Bluetooth Board Reference Guide 1.0

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ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

BIOLOGICALLY INSPIRED
ROBOTICS GROUP (BIRG)

Bluetooth Board Reference Guide

Date	Version	Changes
September 3rd, 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 Bluetooth Board rev 1 (2004-08-30) designed for the Modular Robot Unit from BIRG (Biologically Inspired Robotics Group).

1.2 Audience

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

1.3 Organization

The following chapters "Overview" and "Getting Started / First Test of Bluetooth Board" will give a first introduction in using the Bluetooth board while the chapters afterwards go more into 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]	ZV4002 Datasheet	Zeevo
[2]	ZV4002 Hardware Design Guide	Zeevo
[3]	K6X8016 datasheet	Samsung Electronics
[4]	SST39VF datasheet	SST
[5]	Q12.0JX63 datasheet	Jauch
[6]	Application Note 16 Crystal tuning	Zeevo

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 Bluetooth board contains the following main components:

- ZV4002
  Combination of an ARM7TDMI microcontroller core and Bluetooth functionalities in a chip.
- 16 Mbit (1Mx16 bit) flash memory
- 512Kx16 bit low power SRAM
- JTAG connector
- Connector providing access to 6 GPIO pins, UART and reset
- 2 GPIO LEDs
- 2.4Ghz SMD antenna
- Quartz with 12.0 MHz

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

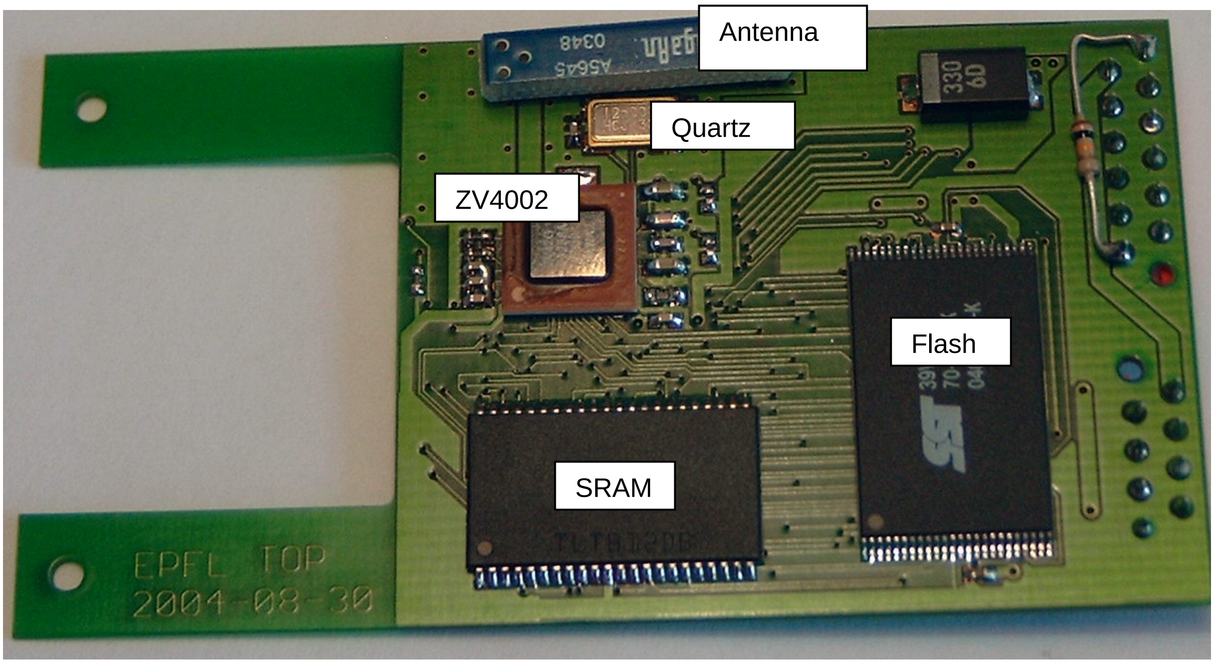


Figure 1: Bluetooth board (top)

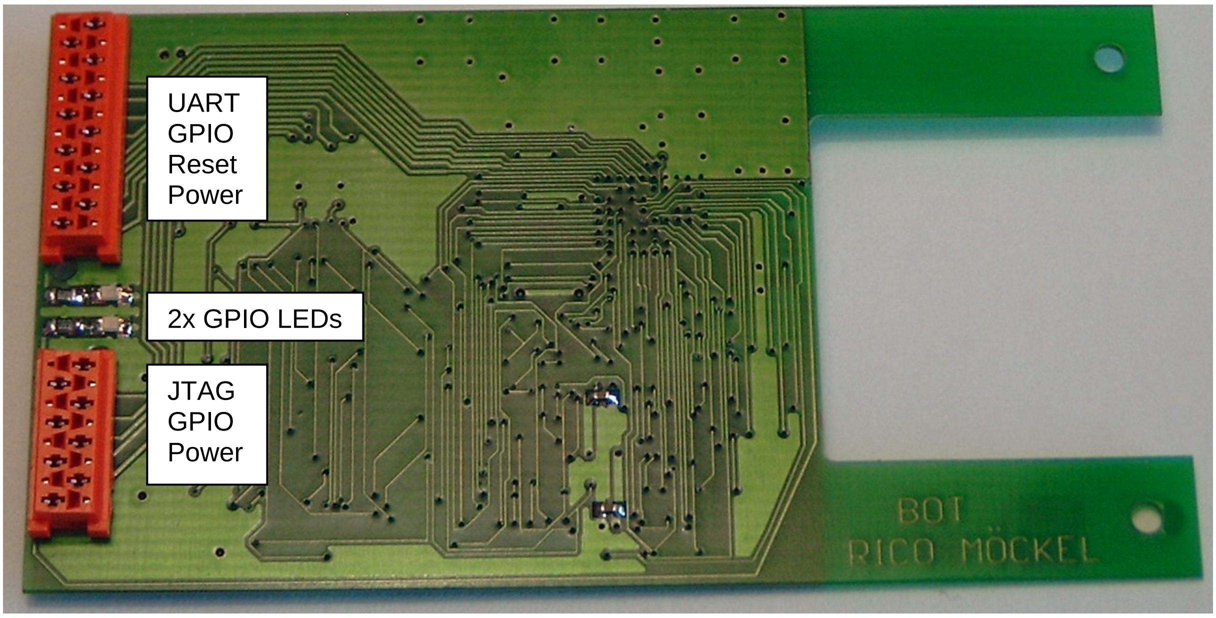


Figure 2: Bluetooth board (bottom)

3 Getting Started / First Test of Bluetooth Board

For testing a Bluetooth board you need:

- A second Bluetooth board.
- A PC with two serial interfaces (COM1, COM2) or two PCs with one serial interface.
- Two serial cables with level converter.
- Software “Zerial” from Zeevo (Compiled file and script files).
- Software “ZvDosFlashTool.exe” from Zeevo.
- Microsoft HyperTerminal

Please do the following for both Bluetooth boards:

A Hardware setup

When the Bluetooth board is not included in a robot unit

1. Connect “Ground” to the Bluetooth board.
2. Connect the 3.3V power supply to the Bluetooth board.
3. Connect the cable for UART communication between the serial interface of a PC and the Bluetooth board.

When the Bluetooth board is already included in a robot unit

1. Switch the power supply on.
2. Connect the cable for UART communication between the serial interface of a PC and the Bluetooth board.

Attention: The UART connector of the Bluetooth board is designed for 3.3V. You will need a level converter to connect the serial interface of a PC to a Bluetooth board.

B Programming of the Bluetooth boards

1. Start the download manager “ZvDosFlashTool.exe” to program the flash memory of the Bluetooth board.
2. Select a COM port.
3. Reset the Bluetooth board by switching the power supply off and on.
4. Press “1” on the keyboard
5. The flash memory will be programmed. This will take some time.
6. Close the download manager by pressing “9” on the keyboard.
7. After closing the download manager the green LED of the Bluetooth board should be blinking.

C Establish a Bluetooth connection

1. Please start the “Hyper Terminal” and create a new connection as shown in Figure 3.

Figure 3: Create new connection in Hyper Terminal

2. Please choose the port settings as shown in Figure 4. The baud rate should be selected to be 115200 bits per second.

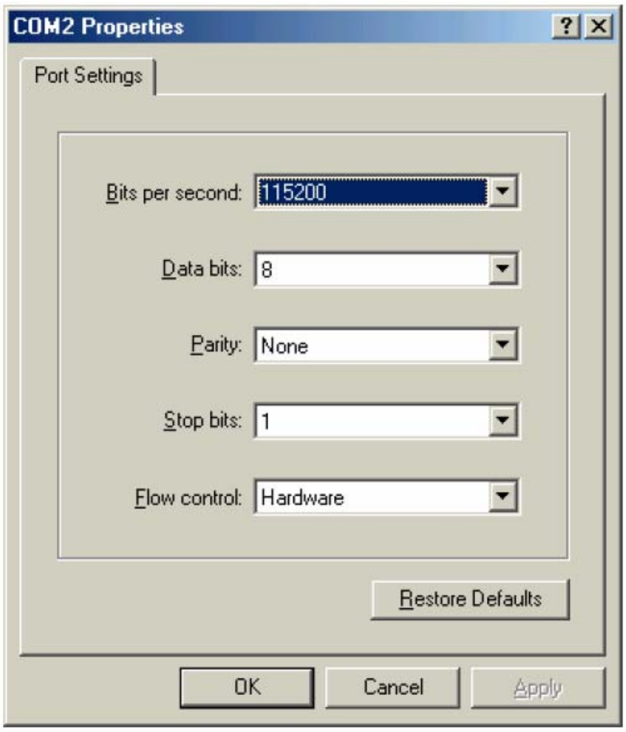


Figure 4: Port settings

When resetting the Bluetooth device (e.g. by switching the power supply off and on) it sends its Bluetooth address to the terminal and tells that it is in the command mode.

Now the Bluetooth device can be controlled by some text commands. These commands can be typed directly into the terminal window. However, it is recommended to write them down into a text file and send them with the Hyper Terminal. You can find these text files in the folder “Final_Presentation” on the project CD of Rico Möckel.

With the command

AT+ZV Discovery

the Bluetooth device is asked to search for other Bluetooth devices. If this was successful, it should print the Bluetooth addresses of the devices found to the terminal window.
Please note that there must be a new line/return/enter after the last word “Discovery”. This command can be found in the text file “discovery.txt”.

3. For invoking the discovery command with the help of a text file please click on “Transfer” in the Hyper Terminal main menu and select “Send Text File” as shown in Figure 5.

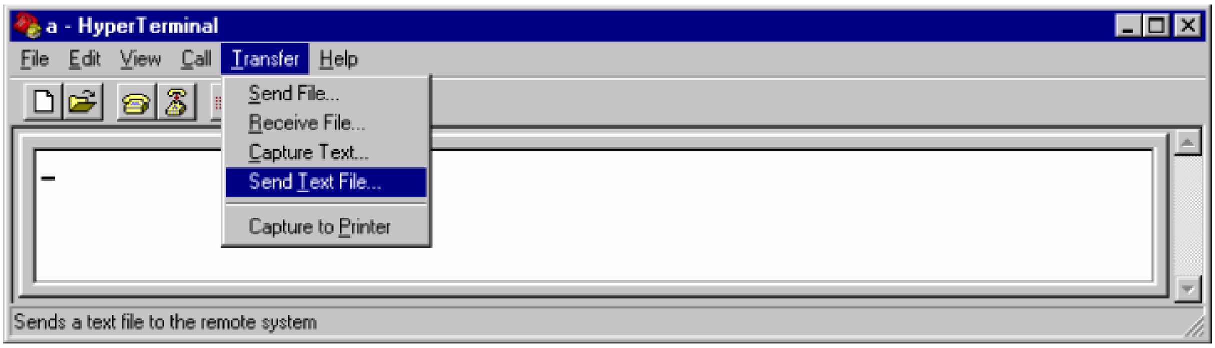


Figure 5: Invoke a command saved in a text file

4. Please select the text file “discovery.txt” and send it.

When the Bluetooth device is found, you can establish a Bluetooth connection with the following command:

AT+ZV SPPCONNECT 00043e000000

where “00043e000000” should be replaced by the Bluetooth address of the device that should be connected. If this was successful the Bluetooth devices goes into “Bypass Mode”. This means that everything typed into the Hyper Terminal will be directly send to the wireless connected device.
Please note that there must be a new line/return/enter after the Bluetooth address. The connect command can be found in the text file “connect_command.txt”.

5. For invoking the connect command with the help of a text file please click on “Transfer” in the Hyper Terminal main menu and select “Send Text File” as shown in Figure 5.

6. Please select the text file “connect_command.txt” and send it.

When the connection is established the greed LED of the Bluetooth boards should stop blinking and stay switched on.

7. After a connection is established, the software goes into a bypass mode: Everything you type into the HyperTerminal will be send to the wireless connected Bluetooth device

Congratulation: the Bluetooth board is working.

4 Bluetooth

In fact, on the market there exist a lot of different wireless technologies e.g. low frequency radio transmitters, UWB, WLAN and Bluetooth.

For the modular robot Bluetooth was chosen because there are some very important constrain the wireless technology has to meet:

- Low Energy consumption
  A wireless connection used inside a robot with limited energy resources should not waste energy.
- Standardization
  It is useful to decide for a technology that is still improved and standardized. This allows taking profit from further developments. Bluetooth is a standard pushed by industries that allows connecting the Bluetooth board also from Bluetooth dongles, PDAs or mobile phones. Bluetooth comes with a standardized software stack which dramatically decreases the time for software development.
- Reliability
  Using a wireless connection always means living with noise, interference and disturbance. That is why it is necessary to choose a technology where already network layers exist that reliably handle errors. Because of the frequency hopping used for Bluetooth, Bluetooth is very robust against disturbing signals.

Low frequency radio transmitter are not used because we would have to develop also an own layer for error handling and a MAC layer that controls which modules is allowed to send data at which time. Furthermore Bluetooth has the advantage in comparison to low frequency radio transmitters that it can transmit through walls or the case of a robot.

At the current moment, UWB is not developed far enough to buy complete solutions on the market. Despite this fact it could become a very interesting wireless interface for modular robots because of its very low energy consumption and low costs.

A comparison between WLAN and Bluetooth is given in Table 3.

	WLAN	Bluetooth
Power consumption:	More than 1W	100mW
Throughput:	11MBit/s – 54MBit/s	721kBit/s – 10MBit/s
Range:	100 m	class 2: 10 m (depends on class of device)
Participants:	255	8 (Piconet) – 255 (Scatternet)

	WLAN	Bluetooth
Pro	• More bandwidth than Bluetooth • No need to form subnets • There are integrated solutions on the market	• Security • Self configuring power control • Less energy consumption
Con	• High power consumption, not for embedded systems • Encoding and decoding necessary for security • More energy consumption	• Overhead for Scatternet forming • Less bandwidth

Table 3: Comparison WLAN and Bluetooth

Because of high power consumption WLAN is not acceptable for embedded low power systems.

5 ZV4002

Even if there are a lot of different products on the market supporting main features of Bluetooth like Scatternets or Master-Slave-Switch, most Bluetooth devices have a lot of limitations. E.g. when developing a new scatternet protocol on the BTnode rev2 developed at the ETH Zurich, we found that it is not possible to build loops. On one hand a slave cannot connect another device and become automatically a master-slave. On the other hand a slave becomes invisible and cannot be connected a second time. A slave cannot be slave inside two different piconets. Of course this are limitations for forming a optimized Bluetooth protocol where packets of data could be send as fast as possible from the sender to a receiver in the network.

However, the ZV4002 supports scatternets with up to 7 slaves and up to 4 piconets. So a Bluetooth device can be both master of a piconet and slave of up to 4 other piconets. That is why the ZV4002 can be used to test new Bluetooth protocols where not only trees but also graphs with cycles are created.

Another advantage of the ZV4002 is that it already includes an ARM7TDMI processor. For programs that do not need a fast processing an extra external microprocessor is not necessary saving space and money.

The ZV4002 provides a JTAG interface for easier debugging of own programs. This feature is very important for a platform for different research projects.

The ZV4002 provides a deep sleep mode for energy saving when Bluetooth functionalities are not required. However the current Bluetooth board does not support the deep sleep mode because there is no 32KHz quartz and the input for the deep sleep quartz is grounded. This was made for simplifying layout and saving space.

For more details about the ZV4002 please see the ZV4002 datasheet [1] and ZV4002 Hardware Design Guide [2].

6 Pin Description

Table 4 gives an overview about the available pins of the ZV4002.

Pin	ZV4002 pin	Connected to	Description
+3V3	VDD	Micromatch-12 (X2) Micromatch-8 (X3)	Power supply; +3.3V
GND	GND	Micromatch-12 (X2) Micromatch-8 (X3)	Power supply; Ground
GPIO_12	GPIO_12	Micromatch-12 (X2) LED2 (red)	GPIO
GPIO_11	GPIO_11	Micromatch-12 (X2)	GPIO
GPIO_10	GPIO_10	Micromatch-12 (X2)	GPIO
GPIO_8	GPIO_8	Micromatch-12 (X2)	GPIO
GPIO_7	GPIO_7	Micromatch-12 (X2)	GPIO
GPIO_4	GPIO_4	Micromatch-8 (X3) LED1 (green)	GPIO
GPIO_0	GPIO_0	Pad 0	Output for crystal tuning
UART_RXD	UART_RXD	Micromatch-12 (X2)	UART_RXD
UART_TXD	UART_TXD	Micromatch-12 (X2)	UART_TXD
UART_CTS	UART_CTS	Micromatch-12 (X2)	UART_CTS
UART_CTR	UART_CTR	Micromatch-12 (X2)	UART_CTR
/RESET	/RESET	Micromatch-12 (X2)	/RESET
ATDO	ATDO	Micromatch-8 (X3)	JTAG ATDO
ATDI	ATDI	Micromatch-8 (X3)	JTAG ATDI
ATCK	ATCK	Micromatch-8 (X3)	JTAG ATCK
ATMS	ATMS	Micromatch-8 (X3)	JTAG ATMS
/ATRST	/ATRST	Micromatch-8 (X3)	JTAG /ATRST

Table 4: Pin description

For more information about the available pins please also see the schematic of the Bluetooth board and the assembly in the appendix.

7 SRAM

The FPGA board contains an additional external SRAM to support more powerful applications and full connection capabilities of the ZV4002. The K6X8016T3B-TF70 from Samsung Electronics is a low power SRAM and provides the following main features:

- Configuration: 512Kx16 bit
- Low power consumption
- Power supply 2.7-3.6V
- Small package: 44-TSOP2
  Using a BGA would result in an even smaller package but provide more difficulties with regard to designing and manufacturing the PCB.
- Speed 70ns

For more details please see the K6X8016 datasheet [3].

8 Flash memory

For the modular robot it is necessary to store both code for the ARM e.g. the Bluetooth software stack and to store some configuration files for the FPGA.
The SST39VF160-70-4C-EK from SST provides the following main features:

- Configuration: 1Mx16bit
- Low power consumption
- Power supply 2.7-3.6V
- Small package: TSOP48
  Using a BGA would result in an even smaller package but provide more difficulties with regard to designing and manufacturing the PCB.
- Speed 70ns

For more details please see the SST39VF datasheet [4].

9 12.0MHz Quartz

The ZV4002 uses a quartz with 12.0MHz for operation. Because this quartz also serves as reference for the Bluetooth signals it has to be very accurate. The recommended values for the quartz are given in Table 5.

Parameter	Value
Frequency	12 MHz
Initial frequency tolerance	+/- 10ppm
Drift over temperature	+/- 7ppm
Aging	+/- 1ppm
C_{load}	9pF
C_{shunt}	max 3pF
Operating temperature	0 to 70°C
Equivalent series resistance	max 40Ohm

Table 5: Recommended values for 12.0MHz quartz

However, it is very difficult to find very accurate quartz in a small period of time. That is why we chose the Q12.0JX63-9-10/10 from Jauch with the values given in Table 6.

Parameter	Value
Frequency	12 MHz
Initial frequency tolerance	+/- 10ppm
Drift over temperature	+/- 10ppm
Aging	< +/- 3ppm
C_{load}	9pF
C_{shunt}	< 7pF
Operating temperature	-20 to 70°C
Equivalent series resistance	max 60Ohm; typical 20Ohm

Table 6: Values ot the Q12.0JX63-9-10/10

The higher shunt capacitance will result in a longer start up time and should not cause problems.

Because the tolerance for Bluetooth normally is 20ppm a bigger tolerance in terms of temperature and aging will create worse performance of the wireless communication. The idea behind the recommended values is a life time of the product of 3 years over full temperature range:

20ppm = 3 years * 1ppm/year + 7ppm over temperature

This is especially interesting for products that are sold to customers where recalibrating the internal trim capacitors (see section???) inside the ZV4002 is impossible or costs a lot of money. For a research module like the modular robot it should not be a problem to recalibrate the trim capacitors every year if needed:

20ppm = 1 year * 3ppm/year + 7ppm over temperature

Please also recognize that the given values in Table 5 are worst case values.

However, for the next Bluetooth boards I recommend using the Q12.0JX63-9-10/7 from Jauch that is more expensive but has a better drift over temperature of the recommended 7ppm. It was not possible to use them for the first modules because of its bigger lead time.

For more details about Q12.0JX63-9-10/10 and Q12.0JX63-9-10/7 see Q12.0JX63 datasheet [5].

Crystal tuning, choice of capacitors
To achieve a good accuracy of the Bluetooth frequency load capacitors with 5% or better tolerance are recommended. For the Bluetooth board some NPO capacitors with 5% are used. Because the quartz is already using the full Bluetooth tolerance of 20ppm there is no space for some tolerances of the capacitors. That is why there are 15 internal trim capacitors of 0.25pF included on both the XTAL_IN and XTAL_OUT pins of the ZV4002. So you can add by software up to 3.75pF additional load on each pin.

For calibrating the Bluetooth frequency three different methods exist:

- Frequency counter method
- Spectrum analyzer method
- Bluetooth tester method

The second and the last calibrating methods are especially interesting for commercial projects whre a large amount of devices should be calibrated. Because these methods need expensive test devices, for calibrating the Bluetooth boards the frequency counter method was chosen. The frequency counter method requires only a frequency counter which is directly connected to the GPIO0 pin. That is why there is a test pad called PAD1 (please see the schematics in the appendix) included in the design that is directly connected to GPIO0.

For further details about choosing quartz and capacitors and about crystal tuning please see ZV4002 Hardware Design Guide [1] and Application Note 16 Crystal tuning [6].

10 Layout

Placement of antenna
When placing the antenna on the board you should be careful not to produce a short circuit with regard to the electromagnetic field. There for the antenna is placed as far as possible from metal planes like the batteries. To reduce interference the distance to other switching devices with high frequency like on the power supply board is increased.

The antenna should be placed directly over a ground plane on the bottom side and with a ground plane around the antenna on the top side of the board. Furthermore, there are vias that are connecting top and bottom ground plane to make sure that both have the right potential.

The wire from the RF output of the ZV4002 is made as short as possible and with regard to its width adapted to the frequency of the Bluetooth. For more information about choosing the right width of the wire please see ZV4002 Hardware Design Guide [1].

Ball grid array (BGA) of the ZV4002
Manufacturing and soldering the BGA provides a lot of challenges. Although vias with a hole of 0.2mm diameter are recommended we chose a hole of 0.3mm because this was the minimum that could be manufactured at the EPFL. To make sure that the vias still fit between the SMD pads for the BGA we reduced the copper around the holes of the vias to reach the recommended diameter for the vias of 0.4mm.

To support a consistently good soldering of the balls in the oven the connections to the SMD pads should all have the same size. The connections from the SMD pads should all have a width of 0.127mm. There should not be more than one connection for every SMD pad.

When manufacturing a board normally all pads and vias are covered with tin to support easier soldering. When doing the Bluetooth board please make sure the “old process” with sn-pb is used.

At the beginning for the first prototype of the boards we were using the new process. However, then there are small tin balls on the pads for soldering the BGA that be in the way when placing the ZV4002. That is why we decided to take a board without tin.

To avoid short circuits the vias on the top layer must be covered with solder mask. It could be helpful not to cover the bottom side of the vias with copper. This could improve soldering in the oven. Because there can be some air in the hole between top and bottom solder mask the top solder mask could be destroyed when the air is heated up during the soldering of the BGA in the oven.

For more information about the BGA please see ZV4002 Hardware Design Guide [1].

Placing of the auxiliary components
The auxiliary components like the filters for the power supply should be placed as close to the ZV4002 as possible and on the same side of the board. There should not be routed any wires under the quartz to provide interference.

There is also a 330µF tantalum capacitor on the input because of the distance to the power supply board to provide a stable voltage of 3.3V.

Routing of the wires

It is recommended to provide a full ground plane under the ZV4002. Since the Bluetooth board is designed with only a two layer PCB board to reduce costs, this recommendation was ignored. To provide a good power supply the ground and 3.3V connections are made as big as possible using planes where possible.

SRAM, FLASH

As recommended there are 100nF capacitors for bypassing the power supply inputs of the memories.

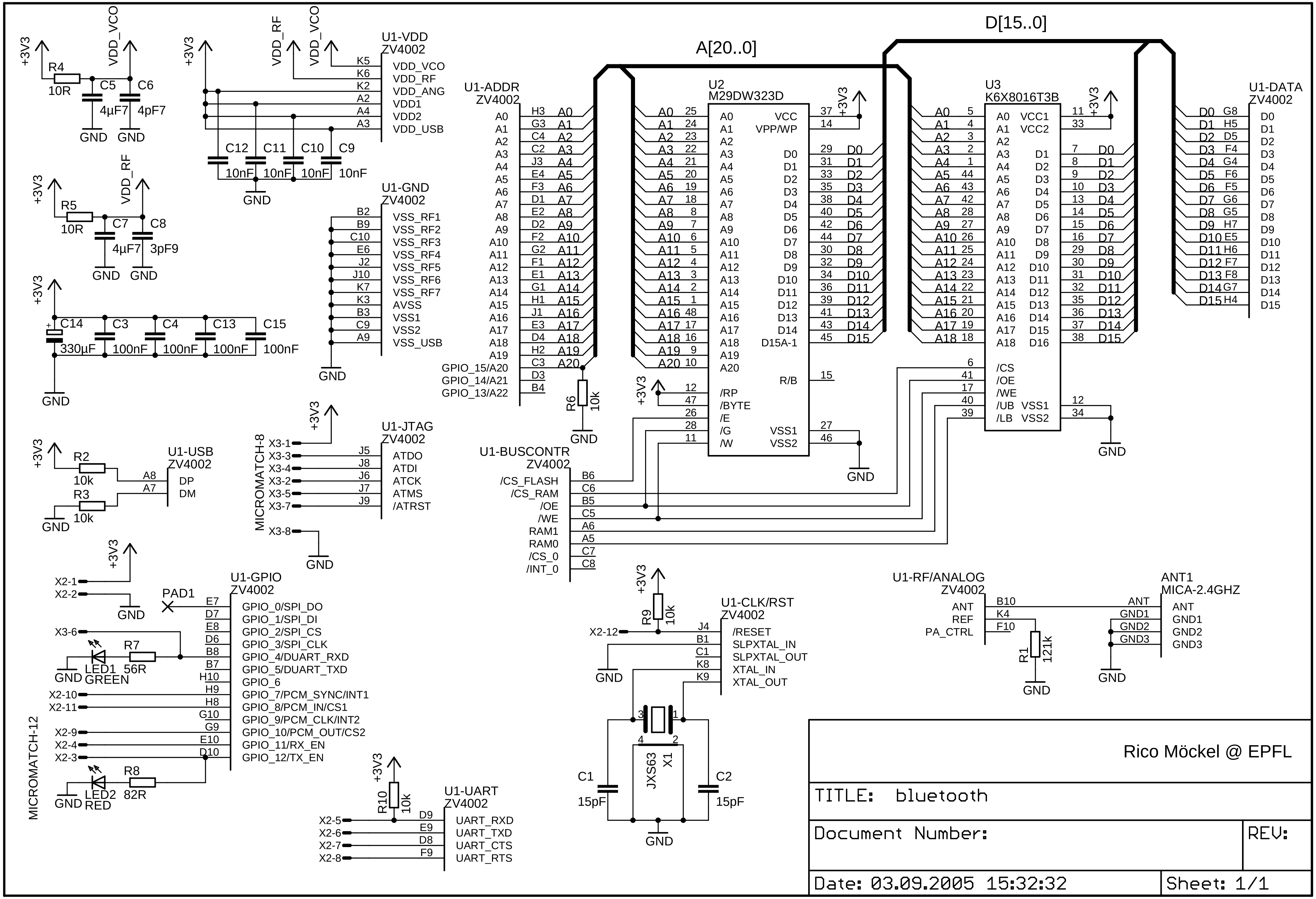
11 Manufacturing of Bluetooth Board

Attention: Sequence of soldering
Both the ZV4002 and the antenna should be soldered together in an oven before all the other components.

12 Bill of Materials

Symbol	Qty	Value	Manufacturer	Description	Package	Order Number	Price		Min pc.	Price [CHF]	Distributor
U1	1		Zeevo	Bluetooth/Microcontroller		ZV4002	20,00	EUR	10	30,69	Azzurri Technology GmbH
U3	1		Samsung	SRAM | 512k x 16bit | 3.3V | 70ns	44-TSOP2	K6X8016T3B-TF70	6,70	CHF	10	6,70	WBC GmbH
		The following Flash memory works together with the Flash tools from Zeevo									
U2	1		SST	Flash | 16Mbit (1M x 16bit) | 3.3V	TSOP48	SST39VF160-70-4C-EK	5,45	CHF	10	5,45	Reselec AG / Memec
ANT1	1		gigaAnt	Antenna | SMD | 2.4GHz		MICA-2.4GHz	9,90	EUR		15,19	
X1	1		Jauch	Quartz		Q12.0 JXS63-9-10/10	3,50	CHF	10	3,50	Dätwyler Electronics AG
		Please replace the quartz above for bigger numbers of modules through the more accurate one:									
X1	0		Jauch	Quartz		Q12.0 JXS63-9-10/7	8,10	CHF	100	???	Dätwyler Electronics AG
X2	1		Tyco	Micromatch connector | 12 pins		128486	1,20	CHF	1	1,20	Distrelec
X3	1		Tyco	Micromatch connector | 8 pins		128484	0,95	CHF	1	0,95	Distrelec
C1, C2	2	15pF	Phycomp	5% | NPO | 50V	SMD 0402 (1.0mm x 0.5mm)	3019172	0,10	CHF	10	0,20	Farnell
C6	1	4.7pF	Phycomp	5% | NPO | 50V	SMD 0402 (1.0mm x 0.5mm)	3019147	0,11	CHF	10	0,11	Farnell
C8	1	3.9pF	Phycomp	5% | NPO | 50V	SMD 0603 (1.6mm x 0.8mm)	721918	0,12	CHF	10	0,12	Farnell
C5, C7	2	4.7u	Murata	10% | X5R | 6.3V	SMD 0603 (1.6mm x 0.8mm)	823504	0,18	CHF	25	0,36	Distrelec
C9, C10, C11, C12	4	10n	Phycomp	10% | X7R | 16V	SMD 0402 (1.0mm x 0.5mm)	3019275	0,13	CHF	10	0,52	Farnell
C14	1	330u		10% | 6.3V	D (7.3mm x 4.3mm x 2.8mm)	812192	1,70	CHF	1	1,70	Distrelec
C3, C4, C13, C15	4	100n	AVX	+80/-20% | Y5V | 16V	SMD 0402 (1.0mm x 0.5mm)	316581	0,07	CHF	10	0,28	Farnell
R1	1	121k	MULTICOMP	1% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	4224863	0,05	CHF	50	0,05	Farnell
R2, R3, R6	3	10k	MEGGITT	5% | 0.063W | 50V	SMD 0402 (1.0mm x 0.5mm)	3898659	0,08	CHF	50	0,24	Farnell
R4, R5	2	10R	PHILIPS	5% | 0.063W | 50V	SMD 0402 (1.0mm x 0.5mm)	194797	0,11	CHF	50	0,22	Farnell
R7	1	56R	MULTICOMP	5% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	612339	0,05	CHF	10	0,05	Farnell
R8	1	82R	MULTICOMP	5% | 0.063W | 50V	SMD 0603 (1.6mm x 0.8mm)	612352	0,05	CHF	10	0,05	Farnell

LED1	1	Red	Agilent Technologies	LED Red	SMD 0603 (1.6mm x 0.8mm)	250161	0,35	CHF	5	0,35	Distrelec
LED2	1	Green	Agilent Technologies	LED Green	SMD 0603 (1.6mm x 0.8mm)	250164	0,35	CHF	5	0,35	Distrelec
									total:	68,28	



Rico Möckel @ EPFL

TITLE: bluetooth

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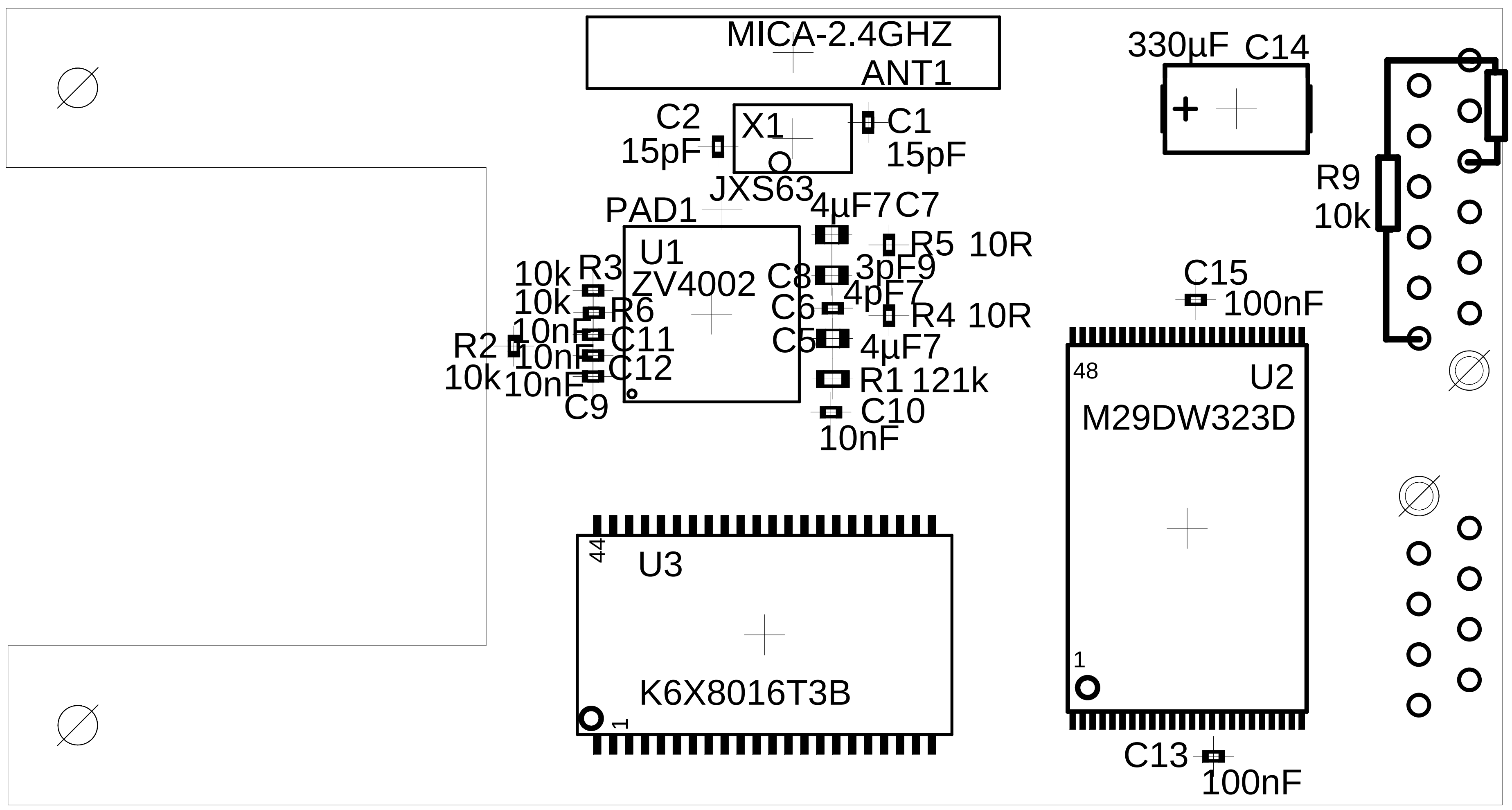
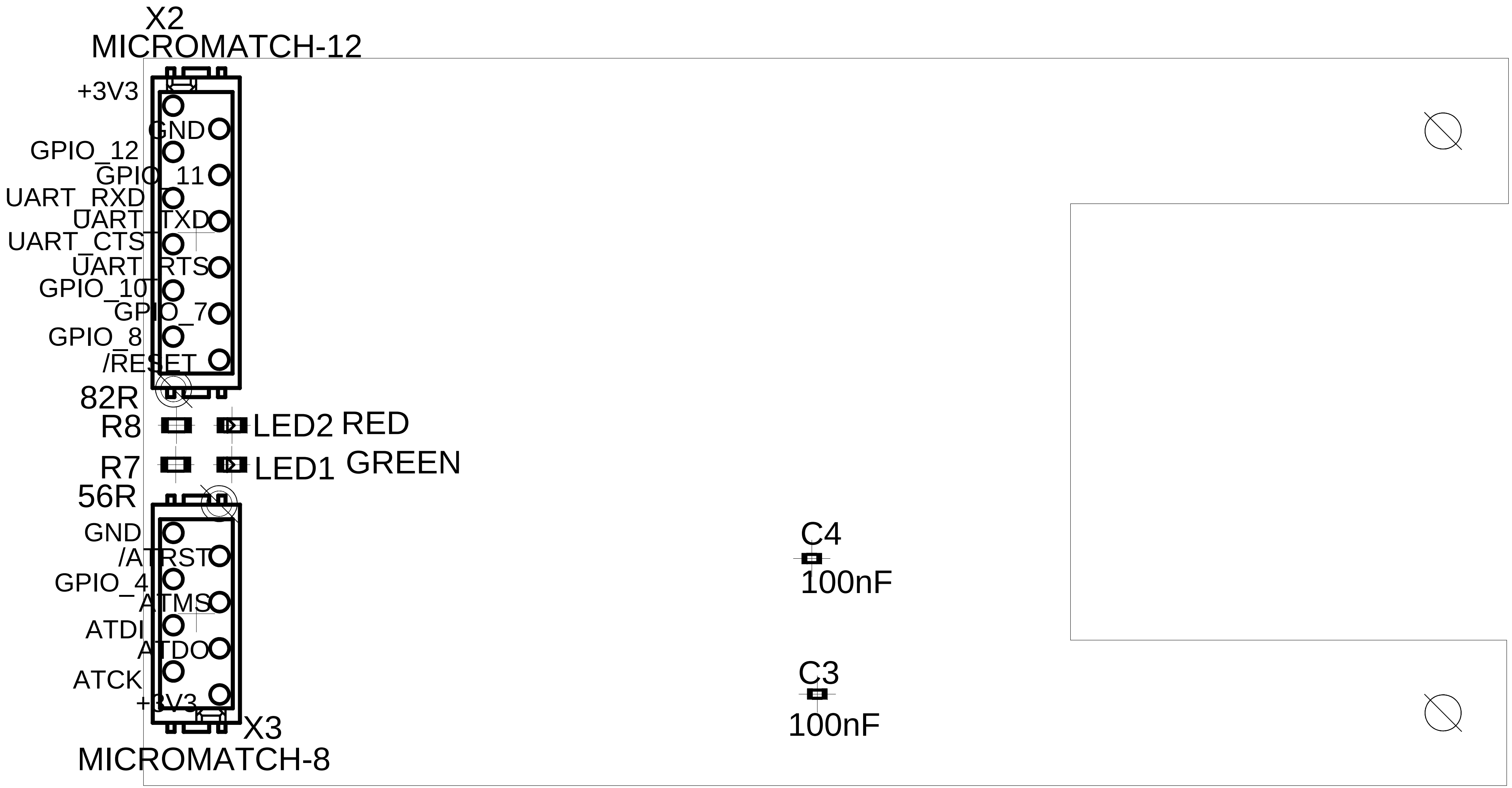
Sheet: 1/1



Attention:

Solder ZV4002 and antenna
first (oven)

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



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