Politecnico di Torino

Electronic systems engineering

DATAHSS
Advanced Project Report

Master degree in Electronics Engineering

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January 29, 2018

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CHAPTER 1

Introduction

DATAHSS (Digital Ambient Temperature And Humidity Smart Sensor) is a project capable to monitor indoor air quality.

1.1 Specifications

In order to accomplish this aim the project takes advantages of several sensors from different manufacturers.
The sensor can measure:

- Temperature and Humidity;
- Particulate matter (1μm and 10 μm) levels ;
- Carbon Dioxide concentration;
- Carbon Monoxide concentration;

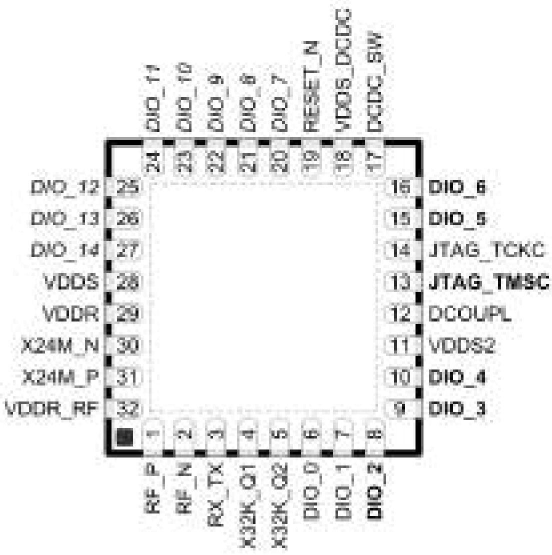
Moreover, the project has a battery with micro-USB fast charge, and an embedded Bluetooth module.

CHAPTER 2

Components Selection

2.1 Microcontroller

For this project, the Bluetooth communication was one of the mandatory requirements, for this reason we opted for the CC2650 family. This kind of microcontroller has an embedded bluetooth module, which just requires an external antenna. In particular, the most suitable for this project is the CC2650 32-pin with RHB package.



This model was preferred to the RSM one because of the larger number of generic GPIOs, which is needed in this design project.
Another important feature is the internal DC-DC regulator capable to take an external voltage in the range 1.8 - 3.8 V and adjust it to a suitable level for the chip supply.

NAME	NO.	TYPE	DESCRIPTION
DCDC_SW	17	Power	Output from internal DC-DC[1]
DCOUPL	12	Power	1.27-V regulated digital-supply decoupling[2]
DIO_0	6	Digital I/O	GPIO, Sensor Controller
DIO_1	7	Digital I/O	GPIO, Sensor Controller
DIO_2	8	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_3	9	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_4	10	Digital I/O	GPIO, Sensor Controller, high-drive capability
DIO_5	15	Digital I/O	GPIO, High drive capability, JTAG_TDO
DIO_6	16	Digital I/O	GPIO, High drive capability, JTAG_TDI
DIO_7	20	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_8	21	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_9	22	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_10	23	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_11	24	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_12	25	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_13	26	Digital/Analog I/O	GPIO, Sensor Controller, Analog
DIO_14	27	Digital/Analog I/O	GPIO, Sensor Controller, Analog
JTAG_TMSC	13	Digital I/O	JTAG TMSC, high-drive capability
JTAG_TCKC	14	Digital I/O	JTAG TCKC
RESET_N	19	Digital input	Reset, active-low. No internal pullup.
RF_N	2	RF I/O	Negative RF input signal to LNA during RX Negative RF output signal to PA during TX
RF_P	1	RF I/O	Positive RF input signal to LNA during RX Positive RF output signal to PA during TX
RX_TX	3	RF I/O	Optional bias pin for the RF LNA
VDDR	29	Power	1.7-V to 1.95-V supply, typically connect to output of internal DC-DC[3][2]
VDDR_RF	32	Power	1.7-V to 1.95-V supply, typically connect to output of internal DC-DC[2][4]
VDDS	28	Power	1.8-V to 3.8-V main chip supply[1]
VDDS2	11	Power	1.8-V to 3.8-V GPIO supply[1]
VDDS_DCDC	18	Power	1.8-V to 3.8-V DC-DC supply
X32K_Q1	4	Analog I/O	32-kHz crystal oscillator pin 1
X32K_Q2	5	Analog I/O	32-kHz crystal oscillator pin 2
X24M_N	30	Analog I/O	24-MHz crystal oscillator pin 1
X24M_P	31	Analog I/O	24-MHz crystal oscillator pin 2
EGP		Power	Ground – Exposed Ground Pad

2.2 Sensors

2.2.1 Temperature and Humidity

The final choice was the HTS221 from STM. It is an ultra-compact sensor for relative humidity and temperature. It includes a sensing element and a mixed signal ASIC to provide the measurement information through digital serial interfaces.
The sensing element consists of a polymer dielectric planar capacitor structure capable of detecting relative humidity variations and is manufactured using a dedicated ST process.
The HTS221 is available in a small top-holed cap land grid array (HLGA) package guaranteed to operate over a temperature range from -40°C to +120°C.

Features

- 0 to 100% relative humidity range
- Supply voltage: 1.7 to 3.6 V
- Low power consumption: 2 μA @ 1 Hz ODR
- Selectable ODR from 1 Hz to 12.5 Hz
- High rH sensitivity: 0.004% RH/LSB
- Humidity accuracy: ± 3.5% RH, 20 to +80% RH
- Temperature accuracy: ± 0.5°C,15 to +40°C
- Embedded 16-bit ADC
- 16-bit humidity and temperature output data
- SPI and I^2C interfaces
- Factory calibrated
- Tiny 2 x 2 x 0.9 mm package

Electrical Connection

For the electrical connection is sufficient to put a decoupling capacitor close to the Vdd pin.

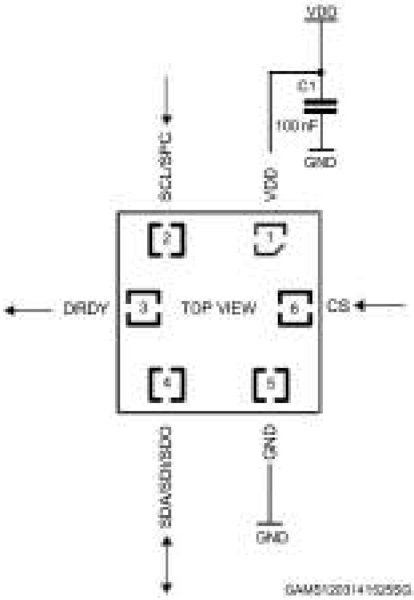


Figure 2.1: Electrical connection

2.2.2 Carbon monoxide

The CCS811 is an ultra-low power digital gas sensor solution which integrates a metal oxide (MOX) gas sensor for monitoring indoor air quality (IAQ), including a wide range of Volatile Organic Compounds (VOC), a microcontroller unit (MCU), an Analog-to-Digital converter (ADC), and an I^2C interface.

Features

- Integrated MCU
- On-board processing
- Standard digital interface
- Optimized low-power modes
- 2.7 x 4.0mm LGA package
- Interface Digital CO2 eq, TVOC eq, Rs
- Supply voltage 1.8 to 3.6 V
- Power consumption 1.2 to 46 mW
- Dimension [mm] 2.7 x 4.0 x 1.1 LGA
- Ambient temperature range -5°C to 50°C
- Ambient humidity range 10%RH to 95%RH

Electrical Connection

The suggested connection is shown in figure 2.2. It requires a decoupling capacitor and several pull-up resistors.

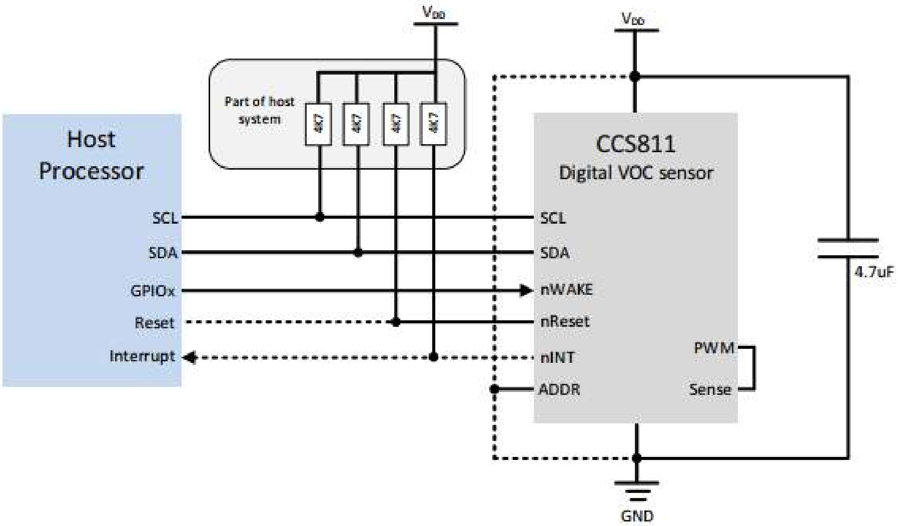


Figure 2.2: Electrical connection

2.2.3 Carbon dioxide

Amphenol's TelAire T6713 2,000ppm Miniature CO2 Sensor combines proven NDIR technology with small size and low power requirements. It is ideal for applications where CO2 levels need to be measured and controlled for indoor air quality and energy saving applications such as demand control ventilation.

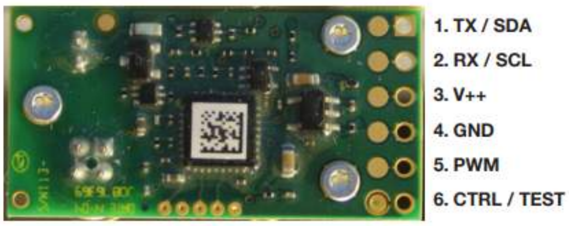
The T6713 continuously monitors the environment and records the lowest values, then uses automatic background calibration (ABC) logic to offset the sensors stored calibration. This means the sensor is best used in applications where the environment periodically drops to ambient (∼400ppm) CO2 levels.

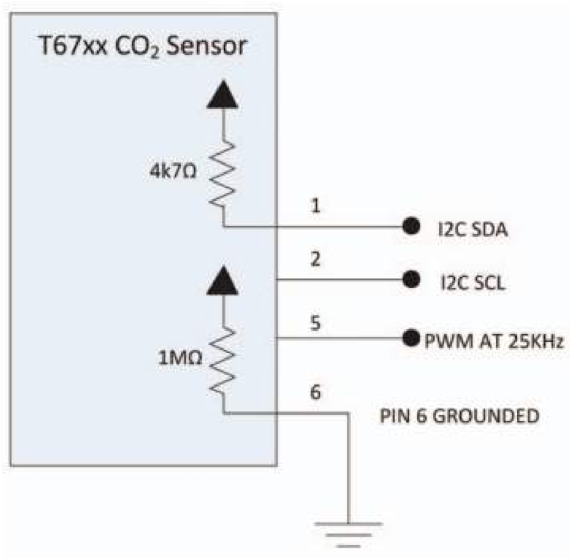
Features

- Measurement Range: 0-2,000ppm CO2
- Accuracy: ± 30ppm ± 3% of reading
- Calibration Interval: Not Required
- Response Time: < 3 minutes for 90% step change
- Signal Update: Every 5 seconds
- Warm Up Time: < 2 minutes to operation
- Warm Up Time: 10 minutes to max accuracy
- Digital Output: I2C, UART via Modbus
- PWM Output: Cycle period 1002ms (∼ 1Hz) or 40μs (25kHz)
- Altitude compensation can be added if altitude is known
- Dimensions: 1.08 x 0.787 x 0.34 in (30 x 15.6 x 8.6 mm)
- Power Input: 4.5-5.5 VDC
- Current Consumption: 200mA peak, 25mA average

Electrical Connection

This sensor is different respect to the others. It is not an integrated circuit: it is already a little PCB. This means that there is no requirement to put a bypass capacitor. The same holds for the pull-up resistors, which are already embedded in the board. Since it is a two side PCB a particular attention must be taken in order to not short anything while placing the component.





2.2.4 Particulate Matter

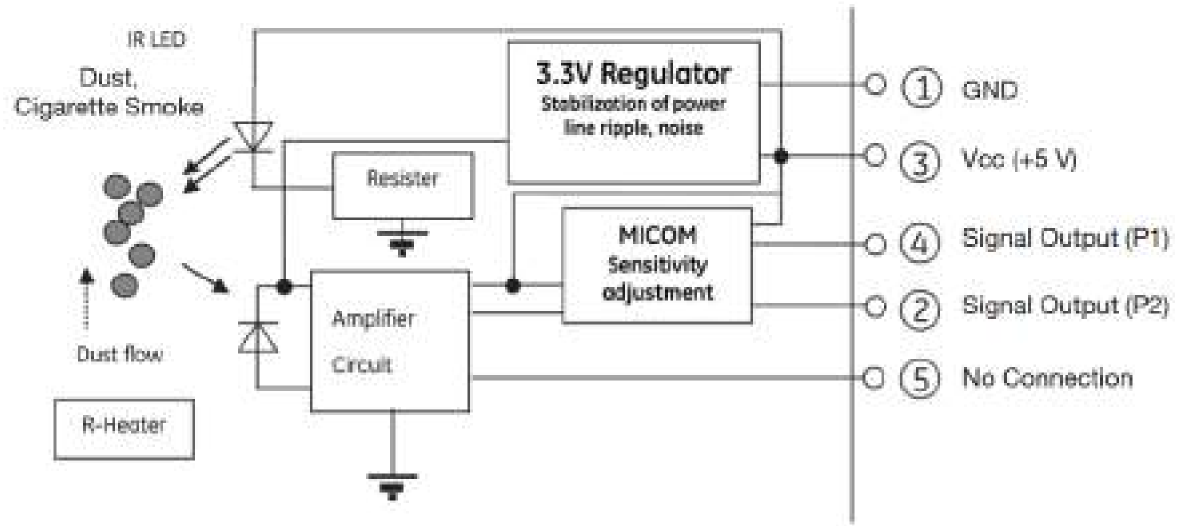
The used sensor is a SM-PWM-01C produced by Amphenol. This sensor is capable to detects the dust particle concentration (PM1 or PM10) in the air by using optical sensing method. An infrared light emitting diode (IR LED) and a photo-sensor are optically arranged in the device. The photo-sensor detects the reflected IR LED light by dust particles in air. The SMART Dust Sensor can detect the small particles like cigarette smoke from large house dust by pulse pattern of signal output.

Features

- Compact size, light weight (W59x H46x D18 mm, 20g)
- The Low pulse width correspond to the particle size
- Lead free and RoHS directive compliant
- Minimum particle size can be detected over 1μm
- Operating voltage: 5 ± 5% V
- Current consumption: < 90 ±10%mA
- Power up time: 90 sec
- Operating Temperature: -10°C - 45°C
- Operating Humidity: < 85%RH

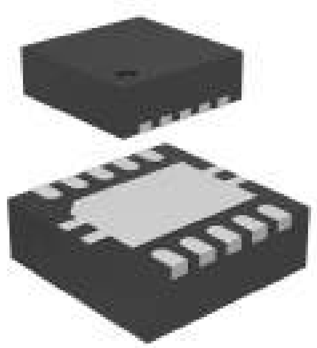
Electrical Connection

As the carbon dioxide, this is already a small PCB. For this reason there is no need for a decoupling capacitor. Furthermore it is written that there is no need for pull-up resistors since they are already embedded in the sensor. Also in this case particular attention must be given to not short the bottom components of the board.



2.3 Power

2.3.1 Li-Ion and Li-Pol Charger



- Integrated Power FET and Current Sensor for Up to 1-A Charge Applications From AC Adapter
- Precharge Conditioning With Safety Timer
- Charge and Power-Good Status Output
- Automatic Sleep Mode for Low Power Consumption
- Integrated Charge-Current Monitor
- Fixed 7-Hour Fast Charge Safety Timer
- Ideal for Low-Dropout Charger Designs for Single-Cell Li-Ion or Li-Pol Packs in Space-Limited Portable Applications
- Small 3.00-mm 3.00-mm VSON Package
- Max Input voltage : 7 V

Electronic Connections

For this project it is necessary to provide fast charge capabilities due to high demand of current from the sensors onboard. In the figure 2.3 is shown the typical configuration for the following parameters.

PARAMETER	**VALUE**
Supply Voltage	5 V
Fast-charge current	750 mA

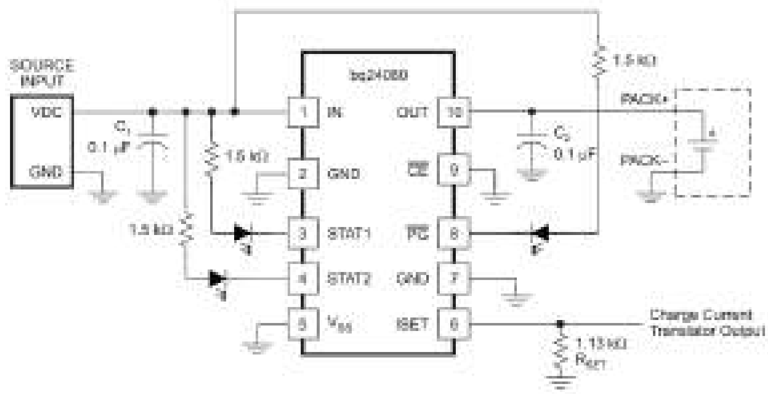


Figure 2.3: Typical configuration

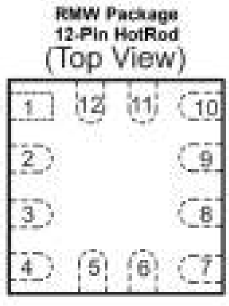
In most applications, all that is needed is a high-frequency decoupling capacitor on the input power pin. A 0.1 µF ceramic capacitor, placed in close proximity to the IN pin and GND pad works well. The device only requires a small capacitor for loop stability. A 0.1 µF ceramic capacitor placed between the OUT and GND pad is typically sufficient.

The status pins can be observed using LEDs. LEDs with a current rating less than 10 mA are used. The resistors needed in series with the LEDs can be chosen using the following formula.

$$R_{LED} = [(V_{IN} - V_{LED})/I_{LED}] = (5V - 2V)/1.5mA = 2\,\mathrm{k}\Omega$$

2.3.2 Buck-Boost Converter

- Real Buck or Boost with Seamless Transition Between Buck and Boost Mode
- 2.5 V to 5.5 V Input Voltage Range
- 0.5A Continuous Output Current: $V_{IN} \geq 2.5$ V, $V_{OUT} = 3.3$ V
- Adjustable and Fixed Output Voltage Version
- Efficiency > 90% in Boost Mode and > 95% in Buck Mode
- 2.5-MHz Typical Switching Frequency
- Adjustable Average Input Current Limit
- Adjustable Soft-Start Time
- Device Quiescent Current < 60 μA
- Automatic Power Save Mode or Forced PWM Mode
- Load Disconnect During Shutdown
- Overtemperature Protection
- Small 1.6mm x 1.2mm, 12-pin WCSP and 2.5mm x 2.5mm 12-pin HotRod^{TM} QFN package

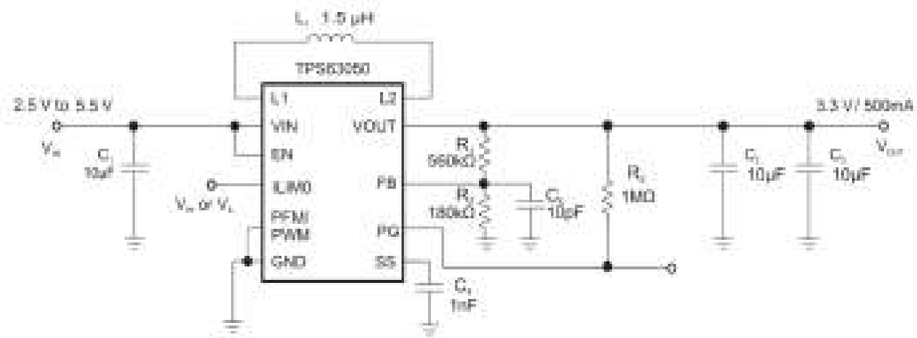


Electronic Connection

Due to the high current demand, it has been chosen to use a buck-boost converter capable to provide an average current of 500 mA. In figure below the typical configuration used to provide 3.3V is shown. It is possible to modify the output voltage changing R_1 and R_2 values.

$$R_1 = R_2 \cdot (\frac{V_{out}}{V_{FB}} - 1)$$

The datasheet suggests to keep the value of R_2 as close a possible to 200kΩ.



CHAPTER 3

OrCad

3.1 TOP level

The schematic below represents the connection between the different sensors and the microcontroller. It is important to recall that the I^2C communication requires pull-up resistors in order to correctly bias the signal.

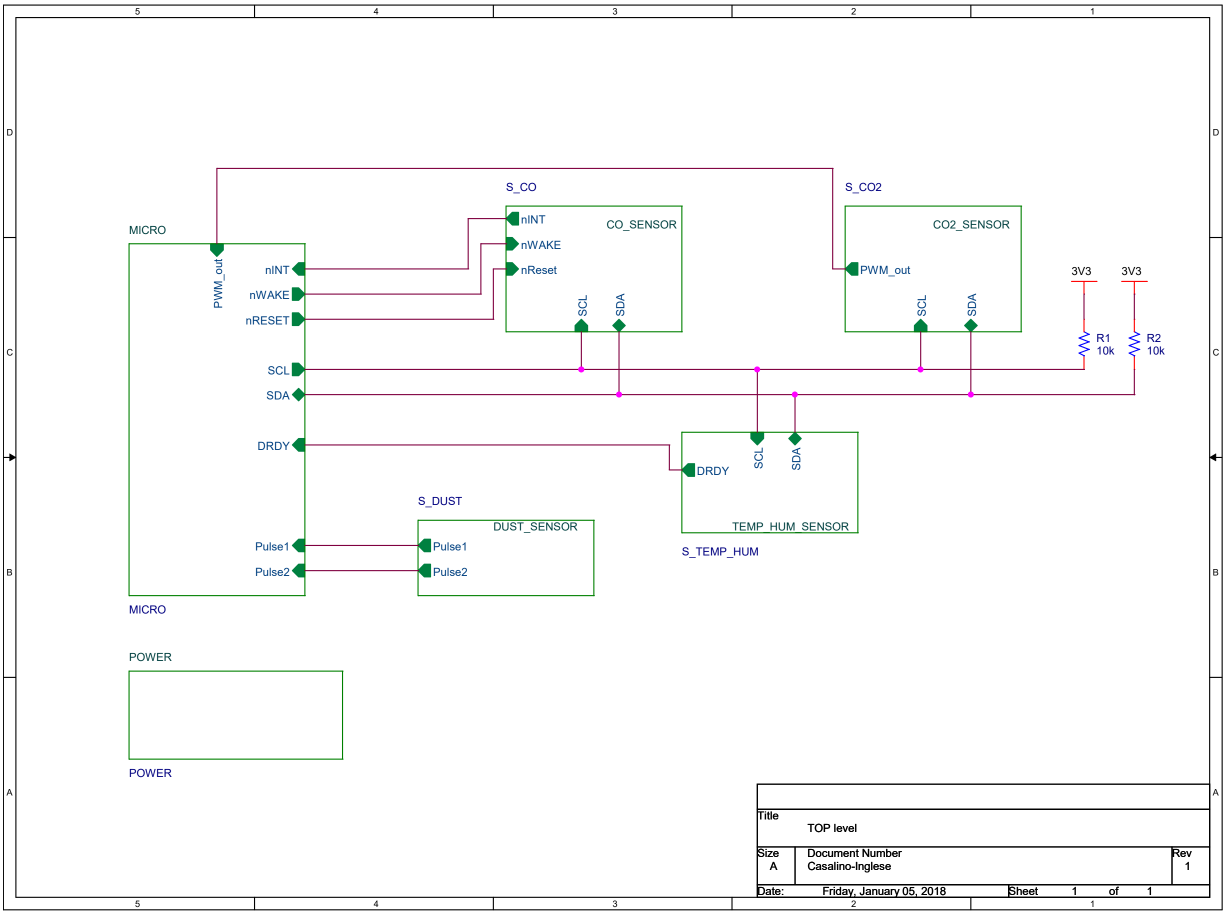


Figure 3.1: Top level hierarchical view

3.2 POWER

One of the main issue of this project is the high requirement of current. This not only due to the number of sensors, but also to the fact that two of them (dust and CO2) do require a remarkable amount of current. Another issue is the request of two different bias voltages (3.3V and 5V). To fulfill this request, the project needs two different buck-boost amplifiers.
To charge the battery taking into account the requirements, it has been used a fast charge module. This is capable to provide an high current to the battery. No battery protection circuit was implemented, hence there is NO overdischarge or overcharge protection. Moreover a switch was used in order to turn on and off the power of the whole circuit.

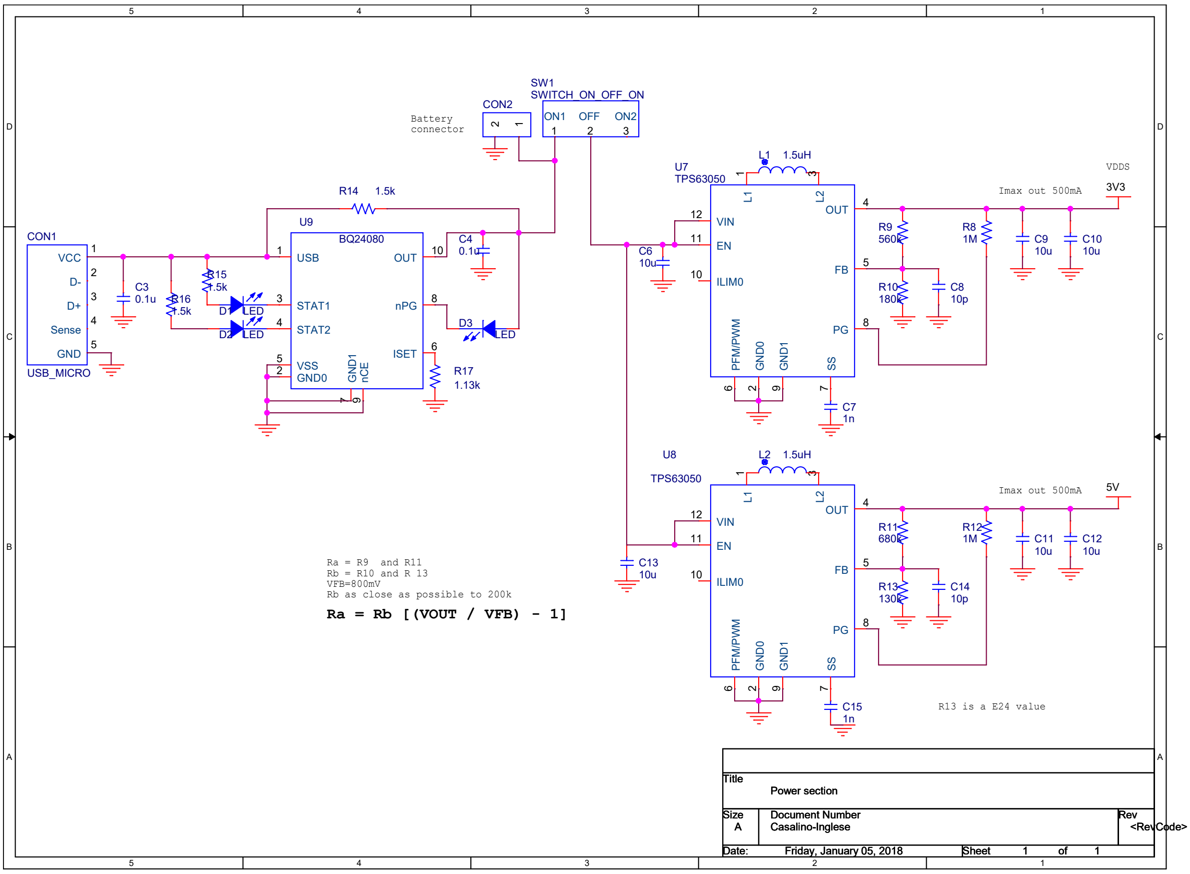


Figure 3.2: Power configuration

3.3 Microcontroller

The schematic below represents the recommended setup from the microcontroller manufacturer. The large number of capacitors are used in order to filter the supply source. This design takes advantage of the internal DC-DC regulator of the micro. The external supply provides a DC 3.3V value, and the internal regulator adjusts it in order to obtain a DC value close to 1.8V.
The micro has an embedded bluetooth module, but requires anyway an external antenna. The signal is provided to the antenna following the manufacturer specifications.
All the GPIOs are connected. Most of them are connected to the PCB sensors, others are used for the JTAG connection, and the remaining are routed to an external connector in order to let the user access them anyway.

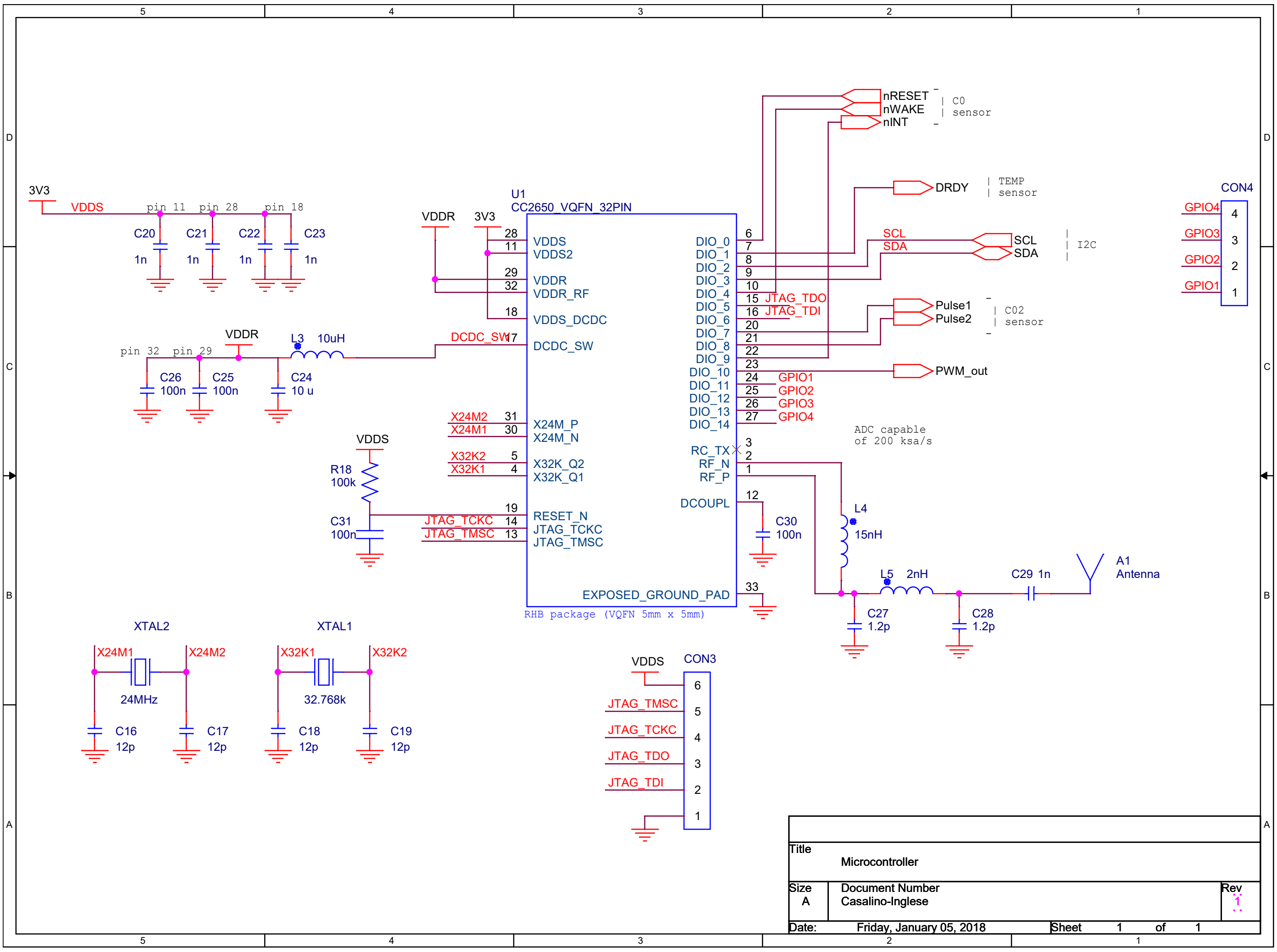


Figure 3.3: Microcontroller

3.4 Temperature and humidity sensor

This sensor is capable to communicate both in I^2C and SPI. In order to select I^2C the CS pin must be left unconnected. In addiction to the SCL and SDA pins, a further connection to the microcontroller must be established in order to notify when the output is ready.

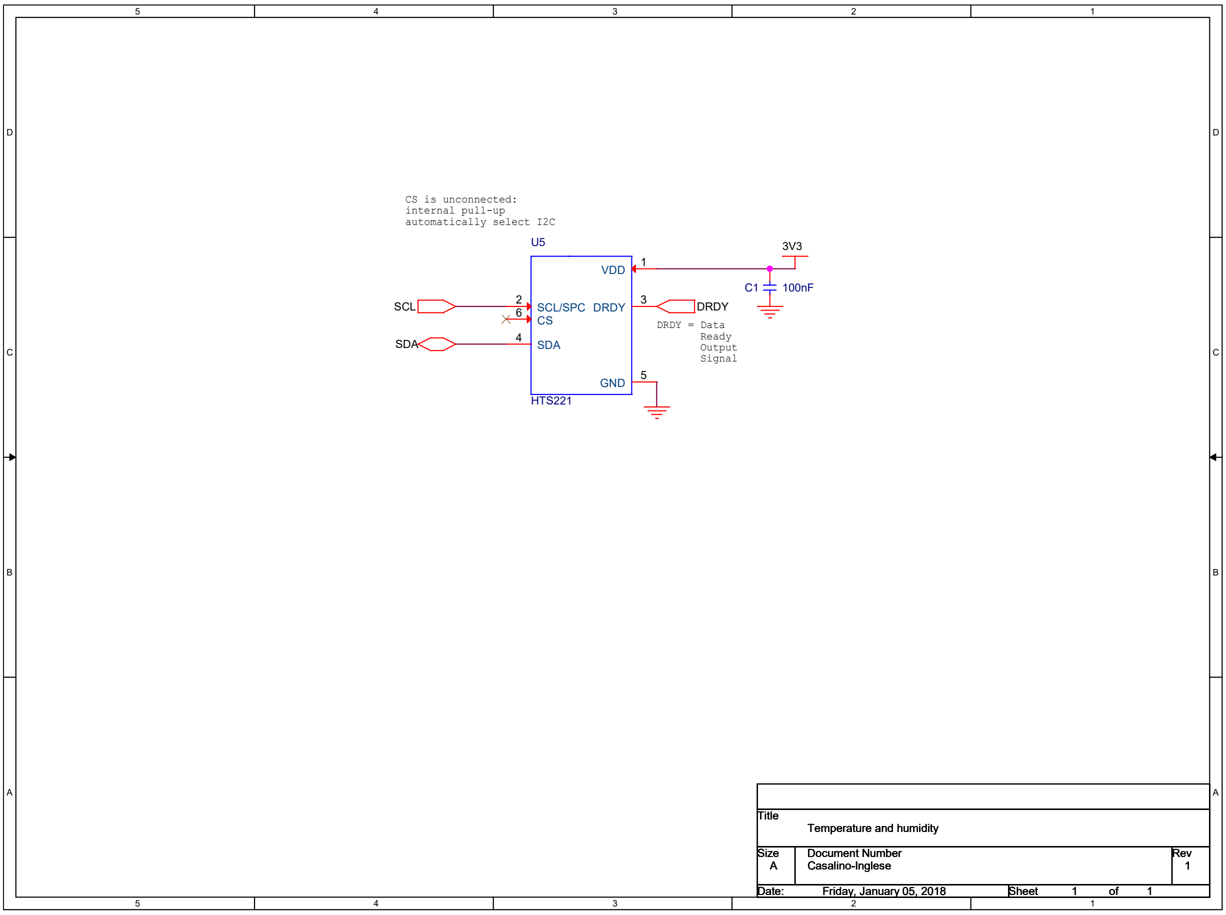


Figure 3.4: Temperature and humidity sensor

3.5 Carbon Monoxide sensor

This sensor is connected using I^2C protocol. Furthermore a negate interrupt (nINT) provides a feedback to the microcontroller in order to signal when a measurement is finished.

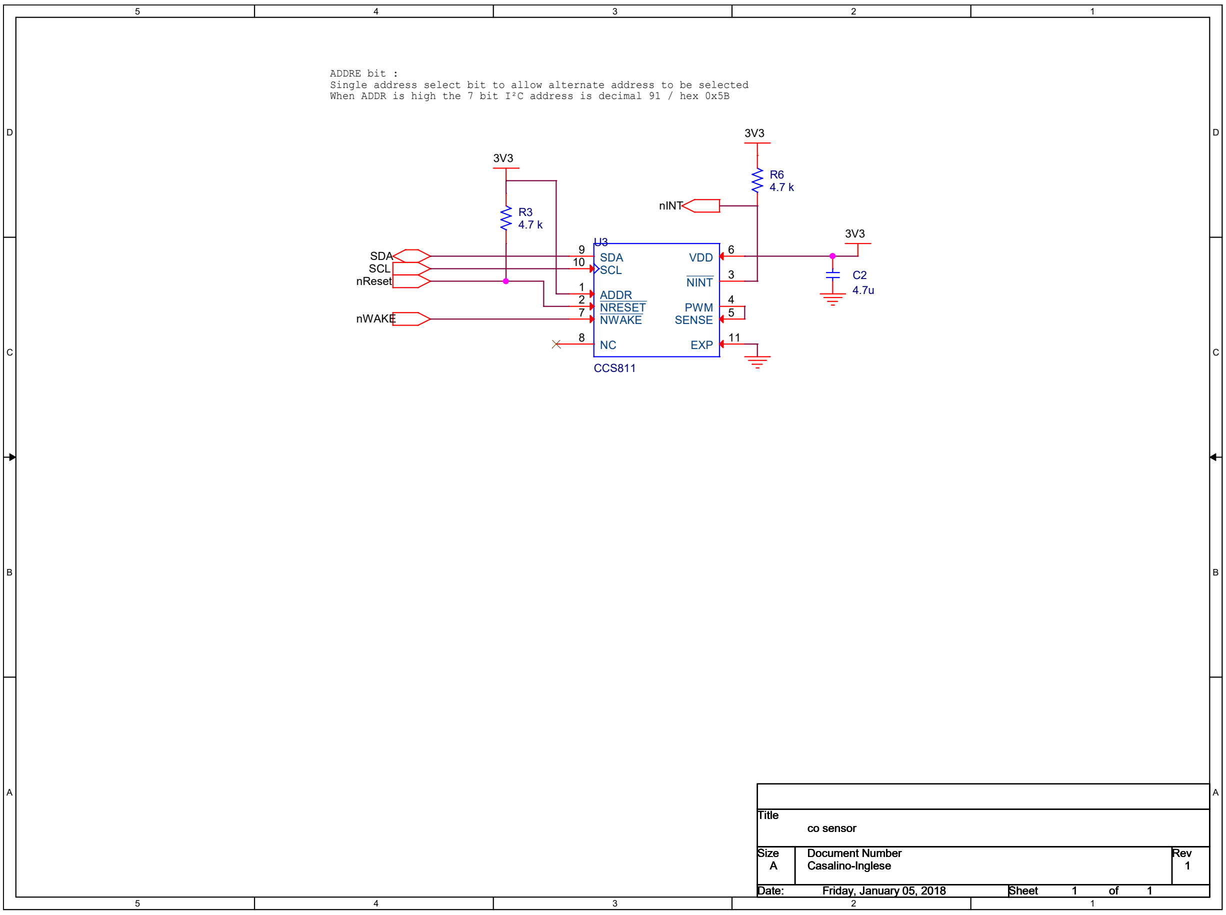


Figure 3.5: Carbon Monoxide sensor

3.6 Carbon Dioxide sensor

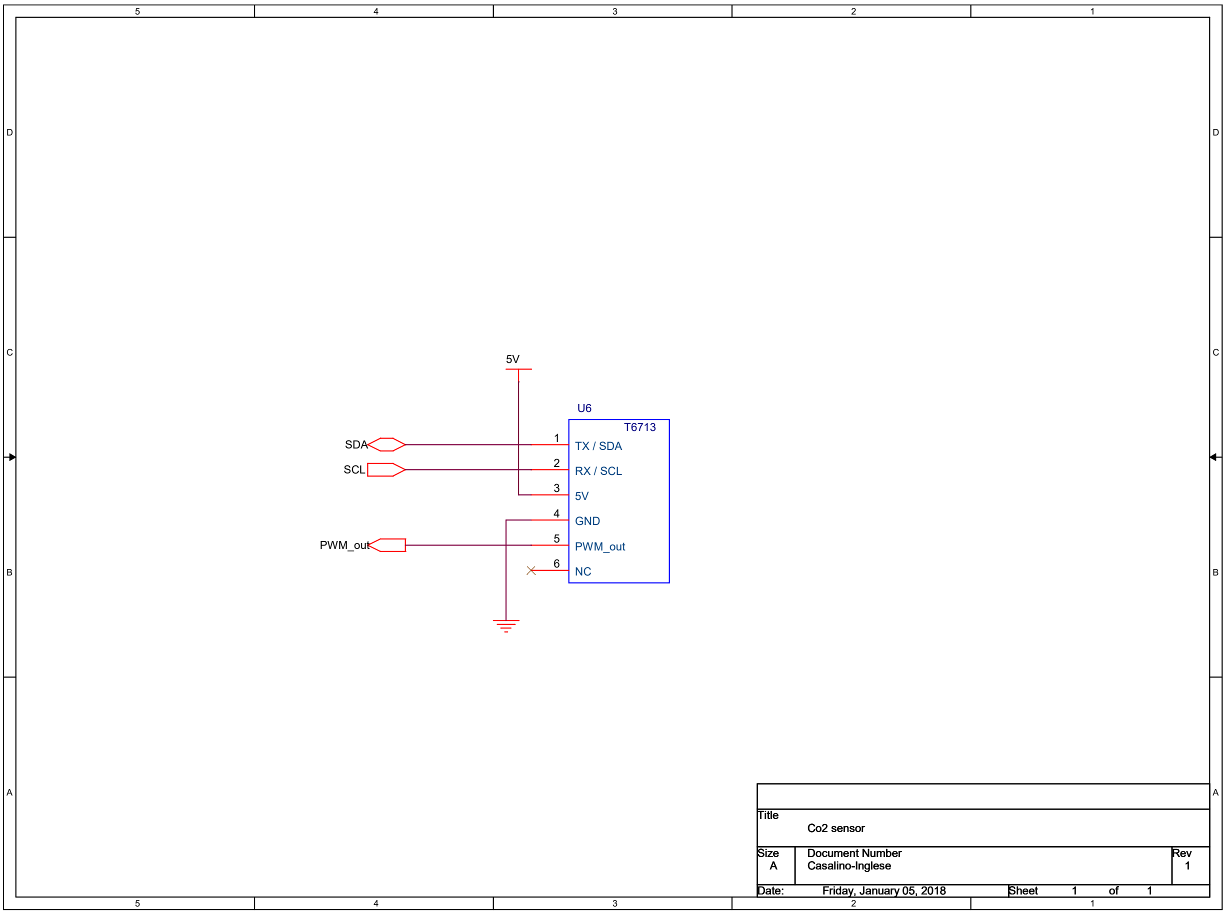


Figure 3.6: Carbon Dioxide sensor

3.7 Dust sensor

This is the only sensor not using the I^2C protocol. In order to communicate two pulse signal are used, one for small particles (1-2 μm) and the other for bigger one (3-10 μm)

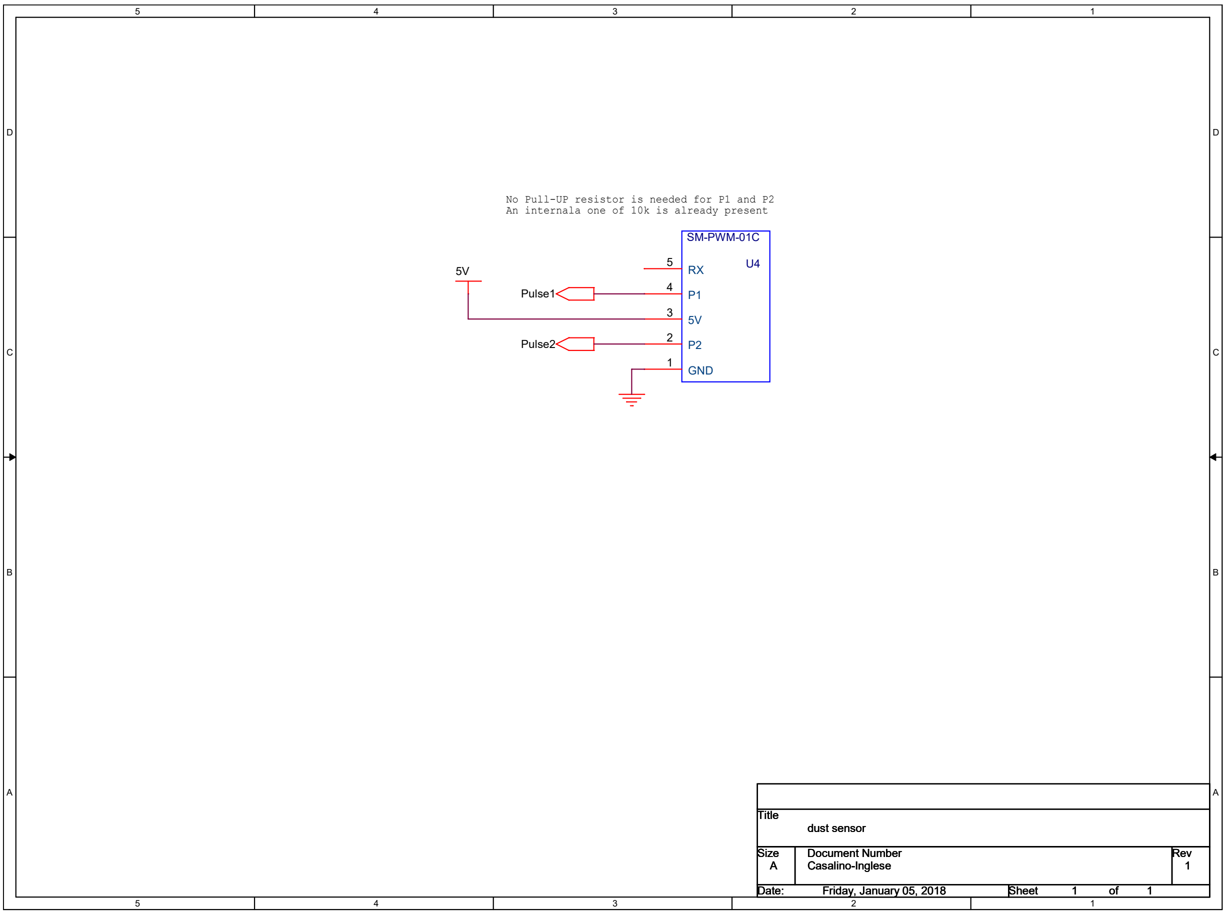


Figure 3.7: Dust sensor

CHAPTER 4

Allegro, OSH and BOM

Using Allegro the PCB project has been created, then the gerber files have been renamed following the OSH Park guide. Here below are reported the top and bottom layers reported by the PCB manufacturer.

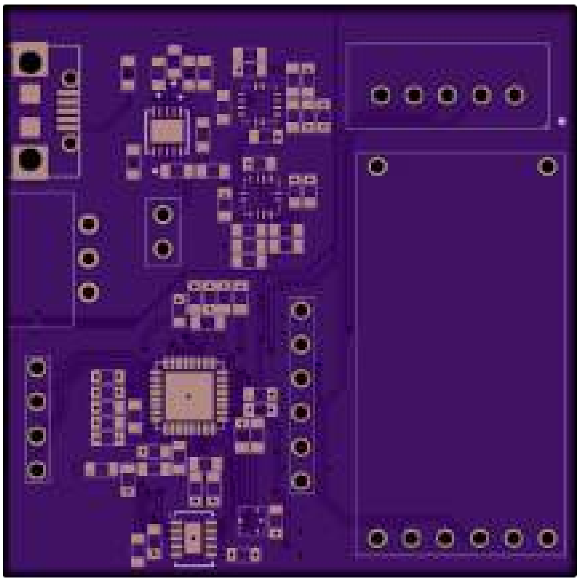


Figure 4.1: Top layer

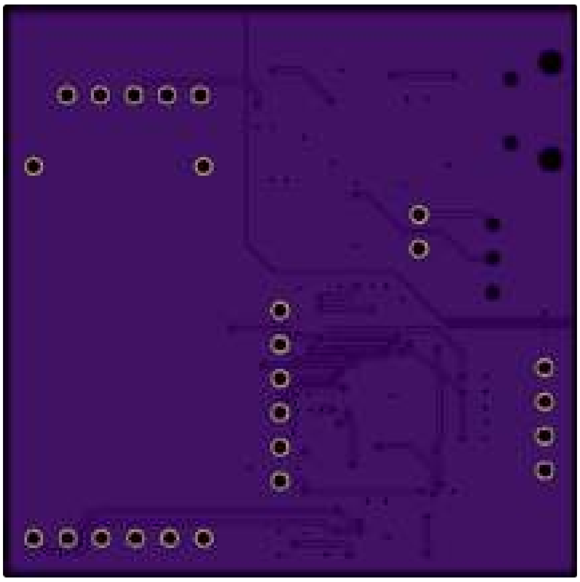


Figure 4.2: Bot layer

Figure 4.3: OSH notes

4.1 BOM and costs

Item	Quantity	Reference	Part	Price
1	1	A1	Antenna	€ 1.38
2	1	CON1	USB_MICRO	€ 0.60
3	1	CON2	CONNECTOR_2	€ 0.10
4	1	CON3	CONNECTOR_6	€ 0.10
5	1	CON4	CONNECTOR_4	€ 0.10
6	1	C1	100nF	€ 0.20
7	1	C2	4.7u	€ 0.20
8	2	C3,C4	0.1u	€ 0.40
9	2	C6,C13	10u	€ 0.40
10	7	C7,C15,C20,C21,C22,C23,C29	1n	€ 1.40
11	2	C8,C14	10p	€ 0.40
12	4	C9,C10,C11,C12	10u	€ 0.80
13	4	C16,C17,C18,C19	12p	€ 0.80
14	1	C24	10 u	€ 0.20
15	4	C25,C26,C30,C31	100n	€ 0.80
16	2	C27,C28	1.2p	€ 0.40
17	3	D1,D2,D3	LED	€ 0.78
18	2	L1,L2	1.5uH	€ 0.34
19	1	L3	10uH	€ 0.17
20	1	L4	15nH	€ 0.17
21	1	L5	2nH	€ 0.17
22	2	R1,R2	10k	€ 0.18
23	2	R3,R6	4.7 k	€ 0.18
24	2	R8,R12	1M	€ 0.18
25	1	R9	560k	€ 0.09
26	1	R10	180k	€ 0.09
27	1	R11	680k	€ 0.09
28	1	R13	130k	€ 0.09
29	3	R14,R15,R16	1.5k	€ 0.27
30	1	R17	1.13k	€ 0.09
31	1	R18	100k	€ 0.09
32	1	SW1	SWITCH_ON_OFF_ON	€ 2.95
33	1	U1	CC2650_VQFN_32PIN	€ 4.85
34	1	U3	CCS811	€ 9.71
35	1	U4	SM-PWM-01C	€ 14.22
36	1	U5	HTS221	€ 2.95
37	1	U6	T6713	€ 89.00
38	2	U7,U8	TPS63050	€ 3.10
39	1	U9	BQ24080	€ 1.55
40	1	XTAL1	32.768k	€ 0.81
41	1	XTAL2	24MHz	€ 0.58

all prices are referd to mouser

Total Components cost	€ 140.98

1	BATTERY 3.7V 800mAh with protection circuit		€ 1.40
1	PCB cost		€ 14.10

TOTAL production cost	€ 154.00