Power Board Reference Guide 1.0

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ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

BIOLOGICALLY INSPIRED ROBOTICS GROUP (BIRG)

Power Board Reference Guide

Date	Version	Changes
September 25th, 2004	1.0	-

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1 Preface

This section explains the purpose of this document. It gives an overview about the audience and organization of the document and gives some information about references and definitions used.

1.1 Purpose

This document describes the Power Board rev 1 (2004-09-09) designed for the Modular Robot Unit from BIRG (Biologically Inspired Robotics Group).

1.2 Audience

This document is written for users of the Modular Robot Unit from BIRG called YaMoR or just of the Power board alone. The user should have some basic knowledge about power supply.

1.3 Organization

The following chapters "Overview" and "How to use the Power board" give an introduction in using the Power board while the chapters afterwards describe the electronic components as well as layout and manufacturing issues detail. For schematics and assembly instruction please see the appendix.

1.4 Reference

In this document the following references are used.

Num	Document	Source
[1]	MAX1774 datasheet	Maxim Dallas
[2]	LT1765 datasheet	Linear Technology
[3]	BQ24005 datasheet	Texas Instruments
[4]	Battery datasheet HLP072247	HUANYU POWER SOURCE CO., LTD
[5]	STPS340U datasheet	ST
[6]	FDN360P datasheet	Fairchild

Table 1: References

1.5 Definitions

In the document the following definitions with the following meaning are used:

Definition	Meaning
BIRG	Biologically Inspired Robotics Group
YaMoR	Yet another Modular Robot

Table 2: Definitions

2 Overview

The Power board has the following main tasks:

- It provides the three different voltages 3.3V (used by most electronics like microcontroller, FPGA), 1.2V (core voltage of the FPGA) and 6V (servo). Other voltages can be achieved by simply changing some resistor values (please see Chapter 4).
- It monitors the batteries automatically and switches the electronics off when the batteries are discharged to a certain voltage. When using Li-ION batteries you must make sure that the batteries are not discharged too much. Otherwise you risk damaging the batteries.
- It contains a battery charger.
- It supports an automatic switchover from battery to external power supply when external power supply is connected.
- It gives a simple way of controlling the power supply for a user.

The Power board contains the following main components:

- Dual step down converter (with battery management) (3.3V and 1.3V)
- 3A step down converter (servo)
- Two cell Li-ION charge management
- Four power switches
- Connector for external power supply
- Pads for giving access to output voltages and to connect the batteries

An overview about the Power board is given in Figure 1. The Power board can be driven by an external power supply or by batteries. When the Power board is powered by external power supply, power supply from batteries is automatically switched off and the batteries can be charged by the on-board battery charger.

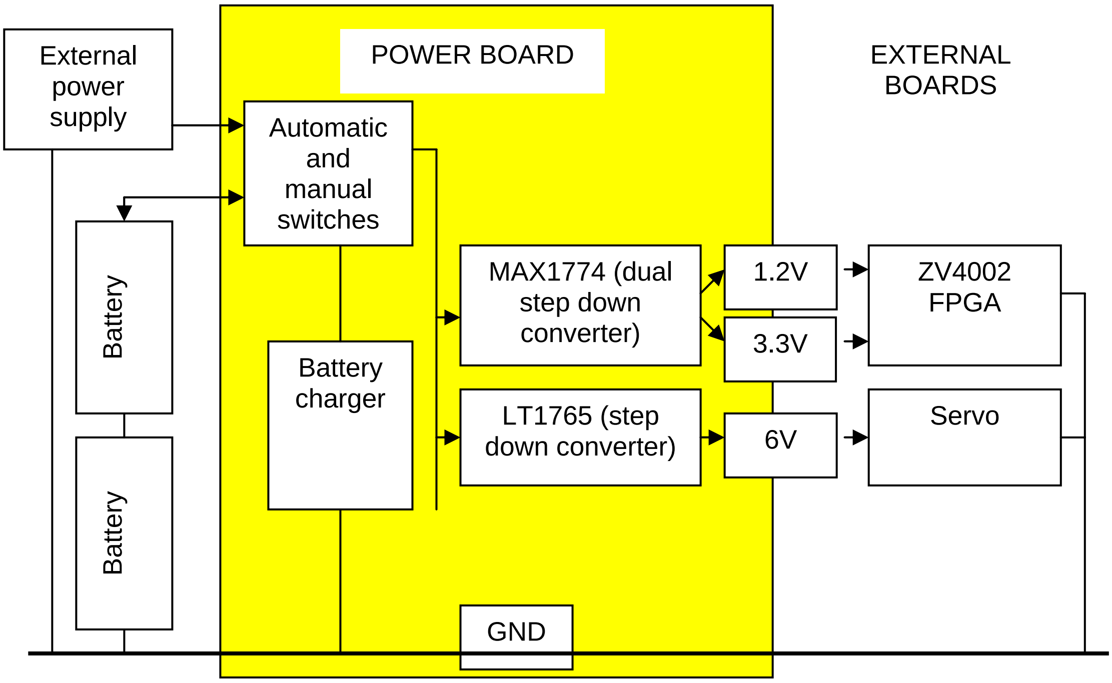

Figure 1: Overview Power board

A picture of the top and bottom side of the Power board is shown in figure 1 and 2.

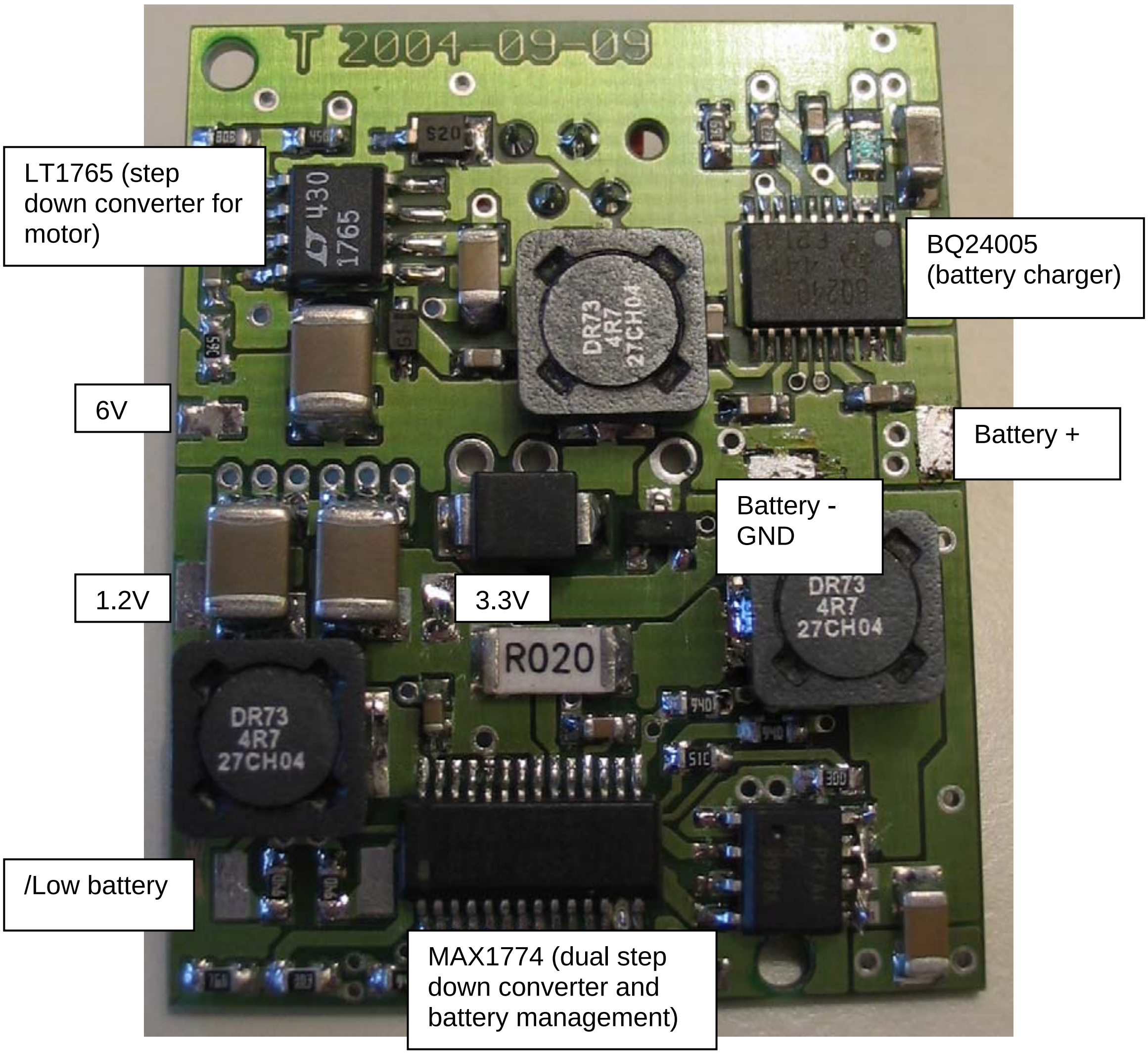

Figure 2: Power board (top)

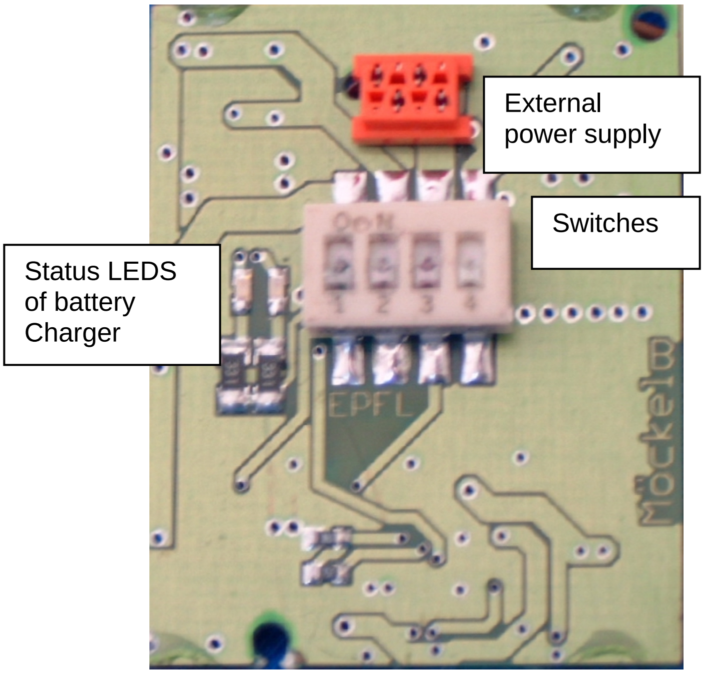

Figure 3: Power board (bottom)

The Power board was designed under three constrains:

1. High efficiency to reduce power consumption
2. High density to reduce place consumption
3. Cheap design

Because of the limited size of the Power board and the limited energy resources, designing the Power board means living with compromises. For producing the different lower voltages from a higher voltage there are two main techniques:

- Linear regulators
  On the one hand these linear regulators are very small for low current and do not need a coil or a lot of other external components. On the other hand they have a low efficiency because they are converting a lot of energy into heat. That is why often a big cooler taking a lot of place is needed to get the heat out of the integrated circuit.
- Switching step down converters
  Using an external coil and other external components these devices need a lot place on the board. But because of there high efficiency they are especially interesting for applications where high current is needed producing less heat, saving energy and being not much bigger than linear regulators for the same high current with big coolers.

For the modular robot we decided to use switching step down converters to provide the three different voltages for driving the electronics because especially here big currents could be needed and the electronics have to be powered by battery. For charging the batteries we choose a battery charger with a linear regulator because the charging process will always be driven by an external power supply. In this case not efficiency but saving place on the board has the most important priority. An overview about the different voltages and the expected maximum currents is given in Table 1.

Voltage:	1.2V	3.3V	6V	8.4V
Max expected current:	1A	1A	1.5V peek voltage (one servo)	700mA (rapid charge of batteries)
Needed for:	FPGA core voltage	Most electronics e.g. ZV4002, SRAM, FLASH, FPGA (outputs)	Servo (expects voltage between 5V and 7V)	Battery charging
Provided by:	MAX1774	MAX1774	LT1765	BQ24005

Table 3: Overview power supply

3 How to use the Power board

To give the user full control about the different power supplies and battery management, the Power board provides four different switches. Every switch can switch up to 3A.

1. Switch one disables the power supply of the electronics form the batteries. However, the electronics can still be driven by the external power supply.
2. Switch two provides control over the battery charger BQ24005.
3. Switch three turns the external power supply on and off for all step down converters. So the power for all electronics e.g. Servo, FPGA board and Bluetooth board are turned on or off if the batteries are discharged. However, it is still possible to charge the batteries or to drive all components by battery.
4. Switch four turns the power supply for the LT1765 on and off and gives the user by this way control over the servo. However, the servo will only be switched on if either the external power supply or the batteries are switched on, too.

Please see also Figure 4.

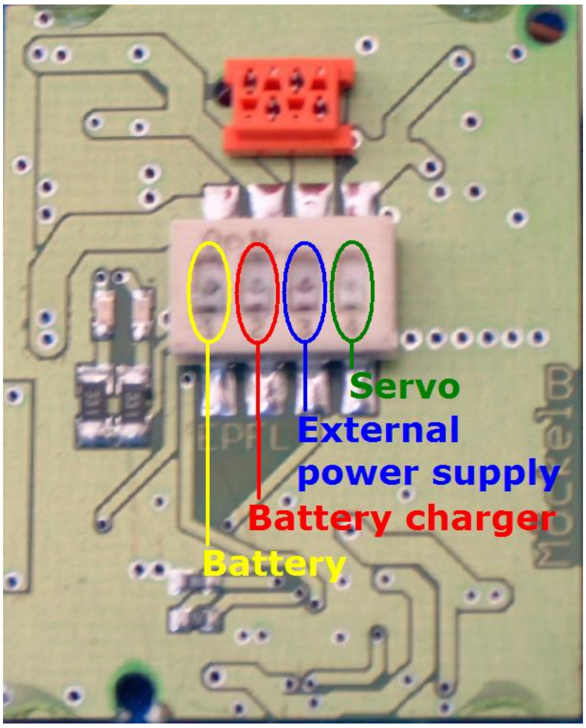

Figure 4: Switches

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4 Electronic components

This chapter describes the electronic components of the Power board in more detail.

4.1 Dual step down converter with battery management

The MAX1774EEI is a dual step down converter from Maxim/Dallas with the following features:

- Main power adjustable from +1.25V to +5.5V and over 2A
- Core power adjustable from 1V to 5V and up to 1.5A
- High efficiency of up to 95% for main power and up to 91% for core voltage
- Senses external power supply and supports together with external p-channel transistor an automatic switchover from battery to external power supply
- Senses battery voltage and supports automatic switch off for low battery voltage
- Small package: QSOP with 28 pins
- Automatic main battery switchover (not used)

The main voltage is selected to be 3.3V with help of the two resistors R11 and R12 (please see schematic in Appendix I). The core voltage is chosen with the resistors R16 and R17 (please see schematic in Appendix I) to provide 1.2V. However, if e.g. the FPGA board should be replaced by a sensor board using another voltage like 5V the output voltages of the MAX1774 can be adjusted just by changing the two resistors per voltage. Because the input pin INC for the core voltage cannot be driven with 10V the core input is connected to 3.3V.

Because the MAX1774 is providing two different voltages it is ideal for applications like the robot module where space is very limited. The power supply board gives access to the outputs /ACO and /LBO of the MAX1774 via the pads /ACO and /LBO supporting applications where the main controller has to be aware of the battery and power supply status. The signal /ACO is low when there is no external power supply. A low level at /LBO shows that there is a low voltage at the input. So a robot module can know when its batteries run out of charge and the whole robot or just the module could try to move to a charging station or just send a message via Bluetooth to a central station like a PC. The MAX1774 puts /LBO to low level when the battery voltage falls below 7V and shuts down when the battery voltage falls below 6V. These values can be adapted by changing the resistors R18, R19 and R20 (please see schematic in Appendix I). For more information about shutdown and low battery signal of the MAX1774 please see Section 5.

Although the MAX1774 features a backup battery switchover this function is not implemented on the Power board. An additional battery and the additional external components like the coil for the step up converter would have taken too much place.

For more information about the MAX1774 please see the MAX1774 datasheet [1].

4.2 3A step down converter

The LT1765ES8 is a single step down converter from Linear Technologies with the following features:

- Operating voltage of 3V to 25V
- High efficiency
- Internal switch using less space
- Small package: SO8
- Automatic shutdown for low input voltage
- Up to 3A

The output voltage of the LT1765 is selected to be 6V. Because the LT1765 can provide up to 3A the power supply board can easily be used to power a robot module with two degrees of freedom / two servos. To change the output voltage of the LT1765 you only have to change the resistors R8 and R9 (please see schematic in Appendix I).

The LT1765 is configured to shutdown if the input voltage falls below 6.8V. This threshold can be adapted by changing the values of the resistors R6 and R7 (please see schematic in Appendix I). For more information about shutdown of the LT1765 please see Section 5.

For more information about the LT1765 please see the LT1765 datasheet [2].

4.3 Two cell Li-ION charge management

The BQ24005PWP is a charge management circuit from Texas Instruments for two Li-ION batteries. The BQ24005PWP has the following features:

- Internal power switch reducing necessary space
- High accuracy voltage regulation
- Optional temperature or input power monitoring
- Charge termination by minimum current and time
- Small package: 20-lead TSSOP PowerPAD

On the power board the BQ24005 is set to monitor input voltage via the resistors R3 and R4 (please see schematic in Appendix I). The current is selected to be 700mA with help of the resistor R5 while the charge voltage is set to 8.4V both as recommended by the battery data sheet (please see Appendix I). The BQ24005 features an internal timer for charge termination. This timer is programmed by the pin TMRSEL to stop charging after 3 hours. The charge status is displayed with help of the two LEDs: LED1 and LED2. LED1 (red) is on during charge while a turned on LED2 (green) shows that the battery is charged over 90%.

For more information about the BQ24005PWP please see the BQ24005 datasheet [3].

5 Battery management

Inside the robots modules there are two Li-ION batteries arranged in a chain to provide together at least the necessary voltage for the servo. When choosing batteries you always have the problem that you might find some one with the necessary voltage of at least 6V but with to low power of only a few mAh limiting the working time of the robot module too much. When choosing batteries with a higher value of more mAh most ones only provide voltages of at least 3V. That is why we decided to take two batteries in a chain having good results for both power and voltage.

However, in terms of security and power management batteries need some additional attention because

- You have to make sure that the batteries are not discharged too much. Otherwise you risk to damage or destroy them.
- When recharging batteries you have to use the correct voltage and current and make sure that you do not damage them because of overloading.
- Batteries have a nominal voltage which does not mean that they are providing the same voltage over full discharging time. Because electronics like integrated circuits need constant voltage you have to provide extra linear regulators or step down / step up converter to produce constant voltages.
- You should not try to discharge the batteries while charging them.

To make sure that the batteries are not discharged too much all step down converters providing the constant voltages for the other electronics automatically shut down when the batteries are discharged too much:

When fully charged the batteries provide together up to 8.4V. After reaching a combined voltage of 7V the /LBO (low battery output) of the MAX1774 turns to low level. At 6.8V the LT1765 shuts down which results in the fact that the servo will be turned off while the other electronics remain working until the voltage level reaches 6V. Afterwards also the MAX1774 will turn off and disable all electronics. Due to the fact that the servo is turned off before the electronics have no longer power supply, a user of the robot module has the time to provide external power supply for the robot module before e.g. the FPGA or the microcontroller looses data and has to be reconfigured or reprogrammed.

To make sure that there is no energy taken from the batteries while they are charged, the MAX1774 and the Power board are configured to make sure that the power supply for the step down converters is automatically switched to the external power supply when there is an external one. For this reason the ACI input of the MAX1774 is sensing for an external voltage. If there is an external power supply the MAX1774 turns the p-channel transistor U5 (please see schematic in Appendix I) off to make sure that no more energy is taken from the batteries. The MAX1774 and the LT1765 are arranged in a chain so that the power supply for the LT1765 is also automatic switched by the MAX1774.

For more information about the batteries please see the battery datasheet HLP072247 [4]
For more information about the other electronic components please see the MAX1774 datasheet [1] and the LT1765 datasheet [2].

6 Using power board together with 2 servos

The Power board can be used in a robot module with two degrees of freedom. For using the Power board together with two servos please recognize:

- The LT1765 provides up to 3A.
- Please check that all electronics on the way from the external power supply and from the battery to the LT1765 can be used with the necessary current especially the diode D3 and the p-channel transistor U5 (please see schematic in Appendix I).

The servo currently used in the robot module works in a voltage range from 5 to 7V and has a peek current of 1.5A when lifting very fast high loads.

When selecting another diode or transistor you have to be aware of

- The place needed on the board
- Please make sure that the device has a low internal resistance. Otherwise you will have a high voltage drop over the device because of the high current that is used.
- Check that the device can be used with the necessary current.

Currently the power board uses for D3 the diode STPS340U that can be used with an average forward current of 3A and for U5 the transistor FDN360P which features a continuous drain current of 2A and a pulsed drain current of up to 20A.

For more information about the device STPS340U please see the STPS340U datasheet [5].
For more information about the device FDN360P please see the FDN360P datasheet [6].

7 Layout

For doing or changing the layout of the Power board there are some constrains that should be aware of.

7.1 Wires

All wires driving high current should be as wide as possible. A wire with a width of 1mm should never drive more than 3A. Otherwise you risk damaging it. Even if it there is no damage small wires always mean high internal resistance producing voltage drops and heat.

7.2 Electronic components

The step down converters are switching devices which are using high frequencies. Please make sure that the auxiliary electronics for the switching paths are placed as close to the integrated circuits they belong to e.g. the MAX1774 and the LT1765 as possible. To reduce influence between the electronics the circuits MAX1774, LT1765 and BQ24005 should be placed as far away from each other as possible.

7.2.1 LT1765

For the LT1765 please place the diodes D1 and D2, the coil L1, the input capacitor C6, the output capacitor C9 and the capacitor C8 as close to the LT1765 as possible. Because of the high switching frequency of 1.25 MHz and the high currents, all wires in the switching path should be as wide as possible. Using switching devices with high frequencies also means producing fast changing electromagnetic fields that might influence other devices. All elements should have a good contact to ground and there should be a ground plane on the bottom side of the device to reduce electromagnetic fields and influence on the other circuits. To reduce influence, other switching devices are placed as far away from the LT1765 as possible.

For more information about the layout for the LT1765 please see LT1765 datasheet [2].

7.2.2 MAX1774

All capacitors especially the input capacitor C16 for the main voltage and the input capacitor for the core voltage but also the device U4 and the coils should be placed as close to the circuit as possible. Because of its low resistance the resistor R10 for current sensing should be connected with wide wires and should be very close to the MAX1774. Otherwise the resistance of the wires will increase overall resistance value too much. Please make sure that there are good connections to the ground plane. The power path starts from the batteries through U5 and from the external power supply through D3. It is going on through U4, L2 and R10 both to the 3.3V pad and to the core voltage input and from the core voltage output LXC through L3 to the 1.2V pad. Make sure that all wires connecting this electronics are as wide wires as possible.

For more information about the layout for the MAX1774 please see the MAX1774 datasheet [1].

7.2.3 Battery charger

Because the BQ24005 is a linear regulator it has no switching path with high frequencies. Despite this fact all capacitors should be placed as close to the circuit as possible. Especially care should be taken with the resistor R5 for current sensing. Connecting R5 to the BQ24005 with thin and long wires would mean adding resistance from the wires to the small value of R5 and changing the value of the charging current.
A special feature of the BQ24005 is its power pad under the package. The BQ24005 produces much heat because it is a linear regulator. The power pad supports getting the heat out of the circuit and should be connected to a big plane of copper.

For more information about the layout for the BQ24005 please see the BQ24005 datasheet [4].

8 Manufacturing of Power board

When soldering the components on the Power board, the battery charger BQ24005 should be soldered first. Make sure that the power pad at the bottom of the BQ24005 is soldered correctly.

There are two mistakes made when designing the Power board layout. There for the Power board has to be patched:

- Change the PCB under U4 (FDS8928A) Disconnect PCB at red position and connect the PCB at blue position as shown in Figure 5.

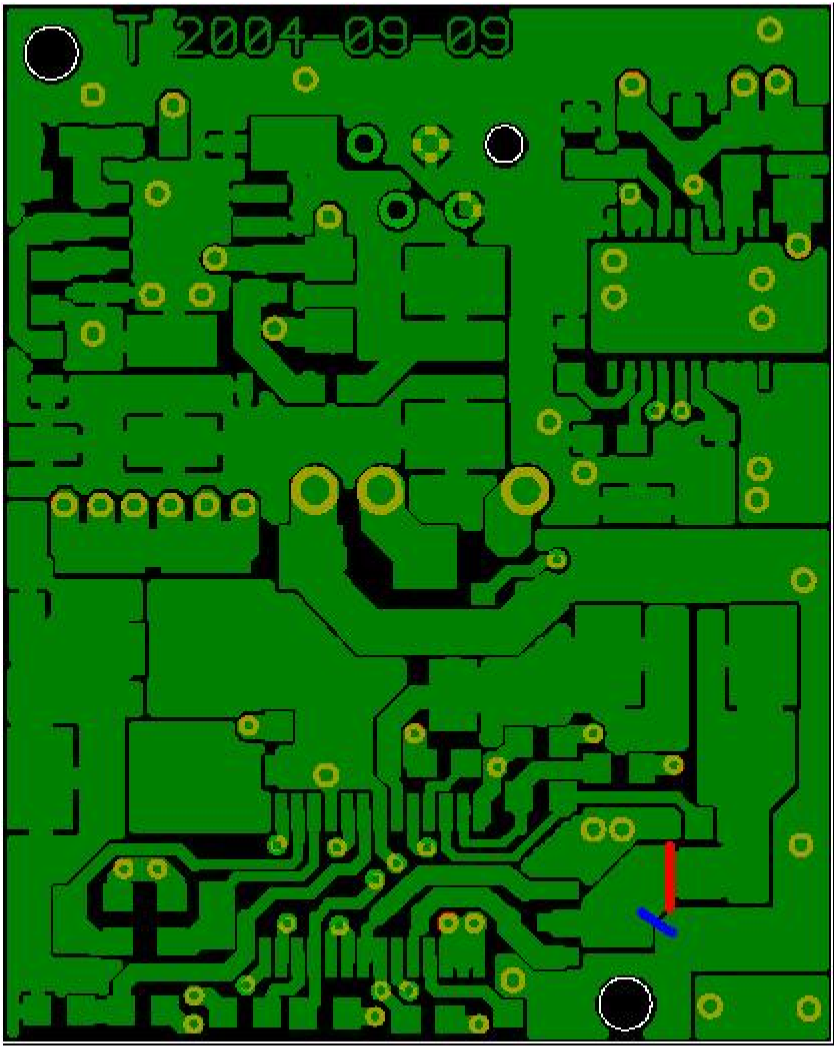


Figure 5: Change PCB under U4

- Change PINS of U4 (FDS8928A) as shown in Figure 6.

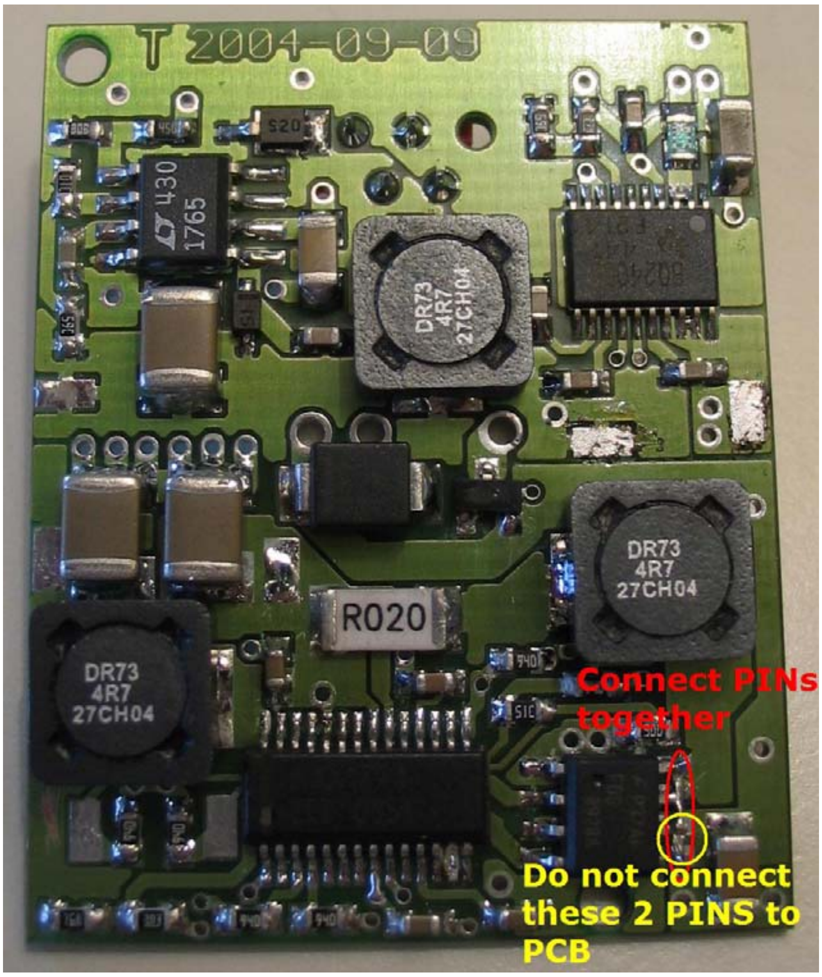


Figure 6: Change PINS of U4 (FDS892A)

- Disconnect PIN 13 (BIN) from U1 (MAX1774) as shown in Figure 7.

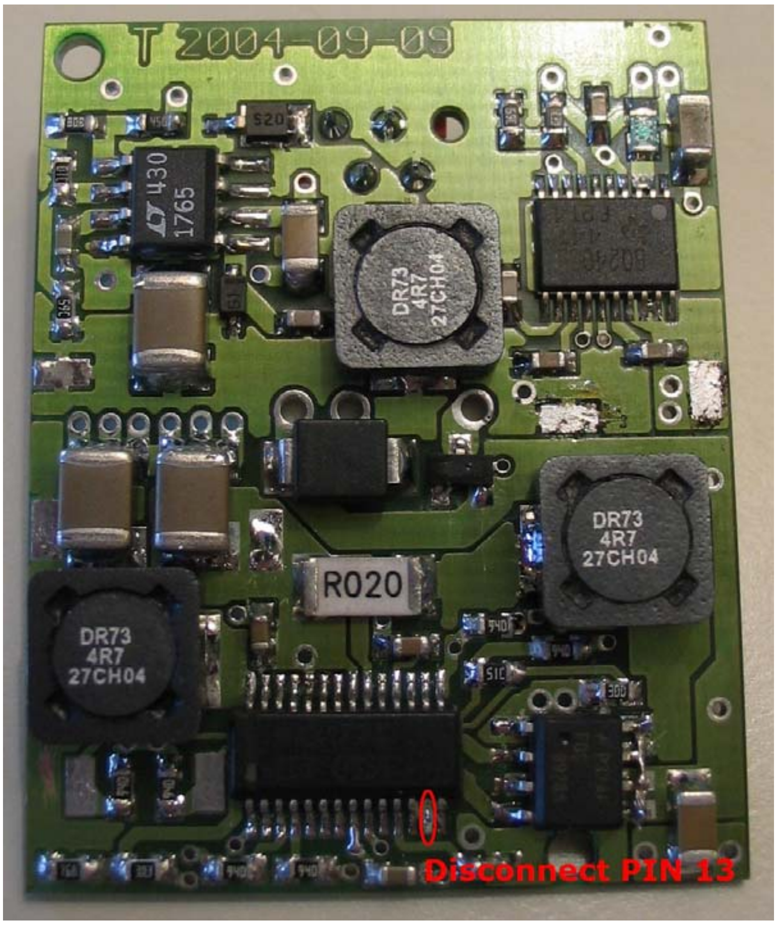
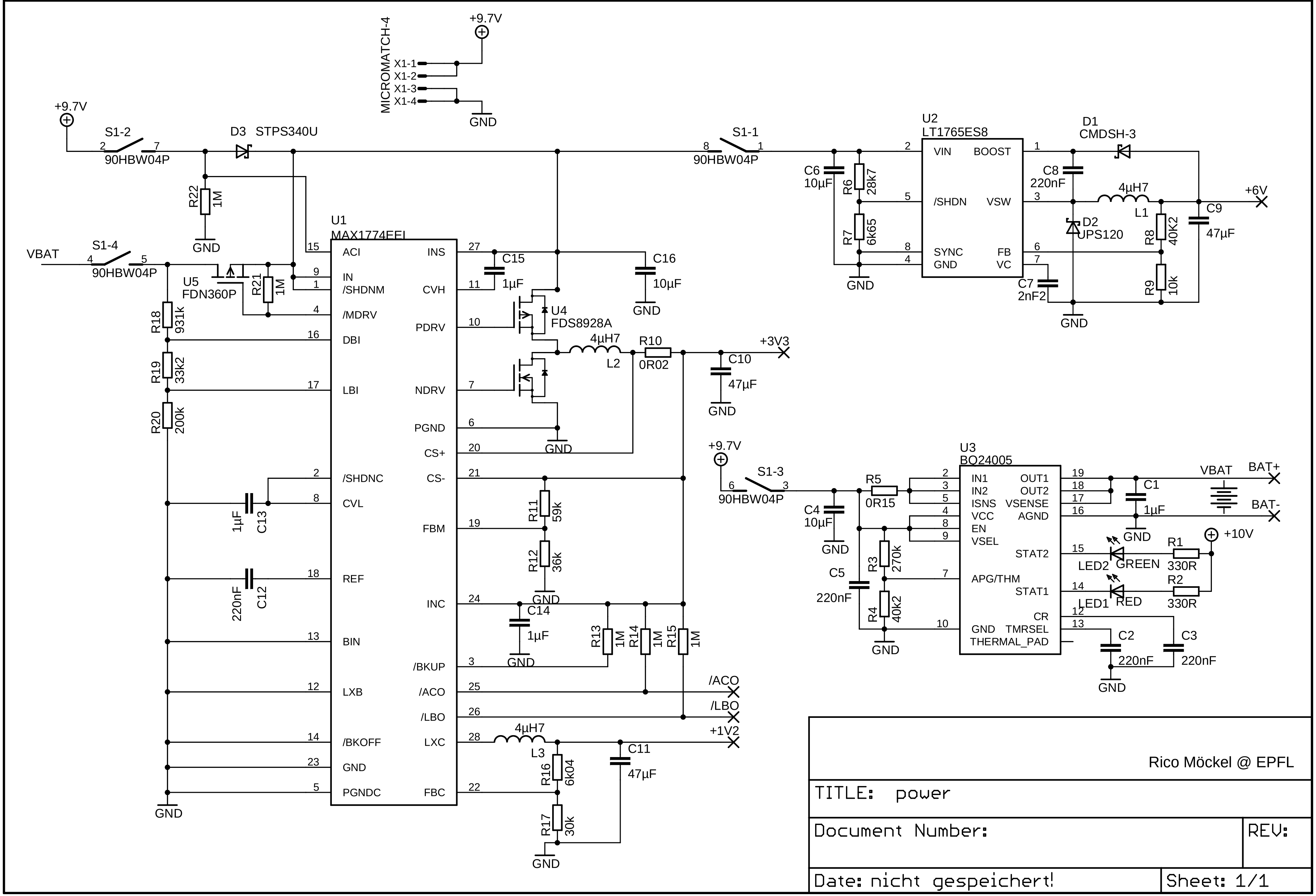


Figure 7: Disconnect PIN 13 of MAX1774

9 Bill of Materials

Symbol	Qty	Value	Manufacturer	Description	Package	Order Number	Price		Min pc.	Price [CHF]	Distributor
U1	1		Maxim/Dallas	Dual step-down converter with backup battery switchover	28 PIN QSOP	MAX1774EEI	6,97	USD	1 to 24	8,76	Maxim direct!
U3	1	700mA, 8.4V	Texas Instruments	Two-cell Li-ION charge management	TSSOP20 (6.6mm x 6.4mm)	bq24005PWP	3,50	CHF	70	3,50	EBV Elektronik GmbH
U2	1	3A, 6V	Linear Technology	Step-down converter	SO8 (5mm x 6.2mm)	LT1765ES8	10,85	USD		13,65	Memec AG
U4	1	4A, 20V	Fairchild	Dual N & P-Channel MOSFET | FDS8928A	SO-8 (5mm x 6mm)	FDS8928A	0,92	CHF		0,92	EBV Elektronik GmbH
U5	1	2A, 30V	Fairchild	Single P-Channel MOSFET | FDN360P	SuperSOT-3	610034	0,75	CHF	5	0,75	Distrelec
X1	1		Tyco	Micromatch connector | 4 pins		128482	0,65	CHF	1	0,65	Distrelec
S1	1	3A	Grayhill	DIL Switch 90HBW04P	SMD	102532	3,55	CHF	10	3,55	Farnell
D1	1		Central Semiconductor	Schottky diode	SOD-323 (2.6mm x 1.35mm)	CMDSH-3	1,20	CHF		1,20	Computer Controls AG
D2	1	1A, 20V	Microsemi	Schottky diode	(2.05mm x 3.90mm)	UPS120	1,20	CHF	45	1,20	MPI Distribution
D3	1	3A, 40V	ST	Schottky diode | STPS340U	SMB	600315	1,20	CHF	5	1,20	Distrelec
C9, C10, C11	3	47u	Murata	10% | X5R | 10V	SMD 1812 (4.5mm x 3.2mm)	823526	4,40	CHF	25	13,20	Distrelec
C1, C13, C14, C15	4	1u	Murata	10% | X5R | 25V	SMD 0603 (1.6mm x 0.8mm)	823495	0,20	CHF	25	0,80	Distrelec
C4, C6, C16	3	10u	Murata	10% | X5R | 25V	SMD 1206 (3.2mm x 1.6mm)	823513	0,55	CHF	25	1,65	Distrelec
C2, C3, C5, C8, C12	5	220n	Murata	10% | X7R | 25V	SMD 0603 (1.6mm x 0.8mm)	823501	0,18	CHF	25	0,90	Distrelec
C7	1	2.2n	Murata	10% | X7R | 50V	SMD 0603 (1.6mm x 0.8mm)	830117	0,07	CHF	25	0,07	Distrelec
R18	1	931k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	4225673	0,05	CHF	50	0,05	Farnell
R19	1	33.2k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	4224358	0,05	CHF	50	0,05	Farnell
R20	1	200k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	3571671	0,05	CHF	50	0,05	Farnell
R11	1	59k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	4224590	0,05	CHF	50	0,05	Farnell
R12	1	36k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	3571580	0,05	CHF	50	0,05	Farnell
R16	1	6k / 6.04k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	4223706	0,05	CHF	50	0,05	Farnell
R17	1	30k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	3571579	0,05	CHF	50	0,05	Farnell

R13, R14, R15, R21, R22	5	1M	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	**911598**	0,05	CHF	50	0,25	Farnell
R6	1	28.7k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	4224292	0,05	CHF	50	0,05	Farnell
R7	1	6.65k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	4223743	0,05	CHF	50	0,05	Farnell
R9	1	10k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	911355	0,05	CHF	50	0,05	Farnell
R4, R8	2	40.2k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	4224437	0,05	CHF	50	0,10	Farnell
R3	1	270k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	911525	0,05	CHF	50	0,05	Farnell
R10	1	0.02R	WELWYN	1% | 1W	SMD 2010 (5.23mm x 0.8mm)	3610214	1,95	CHF	5	1,95	Farnell
R5	1	0.15R	MEGGITT	5% | 0.125W	SMD 0805 (2.0mm x 1.25mm)	156139	1,40	CHF	5	1,40	Farnell
R1, R2	2	330R	Philips	5% | 0.25W	SMD 1206 (3.2mm x 1.6mm)	512679	0,08	CHF	50	0,16	Farnell
L1, L2, L3	3	4.7uH	Coiltronics	20% | Irms 3.09A | Isat 3.78A | DCR 0.0297Ohm	(7.6mm x 7.6mm x 3.55mm)	350190	2,30	CHF	10	6,90	Distrelec
LED1	1	Red	Agilent Technologies	LED Red	SMD 0603 (1.6mm x 0.8mm)	250161	0,35	CHF	5	0,35	Distrelec
LED	0	Yellow	Agilent Technologies	LED Yellow	SMD 0603 (1.6mm x 0.8mm)	250163	0,35	CHF	5	0,00	Distrelec
LED2	1	Green	Agilent Technologies	LED Green	SMD 0603 (1.6mm x 0.8mm)	250164	0,35	CHF	5	0,35	Distrelec
									total:	64,01	



Rico Möckel @ EPFL

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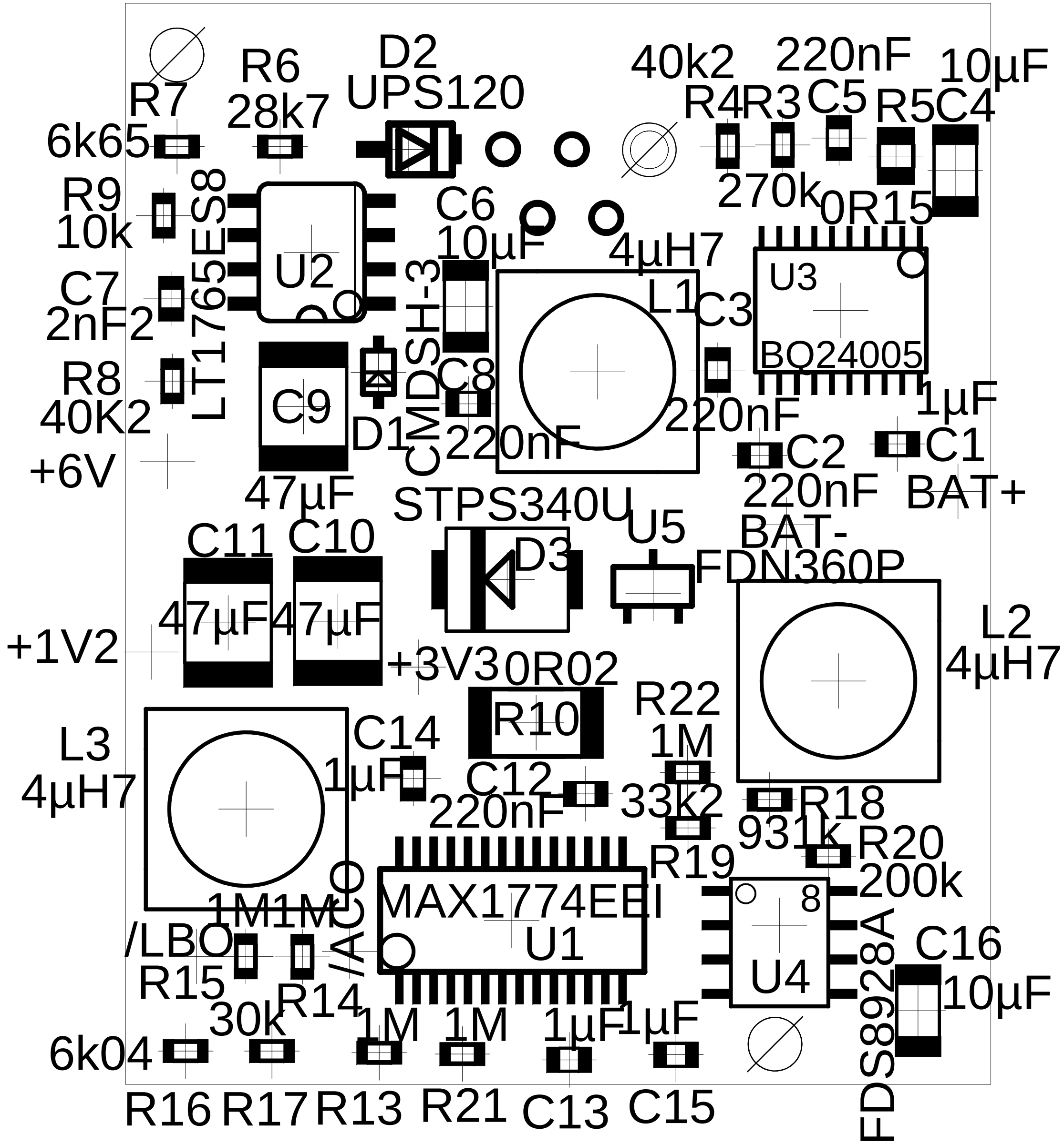
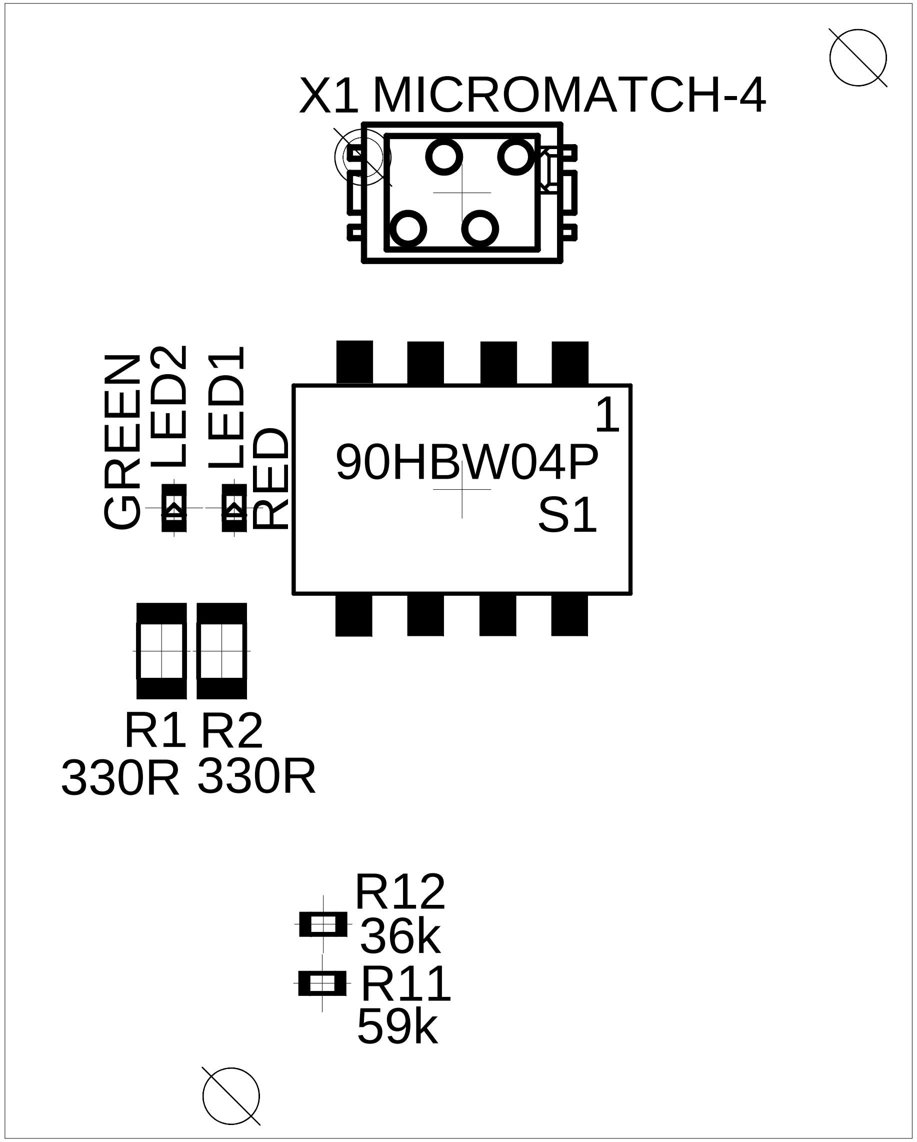


Attention

Patch PCB

Solder BQ24005 first

Rico Möckel @ BIRG (EPFL)	
Power board	Rev 1
Assembly top	



Rico Möckel @ BIRG (EPFL)	
Power board	Rev 1
Assembly bottom	