Design Laboratory

Project of Embedded wristwatch module powered by li-pol cell

AGH-CLK

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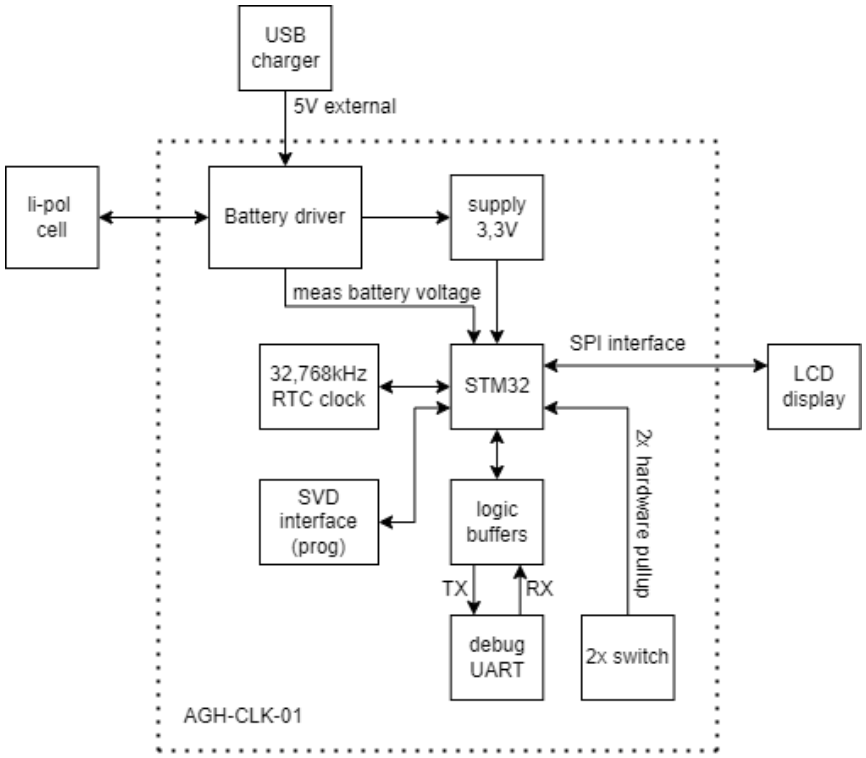
1. Design assumptions

1.1. Project description

The main goal was to make self-contained embedded wristwatch module that could be used with dedicated wrist as a complete wristwatch. That device has his own power supply made by li-pol cell with dedicated hardware driver. As a display full color LCD screen module is used with 240x240px and ST7789 driver. Device will be controlled by microprocessor STM32L051K6T6 that is placed on a dedicated printed circuit board “AGH-CLK-01” with the rest of peripherals.

1.2. Block diagram

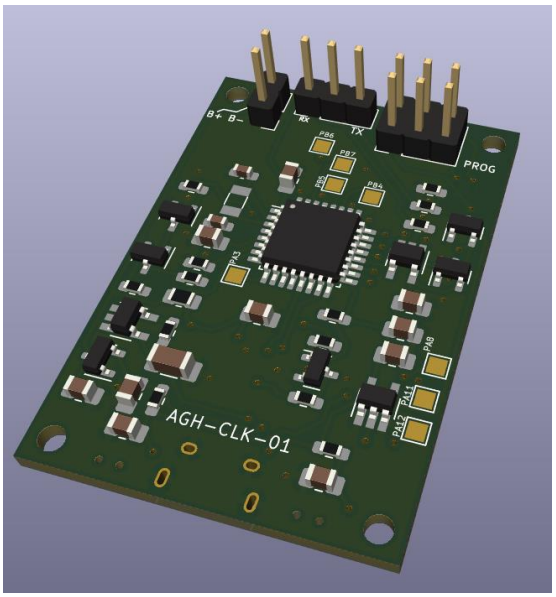


1.3. Technical specification:

- LCD screen 240x240 1,3 inches
- Clock precision: -6 sec/day (would be better with capacitor corrections)
- Current consumption: 54,5 mA (without sleep feature)
- Estimated lifetime per cycle – around 9h (would be better with implemented sleep feature)
- Charging: 5 VDC; 400 mA; around 75 minutes to full charge battery 500mAh

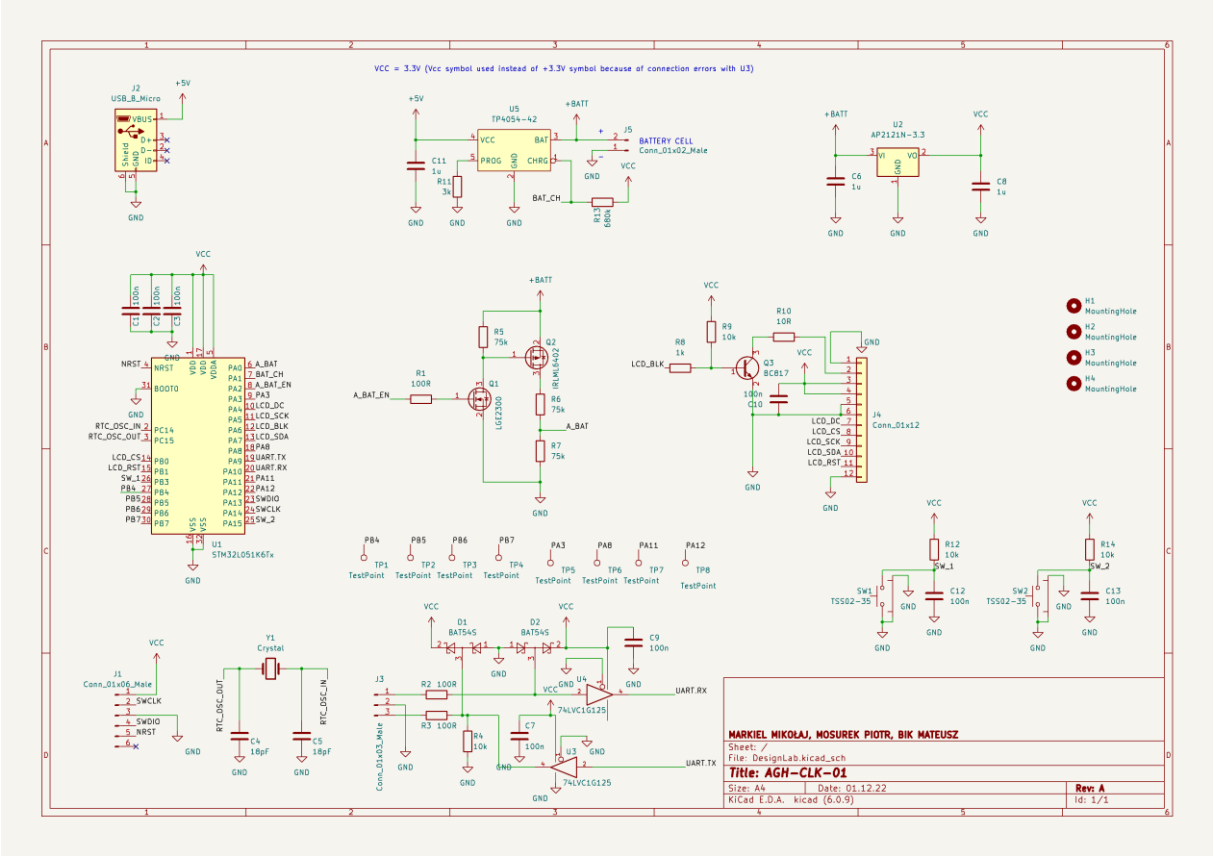
2. Schematic and layout descriptions

Schematic and layout was designed in KiCad Version: (6.0.9). PCB was prepared by JLCPCB company based on gerber files generated by KiCad.



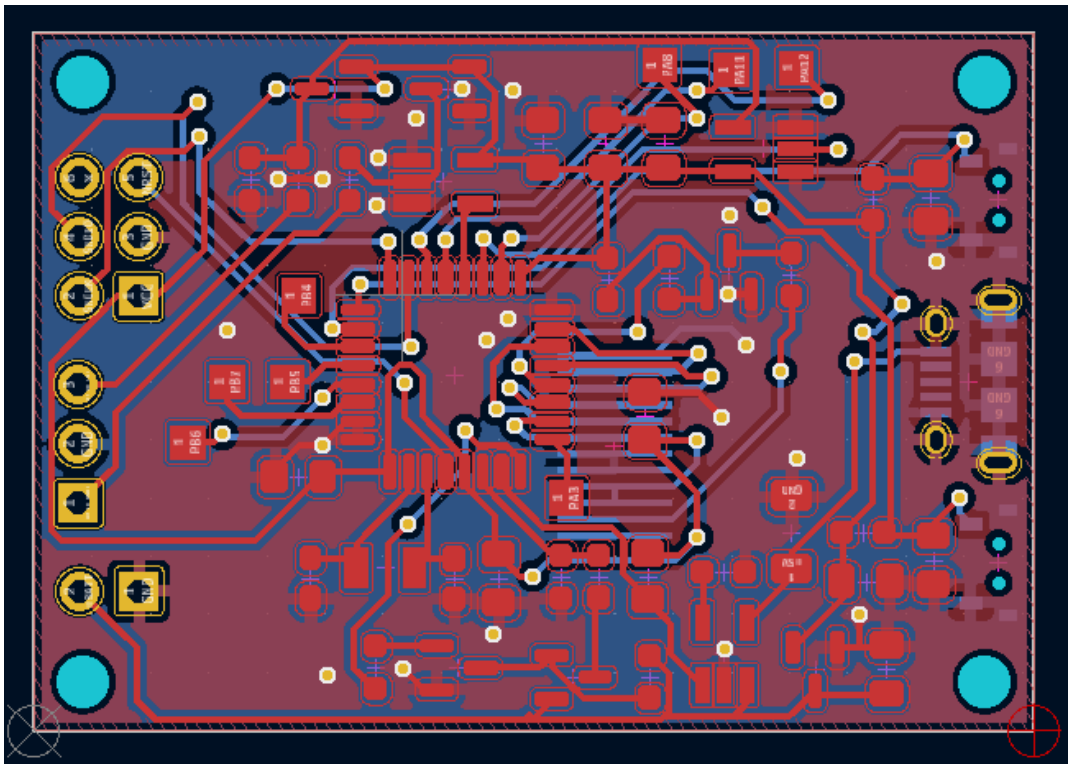
2.1. AGH-CLK-01 schematic

Full documentation is available in https://github.com/MikolajMarkiel/AGH-CLK



2.2. AGH-CLK-01 layout design

Full documentation is available in https://github.com/MikolajMarkiel/AGH-CLK



2.3. AGH-CLK-01 Bill of materials

Ref	Qnty	Value	Footprint	Description
C1, C2, C3, C7, C9, C10, C12, C13,	8	100n	Capacitor_SMD:C_0805_2012Metric_Pad1.18x1.45mm_HandSolder	Unpolarized capacitor
C4, C5,	2	18pF	Capacitor_SMD:C_0603_1608Metric_Pad1.08x0.95mm_HandSolder	Unpolarized capacitor
C6, C8,	2	1u	Capacitor_SMD:C_0805_2012Metric_Pad1.18x1.45mm_HandSolder	Unpolarized capacitor
C11,	1	1u	Capacitor_SMD:C_1206_3216Metric_Pad1.33x1.80mm_HandSolder	Unpolarized capacitor
D1, D2,	2	BAT54S	Package_TO_SOT_SMD:SOT-23	schottky barrier diode
H1, H2, H3, H4,	4	MountingHole	MountingHole:MountingHole_2.2mm_M2_ISO7380	Mounting Hole without connection
J1,	1	Conn_01x06_Male	Connector_PinHeader_2.54mm:PinHeader_2x03_P2.54mm_Vertical	Generic connector, single row, 01x06, script generated (kicad-library-utils/schlib/autogen/connector/)
J2,	1	USB_B_Micro	Connector_USB:USB_Micro-B_Amphenol_10118194_Horizontal	USB Micro Type B connector
J3,	1	Conn_01x03_Male	Connector_PinHeader_2.54mm:PinHeader_1x03_P2.54mm_Vertical	Generic connector, single row, 01x03, script generated (kicad-library-utils/schlib/autogen/connector/)
J4,	1	Conn_01x12	Connector:Flex_Tape_12x0.635	Generic connector, single row, 01x12, script generated (kicad-library-utils/schlib/autogen/connector/)
J5,	1	Conn_01x02_Male	Connector_PinHeader_2.54mm:PinHeader_1x02_P2.54mm_Vertical	Generic connector, single row, 01x02, script generated (kicad-library-utils/schlib/autogen/connector/)
Q1,	1	LGE2300	Package_TO_SOT_SMD:SOT-23	1.2A Id, 60V Vds, 480mOhm Rds, N-Channel HEXFET Power MOSFET, SOT-23
Q2,	1	IRLML6402	Package_TO_SOT_SMD:SOT-23	-3.7A Id, -20V Vds, 65mOhm Rds, P-Channel HEXFET Power MOSFET, SOT-23
Q3,	1	BC817	Package_TO_SOT_SMD:SOT-23	0.8A Ic, 45V Vce, NPN Transistor, SOT-23

R1, R2, R3,	3	100R	Resistor_SMD:R_0603_1608Metric_Pad0.98 x0.95mm_HandSolder	Resistor
R4, R9, R12, R14,	4	10k	Resistor_SMD:R_0603_1608Metric_Pad0.98 x0.95mm_HandSolder	Resistor
R5, R6, R7,	3	75k	Resistor_SMD:R_0603_1608Metric_Pad0.98 x0.95mm_HandSolder	Resistor
R8,	1	1k	Resistor_SMD:R_0603_1608Metric_Pad0.98 x0.95mm_HandSolder	Resistor
R10,	1	10R	Resistor_SMD:R_0603_1608Metric_Pad0.98 x0.95mm_HandSolder	Resistor
R11,	1	3k	Resistor_SMD:R_0603_1608Metric_Pad0.98 x0.95mm_HandSolder	Resistor
R13,	1	680k	Resistor_SMD:R_0815_2038Metric_Pad1.20 x4.05mm_HandSolder	Resistor
SW1, SW2,	2	TSS02-35	Button_Switch_SMD:SW_SPST_TSS02-035NT	Push button switch, generic, two pins
TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8,	8	TestPoint	TestPoint:TestPoint_Pad_1.5x1.5mm	test point
U1,	1	STM32L051K6Tx	Package_QFP:LQFP-32_7x7mm_P0.8mm	ARM Cortex-M0+ MCU, 32KB flash, 8KB RAM, 32MHz, 1.65-3.6V, 25 GPIO, LQFP-32
U2,	1	AP2121N-3.3	Package_TO_SOT_SMD:SOT-23	300mA low dropout linear regulator, shutdown pin, 2.5V-6V input voltage, 3.3V fixed positive output, SOT-23 package
U3, U4,	2	74LVC1G125	Package_TO_SOT_SMD:SOT-23-5_HandSoldering	Single Buffer Gate Tri-State, Low-Voltage CMOS
U5,	1	TP4054-42	Package_TO_SOT_SMD:SOT-23-5_HandSoldering	
Y1,	1	Crystal	Crystal:Crystal_SMD_3215-2Pin_3.2x1.5mm	Two pin crystal

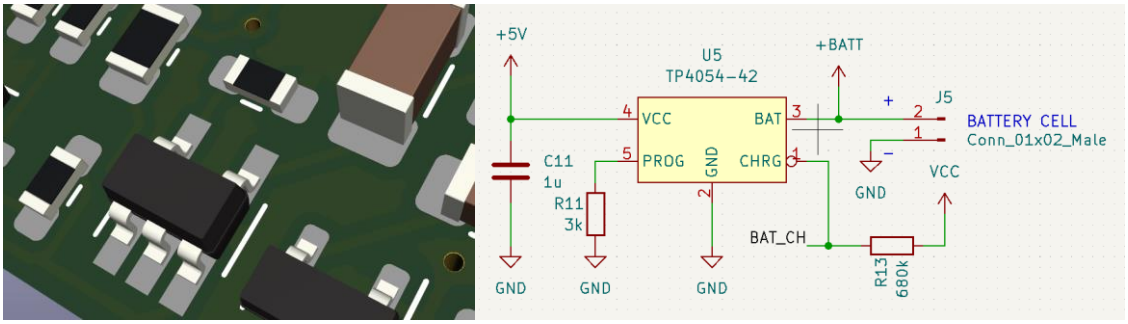
2.4. Battery Driver block

For controlled battery charging TP4054-42 driver has been used. Maximum charging current of this driver is up to 1200mA. The particular value of the maximum current is configured by R_{PROG} connected to PROG pin of driver The R_{PROG} value is calculated by formula:

$$I_{BAT} = \frac{V_{PROG}}{R_{PROG}} * 1200 \ (V_{PROG} = 1V)$$

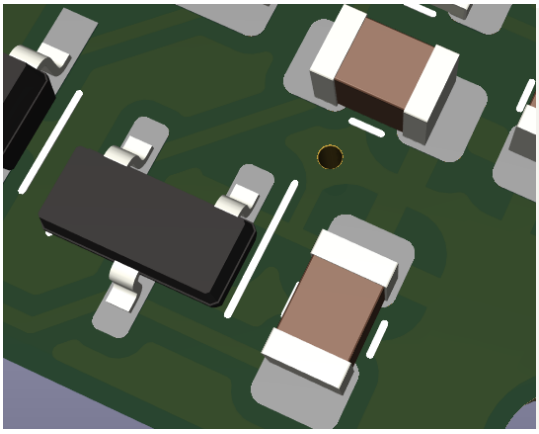
For purpose of this device assumed that the charging current should be around 400mA. The calculated R_{PROG} value should be then no more than 3kΩ. The 3kΩ value has been chosen.

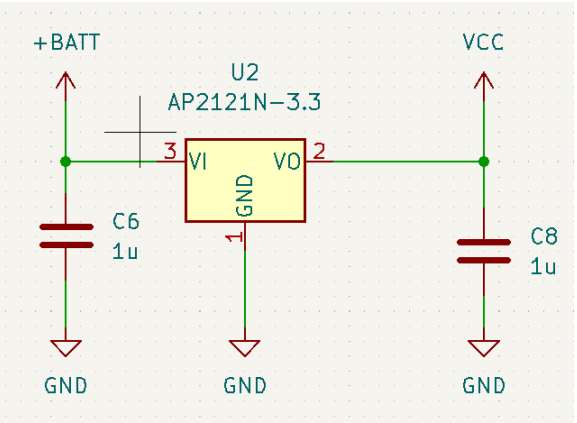
According to documentation weak pull-up should be used for checking battery charging state and connected to CHRG pin and to processor as input.



2.5. Power supply block

The voltage from battery is dropped to 3,3V for purpose of supplying processor and other peripherals. It is done by AP2127-3.3 linear voltage regulator. According to documentation this regulator has 2% accuracy, so the voltage should fit in 3,267-3,333V. The measured voltage is 3,291V, so the value is correct.



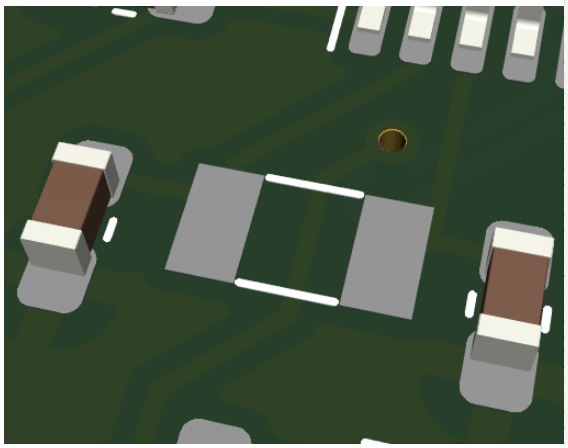


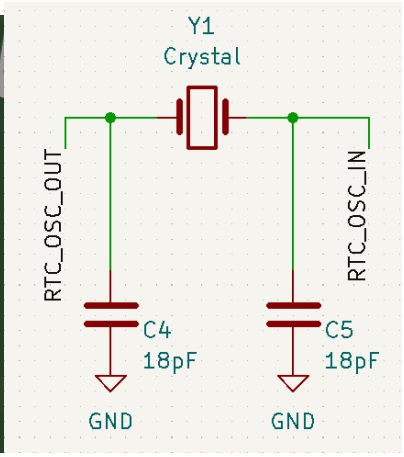
2.6. RTC clock

The STM32L051K6T6 supports external RTC crystal for precise counting. Because of that a ABS07-32.768KHZ-T crystal is used. It has 12.5pF load capacitance (CL). There is necessary to add extra capacitance for both terminals that aggregately should be equal to CL of crystal. We should also predict capacitance of copper paths for calculations (C_{STRAY}) (usually 2-5pF):

$$C_L = \frac{C_{X1} * C_{X2}}{C_{X1} + C_{X2}} + C_{STRAY}$$

We needed to use the same capacitor for this purpose, so the capacitance should then be in range 15-21pF. The correction of capacitance values of this circuit should be verified after assembly by checking clock precision.



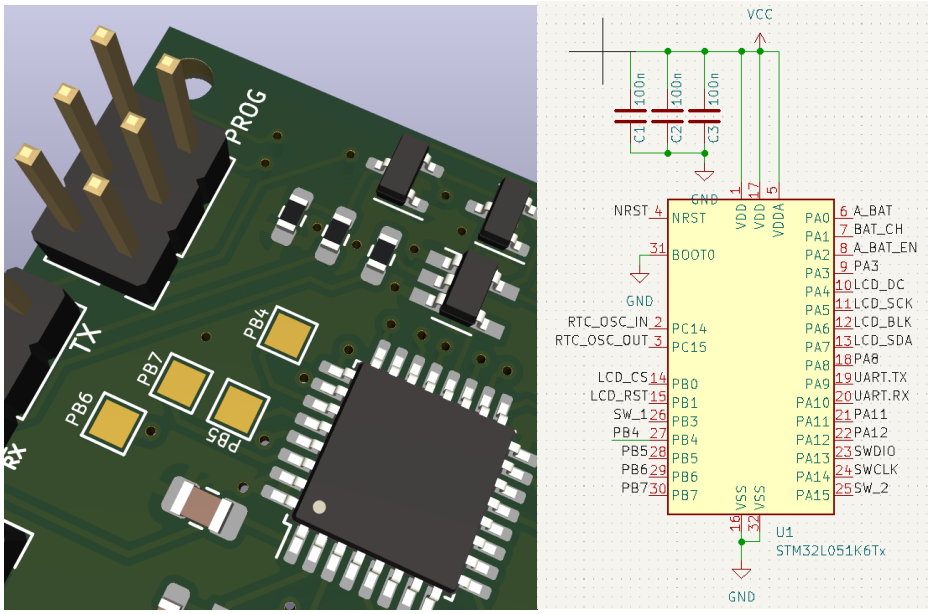


2.7. Processor and programming block

This project hasn't had demanding requirements, so cheap STM32 processor would be enough to fulfil them all. We've decided to use STM32L051K6T6 processor. It has all necessary features and peripherals like SPI communication for LCD screen and RTC based on external clock.

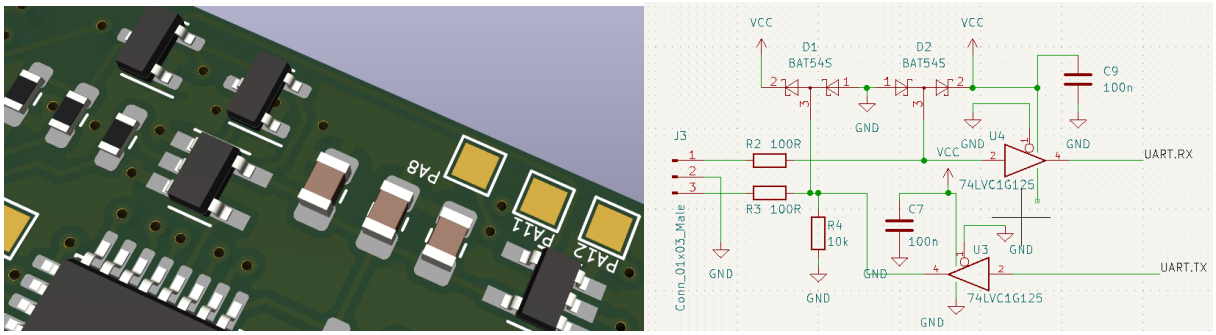
To protect processor from unwanted resetting device we've placed 100nF decoupling capacitors near every power supply pin.

Programming will be realized by SWD interface. Unfortunately, this processor doesn't have SWO pin, so real time debugging will be realized by UART.



2.8. Debug Block

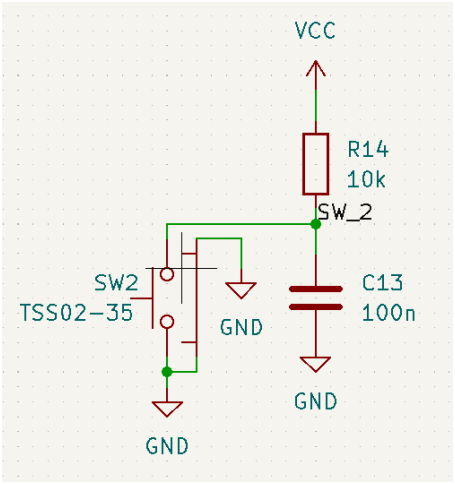
For real time debugging and testing UART communication has been carried to goldpin headers. To protect pins from dangerous signal RXD and TXD pins are buffered and protected from overvoltage. Unfortunately this feature was not necessary to implement in software, and thus wasn't tested.



2.9. Keyboard

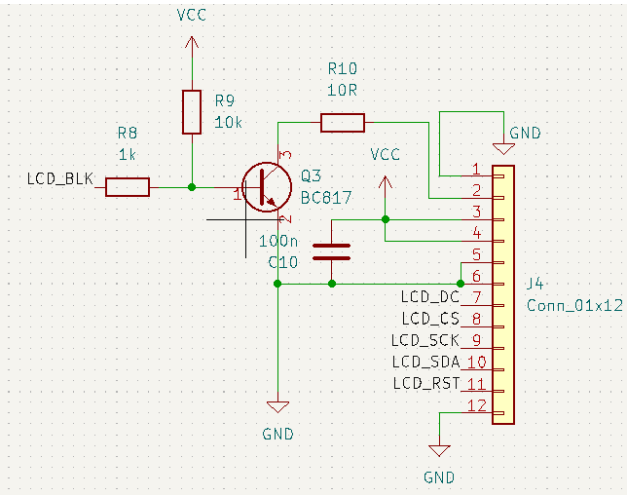
To control device, we've added two switches „<" and „>". They will be used for setting actual time and date feature. To prevent from bouncing effect, we've used 100nF capacitor that filter unwanted noise:

Figure 1: Removing bouncing effect from switches. At the left switch is pressed and pulled to ground, at the right switch is released and capacitor is charging again. The probe was connected directly to processor pin.



2.10. Display block

LCD screen display is communicating with processor via SPI half-duplex interface. The baud rate is 16 MBits/s. To unload processor from long transmission cycle data is transferred by DMA feature. There is also predicted possibility to control backlight of LCD screen.



3. Software description

3.1. Environment:

Software environment: STM32CubeIDE; Version: 1.10.1; Build: 12716_20220707_0928 (UTC)
Programmer: The ST-LINK/V2-1 programming and debugging tool integrated with NUCLEO-L476RG board

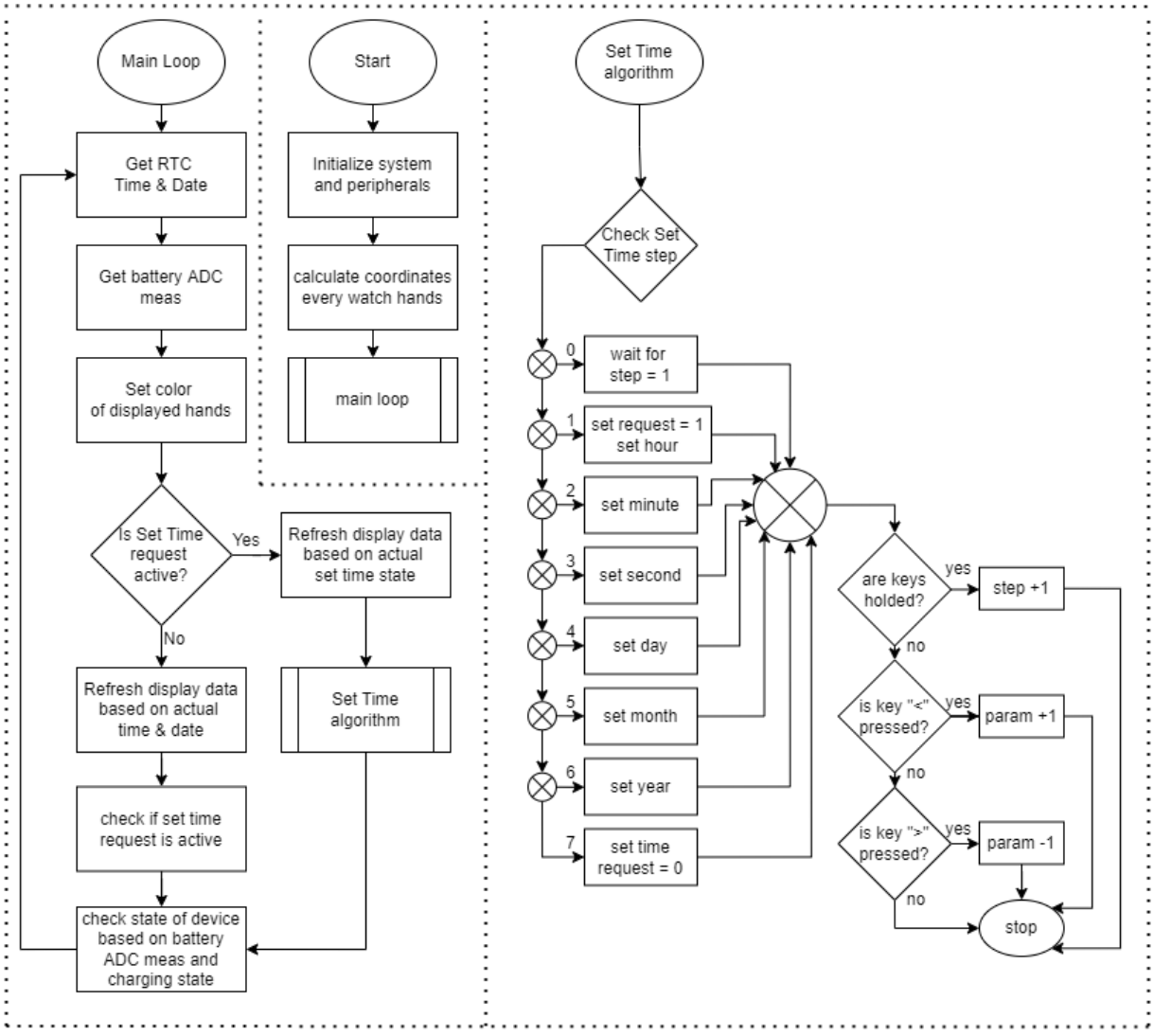
3.2. Code:

Full code is available in https://github.com/MikolajMarkiel/AGH-CLK

Libraries we've used in project:

- ST7789 driver with UGUI: https://github.com/deividAlfa/ST7789-STM32-uGUI

3.3. Performance algorithm

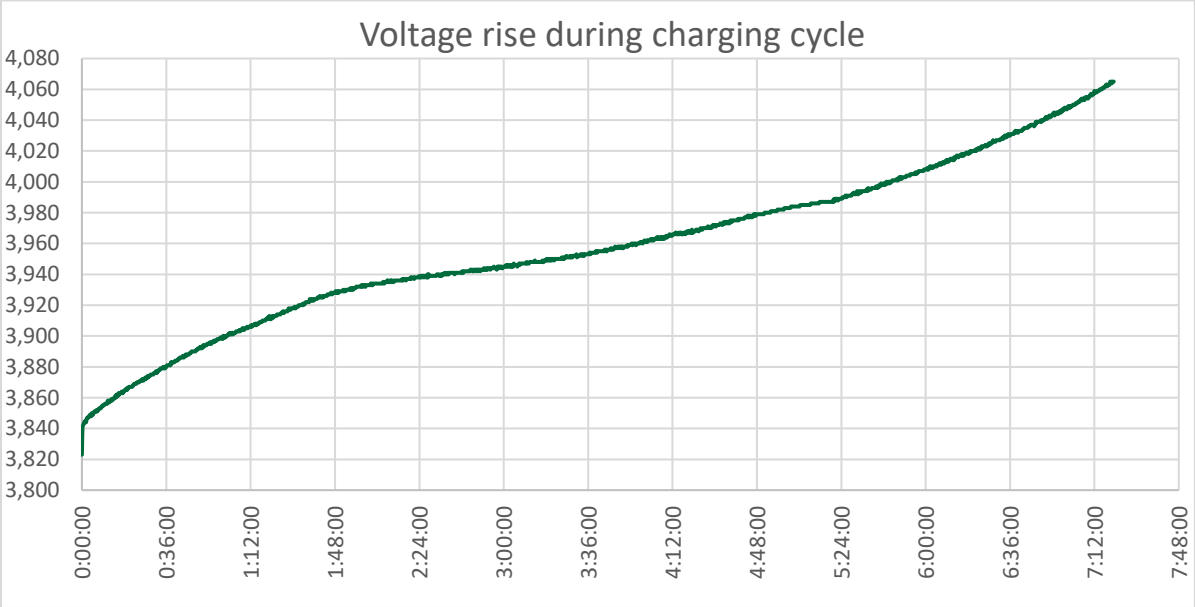


4. Performance tests

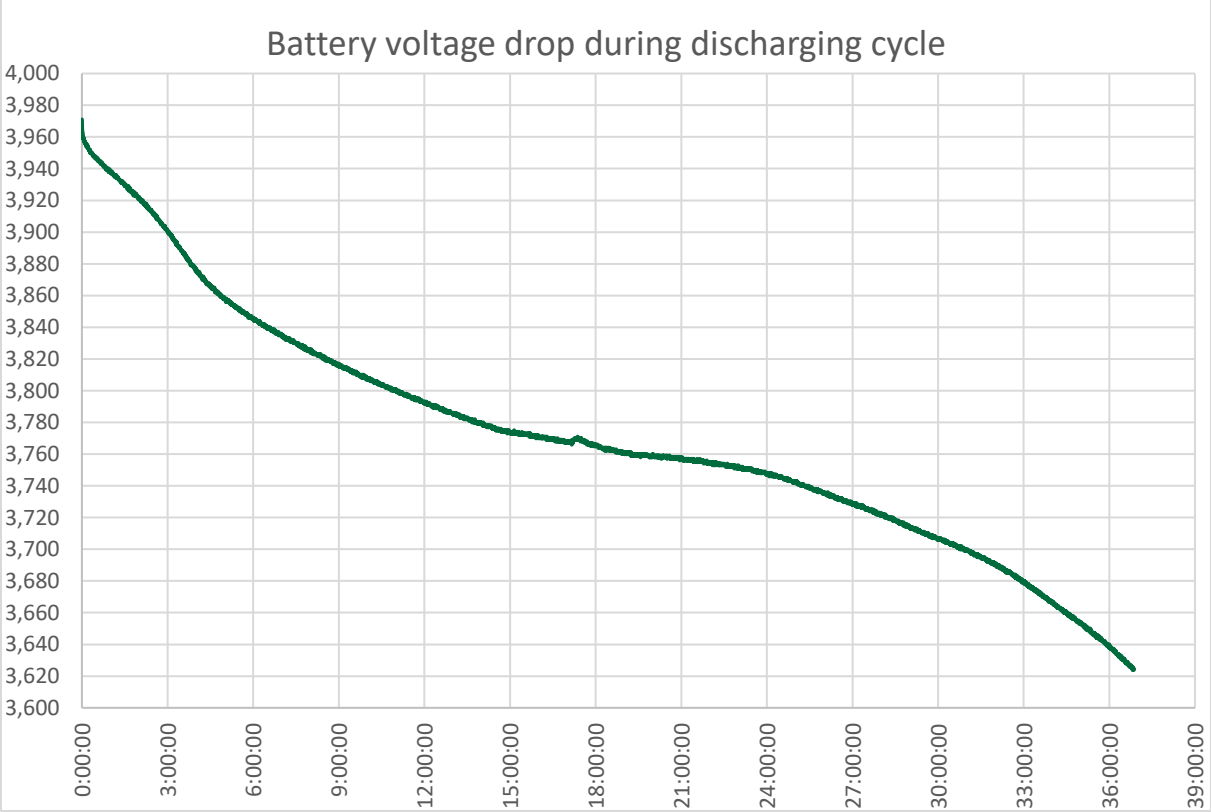
4.1. Battery performance

All tests were performed on a li-pol cell 2650mAh 3,7V.

Charging cycle:



Discharging cycle:



4.2. Clock precision

The test consist in synchronizing the clock and read its state after 24 hours. It was performed only once.

- Test 1: 18.01.23 18:50:00 – synchronize clock
- Test 2: 19.01.23 18:50:00 – read value 18:49:54 - **6s delay/day.**

5. Future improvements and fixes

- **Sleep feature** – to decrease battery consumption and protect battery from over discharging.
- **RTC capacitors update** – for better clock precision.
- **Touch pad** – to allow controlling more features.
- **UART-USB driver** – to allow programming and debug via USB.
- **Wristwatch case** – to make this device wearable.