2. Board description

2.1. The block diagram

The circuit consists of ten blocks depicted in Fig. 1. Each block is later represented by one page of schematic diagram. The central block represents the microcontroller STM32F407VE, housed in LQPF package with 100 pins. Port pins are used to connect the microcontroller with other blocks. All blocks have connectors for external signals, these connectors are distributed along edges of the board for easy access. The power supply is common for all blocks.

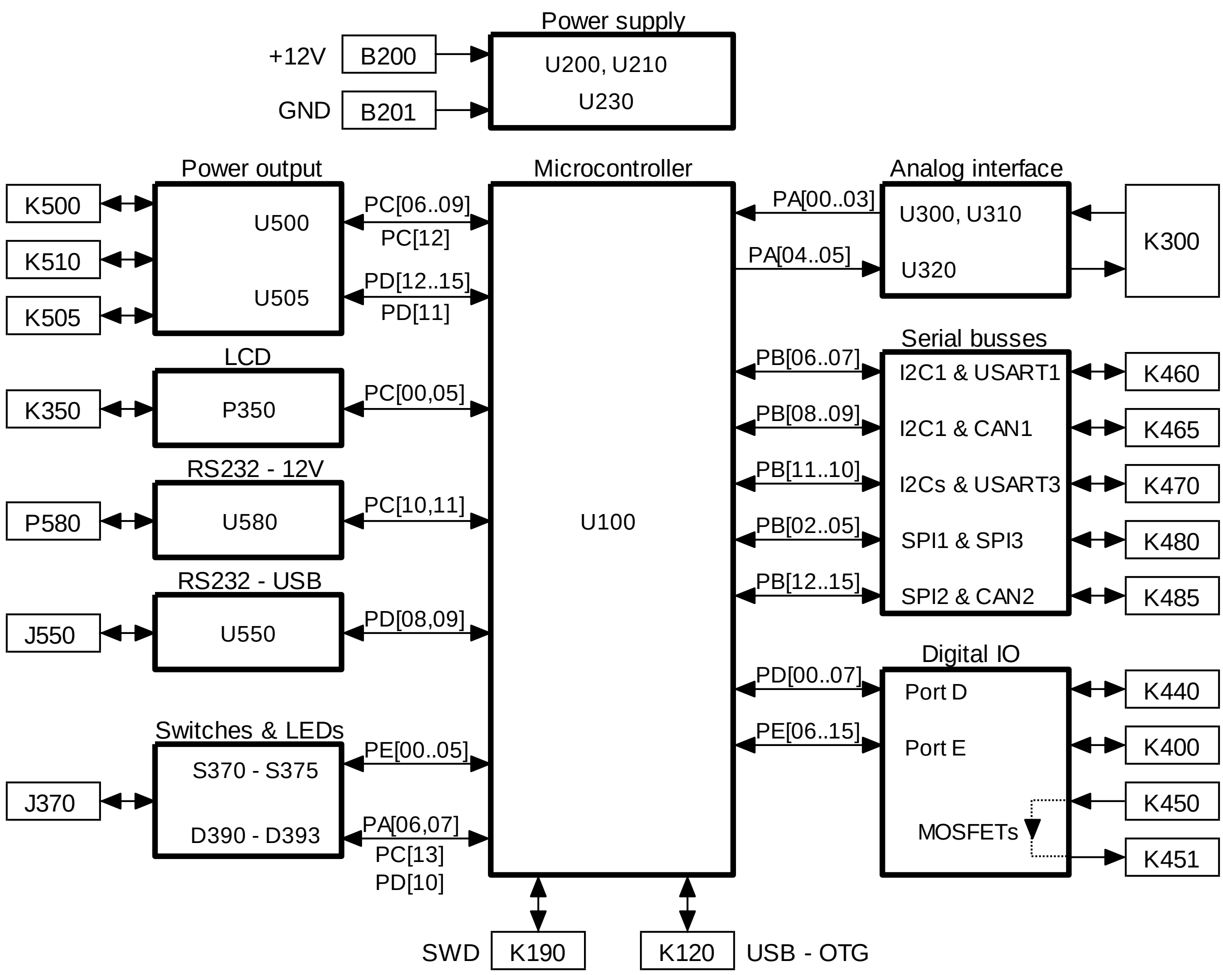

Figure 1: The block diagram of the STM32F407 board. Boxes with thich borders are blocks, boxes with thin borders are connectors.

2.2. The power supply

The board needs +3.3 V power supply for the microcontroller and its peripheral circuits and +5 V for the LCD display. Additionally, the analog electronic circuits in front of the ADC and output buffers for the DAC might need ±5 V power. The power supply circuit provides all required voltages. It consists of three sub-blocks and two headers as shown in Fig. 2.

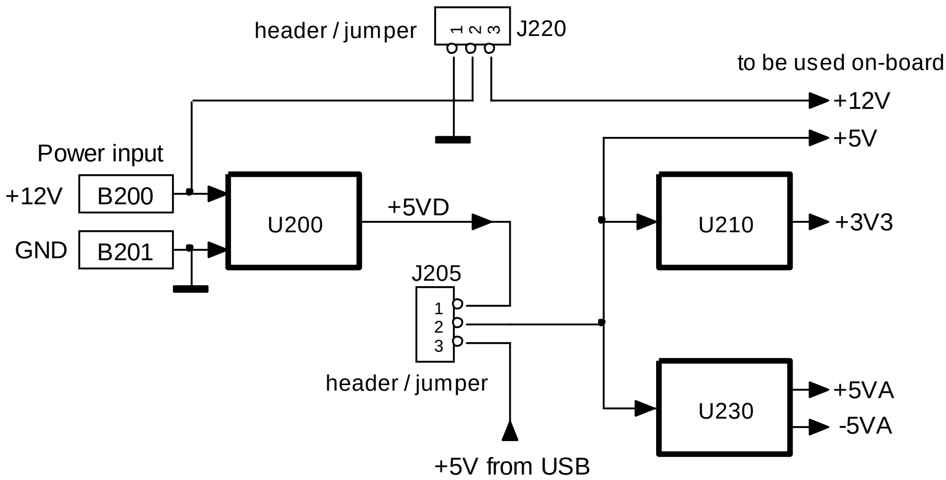

Figure 2: Block diagram of the power supply

The circuit is powered through connectors B200 (+12VIN) and B201 (GND). The voltage applied between these two connectors can range from 7 V DC to 25 V DC (nominally 12 V DC), and is used by the first block built with voltage regulator U200 to provide local +5VD. The rest of the microcontroller circuit can be powered from this +5VD but can also be powered from +5V obtained through a USB connector plugged into a PC compatible computer. The user can select either using a jumper J205. The required current from either source depends strongly on the microcontroller current consumption (about 100 mA) and the current consumption of peripheral circuits (depends…). It is expected that 500 mA should suffice for the microcontroller board.

Voltage regulator U210 is used to reduce the +5V into +3.3V for the microcontroller, and switching regulator U230 is used to transform +5V into ±5V for the analog part of the circuit.

The motor driver requires more than 5 V, and can be powered from B200 directly if a jumper is inserted into the header J220 between pins 2 and 3. Alternatively, the jumper can be removed and external power supply can be applied to header J220 between pins 3 and 1.

The complete schematic diagram of the power supply is given in Fig. 9. Capacitors shown at the schematic are used for decoupling of the power supplies and are distributed along the power lines on the board, mostly around the microcontroller. All three power supplies are also connected to three green LEDs (D240, D241 and D242) to confirm the validity of power supply lines. All headers / jumpers in the power supply lines can also be used to connect an instrument to measure the current consumption.

2.3. The microcontroller

The microcontroller STM32F407 connects to the world using four 16 bit ports (PA, PB, PD and PE) and one 14 bit port (PC). It requires a power supply of 3.3V for digital circuitry and a separate +3.3V power supply for analog circuits. Both can come from the same source, but the power supply for the analog part must be additionally decoupled using inductors and combination of capacitors as shown in Fig. 3. Digital power supply for the microcontroller is provided through several pins on the chip, and each pin should be decoupled with a 100 nF ceramic capacitor to ground using a short connection. This is best achieved by implementing a large ground plane on one side of the board, and using feed-through holes to connect decoupling components to ground.

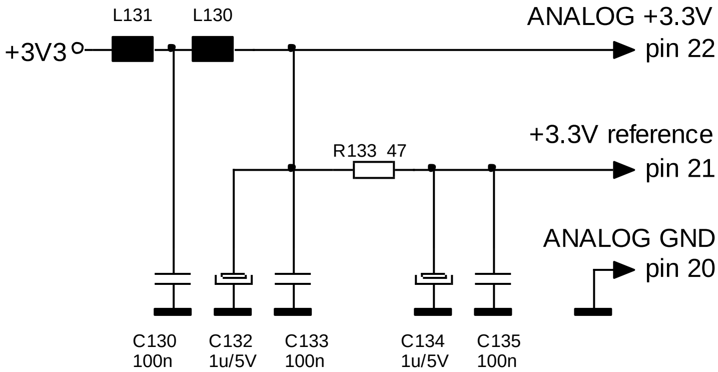

Figure 3: Making of the decoupled version of the +3.3V as an analog power supply for the microcontroller

The microcontroller includes crystal oscillator circuits for two crystals (8 MHz and 32768 Hz).

Two options are available to program the microcontroller: JTAG and SWD. The board implements only the SWD bus for programming. The SWD bus is available on header K190. The microcontroller normally gets a reset signal through the SWD bus, local RESET pushbutton is also available (S110).

The microcontroller implements a USB "On-The-Go" bus. Its implementation is copied from the DISCOVERY board, but with different overvoltage protection chip (SN75240). This chip might not be the best solution, but will hopefully do its job. The USB OTG bus is available on mini USB connector K120. Jumper J263 can be used to select the power supply on the USB-OTG connector.

The complete schematic diagram of the microcontroller is given in Fig. 10.

2.4. The analog interface

2.4.1. Input buffer for ADC

The allowed range for ADC input signals is from 0 V to +3.3V, as defined by the analog power supply for the microcontroller. An operational amplifier is used in front of the ADC to buffer the input signal and provides a low impedance driving required for a high resolution ADC. The schematic diagram of a single buffer is given in Fig. 4.

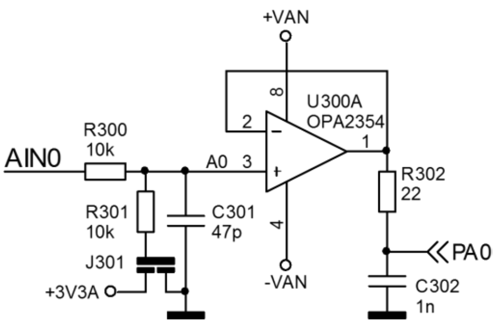

Figure 4: The schematic diagram of the input buffer

The operational amplifier in the prototype is OPA2354, a high speed, rail-to-rail IO, +5.5 V supply, dual amplifier. Other amplifiers will be tested in due time. The amplifier is powered from +3.3 V and GND; this is achieved by inserting jumpers J303 and J304 (not shown in Fig. 4) in proper positions so that +VAN becomes +3.3 V and –VAN becomes GND. Both power supply pins are decoupled by 100 nF capacitors. Since the output signal of the amplifier cannot go beyond the power supply lines, such selection assures the safety of the ADC input, and no further protection is needed at the output of the operational amplifier.

The amplifier has a gain of one, giving it a bandwidth of more than 10 MHz. The input signal AIN0 first enters the combined resistor divider (R300, R301) and RC filter (R300||R301 and C301). A jumper J301 selects the function of the resistor divider. There are three options:

- Unipolar mode 3.3: Jumper is not inserted: In this case the input signal appears directly at the input of the buffer, therefore 0 V DC at the input AIN0 is translated into 0 V DC at the input of the ADC PA0, and +3.3 V DC at the input AIN0 is passed to the ADC input PA0 as +3.3 V DC. The range of input voltages is 0 to 3.3 V.
- Unipolar mode 6.6: Jumper shorts R301 to GND: In this case the input signal is reduced to ½ before entering the buffer, therefore 0V DC at the input AIN0 translates as 0 V at the input of the ADC, and +6.6 V DC translates as +3.3 V DC. The range of input voltages is 0 to 6.6 V.
- Bipolar mode: Jumper shorts R301 to +3.3V: In this case the input signal is reduced to ½ and bias is added to the result before entering the buffer; +3.3 V DC at the input AIN0 translates as +3.3 V DC at the input of the ADC, and -3.3 V DC at the input AIN0 translates as 0 V DC to the input of the ADC. The range of input voltages is -3.3 to 3.3 V.

The combined resistance in the resistor divider and the capacitor C301 form a RC low pass filter with a corner frequency of 330 kHz (660 kHz with jumper inserted). A protective diode D301 can be soldered into the circuit (see the complete schematic diagram) to clamp the input signal to an acceptable level at the input to the operational amplifier when excessive input voltages are applied at the input AIN0.

The output of the buffer is connected to the input of the ADC using another RC low pass filter formed by R302 and C302. This is not really a filter; the capacitor is needed as a charge reservoir to allow error-free sampling of the signal at the input to the ADC. A resistor R302 is added in series to reduce capacitive loading of the operational amplifier and prevent oscillations. The capacitor C302 is connected between the analog input pin of the microprocessor (PA0, pin 23) and ground plane with a shortest possible wire, while the connection from operational amplifier to resistor R302 can be longer. All analog part of the board is built with the ground plane on the opposite side of the board.

Four such amplifiers are implemented, one for each input channel AIN0 to AIN3, see the complete schematic diagram in Fig. xx. Some decoupling capacitors are distributed on the analog part of the board.

The suggested operational amplifier is a Rail-to-Rail type, and its output can almost reach power supply rail; it's saturation voltage is about 60 mV. This means that, when unipolar mode 3.3 is selected, the ADC can measure voltages from about 60 mV to about 3.24 V. The first and the last 60 mV cannot be measured since the operational amplifier cannot pass such signals to the ADC. In order to avoid this situation a regular fast dual operational amplifier (initial suggestion: AD8034) with elevated power supply voltage can be soldered in place of OPA2354, but the power supply for it should be increased to ±5 V. Such power supply is available on the board when the U230 is soldered into the board. Jumpers J303 and J304 must be re-inserted in correct positions. However, increasing the power supply opens the possibility for the operational amplifier to pass signal beyond the power supply rails of the microprocessor to the input of the ADC when unappropriate input signal is applied, and this could harm the ADC. Protective diodes D302 must be introduced to clamp the signal to an acceptable level.

2.4.2. **Output buffer for DAC.**

In order to protect the microcontroller and to increase the output current from DAC a buffer amplifier is added in the circuit. The schematic diagram of the buffer is shown in Fig. 5.

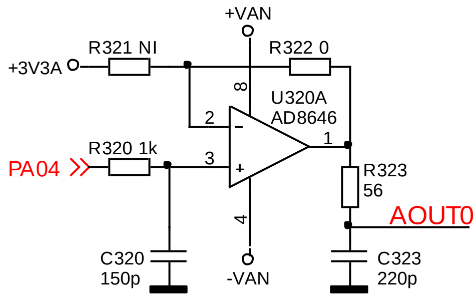

Figure 5: The schematic diagram of the output buffer

The output signal from DAC is between 0 V and +3.3 V. This signal is first feed to a low pass filter formed by resistor R320 and capacitor C320. Values of components are selected to give the corner frequency of about 1 MHz. Filtered signal is fed to the operational amplifier. There are two options:

- Unipolar mode: In this mode the operational amplifier is connected to have a gain of +1, therefore resistor R321 is not soldered into the circuit (NI, not inserted), and resistor R322 is replaced by a short circuit. The operational amplifier simply repeats the input signal. The power supply in this mode can be either single (+3.3 V and GND) or dual (+5 V and -5 V). Jumpers J303 and J304 select the appropriate power supply. As with the input buffer the saturation voltage of the operational amplifier limits the output signal to a range from about 60 mV to 3.24 V when a single supply is selected. When such limited range of output voltages is not sufficient a dual power supply should be activated by proper selection at jumpers. This might require a different operational amplifier. For initial testing the operational amplifier AD8646 was used.
- Bipolar mode: In this mode both resistors R321 and R322 are soldered into the circuit. This gives a gain of +2 to the operational amplifier and offsets the output signal for -3.3 V: when input signal to the circuit is 0 V DC the output is -3.3 V DC. When input signal is +3.3 V DC the output signal is +3.3 V DC. In order to achieve the extended range of output voltage the operational amplifier must be supplied by ±5 V. This power supply can be selected by jumpers J303 and J304, as for the input buffer, and an operational amplifier with power supply of at least ±5 C must be used.

Please bear in mind that the jumpers J303 and J304 are common for the input and output section. A change in the position of jumpers will therefore affect both buffers and operational amplifiers must be selected accordingly in both sections.

The output signal from the operational amplifier is fed to another low pass RC filter formed by resistor R323 and capacitor C323. The values are selected to give the corner frequency of about 10 MHz and may change when additional tests are performed. Two such output buffers are implemented for two DAC built into the microcontroller. The complete circuit is given in Fig. 11.

2.5. Serial buses

The microcontroller offers a wide variety of serial busses. The required hardware is built into the microcontroller and operates without the intervention of software. The user must only initialize the hardware and supply the data to be transmitted & intercept the received data. Lines used to implement serial buses are available at different ports, but this implementation reserves the port B for serial bus connections.

An example of connection to provide a serial bus I2C or RS232 is shown in fig. 6. Two pins of port B (PB06, PB07) are used as inputs/outputs for corresponding signals of a bus; both are connected to the connector at the edge of the board. Two small value resistors are added in series to reduce the possibility of a failure when connector pins are not properly connected.

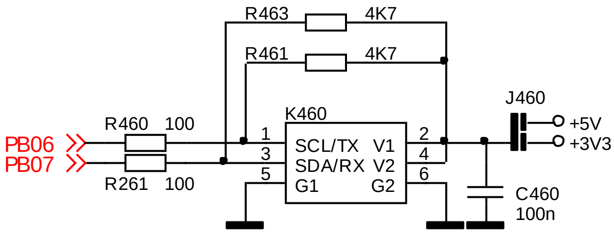

Figure 6: An example of I2C / RS232(TTL) bus

Most of the devices utilizing a serial bus require a power supply, which can be provided from the board. Jumper J460 should be used to select the appropriate voltage. Two resistors R463 and R461 are needed for proper operation of I2C bur which requires pull-up resistors. These resistors can be omitted for RS232(TTL) bus.

A similar circuit is provided on the board also for other bus variants, fig. 7 gives an example for SPI bus.. Again, four resistors are added in series with SPI lines to reduce the possibility of damaging the microcontroller. The power supply for the device utilizing the SPI bus can be selected by means of the jumper J485.

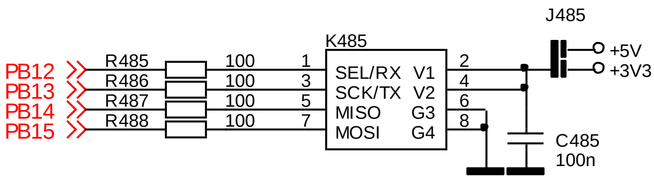

Figure 7: An example of SPI / CAN bus

See Fig. 12 for other busses and the complete schematic diagram.

2.6. On-Board switches and LEDs

Six push-button switches are available on the board to allow the user interaction with the software. Pull-down resistors are provided on the board, so the programmer does not need to activate the pull-down resistors built in the microcontroller. This was provided for simplicity, but can be omitted when soldering the board. The switches are connected to lower six lines of port E, and these lines are also available at the connector J370 for the connection of an external keyboard should this prove necessary. Protective resistors are inserted between the connector and microcontroller for each line.

Four LEDs are available on the board. They are under program control and can be used to signal the state of the user program. LEDs are available on pins PA06, PA07, PC13 and PD10.

The complete connection of switches and LEDs is given in Fig. 13.

2.7. Digital IO – ports

Digital lines to be used as inputs to the microcontroller or outputs from the microcontroller are available on two connectors K400 (upper ten lines of port E, PE06 to PE15) and K440 (lower eight lines of port D, PD00 to PD07). The digital lines are 5 V tolerant, so a signal between 0 V and +5 V can be connected here. Each line has a current limiting resistor inserted to reduce the possibility of damage when signals out of this range are applied.

Both connectors offer a power supply lines +3.3V and +5V to be used by the external circuits.

Four power transistors are available on board. They are BSP296 type MOSFETs with low gate-turn-on voltage to allow the driving from +3.3V. Four GATEs of transistors are available at connector K450, and four drains at connector K451. Gates of transistors are terminated to ground on the board. Both connectors also offer the power supply for external circuitry, this time +5 V and +12 V.

The complete schematic diagram for the digital IO is given in Fig. 14.

2.8. RS232 bus - ±12V

A standard RS232 bus utilizing TTL to ±12 V driver is implemented on the board. The drivers receives support from the microcontroller, pins PC10 and PC11, and is connected to standard D9 connector P580 at the edge of the board. Caution: the connector can also supply +5 V to external circuits at pin 9. The complete schematic diagram of the RS232 driver and connector is given in Fig. 15.

2.9. Power output – motor driver

The microcontroller cannot supply much power to the load; it can only give digital control signals. In order to drive for instance a motor, some current is needed and this can be provided by a power driver.

It is expected that two motors might be connected to the board simultaneously. Both motors can be either stepper or regular type. The expected current consumption of these motors is 1 A at most, and the maximum voltage for the motors will be up to 24 V. A standard driver chip L293 is used for each motor. The schematic diagram for one of the chips is given in Fig. 8.

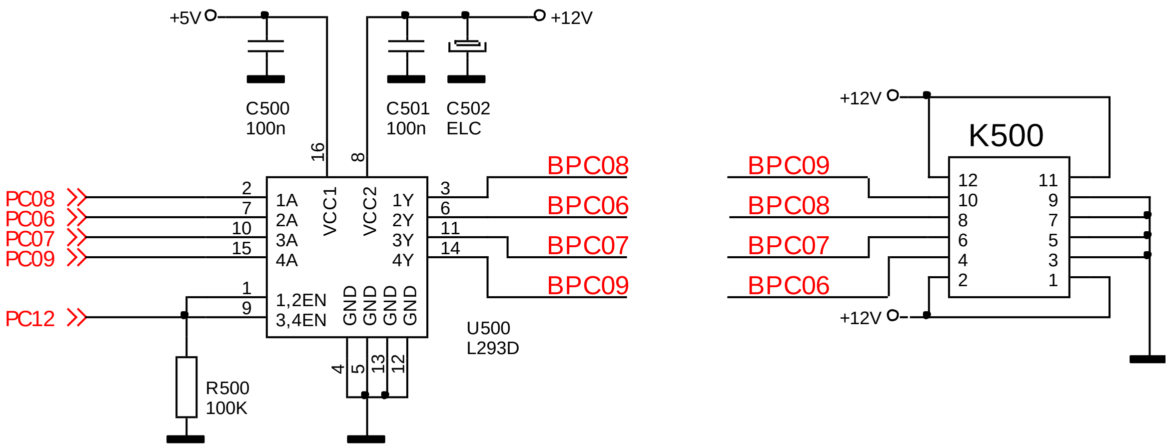

Figure 8: The schematic diagram of a motor driver

The driver chip is connected to suitable output pins of the microcontroller, which allow either the programmatic control of the diver or, when the appropriate function is selected, the PWM control. Pin PC12 is used to enable the driver, and its outputs are available at the connector K500. The chip has built-in clamp diodes towards the ground and power supply. The VCC1 is connected to +5 V assuring that the chip will correctly interpret 3.3 V signals from the microcontroller. The power output stage is supplied by +12 V, the same as connected to B200 or connector J220, as selected by the user. The chip is decoupled to ground using capacitor C502 (as big as possible to fit within the space on the board and to withstand the supply voltage) and C501.

The complete schematic diagram is available in Fig. 16.

2.10. RS232 bus – USB interface

The board hosts a FTDI chip to convert between USB and RS232. The complete schematic of the circuit is given in Fig. 17. The FTDI chip is supplied from the USB bus. It can be galvanically separated from the microcontroller when optocouplers U555 and U556 are inserted and jumpers J554 and J557 are properly selected or connected directly to the microcontroller. Pins PD08 and PD09 are used as a source for the microcontroller RS232 bus.

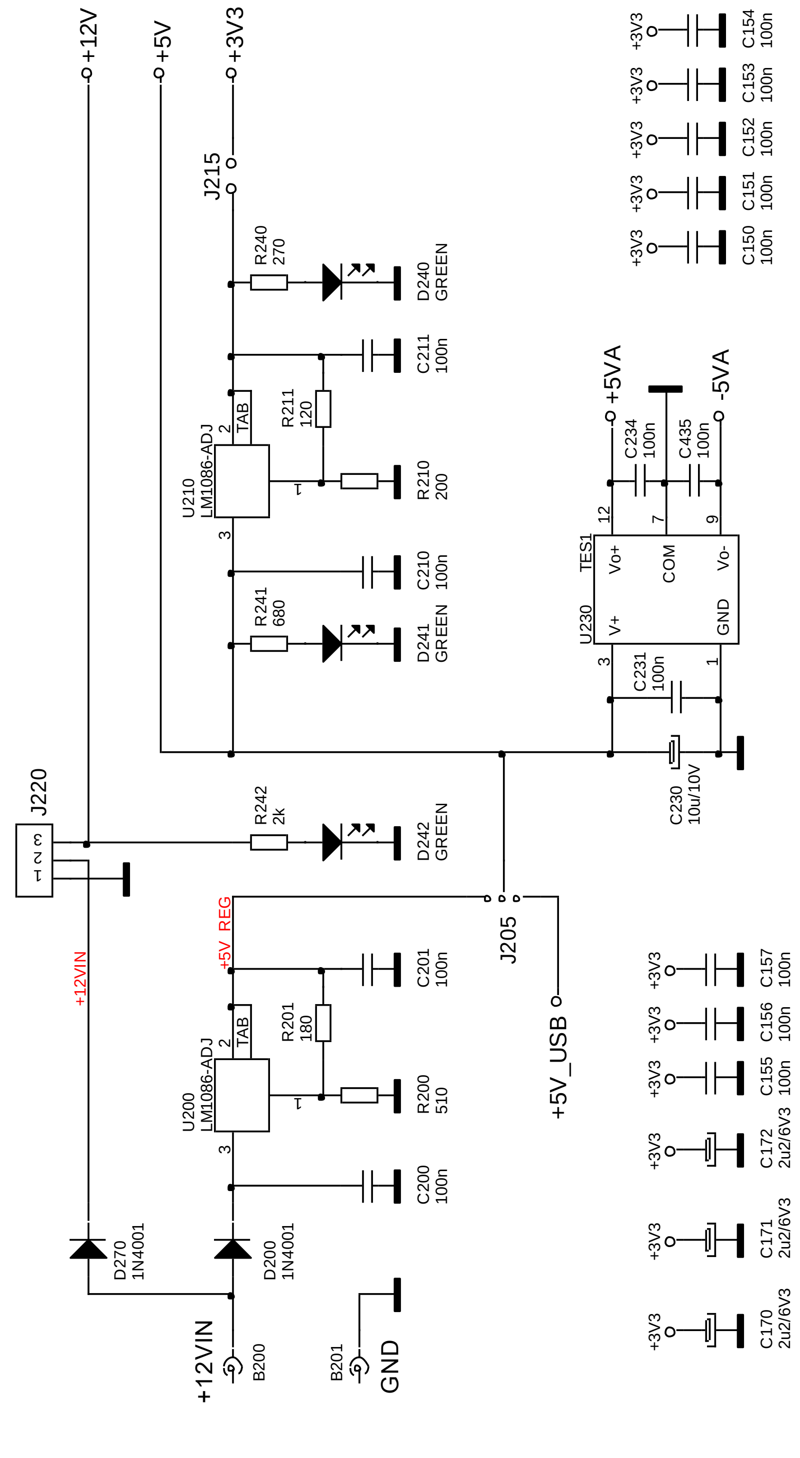

Figure 9: The schematic diagram of the power supply

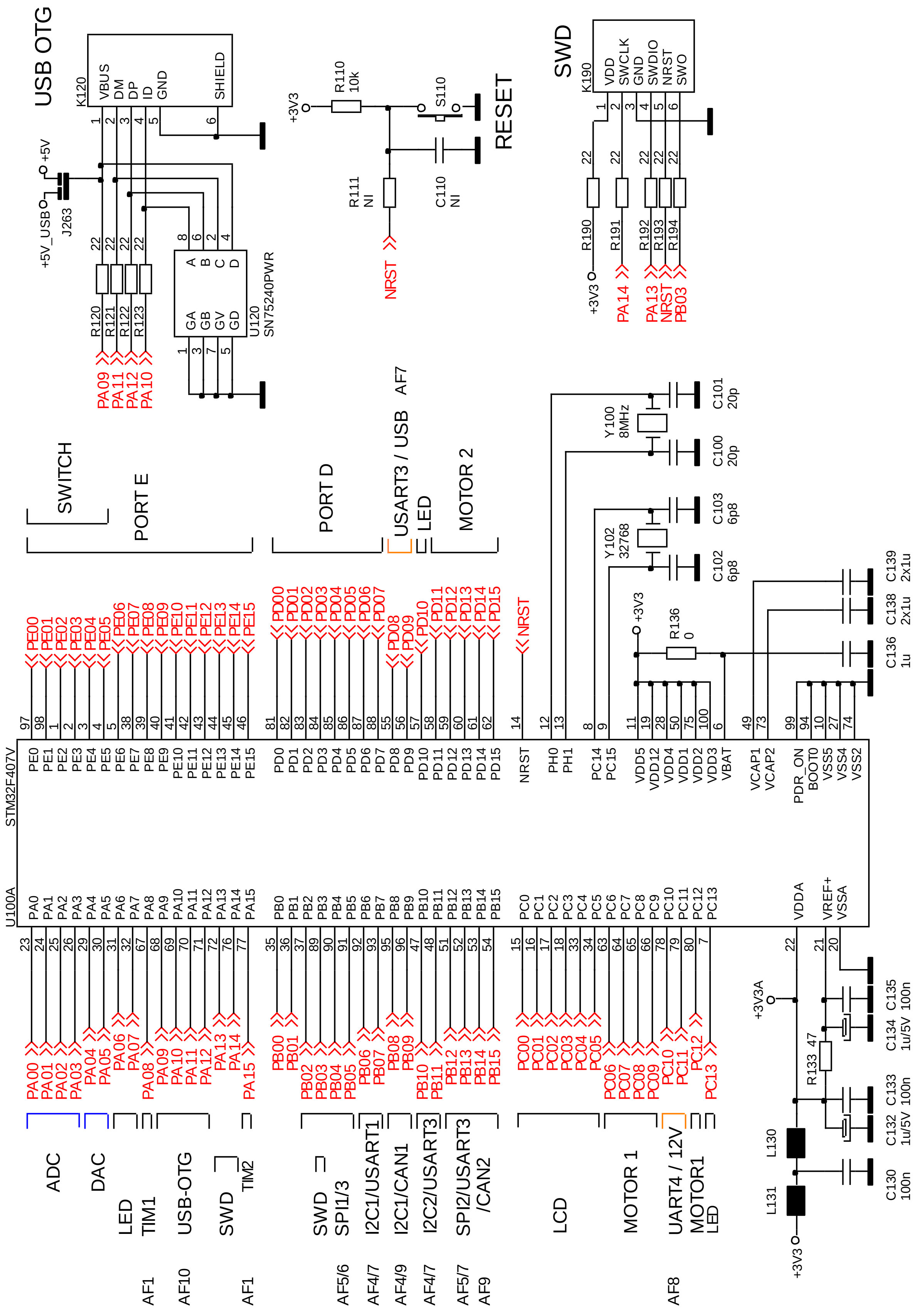

Figure 10: The schematic diagram of the microprocessor

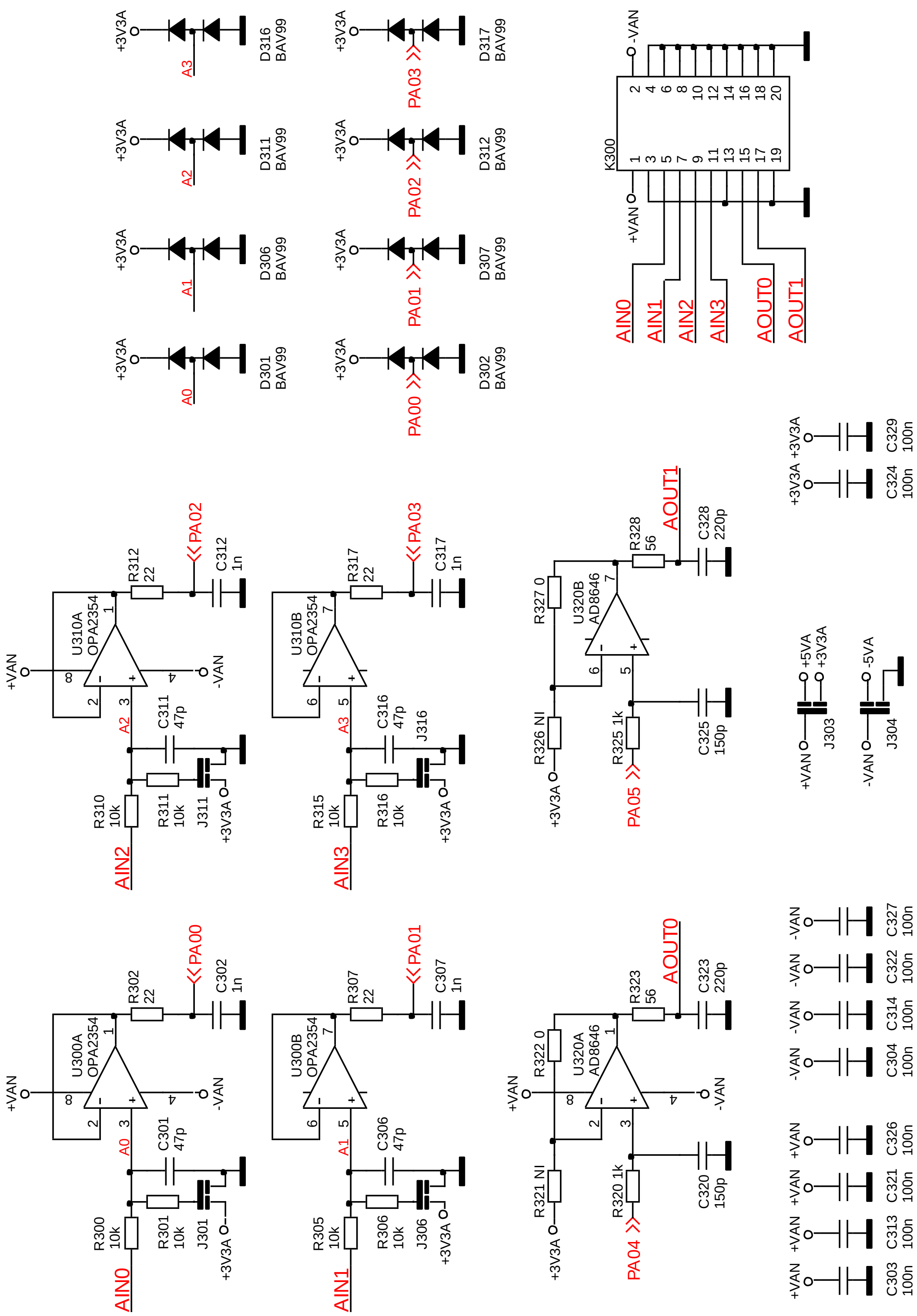

Figure 11: The schematic diagram of the analog interface

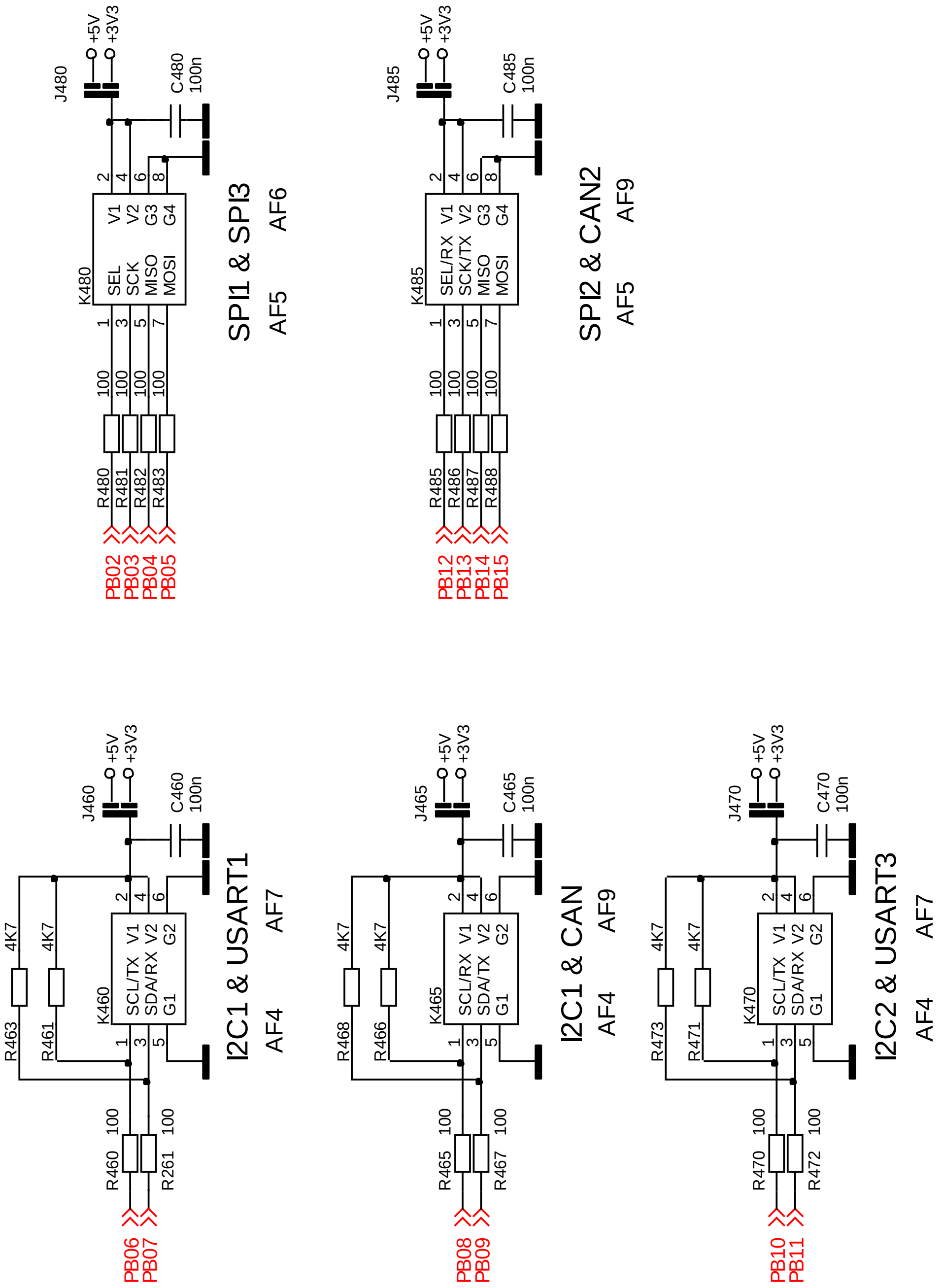

Figure 12: The schematic diagram of connections for serial buses

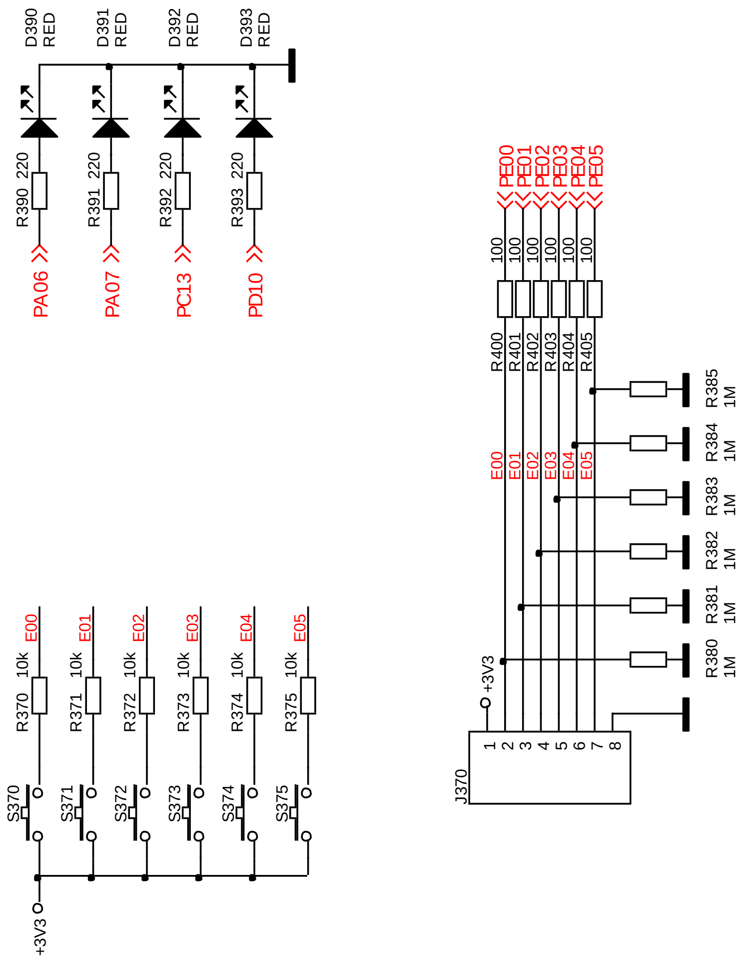

Figure 13: The schematic diagram for switches, LEDs and external keyboard

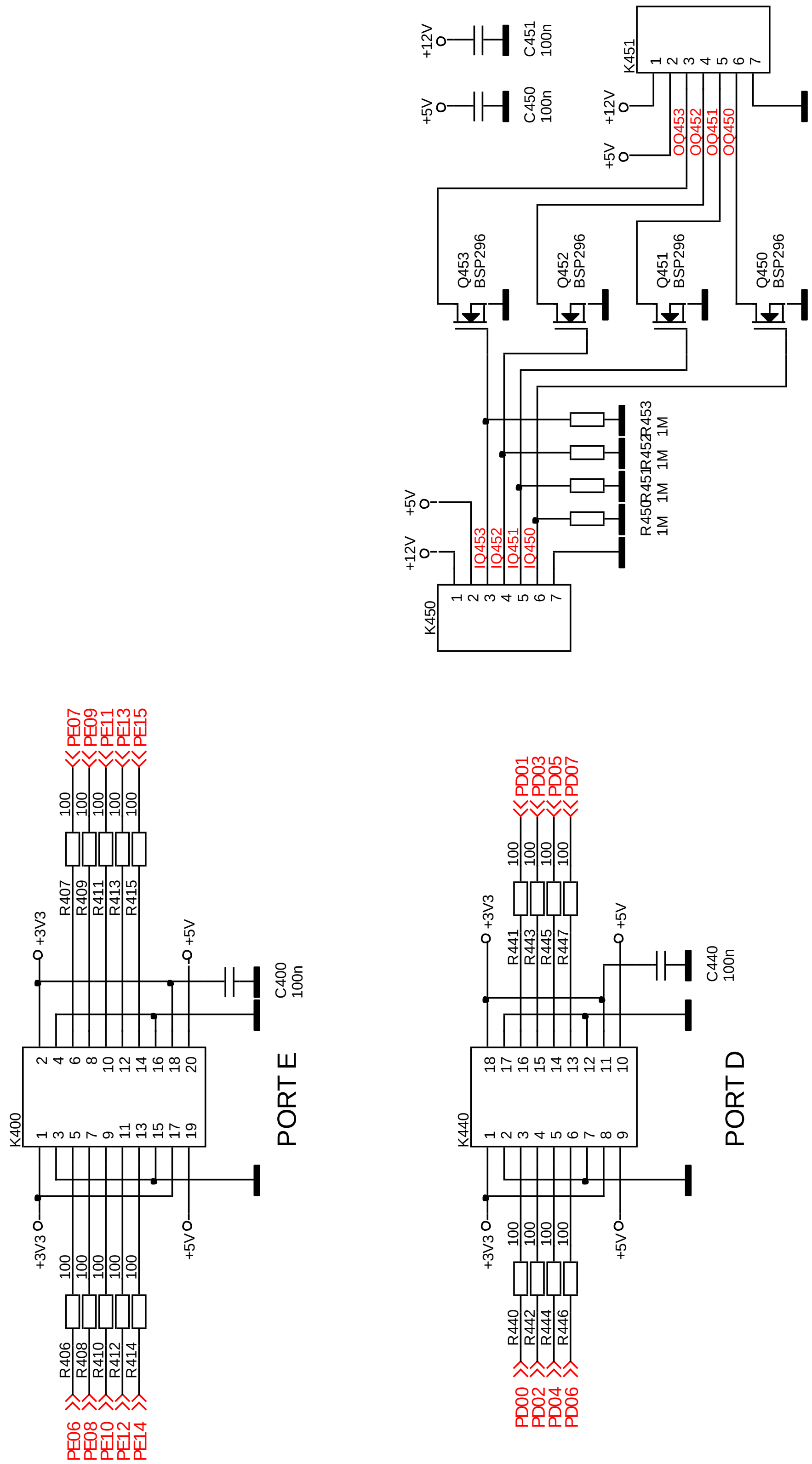

Figure 14: The schematic diagram of digital IO connectors and power transistors

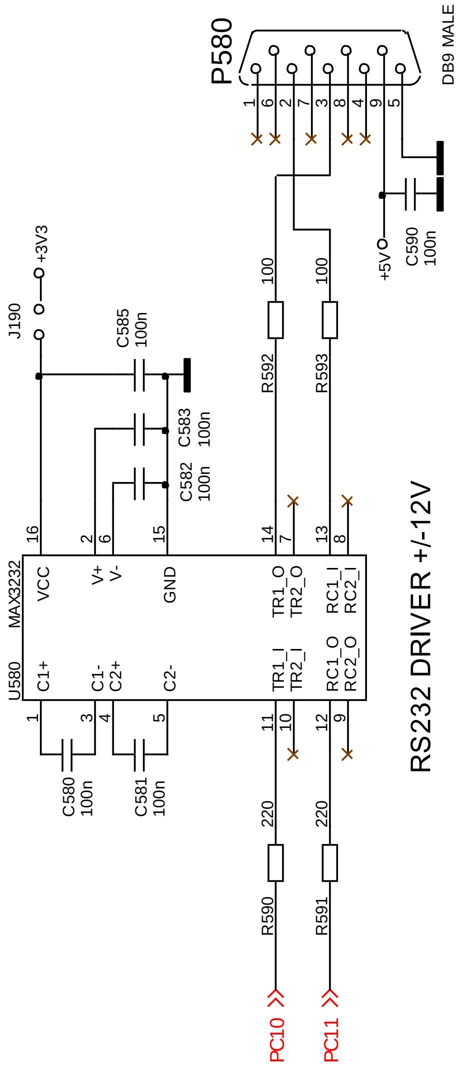

Figure 15: The schematic diagram of the TTL to RS232 translator

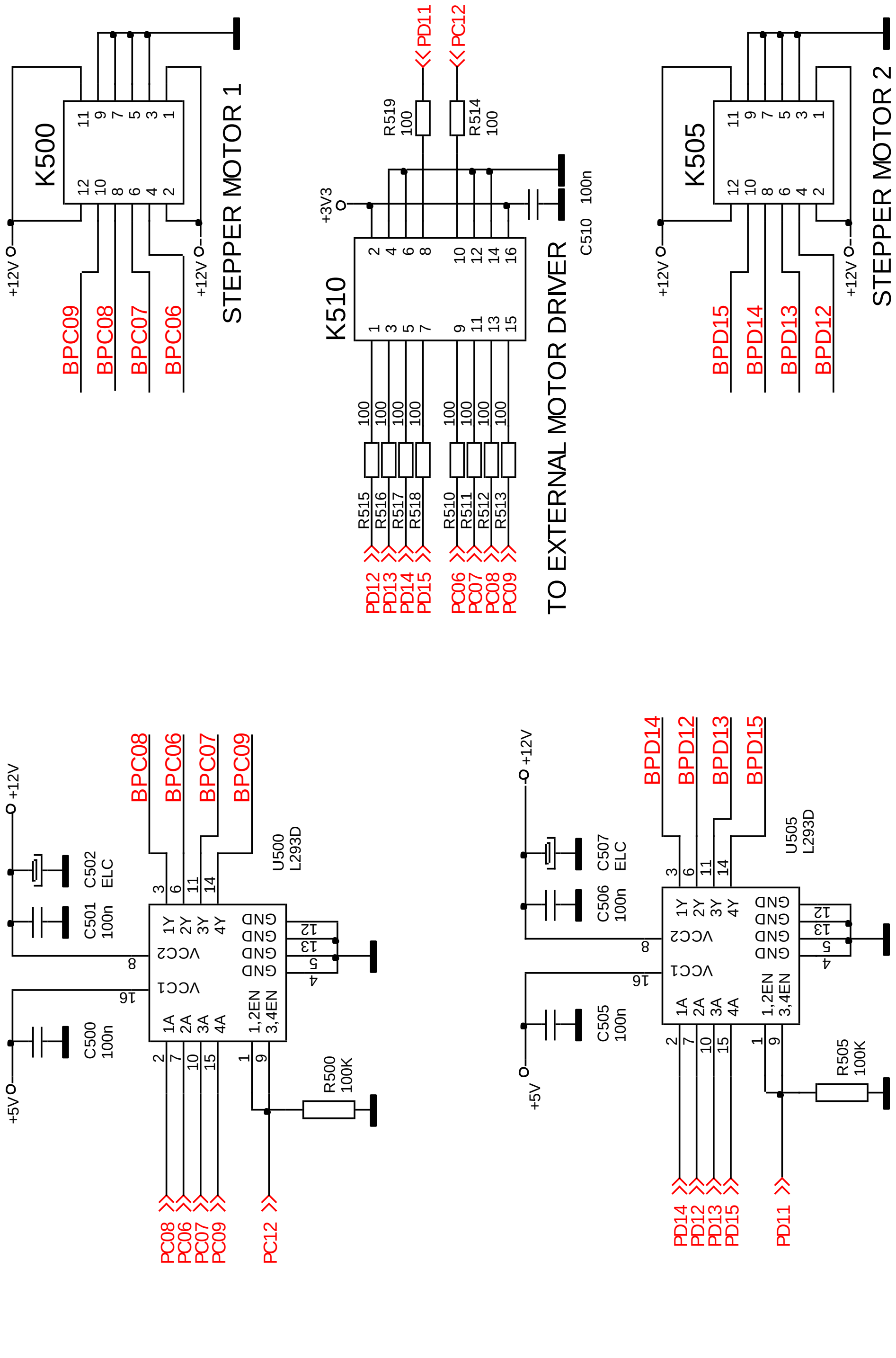

Figure 16: The schematic diagram for power drivers – stepper motors

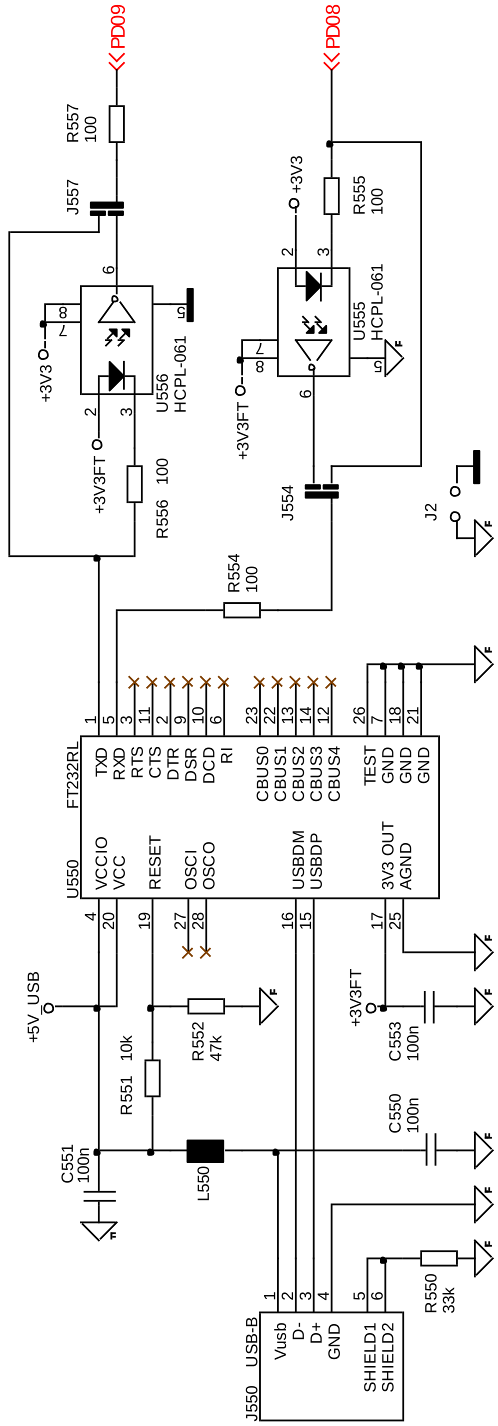

Figure 17: The schematic diagram of the USB to TTL-RS232 converter

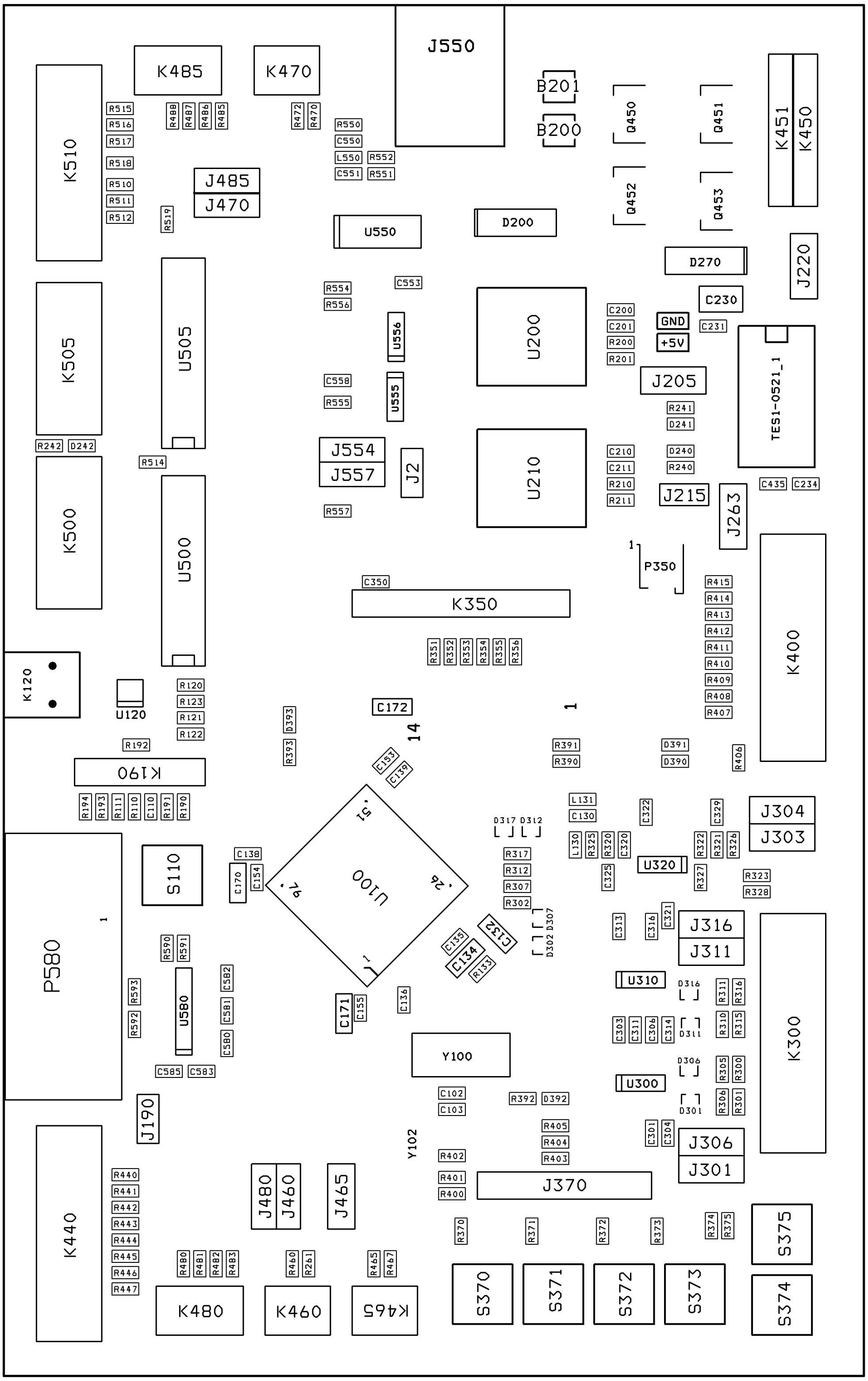

Figure 18: Component stuffing diagram, top side

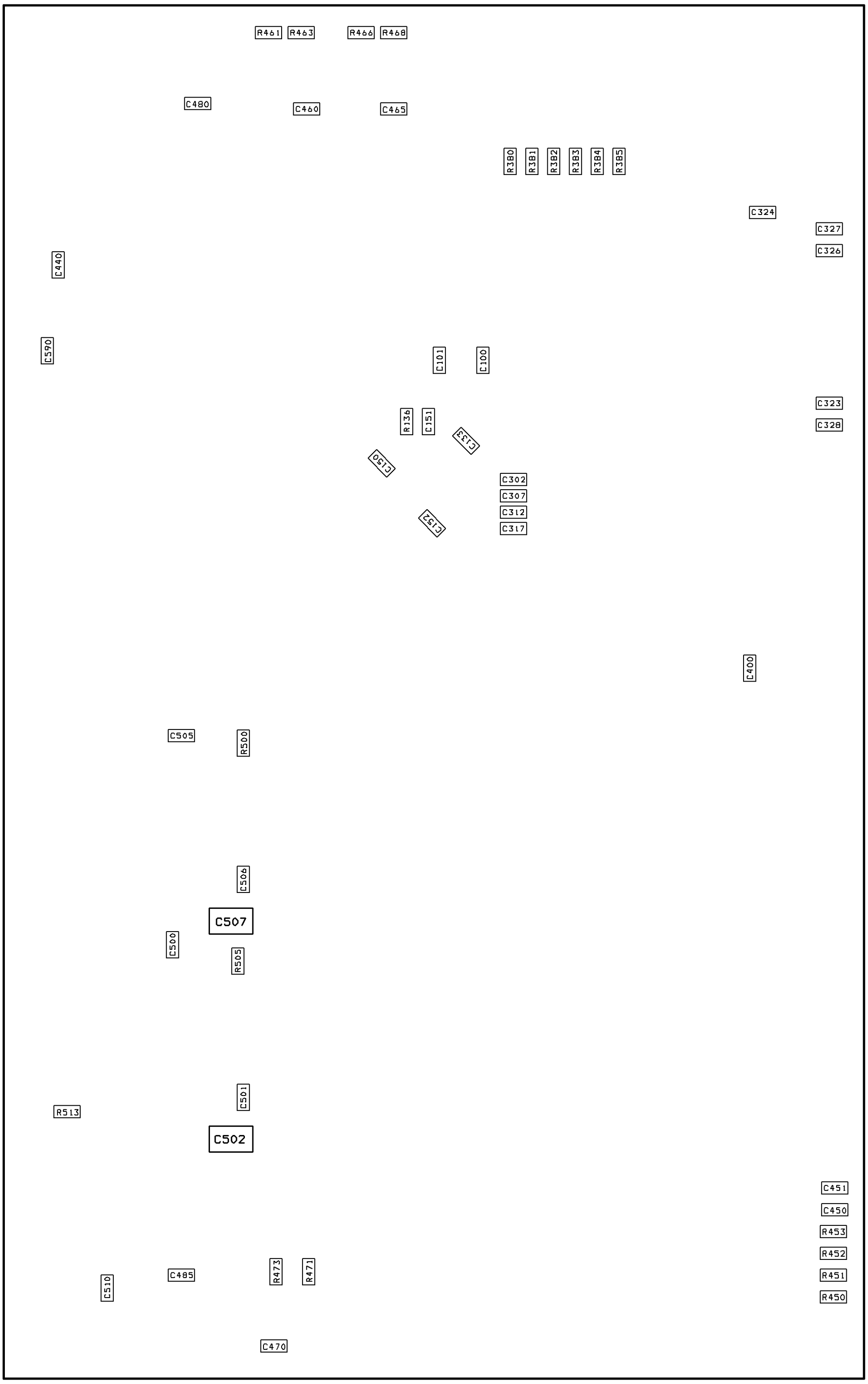

Figure 19: Component stuffing diagram, bottom side

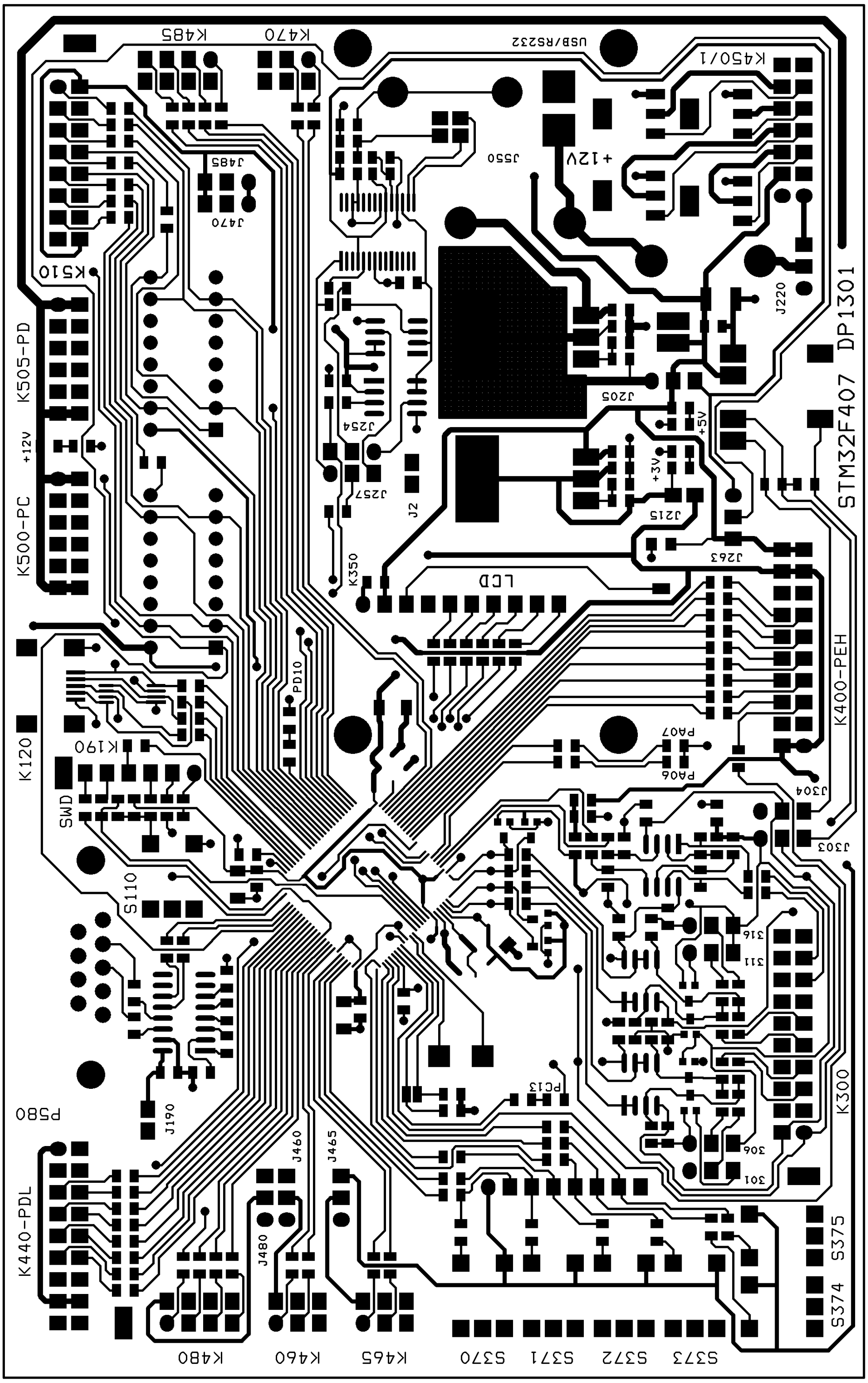

Figure 20: Board layout, top layer

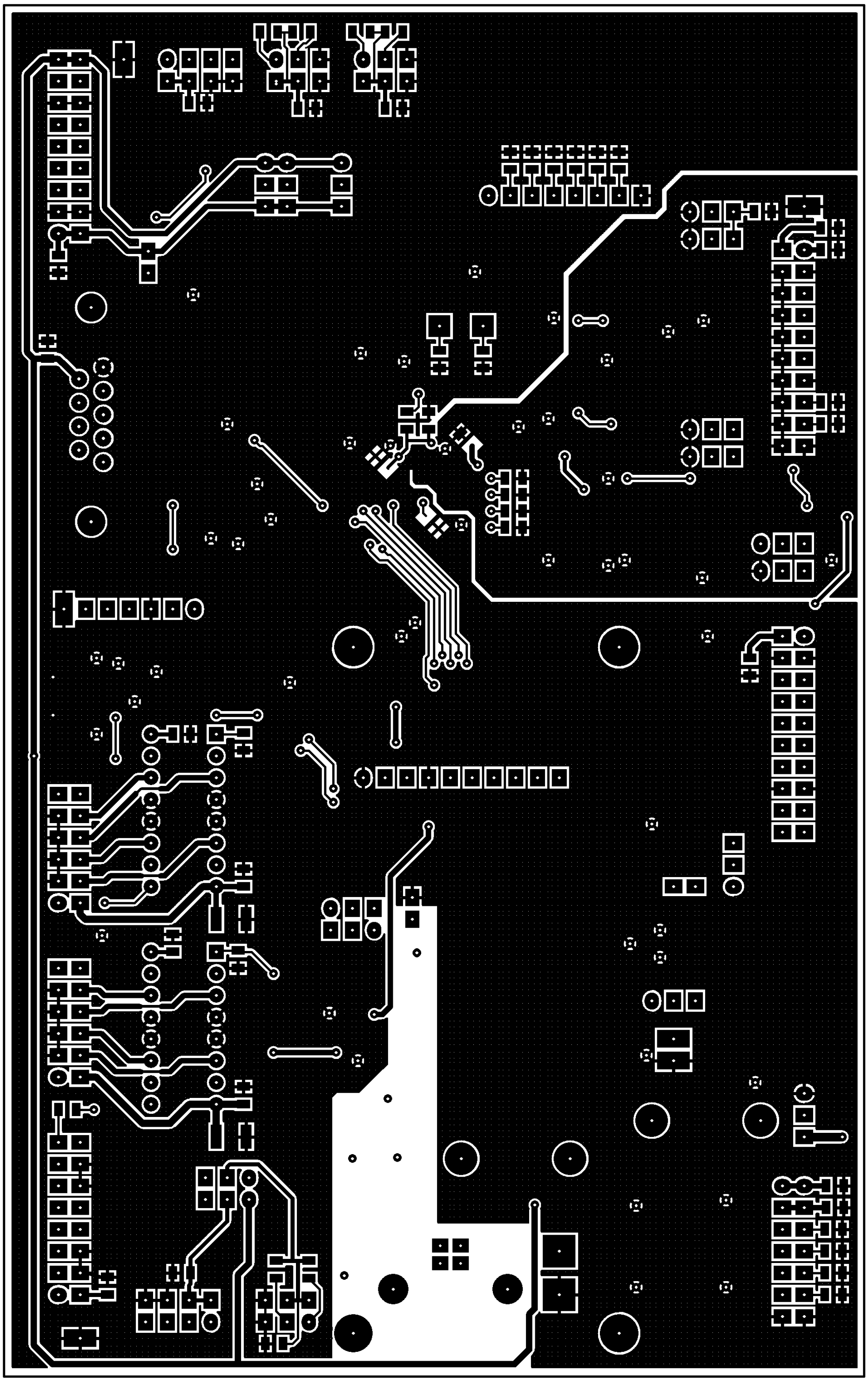

Figure 21: Board layout, bottom layer, mirrored

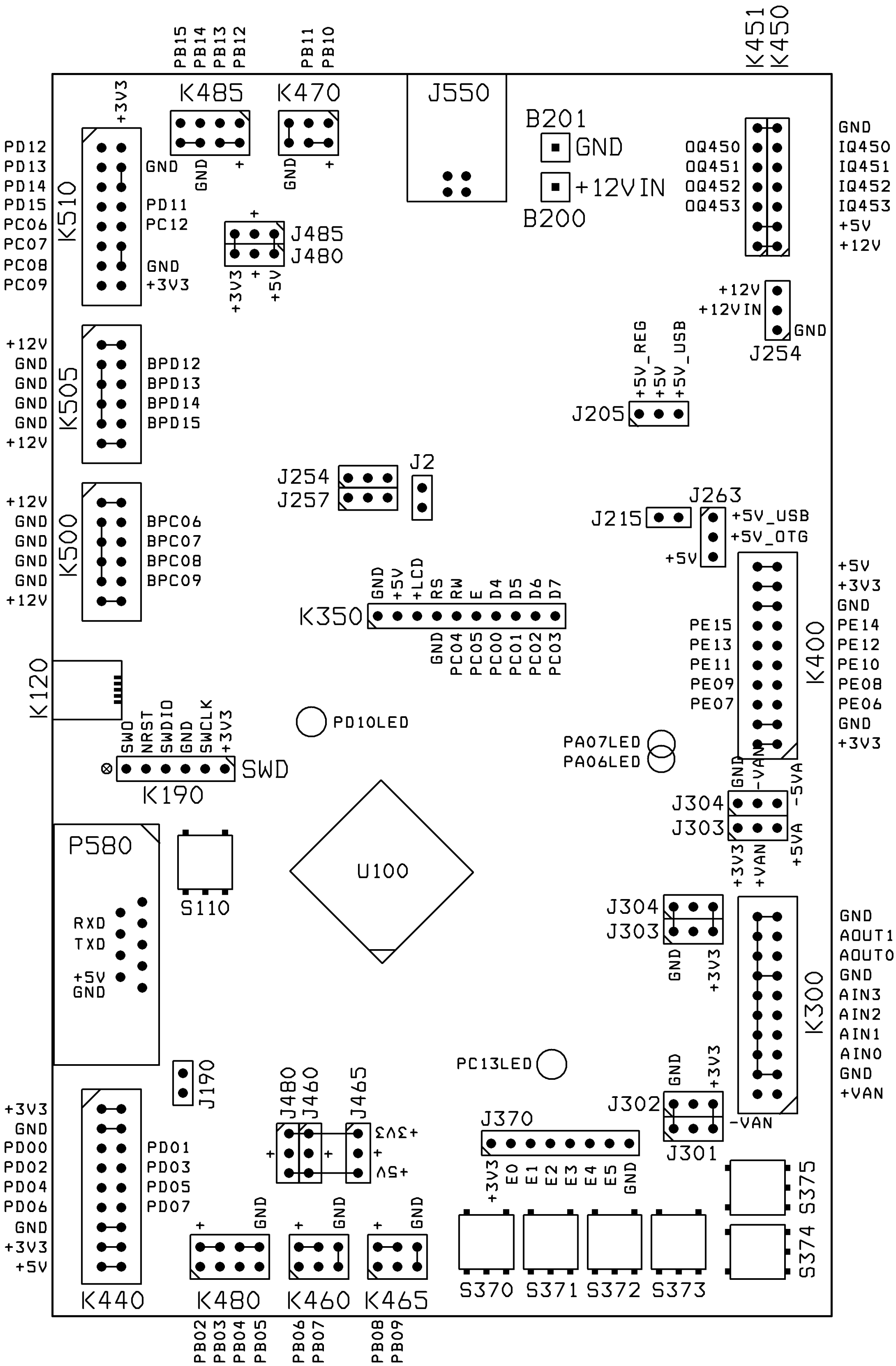

Figure 22: Signal & connector layout

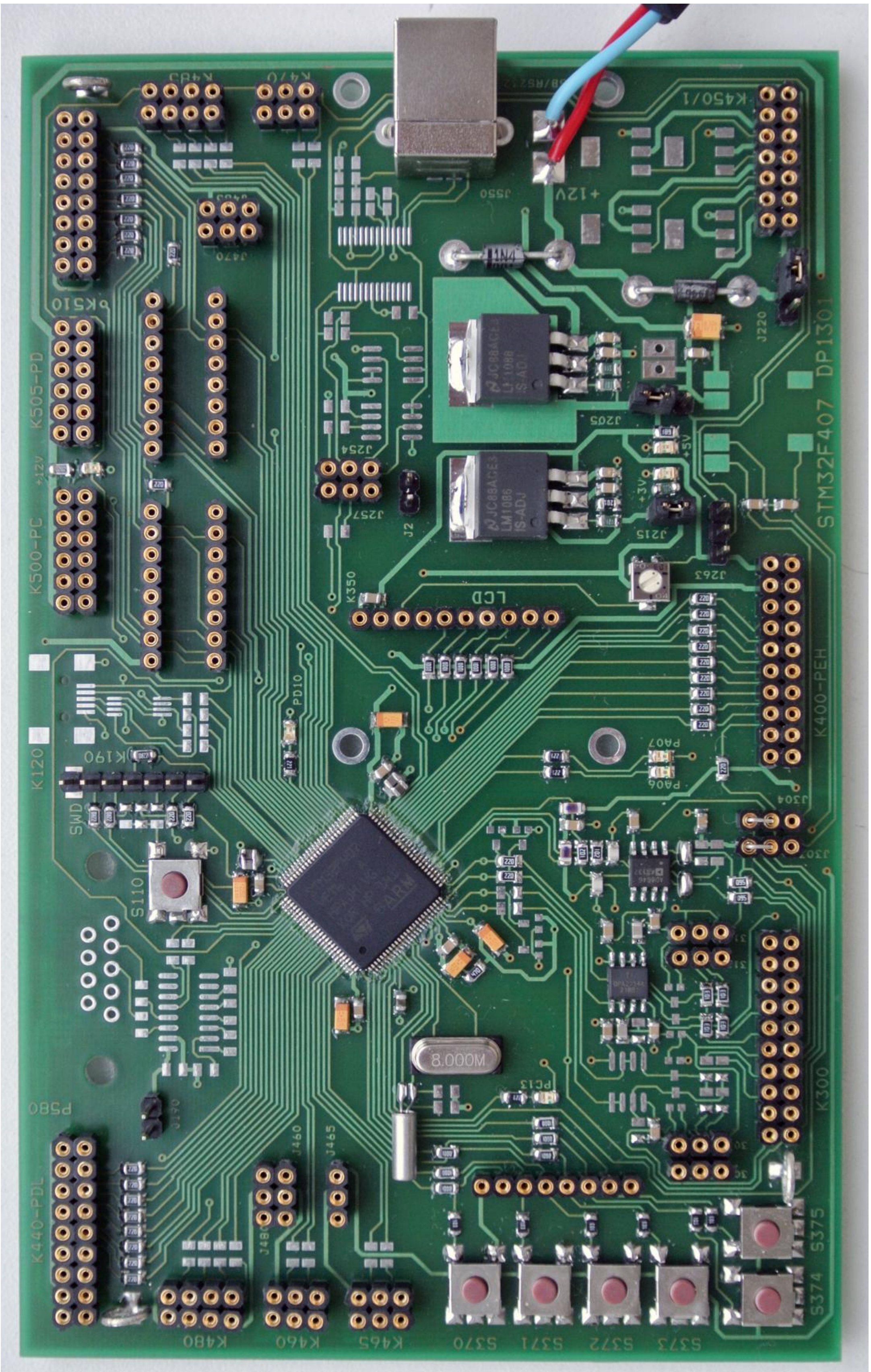

Figure 23: Photo of the assembled board, top view, not finished