Politecnico di Torino

Electronic Systems Engineering

ABDM ALARM

BLUETOOTH MOTION DETECTOR WITH ACOUSTIC WARNING

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DEVICE OVERVIEW

1.1 Description

The ABDM device is a cost-effective low power wireless intruder detector. When a movement is detected, an acoustic alarm is activated and a notice is immediately sent via Bluetooth to a dedicated Android application, from which it is possible to deactivate it (otherwise it will last 5 minutes once activated).

The detector can be enabled and disabled from the Android application. It can also be configured to automatically send an alert to a police station or to a specific phone number when an intrusion is detected.

The system is battery-powered. It is rechargeable by means of a common micro-USB connector and the battery status can be visualized in the Android application. A notification is sent when the battery charge level falls under a minimum threshold.

The Android application is called *ABDM alarm*, it can be downloaded for free from the offical Play Store and it can be periodically updated to newer versions (therefore, other functionalities may be developed in future without the need of changing the device).

1.2 Features

- Ultra-low power device
- Infrared movement detection
  - Long distance detection (up to 7m)
  - Large field of view (90°)
- Battery-powered system
  - 6 days duration
  - Micro-USB connector for battery charge
  - Capability of working while on charge
- BLE communication by means of a free Android application
  - Immediate notification of a movement detection
  - Capability of enabling/disabling the detection
  - Battery charge status indication
  - Immediate notification when the battery charge level falls under 10%
- Acoustic alarm
  - 82db acoustic sound
  - Automatic deactivation after 5 minutes
- Manual shutdown (mechanical switch) and reset (mechanical pushbutton)
- Device protection
  - The switch and the pushbutton can be reached only by opening the device package
  - The device package can only be opened with a suitable key (provided within the device itself)

1.3 Functional Block Diagram

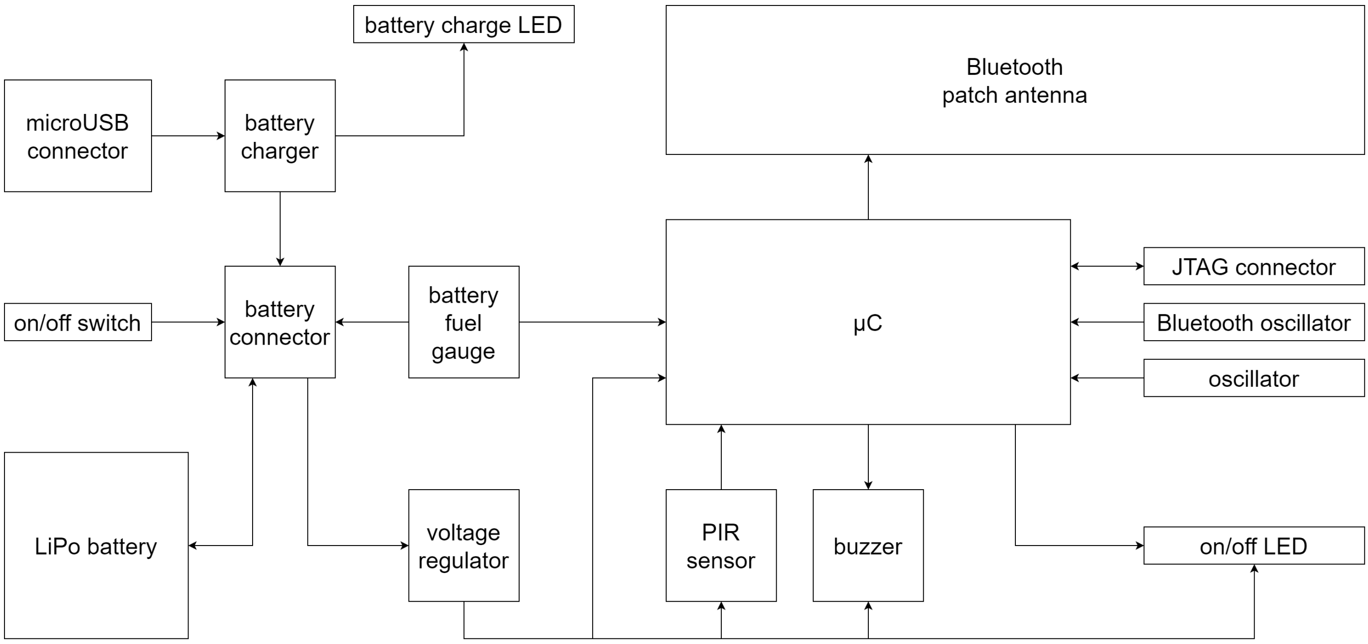

Figure 1.1: device functional block diagram

- An external **LiPo battery** is connected to the device through a **battery connector** and it can be recharged using an external 5V power source by means of a **battery charger**. The external power source is connected to the device through a **microUSB connector**. When the battery is on charge, the **battery charge LED** is turned on and the system is powered by the external source. The charge level of the battery is detected by means of a **fuel gauge** which communicates with the microcontroller using an I2C protocol.

- The **on/off switch** allows to disconnect the battery from the device, switching it off. The **on/off LED** is turned on when the device is powered.

- A **voltage regulator** (buck converter) is employed to convert the battery voltage (3.7V) or the esternal source voltage (5V) in a suitable value for the microcontroller and its external peripherals (3.3V).

- A **PIR sensor** is used for detecting any movement in the surrounding area (7m distance, 90° angle). The output is a simple digital signal (high if a movement is detected, low otherwise) compatible with the voltage levels of the microcontroller.

- An internally-driven electromechanical **buzzer** is employed to generate the acustic alarm when an intrusion is detected.

- The **microcontroller** is the real core of the system. It read the status of the PIR sensor and the status of the fuel gauge, it activates the buzzer when required and it manages the communication with the Android application via Bluetooth (it has an integrated BLE interface). It is programmed by means of a **JTAG connector** and it requires a generic **esternal oscillator** (24MHz) and a **Bluetooth external oscillator** (32.768 kHz). The BLE communication is realized using a suitable **patch antenna**.

- The device is incapsulated inside a safety box, which can be opened using the key provided to the customer with the device itself. The LEDs status can be seen from the otuside, but the mechanical switch cannot be reached without opening the box.

BILL OF MATERIALS

Item	Qty	Reference	Part	Manufacturer	Manufacturer Part Number	Main Vendor	Main Vendor Part Number	Secondary Vendor	Secondary Vendor Part Number
1	2	C1,C2	C_4.7uF	Murata Electronics	GRM21BR71A475ME51K	Mouser	81-GRM21BR71A475ME1K		
2	1	C3	C_470nF	Murata	GRM155R61A474ME15D	Mouser	81-GRM155R61A474ME5D		
3	2	C4,C10	C_1uF	Yageo	CC0603KRX5R5BB105	Mouser	603-CC603KRX5R5BB105		
4	1	C5	C_12pF_highQ	Vishay	VJ0402D120GXCAJ	Digikey	VJ0402D120GXCAJ-ND		
5	2	C6,C7	C_1200pF_highQ	Vishay	VJ0805D122KXXAJ	Digikey	720-VJ0805D122KXXAJTR-ND		
6	2	C8,C9	C_12pF	Murata	GRM1885C1H120JA01J	Mouser	81-GRM185C1H120JA01J		
7	7	C11,C12,C14,C15, C16,C17,C18	C_100nF	Kemet	C0402C104M8RAC7411	Mouser	80-C0402C104M8RACLR		
8	3	C13,C19,C20	C_10uF	Murata	GRM21BR71A106MA73K	Mouser	81-GRM21BR71A106MA3K		
9	1	C21	C_120pF	Samsung ElectroMechanics	CL10C121JB8NNNC	Mouser	187-CL10C121JB8NNNC		
10	1	C22	C_4.7uF	Murata	GRM21BR71A475ME51K	Mouser	81-GRM21BR71A475ME1K		
11	2	D1,D4	LED_R_1.7mV_1mA	Broadcom	HLMP-K150	Mouser	630-HLMP-K150		
12	1	D2	Schottky_BAT32LSQYL	Nexperia	BAT32LS-QYL	Mouser	771-BAT32LS-QYL		
13	1	D3	Diode_BAS16LD315	Nexperia	BAS16LD,315	Mouser	771-BAS16LD315		
14	1	FL1	Ferrite_BLM18HE152SN1	Murata	BLM18HE152SN1D	Mouser	81-BLM18HE152SN1D		
15	1	L1	L_15nH_highQ	Vishay	IMC0603ER15NJ01	Digikey	IMC0603ER15NJ01-ND		
16	1	L2	L_2nH_highQ	Vishay	IMC0603ER2N0S01	Digikey	IMC0603ER2N0S01-ND		
17	1	L3	L_10uH	TDK	MLF1608E100MTD00	Mouser	810-MLF1608E100MTD00		
18	1	L4	L_470nH	Murata	DFE201610E-R47M=P2	Mouser	81-DFE201610E-R47MP2		
19	3	M1,M2,M3	nMOS_SSM3K16CTL3F	Toshiba	SSM3K16CT,L3F	Mouser	757-SSM3K16CTL3F		
20	1	R1	R_3300_1%	Vishay	CRCW06033K30FKEA	Mouser	71-CRCW0603-3.3K-E3		
21	2	R2,R13	R_1k_5%	Vishay	CRCW04021K00JNED	Mouser	71-CRCW0402J-1.0K-E3		
22	1	R3	R_10m_1%	Bussman / Eaton	MFSA1206R0100FCM	Mouser	504-MFSA1206R0100FCM		
23	2	R4,R5	R_5k_1%	Yageo	RC0402FR-075KL	Mouser	603-RC0402FR-075KL		
24	1	R6	R_100k_5%	Vishay	CRCW0603100KJNEA	Mouser	71-CRCW0603J-100K-E3		
25	2	R7,R8	R_1M_1%	Vishay	CRCW04021M00FKEE	Mouser	71-CRCW04021M00FKEE		
26	1	R9	R_1600_5%	Vishay	CRCW08051K60JNEA	Mouser	71-CRCW08051K60JNEA		
27	2	R10,R11	R_50k_1%	Vishay	CRCW040250K0FKED	Mouser	71-CRCW0402-50K-E3		
28	1	R12	R_100k_5%	Yageo	RT0402FRE07100KL	Mouser	603-RT0402FRE07100KL		
29	1	R14	R_453k_0.1%	Yageo	RT0603BRD07453KL	Mouser	603-RT0603BRD07453KL		
30	2	R15,R16	R_100k_1%	Yageo	RT0402FRE07100KL	Mouser	603-RT0402FRE07100KL		
31	1	SW1	SW_SK12F17G7	C&K	SK-12F17-G7	Mouser	538-105164-0001	Digikey	WM11263CT-ND
32	1	U1	MicroUSB_1051640001	Molex	105164-0001	Mouser	538-105164-0001	Digikey	WM11263CT-ND
33	1	U2	BatCharger_MCP73832T2ATIMC	Microchip Technology	MCP73832T-2ATI/MC	Mouser	579-MCP73832T-2ATIMC	Digikey	MCP73832T-2ATI/MCCT-ND
34	1	U3	CON3_22035035	Molex	22035035	Mouser	538-22-03-5035	Farnell	9979620
35	1	U4	BatteryGauge_BQ27411DRZTG1A	Texas Instruments	BQ27411DRZT-G1A	Mouser	595-BQ27411DRZT-G1A	Digikey	296-39941-1-ND
36	1	U5	uC_CC2640F128RHBR	Texas Instruments	CC2640F128RHBR	Digikey	296-43634-1-ND	Mouser	595-CC2640F128RHBR
37	1	U6	ANTENNA						
38	1	U7	Buzzer_AI1223TWT3V2R	PUI Audio, Inc.	AI-1223-TWT-3V-2-R	Mouser	665-AI1223TWT3V2R	Digikey	665-AI1223TWT3V2R
39	1	U8	CON10_M209720546	Harwin	M20-9720546	Digikey	M20-9720546-ND	Mouser	855-M20-9720546
40	1	U9	pushbutton_EVPBV2C3L000	Panasonic	EVP-BV2C3L000	Mouser	667-EVP-BV2C3L000		
41	1	U10	PIR_EKMC1607112	Panasonic	EKMC1607112	Digikey	255-6546-ND	Mouser	769-EKMC1607112
42	1	U11	Buck_TPS62824DMQR	Texas Instruments	TPS62824DMQR	Mouser	595-TPS62824DMQR	Digikey	296-TPS62824DMQRCT-ND
43	1	Y1	XTAL_32768_SC32S7PF20PPM	Seiko Semiconductors	SC32S-7PF20PPM	Digikey	728-1074-1-ND	Mouser	628-SC32S-7PF20PPM
44	1	Y2	XTAL_24M_ECS240833AGNTR3	ECS	ECS-240-8-33-AGN-TR3	Mouser	ECS-240-8-33-AGN-TR3	Digikey	50-ECS-240-8-33-AGN-TR3CT-ND

The previous table contains all the components employed in the board fabrication. However, it is also necessary to include in the list the battery, which is external with respect to the board but necessary to make it work:

LiPo battery (3.7 V, 980 mAh)
Manufacturer: BAK
Manufacturer product number: LP-523450-IS-3
Vendor: Farnell
Vendor part number: 2077888

SCHEMATICS

3.1 Battery Management Section

The battery voltage is provided to the board using a rectangular connector, whereas the charging voltage is provided by means of a micro-USB connector. When the charging voltage is present the battery is recharged, the charge LED is turned on and the system is powered by this voltage instead of the battery voltage. The battery charge level is detected by the gauge, which measures the current flowing through a sense resistor. The mechanical switch allows to disconnect the battery voltage from the rest of the circuit, turning it off.

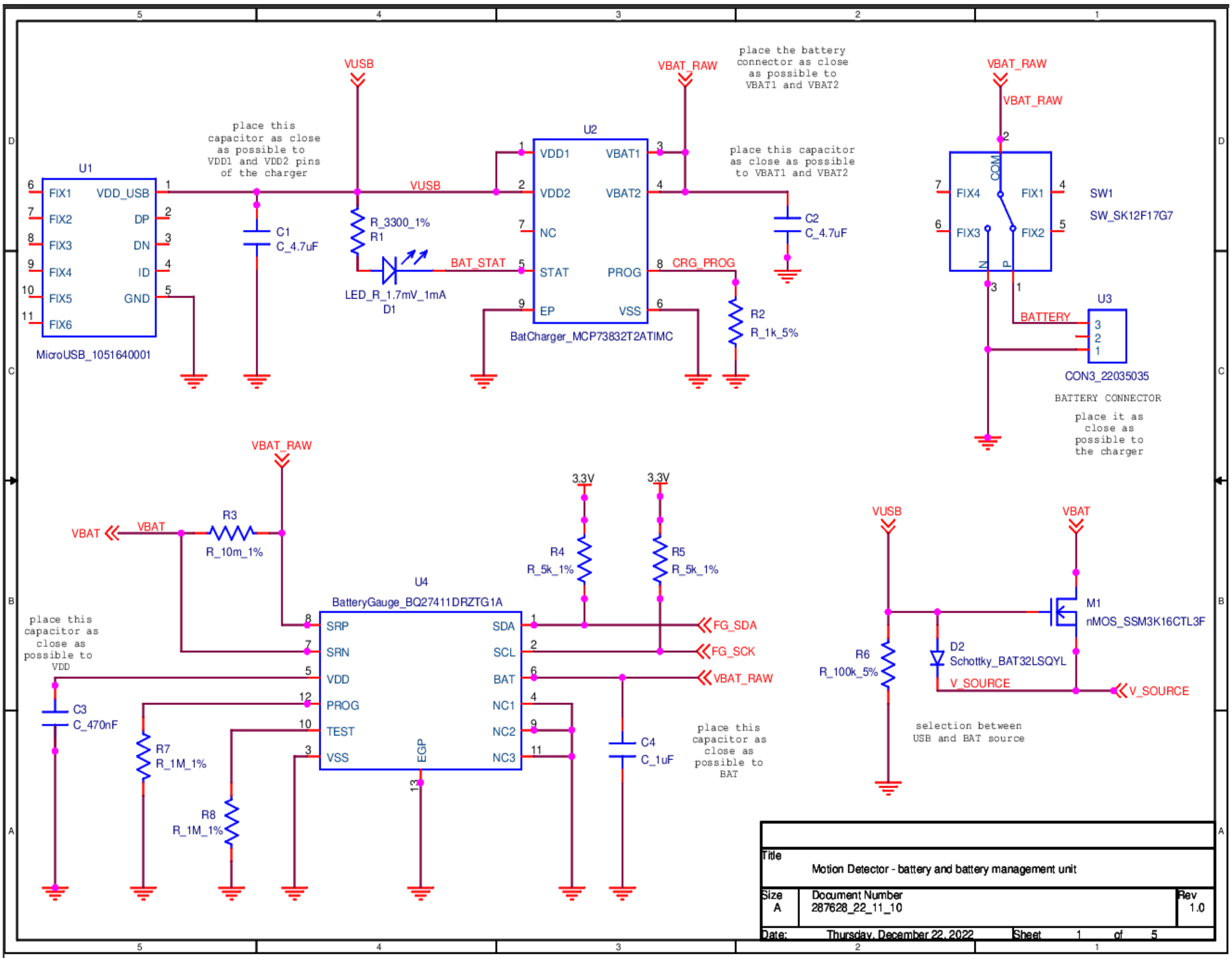

Figure 3.1: Battery management section

- The value of the resistor in series to the LED is such that the current flowing through it and its voltage drop are capable of turning it on. If necessary, both the LED and the resistor can be substituted with different commercial parts as long as the LED can be turned on using $V_{USB} = 5$ V and as long as the power consumption is not significantly increased.
- The MOS transistor and the Schottky diode allows the selection between the USB voltage and the battery voltage. They can be substituted with any other commercial parts as long as they are able to withstand a suitable power consumption (all the current required by the device flows through them).

- All the passive parts (resistors and capacitors) can be substituted with equivalent commercial parts. Their uncertainty is not really important, with the exception of the sense resistor (whose uncertainty must be equal or lower than 1%). It is recommended to use X5R or X7R decoupling capacitors.

3.2 Microcontroller Section

The main clock and the Bluetooth clock are provided using two suitable crystal oscillators. The RF communication is realized employing a patch antenna with a single-ended connection (4XS).

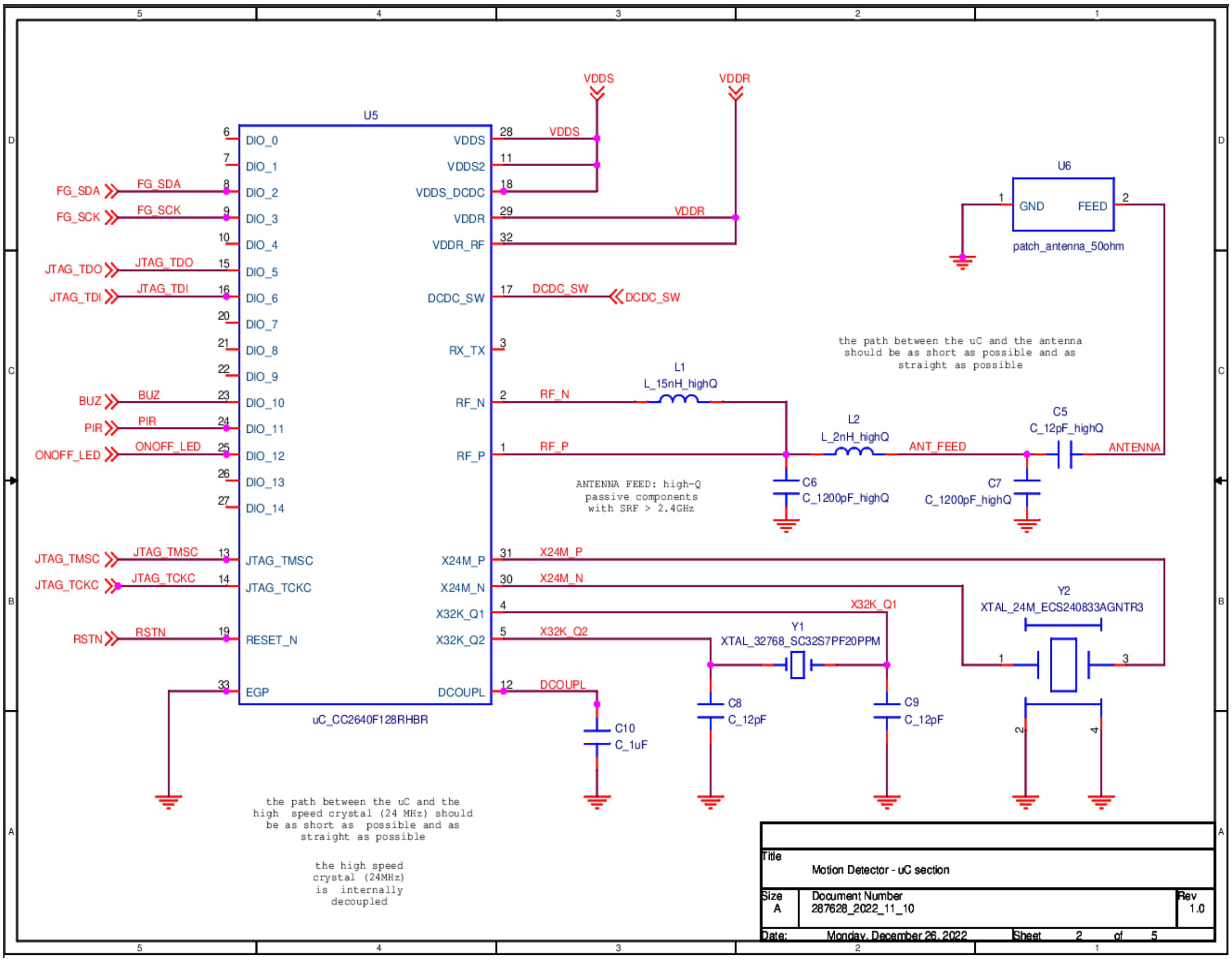

Figure 3.2: Microcontroller section

- The oscillators are chosen in order to respect the requirements stated by the manufacturer of the CC2640 microcontroller. They can be susbtituted with any other part which respects these requirements.
- The components employed in the antenna feed are characterized by a self-resonant frequency higher than the antenna freqeuncy (2.4 GHz) and by a high quality factor. They can be substituted with any other commercial part respecting these requirements.
- All the passive components related to the decoupling network can be substituted with equivalent commercial parts. Their uncertainty is not really important. It is recommended to use X5R or X7R capacitors.

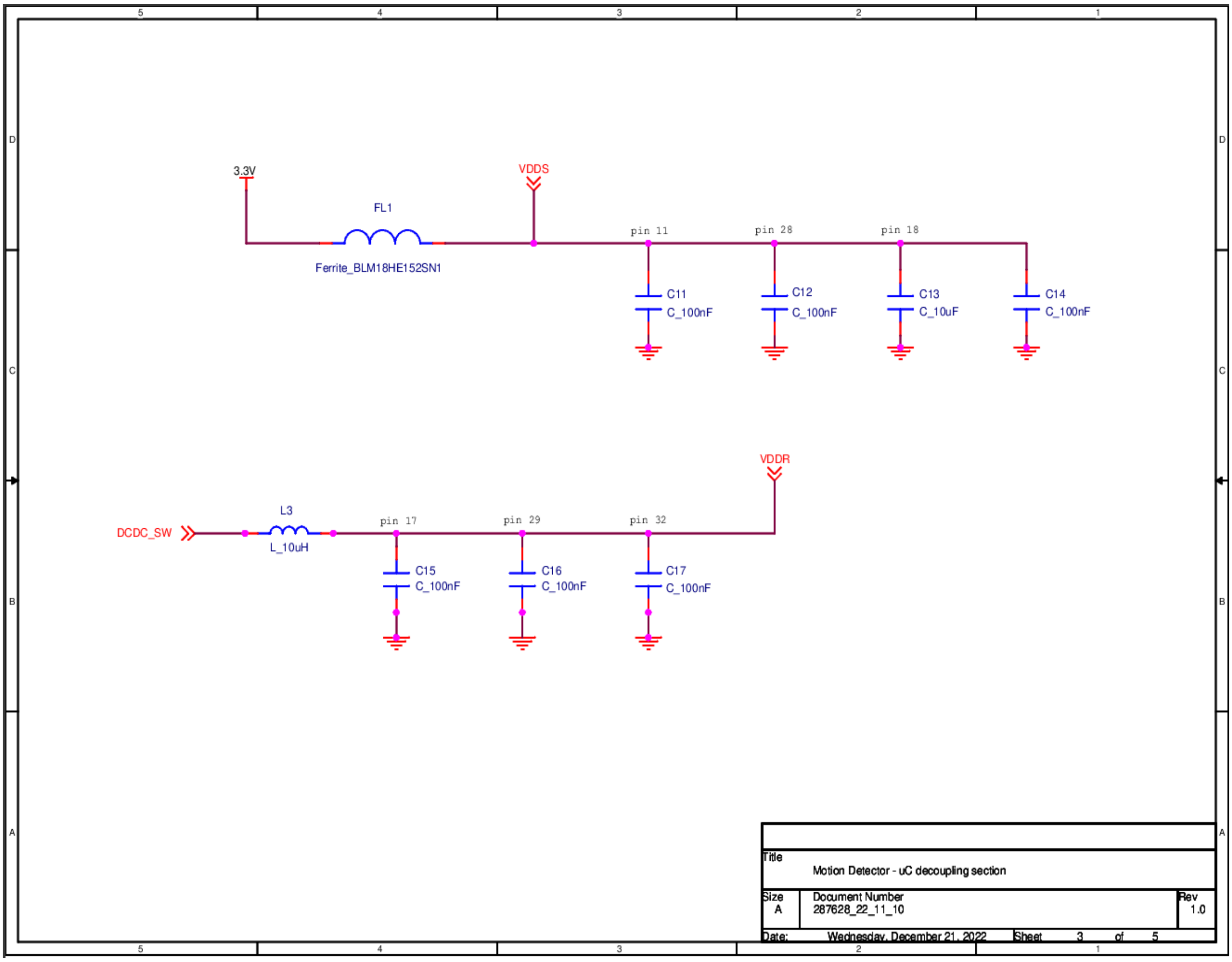

Figure 3.3: Microcontroller decoupling

3.3 Peripherals

The electromechanical buzzer is internally-driven, i.e. it just requires a continuous current in order to be activated. However, the required current is too high to be provided directly by the microcontroller, therefore a simple driver is realized exploiting a MOSFET transistor in common source configuration. A resistor is inserted in series to the transistor gate in order to limit the instantaneous current during the commutations, whereas a protecting diode is inserted in parallel to the buzzer (being it an inductive load).

Similarly to the buzzer case, the current required by the ON-OFF LED is too high, therefore the same driver is employed (without the protectiong diode, since the LED is not an inductive load). Moreover, a proper resistor is inserted in series to the LED in order to obtain the voltage drop and the current flow capable of turning it on.

The output current of the PIR sensor is perfectly maneageable by the microcontroller (since it is low enough), therefore it is not necessary to insert any other circuit.

The microcontroller programming is managed through a JTAG connection, which is realized by means of a pin-strip connector with 10 positions. The extra pins (other than the 4 pins required by the JTAG protocol) are not used at the moment, but they might be employed in future releases to implement different functionalities.

The mechanical pushbutton allows to manually reset the microcontroller. A series resistor is inserted in order to limit the current flowing through the pushbutton.

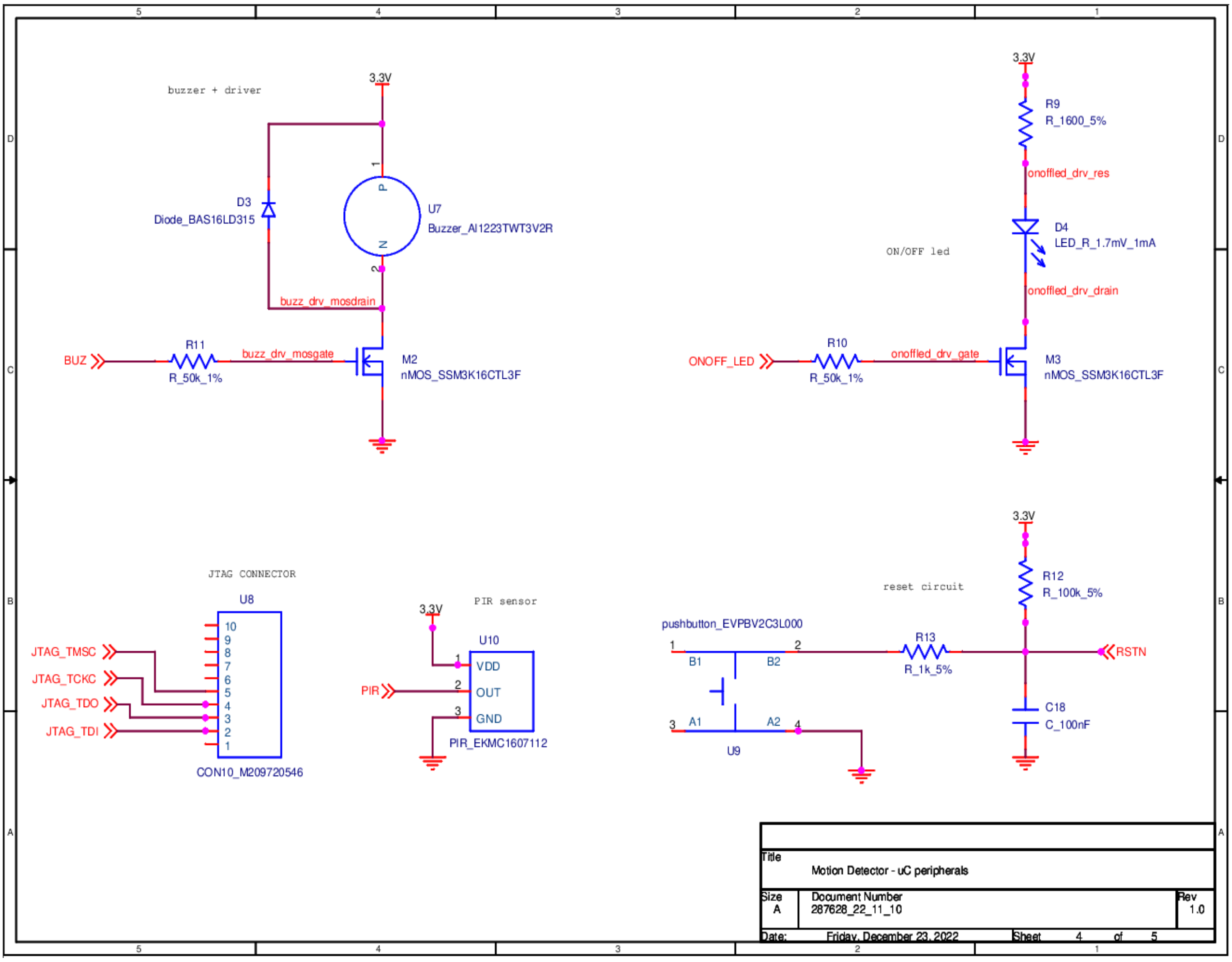

Figure 3.4: Peripherals

- Both the LED and its series resistor can be substituted with different commercial parts as long as the LED can be turned on using $V_{DDS} = 3.3$ V and as long as the power consumption is not significantly increased.
- The protecting diode can be substituted with any other commercial part witha high enough breakdown voltage.
- The MOS transistor can be substituted with any other equivalent commercial part as long as its threshold voltage is compatible with the microcontroller output voltage.
- All the passive components (resistors and capacitors) can be substituted with equivalent commercial parts (their uncertainty is not really important).

3.4 Voltage Regulator

A buck converter is used to transform the battery voltage in a stable value that can be employed by the microcontroller and its peripherals, i.e. 3.3V. The regulation of the output voltage of the buck is obtained by means of a resistor divider, which means that its uncertainty depends on the uncertainty of the employed resistors. For this reason, the resistors can be substituted with any other equivalent commercial part as long as the uncertainty is acceptable. When it comes to the capacitors, the uncertainty is not really important, therefore they can be easily substituted with different commercial parts (it is recommented to use X5R or X7R capacitors).

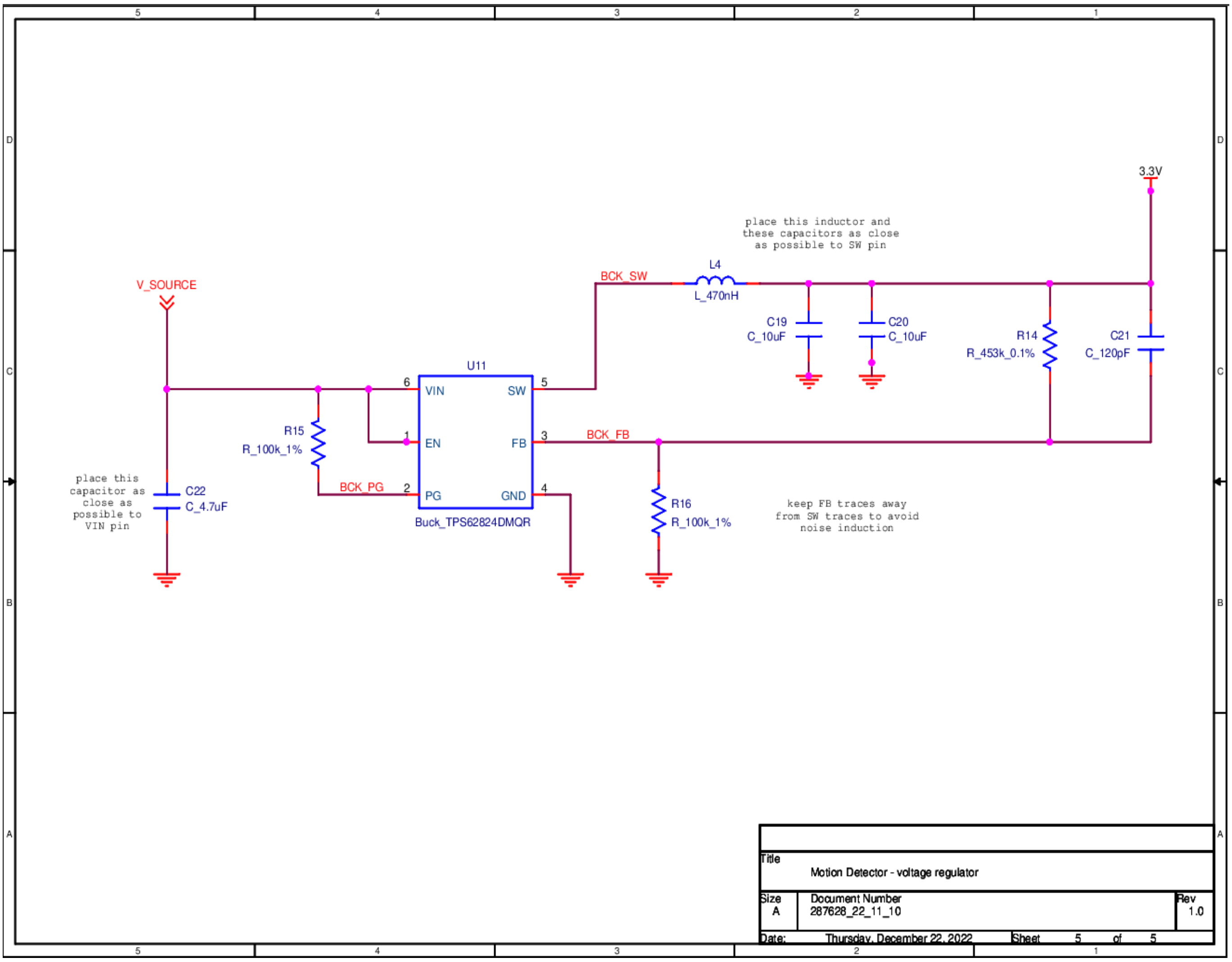

Figure 3.5: Voltage regulator section

BOARD LAYOUT

The PCB is a 2-layer board. The bottom layer is mainly dedicated to the ground plane; indeed, it does not contain any component, the number of traces on it has been reduced to the minimum and the same goes for their lenght. Wider traces have been employed for power supply lines whenever it was possible in order to reduce their resistance. The whole board is compliant with the specifications provided by the manufacturer (EUROCIRCUITS).

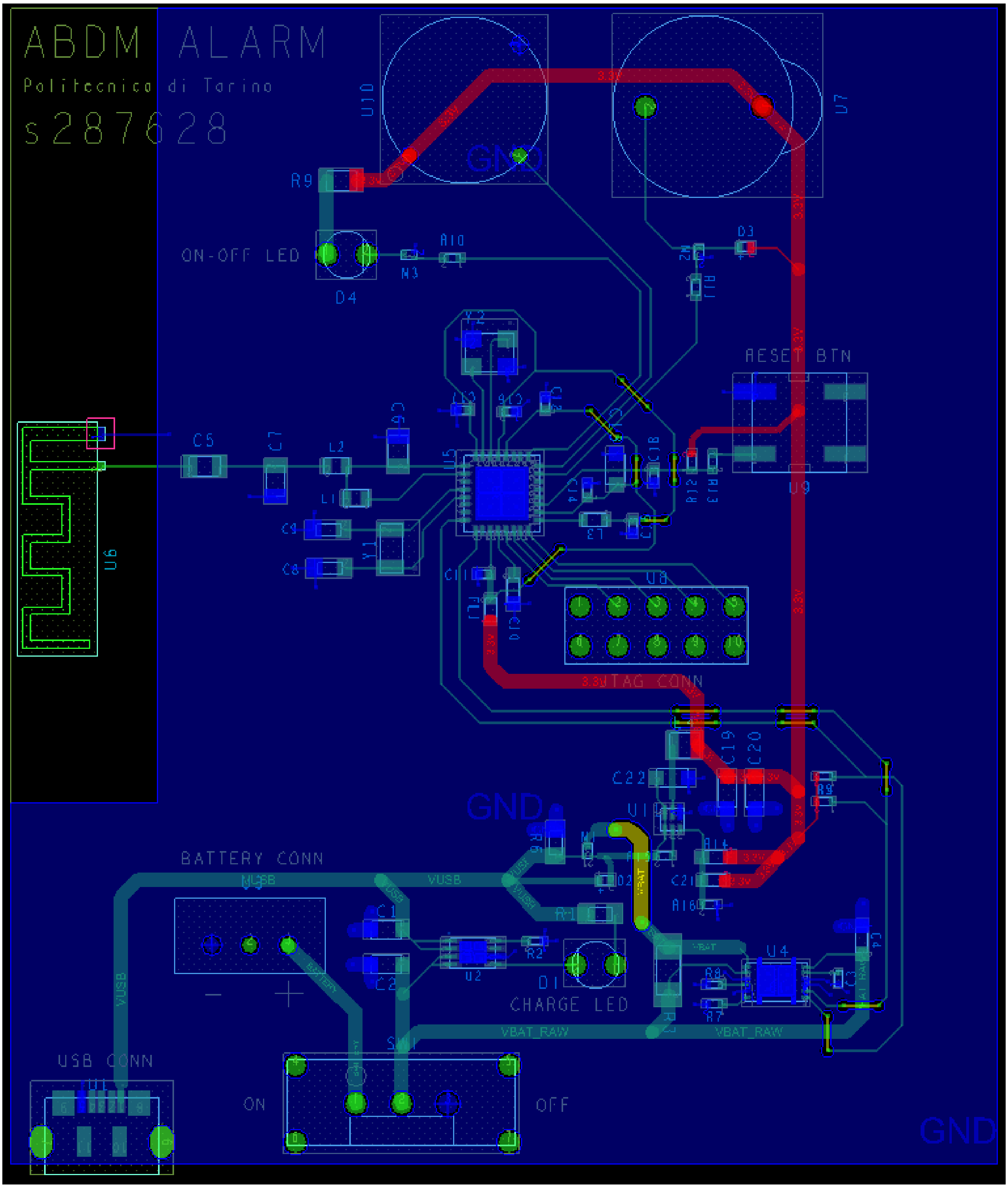

Figure 4.1: Board layout

All the components have been placed according to datasheets recommendations. The decoupling capacitors have been kept as close as reasonably possible to the decoupled pin of the related IC and each of them is connected to the ground plane by means of one or more dedicated VIAs. The antenna has been positioned in a dedicated area without any component or trace nearby and the ground plane has been removed in the region below it. The antenna feed is completely straight, it does not contain VIAs and it is not crossed by any bottom trace; moreover, all the components of the antenna feed are characterized by a self-resonant frequency greater than the antenna frequency (2.4 GHz).

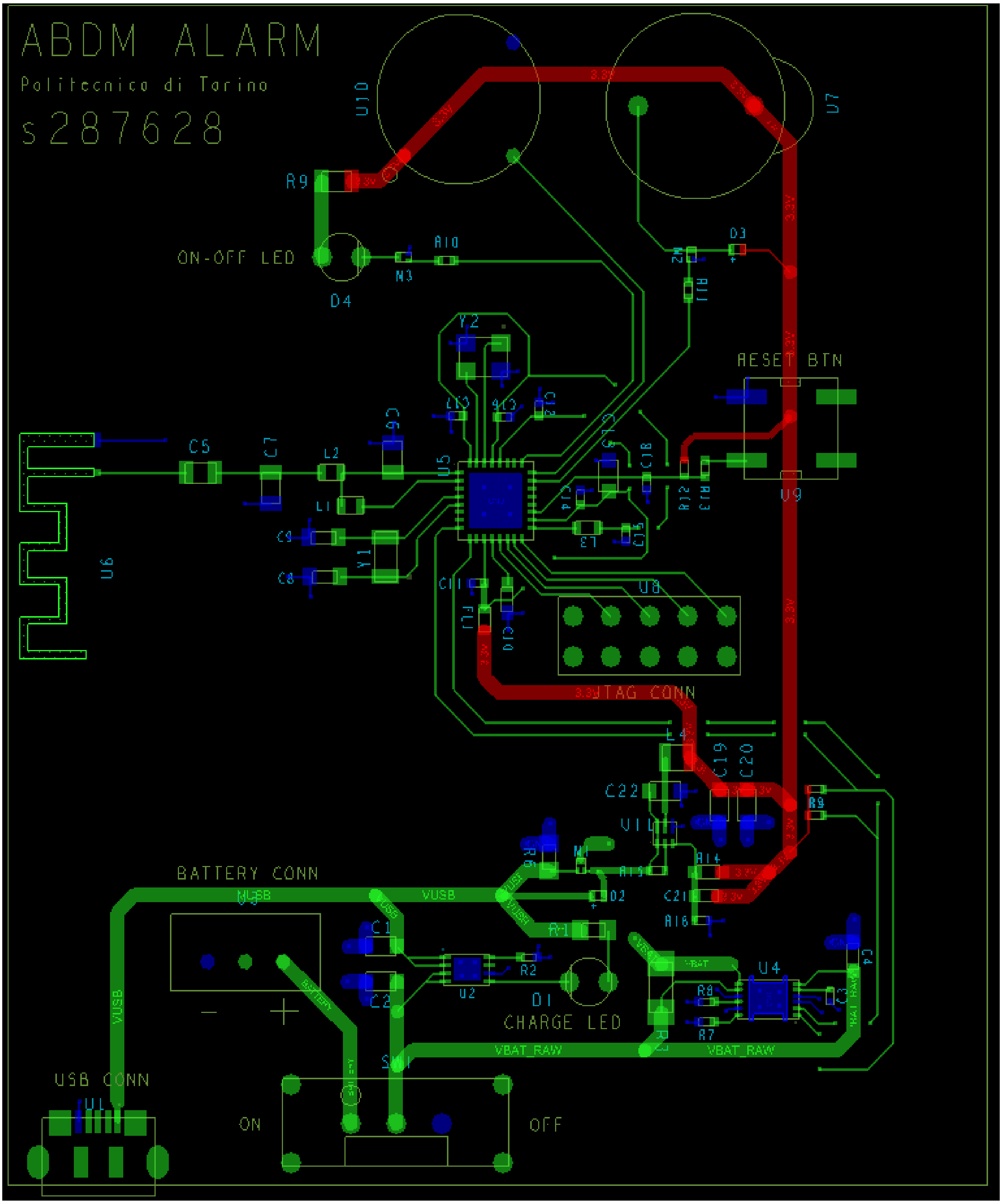

Figure 4.2: Board layout - top view

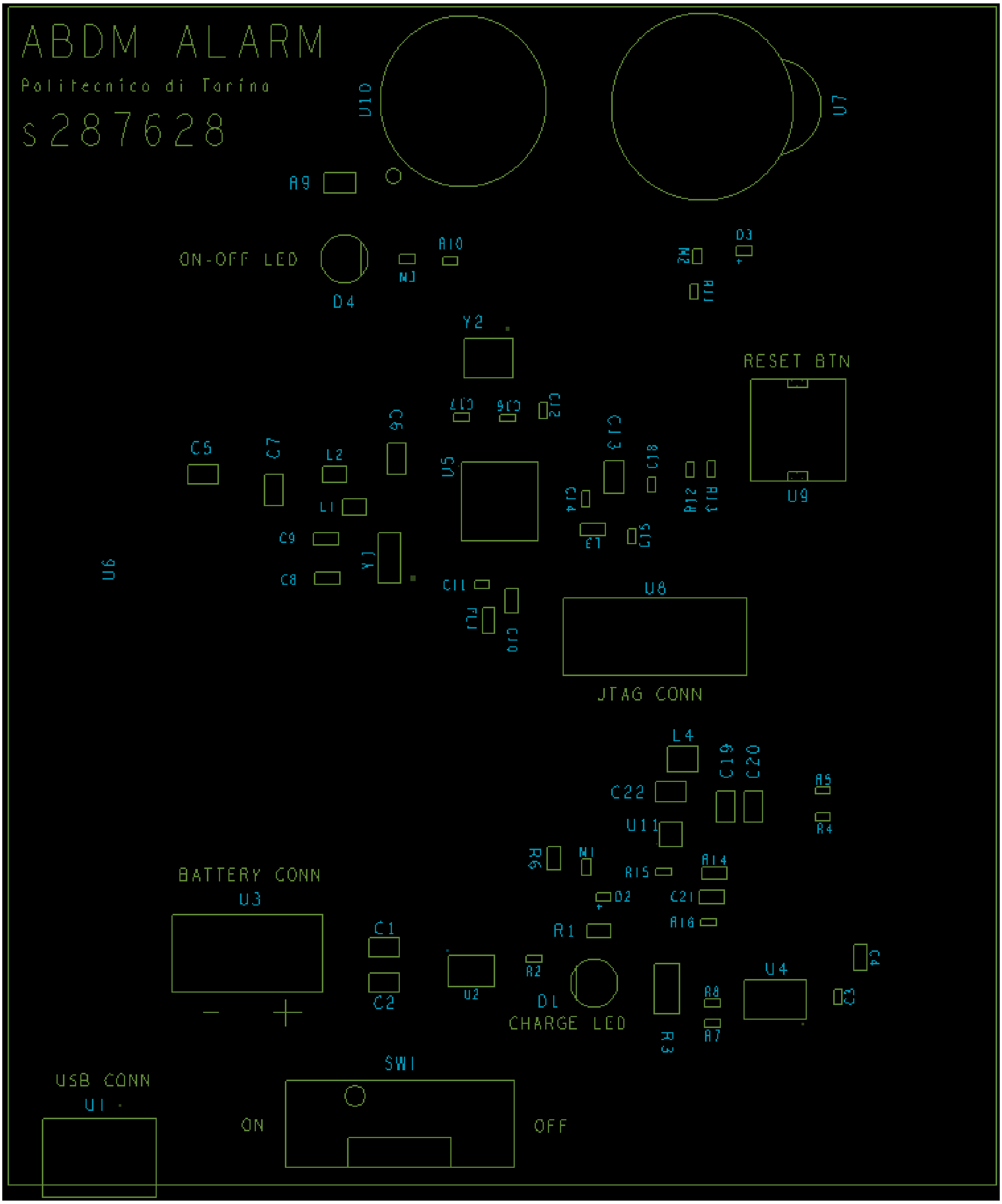

Figure 4.3: Board layout - top view

CURRENT CONSUMPTION

5.1 Microcontroller

The CC2640 current consumption depends on which of its components are in use:

$$\mathbf{I_{TOTAL} = I_{CORE} + I_{PERI}}$$

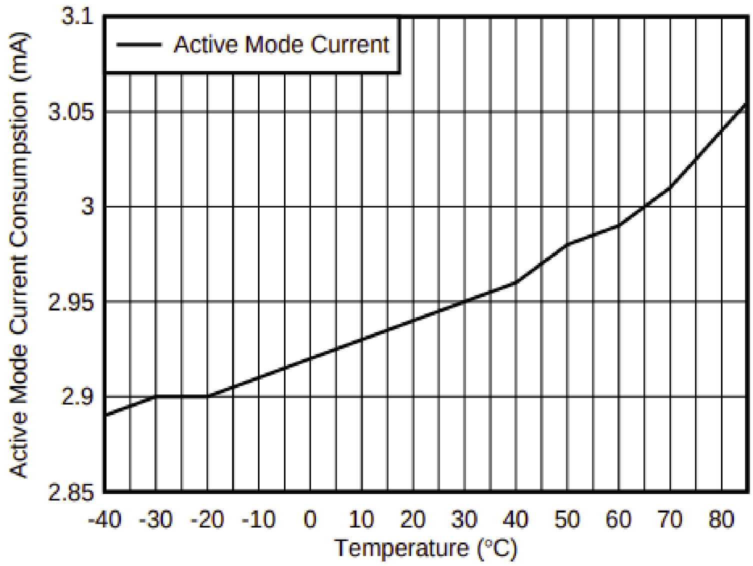

Figure 5.1: $I_{CORE}(T)$ at V_{DDS} = 3V and F_{CLK} = 24MHz in active mode (no RF)

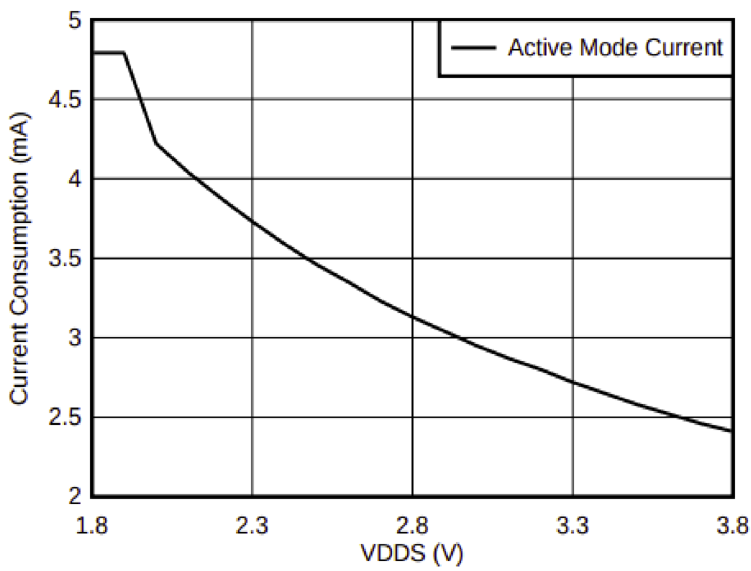

Figure 5.2: $I_{CORE}(V_{DDS})$ at T = 25° and F_{CLK} = 24MHz in active mode (no RF)

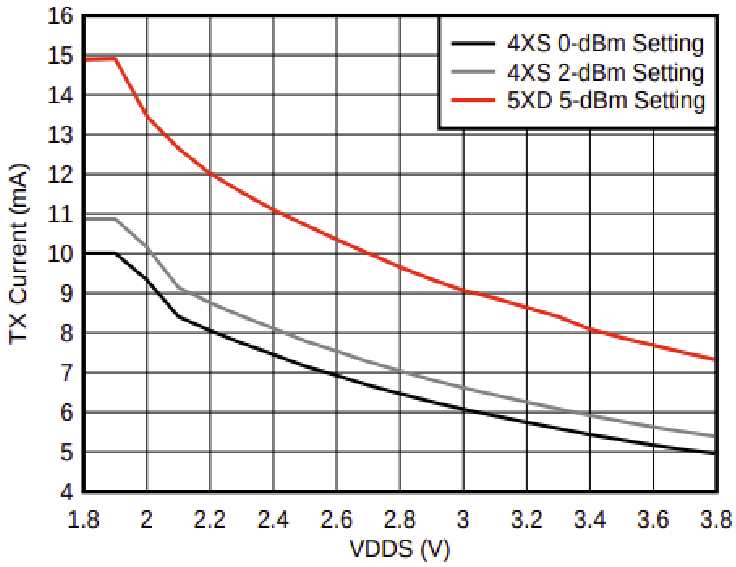

Figure 5.3: $I_{CORE}(V_{DDS})$ in TX mode

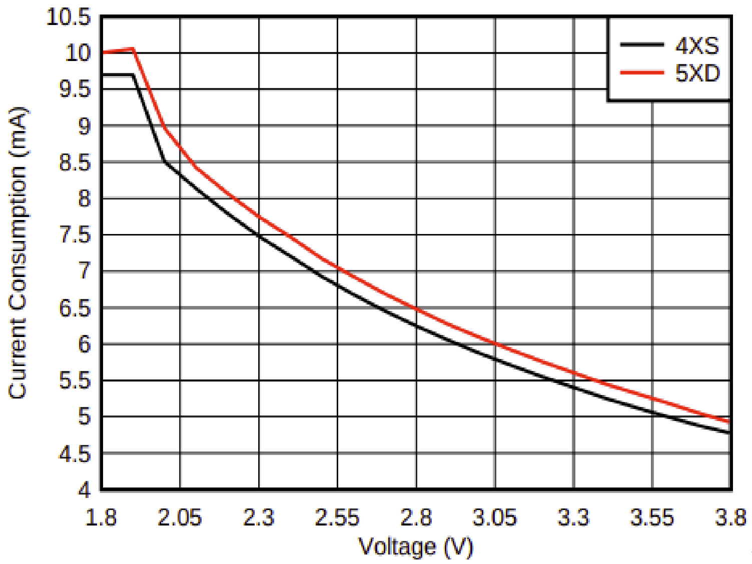

Figure 5.4: $I_{CORE}(V_{DDS})$ in RX mode

Peripheral Current Consumption			
I_{peri}	Peripheral power domain	20	µA
	Serial power domain	13	µA
	RF Core	237	µA
	µDMA	130	µA
	Timers	113	µA
	I^2C	12	µA
	I2S	36	µA
	SSI	93	µA
	UART	164	µA

Figure 5.5: I_{PERI}

In our case, the microcontroller goes in TX mode only when the battery charge status is updated (i.e. once per 10 minutes), when a movement is detected and to notify the user when the detection is turned on or off, therefore we can neglect the TX mode contribution to the average current consumption. On the other hand, the user might send a command from the application at any moment (for instance to disable the detection), which means that the microcontroller must constantly remain in RX mode.

Considering $V_{DDS} = 3.3V$ and a 4XS antenna configuration (i.e. a single-ended connection, which is the one employed in our case) and assuming a temperature of 25 degrees:

$$I_{CORE\ AVG} \approx I_{CORE\ RX} = 5.4\ mA$$

$$I_{PERI} = I_{PERI\ PWR\ DOM} + I_{SER\ PWR\ DOM} + I_{RF\ CORE} + I_{TIMERS} + I_{I2C} = 0.395\ mA$$

$$I_{\mu C} \approx 5.8\ mA$$

5.2 LEDs

The current consumption of each HLMP-K150 LED is equal to 1 mA while active. However, both the LEDs blink with a 50% duty cycle (the frequency is high enough so that the human eye is not able to perceive the blinking), therefore the averege current is equal to 0.5 mA per LED.

5.3 Buzzer

The current consumption of the electromechanical buzzer is equal to 30 mA while active. However, the buzzer is intermittedly turned on for maximum 5 minutes (duty cycle 50%) only when a movement is detected, which is a quite rare occasion. Assuming the detection of 4 intrusion per day (although this number is usually lower in reality), the average current is equal to 0.21 mA.

5.4 Total current consumption and battery duration

All the components which are not related to the battery management are powered by means of the voltage regulator output (which is characterized by an efficiency $\eta \approx 0.9$):

$$I_{OUT\ REG} \approx I_{\mu C} + I_{PIR} + I_{ON\ OFF\ LED} \approx 5.8\ mA + 0.3\ mA + 0.5\ mA = 6.6\ mA$$

$$I_{IN\ REG} \cdot V_{BAT} = P_{IN\ REG} = \frac{P_{OUT\ REG}}{\eta} = \frac{I_{OUT\ REG} \cdot V_{DDS}}{\eta}$$

$$I_{IN\ REG} = \frac{I_{OUT\ REG} \cdot V_{DDS}}{\eta \cdot V_{BAT}} \approx \frac{6.6\ mA \cdot 3.3\ V}{0.9 \cdot 3.7\ V} \approx 6.54\ mA$$

Considering also the battery management components we can estimate the total current consumption and the battery duration:

$$I_{OUT\ BAT} \approx I_{IN\ REG} + I_{CHARGER} + I_{GAUGE} \approx 6.54\ mA + 0.002\ mA + 0.093\ mA = 6.635\ mA$$

$$\text{Battery Duration} \approx \frac{980\ mAh}{6.635\ mA} = 147.7\ h = 6.15\ days$$

PRODUCTION COST ESTIMATION

The following evaluation is performed under the assumption of producing 1000 units. A higher production may lead to an inferior price, whereas a lower production can significantly increase the final cost.

- Microcontroller: 3.98€
- PIR sensor: 6.71€
- Buzzer: 0.68€
- Battery: 13.69€
- Battery charger: 0.645€
- Battery fuel gauge: 1.65€
- Voltage regulator: 0.635€
- Switch: 0.55€
- Pushbutton: 0.35€
- LEDs: 0.166€
- Oscillator (24MHz): 0.224€
- Oscillator (32.768 kHz): 0.215€
- Micro-USB connector: 0.632€
- JTAG connector: 0.257€
- Battery connector: 0.133€
- Capacitors: 0.92€
- Inductors: 0.52€
- Resistors: 0.264€
- Other: 0.47€

- TOTAL PRODUCTION COST: 32.70€

DESIGN HISTORY

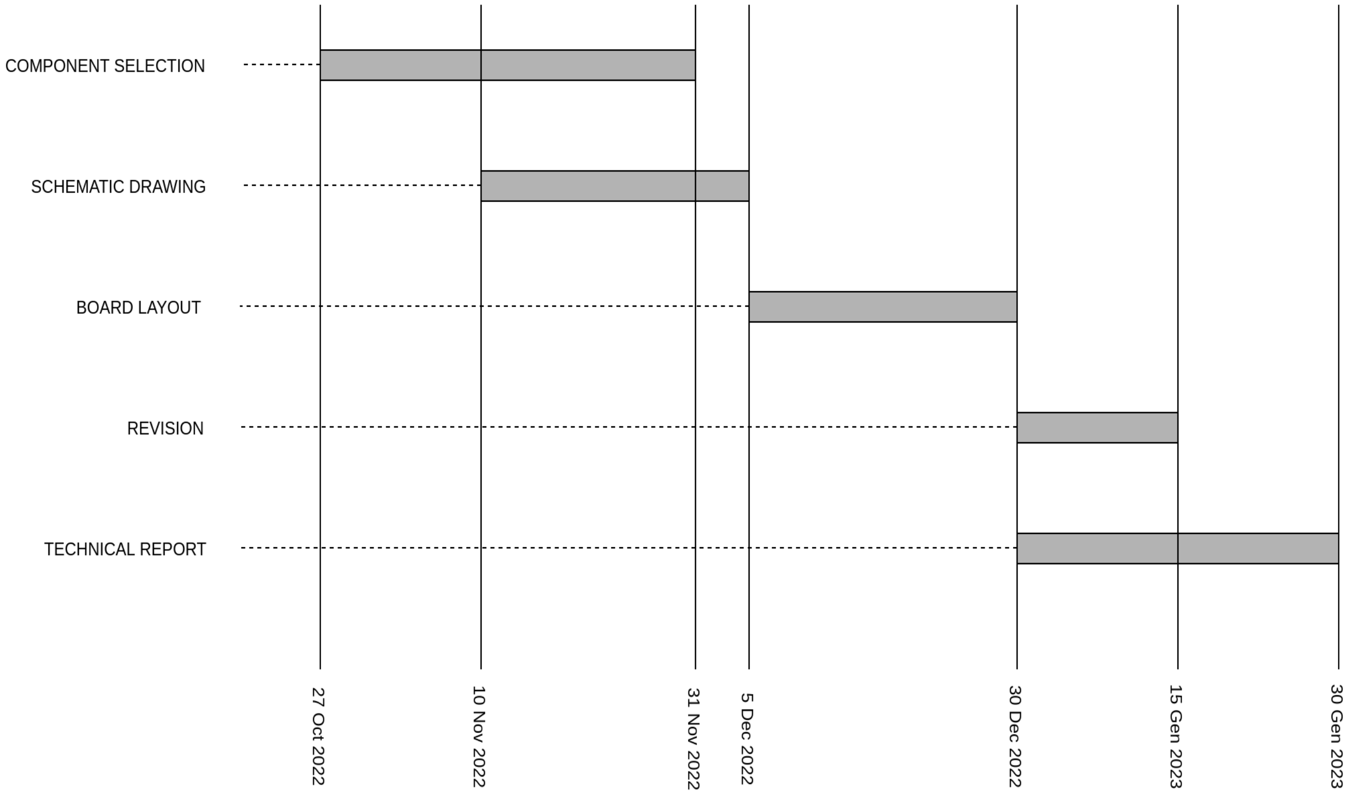

Figure 7.1: GANTT diagram