TECHNICAL UNIVERSITY
OF CLUJ-NAPOCA

OrCad X Capture project

Project theme: Irrigation system

Student:

Oprean Cristian

Coordinator:

Fizeșan Raul

Project content

1. Introduction.

1.1. The target of the Project.

The target of the project is to optimize the humidity of the soil for growing plants by implementing a circuit which controls a water pump automatically.

Soil humidity is represented by the amount of water present in the soil and is one of the indicators of soil health. Soil moisture can be classified into three zones: dry, moist, or saturated.

Keeping the soil humidity in parameters will ensure a good growth of the plant. Here are some ranges of humidity for various plants: - flowers: 21% - 40%

- trees and shrubs: 20% - 60%
- vegetables: 41% - 80%

Having those numbers in mind, a soil humidity sensor is designed, that can measure the humidity of the soil in the range of 5% - 55% such that it can cover the neccesary humidity needed for most of the plants. In the end, the circuit will drive the water pump to keep the soil humidity in the range of 30% - 45%.

1.2. Advantages

There are several advantages of using an automatic irrigation system:

I. <u>Water conservation:</u> Sensors can detect soil moisture levels to avoid over-watering and reduce water wastage.

II. <u>Time saving:</u> Once set up, an automatic irrigation system reduces the need for manual watering, saving time for homeowners, farmers, and gardeners.

III. <u>Cost saving:</u> Prevents water damage to plants and landscapes, which can save money on plant replacement and maintenance. Also, efficient water usage can reduce water bills and it is important to note that the automation reduces the need for manual irrigation labor, which can significantly cut labor costs in large agricultural operations.

1.3 Disadvantages

Of course, there are also disadvantages implying the cost of the whole irrigation system. The installation of an automatic irrigation system can be expensive, including the cost of the circuit itself, but also the cost of the water pump and the rest of the hardware needed such as hoses. Automatic irrigation systems require regular maintenance to ensure they function correctly, which can include, checking for leaks and checking the water pump itself.

Overall, considering the advantages and disadvantages listed above, the automatic irrigation system can be very useful if it is maintained right.

2. The design of the system

2.1 Components list

In order to design an irrigation system circuit, some components are needed such as:

1. Soil humidity sensor: this component will be represented by a resistance that can change its value in the interval [380k, 120k][Ω]. Those values will corespond to a level of humidity of [5, 55][%]. This resistance will be placed in the ground, and based on the level of water in the soil, its resistance will vary.
2. Op-Amps: the Op-Amps will act as „the brain" of the whole circuit since most of the voltage variation will be controlled by them. For this specific application, considering that the circuit will be supplied with 10V, the AD8614 Op-Amp is perfect because of its rail-to-rail property, it can output voltages very close to the supply voltages (10V & 0V). It can accurately process the full range of sensor outputs, even if those outputs are near the power supply limits. This ensures precise control over the moisture sensing and the corresponding activation of the irrigation system.
3. Resistors: Used for voltage dividers, Op-Amp feedback network, limitting current through LEDs and diodes. For this schematic most resistors will have a 1% tolerance because of the high precision needed for this circuit and also because of the wide variety of resistors with such tolerance.
4. Transistor: 2N2222A BJT will be used after the inverting amplifier as a switch, to separate the relay from the rest of the circuit.
5. LED: LO_3366 orange LED will be used to indicate the ON/OFF state of the water pump.
6. Omron G5LE-1 12VDC relay: used to drive the water pump.

2.2 Circuit block diagram

Before going through the circuit schematic, let's analyze the block diagram shown in the *Figure 1* for a better understanding of how the whole system will work:

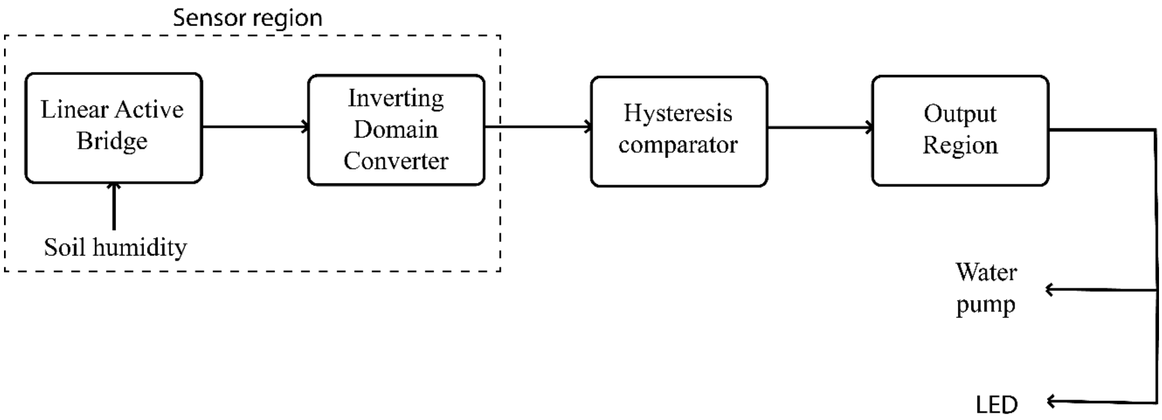

Figure 1: Circuit block diagram

Now let's analyze each block of the diagram:

1. Linear active bridge: The resistive sensor will be part of this bridge, more exactly it will be placed on the negative feedback line. This linear active bridge will output a signal that varies linearly with the soil moisture level in the interval [2,4; 4,15][V]. The first problem that appears is that this voltage range is not large enough to cover the [5, 55][%] soil humidity. To cover that interval of humidity the ideal interval is [8, 2][V]. This problem is easily solveable by using an Op-Amp Inverting Domain converter.
2. Op-Amp Inverting Domain converter: as the name of the block sugests, the role of this block diagram is to modify the voltage interval from [2,4; 4,15][V] to idealy [8, 2][V]. This range is needed since the resistance varies from [380; 120][kΩ] which coresponds to [5, 55][%] humidity. So the 8V voltage will corespond to 55% humidity and the 2V voltage will corespond to 5% humidity. In reality after the standardisation the domain will be [7,79; 1,85][V] which will work aswell.
3. Hysteresis comparator: The comparator is configured with hysteresis to ensure stable switching between the watering on and off states. It compares the sensor voltage with predefined threshold voltages corresponding to the lower and upper moisture limits (30% and 45%). This threshold voltages will be deduced at page number
4. Output region: this stage of the block diagram contains the transistor, led and the relay which will be connected to the water pump.
5. Water pump: since the circuit uses a relay, the water pump model is at the user's choice.

2.3 Circuit Schematic

The circuit schematic can bee seen in the *Figure 2* below:

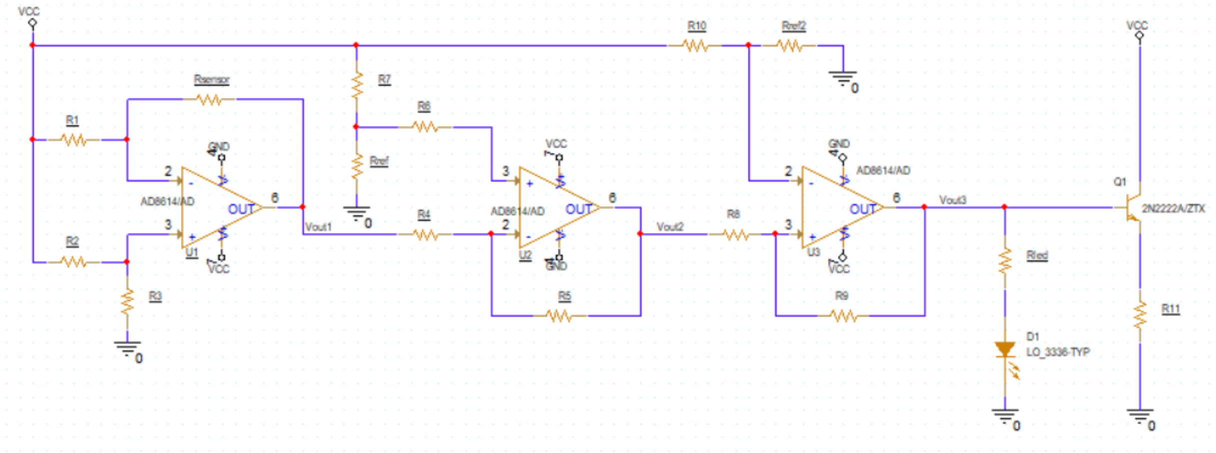

Figure 2: Irrigation system circuit schematic

For now let's take each part of the circuit and compare it with each block of the diagram from the *Figure 1* :

➔ **Linear Active Bridge section:** This part of the circuit can be seen in more detail in *Figure 3.* It consist of one OP-Amp with negative feedback. Its role is to convert the values of the sensor into voltage.

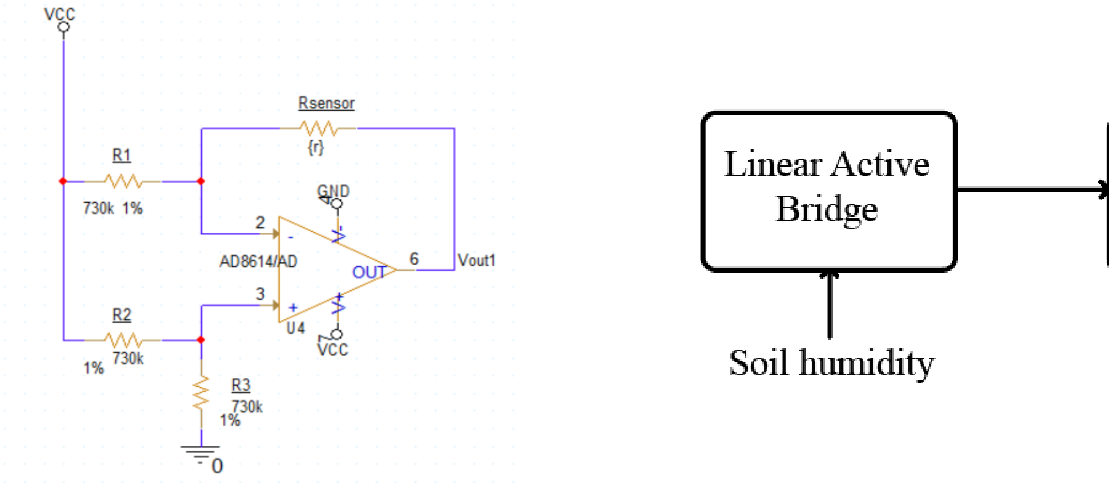

Figure 3: Linear Active Bridge section

➔ **Inverting Domain Converter section:** This part of the circuit consists in an Op-Amp with negative feedback (in inverting configuration) with Vref = 3.66V, Vin = [2.4; 4.2][V]. *Figure 4* shows what part of the circuit coresponds to the block diagram.

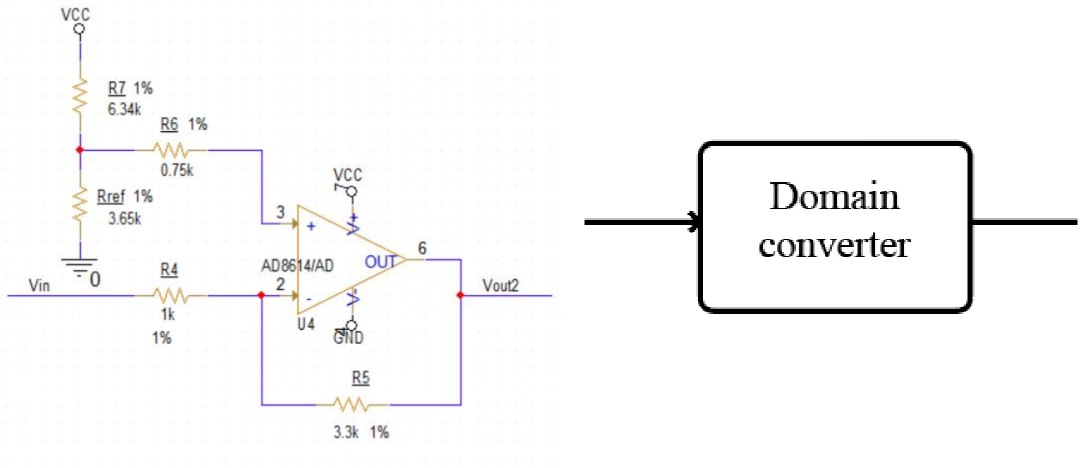

Figure 4: Inverting Domain Converter section

➔ **Hysteresis comparator section:** This part of the circuit is responsible with all the „work”. Its role is to switch from HIGH (10V) to LOW (0V) in order to keep to soil humidity in the interval [30, 45][%]. In *Figure 5* is presented the circuit schematic and the block diagram of the hysteresis comparator.

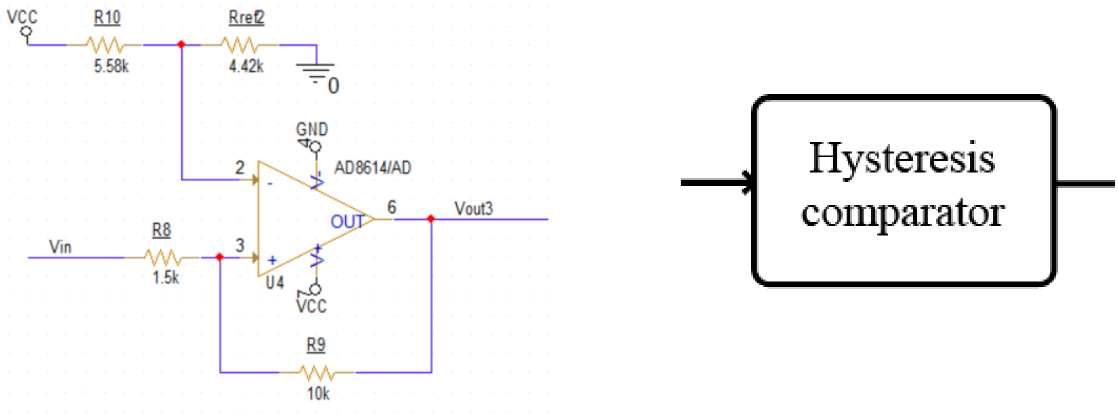

Figure 5: Hysteresis comparator section

➔ **Output region section:** As the name sugests, this part of the circuit is responsible with triggering the relay and turning on the LED.

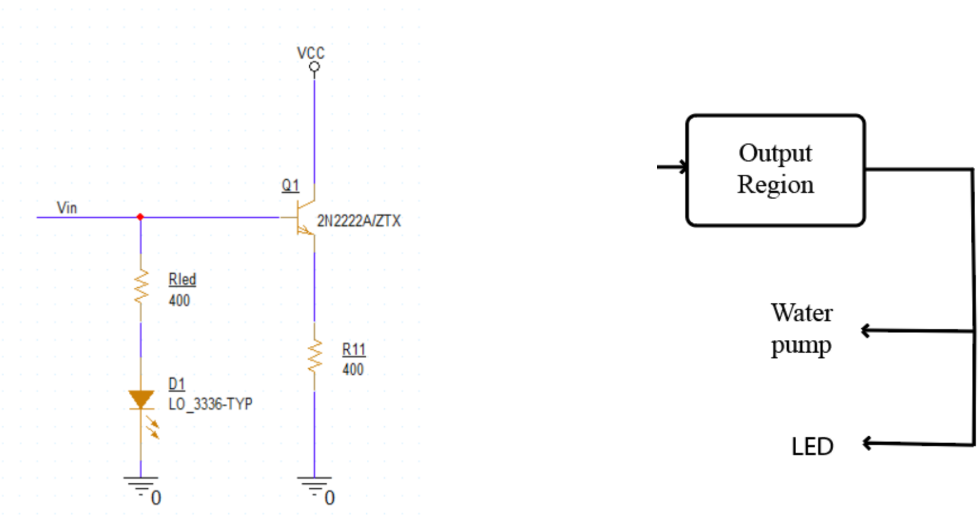

Figure 6: Output region section

2.3.1 Circuit after the standardisation

This schematic includes the values for resistors after standardisation. The calculations for this version of the circuit can be visualized at the next stage of the project.

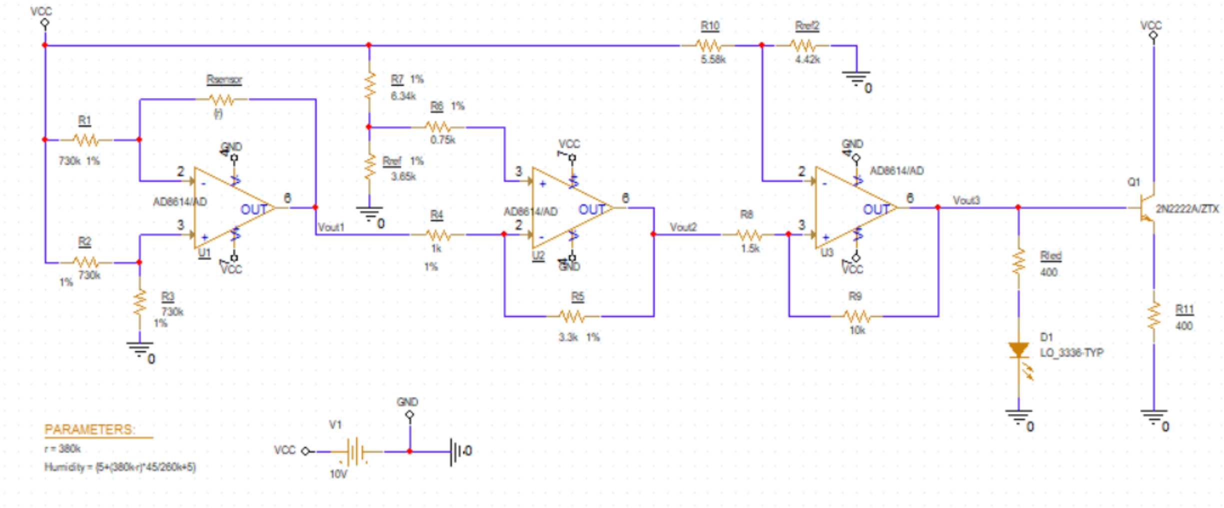

Figure 7: Irrigation system after the standardisation

3.Calculations

One of the most important parts when designing a circuit is to calculate the values for each component. In the following subsections of this part, will be calculated values for the components of this system starting with:

3.1 Linear Active Bridge

Since this part of the circuit will give the values for the next section, it is very important to obain acurate values.

Step 1: Write V_{out1} as a function of V_{CC}

$$V_+ = V_- \ (since\ there\ is\ negative\ feedback) \tag{1}$$

$$V_+ = \frac{R_3}{R_3+R_2} \cdot V_{CC} \tag{2}$$

$$V_- = \frac{R_{sensor}}{R_{sensor}+R_1} \cdot V_{CC} + \frac{R_1}{R_1+R_{sensor}} \cdot V_{out1} \tag{3}$$

$$(1),(2),(3) \Rightarrow V_{out1} = \left(\frac{R_1}{R_1+R_2} - R_{sensor} \cdot \frac{R2}{R_3 \cdot (R_1+R_2)}\right) \cdot V_{CC}$$

Step 2: Since $R_1 = R_2 = R_3$ we will denote these resistors with a. Then we will replace V_{CC} with 10V and R_{sensor} with its minimum and maximum values.

$$V_{out1min} = \left(\frac{a}{2 \cdot a} - R_{sensor\_max} \cdot \frac{a}{a \cdot 2 \cdot a}\right) \cdot 10 = \left(\frac{1}{2} - 380 \cdot \frac{1}{2 \cdot a}\right) \cdot 10 = 5 - \frac{1900}{a}$$

$$V_{out1max} = \left(\frac{a}{2 \cdot a} - R_{sensor\_min} \cdot \frac{a}{a \cdot 2 \cdot a}\right) \cdot 10 = \left(\frac{1}{2} - 120 \cdot \frac{1}{2 \cdot a}\right) \cdot 10 = 5 - \frac{600}{a}$$

Step 3: Now it will be given a value for a, such that the output interval can be as large as possible, in this case a = 730k ($R_1 = R_2 = R_3 = 730k\Omega$ 1%):

$$V_{outmin} = 5 - 2{,}60 = 2{,}40V$$

$$V_{outmax} = 5 - 0{,}85 = 4{,}15V$$

Important note: as it can be seen from the formulas, in this stage the maximum output value is limited at 5V, unless the circuit is supplied with more voltage. Since this is not a good solution, especially for V_{CC} fixed at 10V, the role of the next stage of the system will be to extend the output voltage interval.

3.2 Inverting Domain Converter

This part of the circuit consists in converting the voltage interval obtained previously [2,4; 4,15][V] into idealy [8, 2][V]. These values can be achived by using an Inverting Domain Converter.

Step 1: Calculate the values for R4 & R5 using the following formula derived from the gain of the inverting amplifier:

$$\frac{R_5}{R_4} = \frac{V_{outmax} - V_{outmin}}{V_{inmax} - V_{inmin}} \tag{4}$$

$$\Rightarrow \frac{R_5}{R_4} = \frac{8-2}{4{,}15-2{,}4} = 3{,}3 \Rightarrow R_5 = 3{,}3k\Omega\ (1\%\ tolerance)\ \&\ R_4 = 1k\Omega\ (1\%\ tolerance)$$

Step2: Calculate V_{REF} by using the formula:

$$V_{REF} = \frac{v_{Omin} + \frac{R_5}{R_4} \cdot V_{inmax}}{1 + \frac{R_5}{R_4}} \tag{5}$$

$$\Rightarrow V_{REF} = \frac{2 + 3{,}3 \cdot 4{,}15}{1 + 3{,}3} = 3{,}66V$$

$$V_{REF} = V_{CC} \cdot \frac{R_{REF}}{R_{REF} + R_7} \Rightarrow \frac{3{,}66}{10} = \frac{R_{REF}}{R_{REF} + R_7} \Rightarrow R_{REF} = 3{,}65k\Omega;\ R_7 = 6{,}34k\Omega\ (both\ 1\%\ tol.)$$

Step 3: Calculate V_{Omax} & V_{Omin} with the new values to see the real output voltage:

$$\begin{cases} V_{Omax} = -\frac{R_5}{R_4} \cdot V_{inmin} + \left(1 + \frac{R_5}{R_4}\right) \cdot V_{REF} & (6) \\ V_{Omin} = -\frac{R_5}{R_4} \cdot V_{inmax} + \left(1 + \frac{R_5}{R_4}\right) \cdot V_{REF} & (7) \end{cases}$$

$$\begin{cases} V_{Omax} = -3.3 \cdot 2.4 + 4.3 \cdot 3{,}66 = 7{,}79V \\ V_{Omin} = -3.3 \cdot 4.2 + 4.3 \cdot 3{,}66 = 1.86V \end{cases}$$

3.3 Hysteresis comparator

The hysteresis comparator will have V_{in} in the interval [1,86; 7,79][V] and the output of the hysteresis will switch between 0V and 10V.

Step 1: Compunting the values for V_{thH} &V_{thL}:

What it is known: For the humidity [5; 55][%] it coresponds a voltage of [8; 2][V] and the thresholds should corespond to 30% and 45% humidity. Since the circuit has a linear variation we can start by calculating the resistance values at 30% and 45% humidity by using the linear interpolation formula:

$$R_{x\%} - R_{sensor\_max} = \frac{(R_{sensor\_min} - R_{sensor\_max}) \cdot (x - H_{min})}{(H_{max} - H_{min})} \tag{8}$$

By replacing x with the needed humidity value, the resistances and the humidity with their values we obtain that:

$$R_{30\%} = 380 + \frac{(120-380)\cdot(30-5)}{(55-5)} = 250k\Omega$$

$$R_{45\%} = 380 + \frac{(120-380)\cdot(45-5)}{(55-5)} = 172k\Omega$$

Knowing these values for the resistances, the threshold voltages can be computed by using the formulas:

$$V_{thH} = \frac{V_{inmax} \cdot R_{30\%}}{R_{sensor\_max}} = \frac{7.79 \cdot 250}{380} = 5{,}125V$$

$$V_{thL} = \frac{V_{inmax} \cdot R_{45\%}}{R_{sensor\_max}} = \frac{7{,}79 \cdot 172}{380} = 3{,}526V$$

Step 2: Computing the value for V_{REF}:

Knowing the threshold values, the output voltage interval and the input voltage interval, the value of V_{REF} can be calculated using the formulas:

$$V_{thL} = -\frac{R_8}{R_9} \cdot V_{OH} + \left(1 + \frac{R_8}{R_9}\right) \cdot V_{REF} \tag{9}$$

$$V_{thH} = -\frac{R_8}{R_9} \cdot V_{OL} + \left(1 + \frac{R_8}{R_9}\right) \cdot V_{REF} \tag{10}$$

By denoting the ratio of R_8 and R_9 with the letter a, it is obtained the following relation:

$$3{,}526 = -a \cdot 10 + V_{REF} + a \cdot V_{REF} \Rightarrow \frac{3{,}526 - V_{REF}}{V_{REF} - 10} = a$$

$$5{,}125 = -a \cdot 0 + V_{REF} + a \cdot V_{REF} \Rightarrow \frac{5{,}125 - V_{REF}}{V_{REF}} = a$$

$$\Rightarrow (3{,}526 - V_{REF}) \cdot V_{REF} = (V_{REF} - 10) \cdot (5{,}125 - V_{REF}) \Rightarrow V_{REF} = 4{,}42V$$

Step 3: Computing the values for the input and feedback resistors:

This computation can be done by replacing the input and output max and min voltages and V_{REF} in the equations (9), (10). The notation of the ratio will remain „a” for easier calculation:

$$(9),(10) \Rightarrow a = \frac{3,526-4,42}{4,42-10} = \frac{5,125-4,42}{4,42} = 0,15$$

$$\Rightarrow R_9 = 10k\Omega\ (1\%\ tolerance)$$

$$\Rightarrow R_8 = 1.5k\Omega\ (1\%\ tolerance)$$

After the computation of the components it can be seen in the simulation part that the humidity range will be [30; 41][%].

3.5 Output region

For the output region the main component will be the 2N2222 transistor wich will be responsible with triggering the relay. The LED was connect straight out of the hysteresis comparator’s output since V_{LED} = 2V according to its datasheet wich can be visualized in *Figure 8*. So its voltage won’t influence the transistor since 8V is plenty voltage to turn on the transistor.

Illumination Colour:	Orange
Wavelength/Colour Temperature:	606 nm
Luminous Intensity:	280 mcd
Viewing Angle:	70 deg
If - Forward Current:	20 mA
Vf - Forward Voltage:	2 V
Length:	3.4 mm
Width:	3.4 mm
Height:	4.8 mm

Figure 8: LED Datasheet

The LED will need a resistor which can be calculated with the following formula:

$$R_{LED} = \frac{V_{OUT}-V_{LED}}{I_{LED}} = \frac{10-2}{0.02} = 400\ \Omega \qquad (11)$$

The relay will be considered a resistor with its resistance value equal with the resistance of the coil that triggers the relay, in this case 400 Ω.

4. Simulations

4.1 DC Sweep

This type of analysis is used to see the linearity of the circuit blocks, starting with the Linear Active Bridge in *Figure 9*, then in *Figure 10* the Inverting Domain Converter:

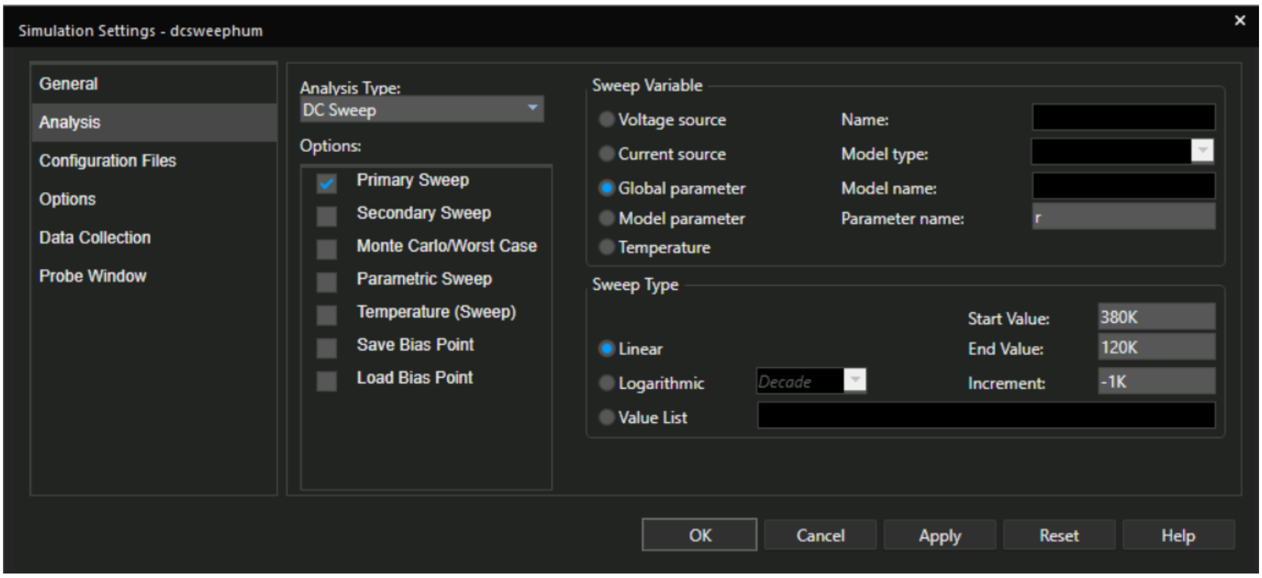

Figure 8: DC Sweep settings

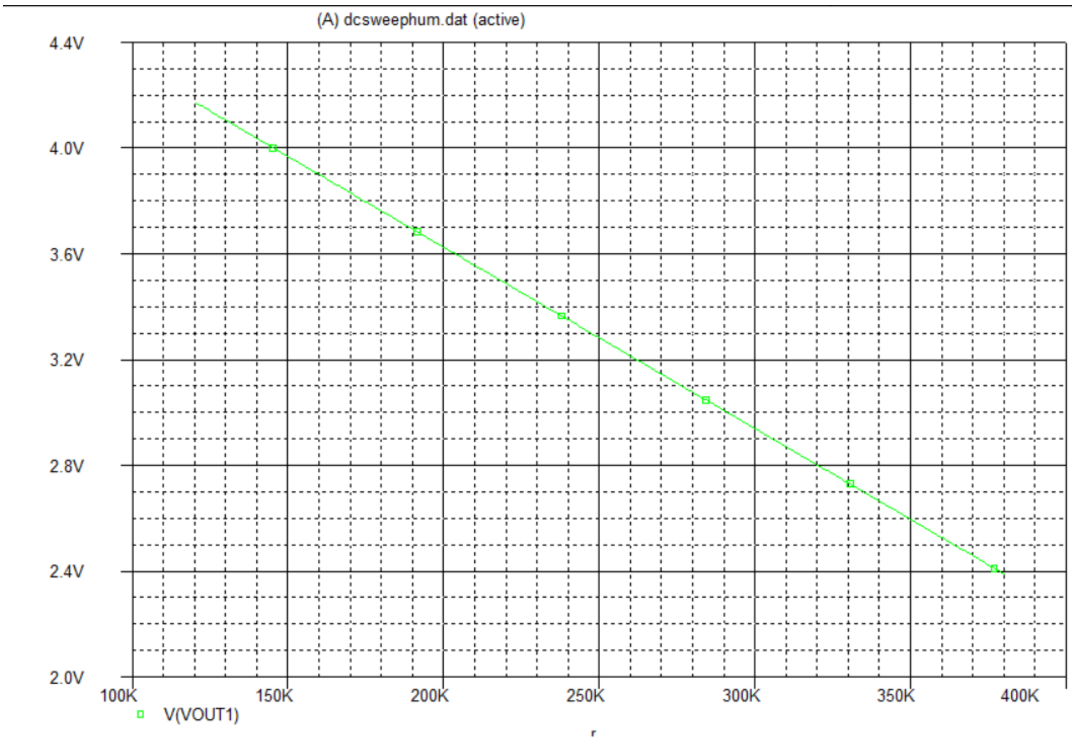

Figure 9: Linear Active Bridge output voltage

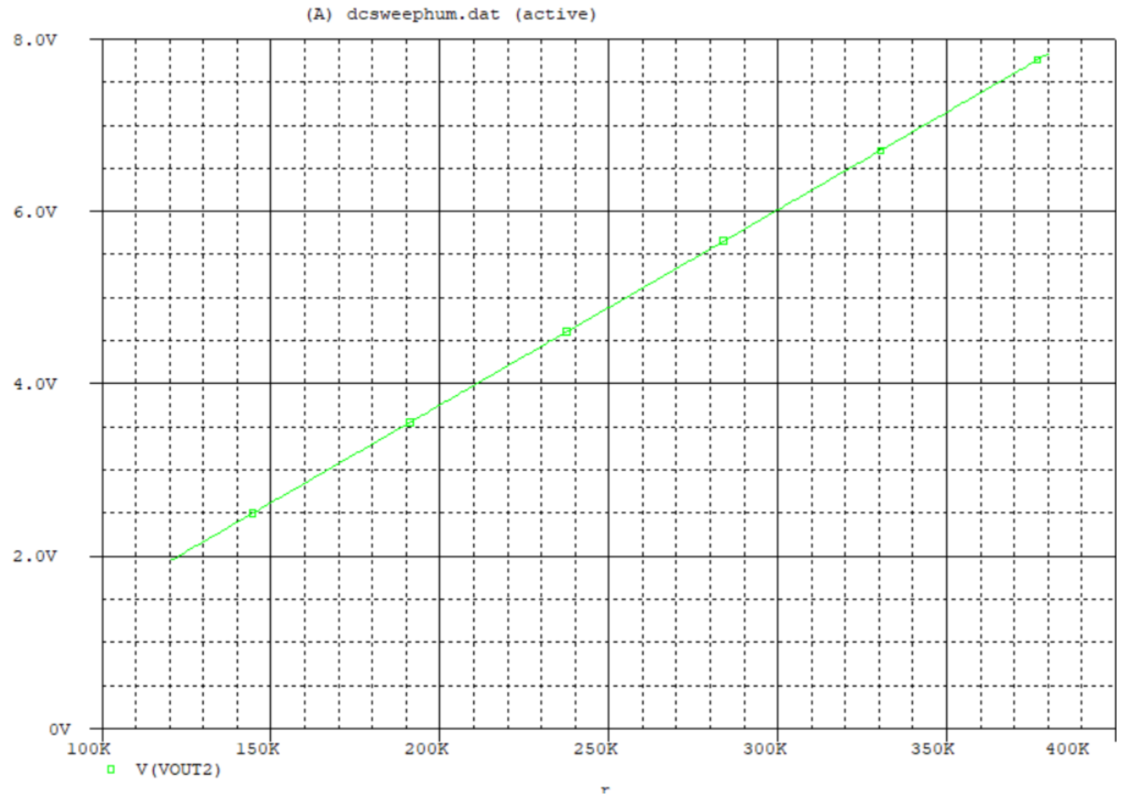

Figure 10: Inverting Domain Converter output voltage

For the hysteresis comparator some changes must be made to see its threshold values in comparison with the humidity of the soil. The following formula was used to convert the resistance into humidity:

$$Humidity = 5 + \frac{(380k - R_{sensor}) \cdot (55-5)}{(380k - 120k)} \quad (12)$$

The VTC of the hysteresis can be seen in both *Figure 11* & *Figure 12*:

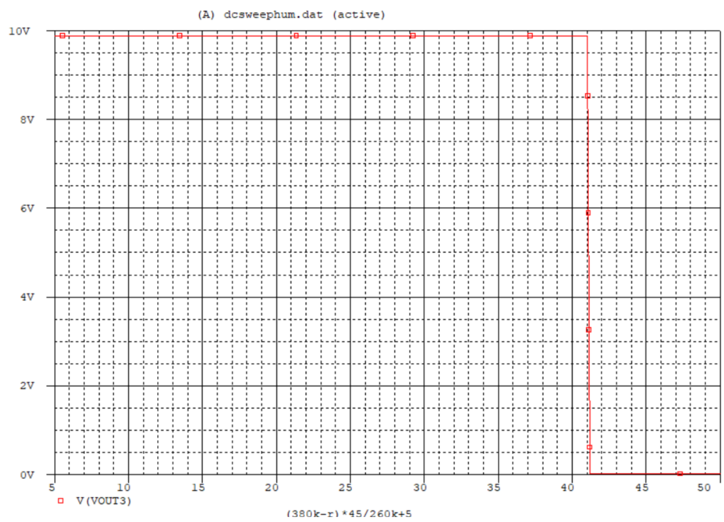

Figure 11: Hysteresis comparator V_thH

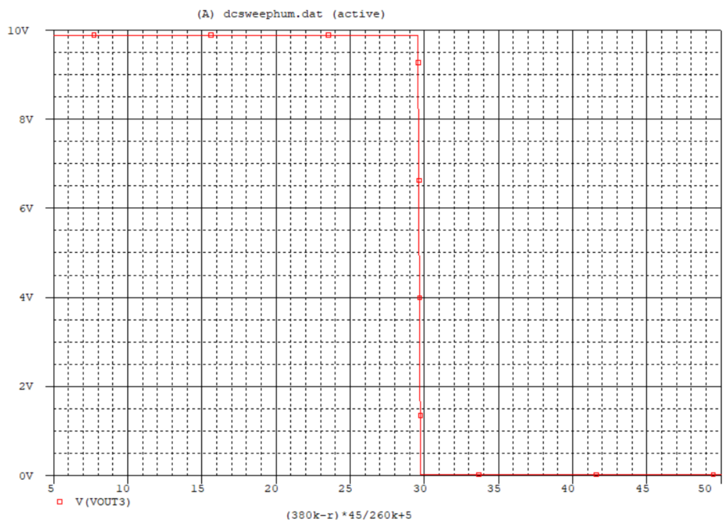

Figure 12: Hysteresis comparator V_thL

Also it is useful to see the current through the LED and the voltage across the relay to ensure they function right. In what's next it is shown the current through LED in *Figure 13* & *Figure 14* and the voltage across the relay in *Figure 16* & *Figure 17*.

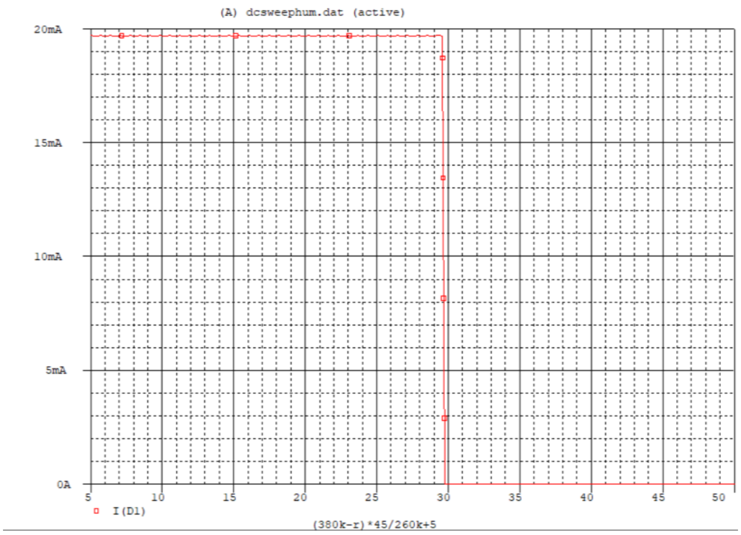

Figure 13: Current through LED for V_thL

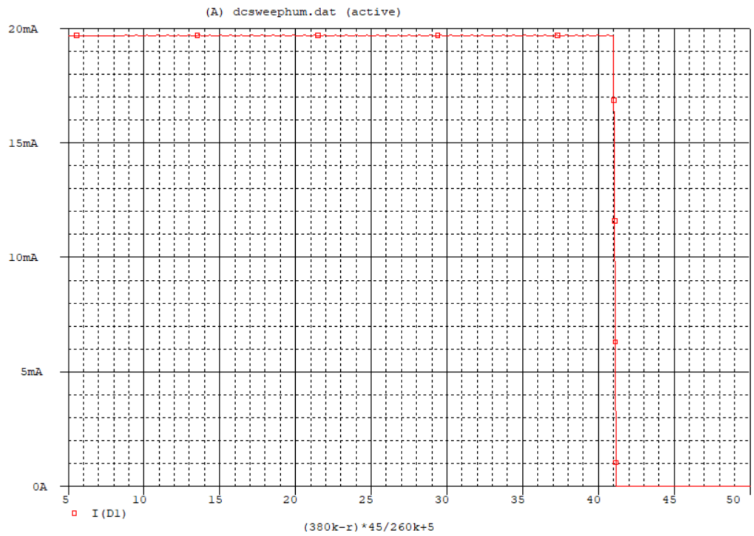

Figure 14: Current through LED for V_thH

For the voltage across the relay it can be seen in *Figure 15* it is 9,17V which is enough to trigger the relay.

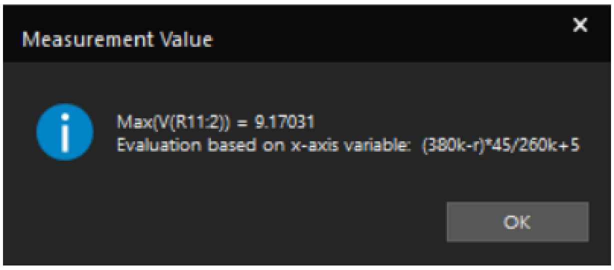

Figure 15: Max voltage across the relay

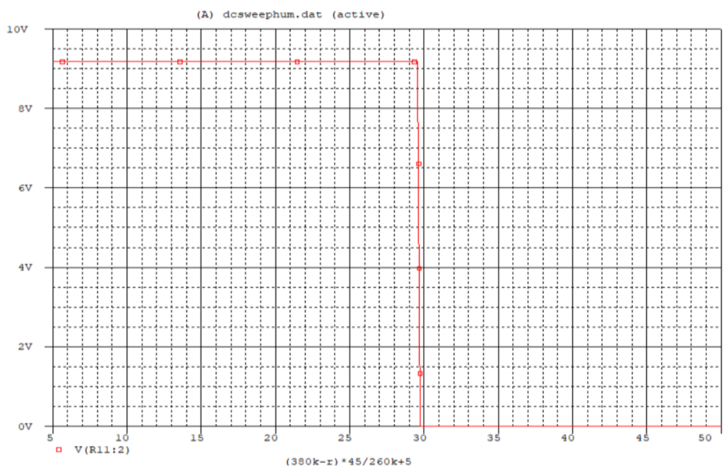

Figure 16: Voltage across the relay for V_thL

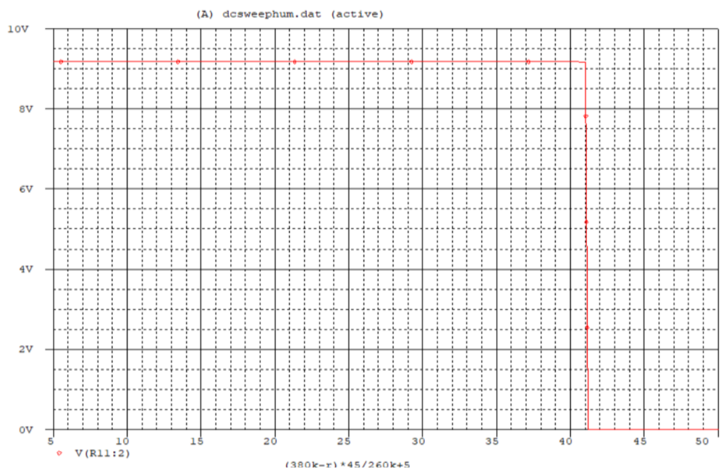

Figure 17: Voltage across the relay for V_thH

4.2 Monte-Carlo

The Monte-Carlo analysis is the best way of analyzing a circuit in statistical terms, to see how the circuit behaves at components values variation. It determines, statistically, the circuit behaviour when the components values are changed in their tolerance domain. The analysis was runned only for half of the hysteresis since the results are the same for the other half. The results can be seen in the *Figure 18* below:

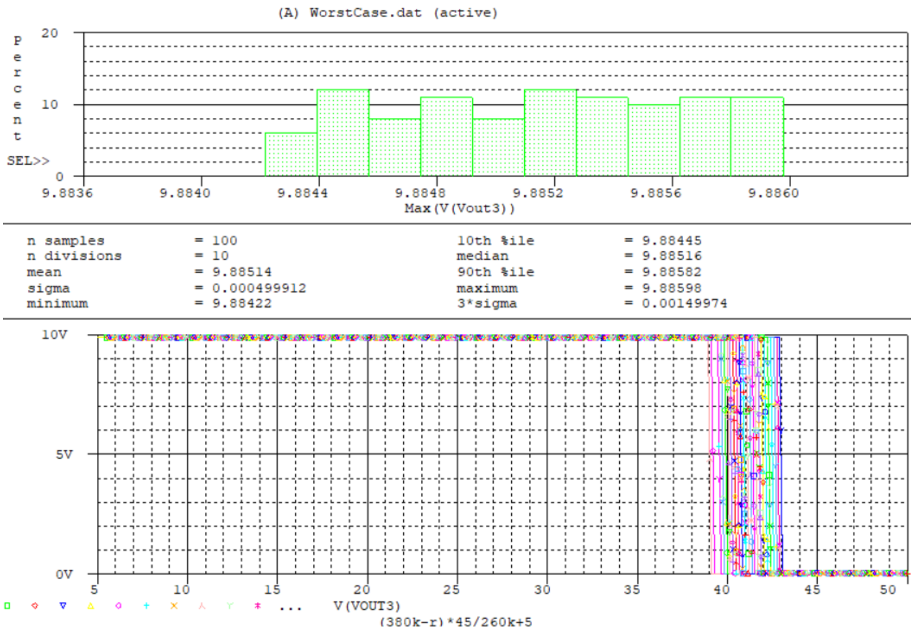

Figure 18: Monte-Carlo analysis

4.3 Temperature sweep

Since the circuit is supposed to control a water pump and is meant for outdoor usage, a temperature sweep analysis was used to see the behaviour of the circuit at certain temperatures in the interval: [-5; 50][°C]. As before, the analysis was runned only for one half of the hysteresis because of the same reasons. The results are displayed in *Figure 19* below:

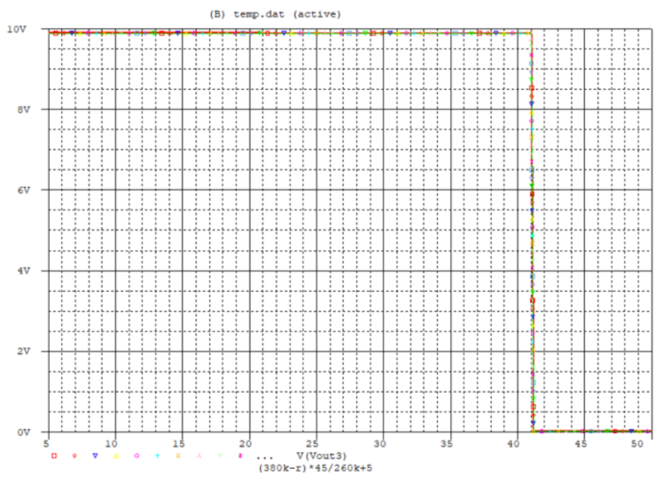

Figure 19: Temperature sweep analysis

5. Conclusion and improvements

As a conclusion, the development and implementation of the irrigation system project has demonstrated its significant potential to address agricultural water management. The system offers efficient water distribution, precise irrigation scheduling, and effective resource utilization. By implementing this project, anybody can use this reliable and user-friendly solution.

It is important to note that this circuit can be improved by adding various sensors to it, others than the soil humidity one such as:

- ➔ A soil temperature sensor that triggers the water pump when the soil has reached a certain temperature
- ➔ A rain sensor which turns off the water pump when it starts to rain
- ➔ A water level sensor in case that the user has a water reservoir that feeds the pump. When the water level is too low the pump turns off so that it won't run dry which could damage it, and the list can continue.

After all the calculations and simulations, the *Figure 20* represents the final schematic of the circuit with all the components updated:

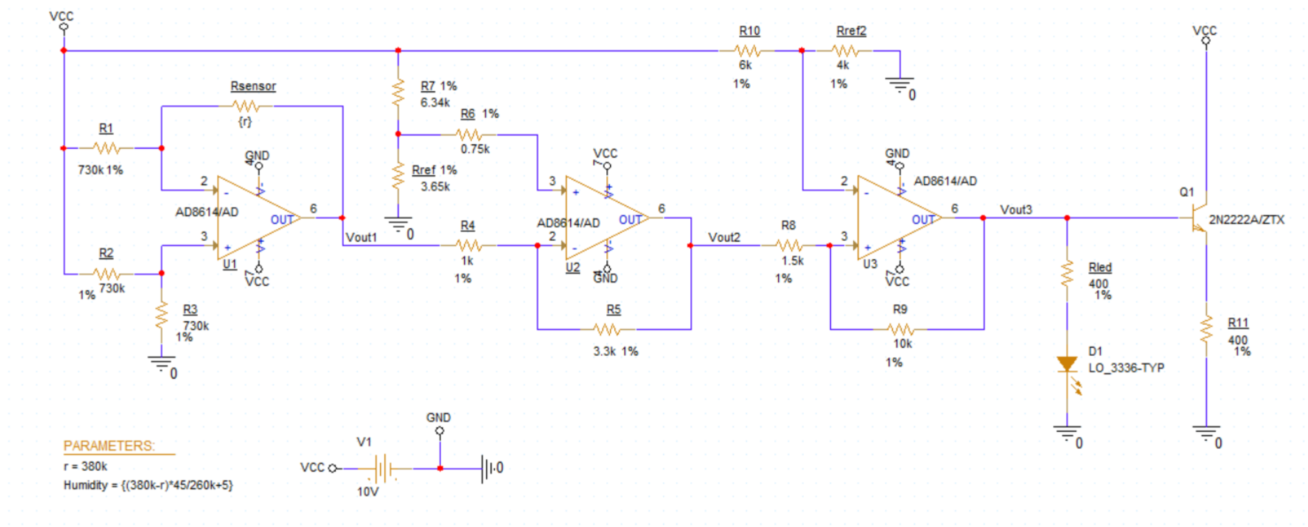

Figure 20: Final Schematic

5.1 BOM

The Bill of Materials is represented in *Table 1*. The parts were searched on the site which can be accesed from the link at the adress [4].

Table 1: BOM

Item	Quantity	Reference	Part	Price ($)
1	1	D1	LO_3336-TYP	0.15
2	1	Q1	2N2222A/ZTX	2.83
3	2	R11,Rled	400	0.4
4	1	Rref	3.65k	0.429
5	1	Rref2	4k	1.52
6	1	Rsensor	[380; 120][kΩ]	1.74
7	3	R1,R2,R3	730k	1.5
8	1	R4	1k	0.1
9	1	R5	3.3k	0.14
10	1	R6	0.75k	0.15
11	1	R7	6.34k	0.2
12	1	R8	1.5k	0.12
13	1	R9	10k	0.22
14	1	R10	6k	0.18
15	3	U1,U2,U3	AD8614/AD	16.34
			Total price	**26.019**

6. Biography

[1] https://www.ambius.com/resources/blog/plant-care/plants-and-soil-moisture

[2] Electronic devices courses:
http://193.226.6.189/dce/didactic/ed/C7.%20Hysteresis%20comparators.pdf

http://193.226.6.189/dce/didactic/ed/C8.%20Electronic%20amplifiers.%20Amplifiers%20with%20OpAmp..pdf

[3] CAD labs & courses:
[20210319]_04.Transient Analysis.pdf
[20210326]_05.Parametric Sweep.pdf
Lab4.TimeDomain_Analysis.pdf
Lab5.Parametric_Analysis.pdf
Lab6.statistical_Analysis.pdf

[4] Components: https://eu.mouser.com