Department of

Electrical & Electronics Engineering

**Abdullah Gül University**

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**EE3003 SSD CAPSULE**

# PROJECT-1 CAPACITIVE SENSOR-BASED RESPIRATION MONITORING

**Submitted on: 16.12.2020**

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# I. INTRODUCTION

Capacitors are used almost every electric circuitry in every area of electronics. Also, the nature of capacitors (occurred by basically just 2 conductive area and filling material), the capacitance value is depending on some parameter according to figure 1.

$$C = \frac{\varepsilon A}{d}$$

*Where,*

C = Capacitance in Farads

ε = Permittivity of dielectric (absolute, not relative)

A = Area of plate overlap in square meters

d = Distance between plates in meters

*Figure 1*

According to this formula, if A and d are fixed, and aren't changed, the capacitance directly depends on changing of permittivity of dielectric. That's why if a physical factor effects this permittivity, then this factor can be detected by a capacitor-based sensor.

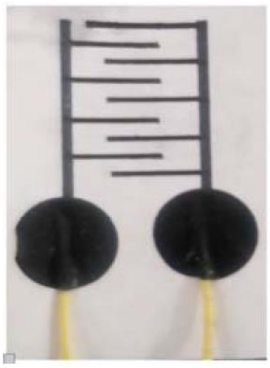


*Figure 2 A Capacitor of The Sensor*

*Figure 2 Typcial Clinical Mask*

In this project, a breath detector sensor will be designed with using the characteristic behavior of the capacitor. This capacitor value depends on human's breathing moisture because moisture is more conductive than air and the capacitance is changing at every breathing.

# II. THE PARTS OF THE PROJECT

This project is occurred by mainly 7 different parts. Each part is explained in detail in different sections. These parts are shown in figure 3.

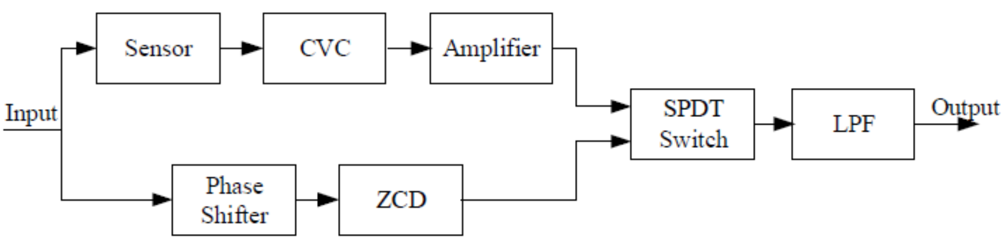



*Figure 3 The Schematic of The Whole Project*

## 1. THE SENSOR DESIGN PART ON ANSYS

### 1.1 INTRODUCTION

In this technical part of the whole project, aimed sensor's Ansys part was designed, and simulated in following three different situations: No-moisture, 50u and 100u meter moister thickness. And the capacitance results were shown and compared.

### 1.2 DESIGNING

In this simulation part, following physical parameters were used for approaching a real mask dimensions and an optimal sensor's characteristics. The dimensions are shown in figure 4.

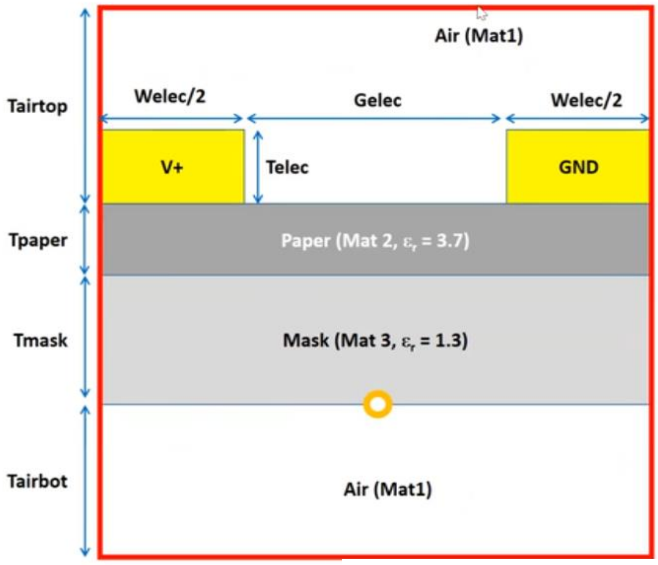



*Figure 4*

**Tairtop: 0.7 mm**

**Tairbot: 0.6mm**

**Tmask: 1.5mm**

**Tpaper: 0.7 mm**

**Welec: 0.5 mm**

**Telec: 0.1 mm**

**Gelec: 0.1mm**

### 1.3 METHODS AND SIMULATIONS

Three different cases are tested according to EEE department wishes.

#### 1.3.1 Case 1 – No Moisture

The capacitance value was 0.166E-10 F between just two conductive in the sensor. The total capacitance is $C = 4.499pF$ according to the formula of whole capacitance calculation. The formula is:

$$Capacitor\ value = The\ number\ of\ fingers * overlapping\ in\ meter * capacitance\ value$$

$$C = 9 * 0.16664 * 10^{-10} * 0.03 : C = 4.499pF$$

The simulation result are shown below.

```
______________ CMATRIX SOLUTION SUMMARY ________________

 *** Ground Capacitance Matrix ***
Self Capacitance of conductor  1. =     0.16664E-10
Ground capacitance matrix is stored in 3d array parameter CMATRIX ( 1., 1.,1)
 *** Lumped Capacitance Matrix ***
Self Capacitance of conductor  1. =     0.16664E-10
Lumped capacitance matrix is stored in 3d array parameter CMATRIX ( 1., 1.,2)

Capacitance values are per unit length

Capacitance matricies are stored in file CMATRIX .txt


 _____________________________________________________
```

*Figure 5 The Capacitance Value of Each Gap in No Moisture*

### 1.3.2 Case 2 – 50u Moisture Level

The capacitance value was 0.547E-10 F between just two conductive in the sensor. The total capacitance is $C = 14.77pF$.

$C = 9 * 0.54722 * 10^{-10} * 0.03 : C = 14.77pF$

The simulation result are shown below.

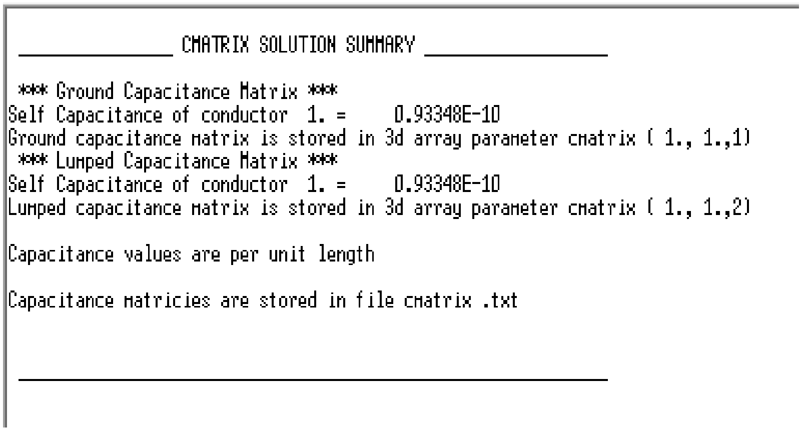
```
______________ CMATRIX SOLUTION SUMMARY ________________

 *** Ground Capacitance Matrix ***
Self Capacitance of conductor  1. =     0.54722E-10
Ground capacitance matrix is stored in 3d array parameter cmatrix ( 1., 1.,1)
 *** Lumped Capacitance Matrix ***
Self Capacitance of conductor  1. =     0.54722E-10
Lumped capacitance matrix is stored in 3d array parameter cmatrix ( 1., 1.,2)

Capacitance values are per unit length

Capacitance matricies are stored in file cmatrix .txt


 _____________________________________________________
```

*Figure 6 The Capacitance Value of Each Gap in 50u Moisture Level*

### 1.3.3 Case 3 – 100u Moisture Level

The capacitance value was 0.935E-10 F between just two conductive in the sensor. The total capacitance is $C = 25.2pF$.

$C = 9 * 0.93348 * 10^{-10} * 0.03 : C = 25.2pF$



```
_____________ CMATRIX SOLUTION SUMMARY _______________

 *** Ground Capacitance Matrix ***
Self Capacitance of conductor  1. =     0.93348E-10
Ground capacitance matrix is stored in 3d array parameter cmatrix ( 1., 1.,1)
 *** Lumped Capacitance Matrix ***
Self Capacitance of conductor  1. =     0.93348E-10
Lumped capacitance matrix is stored in 3d array parameter cmatrix ( 1., 1.,2)

Capacitance values are per unit length

Capacitance matricies are stored in file cmatrix .txt
```

*Figure 7 The Capacitance Value of Each Gap in 100u Moisture Level*

## 1.4 CONCLUSION

In this part of the project, a breathing detecting sensor's ANSYS simulation part was implemented and explained. According to 3 different simulation it is seen that, because of the permittivity value of moisture (80.1) is more and more high than air (1), the capacitance between two conductors were changed. If these 3 results are compared, case 3's capacitance level is higher than case2's and the case2's capacitance level is higher than no moisture situation.

# 2. THE PHASE SHIFTER PART

## 2.1 INTRODUCTION

In this step, a designed quadratic (90 degrees) phase shifter circuitry was explained. The mission of a phase shifter is shifting the signal according to the needed degree. Besides, the phase shifter term is called an all-pass filter. These circuitries give unit magnitude with a shifting.

In the whole project, the idea of using a quadratic phase shifter is the separation of the quadratic part and the output voltage. The developing parts were explained in this part.

## 2.2 DESIGN PART

To made a quadrative phase shifter, following circuitry were taken as example.

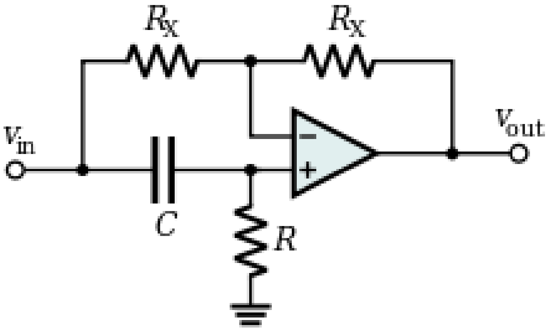



*Figure 8*

R and C values were determined according to sensor design's capacitive and physical characteristics. Rx value was taken as 1M ohm according to the reference article [1]. These values are shown below.

$$C = 9 * 0.16664 * 10^{-10} * 0.03 : C = 4.499 * 10^{-12}$$

The formula that is used in determining of frequency of sensor part:

$$f = \frac{1}{2\pi RC} = \frac{1}{2\pi 10^{6} * 4.499 * 10^{-12}} = 35375\ Hz$$

The frequency of the sensor circuit is 35.375 kHz. If selected cap value be 0.45nF, the R value have to be 10k Ohm according to following formula.

$$f = \frac{1}{2\pi RC} \rightarrow 35375 = \frac{1}{2\pi R * 10^{4}}, C = 0.45nF\ if\ R = 10k\ Ohm$$

0.45nF capacitor and 10k Ohm resistor were used in phase shifter circuit. Also, the input of the quadratic phase shifter sinus waves frequency was arranged to 35.375 KHz.

## 2.3 METHODS

To simulate the quadratic phase shifter, the circuit below is designed in Proteus according to the schematic that mentioned in Design Part. An ideal Opamp was used instead of LM358 for simulation.

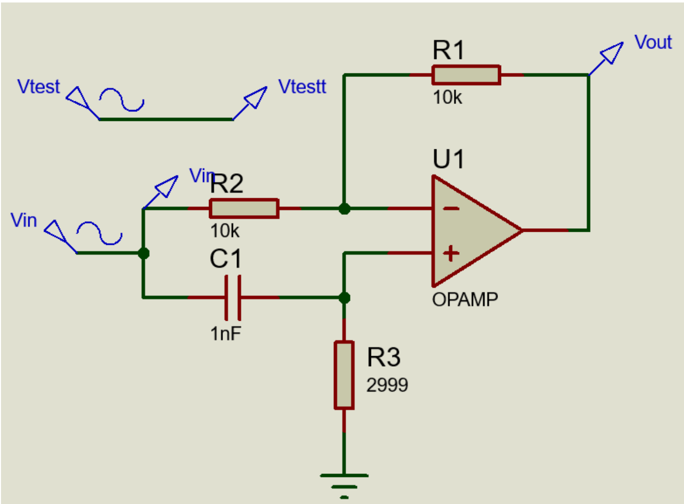



*Figure 9 The Circuitry of The Phase Shifter*

In this circuit, to 10K Ohm resistor were used because of reducing ampere of these lines.

## 2.4 RESULTS

The input and output voltage graphs of the quadratic phase shifter was shown in figure 9. Also, the comparison of the output of the phase shifter and the originally 90 degreed version of input voltage were shown in figure 10. It is clear that, the 90-degree phase shifter is working very well.

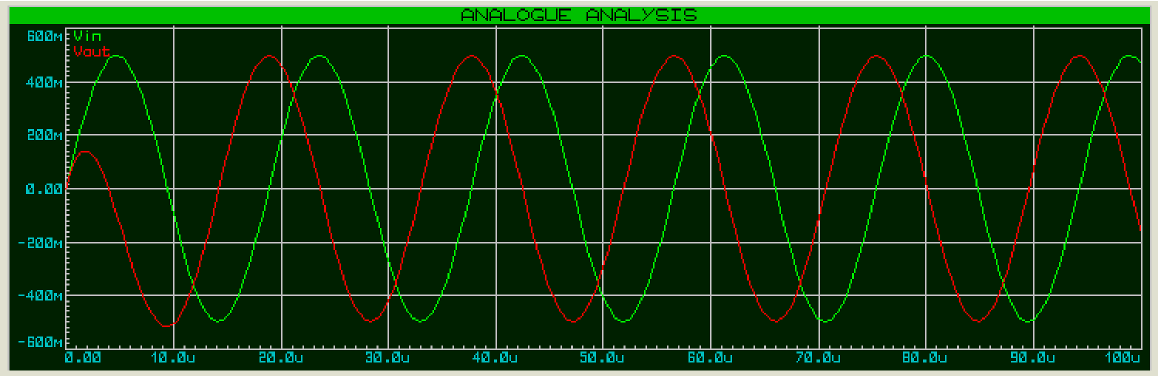



*Figure 9*

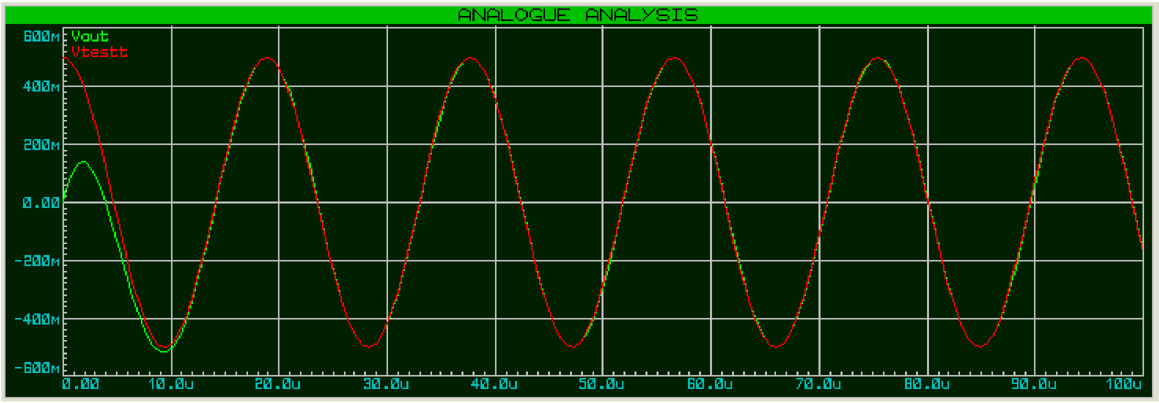



*Figure 10*

## 2.5 DISCUSSION

The results show that the quadratic phase shifter is working very well in a normal way. However, the Proteus part should be improved by changing the ideal opamp with LM358. In this way, the project can be closer than the real version of it. Also, the phase shifter's circuitry calculations and formulas were very complicated when searched on the internet. Instead of calculating by hand, Matlab or any other computer tools can be used. Lastly, the parameters such as the number of fingers, overlapping distance, sensor capacitor value can be changed if the further results are not meaningful or accurate. It will be understood in the future steps.

## 2.6 CONCLUSION

In this part of the project, a quadrative phase shifter was designed in Proteus, according to Ansys part's variables. The phase shifter and SPDT Switch which will be added to the project are used to separate the output voltage and quadratic signal. The phase shifter was working in an expected way.

# 3. CURRENT TO VOLTAGE CONVERTER (CVC)

## 3.1 INTRODUCTION

CVC (current to voltage converter) is used to produce a voltage according to a certain current. The main idea of using CVC is to measure voltage instead of current basically.

## 3.2 DESING PART

### Sensor Representing

The sensor that designed in ANSYS is occurred by mainly two parts which are a capacitor and a resistor. It was added the circuit in Proteus. The capacitor value was changed due to the no moisture, 50u moisture and 100u moisture cases. The calculations are shown below.

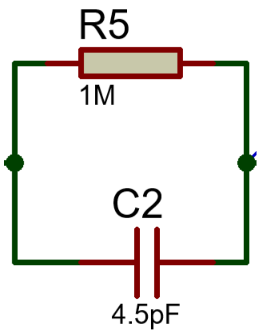



*Figure 11 The Sensor Representing*

$C = 9 * 0.16664 * 10^{-10} * 0.03 : C = 4.499pF$ for no moisture

$C = 9 * 0.54722 * 10^{-10} * 0.03 : C = 14.77pF$ for 50u moisture

$C = 9 * 0.93348 * 10^{-10} * 0.03 : C = 25.2pF$ for 100u moisture

### Current to Voltage Converter

In this project, a current to voltage converter circuit was used for converting the current to voltage for getting a more usable signal because the next parts of the circuit are based on voltage sensing. An opamp based circuitry was designed.

***Vout=IpRf***

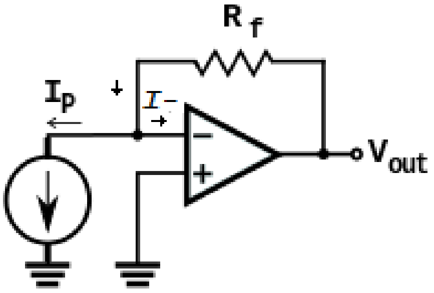



*Figure 12 CVC Circuitry*

## 3.3 METHODS

The CVC's circuitry was designed in Proteus. The scheme is shown below.

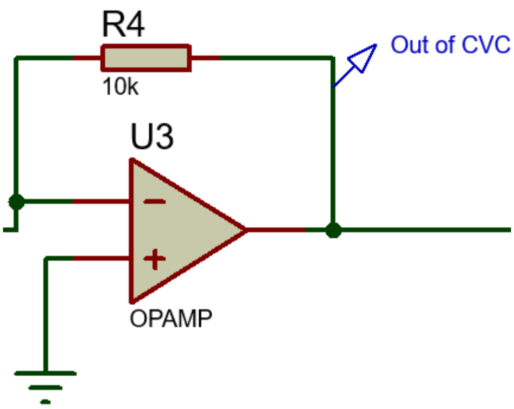



*Figure 13*

## 3.4 RESULTS

**The Input and Output GraphS of CVC**

**For No Moisture**

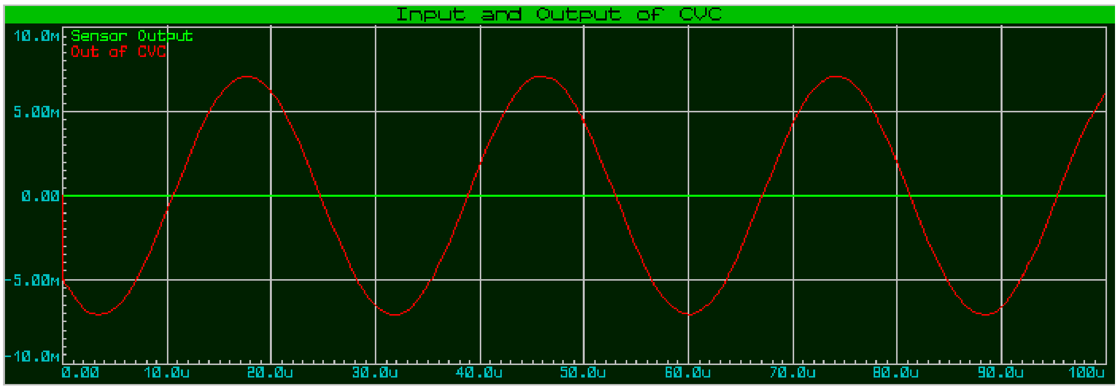



*Figure 14*

**For 50u Moisture**

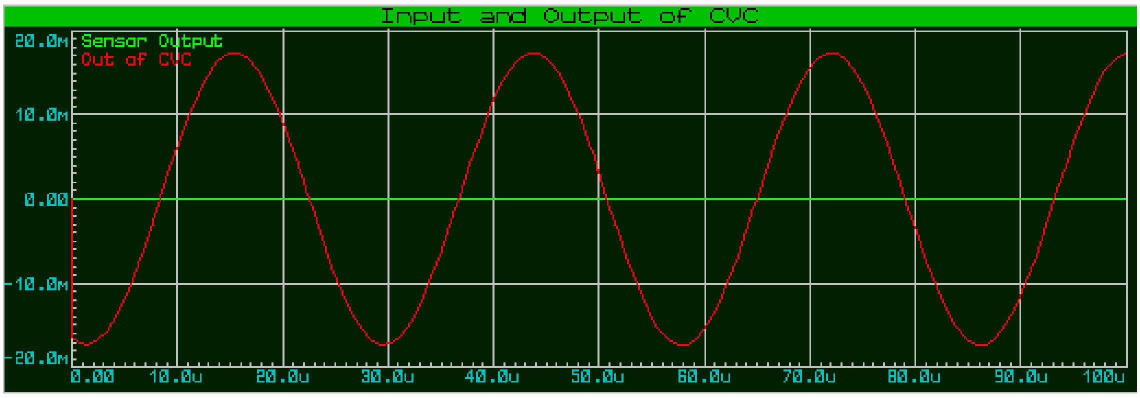



*Figure 15*

**For 100u Moisture**

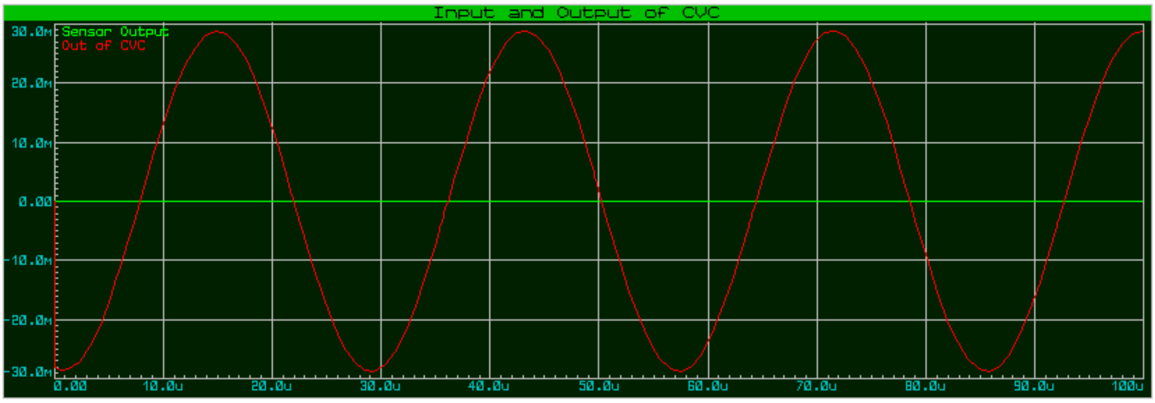



*Figure 16*

## 3.5 DISCUSSION AND CONCLUSION

The voltage level is increasing according to the moisture level at a positive rate in the CVC part. More moisture level equals more voltage in this part.

# 4. AMPLIFIER AND ZERO CROSSING DETECTOR

## 4.1 INTRODUCTION

ZCD (zero crossing detector) is used for detecting zero voltage in a signal and produces a square ware due to this signal. In this project, it is used for converting a sine wave to a square wave. In this way, the signal can be more easily usable. The amplifier part was added to the circuit for amplification of the low voltage output of the sensor and CVC parts.

## 4.2 DESIGN PART

### Amplifier

An opamp based amplifier was designed in this section. The schematic and equation of amplification is shown in the picture.

Rin= 1k Ohm and Rf= 150k Ohm resistors were used in the amplifier part. The aim was achieving a meaningful amplitude for using SPDT in a good way. The amplification level is 150 times.

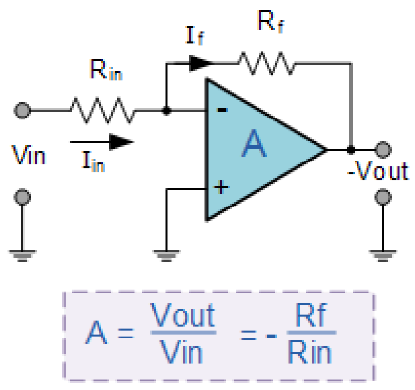



*Figure 17*

**Zero Crossing Detector**

In the project, the + (positive input) pin of the opamp was connected to ground because provide 0 reference volt, - (negative input) pin was connected to the phase shifter.

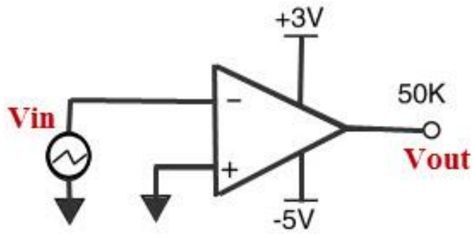



*Figure 18*

## 4.3 METHODS

The circuitries were designed in Proteus.

**Amplifier**

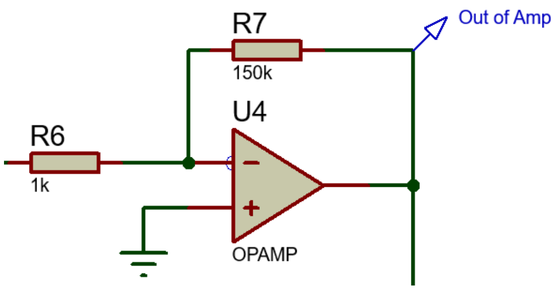



*Figure 19*

**Zero Crossing Detector**

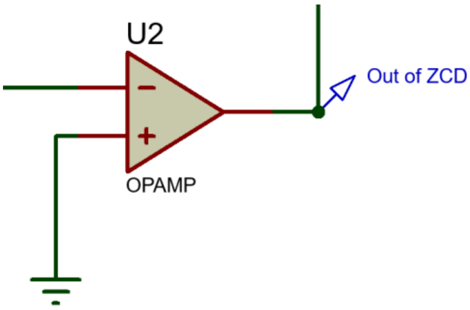



*Figure 20*

## 4.4 RESULTS

### The Input and Output Graph of Amplifier

### For No Moisture

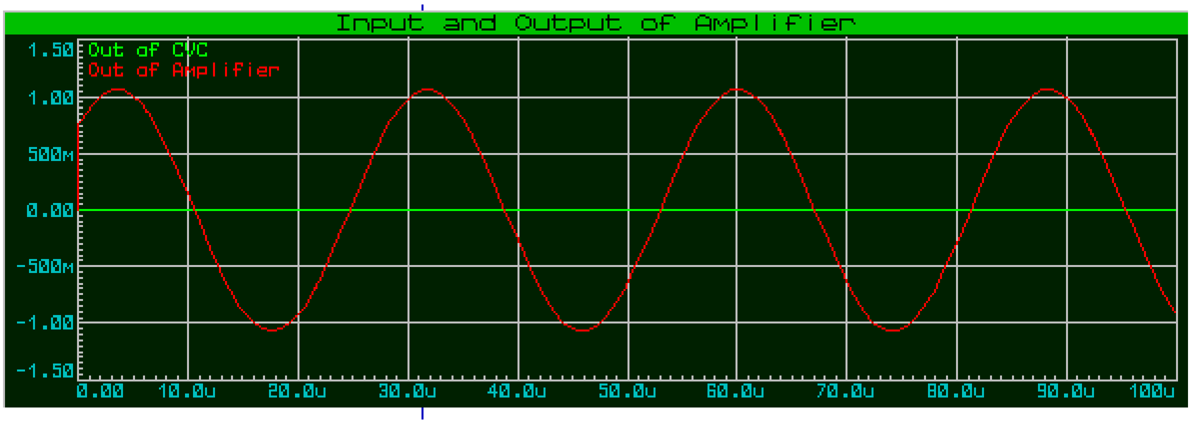



*Figure 21*

### For 50u Moisture

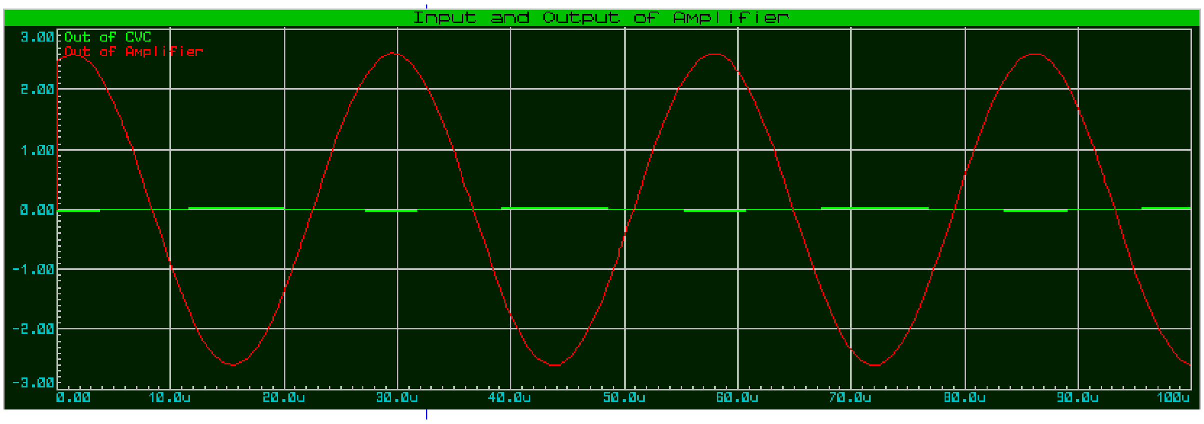



*Figure 22*

### For 100u Moisture

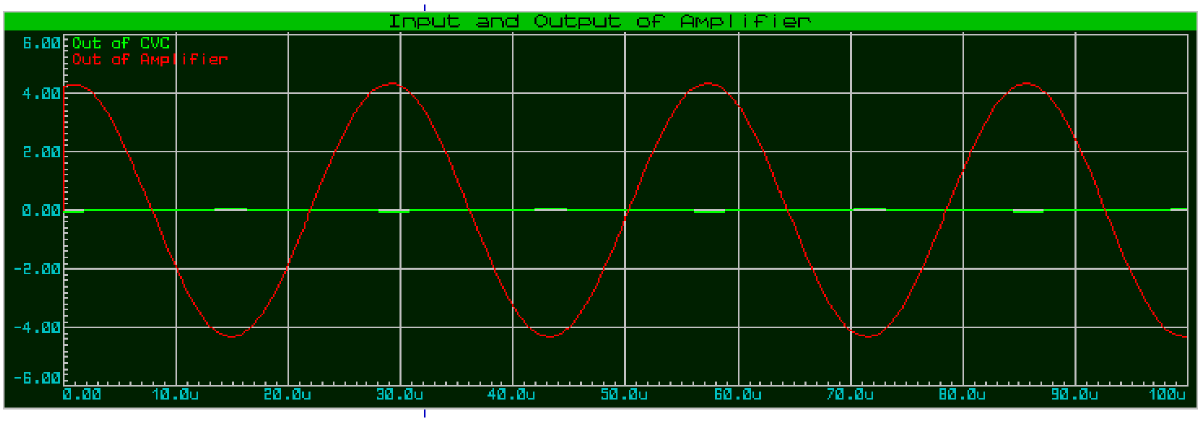



*Figure 23*

## The Input and Output Graph of ZCD

## For No Moisture

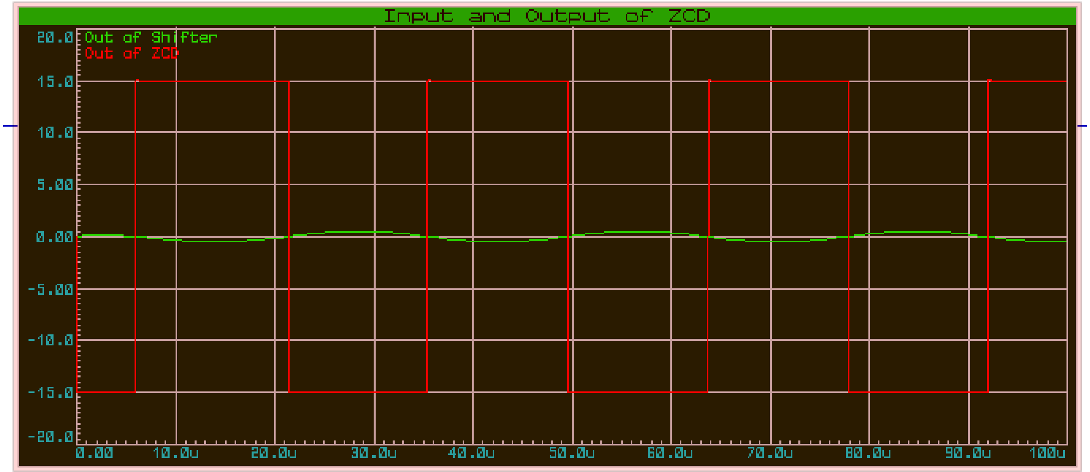



*Figure 24*

## For 50u Moisture

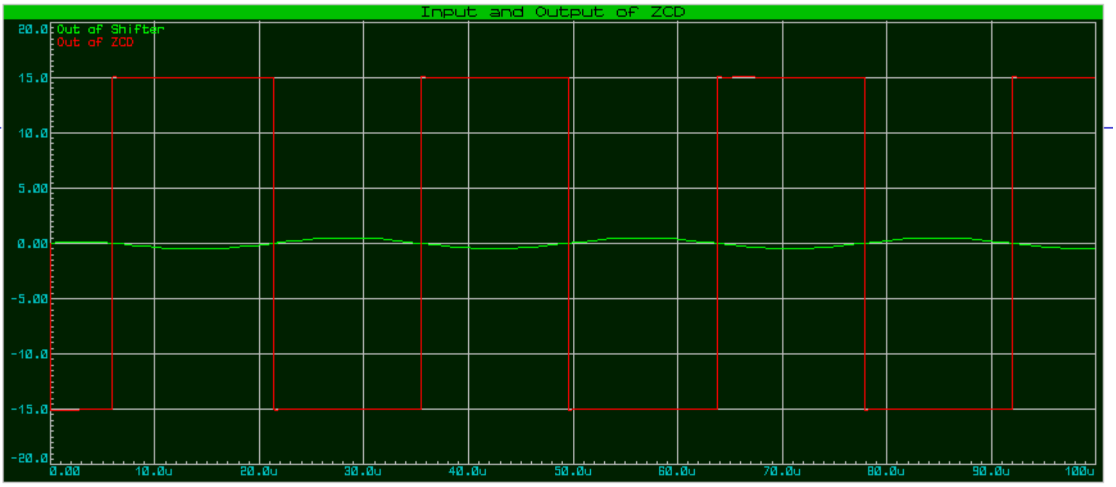



*Figure 25*

**For 100u Moisture**

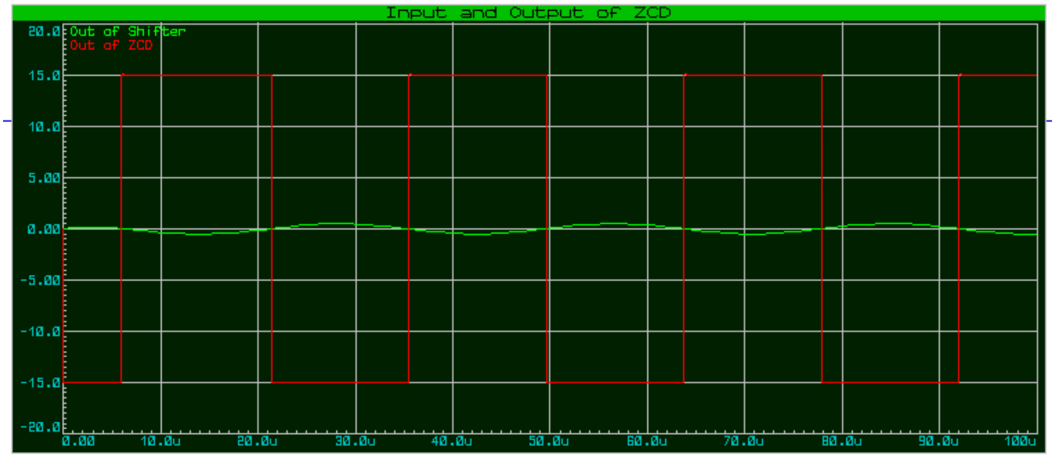



*Figure 26*

### 4.5 DISCUSSION AND CONCLUSION

In the amplifier part, the voltage level was amplificated and there were three different voltages at the output line of this amplifier. The rate of amplification was the same but output voltages were different. The reason is the differences between input levels of amplification opamp due to the no moisture 50u and 100u moisture levels. Therefore, this part also is working healthy. In the part, ZCD, all of the graphs were the same as expected. Because ZCD's working has no relation between the sensor part, it can be just affected the input signal.

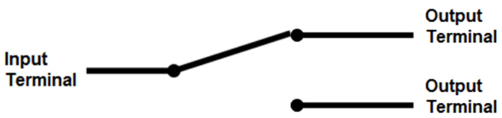
## 5. SPDT (Single Pole Double Throw Switch)

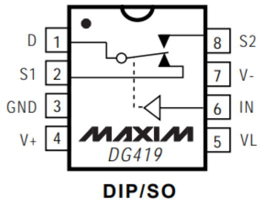
### 5.1 INTRODUCTION

SPDT part is used to separate the quadrature part from the output voltage. SPDT's function is to switch between one fixed terminal and two switchable terminals due to an input signal.

### 5.2 DESIGN PART

DG419 IC was used as SPDT switch in the project. The basic diagram of a SPDT switch and DG419's diagram switch is shown below.




| DG419 | | |
|---|---|---|
| LOGIC | SWITCH 1 | SWITCH 2 |
| 0 | ON | OFF |
| 1 | OFF | ON |

*Figure 27*

*Figure 28*

### 5.3 METHODS

The circuitry was designed in Proteus. The schematic of SPDT is shown below.

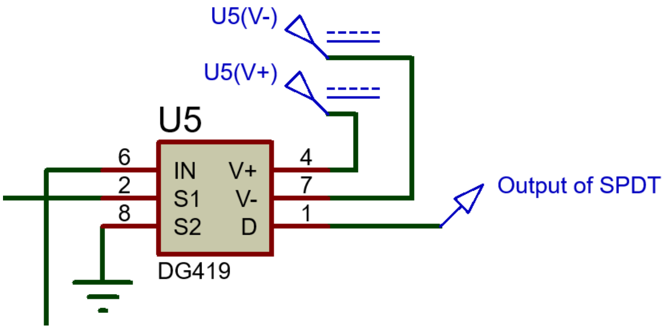



*Figure 29*

### 5.4 RESULTS

**The Output Graphs of SPDT**

**For no Moisture**

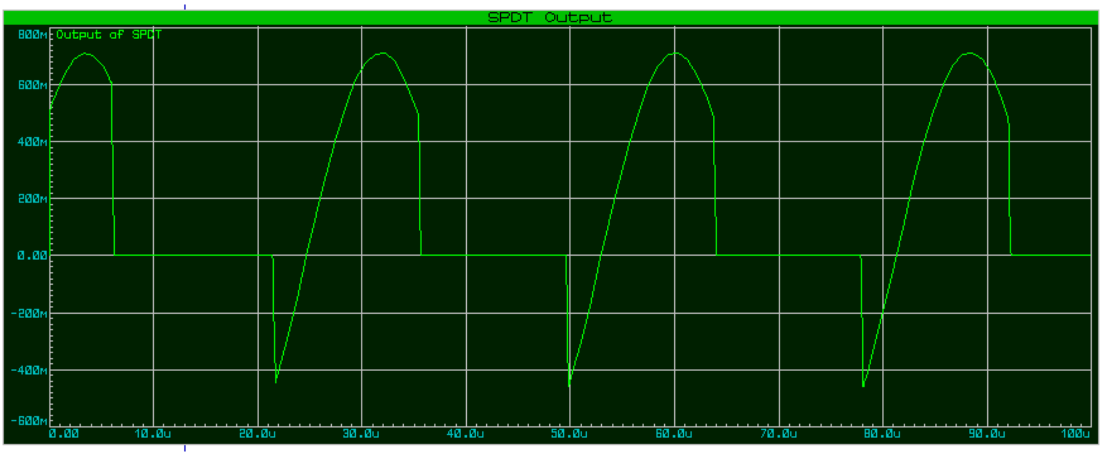



*Figure 30*

**For 50u Moisture**

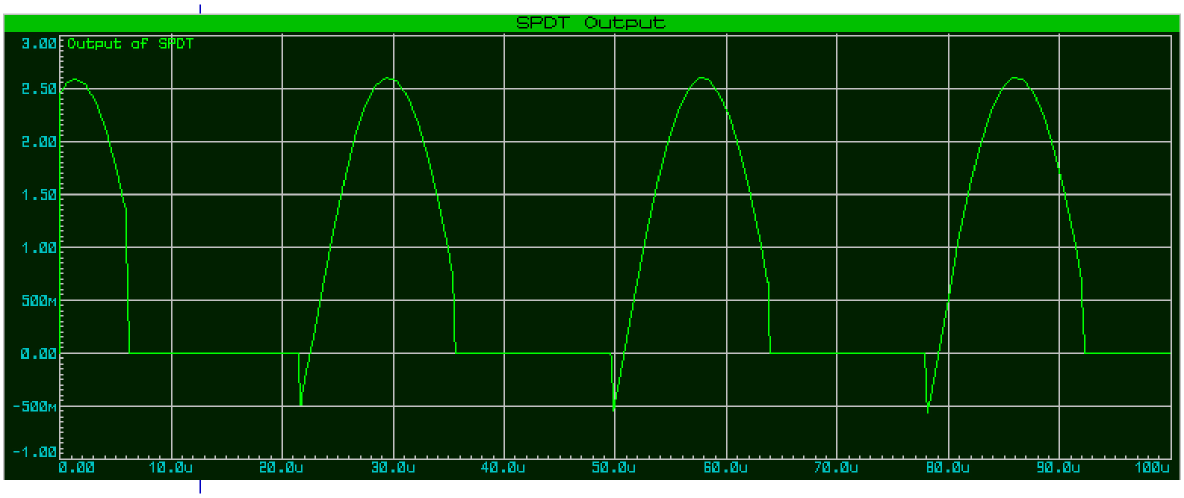



*Figure 31*

**For 100u Moisture**

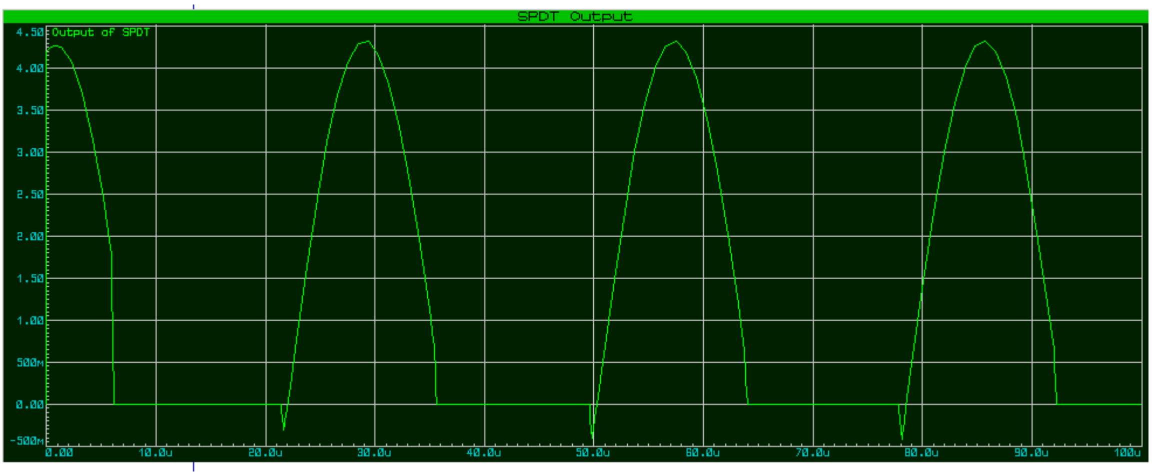



*Figure 32*

## 5.5 DISCUSSION AND CONCLUSION

In the SPDT, the three graphs have different shapes and voltage levels. The voltage levels increase with moisture levels in a positive relation. The output graphs showed the expected results.

# 6. LOW PASS FILTER PART

## 6.1 INTRODUCTION

In this part, a low pass filter that is the last part of the system was explained. Low pass filters are used for eliminate signals that have a greater frequency than the cutoff frequency. The main idea of using a low pass filter in this project is to eliminate the signals apart from the needed signal that is caused by human breath. The voltage level of the output of the low pass filter is changing due to the capacitance level of the sensor capacitor. There are there different capacitance values according to three difference cases in moisture level.

## 6.2 DESIGN PART

To design a low pass filter, following circuitry were taken as reference.

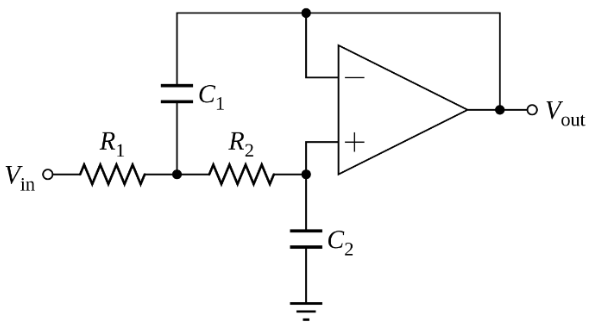



*Figure 33*

A second-order active low pass filter was designed. The main idea of using the second-order filter is to obtain a sharp voltage response at the output of the filter. The cut-off frequency was arranged to 144.68 Hz.

The cut off frequency calculation is shown below.

$$f = \frac{1}{2\pi RC} = \frac{1}{2\pi * 11 * 10^3 * 10^{-7}} = 144.68\ Hz, C: 0.1uF, R: 11k\ Ohm$$

It is arranged to this value because when the cut-off frequency is decreased, the response time increased. On the other hand, when the cut-off frequency is increased, an oscillation occurs. 500 Hz and 50 Hz cutoff frequencies cases are shown below orderly.

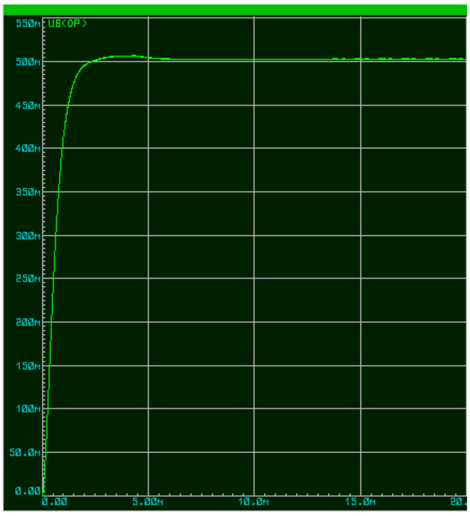


*Figure 34*

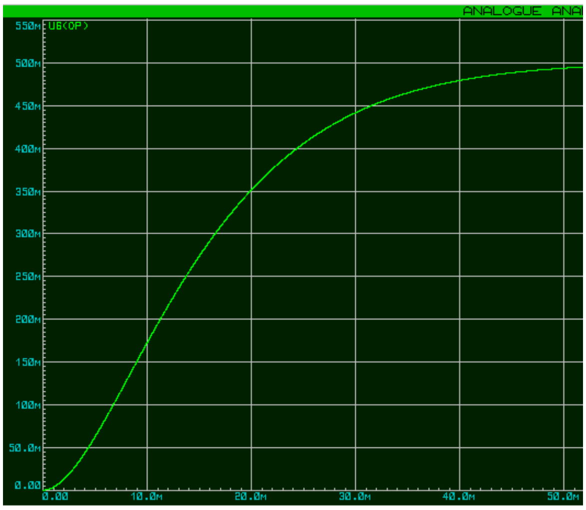


*Figure 35*

## 6.3 METHODS

To simulate the low pass filter, the circuit was designed in Proteus according to the schematic that mentioned in Design Part. The cut-off frequency is 144.68 $Hz$.

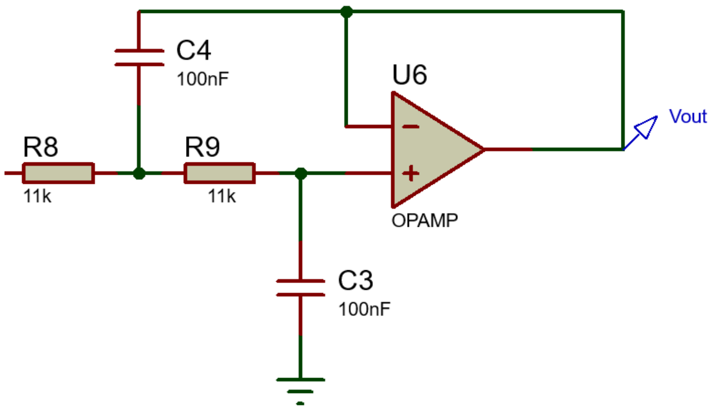



*Figure 36*

## 6.4 RESULTS

The output of the low pass filter is monitored in three cases these were no moisture, 50u moisture and 100u level moisture.

**No Moisture**

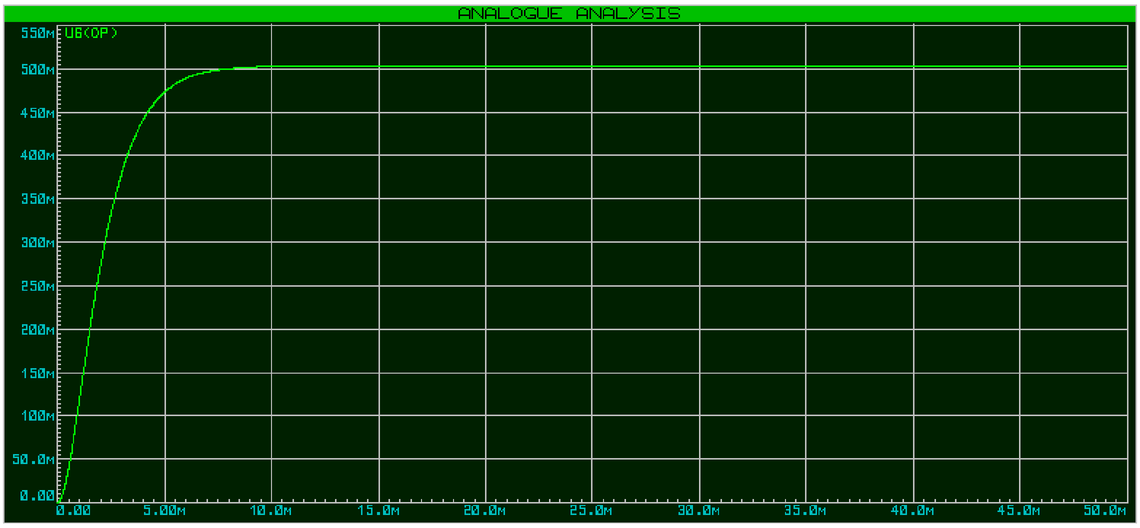



*Figure 37*

**50u Moisture**

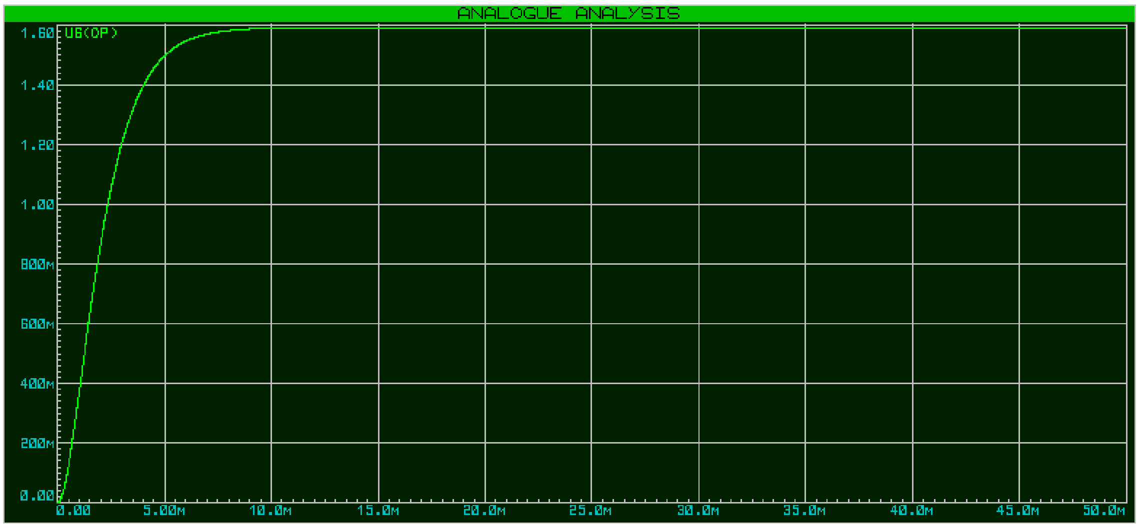



*Figure 38*

**100u Moisture**

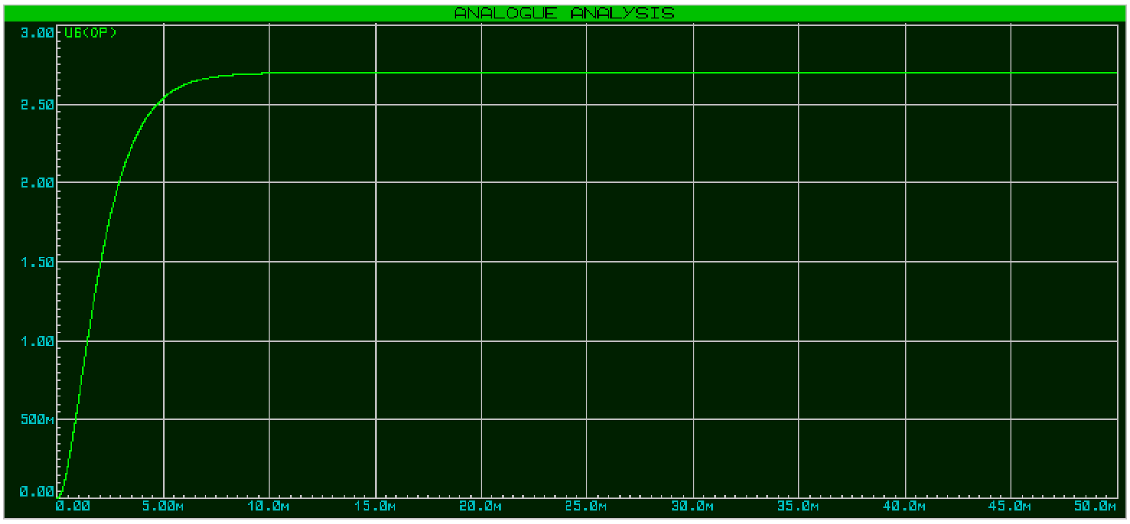



*Figure 39*

In these results, it can be said that the moisture level and the output voltage of the low pass filter have a positive relationship. When the moisture level is increasing, the output voltage increases. The voltage differences between the three cases show that the system is working sufficiently and these voltage levels can be read by an ADC (analog to digital converter).

## 6.6 DISCUSSION

The results show that the low pass filter is working and giving expected results. The ideal opamp can be replaced with LM358 in Proteus. Also, to reduce energy consumption and cost, an active filter circuit can be replaced with a passive circuit, but the sharpness of the output signal will be decreased in this way. Another important point is the amplification of the opamp. If amplification was needed and resistors were added to the low pass filter circuit, the output signal oscillated significantly. However, if amplification is made in the previous Amplification Part in the whole project, there is no oscillation observed. That’s why all of the amplification process was made in the Amplification Part.

### 6.7 CONCLUSION

In this part of the project, a low pass filter was designed in Proteus, due to the second order active low pass filter circuitry. With the using low pass filter at the end of the whole project circuitry, three clear non-noisy signals were obtained. Also, these outputs can be connected to an ADC and evaluated easily.

## III. THE GENERAL OUTPUTS OF THE WHOLE SYSTEM

In this section, the three different capacitor values were tested with three different Rx values which are 100k, 1M and 10M ohm. These graphs showed that if moisture level is increase, the differences of outputs of circuitry that has 100k, 1M and 10k Rx are more smaller.

### 1. No Moisture

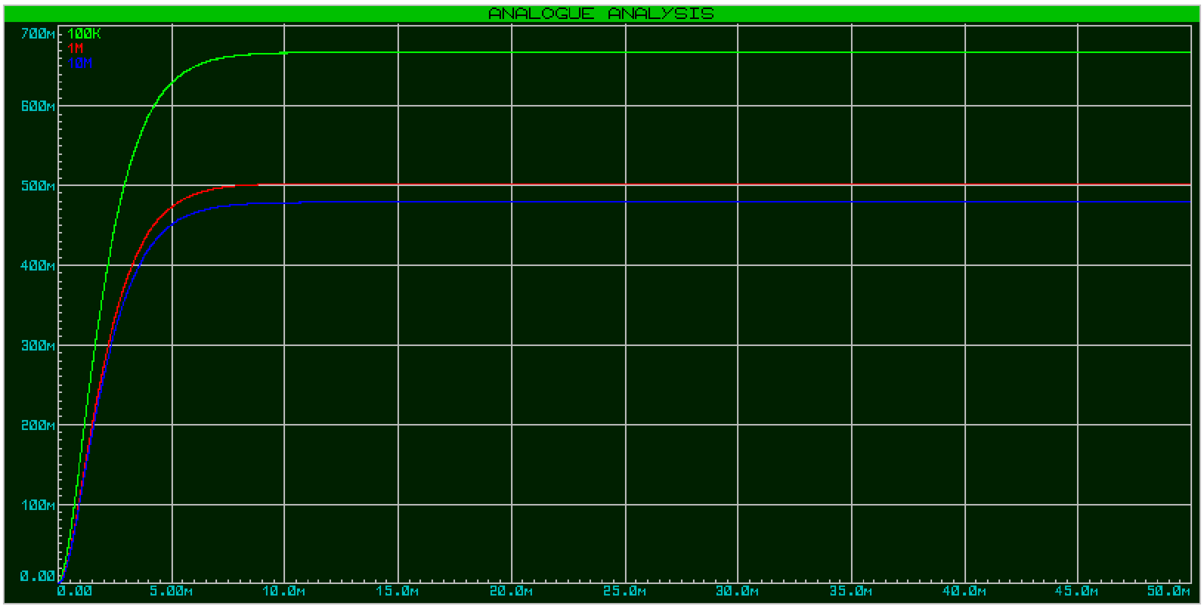



*Figure 40*

### 2. 50u Moisture Level

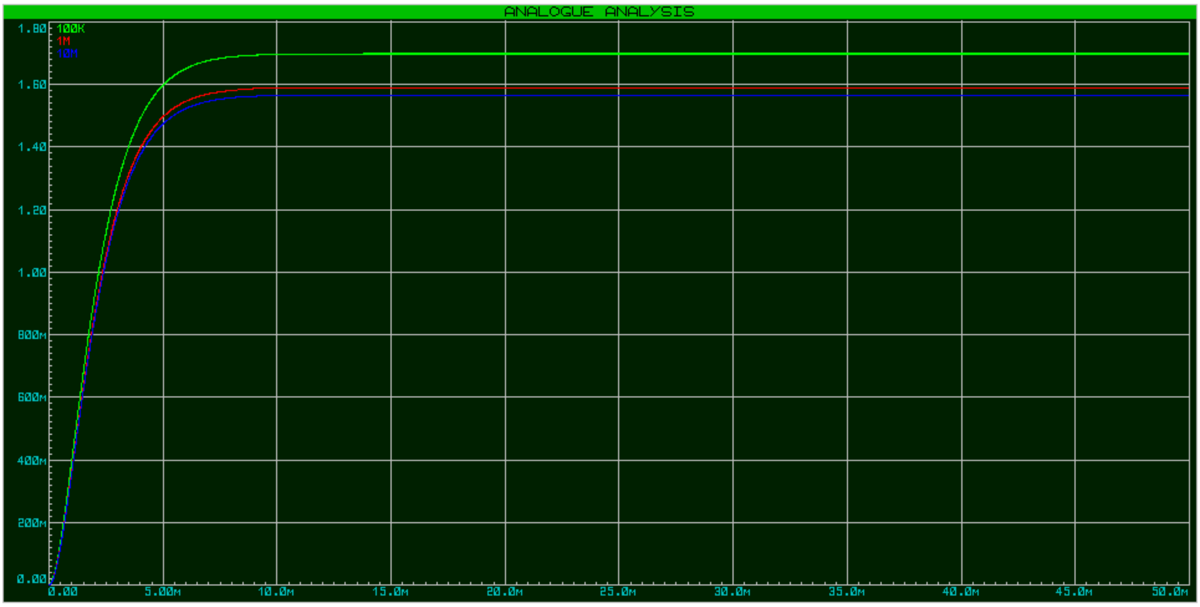



*Figure 41*

### 3. 100u Moisture Level

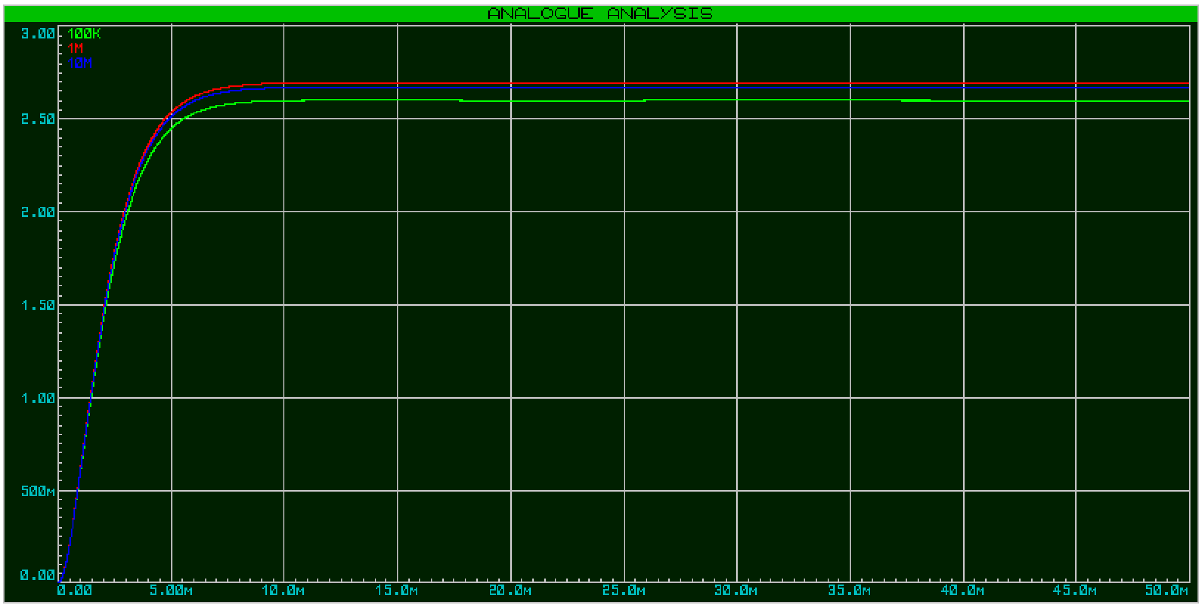



*Figure 42*

## IV. SENSITIVITY, LINEARITY, MAXIMUM AND MINIMUM RANGE OF THE SENSOR

0, 50um and 100um moisture levels are compared due to the EEE department's commands. Three different moisture levels' voltage values are shown in the graph below.

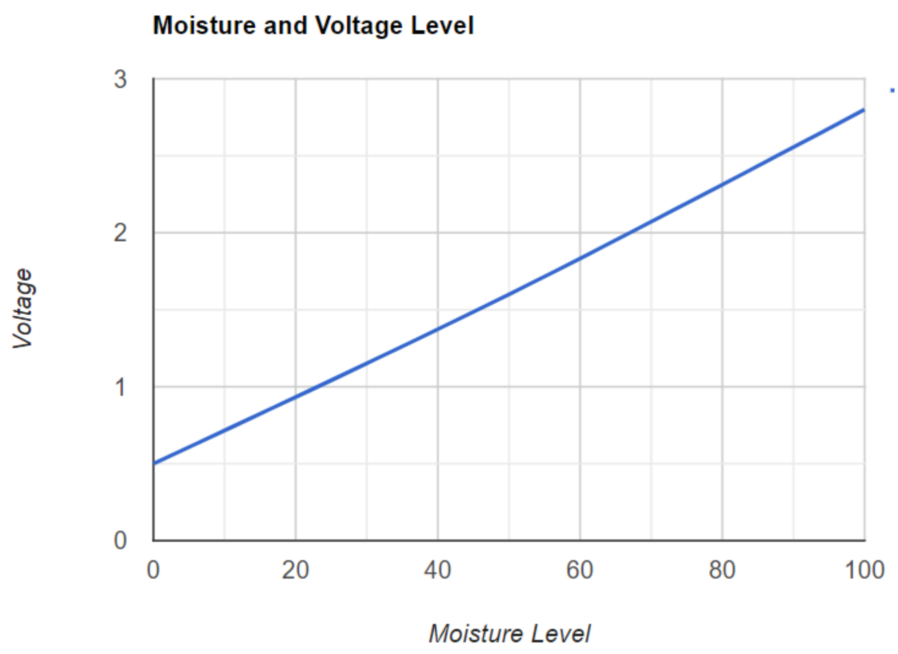



*Figure 43*

### Sensitivity

The sensitivity is equal to the slope of the graph above. The sensivity is : 2.3V/100um = 0.023V/um.

### Linearity

The sensor gives a linear behavior in 0-100um moisture level interval. It can be used in this interval.

### Maximum and Minimum Range

To detect the maximum and minimum values that the sensor can measure correctly, the sensor should be tested with different moisture levels.

## V. CONCLUSION

From the starting point of the circuitry to signal output of the circuitry, the signal was processed and gives different outputs according to the changing of capacitance due to the moisture level. The output voltage levels showed that the sensor is working 0-100um moisture level very well. To detect out of this range, it should be tested with different moisture levels.

## VI. REFERENCES

[1] Malik, S., Ahmad, M., Punjiya, M., Sadeqi, A., Baghini, M. S., & Sonkusale, S. (2018). Respiration Monitoring Using a Flexible Paper-Based Capacitive Sensor. 2018 Ieee Sensors. doi:10.1109/icsens.2018.8589558

[2] http://sim.okawa-denshi.jp/en/CRtool.php

[3] https://www.electronics-tutorials.ws/filter/second-order-filters.html

[4] https://commons.wikimedia.org/wiki/File:Second_order_low_pass_filter.svg

https://www.electronics-tutorials.ws/opamp/opamp_8.html

[5] https://www.miwv.com/spdt-switch

[6] https://www.elprocus.com/zero-crossing-detector-circuit-and-working/

[7] https://datasheets.maximintegrated.com/en/ds/DG417-DG419.pdf

[8] http://electronics-course.com/current-voltage-converter