Politecnico di Torino

III Facoltà di Ingegneria

Bluetooth CO sensor - Report
Electronic Systems Engineering

Master degree in Electrical Engineering

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Contents

CHAPTER 1

Specification

1.1 Purpose

The goal of the project is to design a low cost and low energy Carbon Monoxide sensor able to measure the quality of the air in an home environment. All measurements are sent to an Android application via Bluetooth communication. The device indicate when the CO concentration is too high.

1.2 Features and Ratings

The main characteristics of the device are:

- Rechargeable LiPo battery through USB connector;
- Portable device;
- Indoor sensor [0-40°C];
- Low power device;
- Low cost device;
- Device not for safety purposes;
- Double layer SMT;
- Bluetooth communication;

The shape of our PCB is similar to the CO particle.

1.3 Typical application

Our sensor is designed to work in a home environment. We discourage to use it in critical and dangerous situations. Due to the cheaper components, the CO measure cannot have high precision and reliability, but its merit is the low cost. Besides, it's a portable device, so it is easy and fast to measure the CO level in different places.

1.4 BOM and Cost Estimation

Item	Quantity	Reference	Part
1	6	C1,C5,C6,C8,C10,C11	100nF
2	1	C2	1uF
3	2	C3,C4	12pF
4	2	C7,C9	10uF
5	3	C12,C17,C18	1u
6	1	C13	10n
7	1	C14	12p
8	2	C15,C16	1.2p
9	2	C19,C21	10u
10	1	C20	330n
11	1	D1	KG_DELLS1.22-JHKI-1_red
12	1	D2	KG_DELLS1.22-JGKH-24_green
13	1	J2	B2B-PH-K-SLFSN
14	1	J3	10118193-0001LF
15	1	L1	BLM18HE152SN1D
16	1	L2	10uH
17	1	L3	2nH
18	1	L4	15nH
19	1	R1	100kohm
20	2	R2,R3	220ohm
21	2	R4,R5	33kohm
22	2	R6,R7	1kohm
23	1	S1	JS102011SAQN
24	1	U1	CC2640R2FRGZ
25	1	U2	TSK-322524_0000MF15X-AC3
26	1	U3	SC20S-7PF20PPM
27	1	U6	LMP91002SD
28	1	U7	3SP CO 1000 package 110-109
29	1	U8	Cortex Connector
30	1	U9	TI AN043
31	1	U10	MAX1555
32	1	U11	MAX1759

Table 1.1: Bill of materials

Item	Quantity	Component	Description	Costs
1	6	GRM0335C1ER10WA01D	100nF smd capacitor	€0.005*6
2	1	JMK063ABJ105KP-F	1uF smd capacitor	€0.024
3	2	06035J120FBSTR	12pF smd capacitor	€0.36*2
4	2	F381A106MMA	10uF smd capacitor	€0.16*2
5	3	JMK063ABJ105KP-F	1uF smd capacitor	€0.119*3
6	1	50MU103KY11608	10nF smd capacitor	€0.636
7	1	06035J120JBSTR	12pF smd capacitor	€0.737
8	2	06035J1R2BBSTR	1.2pF smd capacitor	€0.855*2
9	2	F381A106MMA	10uF smd capacitor	€0.16*2
10	1	JMK063BJ334MP-F	330nF smd capacitor	€0.237
11	1	KG_DELLS1.22-JHKI-1_red	red LED	€0.322
12	1	KG DELLS1.22-JGKH-24	green LED	€0.424
13	1	B2B-PH-K-SLFSN	connector header through hole	€0.17
14	1	10118193-0001LF	micro B USB 2.0	€0.48
15	1	BLM18HE152SN1D	ferrite bead 1.5 kohm	€0.19
16	1	LQM18FN100M00D	10uH smd inductor	€0.109
17	1	0603CT-2N0XJLW	2nH smd inductor	€0.922
18	1	LQW18AS15NG0ZD	15nH smd inductor	€0.203
19	1	WK73R1JTTD104J	100 kOhm smd resistor	€0.019
20	2	CR0603-10W-2200FT	220 Ohm smd resistor	€0.00177*2
21	2	CR0603-10W-333JT	33 kOhm smd resistor	€0.00147*2
22	2	CR0603-16W-1001FT	1 kOhm smd resistor	€0.00177*2
23	1	JS102011SAQN	Switch Slide	€0.63
24	1	CC2640R2FRGZT	Microcontroller RF	€4.30
25	1	TSK-322524_0000MF15X-AC3	Oscillator	€0.33
26	1	SC20S-7PF20PPM	CRYSTAL 32.7680KHZ 7PF SMD	€0.68
27	1	LMP91002SD	AFE system	€3.68
28	1	3SP CO 1000 package 110-109	CO sensor	€20.00
29	1	Molex 1051640001	USB 2.0 connector	€0.378
31	1	MAX1555EZK+T	charge controller	€1.86
32	1	MAX1759EUB+T	Buck/Boost regulating charge pump	€4.91
total				€41.36

Table 1.2: Cost Estimation

1.5 Board costs and class

From Eurocircuit web page one gets that the cost of the prototype PCB is 39.67€ and the class is 6C.

1.6 Power estimation

we assume this equivalent circuit:

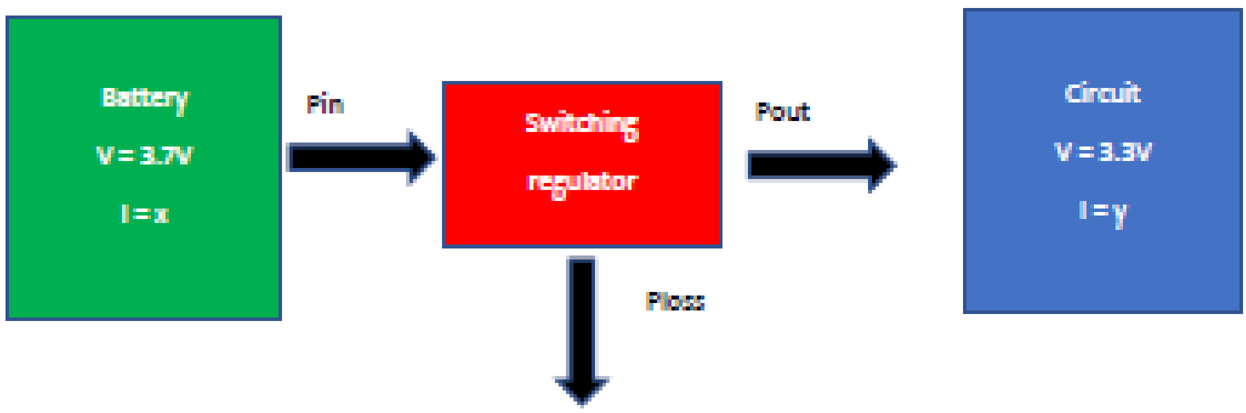


Figure 1.1: Equivalent circuit

We assume η the efficiency of the switching regulator. In our case is 90%. The capacity of our battery is 150mAh. Here we estimate the duration of our battery.
Vin = 3.7V; Iin = x; Vout = 3.3V; Iout = 100mA;

$$\begin{cases} Pout = Pin * \eta \\ Pout = Vout * Iout \\ Pin = Vin * Iin = Vin * x \end{cases}$$

Solving the system, we obtain **Iin = 8.92mA**. So considering the capacity of our battery we obtain a duration of: **16 Hours.**

The battery is recharged through the USB port.

1.7 Android App

The italian health ministry indicates that the maximum limit of CO concentration should be 60 mg/m^3 (52 ppm) for a home environment. Our device sends, via Bluetooth, every second the measure of the CO concentration. If the measured level exceeds for 20 consecutive times the maximum limit, a notification on the smartphone will appear and a red LED on the board will light up. It's an alert that indicates a dangerous gas concentration in the environment. The app is compatible with all android smartphones and its user interface is minimal and simply to use. At the center of the screen the app will report the average value of the gas concentration in ppm and mg/m^3. The color of the value will be green, yellow, orange or red based on the concentration of CO. If the gas concentration is near to its allowed maximum (60 mg/m^3) a notification appears on the smartphone, if the value is greater than 60 mg/m^3 then the smartphone's alarm will be turned on (deactivating eventually the android's system "do not disturb" mode).

1.8 GANTT

In the following a gantt table is reported that illustrates the project scheduling:

Step	Activity	Start	End
1	Choosing of component	20-11-2020	05-12-2020
2	Schematic of the circuit	06-12-2020	10-12-2020
3	Component's footprint realization	11-12-2020	22-12-2020
4	PCB design	23-12-2020	08-01-2021
5	Video realization	09-01-2021	09-01-2021
6	Report	10-01-2021	14-01-2021

Table 1.3: GANTT

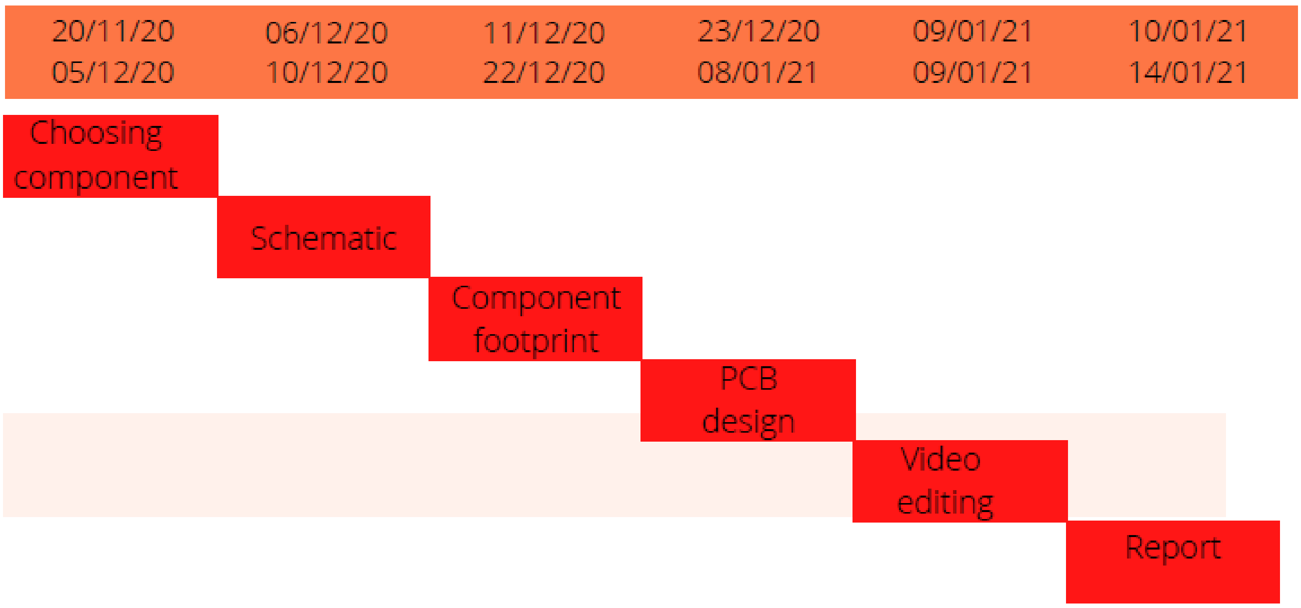


Figure 1.2: Gantt chart

CHAPTER 2

Design flow

2.1 Completed steps

Until now we have performed these steps:

- Project specification;
- Choose of components;
- Component footprints;
- Design schematics in OrCad CAPTURE CIS;
- Design PCB in OrCad PCB Editor
- Report

2.2 Future steps

The next future steps to complete the project are:

- PCB realization;
- Firmware development;
- Soldering compononent on bare board;
- Testing device;
- Android App;

CHAPTER 3

Block diagram

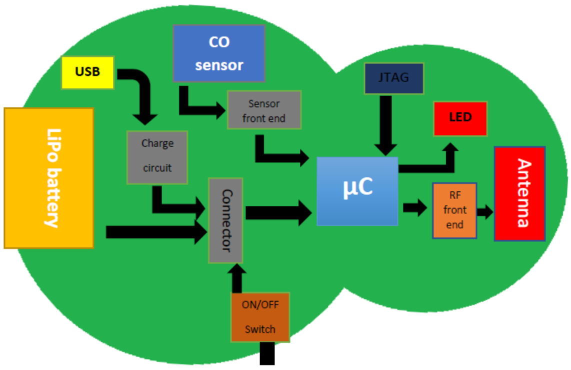


Figure 3.1: Block diagram CO sensor

3.1 shows the block diagram of our project. The shape of the board is similar to the CO particle. The bigger circle refers to the carbon particle, while the smaller circle refers to the oxygen one. In particular the system consists in:

- **Lipo battery:** the power source of the whole system. It's a rechargeable LiPo battery.
- **USB:** usb port to connect an external power supply to recharge the battery.
- **Charge circuit:** MAXIM1555 manage the recharge of the battery.
- **ON/OFF switch:** mechanical switch to turn on and off the circuit.
- **CO sensor:** measures the level of CO in the air.
- **Sensor front-end:** configurable interfaces the CO sensor and the microController.
- **MicroController:** microcontroller, external quartz and passive components.
- **Antenna:** patch antenna to comunicate the CO measurements.
- **LEDs:** to indicate the status of the device.
- **JTAG:** it is used to program the microController.

CHAPTER 4

Choose of components

4.1 CO sensor

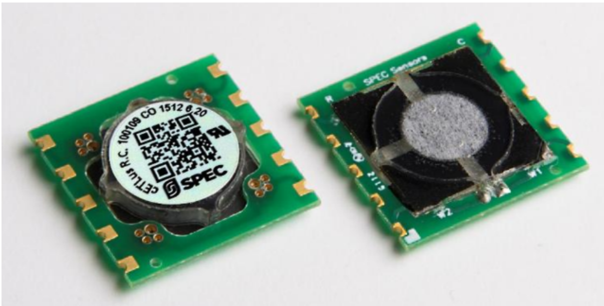
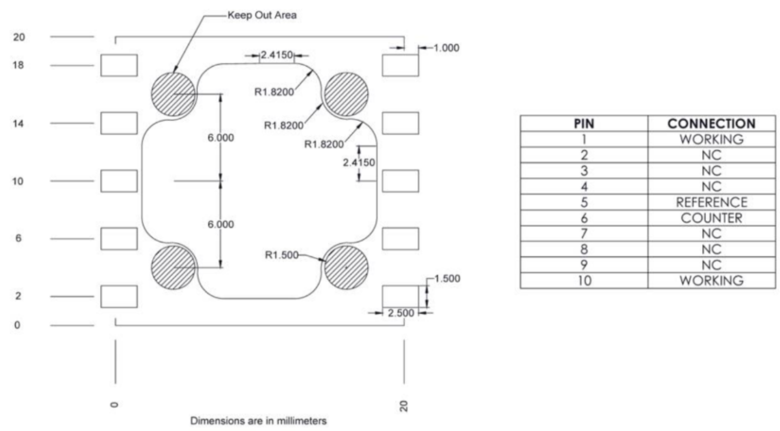


Figure 4.1: CO sensor

We select the **3SP CO 1000 Package 110-109** of SPEC sensor company.
Main features:

- Dimension 20x20x3.8 mm.
- More then 10 years expected life.
- Fast response (15 seconds).
- Resolution: 15ppb.
- Individually calibrated.
- Sensitivity: 4.75 +/- 2.75nA/ppm.
- Operating temperature range: -30 to 55 °C.
- Power Consumption: 10 to 50 uW

PCB guidelines:



PIN	CONNECTION
1	WORKING
2	NC
3	NC
4	NC
5	REFERENCE
6	COUNTER
7	NC
8	NC
9	NC
10	WORKING

Figure 4.2: PCB CO sensor

4.2 CO front-end

The electrochemical gas sensor generates a current proportional to the volumetric fraction of carbon monoxide in the air. The sensor cannot be directly connected with the microcontroller, it needs an hardware interface. To interface the CO sensor with the microcontroller we choose the **LMP91002SD** analog front-end device, that has inside an amplifier programmable through an I2C interface from the microcontroller.

Main features:

- Package 14 pin LLP.
- I2C compatible digital interface.
- Supply voltage: 2.7 to 3.6V.
- Supply current(average over time): 10uA.
- Cell conditioning current up to 10 mA.
- Output drive current: 750 uA.

A typical application of this component is:

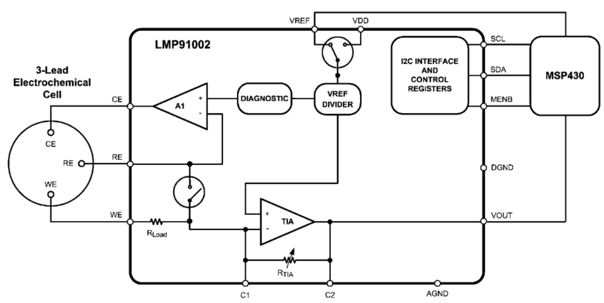


Figure 4.3: CO front-end

4.3 MicroController

Microcontroller **CC2640R2F RGZ VQFN48**.

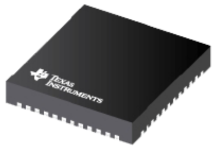


Figure 4.4: Microcontroller

Powerful ARM R Cortex R - M3; Main features:

- Up to 48-MHz Clock speed.
- 2-pin cJTAG and JTAG Debugging.
- 16 bit Architecture.
- Dimensions: 7x7mm.
- I2C protocol available.
- Low Power device.
- Voltage supply: 1.8 V to 3.8 V.
- 4 general purpose timer modules;
- 12 bit ADC.
- 2.4 GHz RF transceiver compatible with Bluetooth low energy.

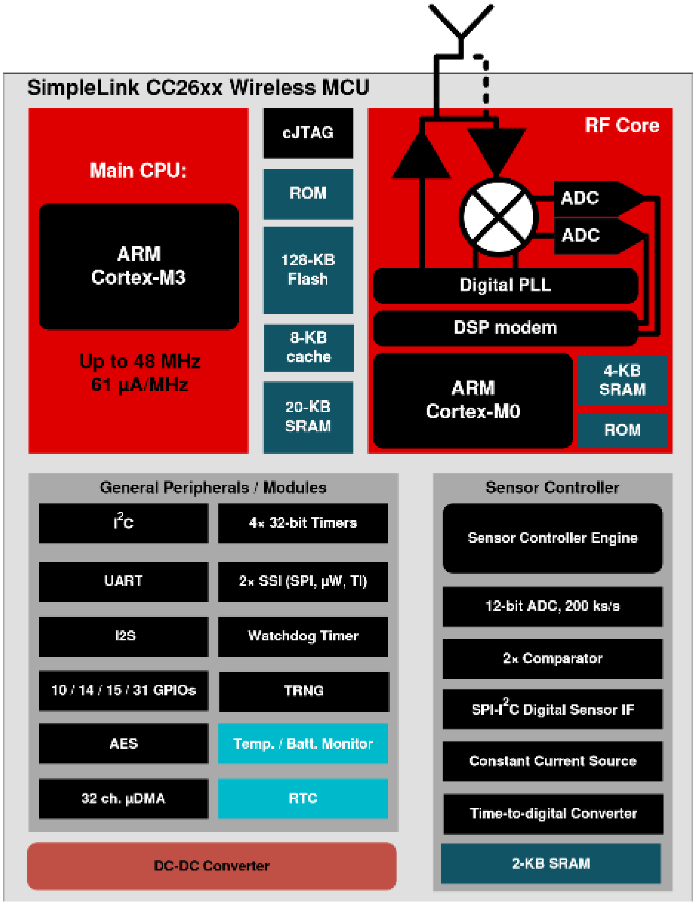
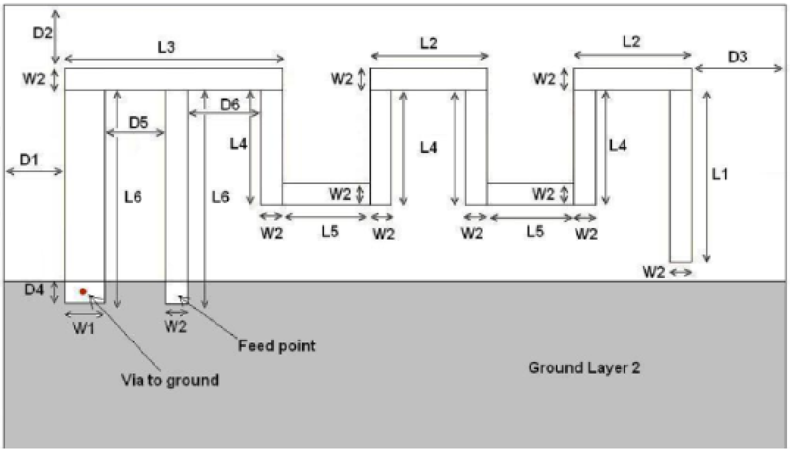


Figure 4.5: Microcontroller block diagram

4.4 Antenna

We select the **AN043** patch antenna. Its design requires no more than 15.2x5.7 mm of space and ensures good performance at 2.4GHz, when connected to a 50 ohm source.



L1	3.94 mm
L2	2.70 mm
L3	5.00 mm
L4	2.64 mm
L5	2.00 mm
L6	4.90 mm
W1	0.90 mm
W2	0.50 mm
D1	0.50 mm
D2	0.30 mm
D3	0.30 mm
D4	0.50 mm
D5	1.40mm
D6	1.70 mm

Figure 4.6: Antenna

4.5 Battery

The LiPo rechargeable battery used in this project is the **LP-402025** of PKCELL company. Main features:

- Capacity: 150mAh.
- Nominal voltage: 3.7V.
- Charging voltage: 4.2V.
- Cycle life: 300 cycles.

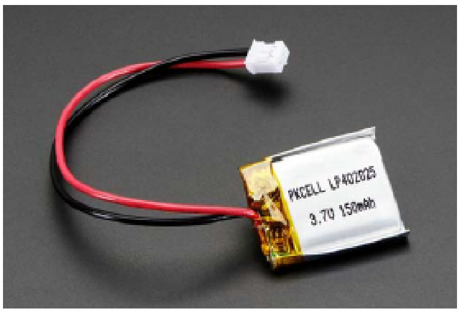


Figure 4.7: Battery

4.6 Battery connector

To connect the battery to the board we choose a JST connector. In particular the **B2B-PH-K-S-LF-SN** from PH connector company.

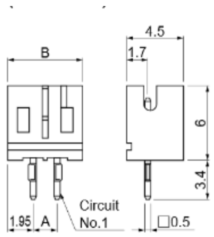


Figure 4.8: Battery connector

4.7 USB

For the USB port we choose the **sd-105164-001** from Molex.

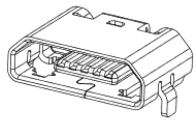


Figure 4.9: USB connector

4.8 Charge controller

The charge controller interface the USB and the battery. We select the **MAXIM1555EZK-T**. We take the input from the USB port and for the output we consider the BAT pin. We connect the CHG pin to the input through a LED, so when the USB is attached the CHG is low and the led is ON. Main features:

- DC Voltage Range: 3.7 up to 7V.
- DC Supply current: 3mA.
- BAT regulation Voltage: 4.141V.
- BAT Supply current: 3mA.
- USB Voltage Range: 3.7 up to 6V.
- USB Supply current: 3mA.
- CHG threshold: 25mA

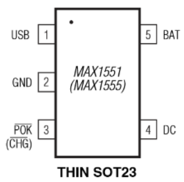


Figure 4.10: MAX1555

4.9 Voltage regulator

We need a voltage regulator to transform the 5 V from battery to 3.3V. So we choose a Buck/Boost regulating charge pump, in particular the **MAXIM1759EUB**. Main features:

- Input Voltage range: 1.6 to 5.5V.
- Output voltage: 3.17 to 3.43V.
- Maximun Output current: 100mA.
- Temperature range 0 to +85°C.

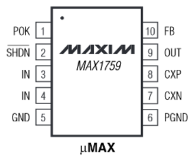


Figure 4.11: MAX1759

4.10 Mechanical switch

To turn ON and OFF our system we select the **JS102011SAQN** of CK company.

Figure 4.12: Switch

4.11 LEDs

4.11.1 Battery LED

The green LED indicates that the circuit is working. When the battery is discharged, the voltage decrease down to a certain threshold and the LED switches OFF. We select the **KG DELLS1.22-JGKH-24** from OSROM.

4.11.2 USB LED

When battery is charging through the USB port (using an external supply), the red LED turns ON. We select the **KS DELLS1.22-JHKI-1** from OSROM.

4.12 Other components

4.12.1 Oscillator

For generating the 12MHz clock we select **TSX-3225 24.0000MF15X-AC6** from EPSON.

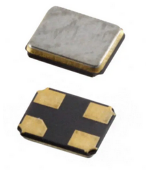


Figure 4.13: 12Mhz clock

For generating 32,7kHz clock we select **SC20S-7PF20PPM** from Seiko.

Figure 4.14: 32.7kHz clock

4.12.2 Resistors

We have used resistors of 220, 1k, 33k and 100k Ohm from KOA speer electronics and Venkel.

4.12.3 Inductors

For the inductances, we have chosen the **LQM18FN100M00D**, **0603CT-2N0XJLW** and **LQW18AS15NG0ZD**.

4.12.4 Capacitors

We have selected bypass capacitor from Rubycon, Taiyo Yuden and AVX companies.

CHAPTER 5

Schematic

- **CO Sensor**

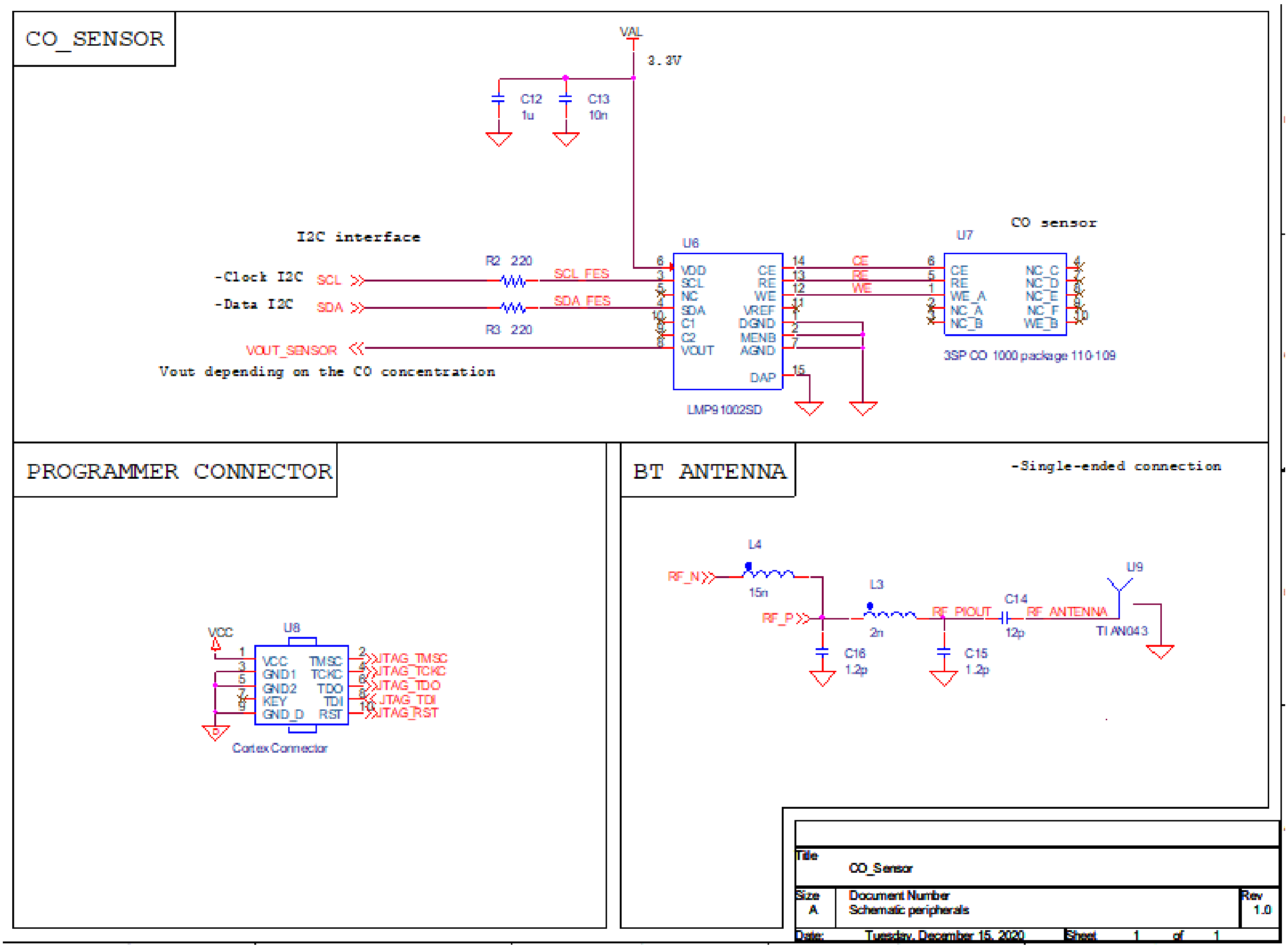


Figure 5.1: CO sensor schematic

- **MicroController**

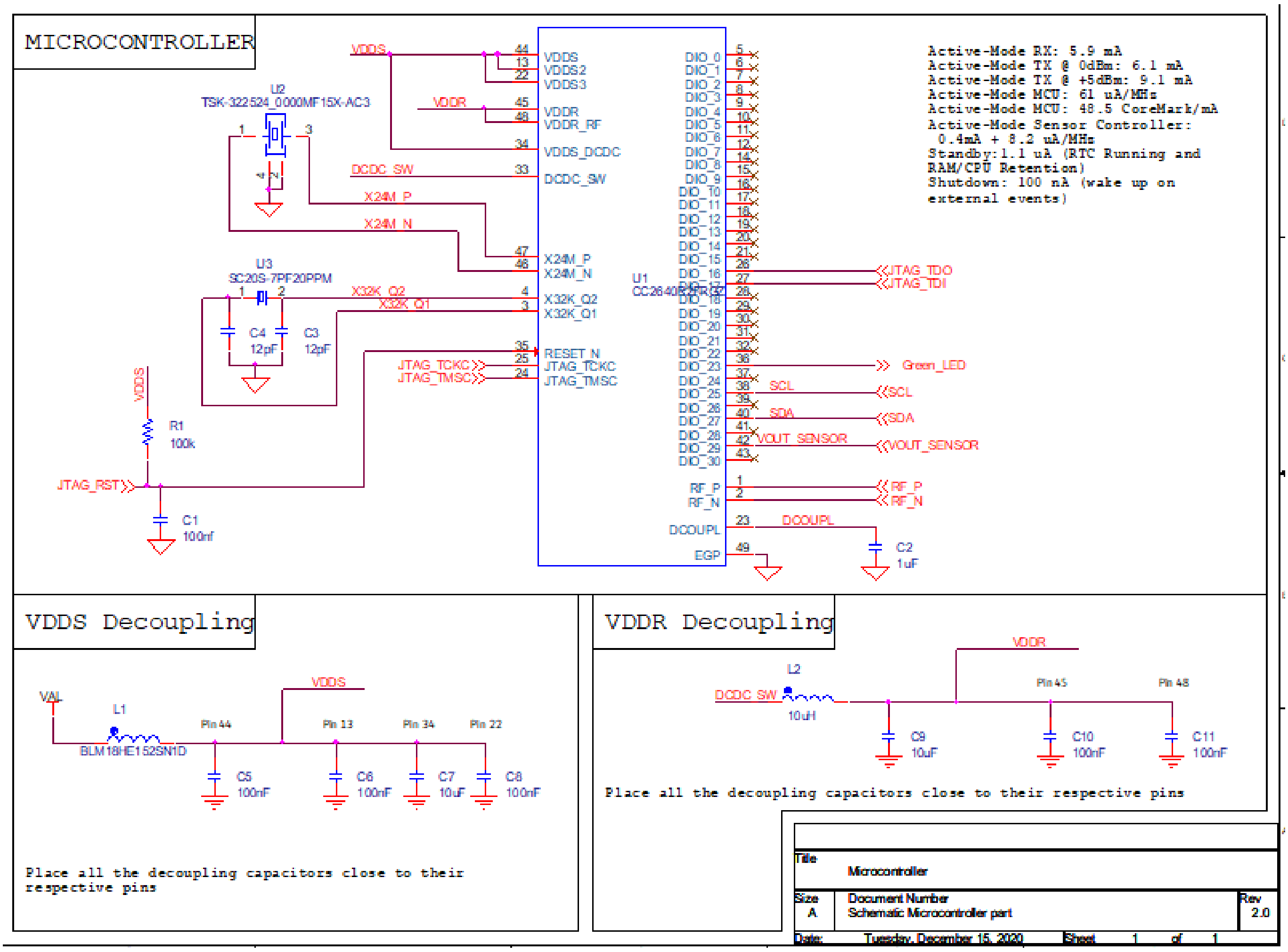


Figure 5.2: Microcontroller schematic

- **Power management**

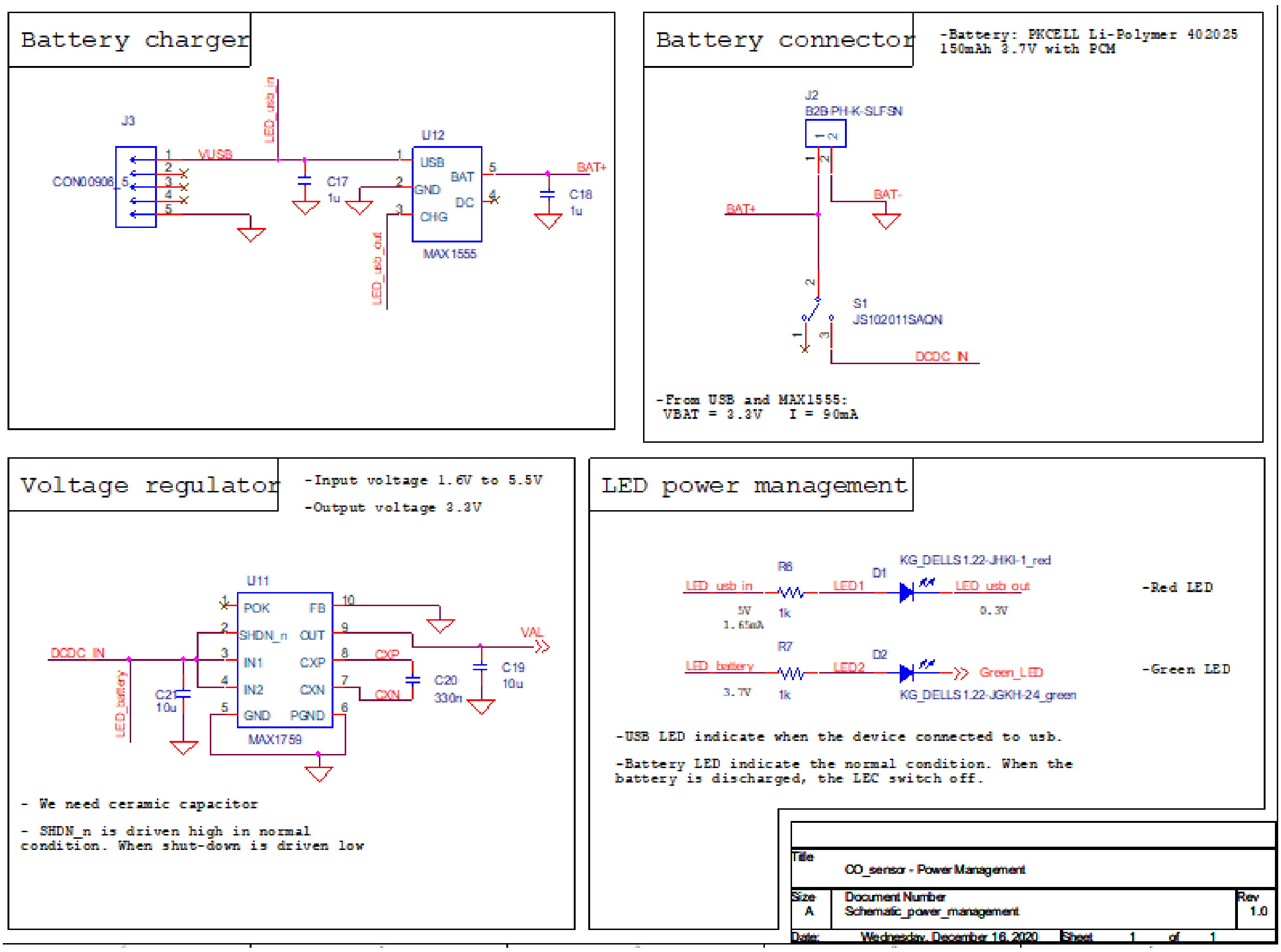


Figure 5.3: Power management schematic

To evaluate R6 of red LED. Vled=2.2V Iled=2mA. The minimum voltage from the USB is supposed to be 4.45V. Besides the CHG input port is at 0.3V.

$$R6 = \frac{4.45 - 2.2 - 0.3}{2 * 10^{-3}} = 1000\Omega$$

To evaluate R7 of green LED. Vled=2.1 Iled=2mA

$$R6 = \frac{3.7 - 2.2}{2 * 10^{-3}} = 750\Omega$$

We consider

$$1000\Omega$$

because we are sure that the current that flow in the diode is lower.

CHAPTER 6

Printed Circuit Board layout

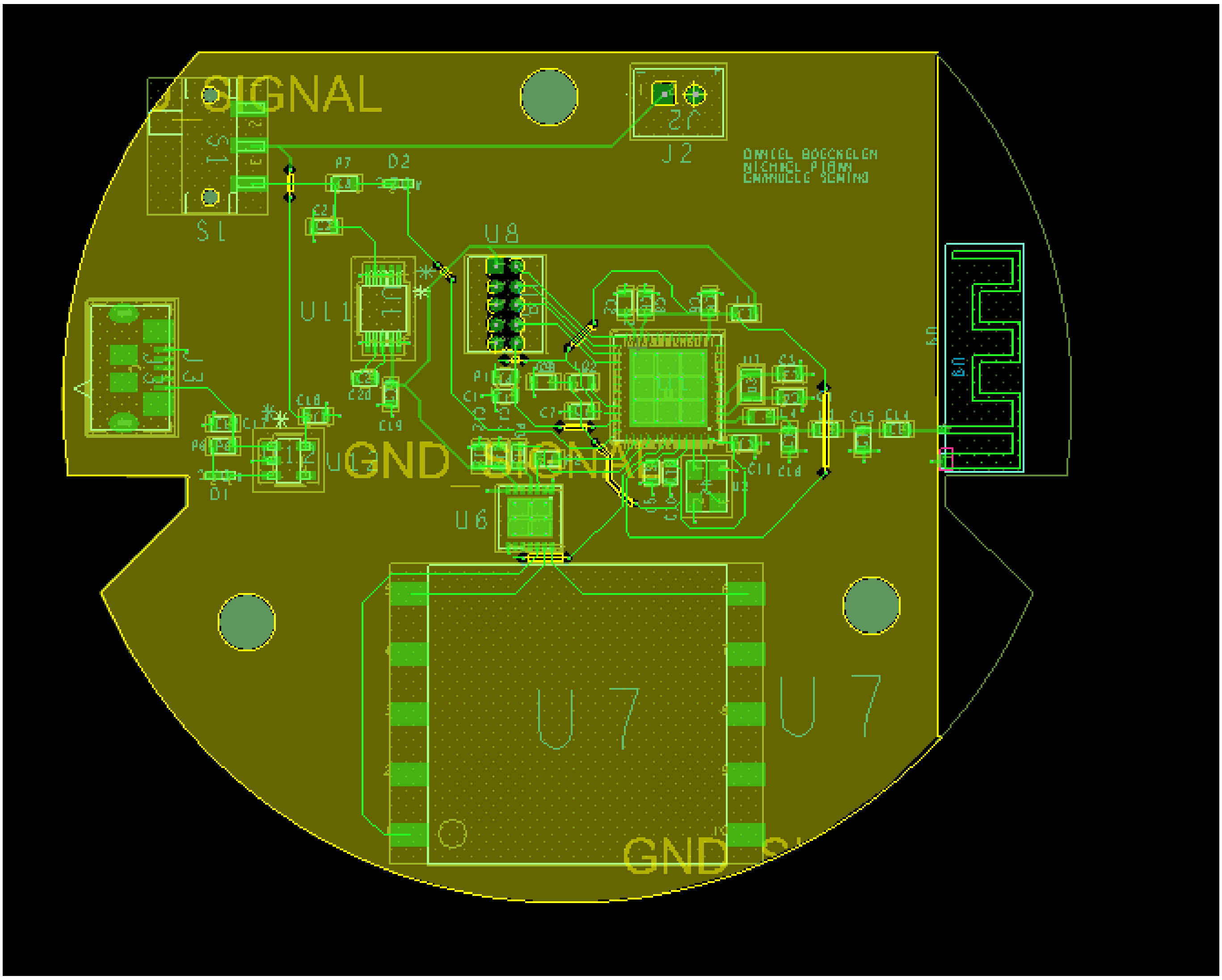


Figure 6.1: PCB of out system

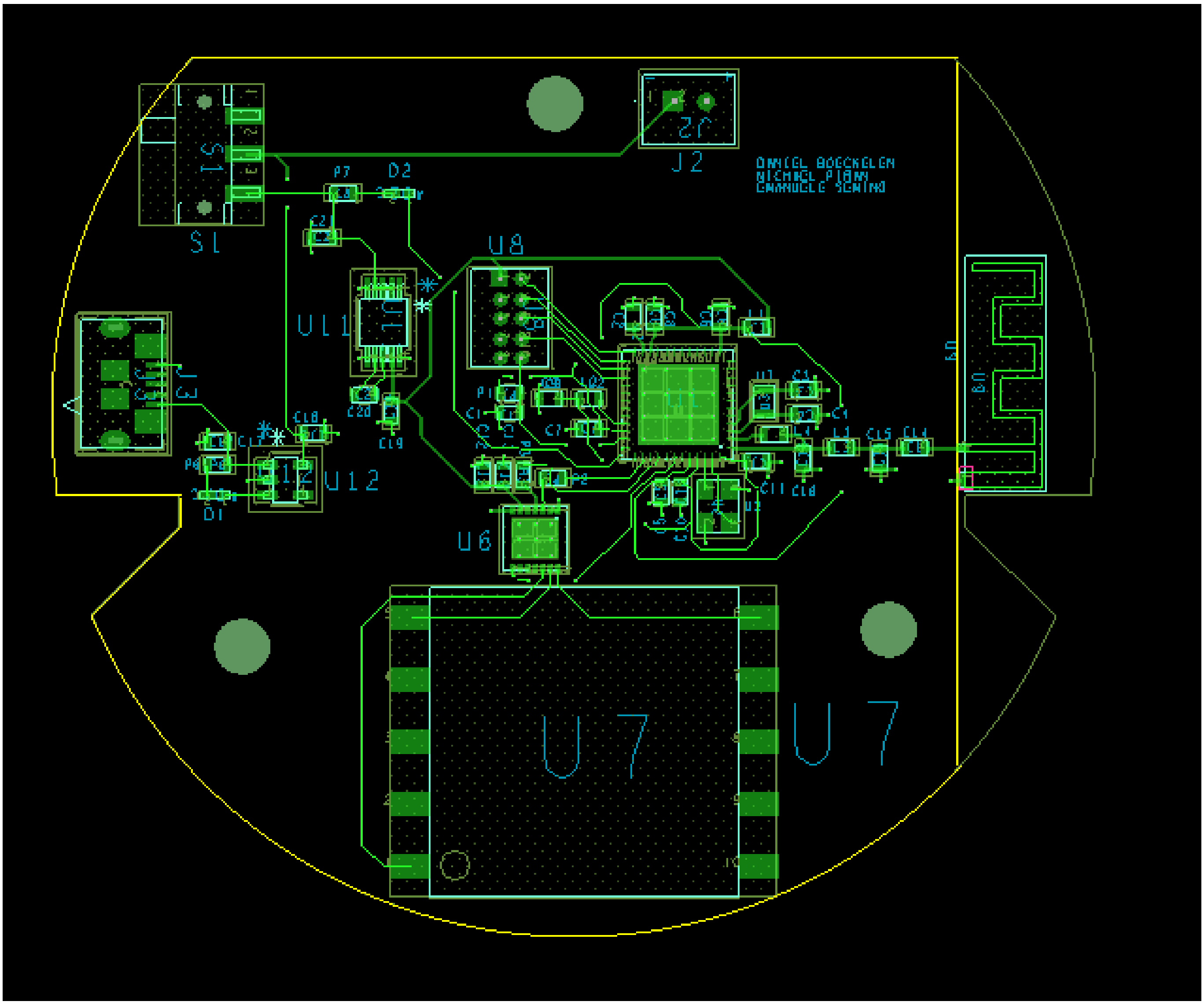


Figure 6.2: PCB of out system without ground plane

CHAPTER 7

References, Acknowledgements, and Intellectual Property

- REPORT_OTW_ESE.pdf
- 2019_MOTTA_S251312_ESE_presentation_Dongiovanni_Motta.pdf
- https://www.teesing.com/en/page/library/tools/ppm-mg3-converter
- http://www.salute.gov.it/imgs/C_17_opuscoliPoster_283_ulterioriallegati_ulterioreallegato_2_alleg.pdf

7.1 Datasheet links

- CO sensor : https://www.spec-sensors.com/wp-content/uploads/2016/04/3SP_CO_1000-C-Package-110-109.pdf
- CO front-end : https://www.ti.com/store/ti/en/p/product/?p=LMP91002SD/NOPB
- MicroController : https://www.ti.com/product/CC2640R2F
- Antenna : https://www.ti.com/lit/an/swra117d/swra117d.pdf
- Battery : https://cdn-shop.adafruit.com/product-files/1317/C1515_-_Li-Polymer_402025_150mAh_3.7V_with_PCM.pdf
- Battery connector : https://www.digikey.it/product-detail/it/jst-sales-america-inc/B2B-PH-K-S-LF-SN/455-1704-ND/926611
- USB connector : https://www.molex.com/pdm_docs/sd/1051640001_sd.pdf
- Charge controller : https://www.maximintegrated.com/en/products/power/battery-management MAX1555.html
- Voltage regulator : https://www.maximintegrated.com/en/products/power/charge-pumps/MAX1759.html
- Mechanical switch : https://www.digikey.it/product-detail/it/c-k/JS102011SAQN/401-1999-2-ND/1640095

- LEDs: https://dammedia.osram.info/media/resource/hires/osram-dam-5423212/KG%20DELLS1.22_EN.pdf

CHAPTER 8

History of the project

Here we have reported a short description of the main steps of the project.

8.1 Choice of components

Regarding the **CO sensor** we have found three different devices:

1. SGX-4CO-LC from Amphenol `https://www.mouser.it/datasheet/2/18/DS-0320-SGX-4CO-LC-datas pdf`
2. MiCS-4514 from Amphenol `https://www.mouser.it/datasheet/2/18/0278_Datasheet-MiCS-4514-r pdf`
3. 3SP_CO_1000 Package 110-109 from SPEC sensors `http://www.spec-sensors.com/wp-content/uploads/2016/04/3SP_CO_1000-C-Package-110-109.pdf`

We discard the first device because of its cost, that is really high with respect to the other two devices. The second device is cheap but too small, therefor the soldering would be really hard. It detects also NO2 and for our application is useless. So we consider the third device because it is cheap, easy to solder, robust and low power. The drawback is the size: a square of 2x2 cm. The sensor has an analog output that generates a current proportional to the volumetric fraction of the gas. So we use the **CO front-end** to interface the signal with the microcontroller.

8.2 Padstack creation

During the creation of the Padstacks it has been decided to make the soldermask 0.05mm larger than the pads to overcome tolerance problems, moreover the pastemask layer 0.05 mm smaller. The filmask layer has been set like the soldermask. These assumptions were used only for customizing padstacks and footprints, because the manufacturer provides almost all the files for the components. So, after a preliminary check, we have cut and pasted it in our design.

8.3 PCB footprint

We have created custom vias, because the standard ones of Allegro were too big. **The diameter of the via is 0.3mm, while the soldermask is 0.6mm**. For the traces we have used these sizes: **0.25mm for power and critical signals and 0.127mm for the others**.