Reef-PI HAT v1.0 build guideline

Contents

Revision	Reason	Date
1.0	Original release for HAT v1.0 building instructions	13 Nov 2018

Table 1: Revision history

Planned updates to this document:

	Planned addition or update
	15 – Add picture of 2x20 female connector flat fit on PCB
	1 – add picture of stacked PI/HAT/PWM
	13 – add DS18B20 wiring diagram
	Add bold to important notes

Table 2: Things to do to this document

1. Introduction

The purpose of this document is to be a guideline to build a Reef-PI_HAT PCBA (Printed Circuit Board Assembled). It's not the intention to describe soldering techniques, soldering equipment and ESD (Electro Static Discharge) topics. There are sufficient guidelines to be found on Youtube for this. If you're completely unfamiliar with this, it's recommended to have a look into this before purchasing any equipment.

This HAT PCBA only uses through hole components (THC) and is therefore easy to assemble.

The use of this PCB is easier than using fritzing techniques as it applies the same soldering techniques and no additional wiring is required since this is already implemented in the PCB design. This also reduces the risk of mistakes. Further it reduces size and can therefore integrate more functions on the same dimension.

This guideline is a step by step assembly per component type covering sequence of components to be placed and some specific notes when applicable. Also alternative solutions are offered.

The individual steps also explain which components support which function, so if you don't need all functionality of the Reef-PI_HAT, you can skip that component.

This should be the outcome of this guideline if all components are going to be installed:

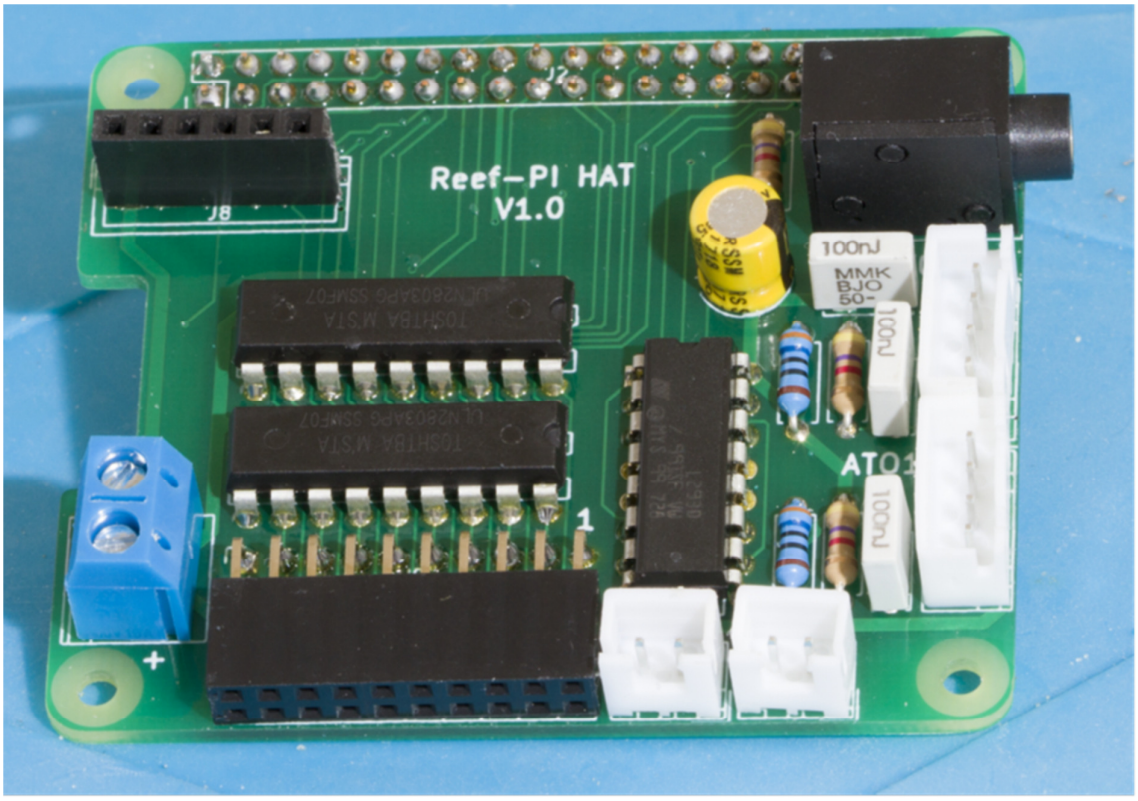

Figure 1: Complete assembled Reef-PI HAT

It fits directly on a Raspberry PI 2 or 3.x GPIO interface and allows other modules to be stacked on top of it.

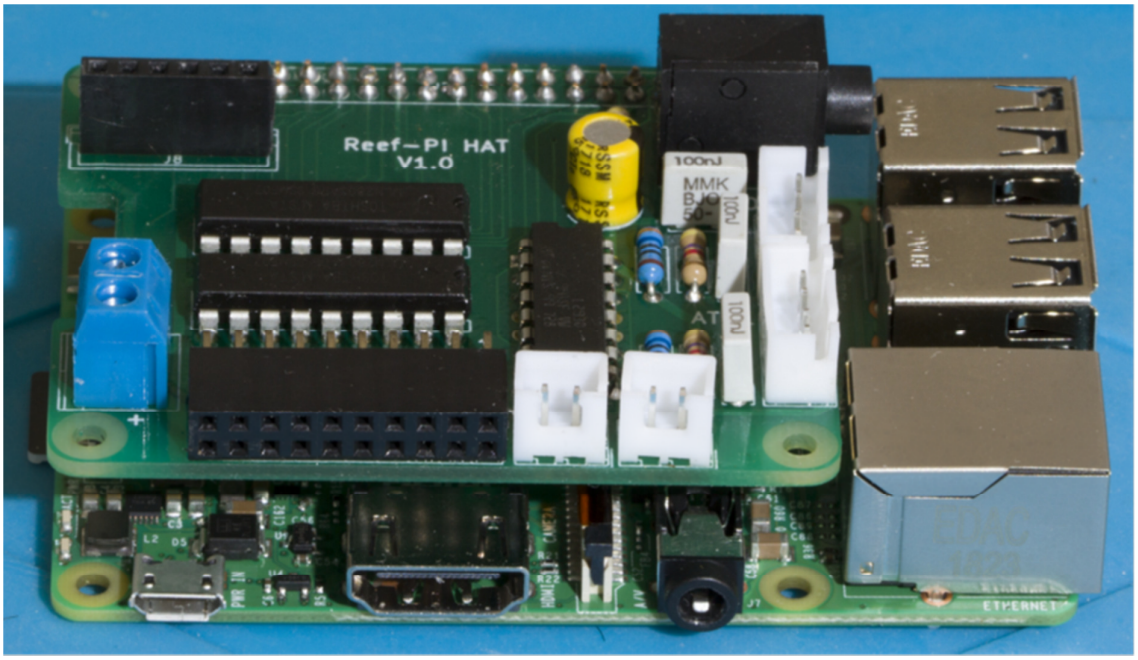

Figure 2: Stacked Reef-PI HAT with Raspberry PI front view

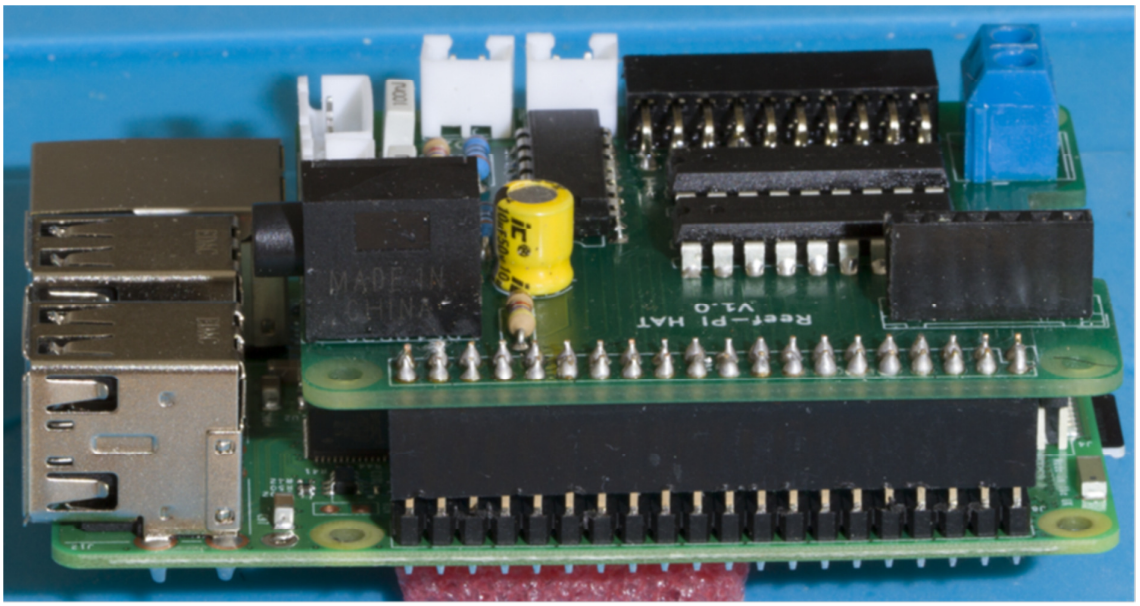

Figure 3: Stacked Reef-PI HAT with Raspberry PI back view

2. Components

Figure 4: All components for a Reef-PI_HAT

The picture above shows all components required to assemble a Reef-PI_HAT. It also shows a bottle of soldering Flux (in my case IF 6000), although not necessary, I highly recommend to add some Flux

with a pencil to the holes on the PCB (Printed Circuit Board) just before they are going to be soldered. It's important to use "No Clean" Flux also for the solder going to be used. "No Clean" means that the remains of the flux don't harm the electrical connections after soldering.

The best way to assemble the Reef-PI_HAT is to start on the top of the PCB with the lowest components and then continue with components with the next lowest height until all components are assembled on the top of the PCB. Thereafter the 2x20 strip is soldered to the bottom of the PCB.

Following components are required when all functions are going to be implemented:

Ref	Qty	Value
	1	PCB
C1 C4 C6	3	100nF
C5	1	10uF
J1	1	Conn_01x02
J2	1	Conn_02x20_Odd_Even
J3 J4	2	Conn_01x02
J5	1	Conn_01x03
J6 J7	2	Conn_01x04
J8	1	Conn_01x06
J9	1	Conn_02x10_Odd_Even
R1 R3 R5	3	4K7
R2 R4	2	360
U1	1	L293D
U2 U3	2	ULN2803A

Table 3: BOM including PCB

It's recommended to collect all components before start building the Reef-PI HAT and place them in a basket, or better in a tray in order of assembly.

For detailed information on the required components, have a look at the HAT.csv file on https://github.com/vandegraaf/Reef-PI_PCBs.

Photos of each component are added to this document for reference only (pictures may differ based on manufacturer and production batch.

3. PCB

The PCB is a custom design for the Reef-PI_HAT based on standard schematics used for instance for fritzing boards. Whereas with fritzing boards you require additional wires to connect the different components, this is not required for the Reef-PI_HAT PCB which contains all the necessary wires for up to 16 external relays, 2 ATO interfaces, 2 12V motor controls and a DS18B20 temperature interface.

The PCB can be ordered by sending the HAT.zip to a PCB prototype supplier (for instance pcbway.com which presently is my preference). All the individual files can be found at https://github.com/vandegraaf/Reef-PI_PCBs.

Of course it's also possible to modify these files to your own preferences. The design is made in KiCad which is an open source PCB schematic and lay-out software.

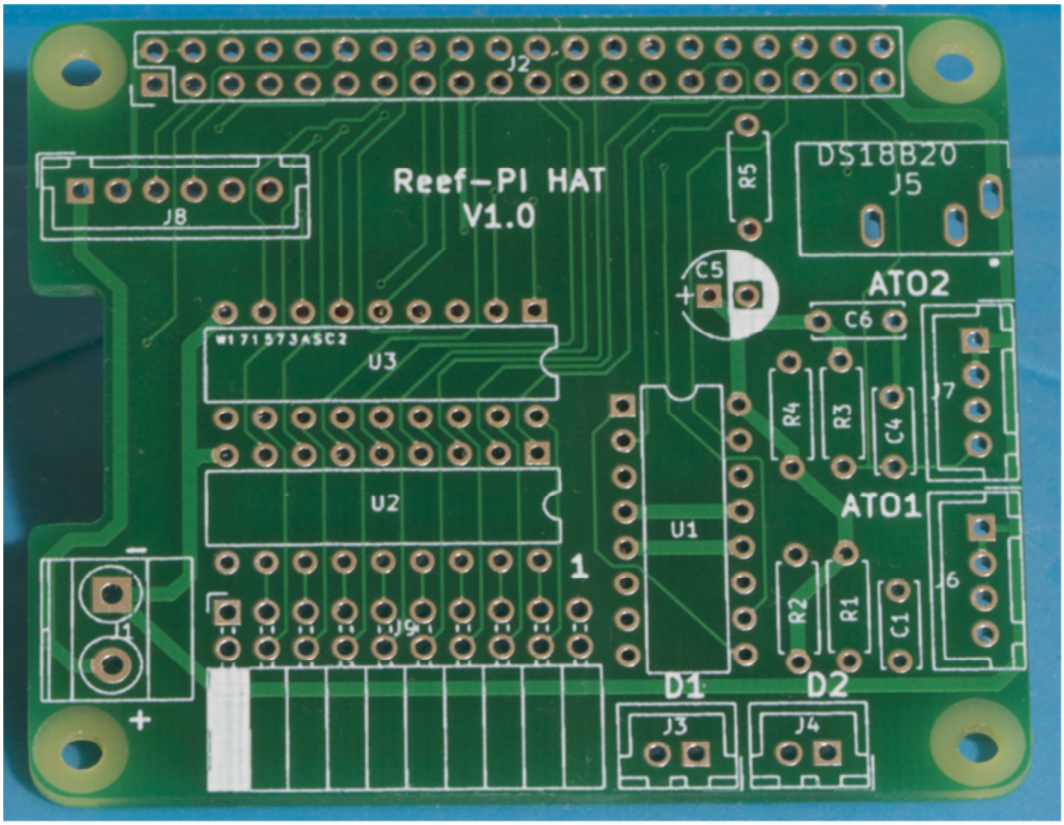

Figure 5: Top view of Reef-PI HAT PCB

An alternative to ordering PCB's from a supplier it's also possible to drill a PCB with a CNC milling machine but it should be noted that the HAT PCB design contains some small via's (very small electrical connections between upper and lower copper side of the PCB).

4. Sequence of assembly

It should be noted that the table shown below is based on the assumption that all functions and components are going to be used as listed in the BOM. Basically the sequence is based on the height of the components, starting with the lowest (resistors) and ending with the 2x20 GPIO interface on the opposite side.

Step	Component	Quantity
	PCB	
1	Resistors	5
2	Integrated Circuits	3
3	Relay connector	1
4	100nF capacitors	3
5	XH connectors	4
6	10uF capacitor	1
7	6 pin strip	1

8	12V 2 pin connector (J1)	1
9	DS18B20 connector	1
10	2*20 female connector (J2)	1

Table 4: Component assembly sequence

5. Step 1: Resistors

There are a total of 5 resistors with 2 different values:

Ref	Value	Function
R1	4K7	ATO#1
R2	360	ATO#1
R3	4K7	ATO#2
R4	360	ATO#2
R5	4K7	DS18B20 temperature interface

Table 5: Resistor values and function

If you do not need any of these functions, you can leave out that component.

5.1.Resistor identification

Resistors are identified with color rings on the housing

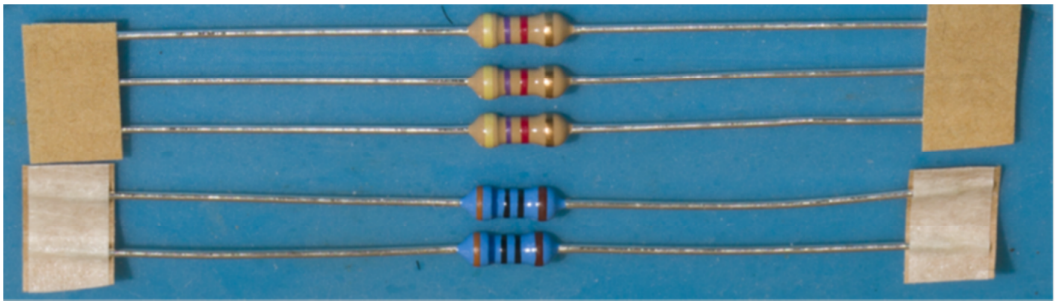

Figure 6: 3 4K7 and 2 360 ohm resistors

4K7	Yellow (4), Purple (7), Red (x 10^2) -> 4700 ohm
360	Orange (3), Blue (6), Black (x 10^0) -> 360 ohm

Table 6: Resistor color code

The outermost right ring indicates the tolerance which is of less importance for this application.

5.2.Preparation

The pins of the resistors all need to be rotated 90 degrees in the same direction. The distance between the pins must be approximately 7 mm.

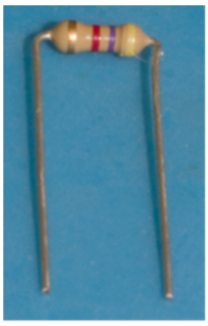

Figure 7: Bended resistor

As you can see from the picture, my resistors need to be bend very sharply to the resistor housing and even then it's a little wider then 7mm. Sometimes when a resistor is inserted only 1 side goes in completely, the other not. If this happens, move back the pin which fits in correctly, a little wider than the pin which didn't go in. Then move the pin which didn't fit before in completely until it fits and then move the other pin in again. Hereafter it will be easy to move them in and out without problem anymore. Sounds strange, but works.

5.3.Assembly

After all resistors have been bended, insert them one by one into the PCB at the correct location see Table 5 and slightly bend the wires outward, this will avoid that they will fall out while adding additional resistors:

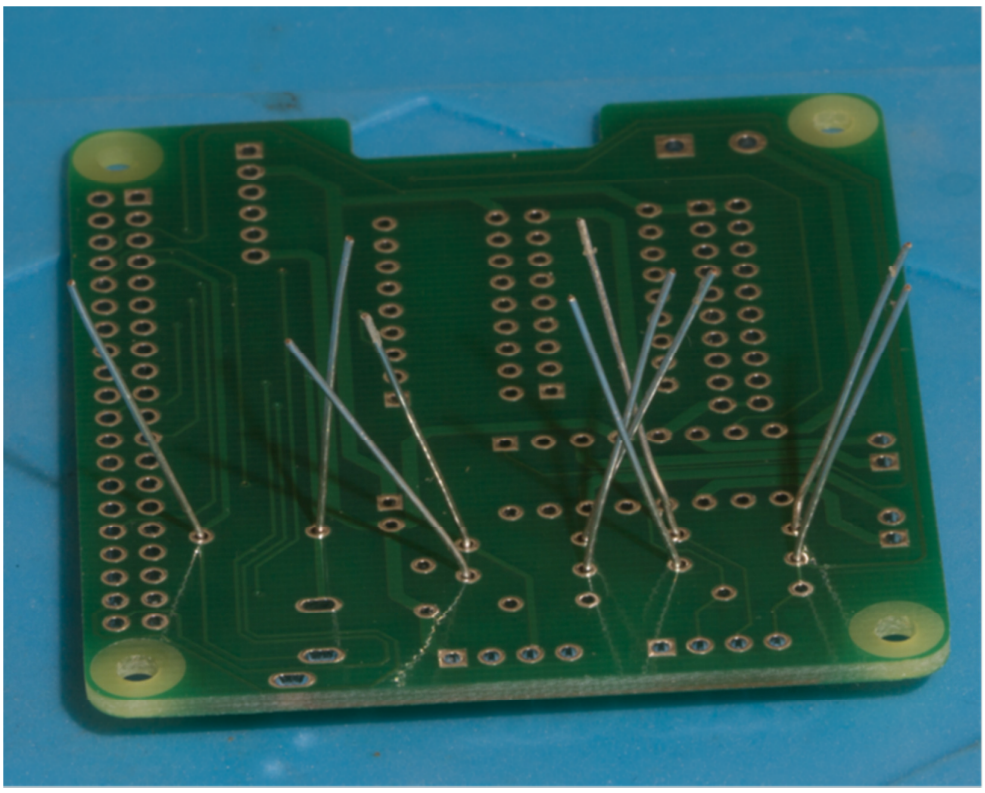

Figure 8: PCB with bended resistor wires

Optional: add Flux to solder points:

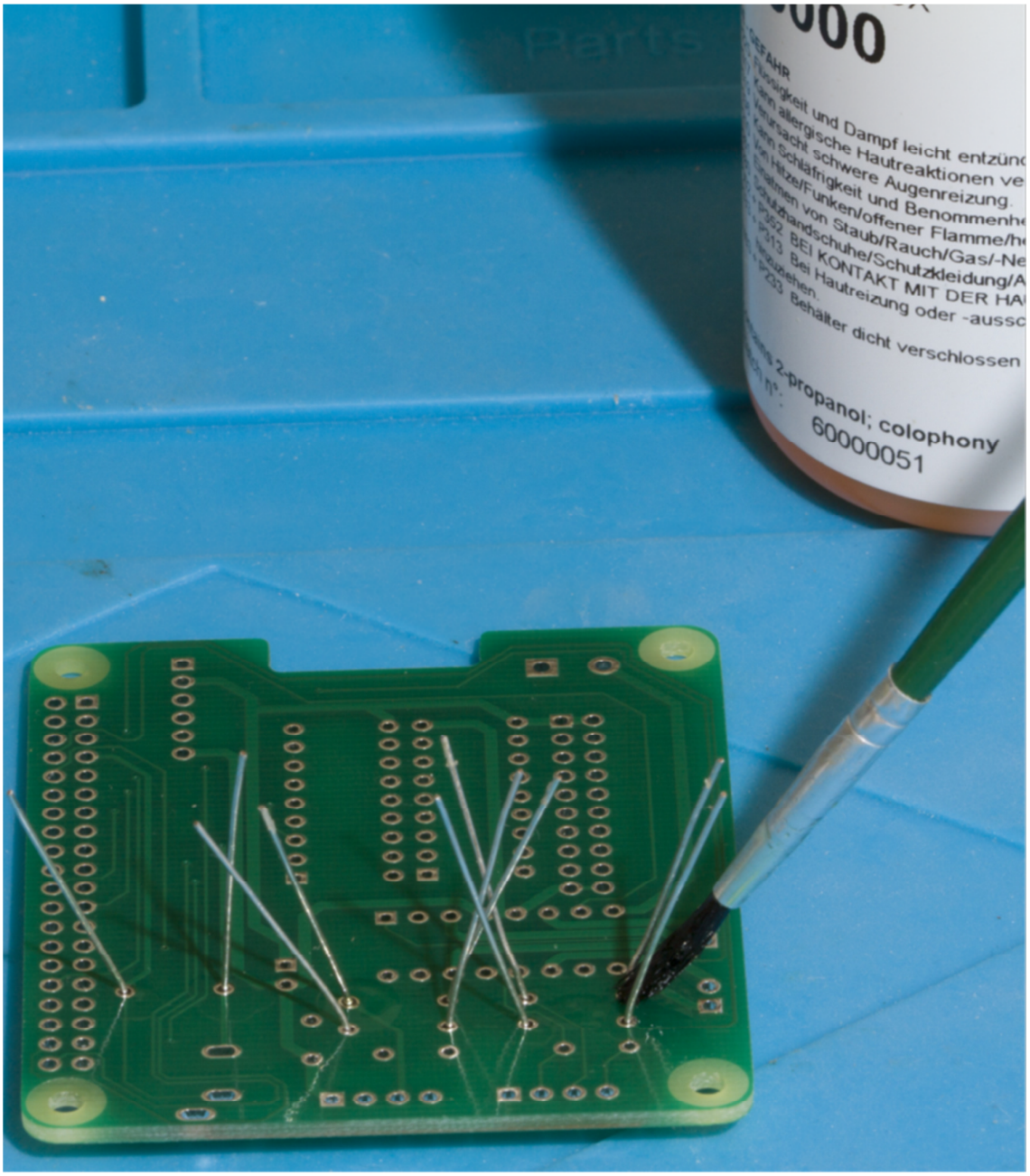

Figure 9: Add Flux to solderpoints

And solder the resistors. A good solder point can be verified when the solder has moved to the opposite site (top) of the solder joint:

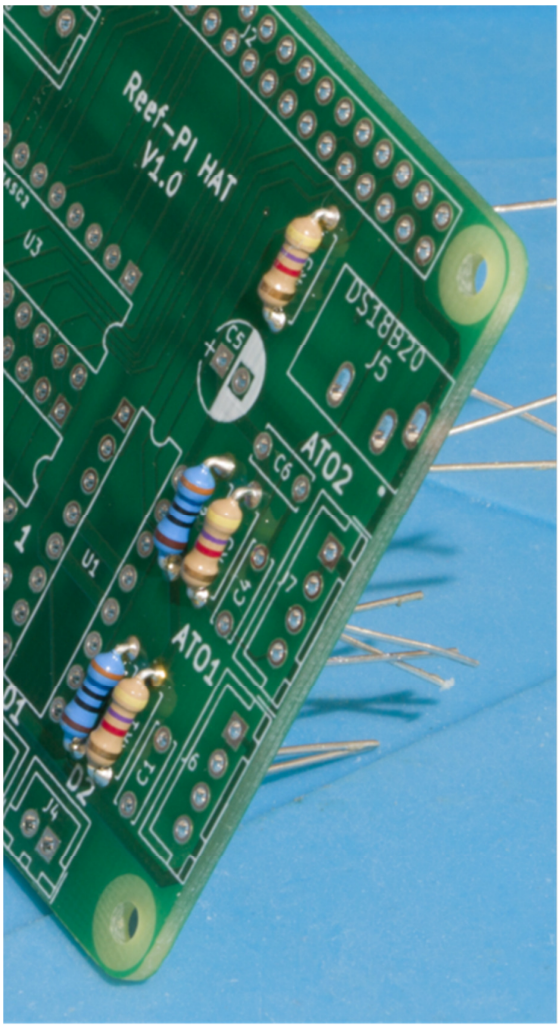

Figure 10: Solder has moved through the hole for good connections

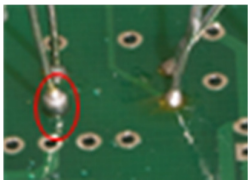

Figure 11: Example of bad solder point on solder side

In Figure 11: Example of bad solder point on solder side it looks like there is solder, but such a shape may indicate there is no connection to the resistor wire. I've heated again the bad solder point and then it was ok. Now you can cut all the wires and the resistors are mounted.

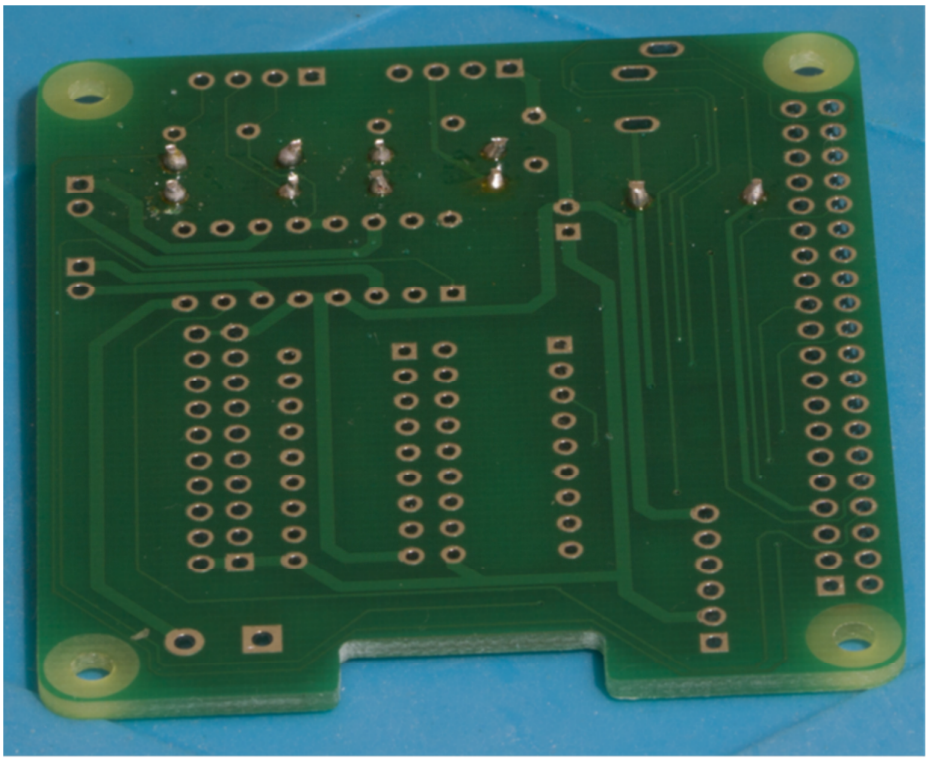

Figure 12: Assembled resistors

6. Step 2: Integrated Circuits

There are 3 Integrated Circuits (IC's) on the HAT of 2 different types:

Ref	Value	Function
U1	L293D	D1 and D2 (Bidirectional 12V motor control)
U2	ULN2803	Controls top 1-10 connectors of relay interface
U3	ULN2803	Controls bottom 11-20 connectors of relay interface

Table 7: Overview IC's and related functions

As usual, when certain functions are not required the related components can be left out.

6.1.Integrated Circuit identification

The printed text on the IC's for the HAT may be difficult to read. Strong light helps in reading the text printed on the packaging. In the picture below I've played around with contrast and exposure to make the text more readable.

The labeling L293D is clearly readable on the upper right side. A L293 (without D) doesn't have protection diodes and should not be used. Do note that the printed text may differ from supplier or batch.

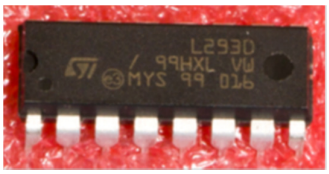

Figure 13: L293D motor driver IC

For the ULN2803A it's more difficult.

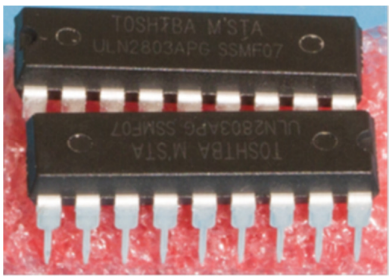

Figure 14: ULN2803A Driver IC's

A clear differentiation between both type is that the U1 L293D has only 16 pins, whereas the U2 and U3 ULN2803A have 20 pins.

6.2.Preparation

As you can see from the picture below the IC's don't fit immediately onto the PCB.

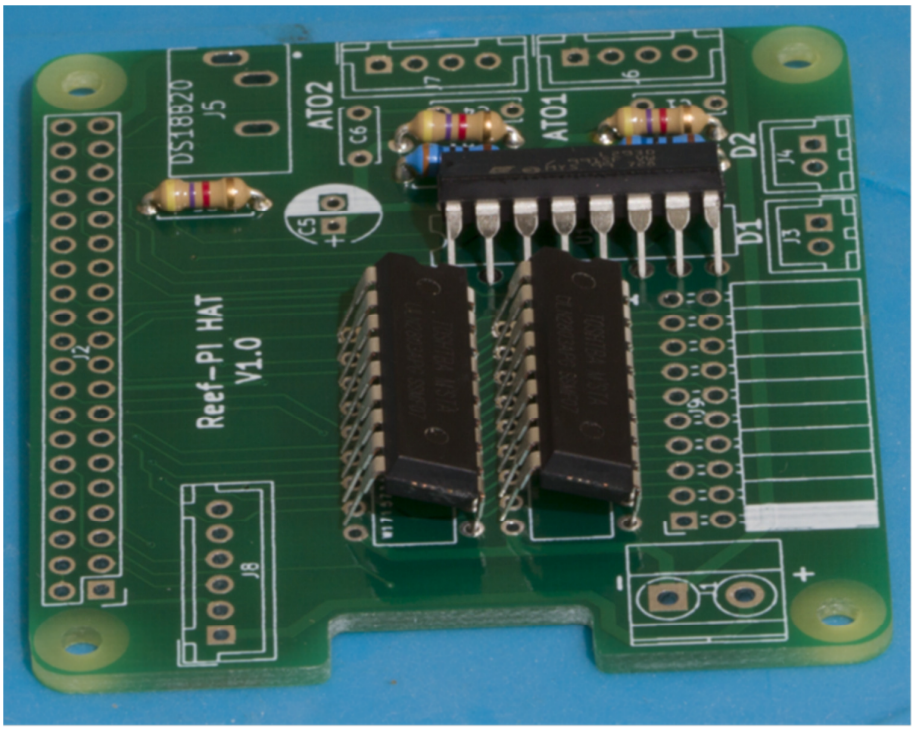

Figure 15: IC footprint too wide and will not directly fit

This is normal, the pins of the IC's need to be slightly bend inwards. There are tools for this, but the simplest way is to place the IC on its side and slightly bend both sides until they fit onto the PCB, this only needs very little and it's more difficult to bend them back!

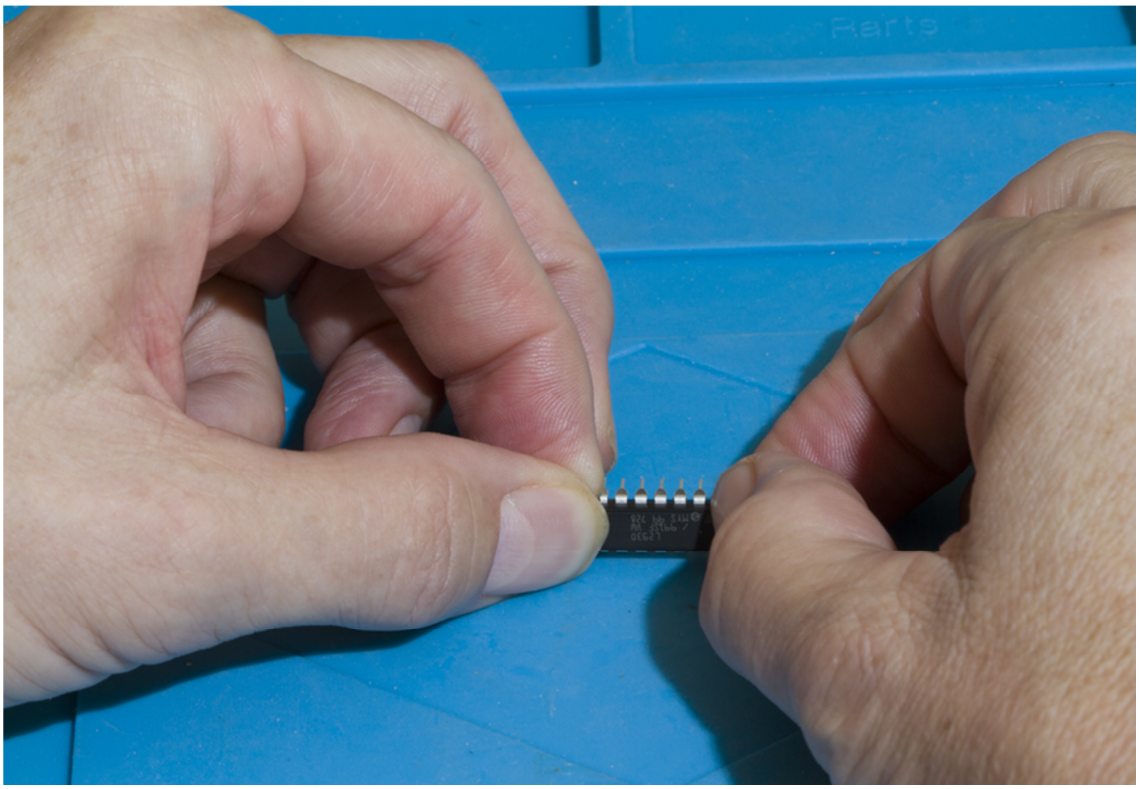

Figure 16: Bend pins of IC's

On Thingiverse tools can be found such as this one:

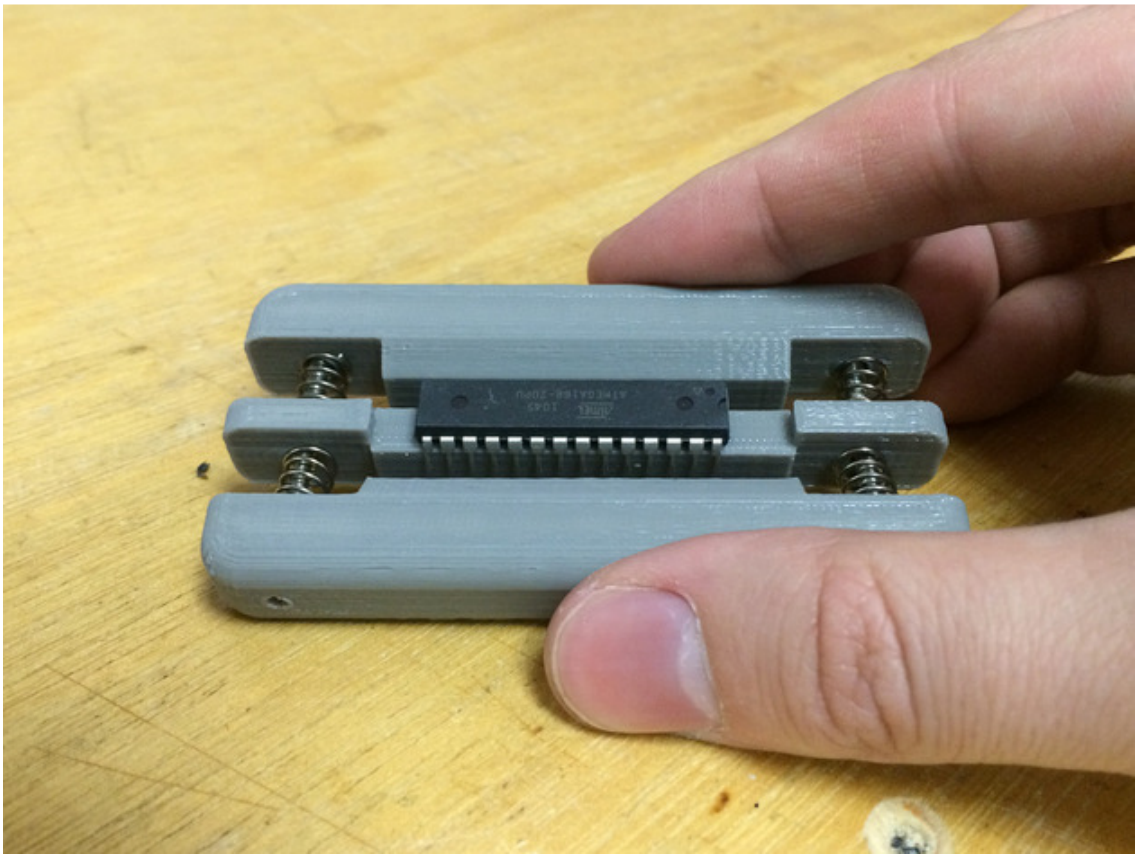

Figure 17: Chip pin bending tool on Thingiverse

I doubt it's needed for 3 IC's, but who want it can find it at https://www.thingiverse.com/thing:1111554 , There are also other tools available on Thingiverse.

After the IC's fit into the PCB they need to be inserted onto the PCB. Important here is the orientation. The white silk screen on top of the PCB shows the outline of the IC package including an half hole on only 1 side. This injection point on the IC packages must be on the same location as shown on the white silk screen.

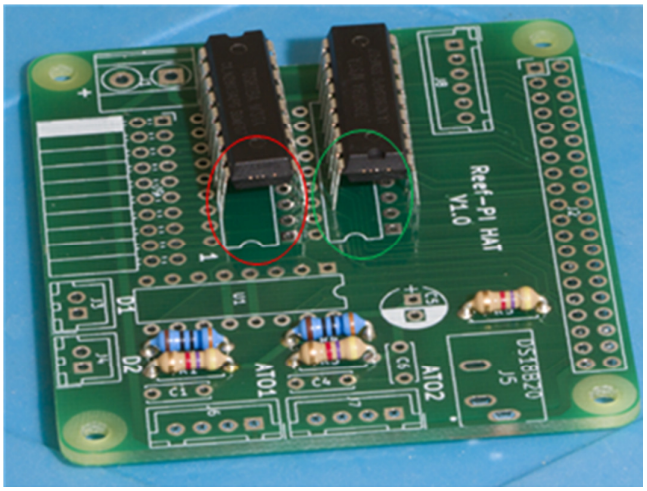

Figure 18: Direction of IC on PCB

The positioning of the ULN2803 with the red circle is wrong. The half hole on the side of the packaging should be in the same place as shown in the green circle. The same is valid for the L293D IC.

6.3.Assembly

Now the IC's can be placed onto the PCB and in order to be able to solder the pins the PCB needs to be turned around. A simple way to avoid that the IC's are falling out of the PCB is to place a small paper over the IC's and then turn it around and place it where it can be soldered. Then only the small paper needs to be removed while keeping the PCB and components in its place.

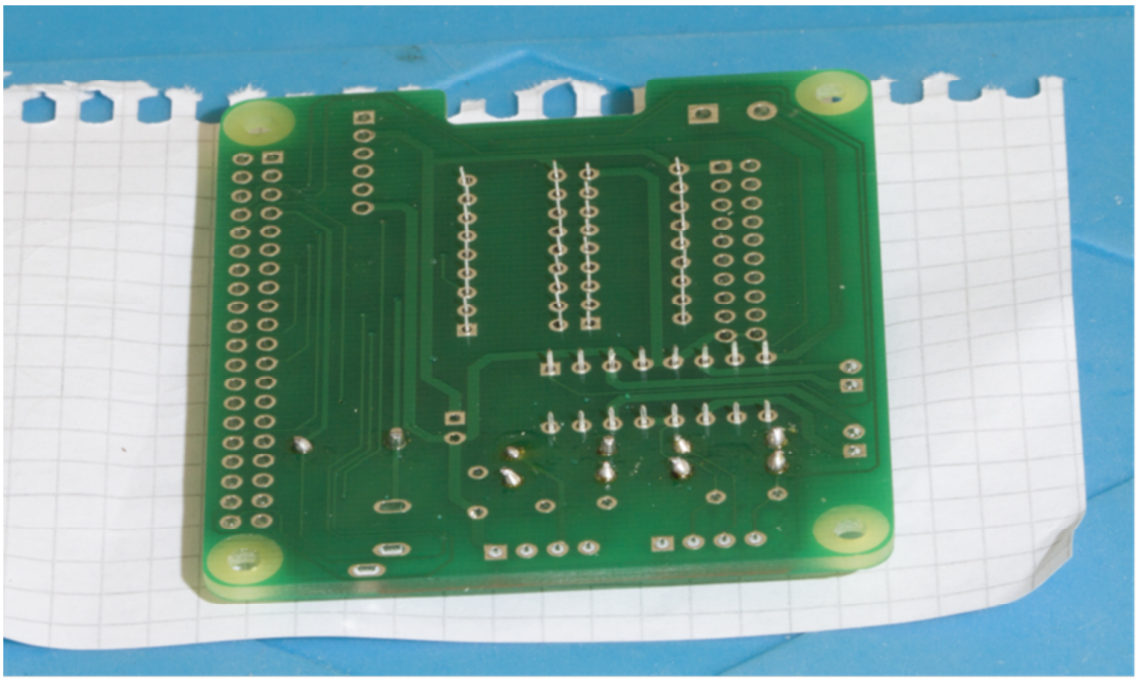

Figure 19: Small paper to help turning the PCB around

Now the same steps as for soldering the resistors can be made, but no pin cutting is required.

- Optional add flux to soldering points
- Recommended: just solder opposite pins of each IC and then verify IC positioning (they will not fall out any more and corrections are still simple to be done). It's also possible to leave the paper beneath until this step is completed.
- Verify positioning of IC's and solder all remaining pins

Also here it's important that solder flows through the holes.

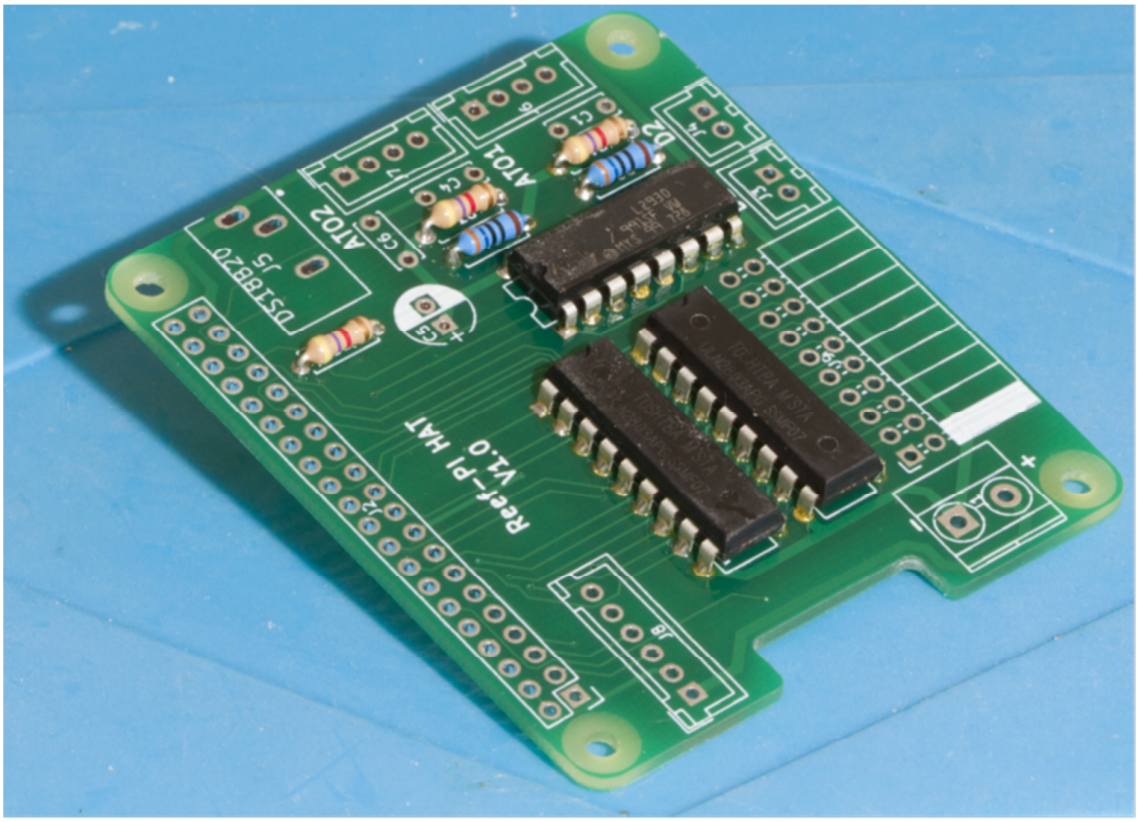

Figure 20: Soldered IC's

7. Step 3: Relays connector

Ref	Value	Function
J9		External relays interface

Table 8: Relays connector

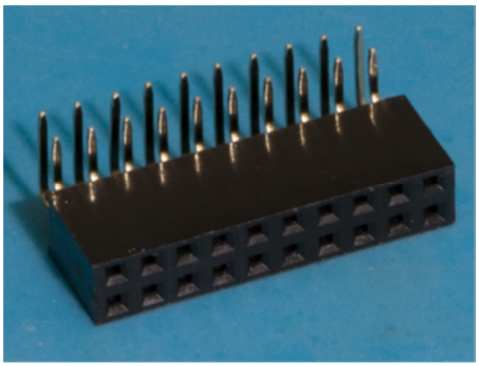

Figure 21: 2x10 pin external relays interface

The layout of this connector is basically a standard 2x10 pin 2.54mm connector. The PCB board design is made for an 90 degree angled female version which completely fits in the footprint of the Raspberry PI dimensions.

There are no specific identifications and also no preparation to this component is required.

You can use any 2x10 2.54mm adapters for which you have, or can make, a connection to your external relay board. Alternatively you can also solder wires directly to the board. Alternatives will be shown in the Reef-PI_HAT documentation. This guideline assumes the installation of the 90 degree angled female connector. Do note that if you plan a different connector to review the height of the connector in relation to the step to add it to the board. If it's planned to have wires directly soldered to the board they can be done as last or fore last step.

7.1.Assembly

Assembly is easy, optionally add flux and solder the pins. It may be helpful to place the 2*20 connector temporarily flat on the opposite side of the PCB as support to keep the relay connector flat to the PCB. Nevertheless it's still recommended to solder first two opposite pins of the connector in case corrections are required.

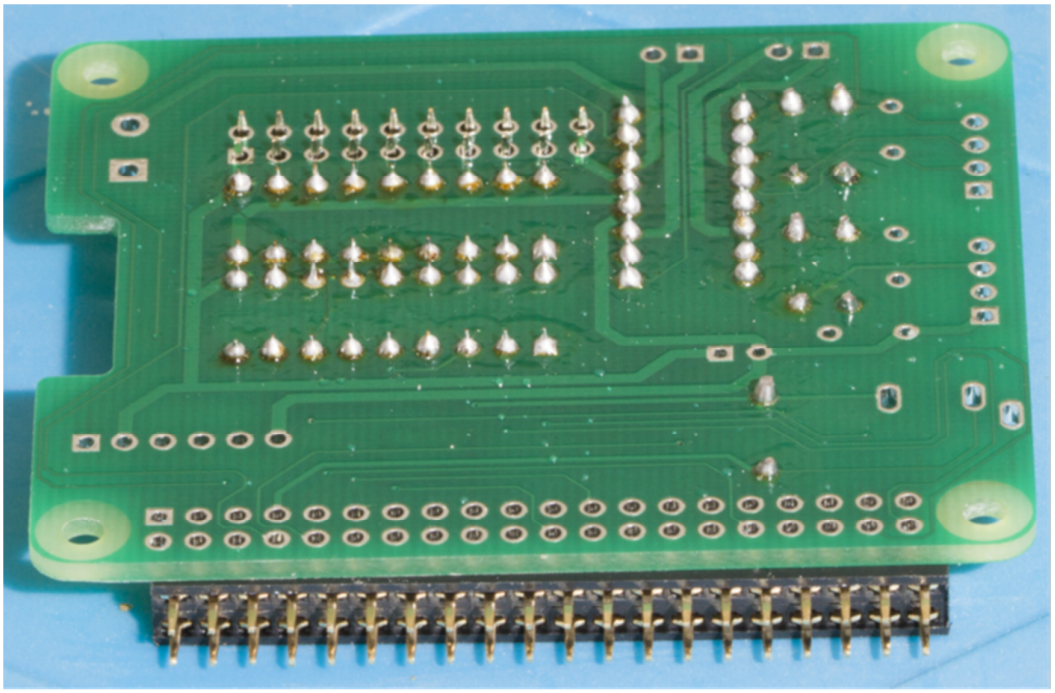

Figure 22: Support to solder relays connector

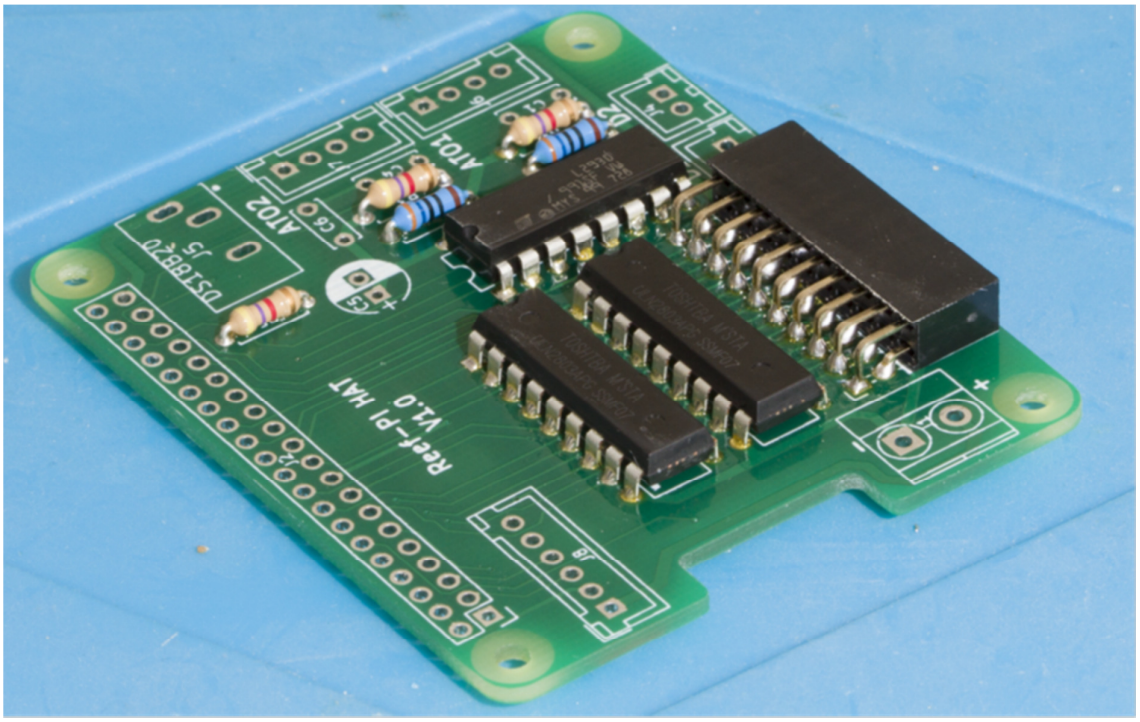

Figure 23: Assembled relays connector

8. Step 4: 100nF capacitors

Ref	Value	Function
C1	100nF	ATO1

C4	100nF	ATO2
C6	100nF	ATO1 & ATO2

Table 9: 100nF capacitors and function

Only in case no ATO at all is used all 3 capacitors can be left out. In case either ATO1 or ATO2 (or both) are used, C6 is required.

8.1.Identification

These capacitors have no polarity, so they can be mounted in any direction. Normally the value is shown on top of the housing with either 100nF, 100uL or 0.1uF

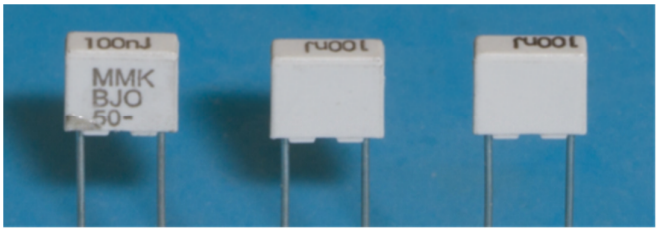

Figure 24: 100nF capacitors

8.2.Assembly

Assembly of these capacitors is very similar to the resistors. Insert the capacitors and bend the pins to avoid that they fall out while adding additional capacitors. Do note we only assemble the 100nF capacitors in this step, the 10uF capacitor will be added later !

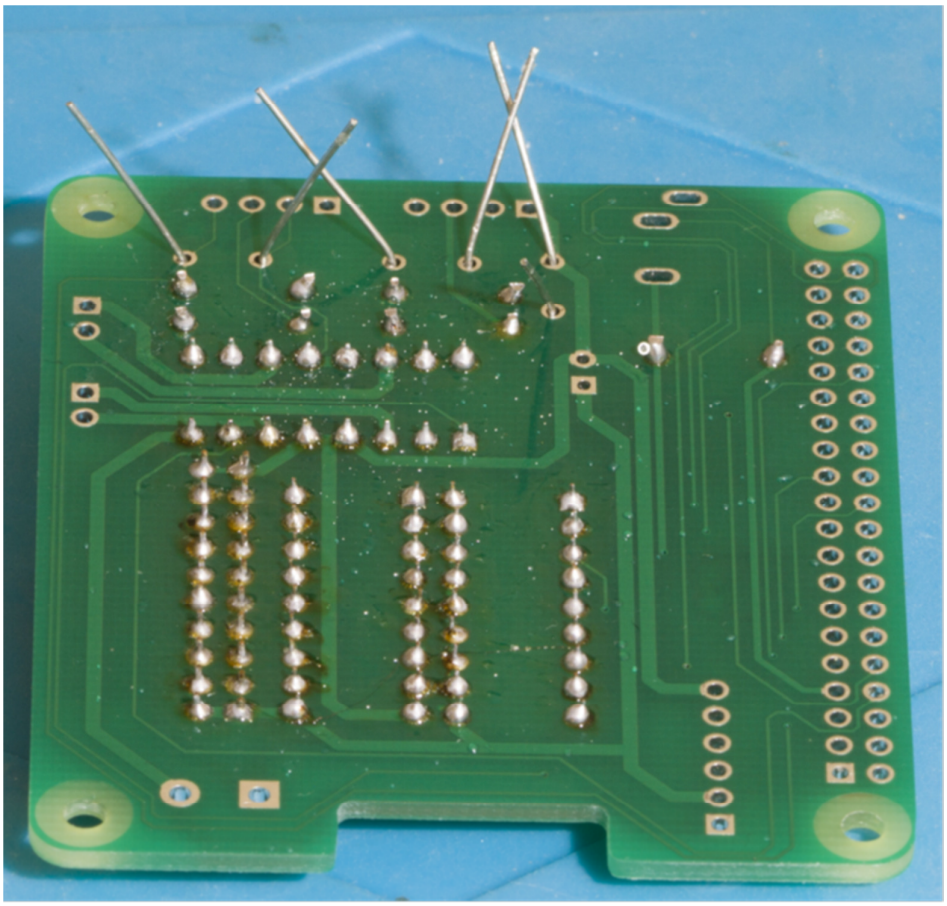

Figure 25: 100nF bended capacitor pins

Then solder only 1 pin of each capacitor, this will enable justification as they may either not fitting directory to the PCB or are bend side wards.

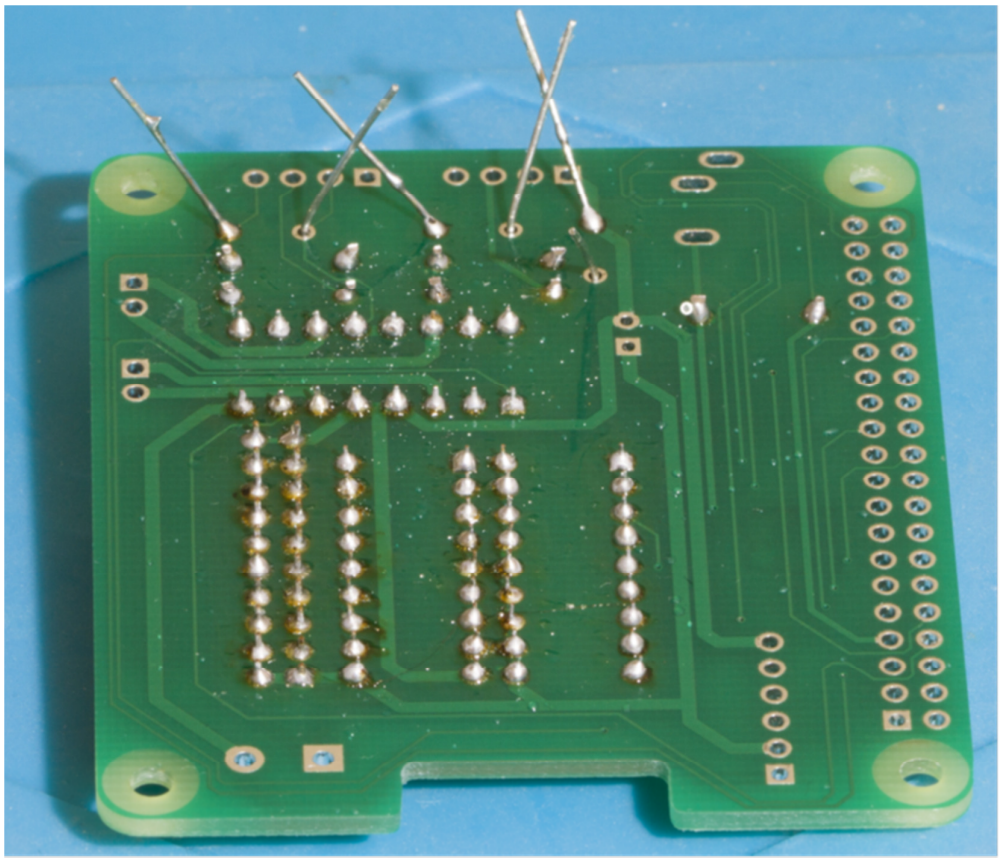

Figure 26: Only 1 side of 100nF soldered

Adjust if necessary by keeping the board by one hand, adjust component with a finger and touch solder iron with other hand to the solder point. This way you can ensure that all capacitors are fitted directly to the PCB and no longer bended in any direction.

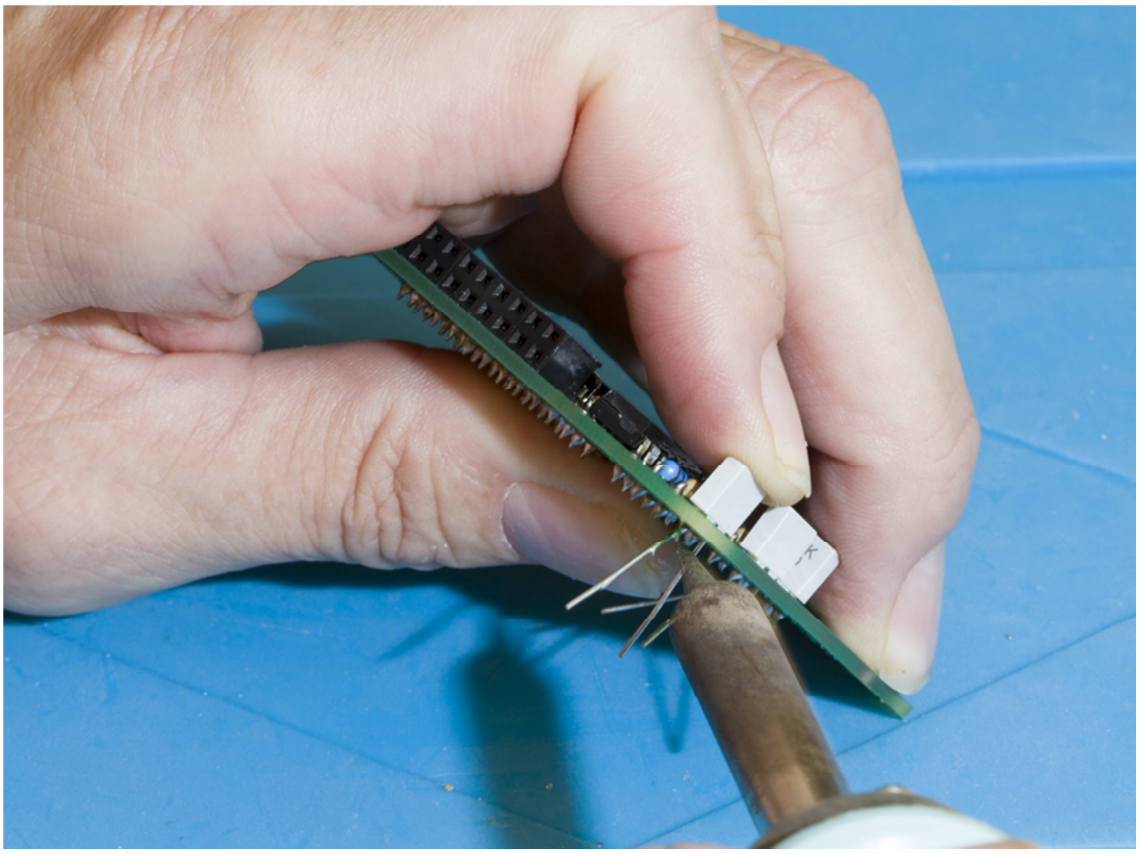

Figure 27: Adjust 100nF capacitors by hand

Only put pressure on the component after the solder has become fluid again, otherwise you can damage the PCB!

After capacitors are positioned correctly, solder the second pin and cut the wires.

9. Step 5: 12V motor and Auto Top Off connectors

Ref	Value	Function
J3	2 pin	D1 (Motor #1)
J4	2 pin	D2 (Motor #2)
J6	4 pin	ATO1
J7	4 pin	ATO2

Table 10: 2 and 4 XH connectors and their function

Also here for respective functions which are not going to be used the connectors can be left out.

Technically you can use any 2.54mm connectors you prefer, but the optical ATO sensors come with a connector which fits directly in the 4 pin connectors proposed here. Since already 4 pin XH connectors were used, it was decided to use the same connector for the 2 pin motor connections.

For the 2 pin motor connectors also 2 pin strips can be used, than it's easier to change the motor direction.

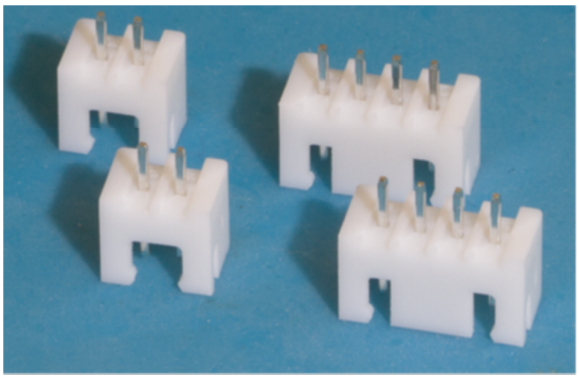

Figure 28: 2 and 4 pin connectors

There are no specific identifications or preparations required for these connectors.

9.1.Insertion

It's important (especially for the 4 pin connectors) that the openings are facing out of the PCB! See Figure 29: XH connectors before soldering and PCB support and Figure 30: XH connectors facing outward.

9.2.Assembly

In order to avoid that the connectors fall out of the PCB, the same paper trick can be used for these connectors. It helps to position the 2x20 and 1x6 connectors on the opposite side of the PCB, then the XH connectors are well positioned for soldering. Solder 1 pin of each connector, review positioning and solder remaining pins.

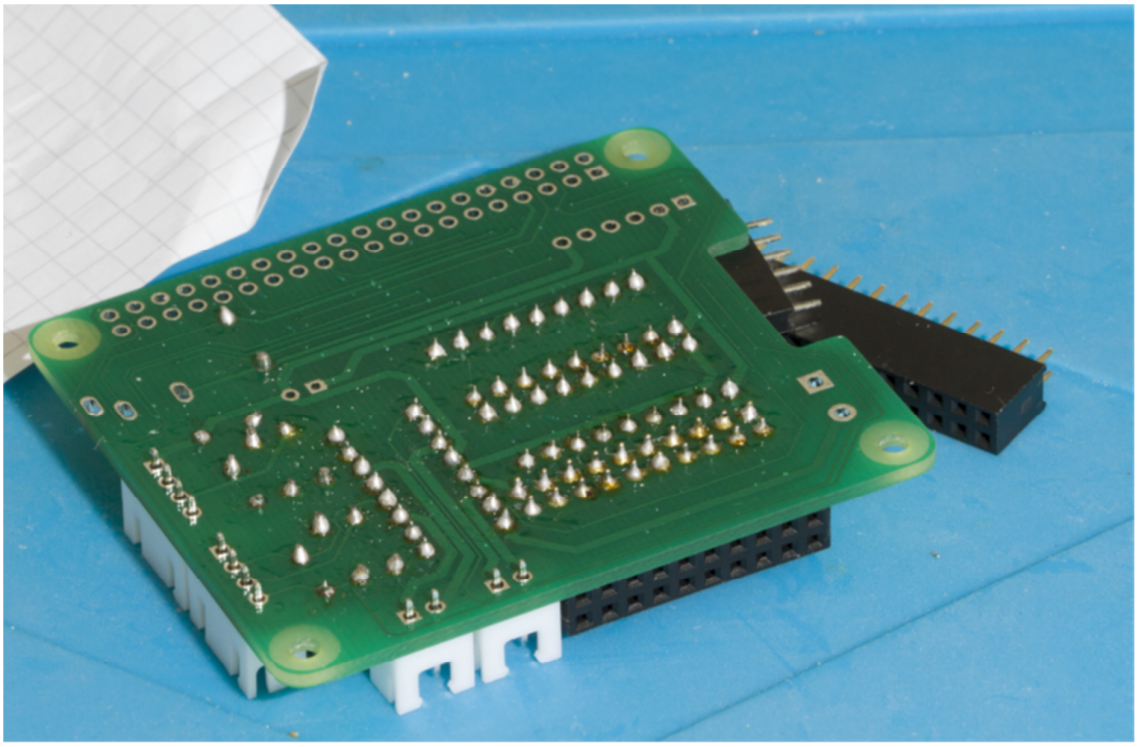

Figure 29: XH connectors before soldering and PCB support

In Figure 29: XH connectors before soldering and PCB support the 2x20 and 1x6 connectors are visible to support soldering the XH connectors at the opposite side.

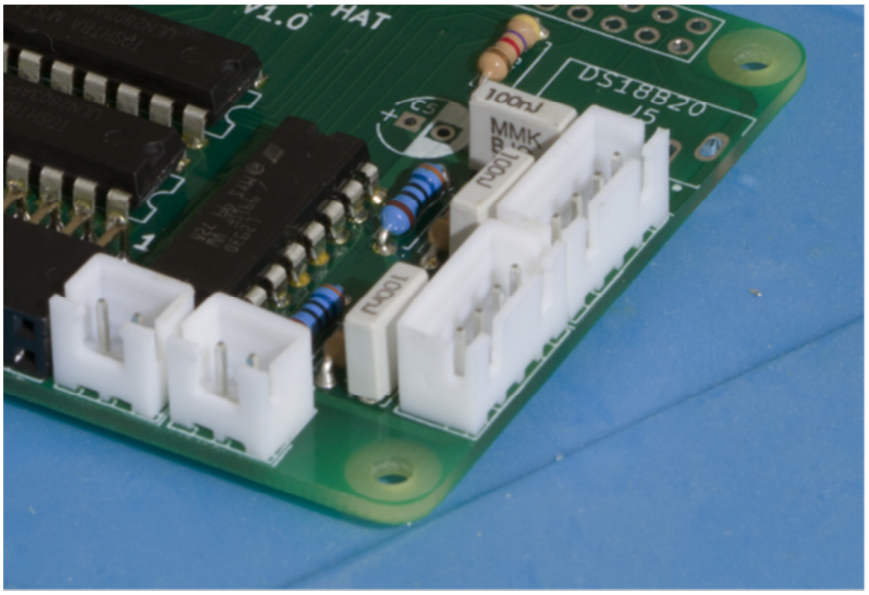

Figure 30: XH connectors facing outward

Figure 30: XH connectors facing outward is made darker to make the openings in the XH connectors more visible.

10. Step 6: 10uF capacitor

Ref	Value	Function
C5	1ouF	ATO1 & ATO2

Table 11: 10uF capacitor and function

The 10uF capacitor is only needed when the ATO function is required.

10.1. Identification

The 10uF capacitor is polarized (orientation specific). The value is normally shown as 10uF and a voltage level (50V proposed, although lower voltages would be possible such as 25 or 35V).

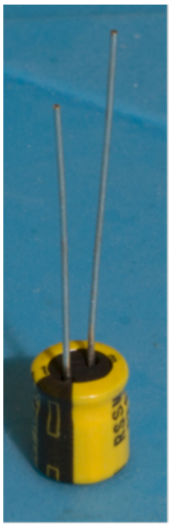

Figure 31: 10uF capacitor

The capacitor has 2 pins identified as "-" and "+". The minus side is shown by the black mark on the yellow housing. Secondly the "-" has a shorter pin than the "+" pin. The 10uF capacitor must be placed accordingly in the PCB.

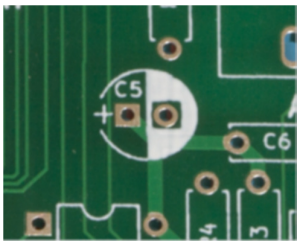

Figure 32: 10uF orientation on PCB

The PCB is clearly marked with a white side ("-") and a "+" sign.

10.2. Assembly

The 10uF capacitor must be inserted accordingly, so the short pin (black mark) should go in the white area and long pin in the "+". Again bend the pins, and/or solder just 1 side, verify and solder the 2nd pin and cut the wires.

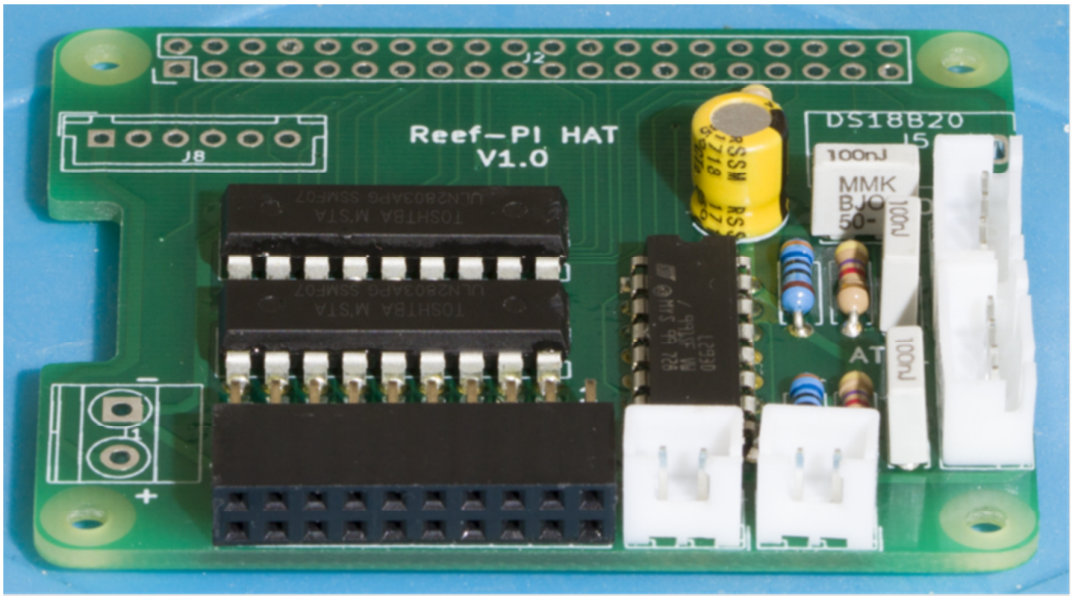

Figure 33: Orientation assembled 10uF capacitor

In Figure 33 the black mark is visible on the right side.

11. Step 7: 6x1 female strip

Ref	Value	Function
J8	1x6	I2C interface (including 12V for additional stacking boards)

The 1x6 female strip connector allows additional Reef-PI PCBA's to be stacked upon the Reef-PI HAT PCBA (Printed Circuit Board Assembled). The first of such boards will be the Reef-PI PWM module which can add up to 16 0-10V outputs to control external light controllers.

There is no specific identification or preparation for this component. It's possible to use a larger female strip, for instance 1x20 and cut it to have 6 pins. Don't try to cut between pin 6 and 7, it's very likely to end up with just 5 pins, therefore better to cut directly on the 7th pin.

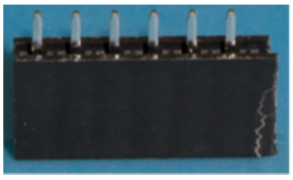

Figure 34: 1x6 female strip

11.1. Assembly

Basically assembly is similar to assembling other connectors (start with just 1 pin), but in order to be able to connect additional Reef-PI modules it's important that the connector sits straight on the PCB (90 degree)

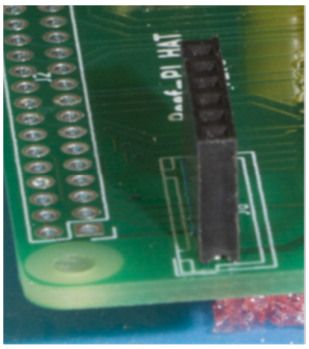

Figure 35: 90 degree angle between PCB and J8

As shown in Figure 35 the connector J8 must be close to 90 degree to the PCB in order to fit additional PCBA's on top of it.

12. Step 8: 12V power input

Ref	Value	Function
J1	1x2	12V power input for 6 pin I2C bus and D1/D2 motor drivers

Table 12: 12V power input connector

This connector is only required when motor control (D1 and D2) are going to be used or additional Reef-PI modules which require a voltage above 5V.

The connector can be replaced by any other available connector with a pen width of 5mm.

12.1. Assembly

Assembly is similar to any other connector and it's always helpful to have some support under the PCB with an equivalent height of the connector to assemble to get a flat surface between PCB and component.

It's important to have the wire inputs to the outside of the PCB

Due to the large amount of metal material within this component it requires more heating time than other through hole components during soldering.

Figure 36: 12V input connector

13. Step 9: 3 pin DS18B20 temperature interface

Ref	Value	Function
J5	1x3	Interface to external DS18B20 temperature sensors

Table 13: Interface to external DS18B20 temperature sensors

This is the last component to be placed on the top side of the Reef-PI HAT PCB when external DS18B20 temperature sensors are going to used. Using multiple DS18B20 sensors is possible with following wiring:

<open: Add DS18B20 wiring diagram>

The 3 pin connector is a specific one, alternatively it's possible to wire directly to the PCB or use wiring to an external 3 pin connector to connect DS18B20 sensors to.

There is no specific identification or assembly instruction as the proposed connector only fits in 1 way on the PCB.

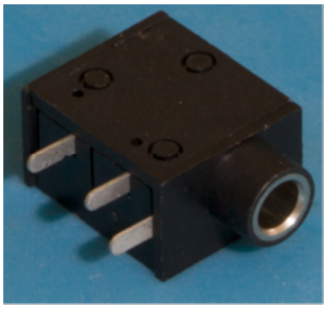

Figure 37: DS18B20 temperature interface connector

13.1. Assembly

Similar to the other connectors, try to level the PCB board to the height of the 3 pin connector and just solder the middle pin and realign when needed.

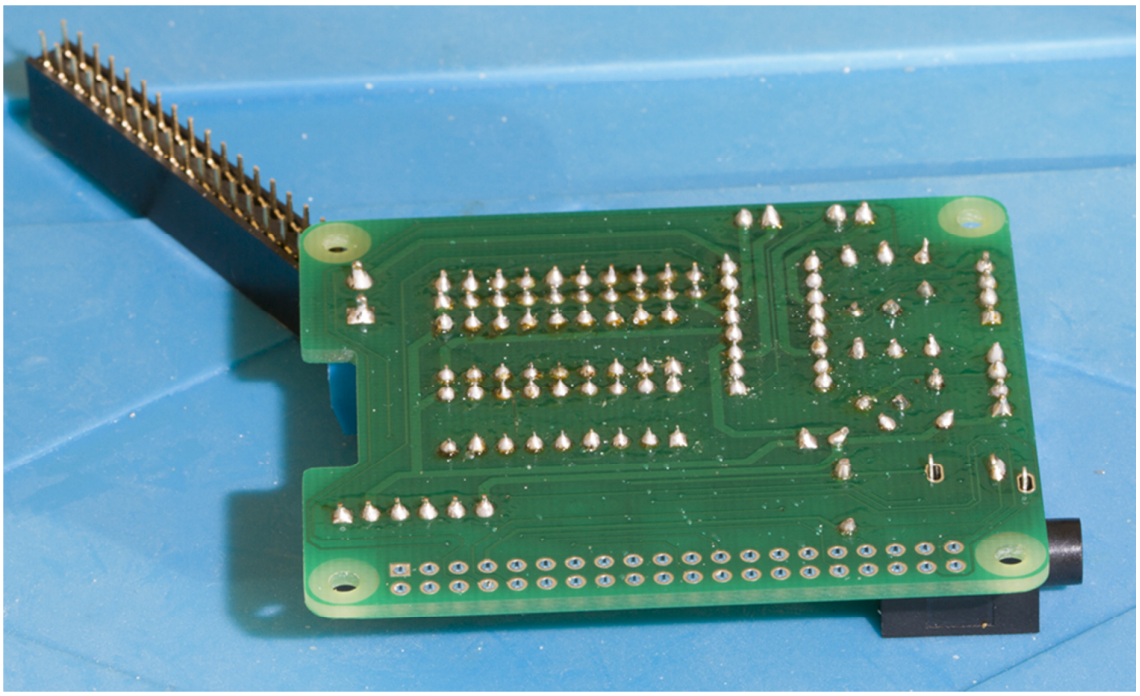

Figure 38: Board leveling and middle pin soldered

If ok, solder the other 2 pins. Also this component requires a little longer time due to the amount of metal in the connector.

Now all components are connected to the top side of the PCB:

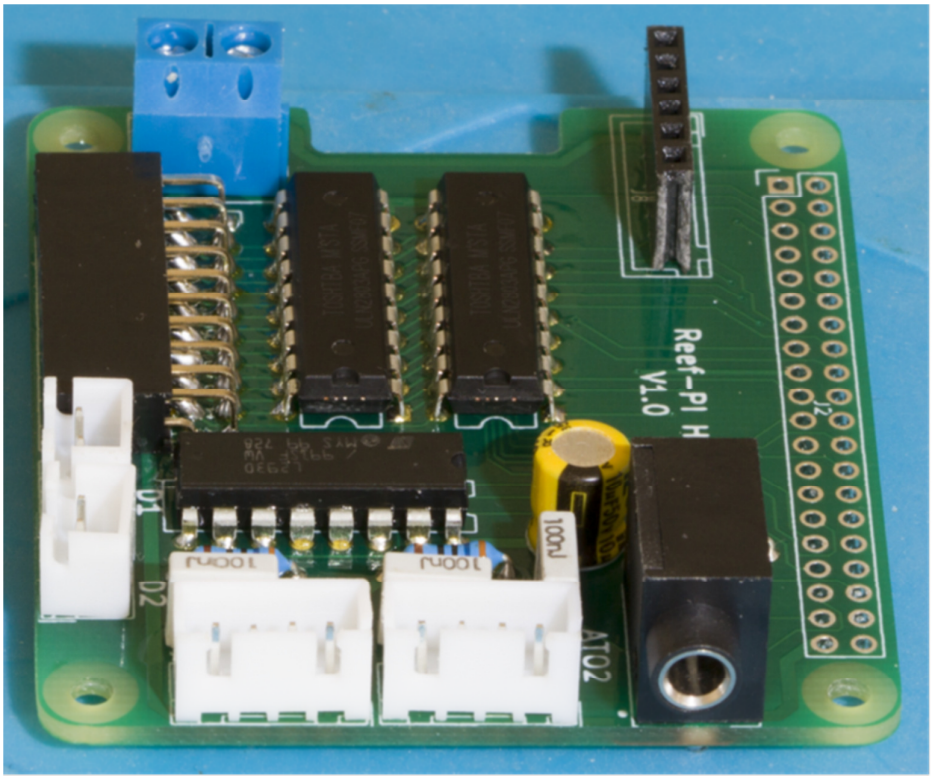

Figure 39: Completely assembled top Reef-PI HAT PCB

The final 2x20 connector is going to be connected to the other side of the PCB in order to be able to stack on the Raspberry PI.

14. Final assembly step 10: 2x20 connector with Raspberry PI GPIO

Ref	Value	Function
J2	2x20	40 pin female interface to Raspberry PI GPIO

Without this connector the Reef-PI HAT has little use, so it will always be required. Although it's the last and final step for building a Reef-PI HAT PCBA it's also the most critical! Following things should be noted for this connector:

- Has a total of 40 solder points, so adjusting or removing will become very difficult
- Solder may get into the contacts which will make it difficult to stack to the Raspberry PI
- It must be completely flat on the PCB in order to align correctly to the Raspberry PI PCBA

Do note that this connector is going to be placed on the opposite side of the PCB! Similar as with other larger components, best is to just solder 2 opposite solder points to ensure that the interface connector is flat on the PCB, then solder all the remaining solder joints.

<Picture of flat fit on PCB missing>

15. Cleaning

Although not necessarily required it's still of good use to clean the PCBA after all the solder work and used Flux. There are special cleaning liquids for this such as

Figure 40: Chemtronics Flux Off

I've tried 99.9% Isopropanol with a toothbrush as recommended by many people but had better luck with Alcohol. Many tips can be found on Youtube on cleaning PCB's after soldering.