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TEMPERATURE MEASUREMENT SYSTEM

Digital System Design

School of Technology

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1 INTRODUCTION

In this project, a temperature measurement system was built. The information is processed in the analog signal processor and then sent from a transmitter to a receiver. The transmitter and receiver can be 100 meters from each other and still have reliable result. The system should be able to measure temperature from -30°C to 30°C with an accuracy of 0.5°C and have a response time of 1 second. The receiver was connected to an Arduino via an analog to digital converter (ADC) circuit.

The project consists of four different circuits, which are: analog signal processing, transmitter, receiver and ADC. The predesign had even more functionalities for the project that was not implemented (see figure 1).

The goal of the project is to learn how a project is carried out, from planning to final testing.

2 PREDESIGN

A Raspberry Pi would be the central unit to receive input, process data and send data output.

There would be several devices and components connected to the central unit. Devices and component would be classified based on their function, which are input or output and types that is digital or analog.

● Temperature sensors as analogue input devices

● Monitor Switches and Smoke Detector as digital input devices

● Radiators, Sirens and Flashing Lights as digital output devices

● Monitor as analogue output device

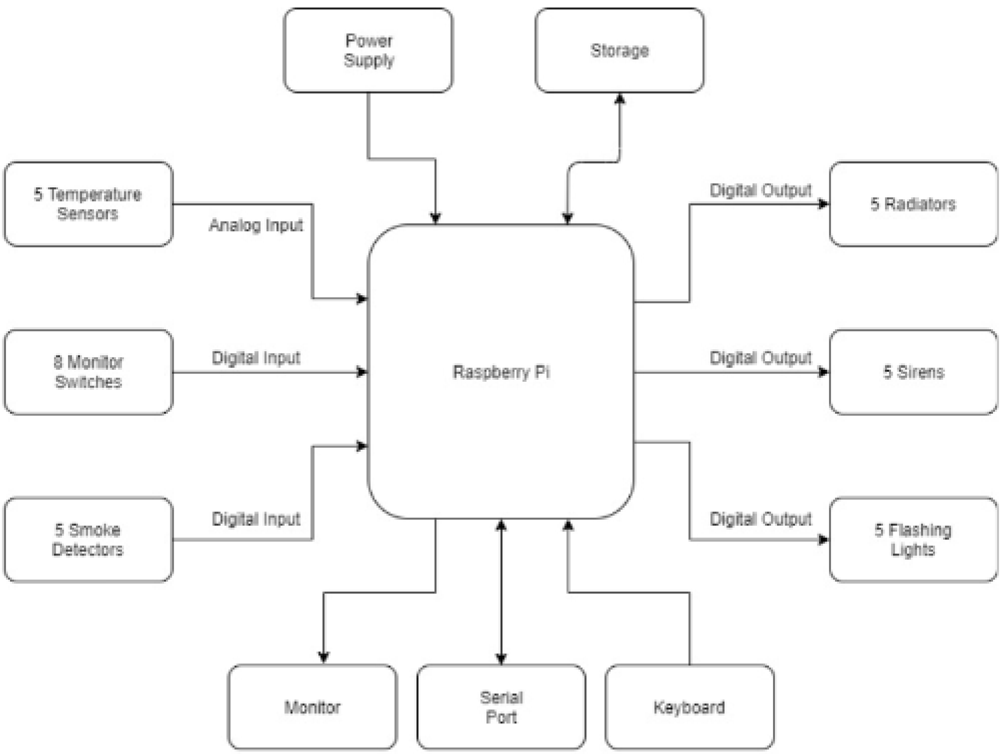

Figure 1. System block diagram

3 CIRCUITS

3.1 Analog signal processing

The first circuit is the part that includes the sensor. The signal coming from the sensor is processed in this part. The sensor gives out voltages between -0.3V and 0.3V. The signal then goes through a differential amplifier, which gives voltages between 0V and 3V. The circuit diagram can be seen in figure 2.

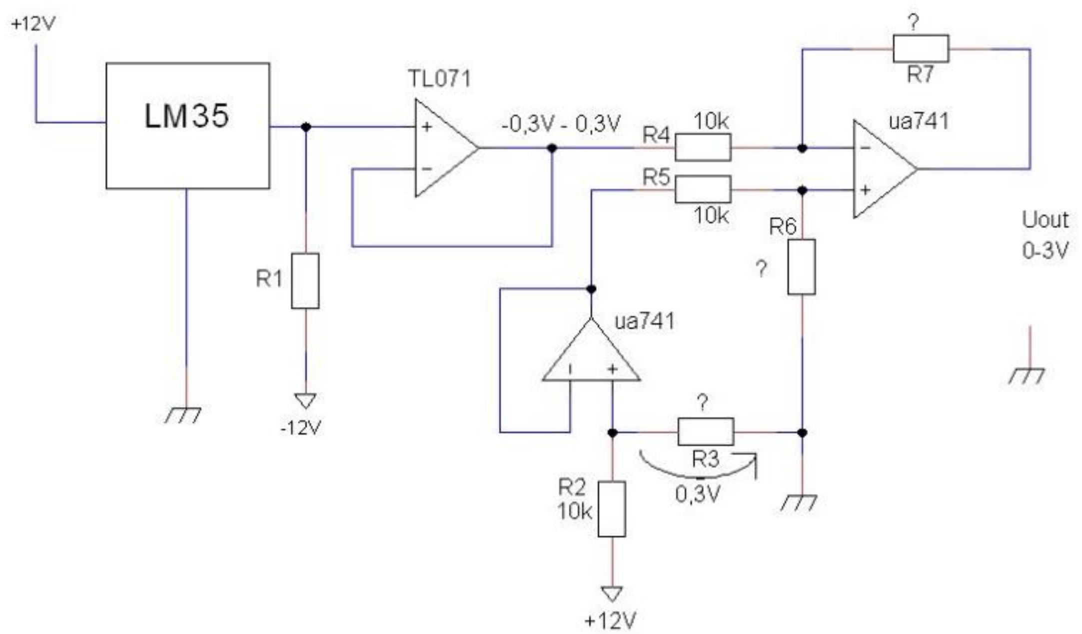

Figure 2. Circuit diagram of the analog signal processor

The first task was to calculate the values of resistors 1, 3, 6 and 7. The result can be seen in table 1.

R1	R3	R6	R7
$R1 = \frac{V+}{50uA}$	$R3 = \frac{-R2 * 0.3}{0.3 - 12}$	R6 = R7	$R7 = -\frac{U_{out} * R4}{(U_{1a} - U_{1b})}$
240 kΩ	256 Ω	50 kΩ	50 kΩ

Table 1. Resistor calculations

After the circuit was complete. The simulation was carried out. The software used was LTSpice. DC sweep from -0.3V to 0.3V was used instead of the LM35 sensor during the simulation. The circuit for the simulation can be seen in figure 3.

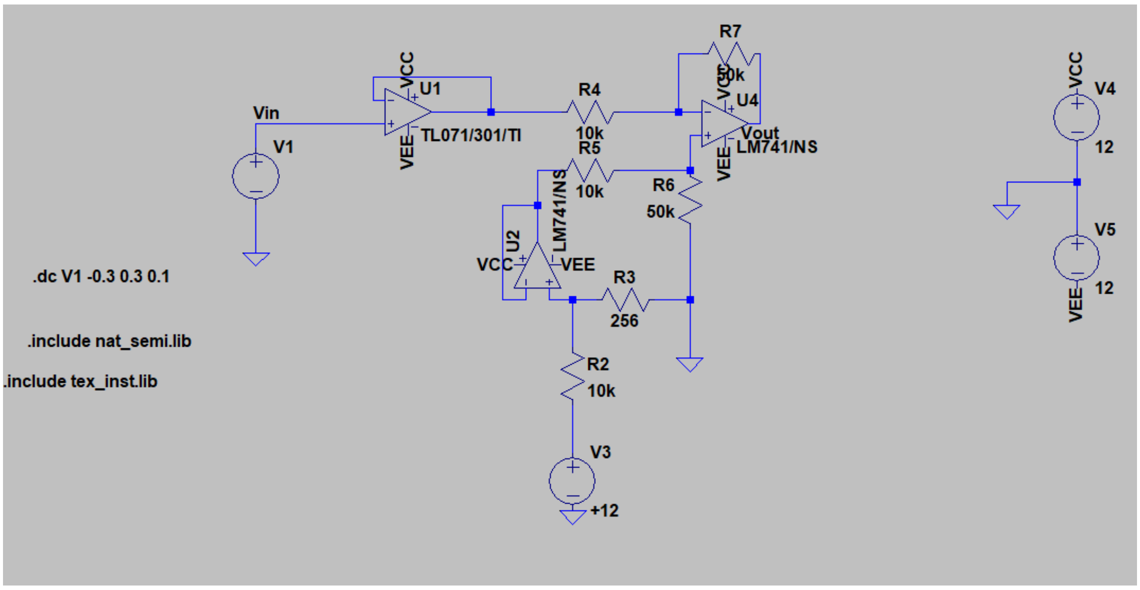

Figure 3. Analog signal processing circuit in LTSpice

As shown in the simulation result in figure 4, when the input voltage is -0.3V, the output voltage is 3V, as it should be. And when the input voltage is 0.3V, the output voltage is 0V.

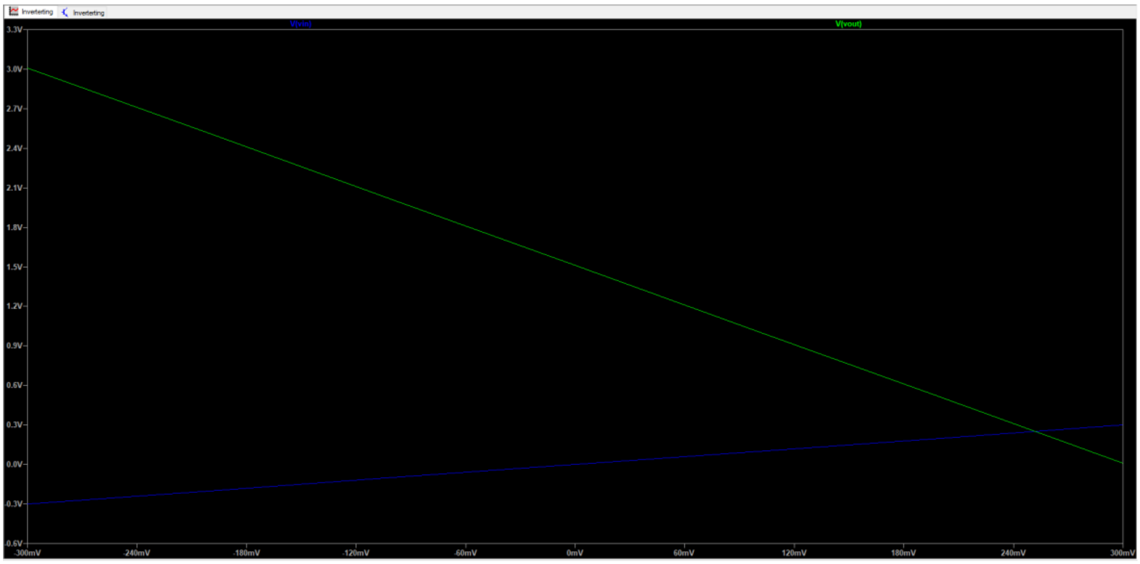

Figure 4. Analog signal processing simulation result

When the simulation was completed, the circuit was made on a breadboard to test the circuit before making the final PCB design. Capacitors were added between ground and the power source for decoupling. The breadboard circuit can be seen on the left side of the red line in figure 5.

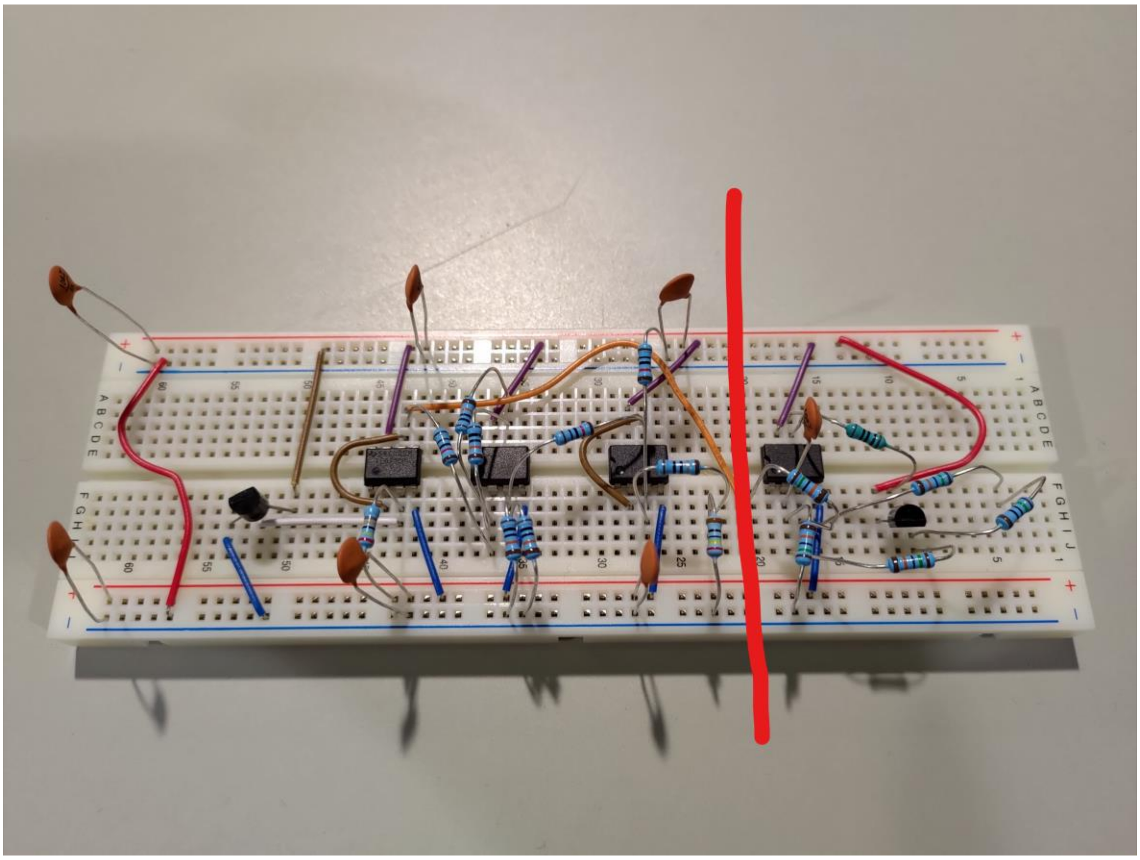

Figure 5. Breadboard circuit

To test the breadboard circuit, a multimeter was connected to the input signal and another multimeter was connected to the output signal. A power supply was used instead of the LM35 sensor to be able to see if the readings were correct. The test results can be seen in figures 6 and 7.

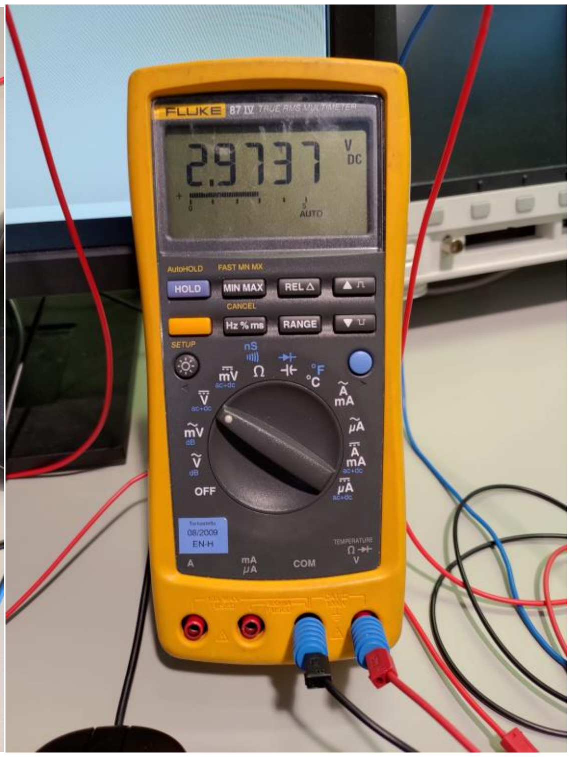

Figure 6. Input voltage **Figure 7.** Output voltage

3.2 Transmitter

The transmitter´s input will come from the analog signal processor. The signal will be 0V-3V and the transmitter will amplify it to 0V-5V and then send it to the receiver (will be explained later). The circuit diagram of the transmitter can be seen in figure 8.

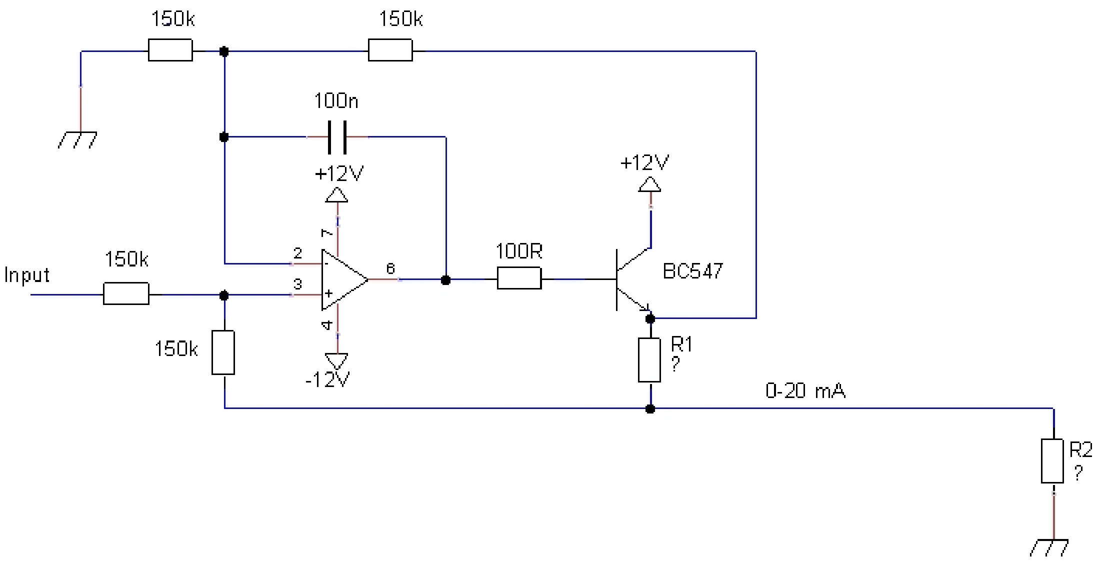

Figure 8. Circuit diagram of the transmitter

Before the simulation could be carried out, the missing resistor values had to be calculated. The results can be seen in table 2.

R1	R2
$R1 = \frac{U_{in}}{I_{out}}$	$R2 = \frac{U_{out}}{I_{out}}$
150Ω	250Ω

Table 2. Values for resistors R1 and R2

With the completed circuit diagram, the simulation circuit can be done. When simulating the transmitter side, the voltage source was replicating the output of the analog signal processor, so a voltage sweep between 0V and 3V was used. The output voltage should be between 0V and 5V. The simulating circuit can be seen in figure 9.

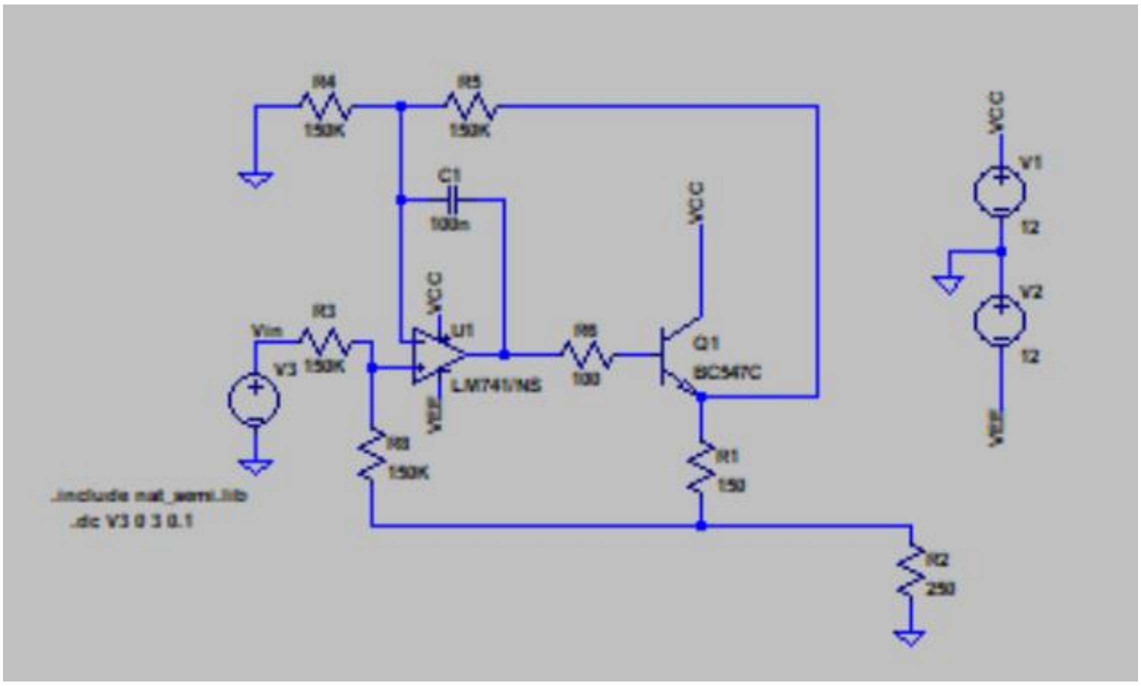

Figure 9. Simulating circuit of the transmitter

As seen in the simulating result in figure 10, when the input voltage is 3V, the output voltage is amplified to 5V.

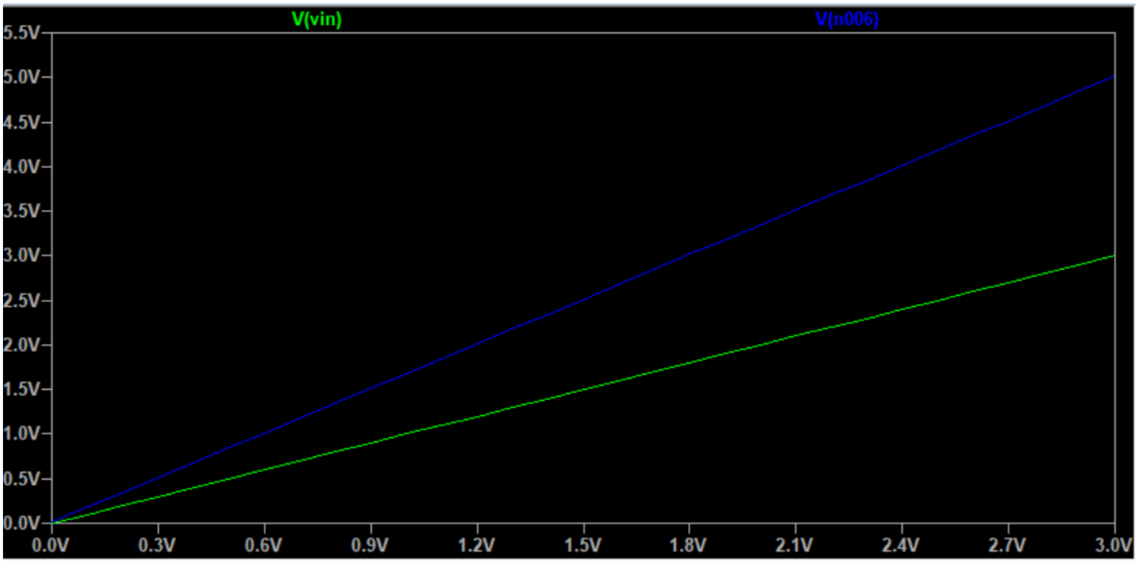

Figure 10. Simulating result of the transmitter

The breadboard circuit can be seen in figure 4 on the right side of the red line.

Similarly, as when testing the analog signal processor, a multimeter was connected to the input and output of that circuit, but now, one more multimeter was added to the end of the transmitter. A 100-meter-long cable was used to carry the signal to the last multimeter, this could be the situation in real life when carrying the signal from the transmitter to the receiver. As shown in figure 11, the output voltage shows approximately 5V when the input voltage is approximately 3V, which was the goal.

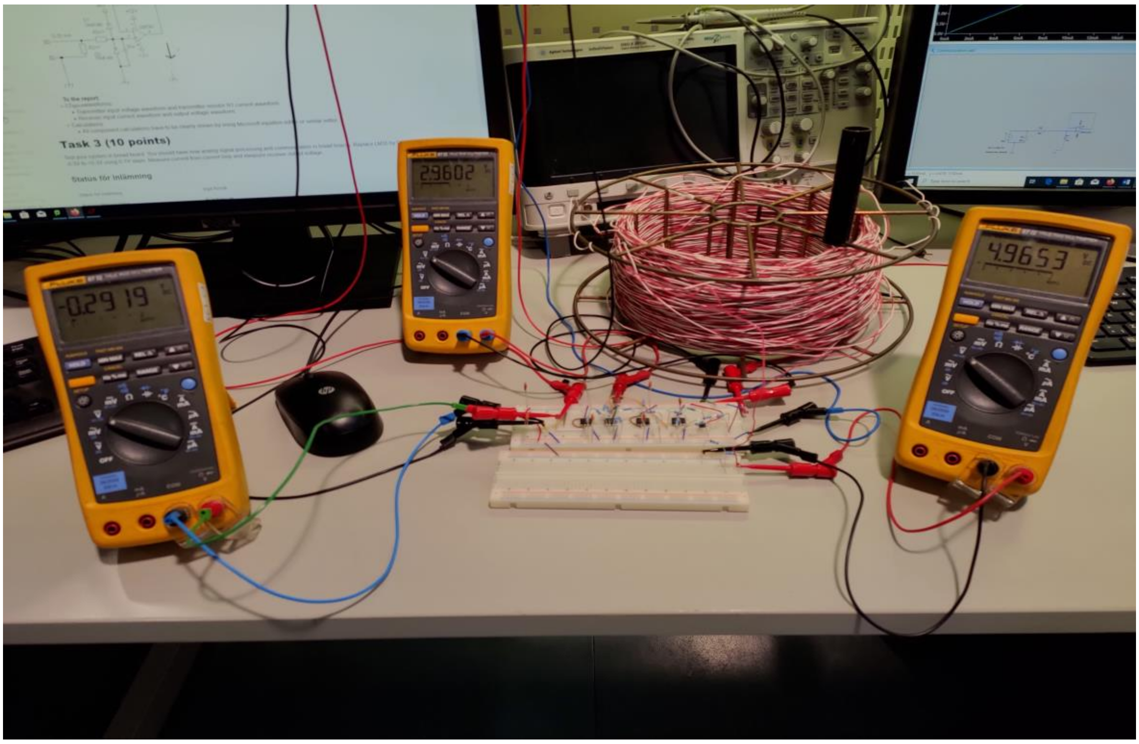

Figure 11. Testing the breadboard circuit

3.3 Receiver

The receiver part is a current to voltage transformer. The input signal that comes from the transmitter is 0-20mA, and this current is changed to voltage for the ADC. The circuit diagram of the receiver can be seen in figure 12. In the figure, R2 is the same resistor as the transmitter R2.

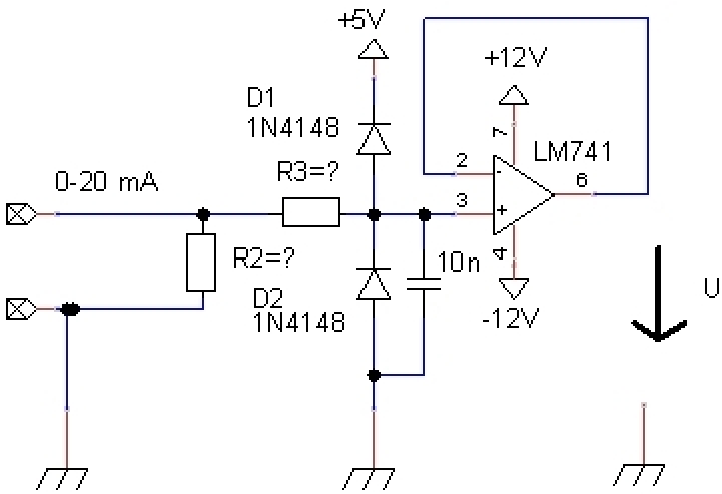

Figure 12. Circuit diagram of the receiver

The task was given, to calculate R3 if the input signal contains 8kV ESD discharge voltage. When the ESD occurs, the signal goes through D1 and D2 with 0.8A. The value of R3 was calculated in the following way:

$$R3 = \frac{V_{ESD}}{I_{D1}} = \frac{8kV}{0.8A} = 10k\Omega$$

The cut of frequency of the low pass filter in the receiver is calculated in the following way:

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2 * \pi * 10k\Omega * 10nF} = 1591.5Hz$$

When simulating the receiver part, the diodes were not used, because the ESD was not simulated. The input signal was 0-20mA. The simulation circuit can be seen in figure 13 and the simulation result can be seen in figure 14.

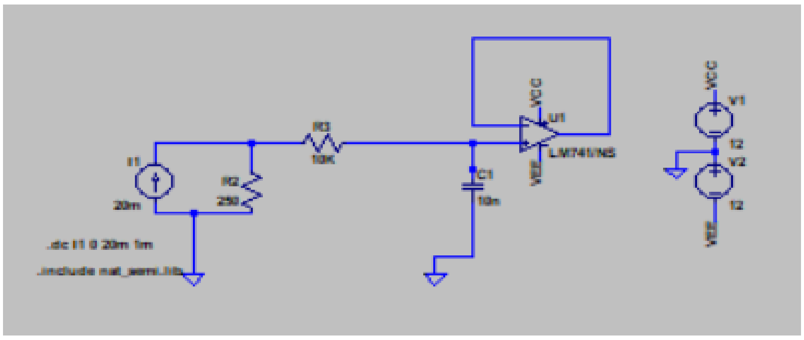

Figure 13. Simulation circuit of the receiver

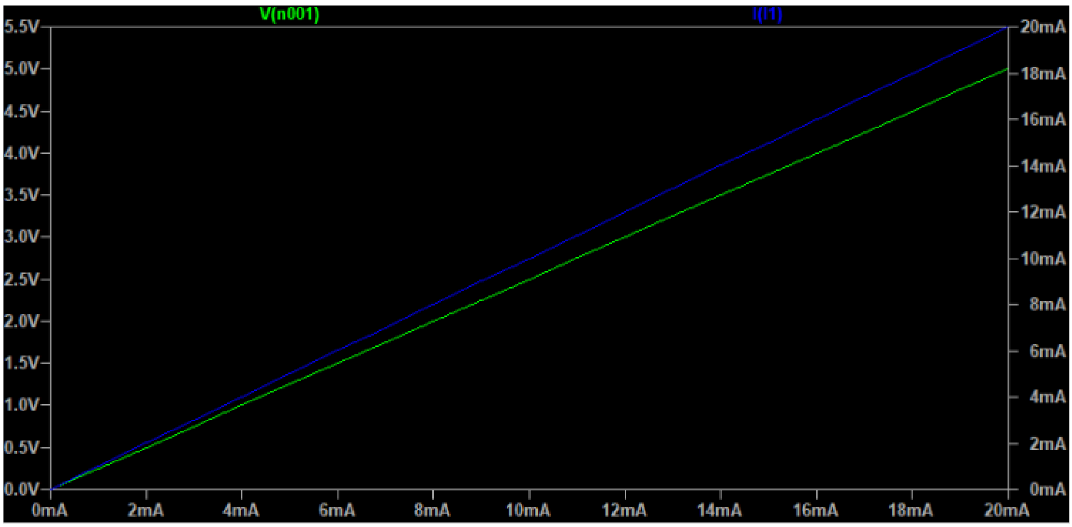

Figure 14. Simulation result of the receiver

The breadboard circuit of the receiver can be seen in figure 15.

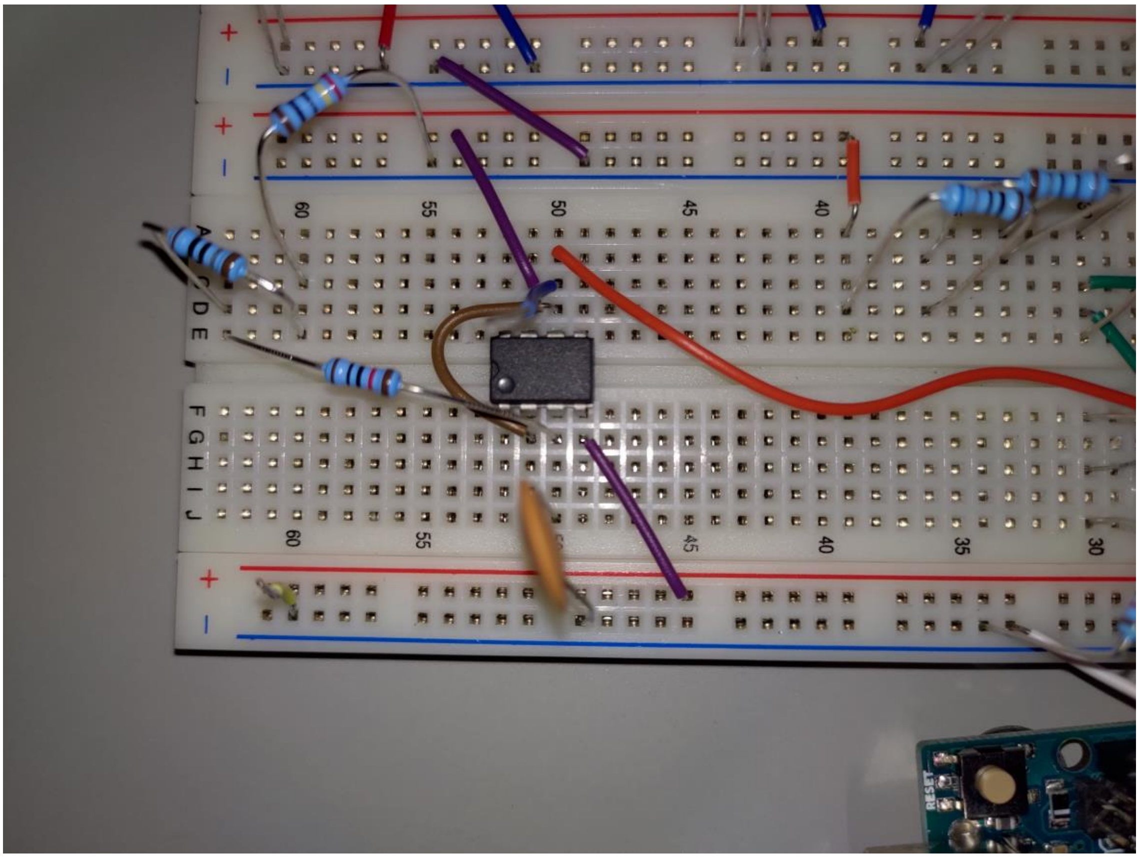

Figure 15. Breadboard circuit of the receiver

The testing of the receiver was done similarly to the testing of the transmitter, except that the last multimeter was connected to the receiver output where the ADC will be connected. The breadboard testing can be seen in figure 16.

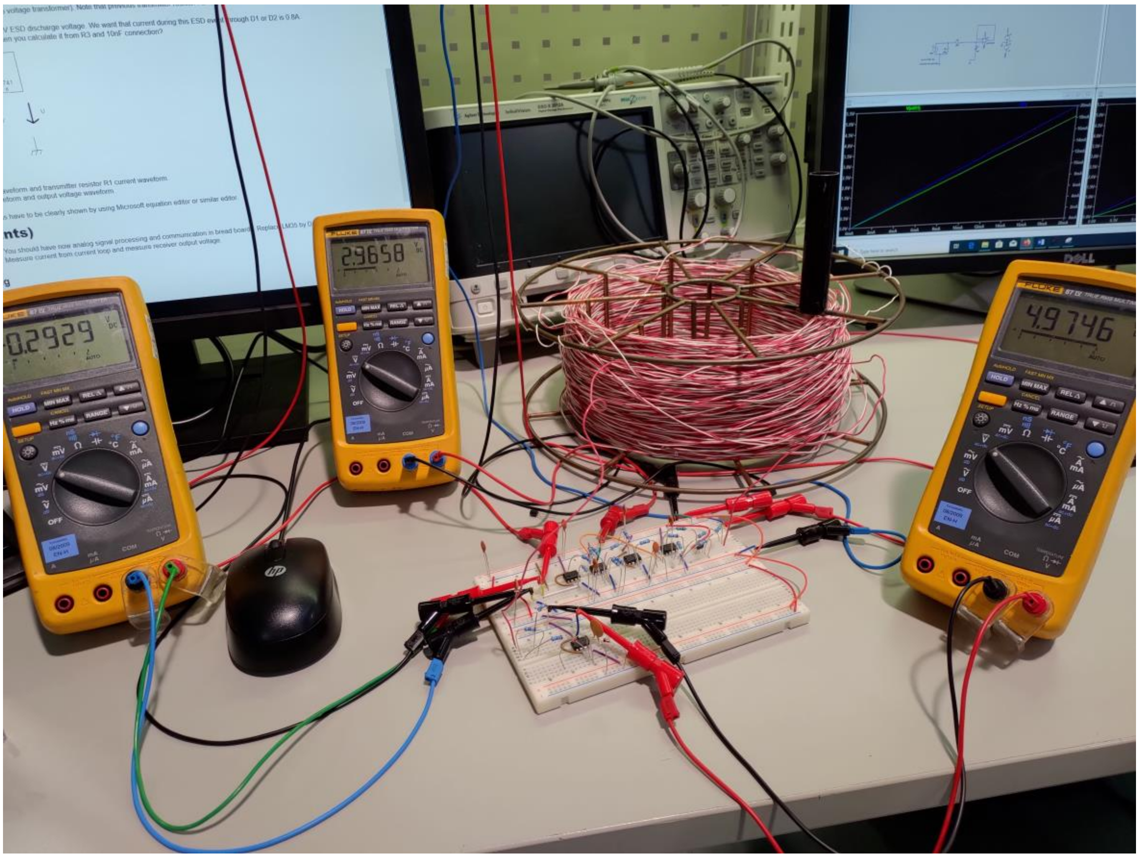

Figure 16. Breadboard testing of the receiver

3.4 Analog to digital converter

An MCP3002 was used as A/D converter and for that a reference voltage was needed, the reference chip used was LM431. Figure 17 shows the circuit diagram of the circuit used to obtain the wanted reference voltage of 5V.

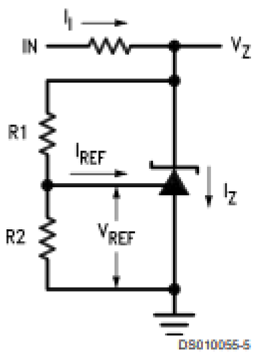

Figure 17. Circuit diagram of the reference circuit

The values used in the circuit to obtain an output voltage (V_Z) of 5V can be seen in table 3.

IN	V_Z	Ii	Ri	V_{REF}	I_{REF}	R1	R2
12V	5V	10mA	700Ω	2.5V	2μA	10kΩ	10kΩ

Table 3. Values used to obtain the correct output voltage

To communicate with the MCP3002, the following signals were taken from the Arduino board: CS, CLK and D_{IN}. V_{REF} was taken from the reference circuit output and channel 1 was used and got the signal from the receiver output. D_{IN} sent the signal to the Arduino board. The MCP3002 pins can be seen in figure 18.

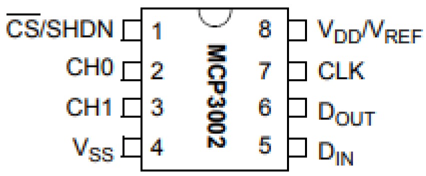

Figure 18. MCP3002 pins

The breadboard circuit can be seen in figure 19.

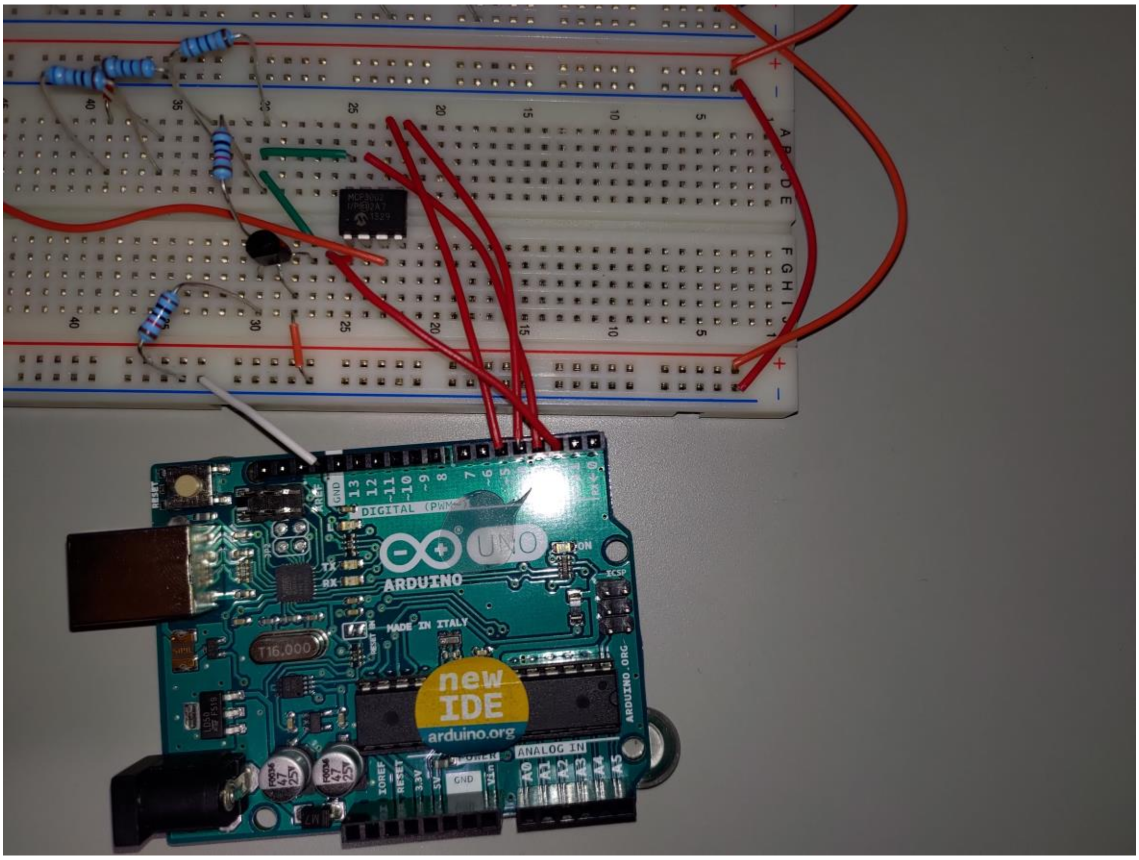

Figure 19. Breadboard circuit of the ADC

When the circuit was done, the power supply was changed to the temperature sensor to test the final version of the breadboard connections. The final breadboard test can be seen in figure 20.

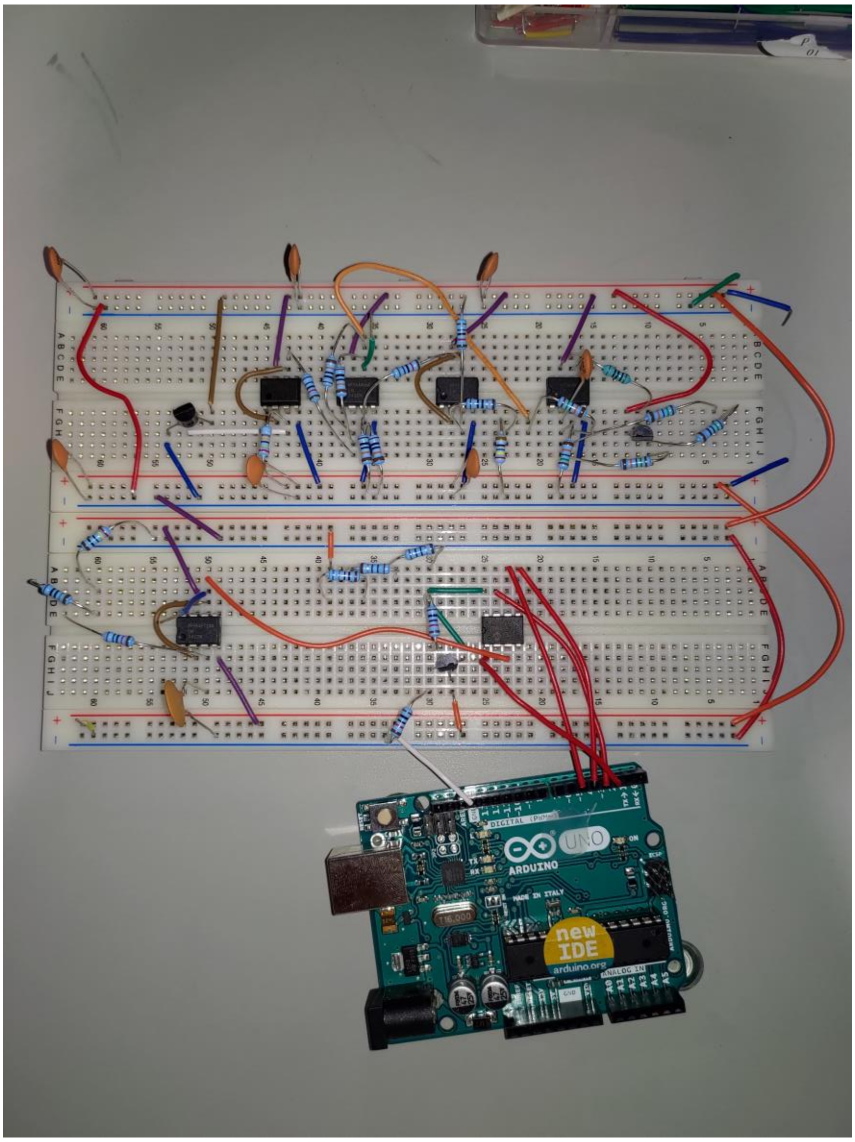

Figure 20. Final breadboard circuit

The code running on the Arduino receives information on port 5 and sends the output message to a terminal. The final testing setup can be seen in figure 21 and the terminal output can be seen in figure 22, it shows both the digital value and the temperature.

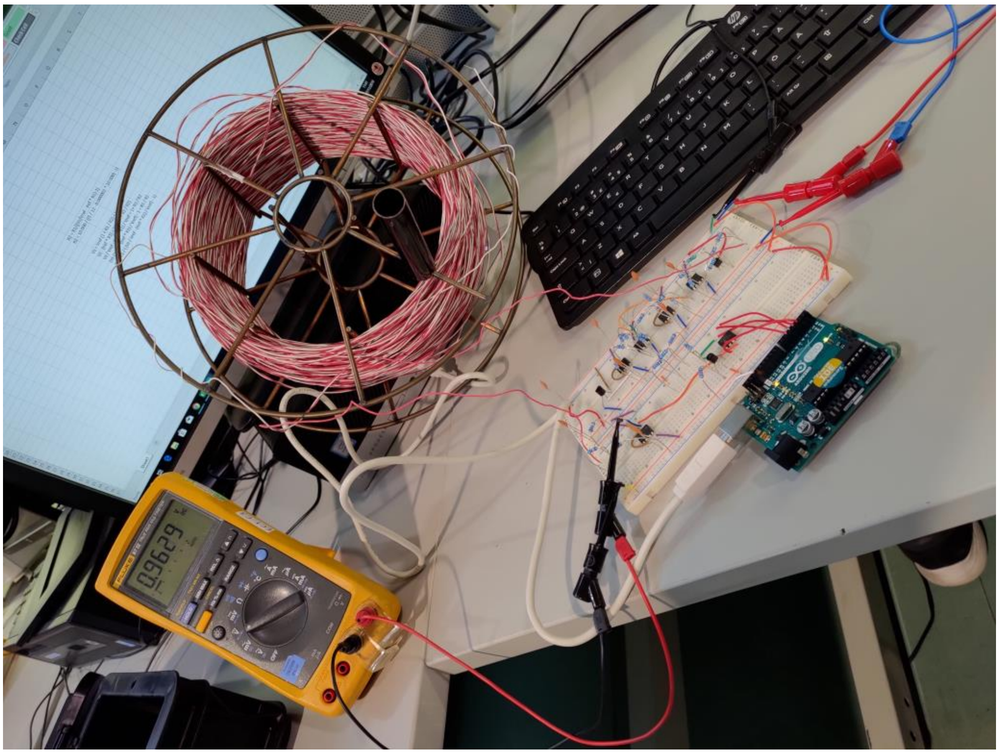

Figure 21. Final testing setup

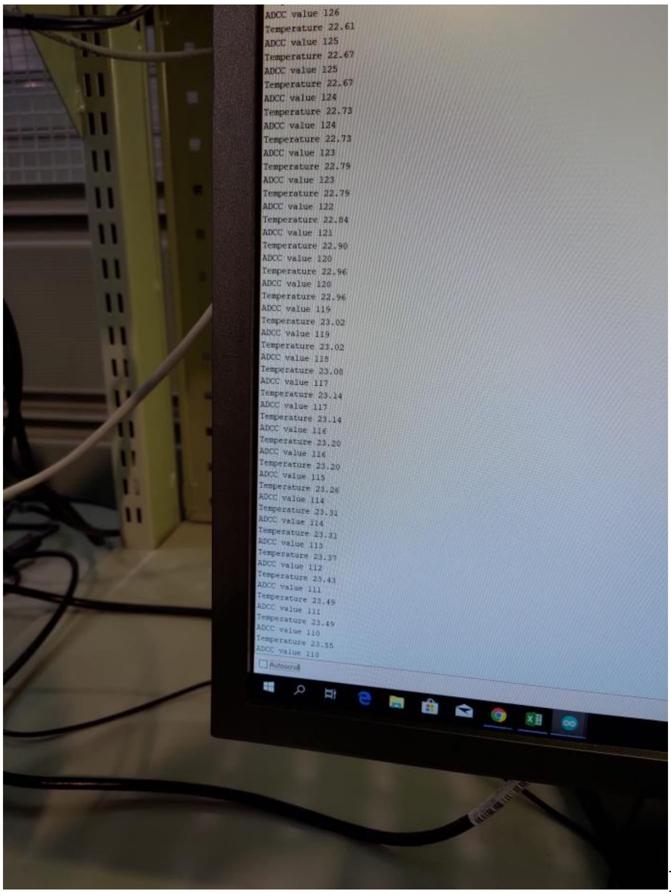

Figure 22. Terminal output

4 PRINTED CIRCUIT BOARD DESIGN

The software for designing the schematic was PADs Logic and the software use to design the PCB was PADs Layout.

SMD components were used to keep the PCB as small as possible.

The schematic of the transmitter can be seen in figure 23.

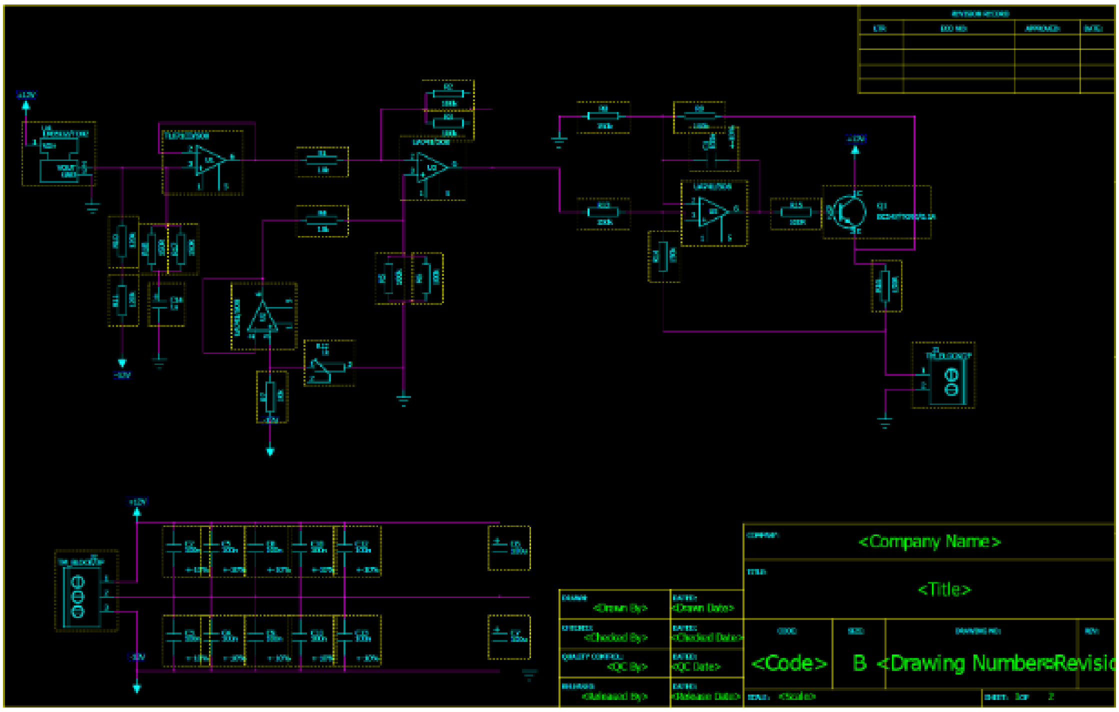

Figure 23. Transmitter schematic

The schematic of the receiver can be seen in figure 24.

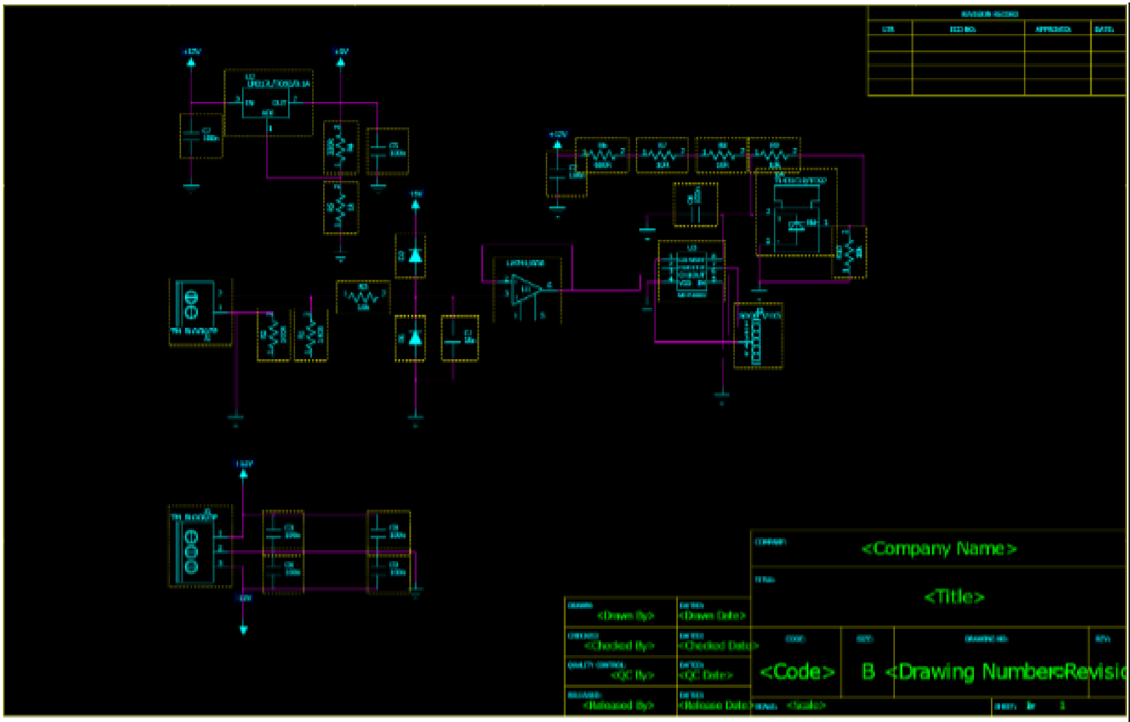

Figure 24. Receiver schematic

When making the PCB design, a set of rules had to be followed to be able to make the PCB, which are the following:

- PCBs are double-sided. On the top, through hole components were placed and SMD´s was placed on the bottom.

- The ground planes on both sides were connected by vias on the edges.

- Traces were 20 millimeters wide, power traces (+/- 12V) were 40 millimeters wide. Clearance were10 millimeters.

- The connectors had to be placed on the edge. This made PCB interfacing easier.

- Avoid less than 90-degree angle on the traces. Preferably 135-degree angles.

- The traces were kept as short as possible. To accomplish this, components were placed in separate blocks and routed, then the block was placed in the design and the rest of them was routed.

- Bypass capacitors had to be as close to the IC pins as possible.

Figure 25 shows the PCB design of the transmitter. The red part is the bottom layer and the blue part is the top layer.

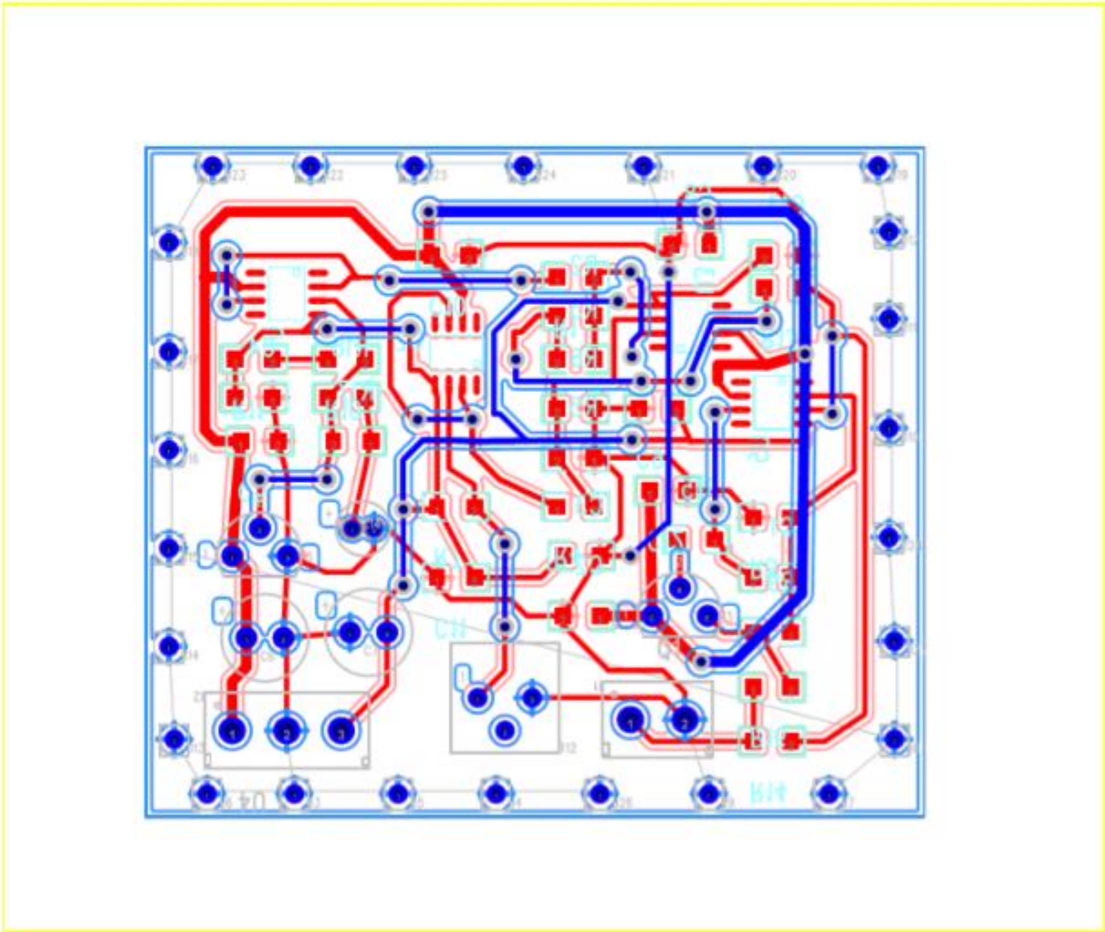

Figure 25. PCB design of the transmitter

The PCB design of the receiver can be seen in figure 26.

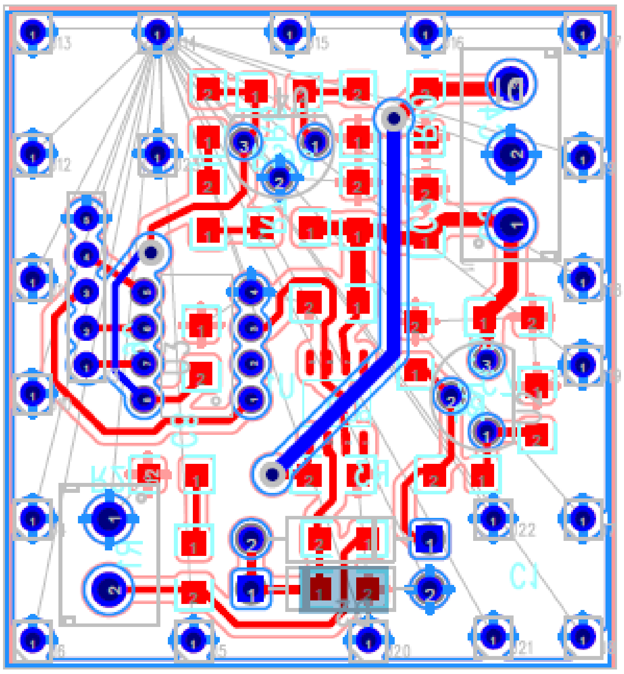

Figure 26. PCB design of the receiver

5 MANUFACTURING OF PRINTED CIRCUIT BOARD

In school, PCB´s are made using the photoresist method. After the design phase, the PCB´s are manufactured with the following steps:

● Step 1: Print the PCB Design.

The PCB design was printed on transparent films using a regular laser printer. The silk-screens and the BOM lists were also printed as reference when soldering.

● Step 2: Print the Copper.

Double-sided photoresist copper boards were used. The printings were aligned together with the board and it was exposed to ultraviolet light for 15 seconds.

● Step 3: Developing and etching.

The PCB is first lowered into a developer solution until the traces are visible. Then, in the etching phase, the copper was eroded away.

● Step 5: Drill.

The holes for through hole components were drilled using a 3-millimeter drill.

● Step 6: Solder.

The SMD components were soldered first using a hot-air solder. The PCBs were not through-hole plated, so the vias were made by putting a resistor leg was soldered on both ends of the hole.

After soldering, a lacquer liquid spray was applied on both sides to protect the copper from oxidation.

The final PCB´s can be seen in figures 27 to 30. Unfortunately, there was not enough time to finish the soldering and test the PCB´s.

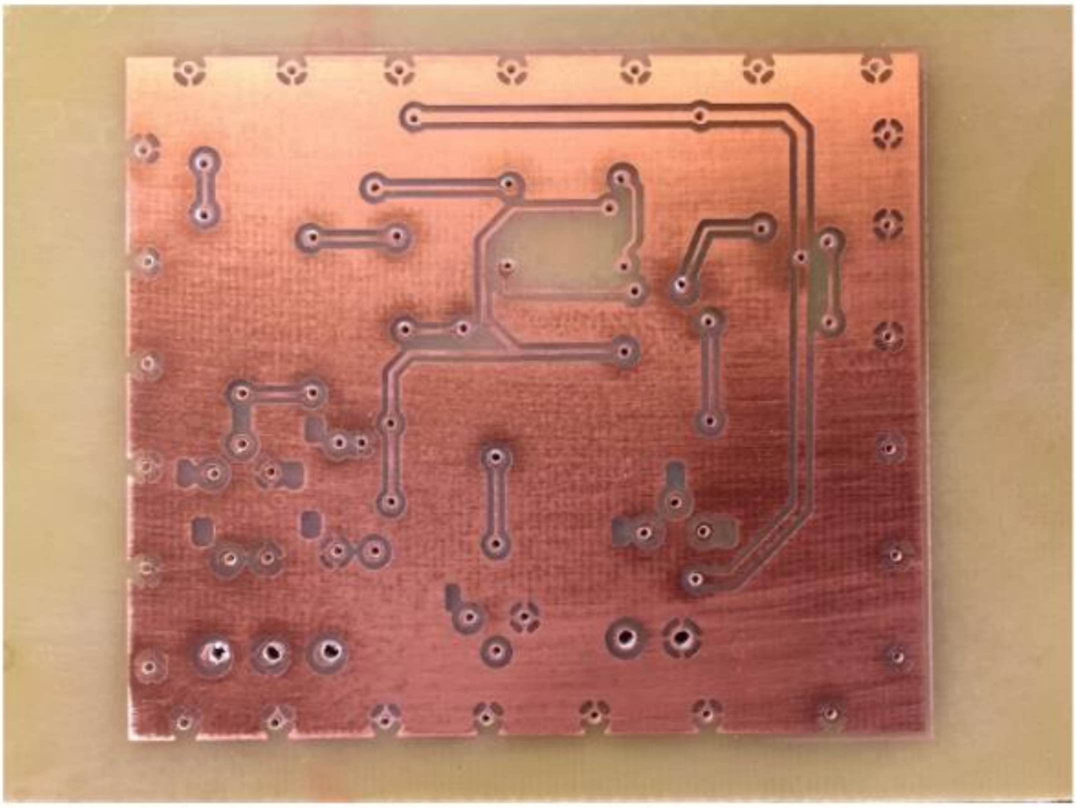

Figure 27. Top side of the transmitter PCB

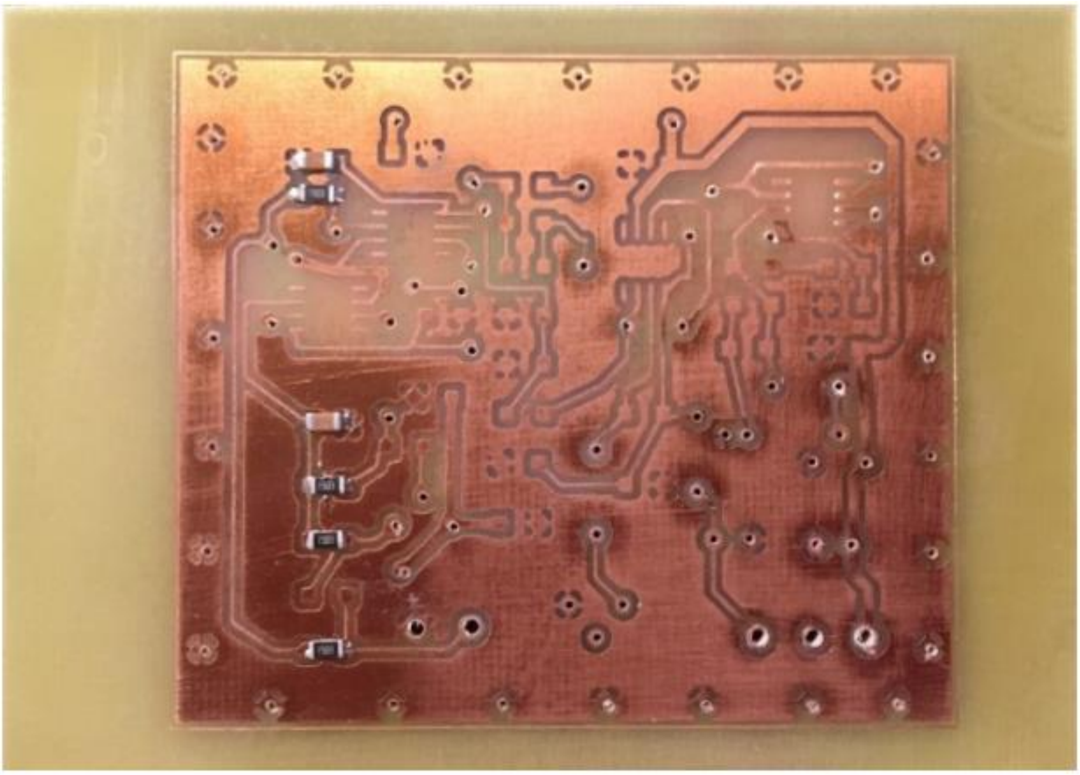

Figure 28. Bottom side of the transmitter PCB

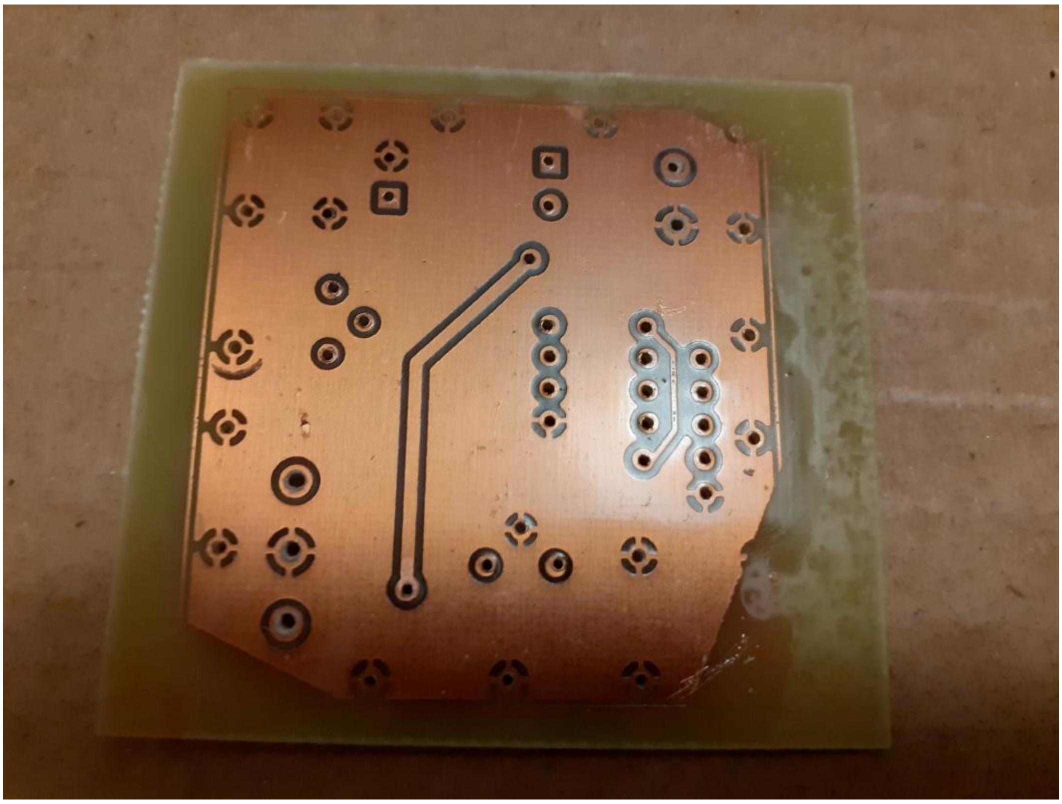

Figure 29. Top side of the receiver PCB

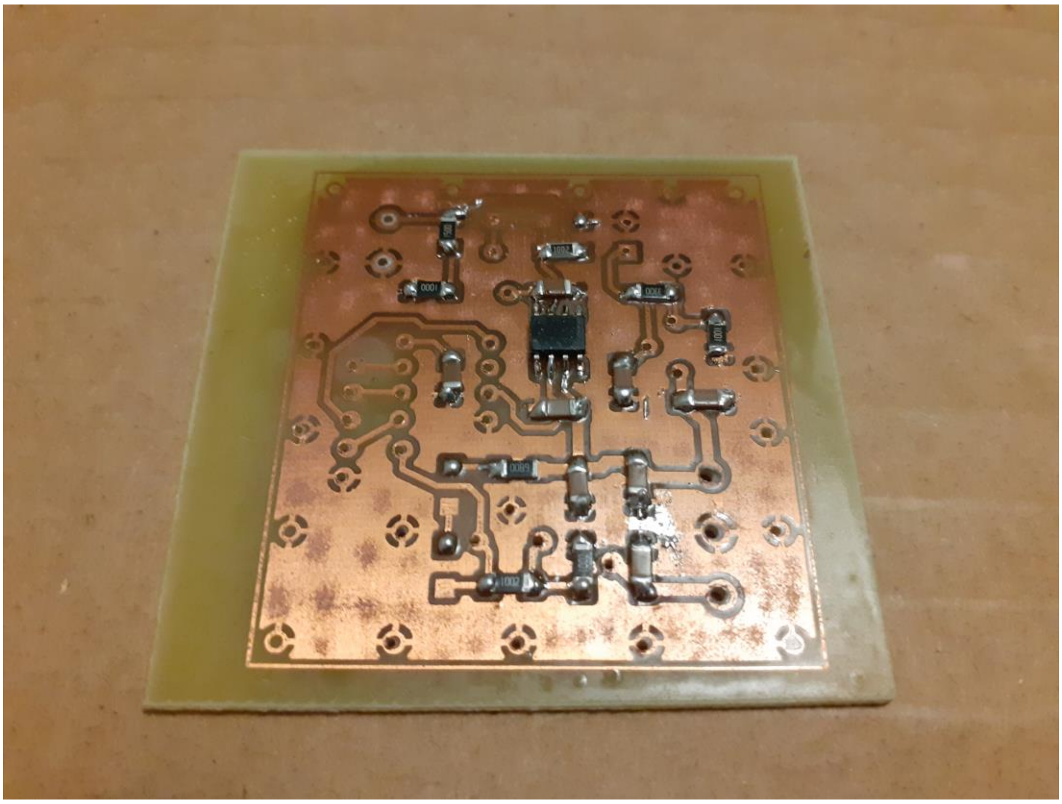

Figure 30. Bottom side of the receiver PCB