Wrocław University of Science and Technology

MICROCONTROLLERS PROJECT REPORT

MICROCONTROLERS PROJECT
Subject: FINAL REPORT
Student:

Miłosz Werner 253141............ Time of class: Th. 13:15-15:00 TP

Assistant: dr inż. Grzegorz Budzyń

1. Introduction

The goal of this project was to design our own PCB, restricted by the rules, parts and dimensions picked by the professor individually. Additionally an obligatory simulation was to be done in LTSpice of analogue and power circuitry.

Each PCB was required to consist of specified components and rules:

- Analogue input
- Digital input
- Power supply for the MCU
- Clocking
- Microcontroller
- Output
- MCU to be programmed by UART
- 2-layer PCB of an area smaller than 20 cm^2
- Components to be available at the time of designing at one of 3 vendors (Farnell, Mouser, TME)

Components assigned:

- Analogue input – Temperature sensor based on Pt1000 with usable range -50 to +200C
- Digital input – 2-axis accelerometer on I2C
- Power supply – Battery double AAA cell (VCC 2,1V)
- MCU – STM8 in TSSOP20
- Clocking – internal
- Output – LCD 2x16 char display

Every component was available for instant order on mouser.com on 24.02.2022

Schematics were done using Altium Designer 2020

2. Components

2.1 Analogue input

For the analogue input matching the requirements, a PTF from MTE Connectivity was selected: PTFC102B1A0.

This is a platinum thin film resistance temperature detector. It consists of a structured platinum film on a ceramic substrate, passivated by a glass coating. The usage of platinum as the resistive material provides excellent long-term stability. Due to small size and low mass this RTD has a fast response time and low time constant.

For ease of use, ability to extend the placement of the RTD and modularity, the Pt is to be made attachable with a standard 2 gold-pin header.

Figure 1 Pt1000 used in the design

Pt-RTD are described as very accurate, with linear characteristics. They are defined by DIN EN 60751 norms with standardised calculation formulas:

For T ≥ 0 °C: $R_{(T)} = R_{(0)} \cdot (1 + a \cdot T + b \cdot T^2)$

For T ≤ 0 °C: $R_{(T)} = R_{(0)} \cdot [1 + a \cdot T \cdot b \cdot T^2 + c \cdot (T - 100°C) \cdot T^3]$

Coefficients:

$$a = 3{,}9083E - 3$$

$$b = -5{,}775E - 7$$

$$c = -4{,}183E - 12$$

Tolerance: $Class\ F\ 0{,}6\ (C)$: $\pm\left(0{,}60 + 0{,}06 \cdot \left|\frac{T}{°C}\right|\right) °C \qquad (-50 \ldots + 600°C)$

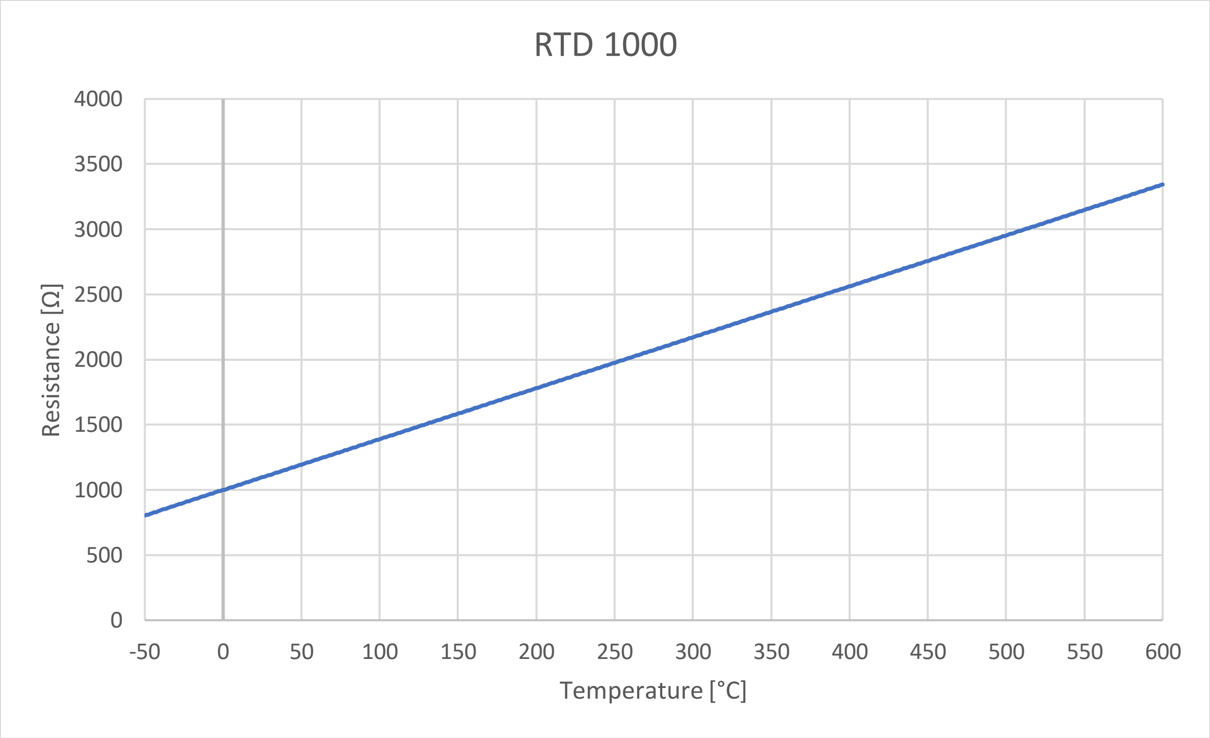


Figure 2 Resistance characteristics

To be able to measure the change of resistance of the RTD a voltage divider was built. Any change of temperature, and therefore resistance, would be noticed as a change in potential. As the baseline voltage drop across the RTD in 0 degrees Celsius would be 190mV in a perfect setup, for R5 being 10kΩ and RTD 1kΩ for said temperature.

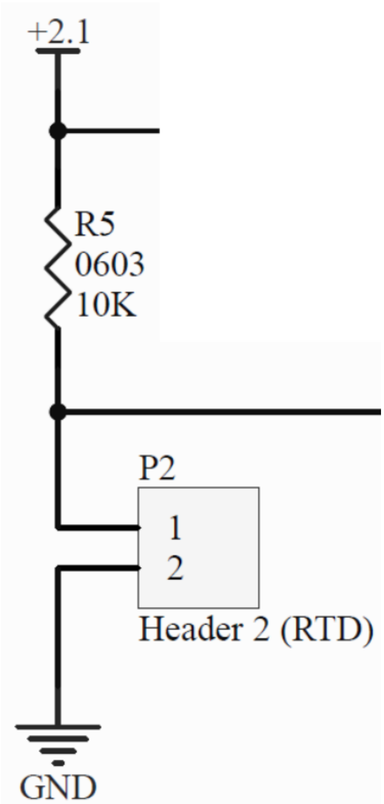


Figure 3 Voltage divider used to measure the temperature of the RTD

To supply the MCU with information an analogue to digital converter was required. For this a classic successive approximation register (SAR) analogue-to-digital (A/D) converter was used, Burr-Brown ADS7816 EB/250 to be exact. The device features a 12-bit successive approximation ADC, Sample/Hold function, a comparator, DAC, and SAR. It requires a 5V supply voltage to operate.

Input voltage is sampled and held steady by a capacitor and a voltage follower which then provides this voltage to the comparator. The SAR then sets the most significant bit of its 10-bit resolution to 1 and sends the value to the DAC. Since the 12 bits sent represent a decimal value of 512, which is half of the total bit value, the output voltage of the DAC is also half of the supply voltage, 2,5V to be exact. If input voltage is higher than the DAC output the comparator outputs a value of 1 which is set to the next-left bit of the SAR. If the input voltage is lower, then comparator outputs value 0. This cycle repeats until all 10 bits are processed and we get the result.

The resolution of this ADC depends on the reference voltage, which can be varied from 100mV to 5V, with a corresponding resolution from 24µV to 1.22mV.

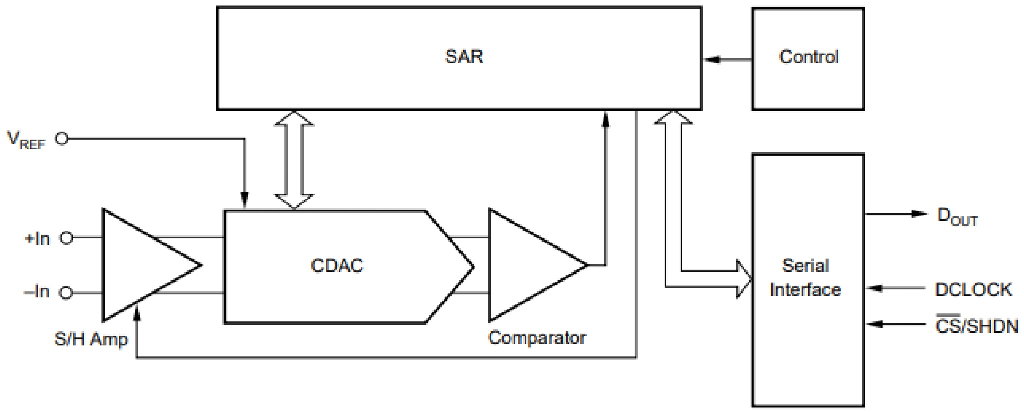


Figure 4 Block diagram of ADS7816

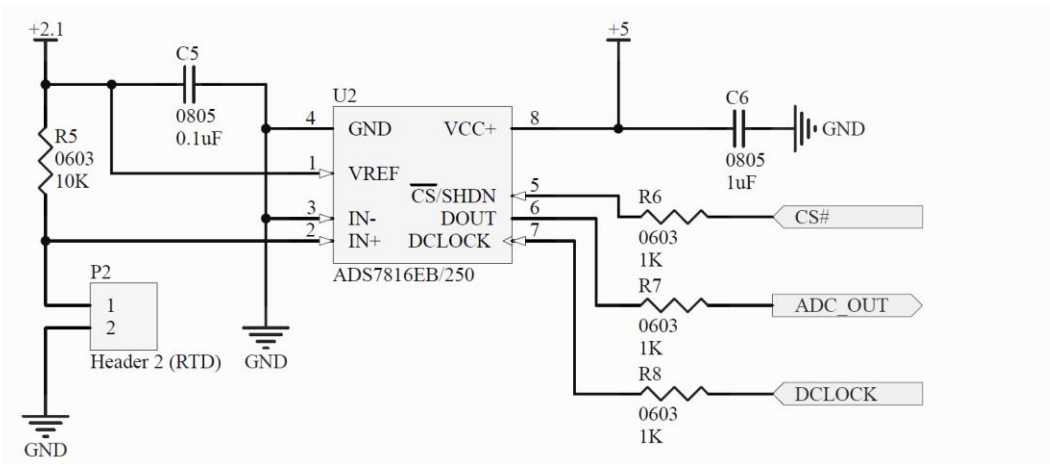


Figure 5 Analogue input and its ADC implementation

The CS#, ADC_OUT and DCLOCK lines would be connected to the MCU via SPI interface.

2.2 Digital input

For the digital input matching the requirements, a 2-axis accelerometer from MEMSIC was selected, MXC6244AU:

This a complete 2-axis accelerometer system with a programmable internal anti-vibration filter. This filter can provide as much as 45dB attenuation above 25Hz, and 60dB attenuation above 50Hz. In addition, the device has 8 built in, I2C programmable angle thresholds. If the device orientation with respect to vertical output changes state to alert the system to a tip-over of fall down event.

The MXC6244AU uses MEMSIC's proprietary thermal accelerometer technology. Because the sensing element uses heated gas molecules instead of a mechanical beam structure, the device is extremely robust and reliable, with 50,000g shock tolerance, no possibility of "stiction," virtually no mechanical resonance, and very high accuracy over temperature.

Accelerometer is power from a single 2,7V to 5,5V supply, and is packages in a small 6-pin 3x3x1 mm LCC package.

Figure 6 MEMSIC MXC6244AU 2-axis accelerator on I2C

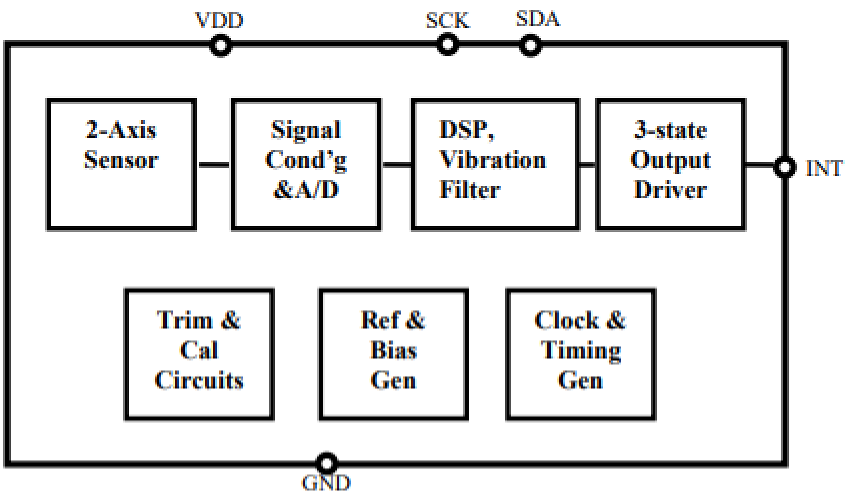


Figure 7 Functional block diagram of MXC6244AU

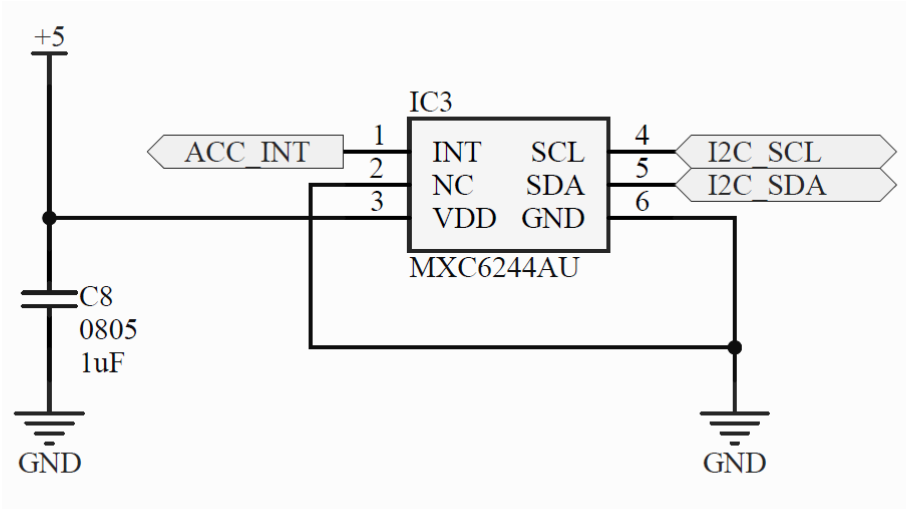


Figure 8 Digital input implementation

2.3 Power supply

The whole PCB is restricted to the power supply chosen individually by the project overseer. Every component is to be power entirely by 2 AAA batteries. For this a switching step-up DC-DC converter was used. Given the requirement of powering some components with a 5V DC supply voltage, a dual converter system was required. First converter would boost the voltage supplied from the batteries connected in series to 5V, with the second one stepping down the voltage to the one specified by the rules, 2,1V to be exact.

To match these tasks, 2 converters from Analog Devices were chosen: LT1110 and its 5V fixed cousin LT1110-5, both being in 8-lead plastic SOIC package, with designator CS8.

The LT1110 is a versatile micropower DC-DC converter. The device requires only three external components to deliver a fixed output. The minimum supply voltage is 1V. The 70kHz oscillator allows the use of surface mount inductors and capacitors. Quiescent current is just 300µA. The device can easily be configured as a step-up or step-down converter.

The device can handle a supply voltage of 15V and 36V for step-up and step-down mode respectively. Step-up is limited to output of 50V with maximum current of 1.5A and power dissipation of 500mW.

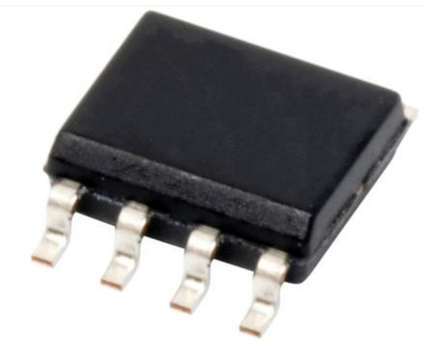


Figure 9 LT1110CS8

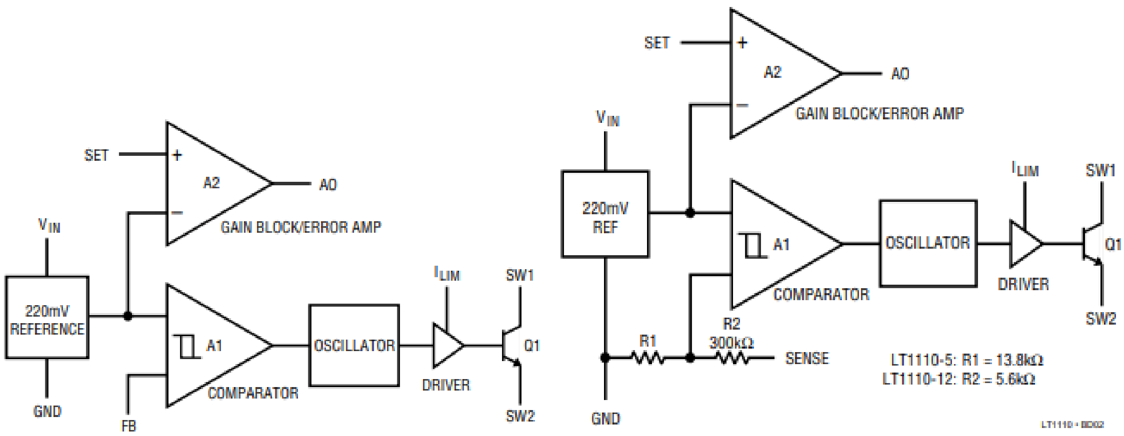


Figure 10 Block diagram of: LT1110 (left), LT1110-5,-12(right)

The documentation consists of a section of typical applications, one of which was a step-up operation from 3V to 5V.

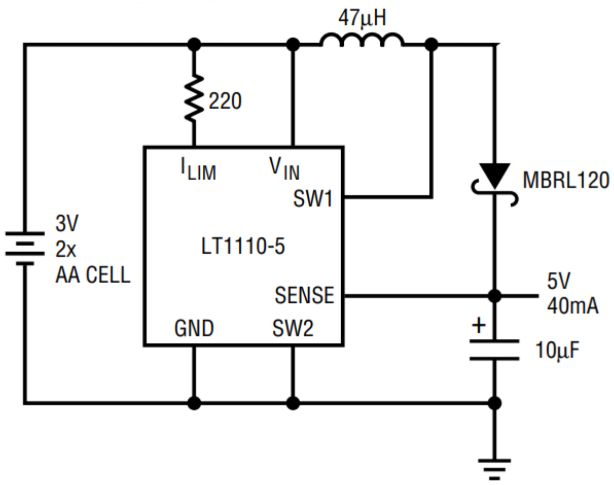


Figure 11 3V to 5V step-up converter

MBRL120 is a surface-mount equivalent of a 1N5818 Schottky diode equivalent. Due to a lack of supply, a SS13-LTP SMD Schottky Diode was used, which also is a 1N5818 equivalent.

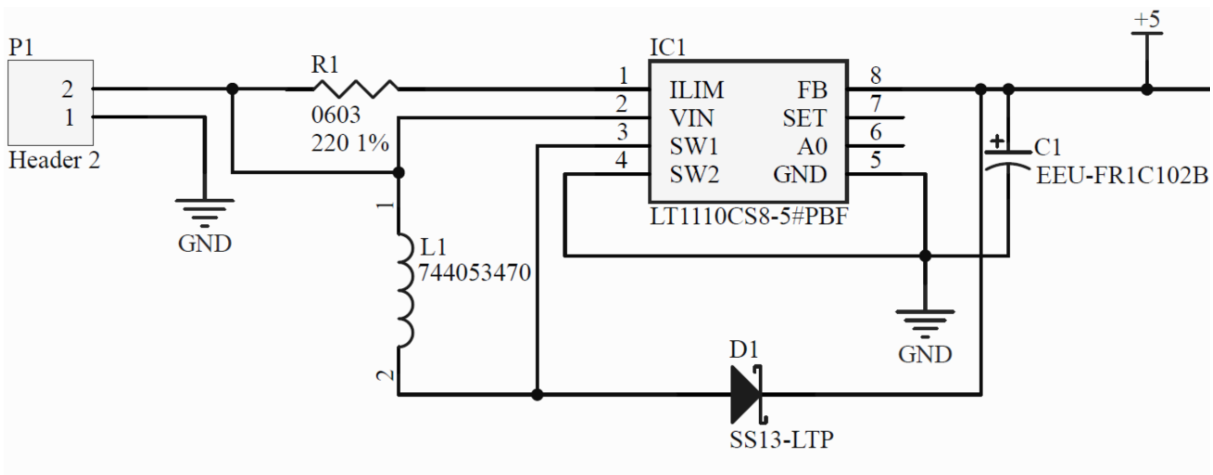
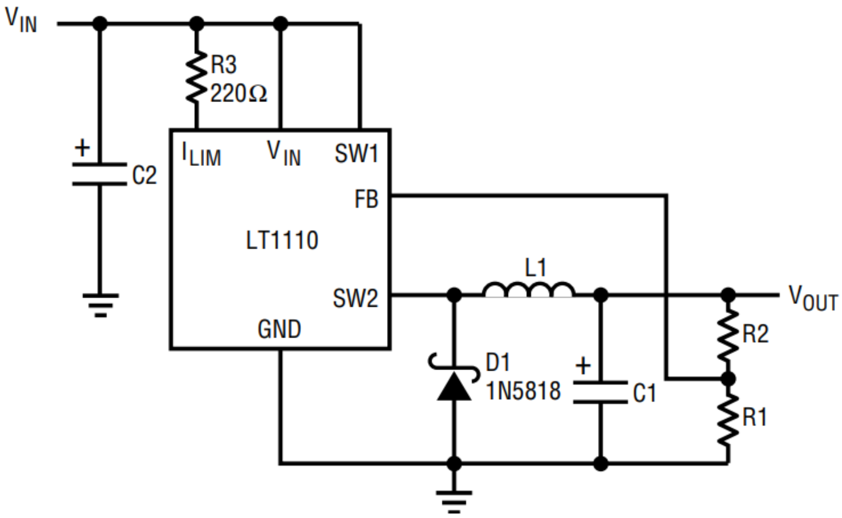


Figure 12 Implementation of a 3V to 5V step-up converter

For the buck mode operation, a LT1110 was used



Where the output voltage is determined by:

$$V_{OUT} = \left(1 + \frac{R2}{R1}\right)(220mV)$$

For which resistors were selected: $R1 = 180\Omega$ designated as R3, $R2 = 1{,}5k\Omega$ designated as R4, giving us a voltage of:

$$V_{OUT} = \left(1 + \frac{1{,}5k\Omega}{180\Omega}\right)(220mV) = \left(\frac{28}{3}\right)(220mV) \approx 2{,}053V$$

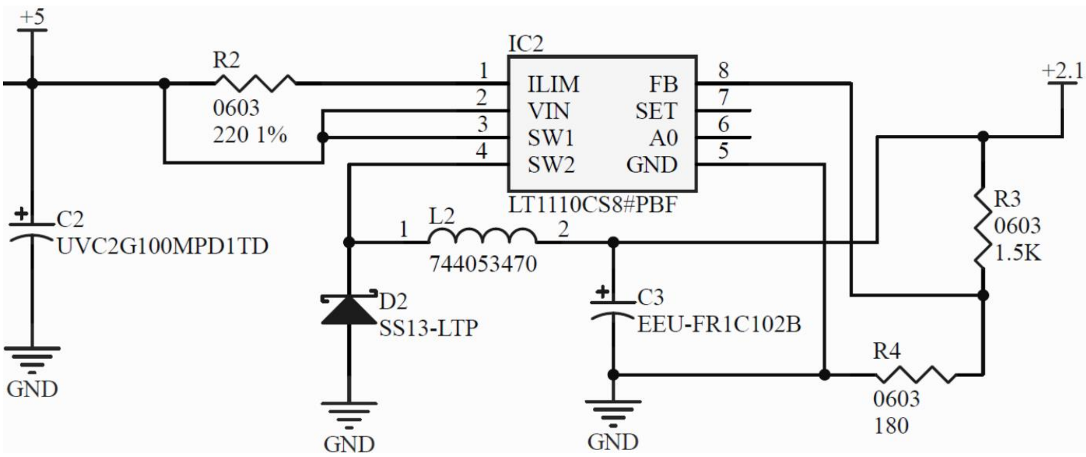


Figure 13 Implementation of 5V to 2,1V step-down converter

SS13-LTP SMD Schottky Diode was used, which is a 1N5818 equivalent.

While for both operations working separately, the 10µF electrolytic capacitor (C1 in both diagrams) would be sufficient, this is not the case when combining them. This resulted in the capacity increase to 1000µF.

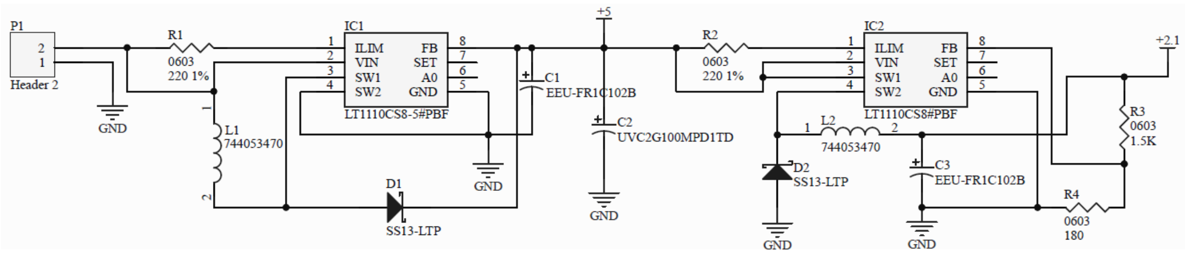


Figure 14 Implementation of a switching power supply

2.4 Microcontroller

The microcontroller chosen by the project overseer was to be a MCU working on a supply voltage of 2,1V and to be a STM8 in TSSOP20 package.

Additionally, considering the components used for other requirements, the MCU was also required to support SWIM, internal clock, UART, SPI and I2C. The required power supply limited the choice of available microcontrollers to select. Finally, STM8L101F2P3 was selected. This is an 8-bit ultra-low power microcontroller with up to 8Kbytes of Flash, with other prominent features:

- Supply voltage range 1,65V to 3,6V
- Low power consumption (Halt: 0.3 µA, Active-halt: 0.8 µA, Dynamic Run: 150 µA/MHz)
- Internal 16MHz RC with fast wakeup time
- Internal low consumption 38kHz RC
- Up to 29 external interrupt sources
- Up to 30 mappable on external interrupt vectors I/O pins with programmable input pull-ups
- 21 internal registers, 20 addressing modes including indexed, indirect, and relative addressing, and 80 instructions

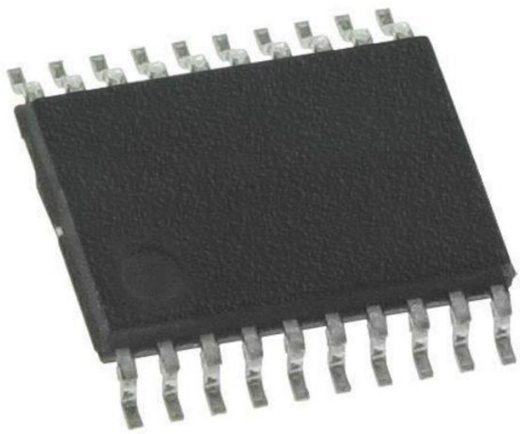


Figure 15 STM8L101F2P3

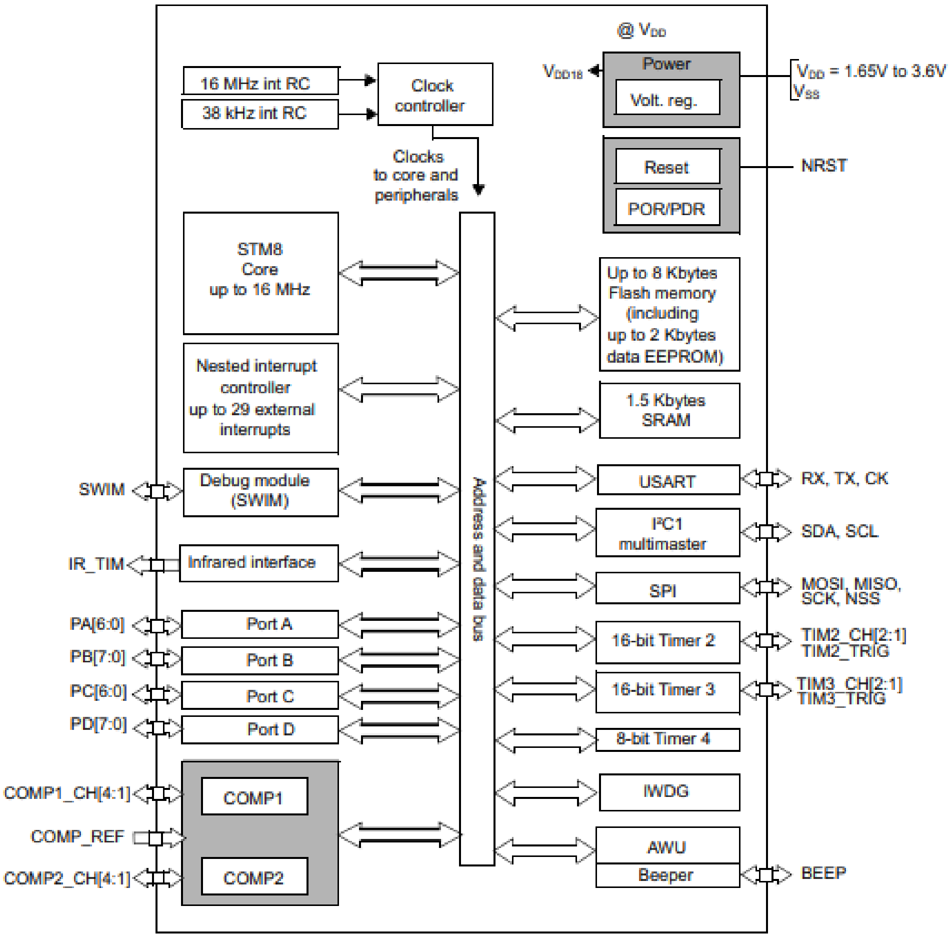


Figure 16 Block diagram of STM8L101xx family

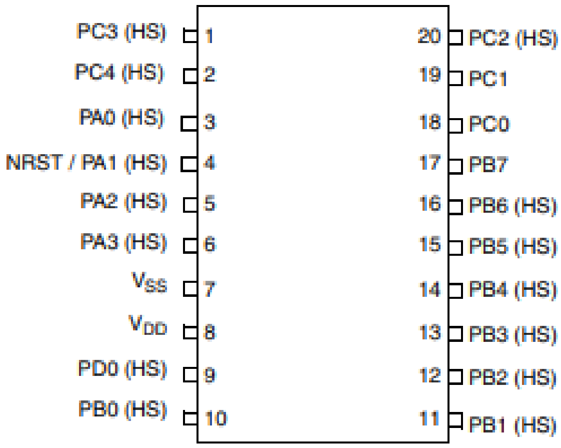


Figure 17 20-pin TSSOP package pinout. HS corresponds to 20mA high sink/source capability

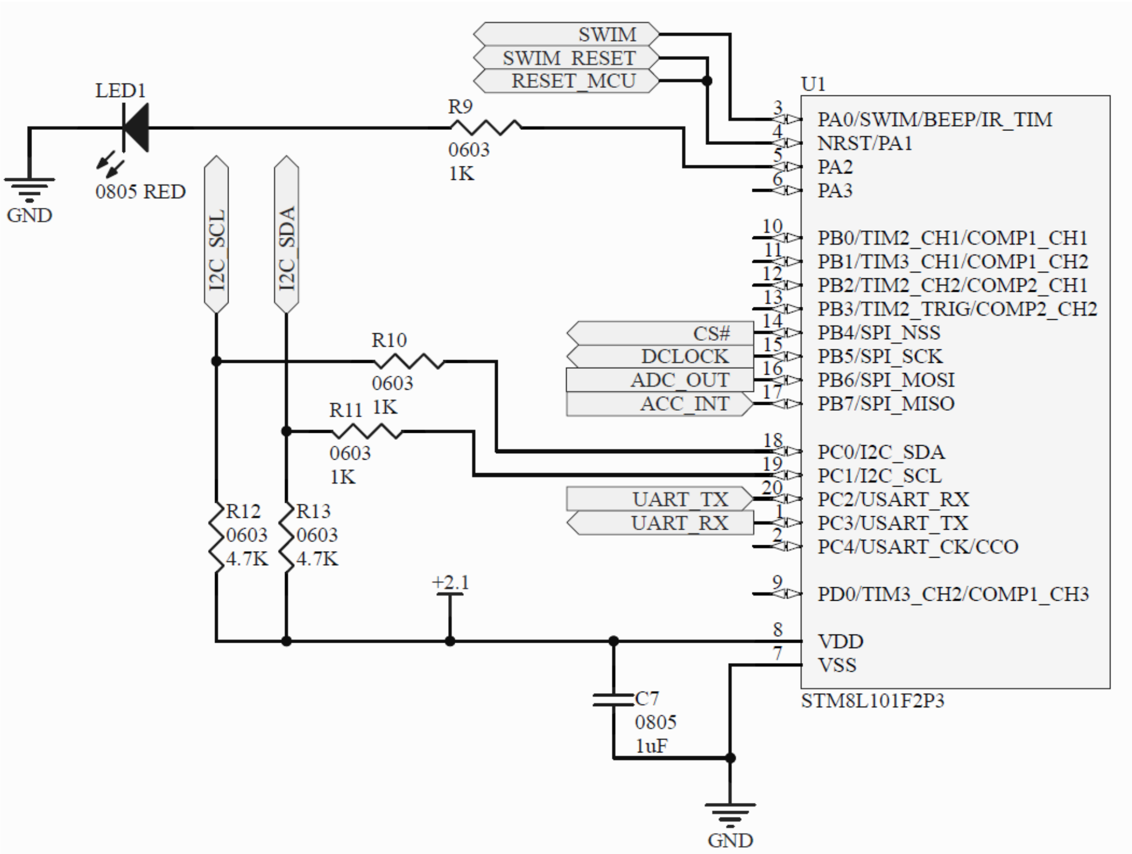


Figure 18 Implementation of STM8L101F2P3 MCU

To facilitate the I2C bus, 4 additional resistors were required, 2 for each lane: 100Ω for data connection and 4,7kΩ for power connection.

Apart from the microcontroller specific requirements, it was also stated to add LED that could blink, which is the red LED1 present on the PA2 with a 1kΩ resistor for current limiting, and an external reset circuit:

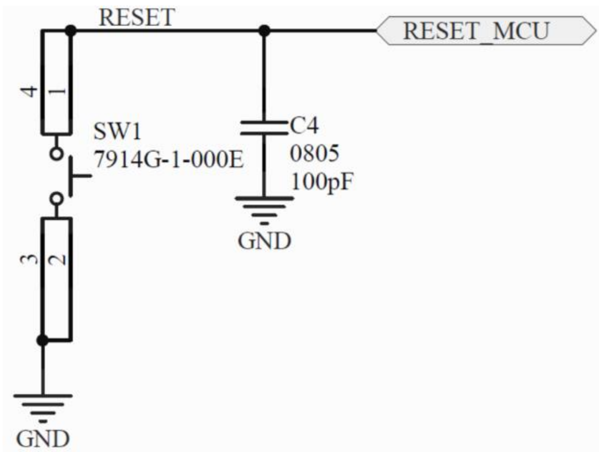


Figure 19 Implementation of a simple reset circuit

SWIM is connected in parallel to the reset circuit, as it possesses an ability to reset the MCU externally.

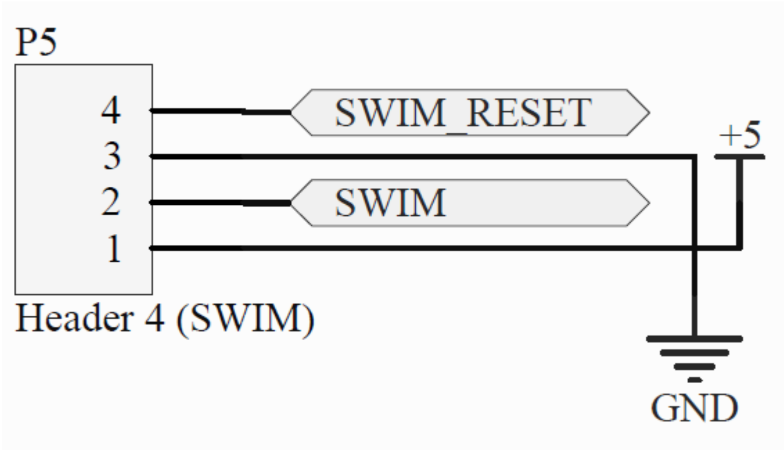


Figure 20 Implementation of SWIM

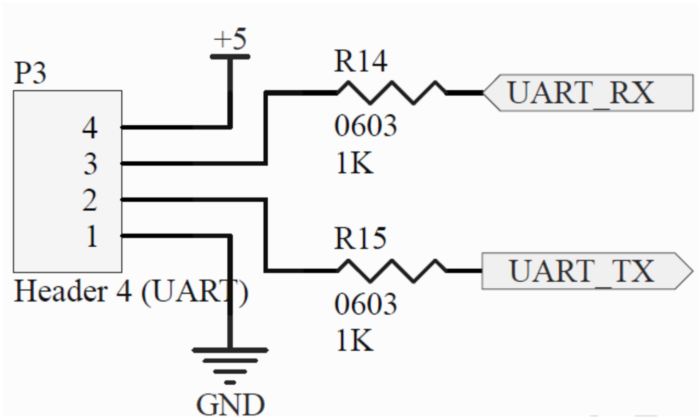


Figure 21 Implementation of UART

2.5 Clocking

Clocking for the PCB was initially set to be an external crystal SMT. This however was changed due lack of supply of STM8 microcontrollers that would both include, low power supply requirement of 2,1V and external clocking. After consultation with the project overseer, it was concluded that the clocking would be changed to internal to accompany a change of the MCU that fit in the desired power requirement and be in stock at the time of design.

2.6 Output

The last required component was an LCD 2x16 char display. With the original plan to connect every required pin to the MCU quickly failing due to already taken pins from all other components a change of approach was needed. In the end it was decided to connect the LCD display via I2C, which would reduce the number of required pins to only 4: VDD, VSS, SDA, SCL.

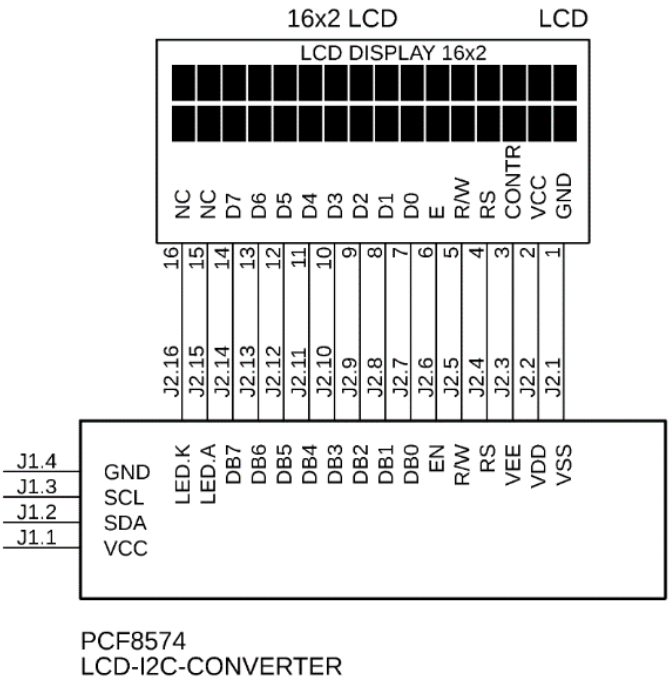


Figure 22 Implementation of PCF8574 I2C converter for a 2x16 LCD display

Additionally, designing of the converter can be omitted, and possible to purchase an external I2C converter separately. Luckily, there is a common solution in amateur electronics, and it is possible to purchase a bundled LCD 2x16 char display with the I2C converter directly soldered with LCD's pins. For this project, LCD with a HD44780 converter was used.

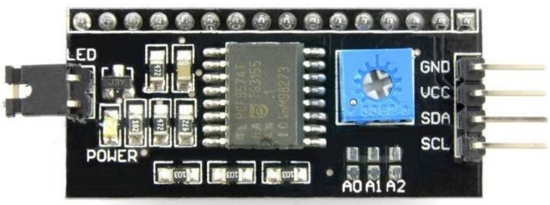


Figure 23 LCD 2x16 char display (left), I2C converter (right)

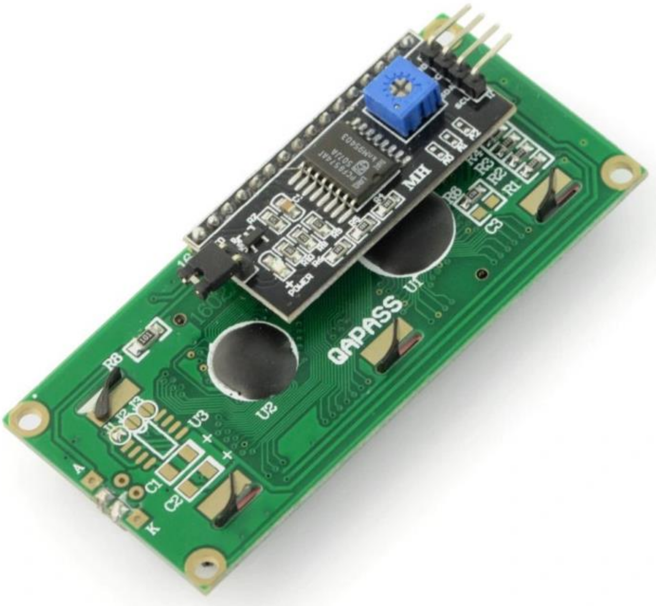


Figure 24 LCD 2x16 char displayed with I2C converter directly soldered on

To connect the display to the board, a set of 4 standard cables would be used between the I2C pins and a 4 gold-pin header.

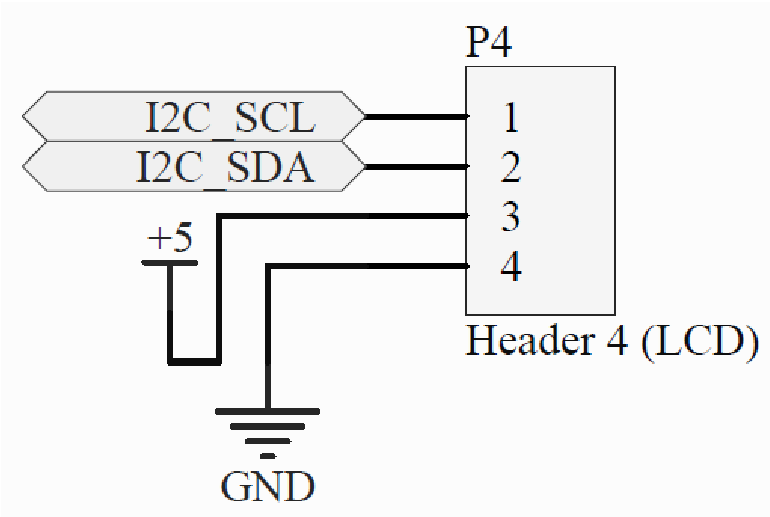


Figure 25 Implementation of LCD connection

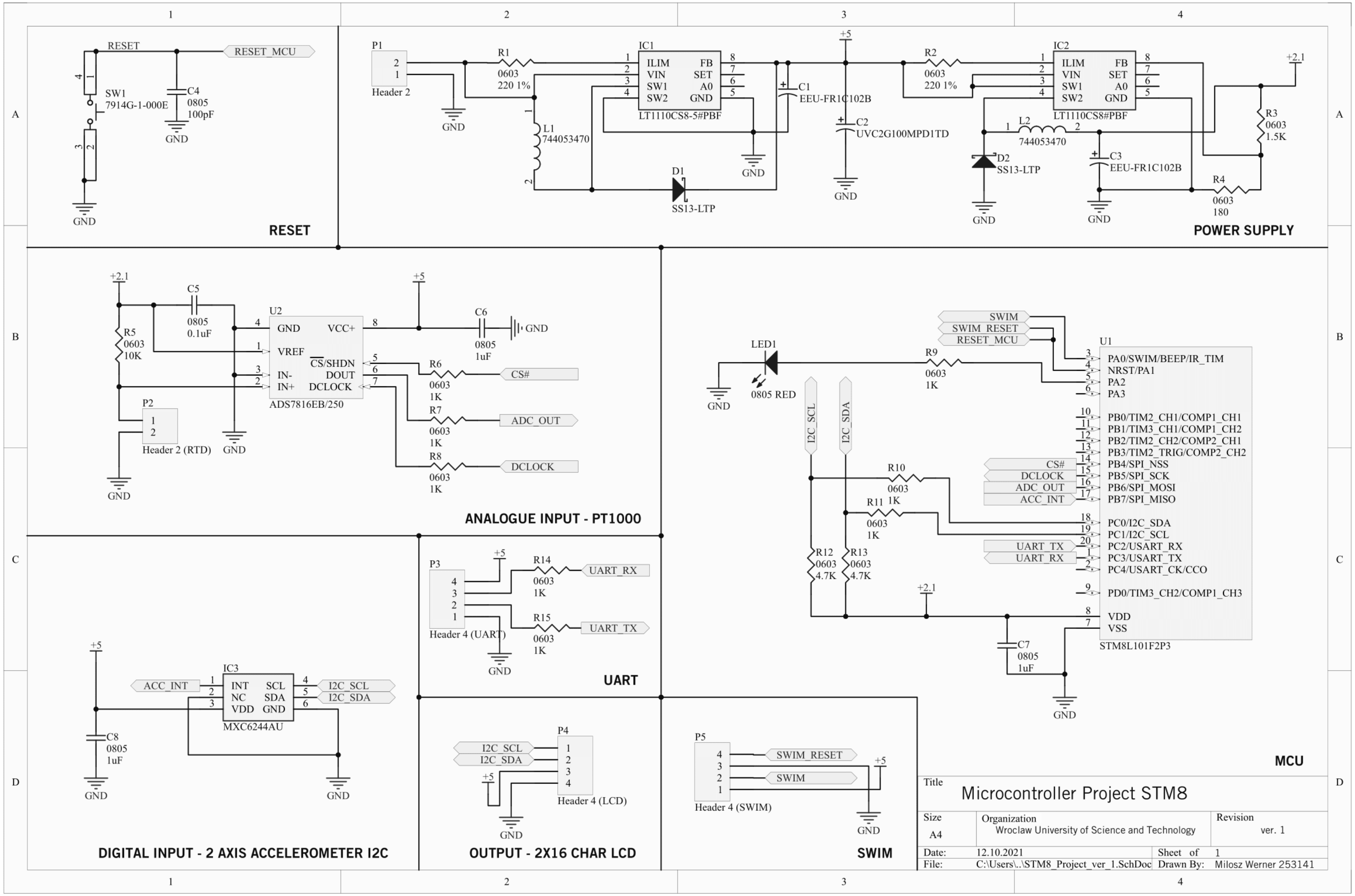


Figure 26 Schematic of the PCB

3. LTSpice simulation

To accomplish the project, it was required to conduct a simulation of the power section of the printed circuit board. This was done to check whether the initial calculations were correct, and their effect on the sensitive analogue circuitry. For this LTSpice was used. It is extremely important to use the most accurate model for each component possible.

Circuits were recreated with utilization of built-in LTSpice models and components.

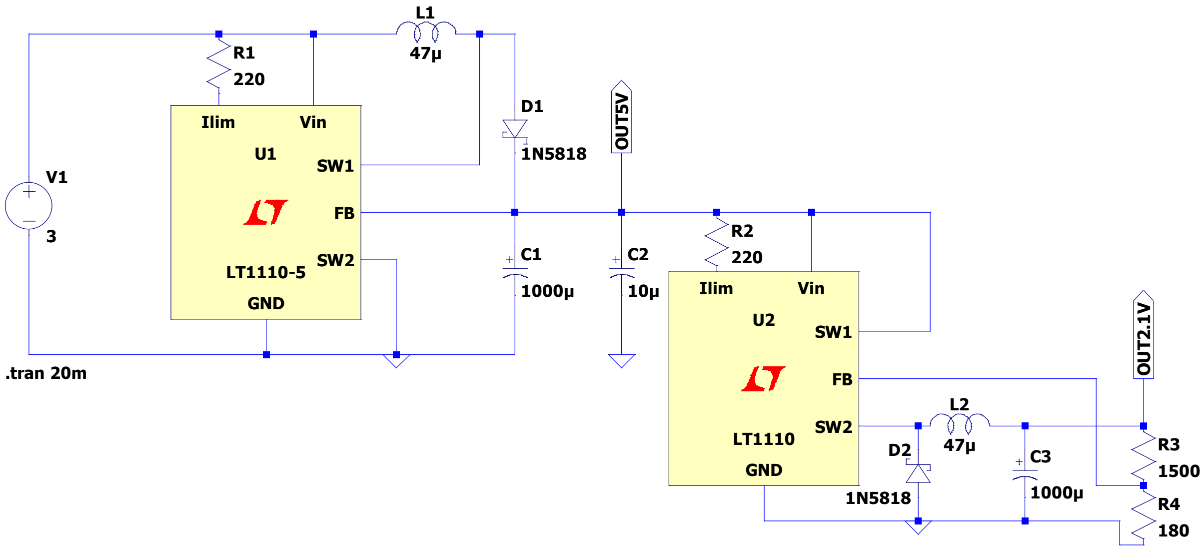


Figure 27 Power circuit model in LTSpice

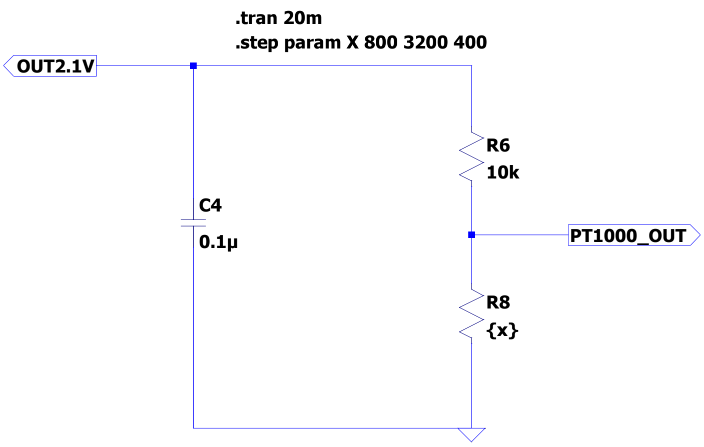


Figure 28 Analogue input model in LTSpice

Full scale simulation required the combination of both circuits, as every change in a switching power circuit would be noticeable.

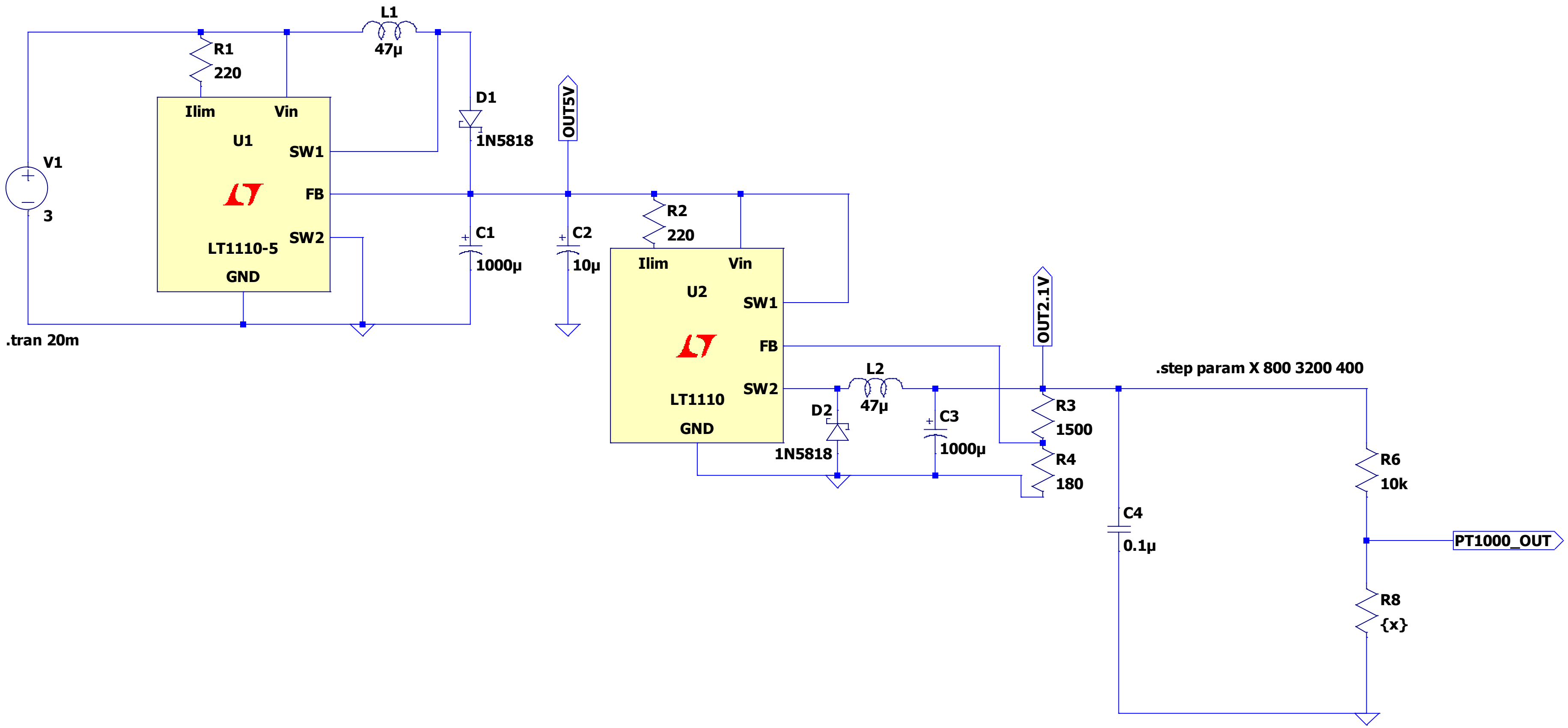


Figure 29 Power and analogue circuit model in LTSpice

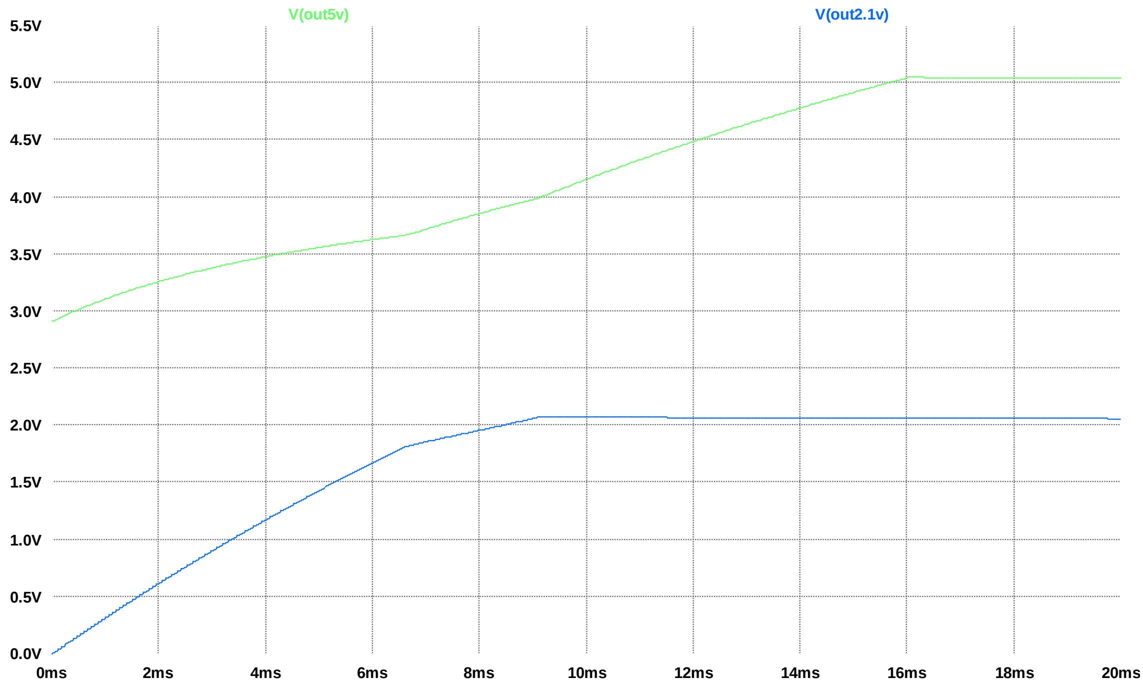


Figure 30 5V and 2.1V power output graph

The 5V circuit reaches its goal of 5,0485 V in 16 ms. This is due to the use of 1000 µF capacitors. After that point, the switching power converter holds the voltage steady, with an overall fluctuation of 0,015 V. The difference between its ideal voltage and the simulated value is less than 1%.

The 2,1V circuit reaches its goal of 2,0728 V in 9 ms. It also holds the voltage steady, with a similar fluctuation of around 0,015 V. The difference between its ideal voltage and the simulated one is around 1,3%.

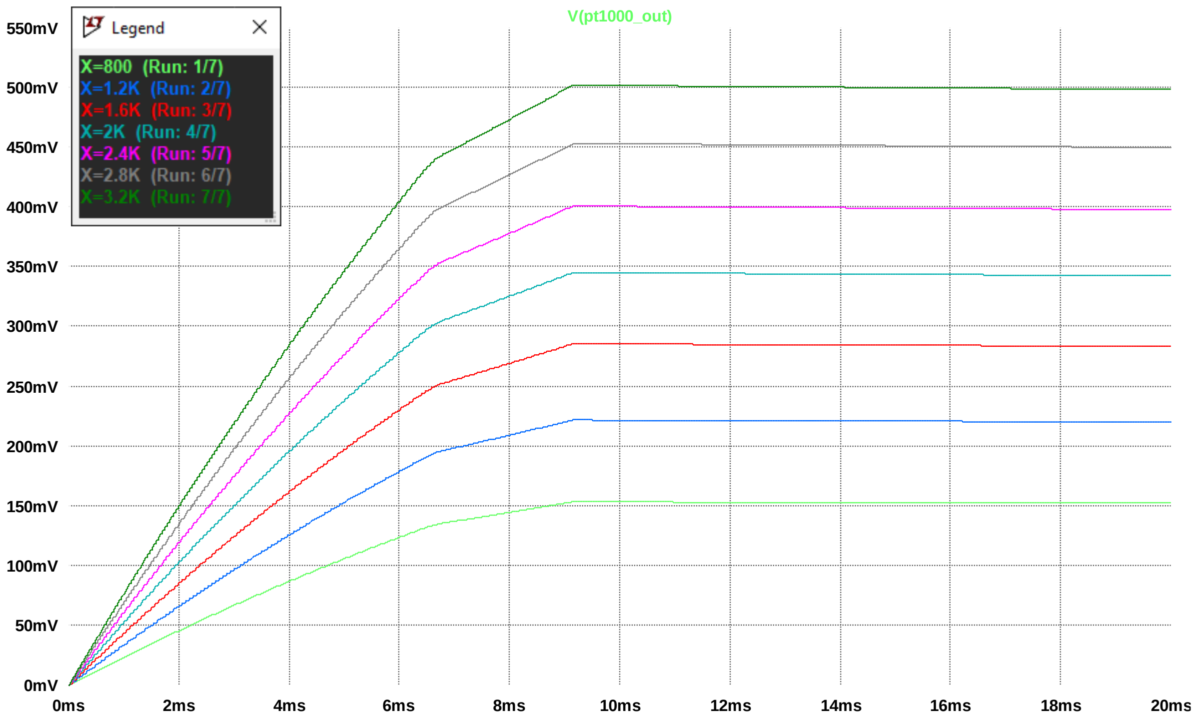


Figure 31 Analogue circuit output for 7 different resistance values

The analogue circuitry simulation was done to check the output of the voltage divider of a 10kΩ resistor and the PT1000. From previous calculations it was established that the resistance of the RTD increases linearly with the temperature. This allowed for a simple *step* function to be run, with its values increasing from 800 Ω to 3,2 kΩ, which correspond to the temperature range of roughly -50 to +570 degrees Celsius.

The *step* function would be run linearly, with every step increasing by 400 Ω, or ≈100°C. At the temperature of -50°C, voltage divider resulted in an output of 152 mV, and at the maximum temperature of +570°C, voltage divider resulted in an output of 500 mV. This gives an estimated change of 0,56 mV per 1 degree.

Given the minimum operating input voltage of the ADC of 100 mV, the system proved that it can be used in the real world.

4. Physical design

During the design, it was important to keep the PCB modular, with the use of header gold-pins, separating the power sensitive components apart from each other. Every component apart from the electrolytic capacitors is mounted using SMT.

Track width is 0,3 mm standard, 0,5mm for power tracks, Via diameter and hole size: 1,27 mm; 0,711 mm.

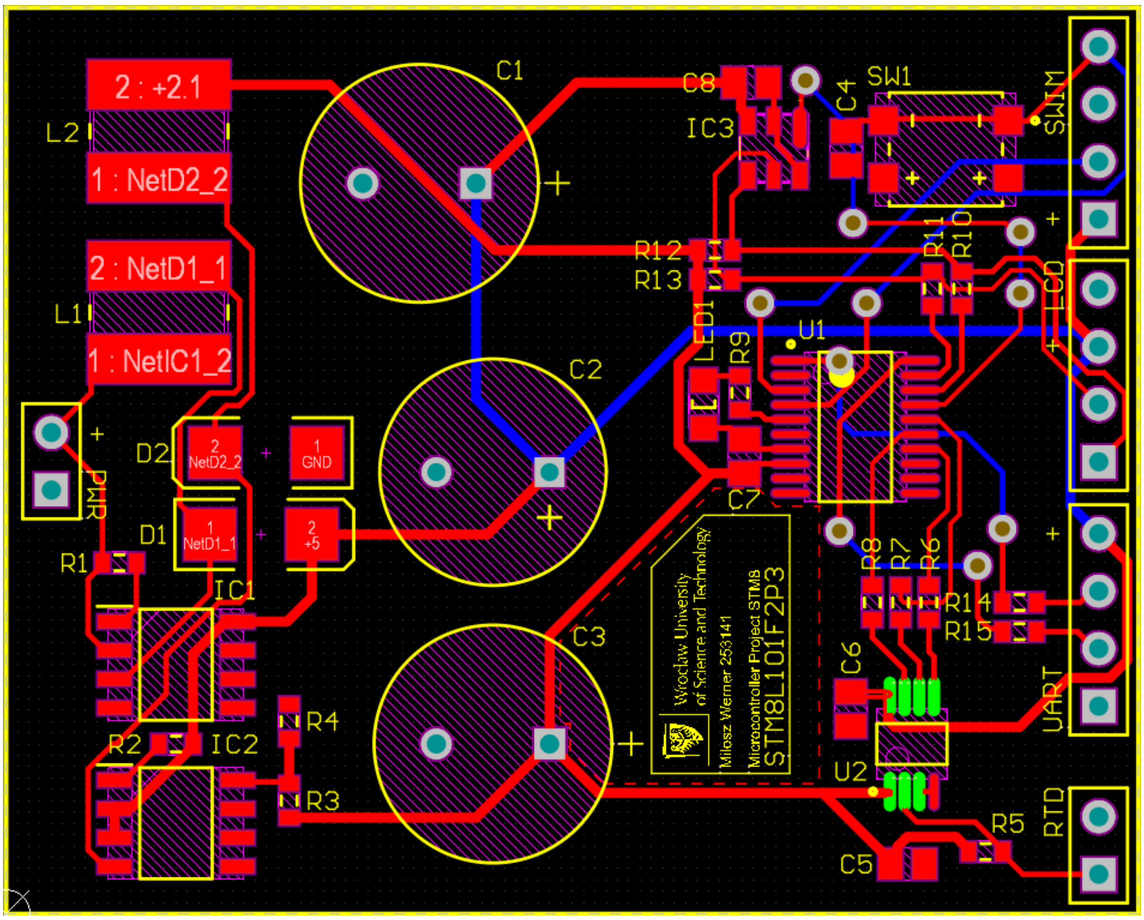


Figure 32 PCB layout without the polygon ground pours

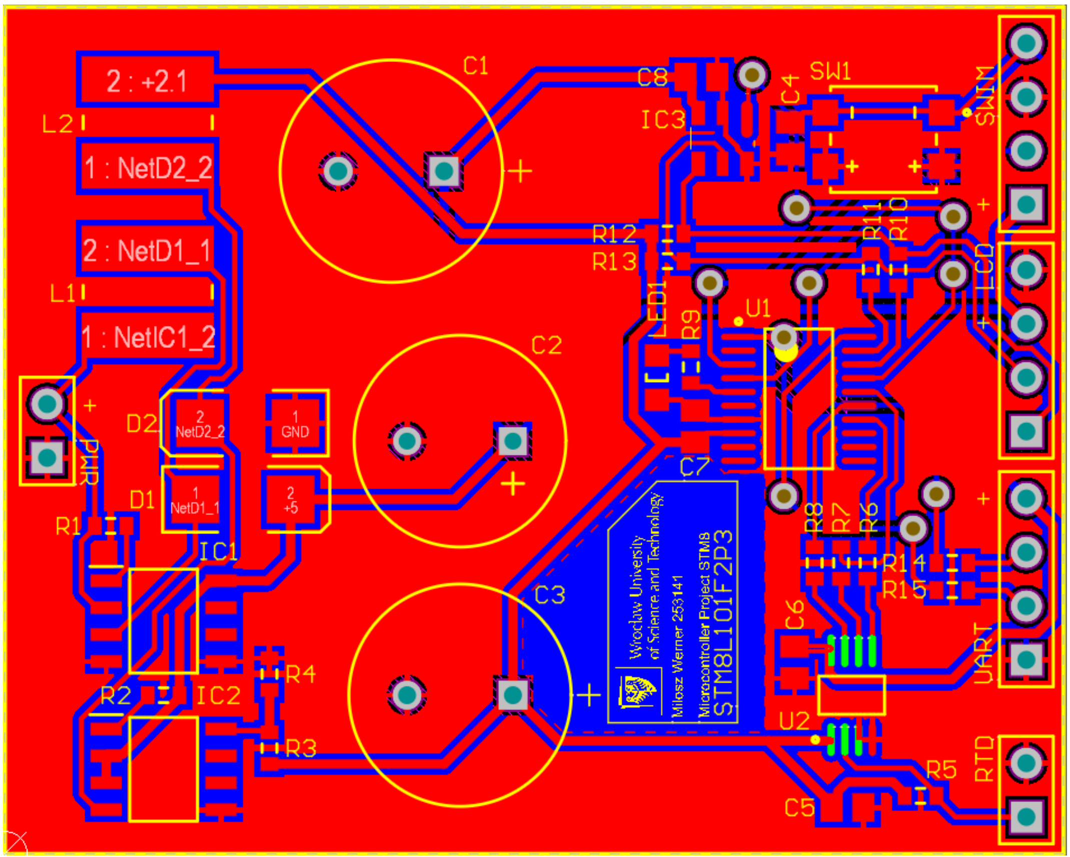


Figure 33 PCB layout with polygon ground pours

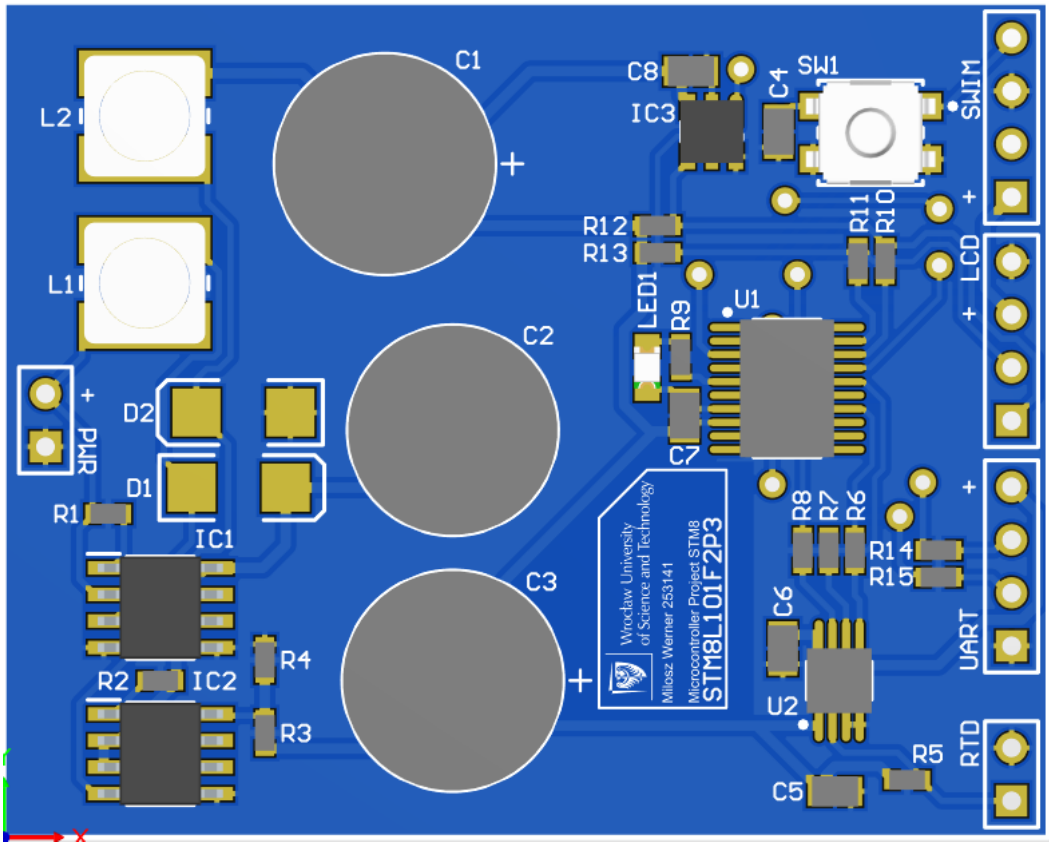


Figure 34 PCB top - 3D orthographic projection

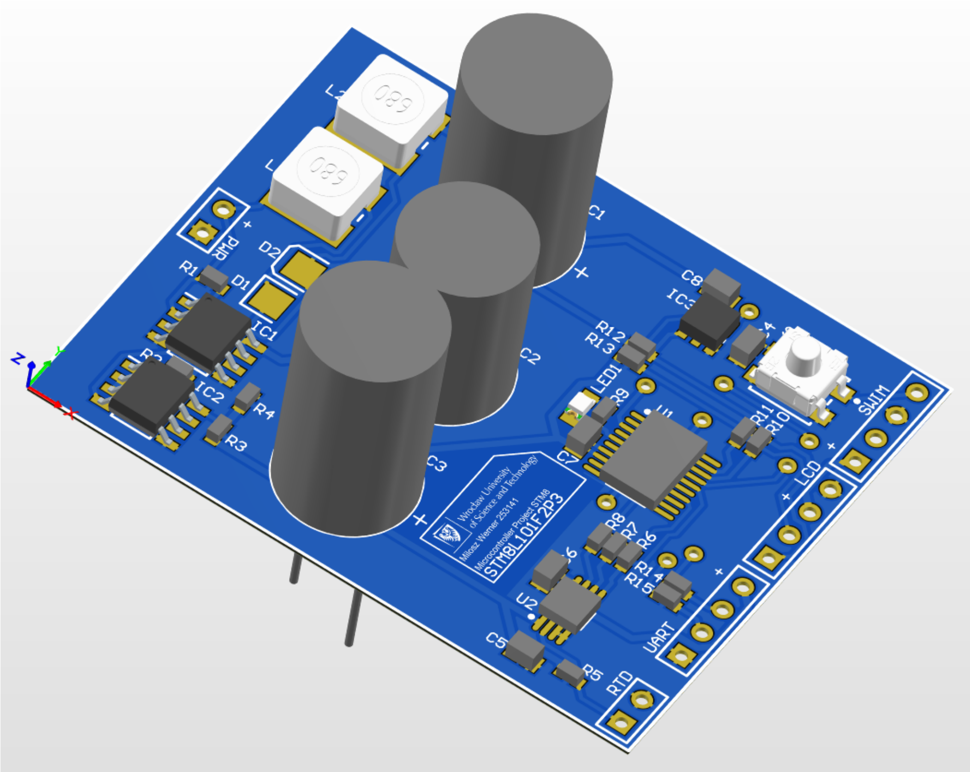


Figure 35 PCB - 3D orthographic projection

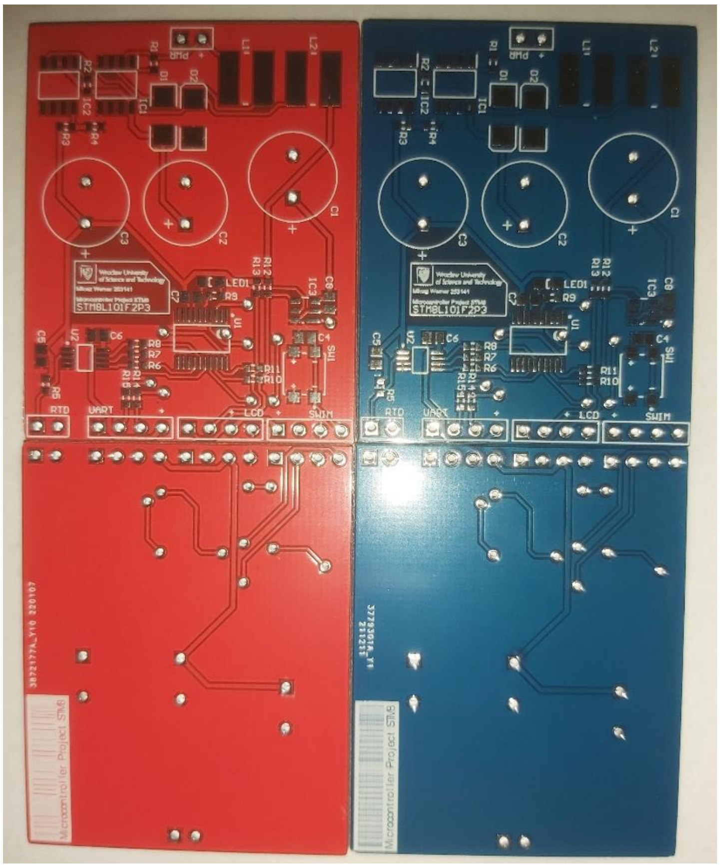


Figure 36 PCBs - physical

5. Conclusions

At the end, the project can be said to be a success. One must be careful when designing the circuit, given the total amount of possible configurations and components available to use. A careful examination of documentation is vital to the project completion. While it seemed complicated at first, the work got linear after the initial component selection, and the insight from the project overseer helped to achieve a positive result.

If it was possible to change something during the development, it would certainly be to change the resistance package size from miniscule 0603 to 0805, given the mid-semester change to a remote form that eliminated the possibly to use the lab equipment, namely a hot air station, a very accurate soldering iron, and a microscope.

To summarize, this project proved to be an invaluable amount of experience in circuit and PCB design, testing given the strict requirements. The involvement required during the length of the project created a realistic showcase of the real-world job of an electronic engineer.

Appendix 1 Bill of materials

Comment	Description	Designator	Footprint	Quantity	Link
Header 2	Header, 2-Pin	P1, P2	HDR1X2	2	
Header 4	Header, 4-Pin	P3, P4, P5	HDR1X4	3	
0603	Resistor	R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13, R14, R15	J1-0603	15	
0805	Capacitor	C4, C5, C6, C7, C8	C0805	5	
EEU-FR1C102B	Aluminum Electrolytic Capacitor, 1000 uF, +/- 20%, 16 V, -40 to 105 degC, 2-Pin THD, RoHS, Tape and Reel	C1, C3	PNSC-EEUFM1H221-2	2	https://pl.mouser.com/ProductDetail/Panasonic/EEU-FR1C102B?qs=%2Fha2pyFadugBt7Rbq2TywtFMJep9FOYkWIut0Els4xANrERhZSeRmw%3D%3D
UVC2G100MPD1TD	Aluminum Electrolytic Capacitor, High Voltage, Ultra-Miniature-Sized for adapters, Polar, 400 V, 10uF, +/-20% Tolerance, -40 to 105 degC, 10 x 12.5 mm D X L, RoHS, Bulk	C2	NIC-UVC2G100MPD1TD-2_V	1	https://pl.mouser.com/ProductDetail/Nichicon/UVC2G100MPD1TD?qs=%2Fha2pyFaduhXy78W%2FpKZv4IRe%2FwcQ6nFXTrRwviJc1MaFQWqd5bsQlM0ubl9Ifgg
0805 RED DIODE	Diode	LED1	0805_A	1	
SS13-LTP	Schottky Diode	D1, D2	SMB	2	https://pl.mouser.com/ProductDetail/Micro-CommercialComponents-MCC/SS13-LTP?qs=%2Fha2pyFadugmA1ReVnaWBX9X5L4%2FgmIwuCF%2Fp5SkdFQ%3D
7914G-1-000E	SPST Gull Wing Sealed Key Switch, 100 mA, 16 V, -55 to 125 degC, 4-Pin SMD, RoHS, Tape and Reel	SW1	BOUR-7914G-1-000E_V	1	https://pl.mouser.com/ProductDetail/Bourns/7914G-1-000E?qs=%2Fha2pyFaduiaOwAjVEJLQwgfQPAS0emteg1uG1pbbmL8tAyZTxB3Ww%3D%3D
744053470	SMD Shielded Tiny Power Inductor WE-TPC, L = 47.0 µH	L1, L2	WE-TPC-5828-LH	2	https://pl.mouser.com/ProductDetail/Wurth-Elektronik/744053470?qs=%2Fha2pyFadujyhOs7azh2GAynjRmBeIbB1Jw%2F1XLToACWHQbfoQNIHQ==
ADS7816EB/250	12-Bit High Speed Micro Power Sampling ADC, -40 to 85 degC, 8pin SOP (DGK8), Green (RoHS & no Sb/Br)	U2	TI-DGK8_N	1	https://pl.mouser.com/ProductDetail/TexasInstruments/ADS7816EB-250?qs=%252BvKcWiXw%252BzTsFLDZRtOPNg%3D%3D
STM8L101F2P3	STM8L ARM-based EnergyLite 8bit MCU, 4 kB Flash, 1.5 kB Internal RAM, -40 to +85°C Temperature, 20-pin TSSOP, Tube	U1	TSSOP20_N	1	https://pl.mouser.com/ProductDetail/STMicroelectronics/STM8L101F2P3?qs=vV0pr1uq7fATYz6T0IxPnA%3D%3D

LT1110CS8-5#PBF	Switching Voltage Regulators Micropower DC-DC Converter Fixed 5V	IC1	SOIC127P599X175-8N	1	https://pl.mouser.com/ProductDetail/Analog-DevicesInc/LT1110CS8-5PBF?qs=sGAEpiMZZMsKEdP9slC0YdDH1gKVEK69kskuKiHKGbw%3 D
LT1110CS8#PBF	Switching Voltage Regulators Micropower DC-DC Converter Adjustable and Fixed 5V, 12V	IC2	SOIC127P599X175-8N	1	https://pl.mouser.com/ProductDetail/Analog-Devices-Inc/LT1110CS8PBF?qs=sGAEpiMZZMsKEdP9slC0YWYvxQmM5KBUeQhxew7%252BR48%3D
MXC6244AU	Accelerometers +/- 8g Complete 2 Axis Accelerometer System with Programmable Internal anti-vibration Filter	IC3	MXC6244AU	1	https://pl.mouser.com/ProductDetail/MEMSIC/MXC6244AU?qs=sGAEpiMZZMvShe%252BZiYheipeTp1U1oOu8PnLmTiqugjU%3D