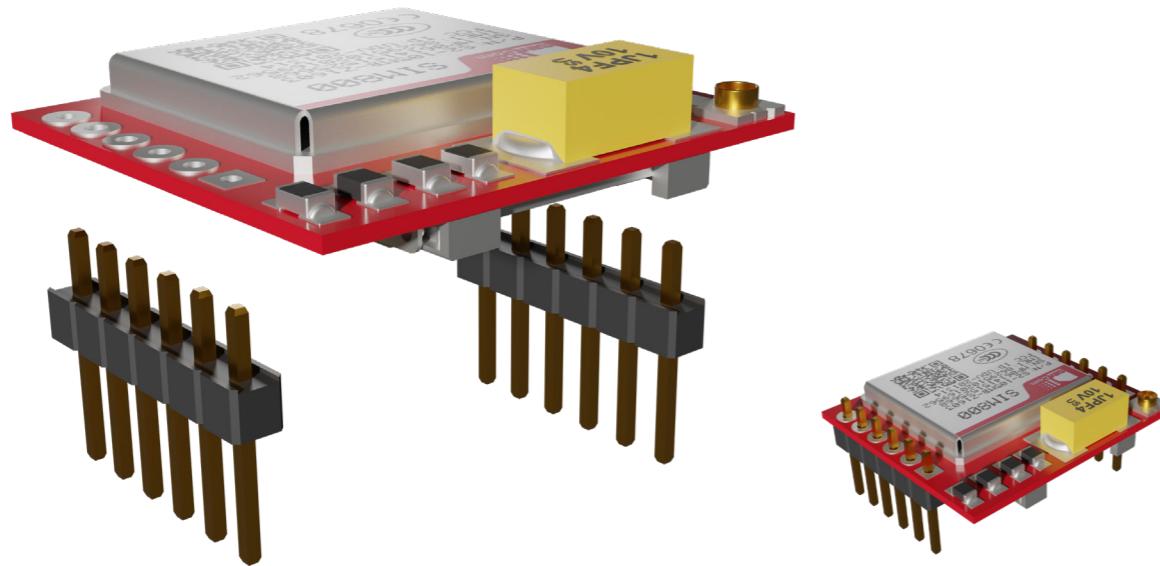


SIM800L module



headerpins

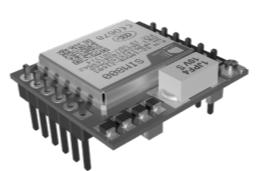
### Task



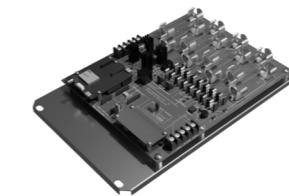
With the GPRS modem two strips of pinheaders are included (6pins). Solder these headerpins to the lowerside of the GPRS modem.

## 4.12. Attach the GPRS OR Xbee module

### Materials needed



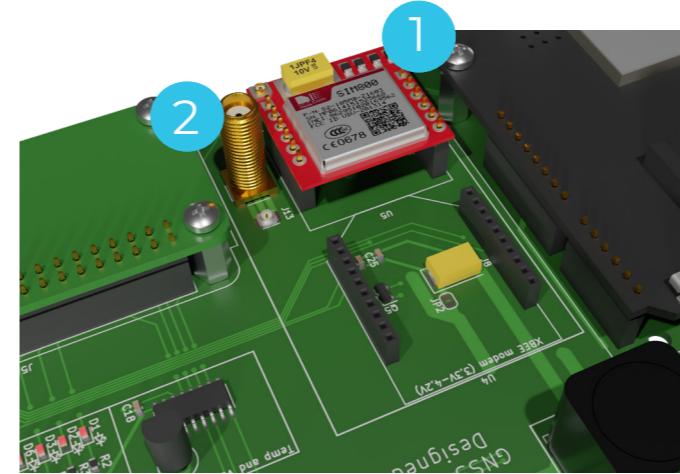
SIM800L module



Assembled backplate

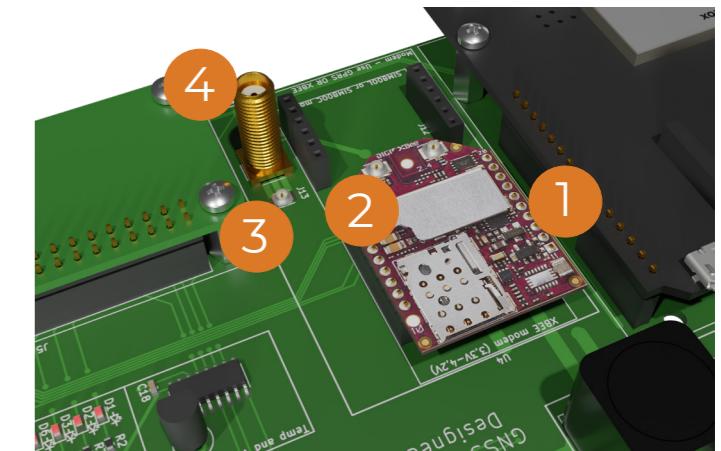
### Task

Attach a GPRS modem module OR a Xbee module for data communication.



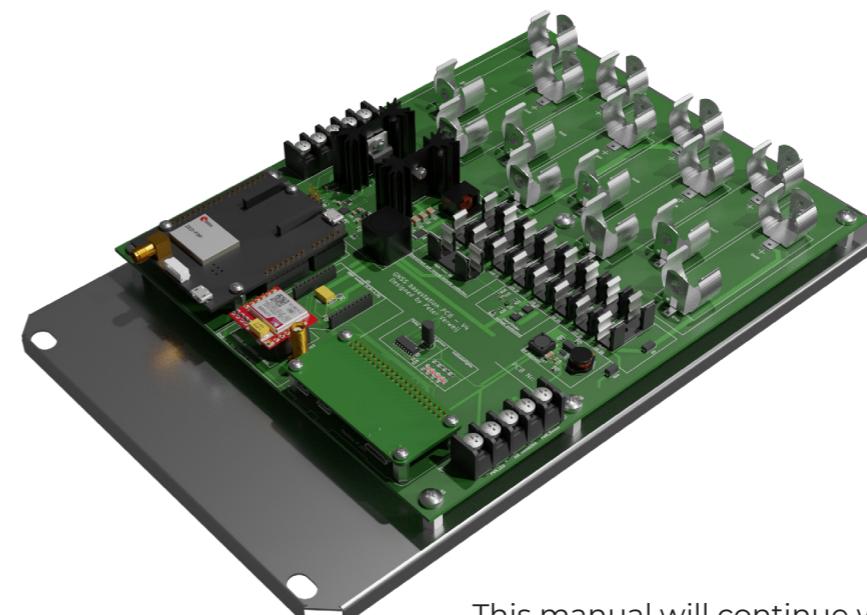
#### GPRS modem

Attach the GPRS modem to its headers (1). The antenna is already wired to the SMA bulkhead internally. A SMA GPRS antenna can be connected to the bulkhead (2).



#### Xbee module (3,3v-4,2v)

Attach the Xbee module to its headers (1). If the Xbee module has a UFL connector (2) the antenna can be linked to the UFL connector on the main PCB (3) with a small UFL to UFL cable. Finally an SMA antenna can be connected to the bulkhead on the PCB (4).



This manual will continue with the GPRS module option.

#### 4.13. Drill holes in bottom of box

##### Tools to use



Drill machine



50mm hole saw  
24mm hole saw



15mm drill bit  
3mm drill bit

#### 4.14. Drill holes in side of box

##### Tools to use



Drill machine



20mm drill bit  
8mm drill bit



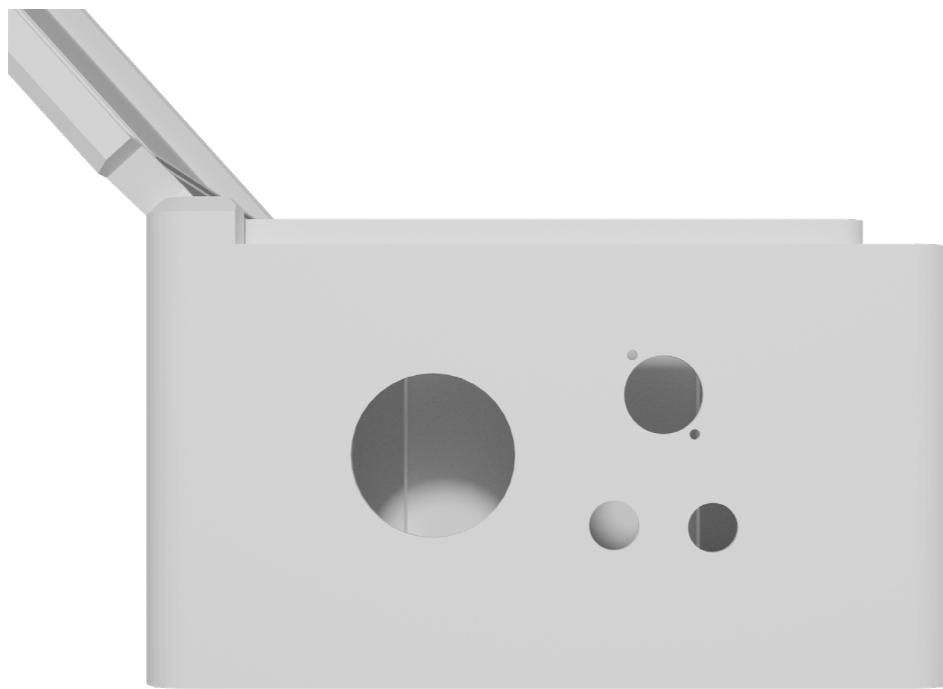
File

##### Materials needed



Case

##### Task



Drill the 6 holes in the bottom side of the box. The larger hole can be made with a hole saw. The exact hole pattern can be found in Appendix...

**Tip:** When using a hole saw try it first in a test piece. The hole saw tends to make a hole with a too big diameter.

**Tip:** having the holes in a slightly different position does not harm the functioning of the device.

##### Materials needed



Case

##### Task



Drill the 8mm hole for the power led and the ...mm hole for the power button. The power button needs an extra slot on the side, which can be made with a file. If the click fingers of the power button do not slide in to the hole two slots can be filed for this purpose as well.

The exact hole pattern can be found in Appendix...

**Tip:** having the holes in a slightly different position does not harm the functioning of the device.

#### 4.15. Assemble solar power cable

##### Tools to use



Crimping tool



Stripping pliers



Solder iron



Heatgun

#### 4.16. Assemble neutric socket

##### Tools to use



Philips head screw  
driver



Spanner 5.5

##### Materials needed



m4 cable lug



Wire 18AWG



Shrink tube



1x NAC3MPX-TOP

##### Materials needed



Assembled solar cable



1X SCNAC-MPX



2x m3 countersunk  
philips head screw



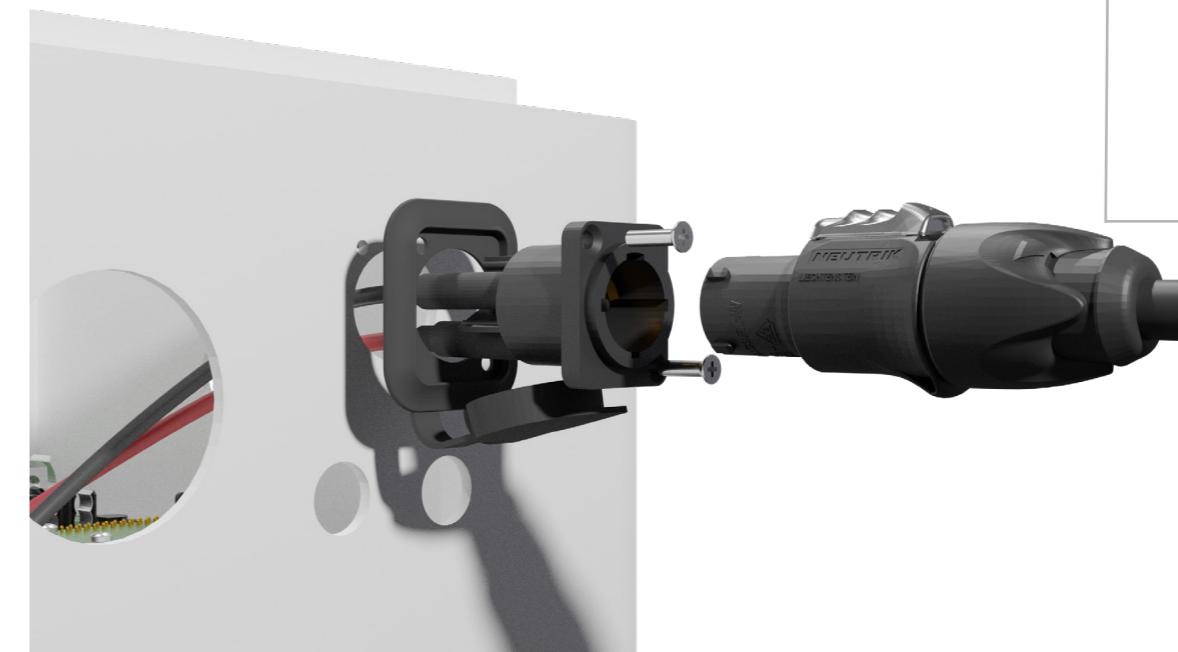
2x m3 nut

##### Task



Solder the red wire to L terminal and the black wire to the N terminal of the Neutric socket. Cover the terminals with shrink tube. The shrinking can be accomplished with a heatgun. Finally the two m4 cable lugs should be crimped to the other side of the wire with the crimping tool.

##### Task



Attach the neutric connector to the housing using 2 m3 countersunk philips head screws and nuts. The male connector does not have to be plugged in yet and is only in the image for illustrative purposes.



Case

#### 4.17. Insert cable glands and water drain

##### Tools to use



Spanner 18

##### Materials needed



2x PG9 cable gland



DD 084 Stego drain



Case with solar cable

#### 4.18. Insert assembled backplate in case

##### Tools to use

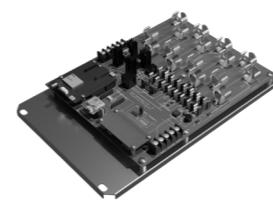


Philips head screw  
driver

##### Materials needed



4x Self tapping screw  
(included with case)



Assembled backplate



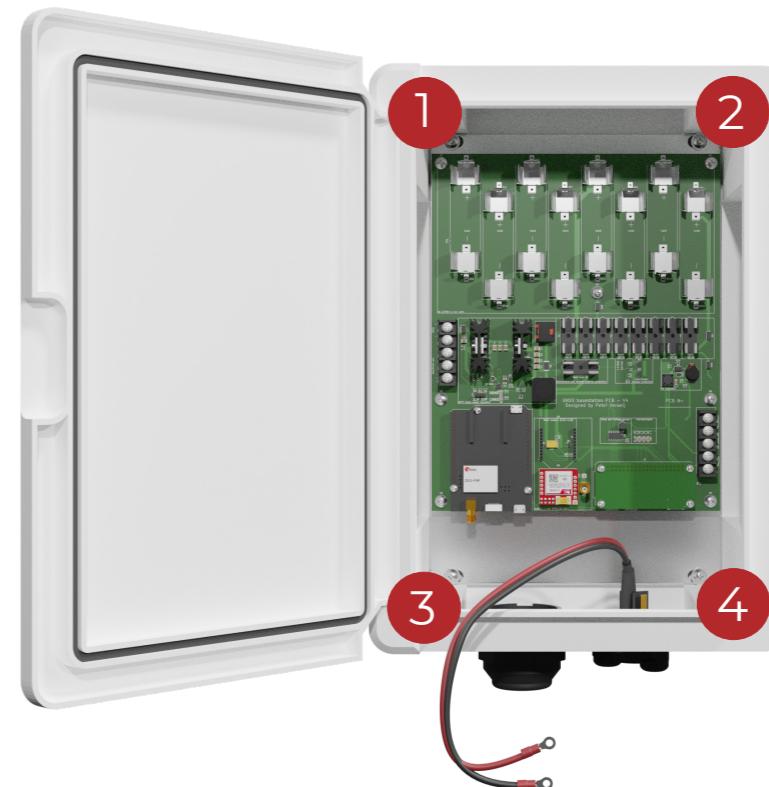
Case with lower side  
assembled

##### Task



Screw the two cable glands in the lower side of the case. Tighten them with spanner 18. The large Stego drain can be tightened by hand easily.

##### Task



Screw the backplate with assembled PCB to the backside of the case using the 4 self tapping screws which were included with the case.

#### 4.19. Attach solar power cable

##### Tools to use



Philips head screw driver

##### Materials needed



Case with PCB

#### 4.20. Assemble powerbutton

##### Tools to use



Crimping tool



Stripping pliers



Solder iron



Heatgun

##### Materials needed



m4 cable lug

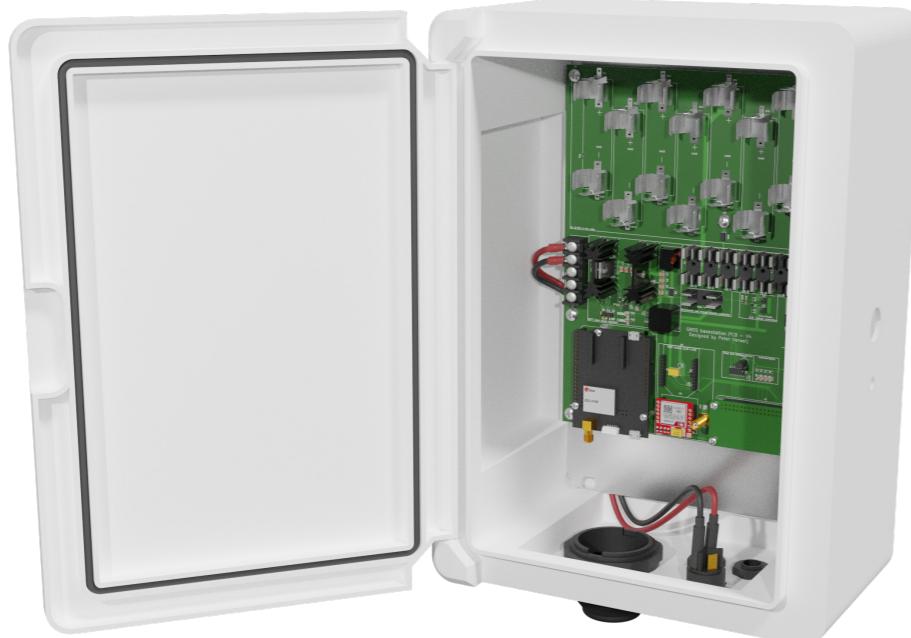


Wire 18AWG



Shrink tube

##### Task



Attach the solar power cable to the solar power terminals on the PCB. The red wire should be connected to the + terminal and the black wire should be connected to the - terminal

The solar power cable can be routed behind the PCB, as is done in the image above, when extra holes are drilled in step 4.3.

##### Task



Solder two black wires to the terminals of the on/off button. Cover the terminals with shrink tube. The shrinking can be accomplished with a heatgun. Finally the two m4 cable lugs should be crimped to the other side of the wire with the crimping tool.

## 4.21. Assemble power LED

### Tools to use



Crimping tool



Stripping pliers



Solder iron



Heatgun

### Materials needed



m4 cable lug



Wire 18AWG



Shrink tube

## 4.22. Insert powerbutton and power LED in case

### Tools to use



Spanner 13



Philips head screw driver

### Task



Solder a red wire to the gold terminal of the LED and a black wire to the silver terminal of the LED. Cover both terminals with shrink tube. The shrinking can be accomplished with a heatgun. Finally the two m4 cable lugs should be crimped to the other side of the wire with the crimping tool.

**Warning:** The cable lugs might not fit through the LED nut or through the hole in the case. Therefore it might be needed to crimp the lugs on after placing the LED in the case.

### Task



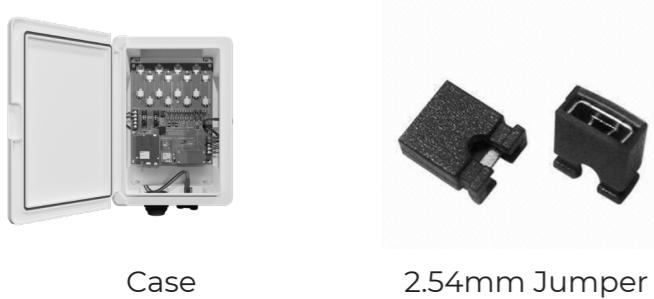
Mount the power LED and power button in the case. When the powerbutton does not click in place properly revisit step 4.10.

Attach the powerbutton cable to the powerbutton terminals (there is no wrong order). When attaching the cables of the power LED, make sure to connect the red wire to the + terminal and the black wire to the - terminal.



## 4.23. Insert jumper

### Materials needed

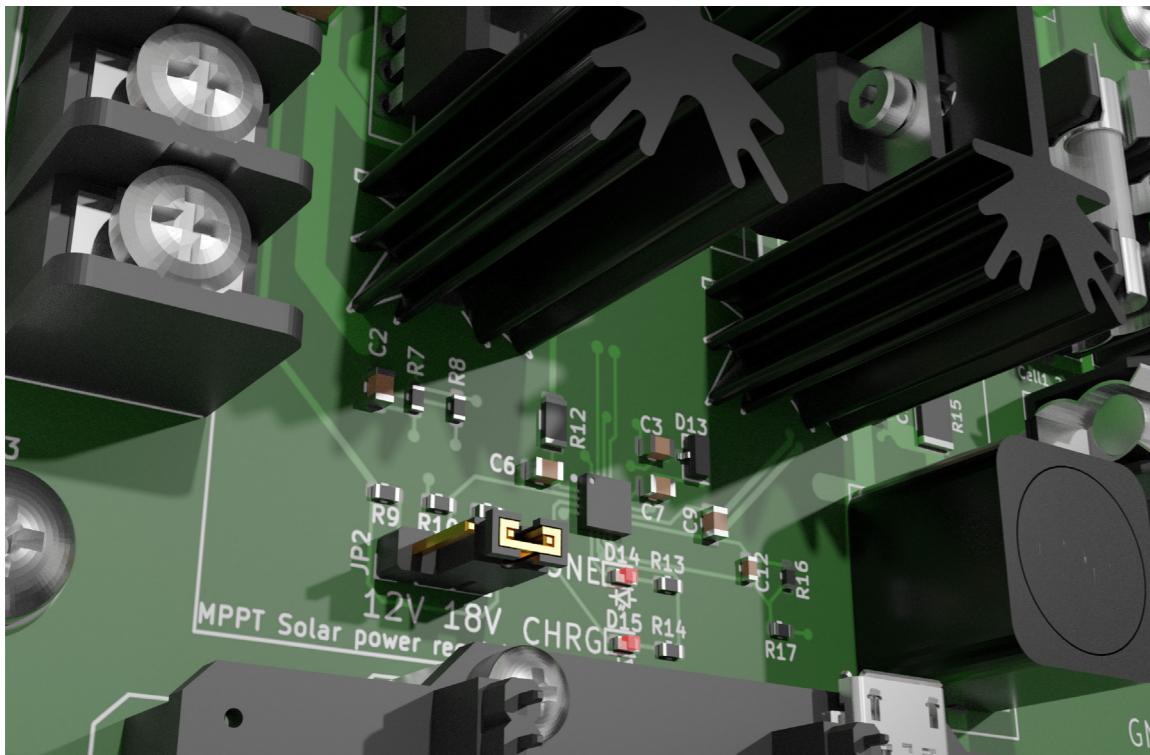


Case



2.54mm Jumper

### Task



Put a 2.54mm jumper to the header pins at the side of which MPPT (Maximum Power Point Tracking) voltage will be used. In the image above 18v has been chosen.

18V is suitable for the Victron solar panel used in this manual.

12V can be used for a fixed DC 12V powersupply. In this case inserted batteries will act as an Uninterruptible Power Supply (UPS). It has to be noted that this feature has not been tested.

## 4.24. Insert fuses

### Tools to use



Multimeter

### Materials needed



Case

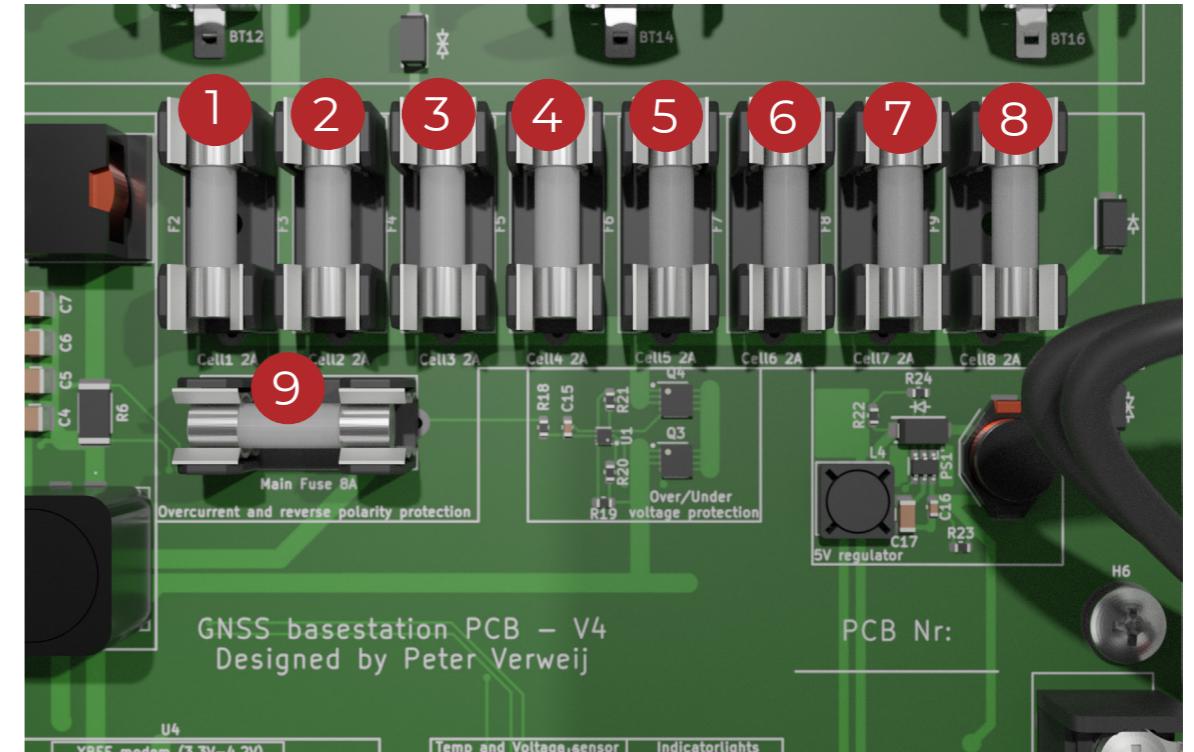


1x Fuse 8A



8x Fuse 2A

### Task



Check the integrity of your fuses by using a multimeter to measure if they conduct any electricity. Place a 2A fuse for each cell which will be in the device (1-8). Finally place a 8A main fuse (9).

## 5. Solar panel assembly

### 5.1. Attach cable to solar panel

#### Tools to use



Crimping tool



Stripping pliers



Philips head screw driver

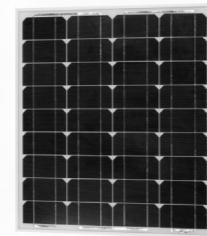
#### Materials needed



2x m4 cable lug



Cable 2 wires 17AWG



20watt solarpanel



Put the cable in the junction box at the back of the solar panel. Crimp two cable lugs to this cable and attach the red wire to the positive terminal (1) and black cable to the negative terminal (2). This can be done with a philips head screwdriver. Finally, clamp the cable down with the bracket (3).



### 5.2. Attach male Neutrik connector to solarcable

#### Tools to use



Stripping pliers



Torx screw driver T8

#### Materials needed

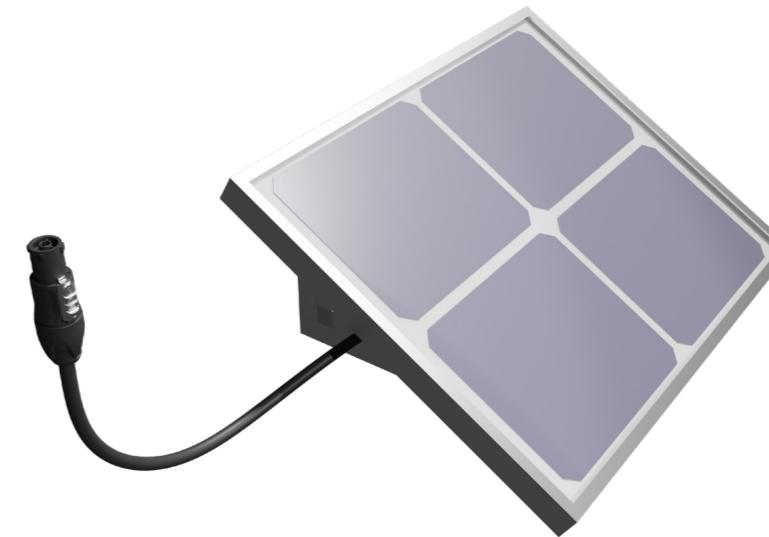


Solar panel with cable



1x NAC3FX-W-TOP

#### Task



Strip cable and mount the Neutrik connector to it. Take care to attach the black wire to the N terminal and the red wire to the L terminal. The terminals can be tightened with a torx screwdriver.

For more in detail assembly instructions of the neutrik connector, take a look at the assembly manual from Neutrik, which can be found at the following webpage;  
<https://www.neutrik.com/en/product/nac3fx-w-top>

**Tip:** When screwed together, the connector locks itself. To open up the connector again, a locking mechanism should be pushed in with a flat head screwdriver. This instruction can also be found in Neutrik's assembly manual.

## 6. Antenna-top assembly

### 6.1. Assemble antennatop

#### Tools to use



Allen key 3



Allen key 6



2x - m4x25



2x m4 nut

#### Materials needed



GNSS antenna



Cellular Antenna

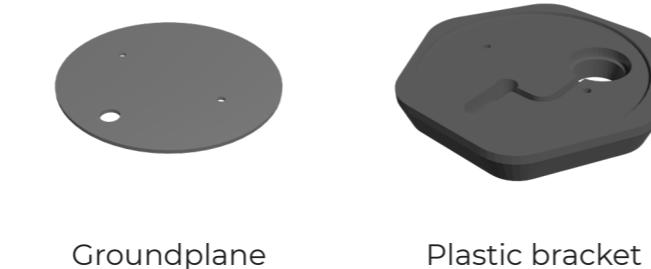
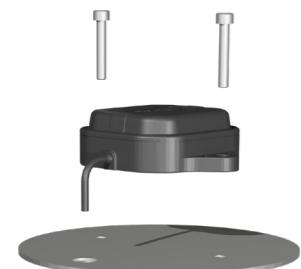


1x - m8x40



1x m8 nut

#### Task



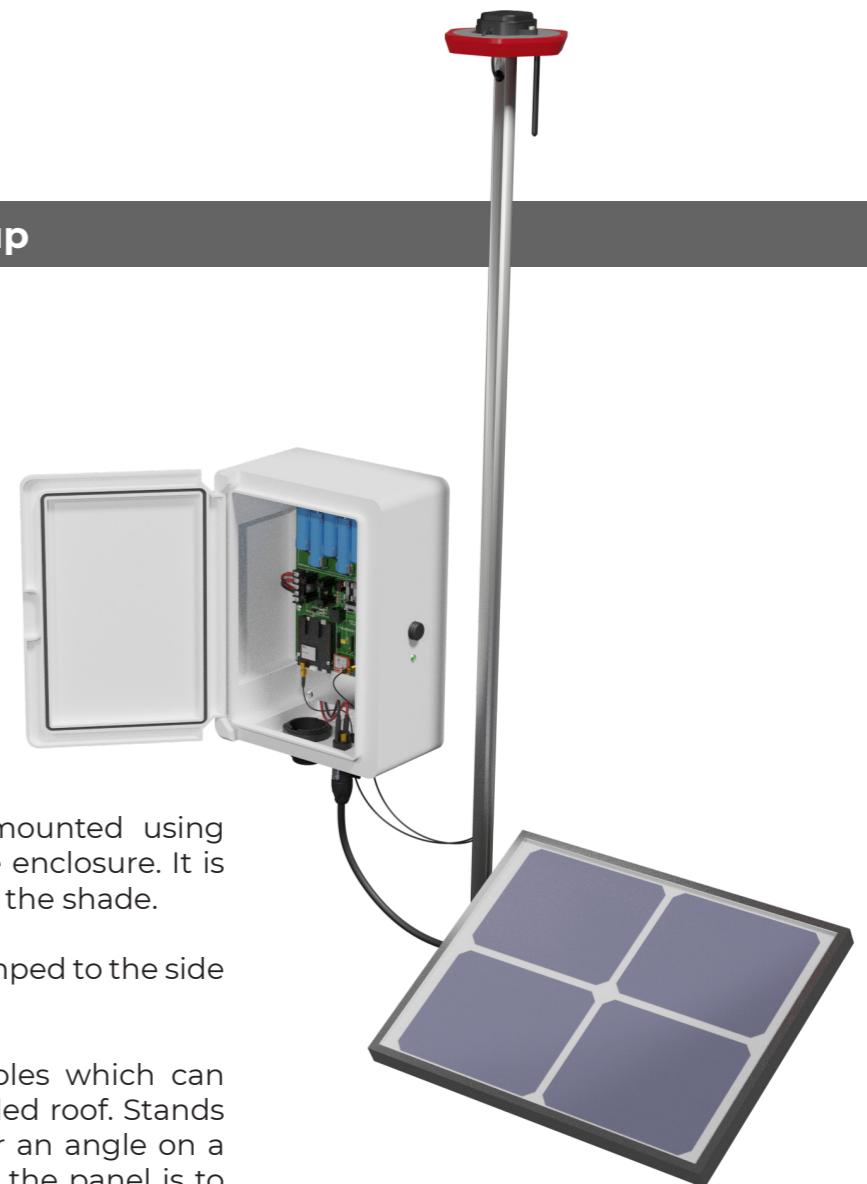
Assemble the antenna top as can be seen in the exploded view on the left side of this page. Use the allen keys to tighten the bolts. Make sure to put the antenna wires through the gutter in the plastic bracket.



## 7. Start using reference station

Now it is time to start using the reference station. The setup could look like the one which can be seen below.

### 7.1. Mounting the setup



The enclosure can be wall mounted using the brackets supplied with the enclosure. It is advised to put the enclosure in the shade.

The antenna pole could be clamped to the side of a wall using an U-clamp.

Finally the solar panel has holes which can be used to mount it to an angled roof. Stands could be made to put it under an angle on a flat roof. The best direction for the panel is to face the equator (geographic south for Ghana). The best tilt angle is on average 17 degrees plus the latitude of the location according to (Uba & Sarsah, 2013)

Probably different mounting methods suit different situations.

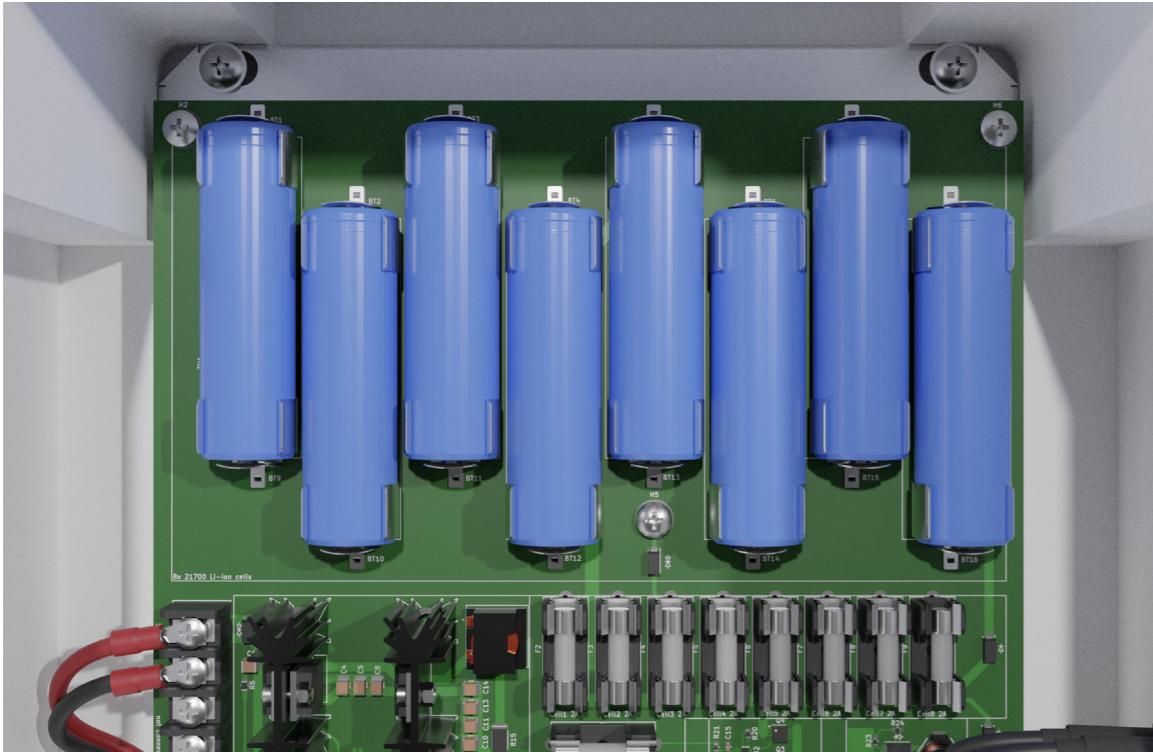
**Warning:** The current antenna cables are about 2,5-3meters. No test has been committed with extension cables.

## 7.2. Insert Lithium cells

### Tools to use



### Task



Handle the lithium batteries with care as there is a fire hazard in over/under charging them and large currents can flow on a short circuit.

Check the voltage of the 21700 cells, the voltage between cells which have to be placed may not deviate more than 0,1v. Insert the 21700 cells one by one with the + side up (as noted on the board)

#### Protection:

A reversed cell will blow the fuse which belongs to the cell.

A bigger deviation than 0,1v from the other cells will cause a large current to flow. This will probably also cause a fuse to blow.

## 7.3. Insert Lithium cells

### Task



Attach the solarpower cable (insert and twist).

**Tip:** The battery protection circuit will only enable the battery after the charger has been applied for the first time. This means that the on/off function will not work before the charger has been attached and charged for a second.

## 7.4. Antenna cables throughput

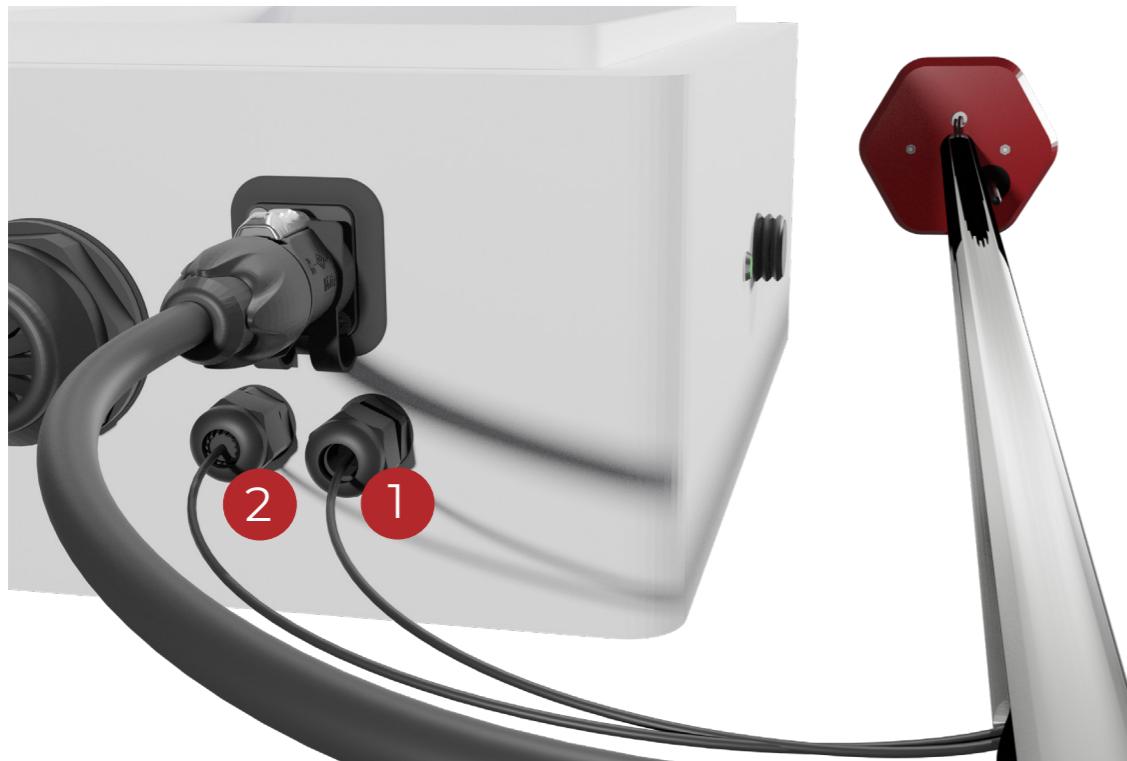
### Tools to use



Allen key 6

### Task

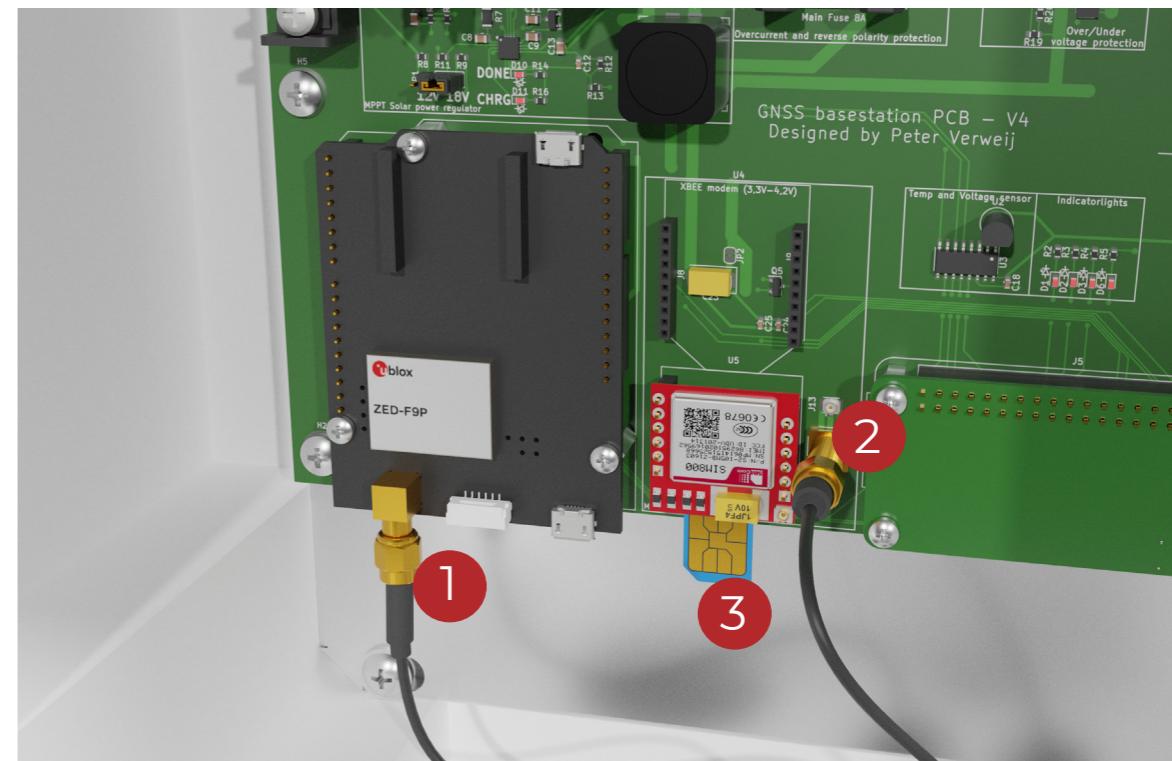
The antenna top can be clamped to the aluminium pole with its m8 socket head bolt. It is possible to wire the antenna cables through the pole.



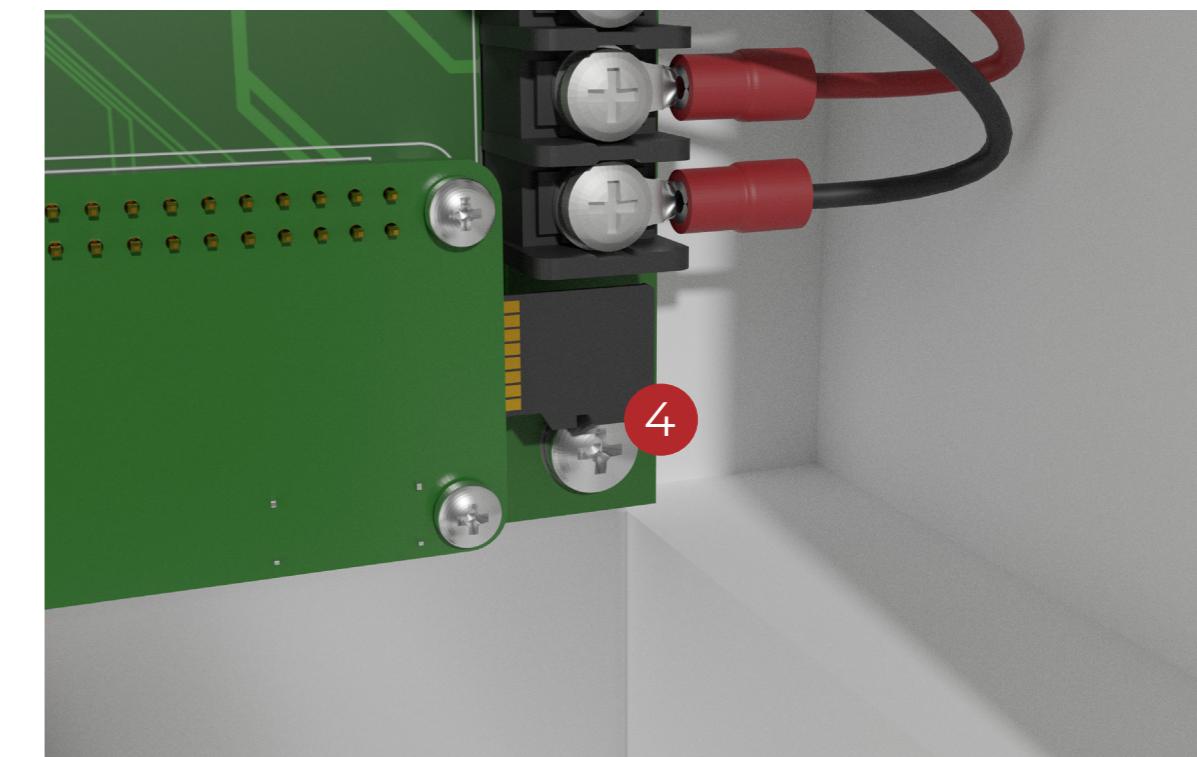
Put the antenna cables through the cable glands (1). Then tighten the nut of the cable gland to make them watertight (2).

## 7.5. Attach antenna cables, SIM and SD card

### Task



The GNSS antenna should be connected to the GNSS receiver (1). The GPRS antenna should be connected to the modem (2). Also, the SIM-card should be installed (3).



Finally the SD-card with the reference station image should be inserted in the raspberry PI (4). For preparing the SD-card I refer to the software manual of Andreas Krietemeyer.

Now the device can be powered on.

## 8. Troubleshooting

On the reference station there are some LED's which give information about the system state;

### Case LED

The LED on the enclosure will be on as soon as the powerbutton is turned on.

### Charger

The Charge LED will be on when there is enough light and the charger has started charging.

The Done LED will be on if the battery voltage has been raised to 4,1V.

When both LED's are on, the charger is in error state. The charger is programmed to shut off under -5 degrees celcius or over 55 degrees celcius. (This is the ambient case temperature, the heatsinks will get hotter).

### Raspberry PI

The raspberry PI internal green LED will blink it's LED on reading the SD card. There are 4 indicator LED's which can be programmed to turn on or off (see test program ...) These LED's can be put to use to troubleshoot software in the Raspberry PI.

### GPRS modem

The GPRS modem has a red LED which blinks slowly on startup. On connection this led will blink fast.

It is possible that the modem is turned off (it turns off under 3,4v) while the raspberry PI is still running.

### GNSS receiver

When the GPS-fix light on the receiver is flashing this means that there are enough satellites in sight to define a position.

## 9. Hardware test

The hardware has been tested from 15 March 2021 until 6 April 2021 (22 days) in the Netherlands to check the behaviour of the power-supply and the cellular connectivity.

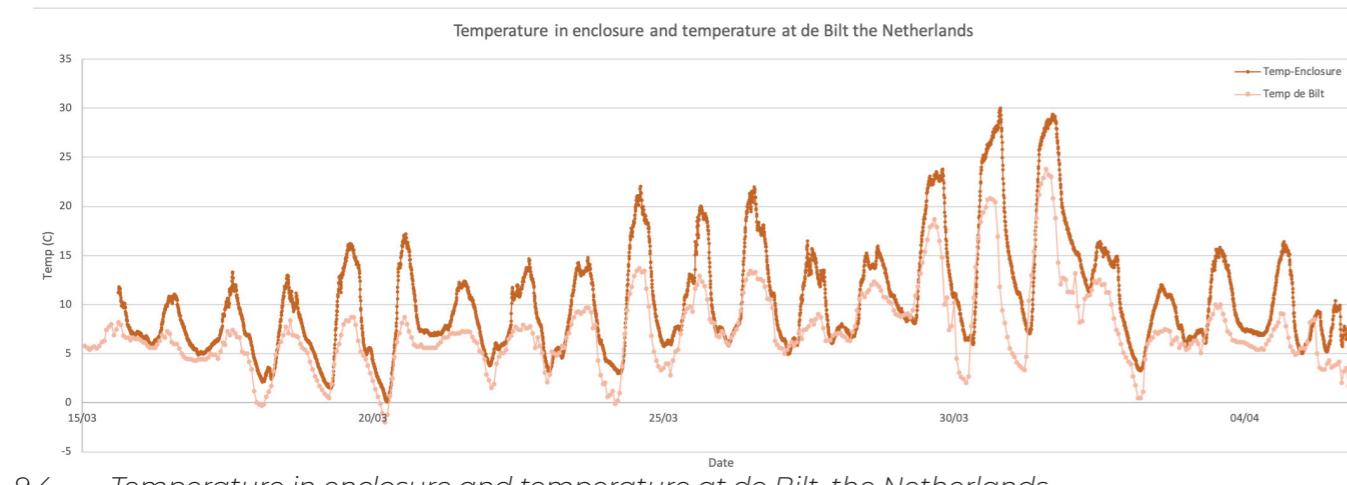
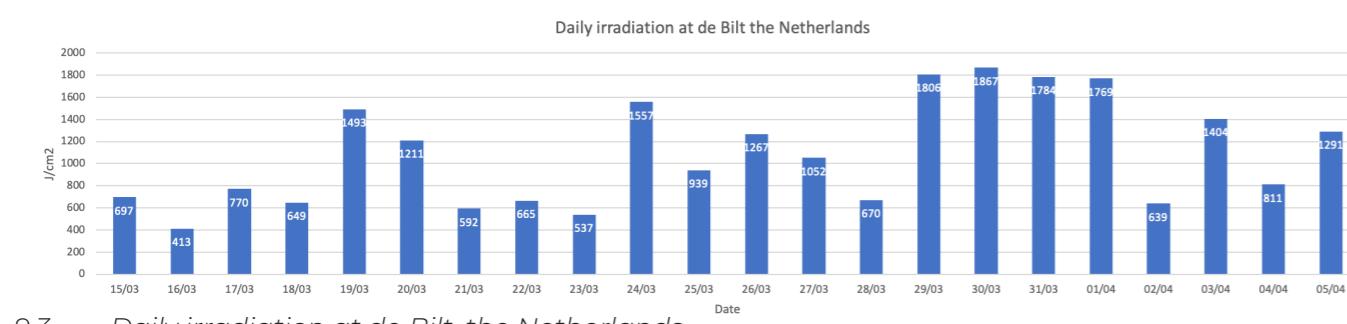
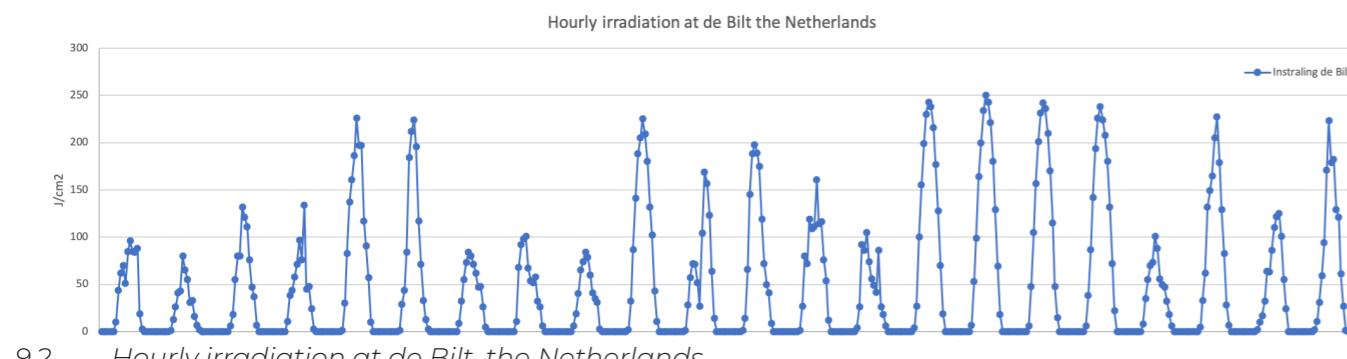
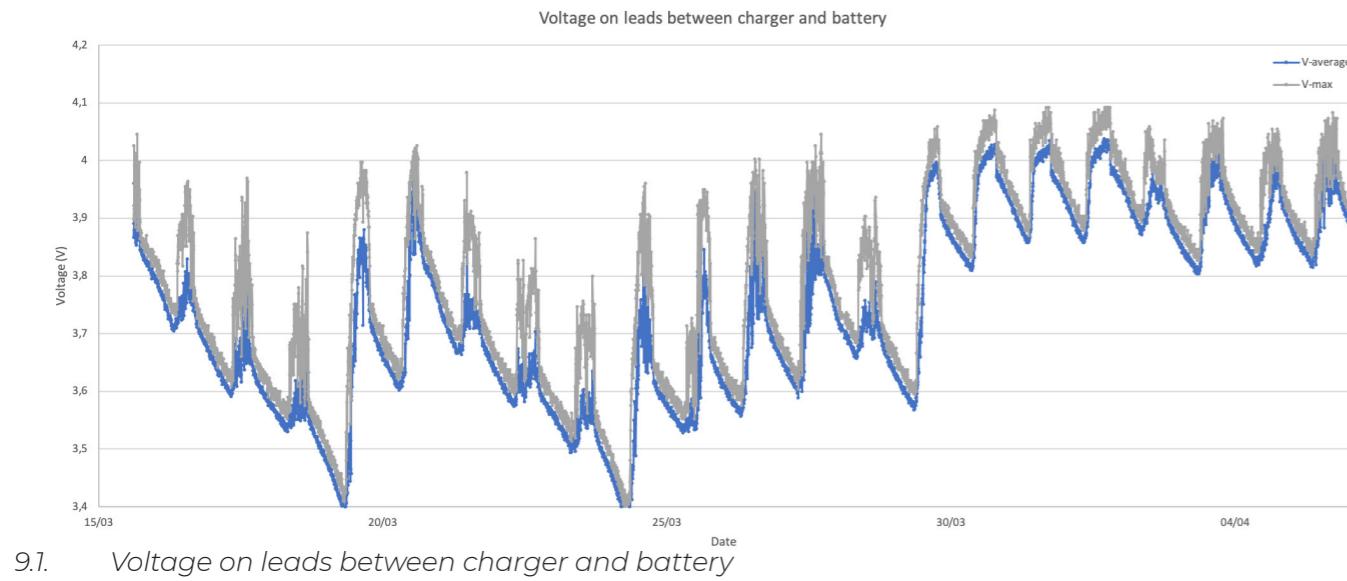
### 9.1. Setup



**Position** As can be seen above the system was placed on a roof next to an existing PV system. The solar panel is tilted 35 degrees and facing a few degrees west from the south axis.

**Data** In 15 days there was no connection loss. In total 1,6Gb of GNSS data has been send over GPRS. Which is about 106mb each day. This might be a little much for future purposes but a heavy load is positive for this power supply test.

## 9.2. Results



## 9.3. Conclusion of test

### Battery voltage:

During daytime the charger raises the voltage on the circuit. Only at night time the true battery voltage can be seen. Also, the voltage measurement lead on the prototype PCB is close to the GPRS modem power input. Therefore the measured voltage is quite unstable and had to be sampled for 20 times over 20 seconds to give stable readings.

Over the 22 days of the test the device did not stop functioning, however the average voltage dropped as low as 3,37V While the modem has a lower limit of 3,4V. Probably its cutoff limit is lower in reality.

It can be concluded that the device can run for 4 to 5 cloudy days with very low irradiation.

It can be concluded that the solar regulator can produce just enough power to exactly compensate for the night time use, when the daily irradiation is 939J/cm<sup>2</sup>. This was the case on 26 March. A lower irradiation will cause the battery to drain, a higher irradiation means that there will be more energy stored than used that day.

In Ghana the month with the least sun radiation is august. The average day in that month still has 3,8Kwh/m<sup>2</sup> of irradiation. (Energy Commission, Ghana, 2001) This equals 1368J/cm<sup>2</sup>. Thus on average there is enough irradiation to keep the device running. The chance that there will be 5 consecutive days with less than 939J/cm<sup>2</sup> irradiation is extremely small.

### Temperature:

The used LM35 temperature sensor can only read positive temperatures.

During night time, the enclosure is only within a degree hotter than the outside temperature. This can be caused by the difference in height and location of the temperature sensors. Or it can be caused by the slight dissipation of heat in the enclosure in combination with almost no wind.

During daytime the temperatures can be raised as much as 10 degrees above the outside temperature. This is probably due to the dissipation of heat by the solar regulator and due to direct sunlight on the enclosure.

### Other:

Despite a lot of wind and rain all electronics in the box were unharmed.

## 10. References

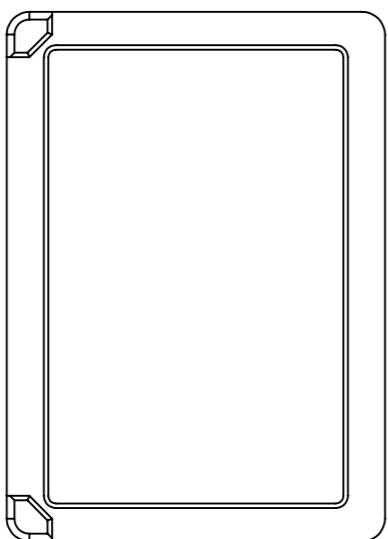
Energy Commission, Ghana. (2001). Energycom.gov.gh. [http://energycom.gov.gh/files/Solar%20Data%20-%20final\(1\).pdf](http://energycom.gov.gh/files/Solar%20Data%20-%20final(1).pdf)

JRC Photovoltaic Geographical Information System (PVGIS) - European Commission. (2016, January 11). Europa.eu. [https://re.jrc.ec.europa.eu/pvg\\_tools/en/tools.html](https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html)

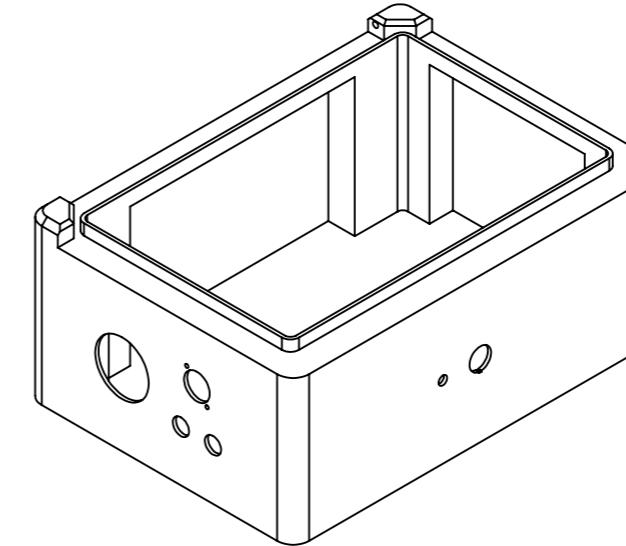
Uba, F., & Sarsah, E. (2013). Optimization of tilt angle for solar collectors in WA, Ghana. <https://www.imedpub.com/articles/optimization-of-tilt-angle-for-solar-collectors-in-wa-ghana.pdf>

## 11. Appendix

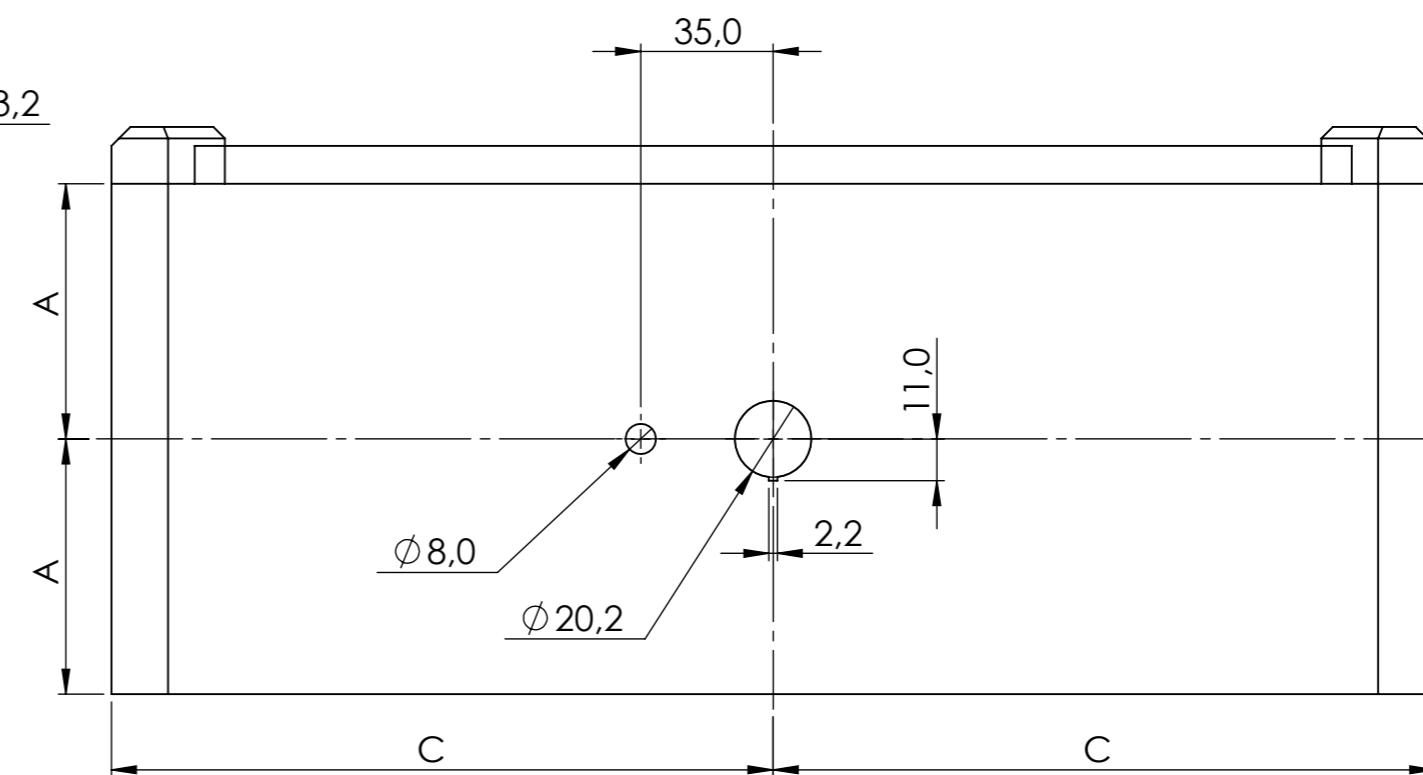
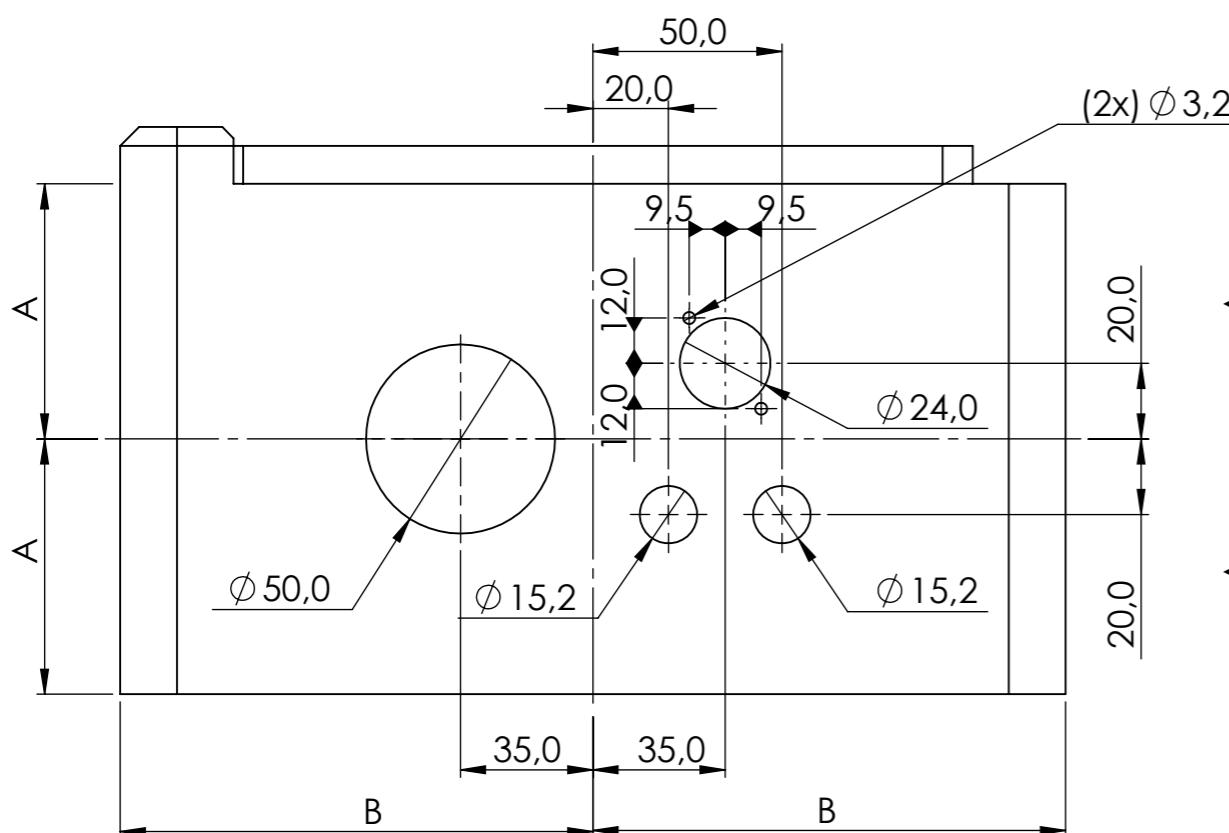
## **Appendix A. Enclosure holes measurements**



Scale 1:5



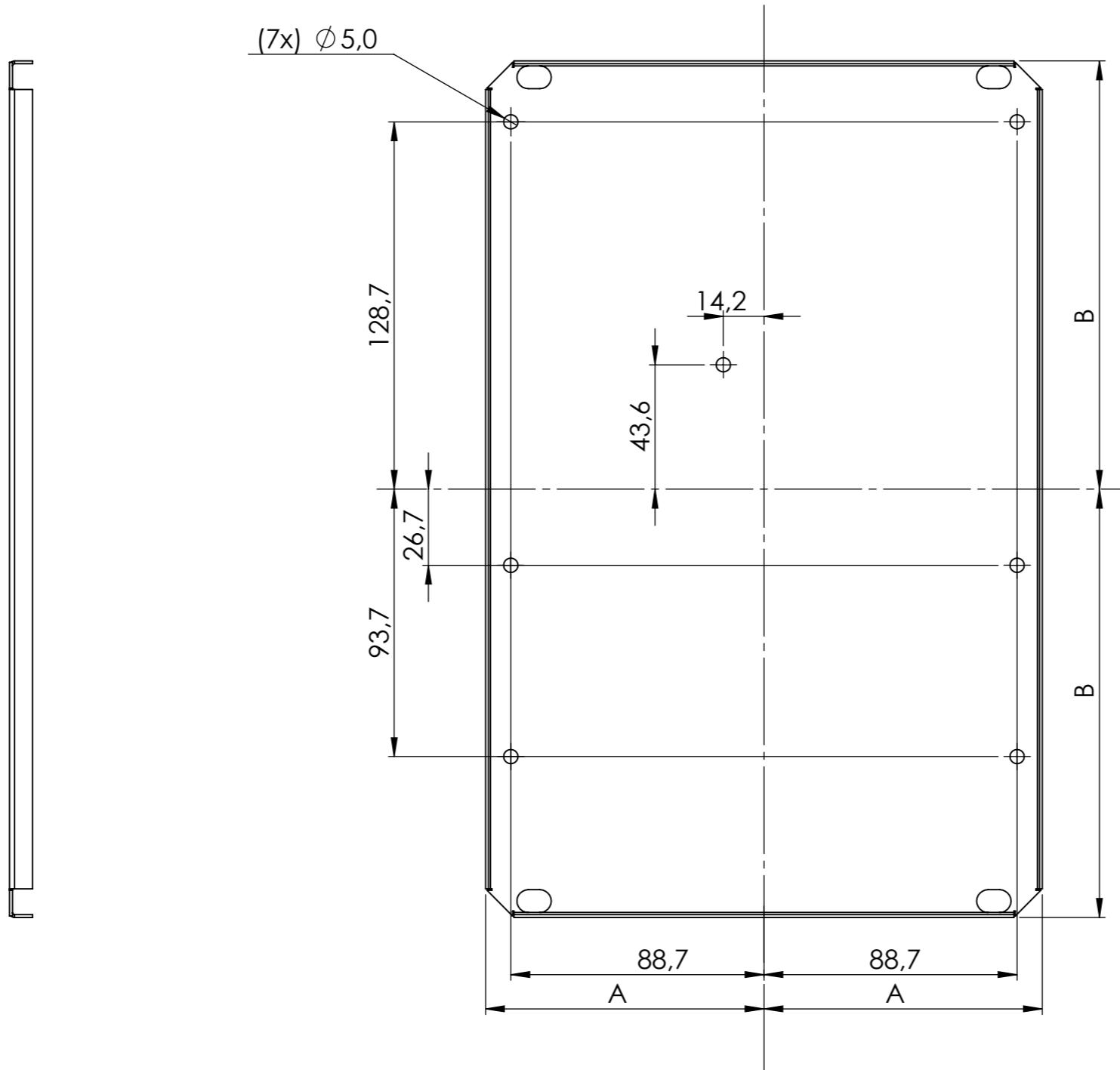
Scale 1:



While outer dimensions of box have not been measured precisely, midpoints are only noted down as equal lengths.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
DRAWN	NAME	SIGNATURE	DATE			TITLE:	Enclosure_Main with drilled holes
CHK'D							
APP'VD							
MFG							
Q.A				MATERIAL:		DWG NO.	Enclosure_Main
							A3
			WEIGHT:		SCALE:1:2	SHEET 1 OF 1	

## Appendix B. Backplate holes measurements



While outer dimensions of backplate have not been measured precisely midpoints are only noted down as equal lengths.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
DRAWN	NAME	SIGNATURE	DATE			TITLE:  Enclosure_backplate with drilled holes	
CHK'D							
APP'D							
MFG							
Q.A							
				MATERIAL:	DWG NO.		
					Enclosure_Backplate		A3
				WEIGHT:	SCALE:1:2	SHEET 1 OF 1	