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Wireless Weather Station

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Bachelor of Engineering

Electronics

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Idea for this project was given by Thierry Baills, after discussing of different applications with a wireless connection.

The goal of this study was to design and build wireless weather station that is capable to measure temperature, luminosity, pressure and humidity. The measured data can be used to trigger automated operations with four relay switches.

With Atmel microprocessors and C++ programming the different sensors and RF modules can be combined to work together. The system will use radio frequency 443MHz to transmit data wirelessly in both directions.

Keywords	Wireless Weather Station, PCB, C++, Antenna

Contents

1 Introduction

Designing of a system that consist of a measuring unit and a control unit which will communicate with each other wirelessly.

It will measure four elements of weather; temperature, pressure, humidity and luminosity. The unit also has possibility for extensions with four relays which can be switched on and off from the control unit or with automatic trigger points.

LCD display is used to show measured values from sensors, and overlay for switches to control relays which allows to interact with the enviroment with any device that consumes less power than the chosen relay can handle.

This thesis required knowledge about C++ programming, computer-aided designing (CAD) of printed circuit boards (PCB) and milling on a computerized numerical control (CNC) machine.

2 Theoretical Background

2.1 Sensors

The main two ways to measure values happens in resistive or capacitive change. For measuring temperature, resistance increases in higher temperatures. Platinum has a high variation in resistance, but it is also expensive. Pressure changes physical shape and alternates resistive value. There will be change in voltage and so temperature or pressure can be calculated with microcontroller. For a capacitive change, discharge time can be measured and compared to a reference value. Sensors for different measurements are seen in listing 1.

Temperature	Resistance temperature detector (RTD), Thermocouple Thermistors
Optical	Photodiodes, Infra-red sensors, Phototransistor
Humidity	Capacitive and resistive sensors, Hygrometers
Pressure	Barometer, Ionization gauge, Pressure gauge

Electromagnetic	Hall effect sensor, Magnetometer
Wind	Anemometer

Listing 1. Different types of sensors.

2.2 Antennas

In different applications, some antennas might fit better, depending on what kind of radiation pattern and physical size is needed, also the frequency used will determine the length of it. In a high frequency application, it is convenient to print the antenna on the circuit board. Higher gain can be achieved with a more directional radiation. Figures 1,2 and 3 below are radiation patterns for monopole, dipole and helical antenna. Figures are simulated with 4NEC2 software.

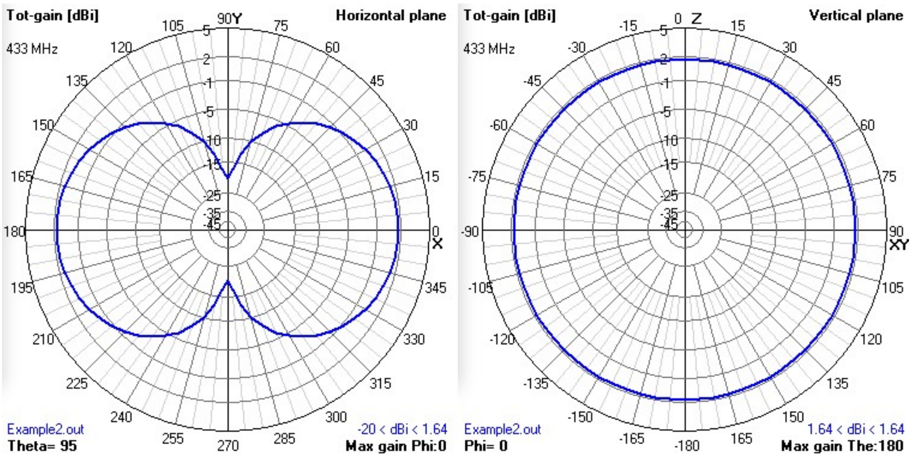


Figure 1. Monopole Antenna Radiation Pattern

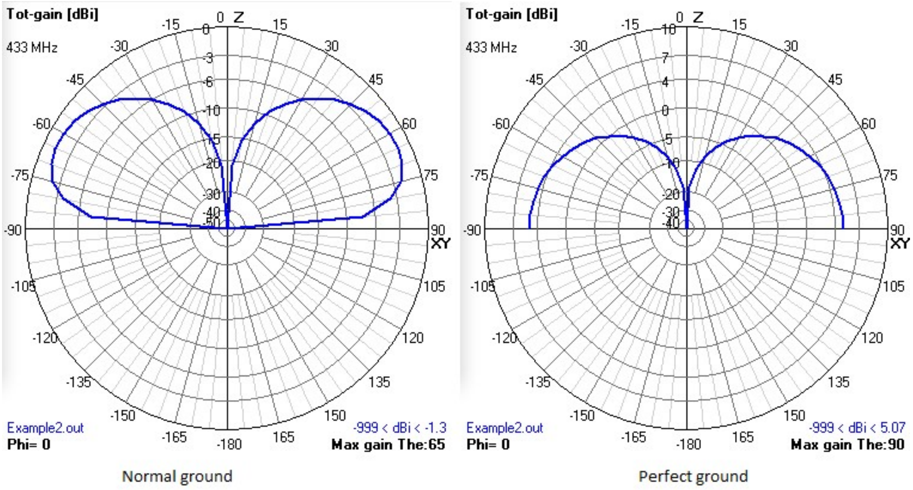


Figure 2. Dipole Antenna Radiation Pattern

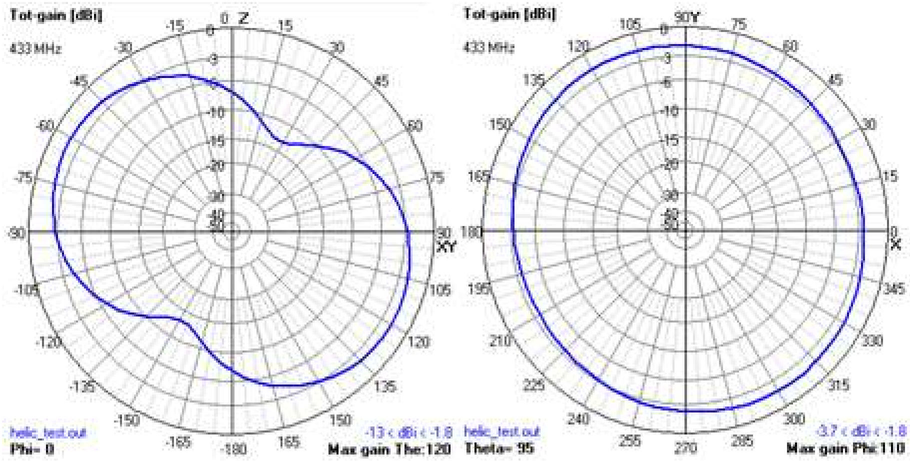


Figure 3. Helix Antenna Radiation Pattern

2.3 ASK Communication

Amplitude-shift keying (ASK) is a form of amplitude modulation that represents digital data as variations in the amplitude of a carrier wave. In an ASK system, the binary symbol 1 is represented by transmitting a fixed-amplitude carrier wave and fixed frequency for a bit duration of T seconds. If the signal value is 1 then the carrier signal will be transmitted; otherwise, a signal value of 0 will be transmitted.

Any digital modulation scheme uses a finite number of distinct signals to represent digital data. ASK uses a finite number of amplitudes, each assigned a unique pattern of binary digits. Usually, each amplitude encodes an equal number of bits. Each pattern of bits forms the symbol that is represented by the particular amplitude. The demodulator, which is designed specifically for the symbol-set used by the modulator, determines the amplitude of the received signal and maps it back to the symbol it represents, thus recovering the original data. Frequency and phase of the carrier are kept constant. Figure 4 explains ASK signal theory. [1]

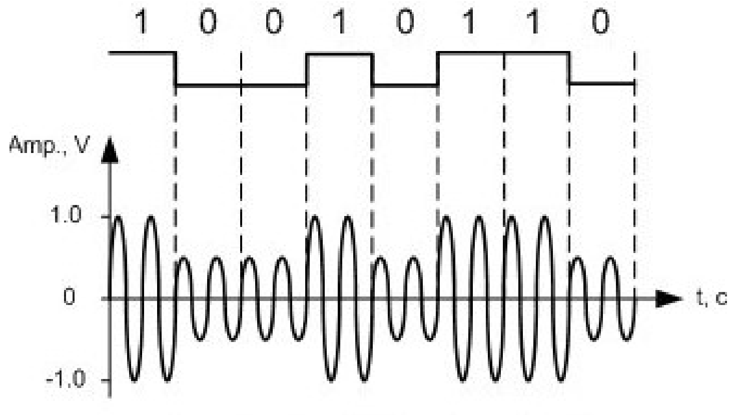


Figure 4. ASK Signal [9]

3 Hardware

The main goal is to keep the project layout simple and affordable. Since this is a prototype, only through-hole components are used. Surface mounted components (SMD) should be used for manufacturing higher volumes, since SMDs are cheaper and can be placed by a machine. Through-hole components are easier for testing purposes, but can only be soldered by hands.

3.1 Arduino Platform with Atmel Processor

Arduino Uno is a microcontroller board based on the ATmega328P. With different I^2C addresses it is possible theoretically to connect 128 devices in parallel and used with Arduino, and to go beyond that or for using same addresses in devices, an I^2C multiplexer can be used. Cables capacitances affects the use of I^2C, and more cables means more capacitance. Arduino also has 14 digital input/output pins of which 6 can be used as pulse width modulation (PWM) outputs and 6 analog inputs. In Figure 5 below has detailed information of pins. [2]

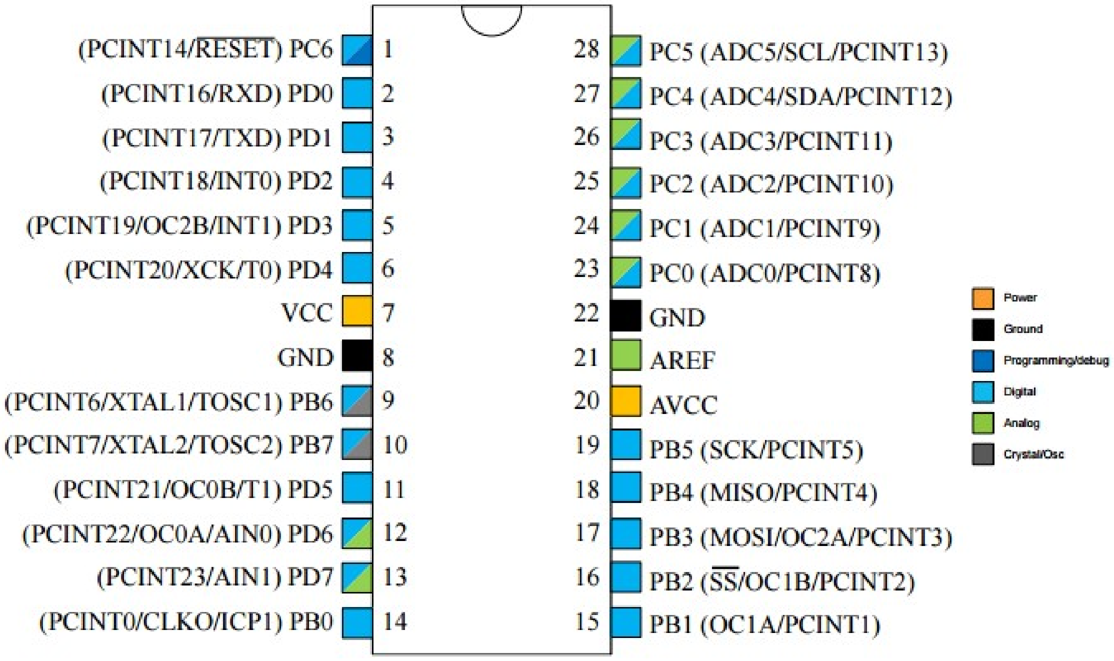


Figure 5. Pin layout of Atmel Atmega328p Microprocessor [3]

The ATmega328 8-bit AVR RISC-based microcontroller combines 32 kB ISP flash memory with read-while-write capabilities, 1 kB EEPROM, 2 kB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter, programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8-5.5 volts. [4]

3.2 Sensors

A BME280 sensor breakout is a good choice, since it can measure three elements with one packet, and therefore less components and code are needed. Luminosity might also be useful in some applications, and for that, a TSL2561 sensor breakout is chosen. Breakout packages are easy to test in prototypes and no extra components are needed.

3.2.1 Temperature, Pressure and Humidity with BME280

The BME280 is an integrated environmental sensor developed specifically for mobile applications where size and low power consumption are key design constraints. The unit combines individual high linearity, high accuracy sensors for pressure, humidity and temperature. Listing 2 below for detailed characteristics of sensor. [5]

Measurement range:

Temperature: -40 to +85°C

Humidity: 0-100%

Pressure: 300-1100 hPa

Accuracy:

Pressure: +- 1hPa,

Temperature: +-1 C,

Humidity: +-3%.

ADC Resolution:

Temperature: 16-bit fixed

Humidity : 20-bit max.

Pressure : 20-bit max.

Listing 2. Sensor characteristics [5]

3.2.2 Luminosity with TSL2561

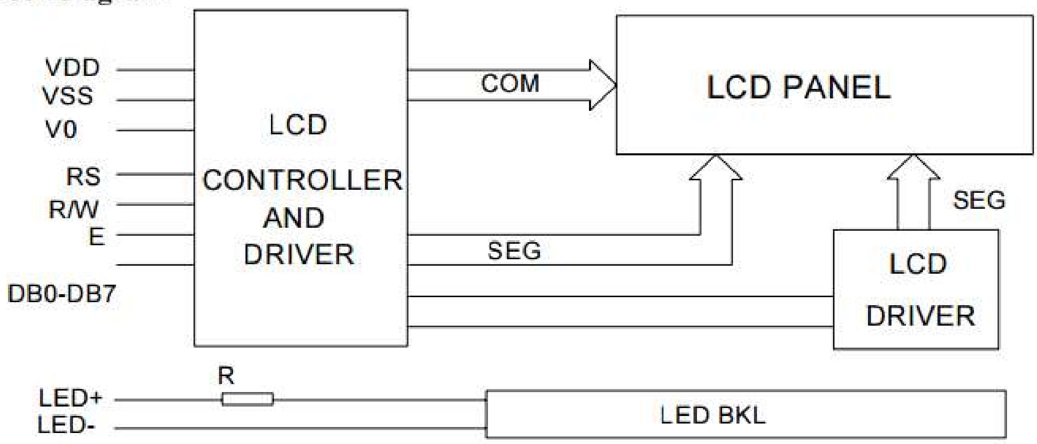
TSL2561 is light-to-digital converter that transform light intensity to a digital signal output capable of direct I^2C or SMBus interface. It combines one broadband photodiode (visible plus infrared) and one infrared-responding photodiode on a single CMOS integrated circuit. Two integrating ADCs convert the photodiode currents to a digital output that represents the irradiance measured on each channel. The output can be used with the microcontroller where illuminance in lux is derived using an empirical formula to approximate the human eye response. [6]

3.3 Liquid Crystal Display 20x4

LCD 2004 display module is used to display values and navigate in controlling settings. It is capable to show total of 80 characters in four rows. Figure 6 below describes pins and block diagram of LCD.

GDM2004D-FL-YBW

Block diagram



Interface pin description

Pin no.	Symbol	External connection	Function
1	V_{SS}	Power supply	Signal ground for LCM (GND)
2	V_{DD}		Power supply for logic (+5V) for LCM
3	V_0		Contrast adjust
4	RS	MPU	Register select signal
5	R/W	MPU	Read/write select signal
6	E	MPU	Operation (data read/write) enable signal
7~10	DB0~DB3	MPU	Four low order bi-directional three-state data bus lines. Used for data transfer between the MPU and the LCM. These four are not used during 4-bit operation.
11~14	DB4~DB7	MPU	Four high order bi-directional three-state data bus lines. Used for data transfer between the MPU
15	LED+	LED BKL power Supply	Power supply for BKL (Anode)
16	LED-		Power supply for BKL (GND)

Figure 6. Picture of LCD block diagram and pin descriptions [7]

With LiquidCrystal library, screen can be controlled with commands shown in listing 3.

```
// pin12 = RS, pin11 = E, pin5 = D4, pin4 = D5, pin3 = D6, pin2 = D7
LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
lcd.clear(); // clear screen
lcd.setCursor(0,1);   // set cursor to row 0, character place 1/20
lcd.print("text");    // print text
lcd.print(tempc);     //print value of int tempc
```

Listing 3. LiquidCrystal Library Commands

3.4 Wireless Transmitter and Receiver

Ready breakout circuits using 433MHz frequency was chosen for testing purposes. Array of bits is sent from microcontroller to transmitter for ASK modulation and amplification for antenna. In image 7 are bits measured with an oscilloscope.

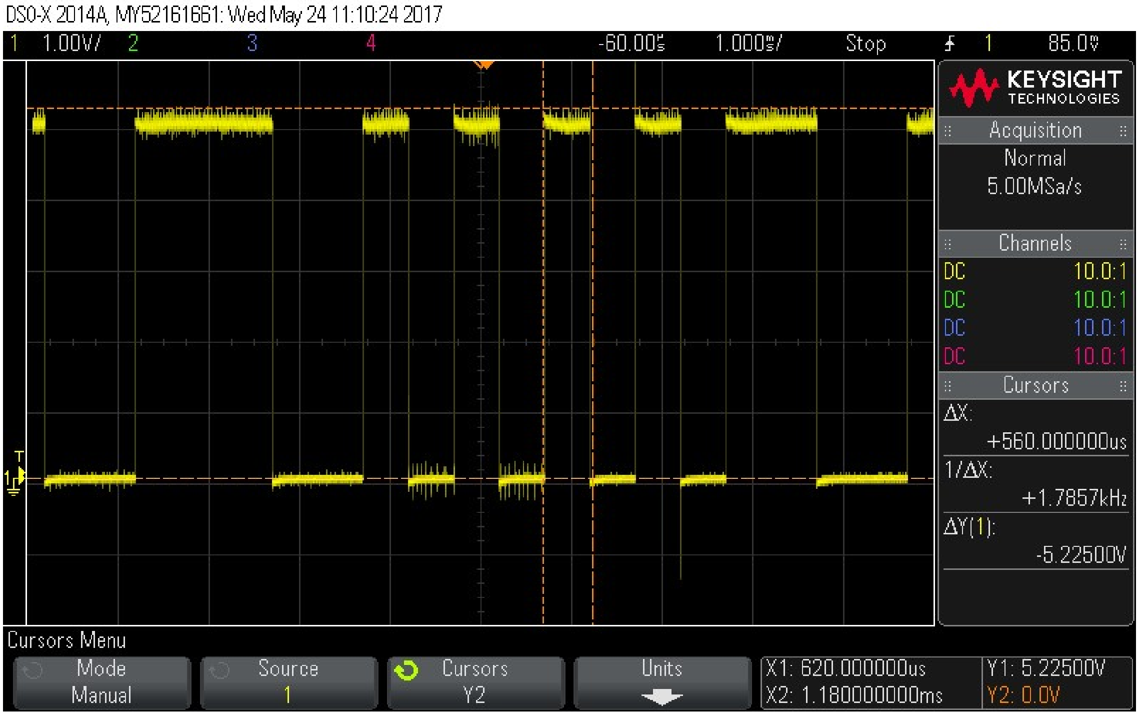


Image 7. Oscilloscope Measurement from Output

3.4.1 Antenna

Antenna chosen to be used in this device is quarter-wave monopole, because it fits sideways on the board. The length is ¼ of wavelength, what can be calculated with following formula:

$\lambda = \frac{v}{f}$ λ = Wavelength, v = Wave velocity, f = Frequency

$$\frac{1}{4} \times \frac{3 \times 10^8}{433 \times 10^6}$$

Calculated length is 17cm if the signal is travelling in vacuum. There is a small change for signal speed in air, but it is not taken in count for this antenna. Figure 8 shows simulation of it.

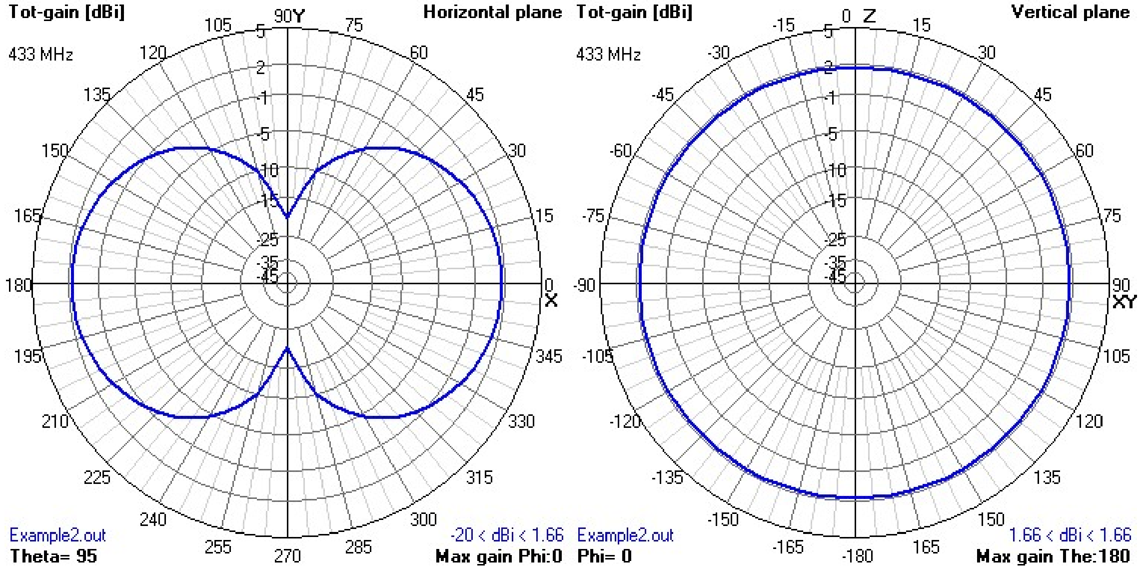


Figure 8. Simulated Radiation Pattern of a 17cm Monopole Antenna.

If longer range is desired for devices, antennas can be turned in vertical position and it will work as a dipole, since there is a ground plane on the PCB. More range can also be gained by increasing the transmitter voltage to 12 volts.

European regulations have limits for the transmit power. Radiations and gains can be measured in an anechoic room. Following table 9 shows conversions for allowed electric field strengths.

Power	P (dBm)	E (mV/m) @3m	E (dBmV/m) @3m	Comments
10mW	10	182,574	105.2	European limit for 433.92MHz
1mW	0	57,735	95.2	Typical 418MHz modules
5.8m W	-22	4,399	72.9	FCC limit for 433.92MHz
5.1m W	-23	4,133	72.3	FCC limit for 418MHz
75nW	-41	500	54	FCC Spurious Emission limit for >470MHz
1m W	-30	1,826	65.2	European Spurious Emission limit for > 1 to 4GHz
0.25m W	-36	915	59.2	European Spurious Emission limit for 25-47, 74-87.5, 118-174, 230-470, 862-1000 MHz
4nW	-54	115	41.2	European Spurious Emission limit for 47-74, 87.5-118, 174-230, 470-862 MHz

Table 1. Maximum Electric Field Strength [8]

Measuring from 1 meter distance with a spectrum analyser, amplitude received with a dipole antenna is shown in image 9.

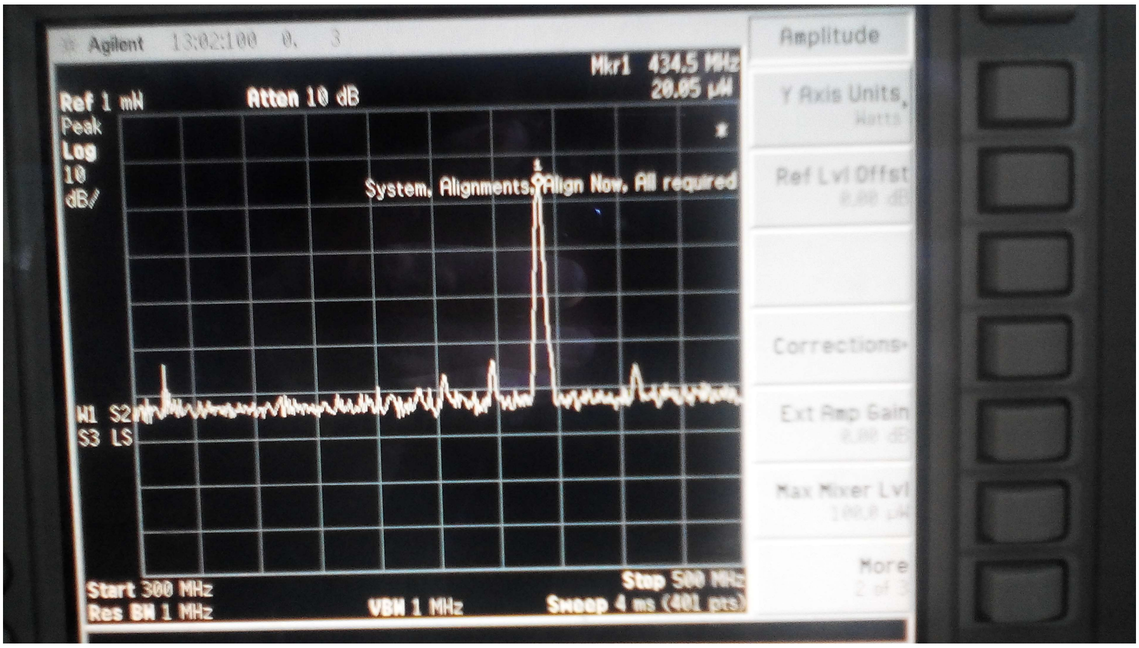


Image 9. Spectrum Analyzer Measurement of RF Transmitter.

Measured value 20 uW is under the limiting standards at distance of 1 meters, even when there are interfering signals. Anechoic room should be used for more accurate measurements.

3.5 Printed Circuit Board Design

Software called PCBWeb Designer is used for designing layouts for PCBs. The software is free to use, but mainly intended for using SMD components.

3.5.1 Receiving Unit

Both devices are designed to use a 12 volt power source, which is converted to 5V with a L7805CV voltage regulator and protected from faulty connection with a diode and a fuse. Maximum input voltage is rated at 35 volts, but it will generate more heat in the component. Four buttons are used to navigate in software to change settings and control relays. In figures 10 and 11 is schematic and layout of the receiver.

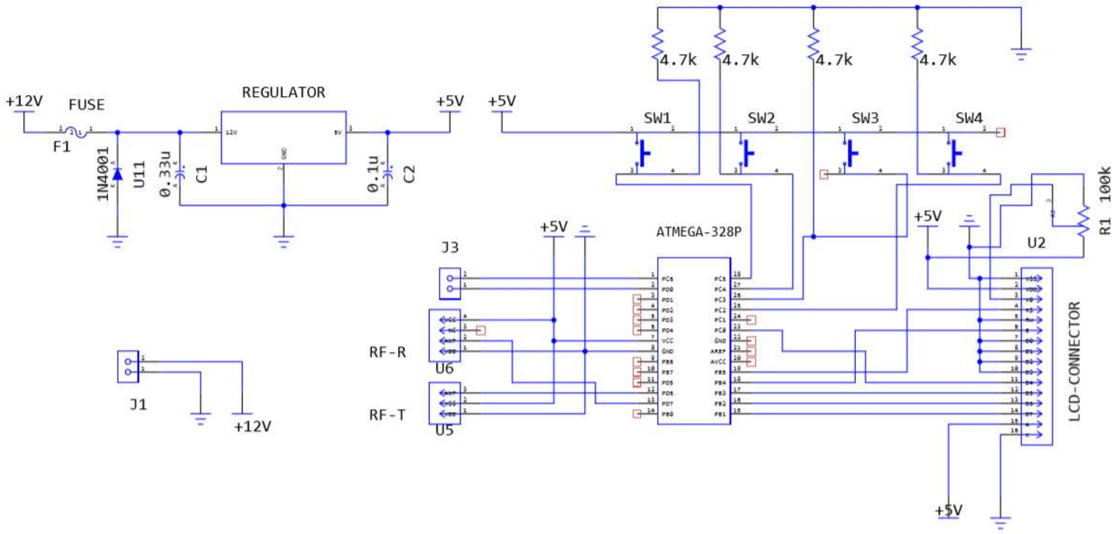


Figure 10. Receiver Schematic

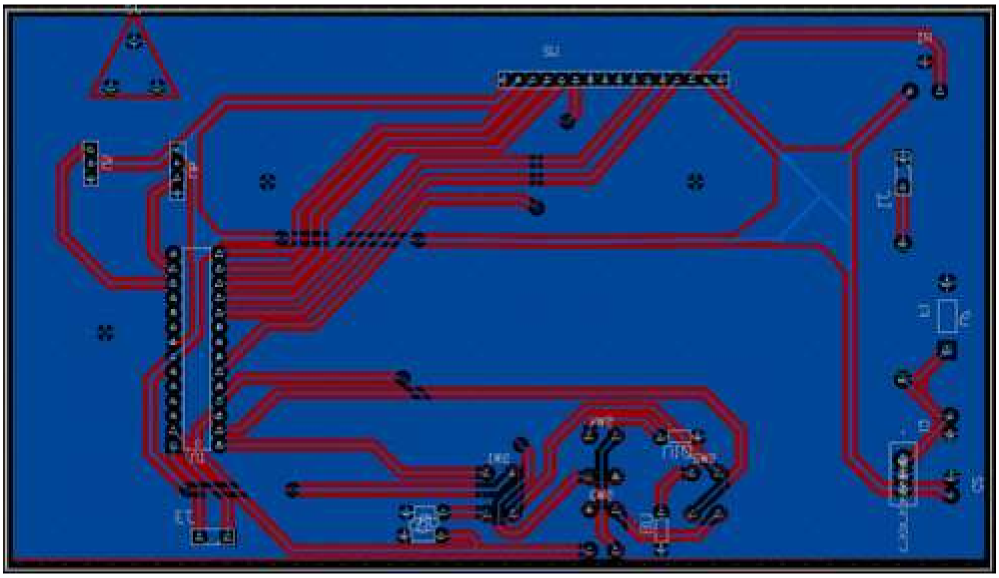


Figure 11. Receiver Layout

3.5.2 Measuring Unit

With combination of PNP and NPN transistors it is possible to control 12V relays with 5V signal from microcontroller. External devices can be connected into connectors bottom of schematic seen in Figure 12 and layout in figure 13.

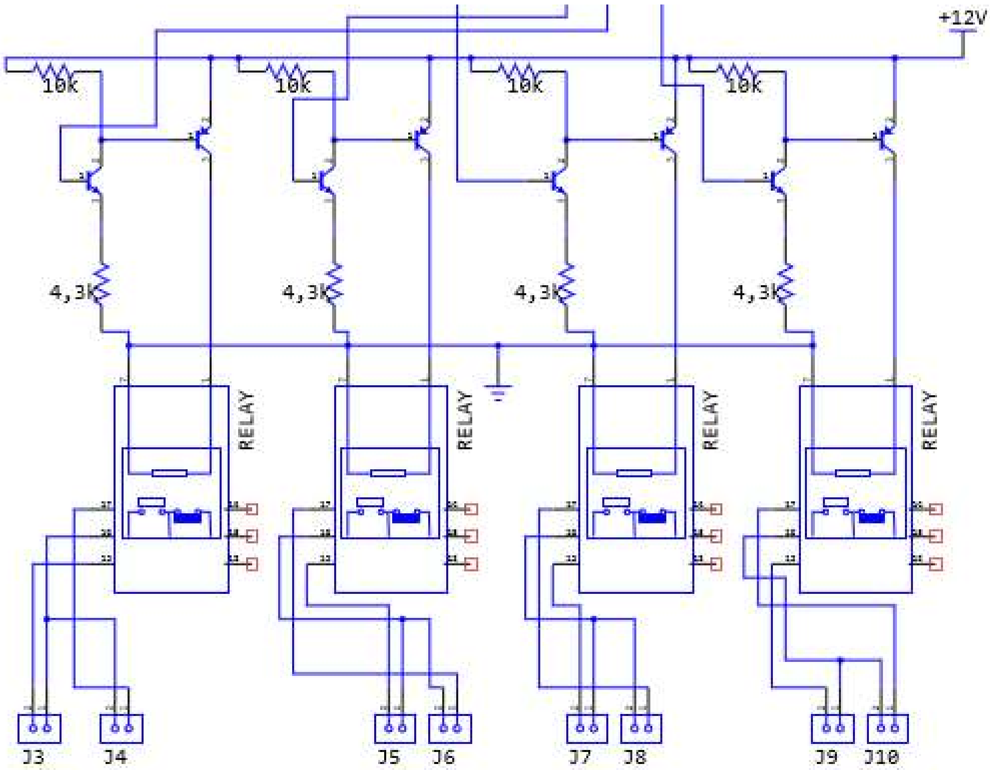


Figure 12. Part of Transmitter Schematic

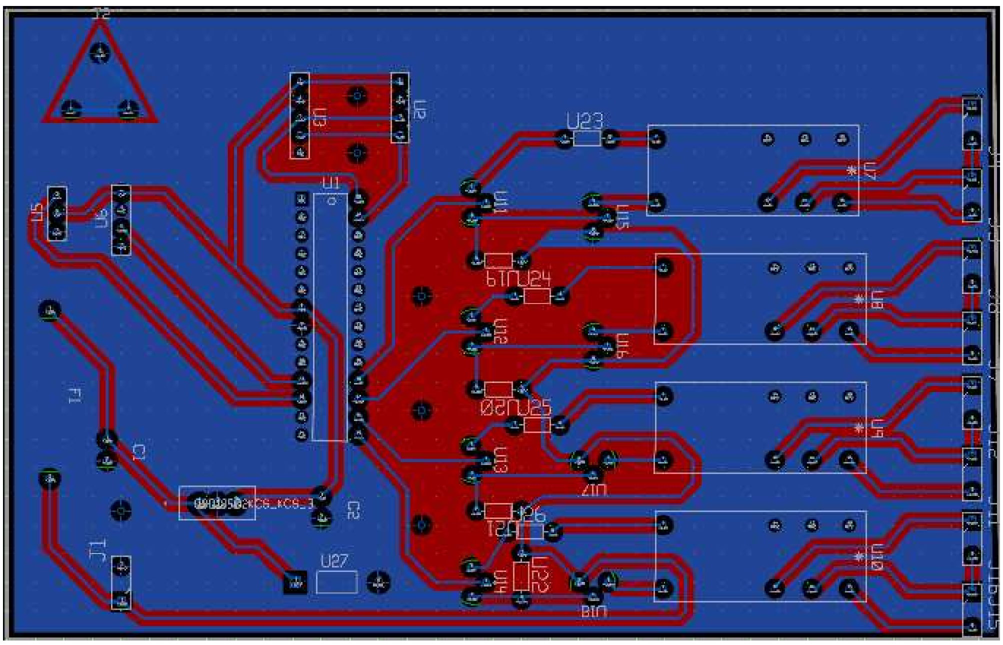


Figure 13. Transmitter Layout

In layout design, sharp corners should be avoided. Unused copper around traces can be used as ground plane to simplify circuit and decrease interference. For supply voltage, wider traces should be used to decrease resistance and voltage drop.

3.6 Milling PCBs

To mill PCBs with a CNC machine, layouts must be converted into G-code. It has x, y and z coordinates for the machine, so it will know how to move the drill on the copper surface with three servos. There will be separate code files for isolation, chopper cut out, drilling holes and board cut out. Since the PCB is double sided, all files must be done for both sides and every file may use a different size drill bit. Alignment holes are needed when turning the PCB, so the traces will be exactly in right places. Other side must be mirrored, depending on which side is milled first. A sacrifice layer, for example wooden plate, is needed to protect the machine and for the alignment holes. It should be a flat surface and have same height in every location. It must be attached to the machine so the alignment holes will stay at same coordinates. The machine can be seen in image 14.

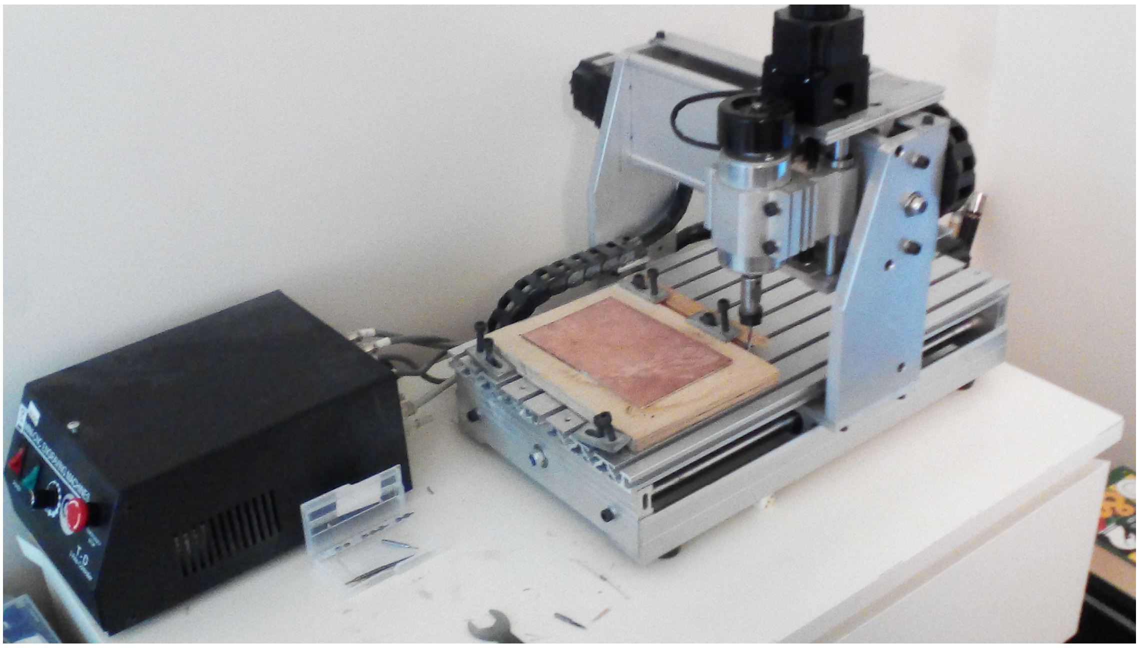


Image 14. CNC 3020 Machine.

Different types of drill bits were tested and best results was achieved with V shaped engraving bit. In following image is the V shape bit and resulting milled PCB for the measuring unit. In the image 15 can be seen few rugged traces, which came from worn out round shaped drill bit. After changing to the V shaped, durability increased and it didn’t show any signs of wearing out.

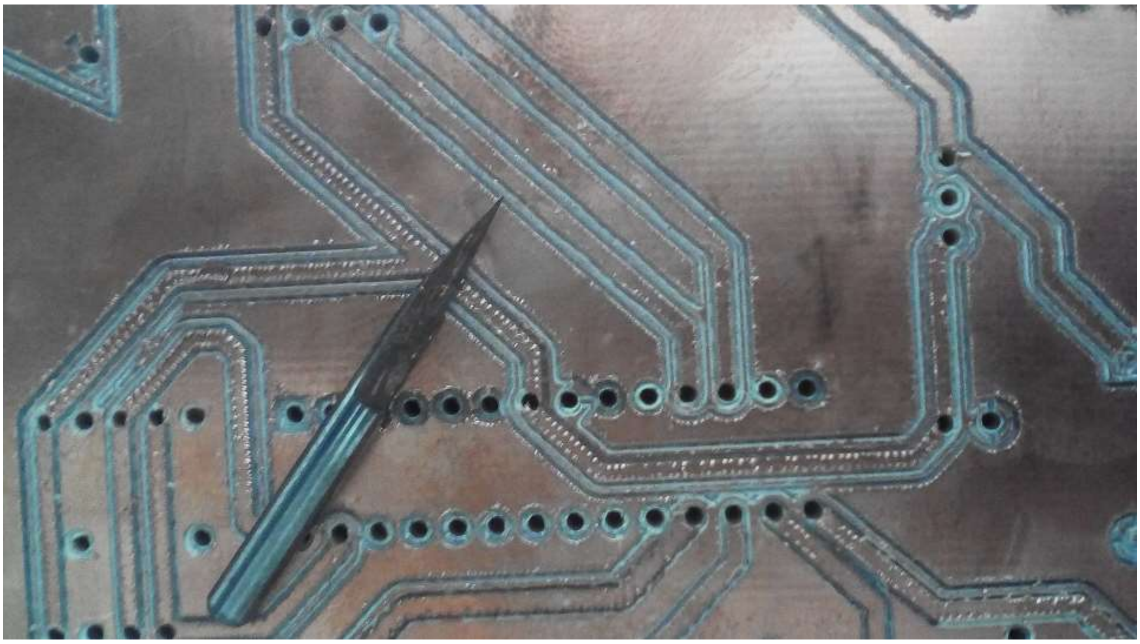


Image 15. V shaped milling bit on top of sensors PCB.

4 Software Programming

Arduino IDE software is used for making C++ code for both devices. There is available other softwares that are compatible with Arduino, for example Eclipse.

4.1 Interface

LCD uses LiquidCrystal library and with lcd.print(); command it displays characters and integers to screen. With multiple print commands used together it can display 4 rows of 20 characters. In the listing 4 is an example of printing values to LCD.

```
//Printing lux
if (light>99) {
          lcd.print("L:");
}
          else {
          lcd.print("L: ");
          }
 lcd.print(light);

if (light>999) {
          lcd.print("Lux");
}
          else {
          lcd.print(" Lux");
}
```

Listing 4. Printing measured values to LCD.

If the integer increases with one digit, it will shift everything behind it with one character.

4.1.1 Control menu

Relays can be switched on and off manually from this control menu. First the wireless connection is tested, if response is received then the last message can be transferred to switch power. All three stages must be completed in right order before relay state can be changed. Since the messages are always same, the device can be invaded easily. Safe way would be to change them every time after use. In listing 5 below is the operation on receiving end.

```
//Pin numbers are different to physical pins
selectA=digitalRead(19);
selectB=digitalRead(18);
selectC=digitalRead(17);  // Reading button values
selectD=digitalRead(16);

        if  (selectA == HIGH &&
             selectB == LOW  &&
           )
          {
                 lcd.clear();           // Printing options for
                 lcd.setCursor(0,0);    // control menu
                 lcd.print("Relays On/Off");
                 lcd.setCursor(0,1);
                 lcd.print("A: Relay 1   B: Relay 2 ");
                 lcd.setCursor(0,2);
                 lcd.print("C: Relay 3   D: Relay 4 ");
           }
           delay(100);

           button = readButtons();

        if (button == 'A') {
                                        //Test connection, returning
            int confirm = 461;          //value should be 401
            int relay_power = 341;      //Turn power on
            int relay_number = 451;     //Select relay 1
            relay_on(confirm, relay_power, relay_number);
            }

           if (confirmR == 401) {
                                        //If received correct
            Serial.print("relay1 on");  //value, Relay 1 will be
            int confirm1 = 441;         //switched on with following
            int relay_power = 341;      //values.
            int relay_number = 451;
            relay_on(confirm1, relay_power, relay_number);
            //Sending values with relay_on function.
            }
```

Listing 5, Control menu.

4.1.2 Reading Button values

Program can be simplified when reading buttons is done with a separate function. It also decreases the size needed for the code in the microcontroller. By calling the function it will return letter from A to D. Underneath listing 6 of buttons function.

```
char readButtons(){

int selectA = 19;
int selectB = 18;
int selectC = 17;
int selectD = 16;

  do
{
 delay(100);
    selectA=digitalRead(19);
    selectB=digitalRead(18);
    selectC=digitalRead(17);
    selectD=digitalRead(16);
}
  while ( selectA != HIGH &&
          selectB != HIGH &&
          selectC != HIGH &&
          selectD != HIGH);

  if (selectA == HIGH){
    char button = 'A';
    return button;
    }
  if (selectB == HIGH){
    char button = 'B';
    return button;
    }
  if (selectC == HIGH){
    char button = 'C';
    return button;
    }
    if (selectD == HIGH){
    char button = 'D';
    return button;
    }
}
```

Listing 6. Reading buttons function.

4.2 Data Handling

Values read from sensors will be combined in to a character array and sent with Virtual-wire library, as seen in listing 7. Different data can be separated with any chosen symbols. Values must be changed from double to integer for easier data transfer. When converting to integer, fractions will be lost. Before transferring a value, it must be rounded, so it will not lose accuracy significantly. It can be done in easy way by increasing the value by 0.5 and then changed to an integer as seen in listing 7 below. With a negative value, it should be decreased with 0.5.

```
double humidityH = bme.readHumidity();   //Reading values from BME280
double pressureP = bme.readPressure()/100.0F;
double temperatureC = bme.readTemperature();
//Serial.print(temperatureC);

double temperatureRound = (temperatureC + 0.5);
int temperature = (int)temperatureRound;    //doesn't work for nega-
tive value

double humidityRound = (humidityH + 0.5);
int humidity = (int)humidityRound;

double pressureRound = (pressureP + 0.5);
int pressure = (int)pressureRound;

light.getLux(gain,ms,data0,data1,lux);      //reading values from
TSL2561

double luxRound = (lux + 0.5);
int light = (int)luxRound;

 char msg3[30];
sprintf(msg3, "%d#%d;%d,%d.%d:",confirmTT, temperature, humidity,
pressure, light);
```

Listing 7. Measuring values and combining data in array.

In listing 8 received data is divided into useful formats, so it can be displayed on LCD.

```
    uint8_t buf[VW_MAX_MESSAGE_LEN];
    uint8_t buflen = VW_MAX_MESSAGE_LEN;

    if (vw_get_message(buf, &buflen)) // Non-blocking
    {
        digitalWrite(led_pin, HIGH); // Flash a light to show received
                                          good message
        // Message with a good checksum received, print it.
        int confirmR = atoi(strtok((char*)buf, "#"));// Look for a ; ,
                                      then return the data before it.
        int tempc = atoi(strtok(NULL, ";")); // Look for a ; , the
                                          return the data before it.
        int humi = atoi(strtok(NULL, ","));  // Look for a comma , the
                                          return the data before it.
        int pres = atoi(strtok(NULL, "."));  // Look for a dot, then
                                          return data before it.
        int light = atoi(strtok(NULL, ":")); // Look for a : , then
                                          return data before it.
        digitalWrite(led_pin, LOW);

        receive(confirmR, tempc, humi, pres, light); // print values
                                   on LCD with receive() function
    }
```

Listing 8. Data receive.

4.3 Control of Operations

Two-way operation is part of this device, and it allows to send commands to the measuring station. By sending predefined packets, it is possible to change delay for reading values and switching relays power.

There might come problems if someone sends the same packet in same frequency. Before any action is made, operation must be confirmed on the other side. Reliable way would be to change confirmation packets after every use.

For automatic operations, settings will be transferred to measuring device. This way there is no unnecessary use of wireless communication.

5 Results

Functioning devices were successfully designed and tested with less than 60 euro's bill of material, but a higher price was paid in spending months developing C++ programs and days for designing and milling PCBs. In return a greater value was received in learning on both fields.

6 Conclusions

In next layout design, flyback diodes should be added to protect transistors from voltage spikes generated in relay coils when switching power off. Future improvements for power source, a solar charger could be connected to recharge the source, also custom designs for RF circuits with a higher transmit power is needed for long distance applications. A helix antenna would be also more convenient choice. Wind measurement could be added and a simple computer program to transfer data thru internet to a mobile application. EMC measurements are not done due to limited time. The project was interesting and practical to learn about C++ language and wireless connections.

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Appendix 1.

Transmitter Schematic

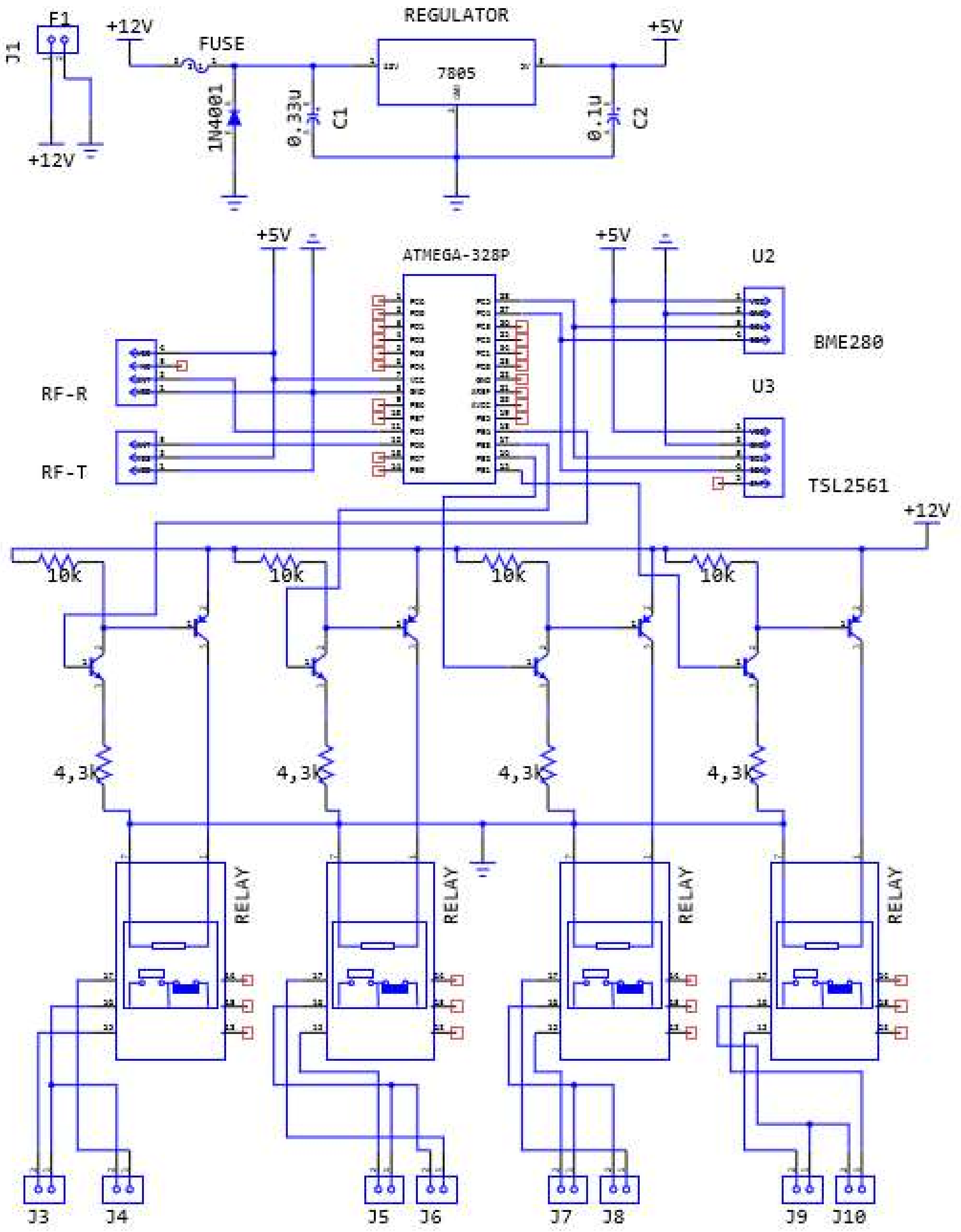

Figure A. Transmitter Schematic.