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Assistant :Mehmet Çetinkaya

Date :28.12.2019
Group : Monday Afternoon

MIDDLE EAST TECHNICAL UNIVERSITY

Department of Electrical and Electronics Engineering

EE213 ELECTRICAL CIRCUITS LABORATORY

SOUND LEVEL DETECTOR

Final Report

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EE213 Final Report

Abstract

In this project, our goal is to design a sound level detector circuit that contains pulse width modulation circuit to adjust the duty cycle of signals with respect to environmental sound level and displays those different duty cycle by a LED. Our circuit design generally consists of 3 units. The first unit, the input unit, consists of a microphone circuit that converts environmental sounds to our input voltage. The decision unit, which is the second unit, consists of a circuit which produces PWM signals according to the 4 different sound levels requested from us by evaluating the received input. The output unit, which is the last unit, consists of a LED circuit that flashes according to the PWM signals produced and shows us the sound level.

In this report, we will examine our project mentioned above in detail and make comparisons on simulation and setup results. Also, we will share the formulations used to determine the resistance and capacitance value of the circuit. And lastly, we will analyze the power consumption of the circuit and cost of the circuit.

Introduction

In both everyday life and work life, sound level is an inevitable factor that effect many decisions or activities. When you pick your new house or office, when you try to take a nap or try to compose the next piece of your album, environmental sound level matters. Hence, measuring the sound level of an environment becomes more vital. Thus, our purpose of this project is to come up with a simple circuit design such that displays the sound level of the environment in a simple manner. This circuit should get the sound level of the environment as an input by a microphone. Afterwards, it should decide the level of the sound and display it. The decision results should be simple. So why not pick 4 sound levels as an output of the decision unit such that no sound, low sound level, moderate sound level, high sound level. Also, the display can be done with a wide range of ways, of course. But since we are interested in simplicity, we will display the sound levels with a LED. Brightness of the LED would not be clear to understand the sound level, so we ought to use another method. If the decision unit gives the 4 distinct outputs as time intervals, then sound level of the environment can be understood easily. For example, if the LED is on longer than it is off in a second, we can understand that the sound level is high. Similarly, if the LED is off longer than it is on in a second, we can understand that the sound level is low. And if the LED is on half of a second and off in the other half or off all the time, we can say that sound level of the environment is moderate, or no sound is present respectively. Taking these in consideration, we constructed a circuit demonstrates the sound level of the environment. The display method mentioned above is called pulse width modulation, i.e. PWM. PWM is a way to control analog devices with a digital output. It represents amplitudes with percentage width of pulses. These percentages are called duty cycles and it is used in many fields of engineering. A typical example of a PWM and its duty cycle is given in Figure 1.

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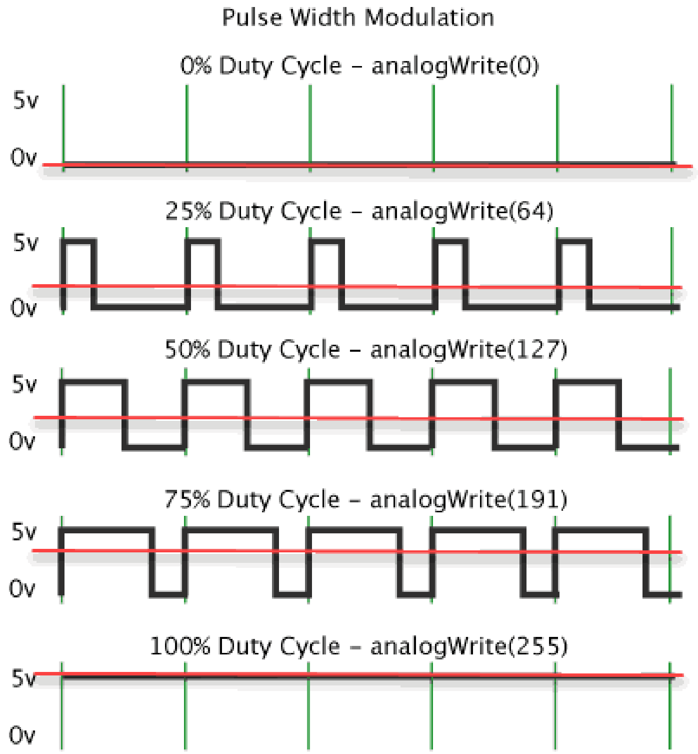

Figure 1: An example of PWM and its duty cycle between 0 and 255

Description of Circuit Operation

The purpose is to demonstrate the environmental sound level by the help of a LED according to 4 sound levels requested. As a result of our research, we decided to use an electret microphone and driver circuit as input unit. With this circuit, we aimed to receive environmental sounds as input. But since the voltage difference produced by input unit is very low, we decided to amplify it using op-amps. In the decision unit, we created a comparator system by using op-amps and obtained a new output according to the sound level. In order to convert the resulting output to PWM signals, we compared the output with a triangular wave obtained from the triangular signal generator using a comparator opamp. In the last unit there is a LED which will blink according to the PWM signals we have obtained and a resistor to keep the LED from burning because of the high voltage. The whole schematics of the circuit is illustrated in Figure 2. Also, the real-life version of the overall circuit is given in Figure 3.

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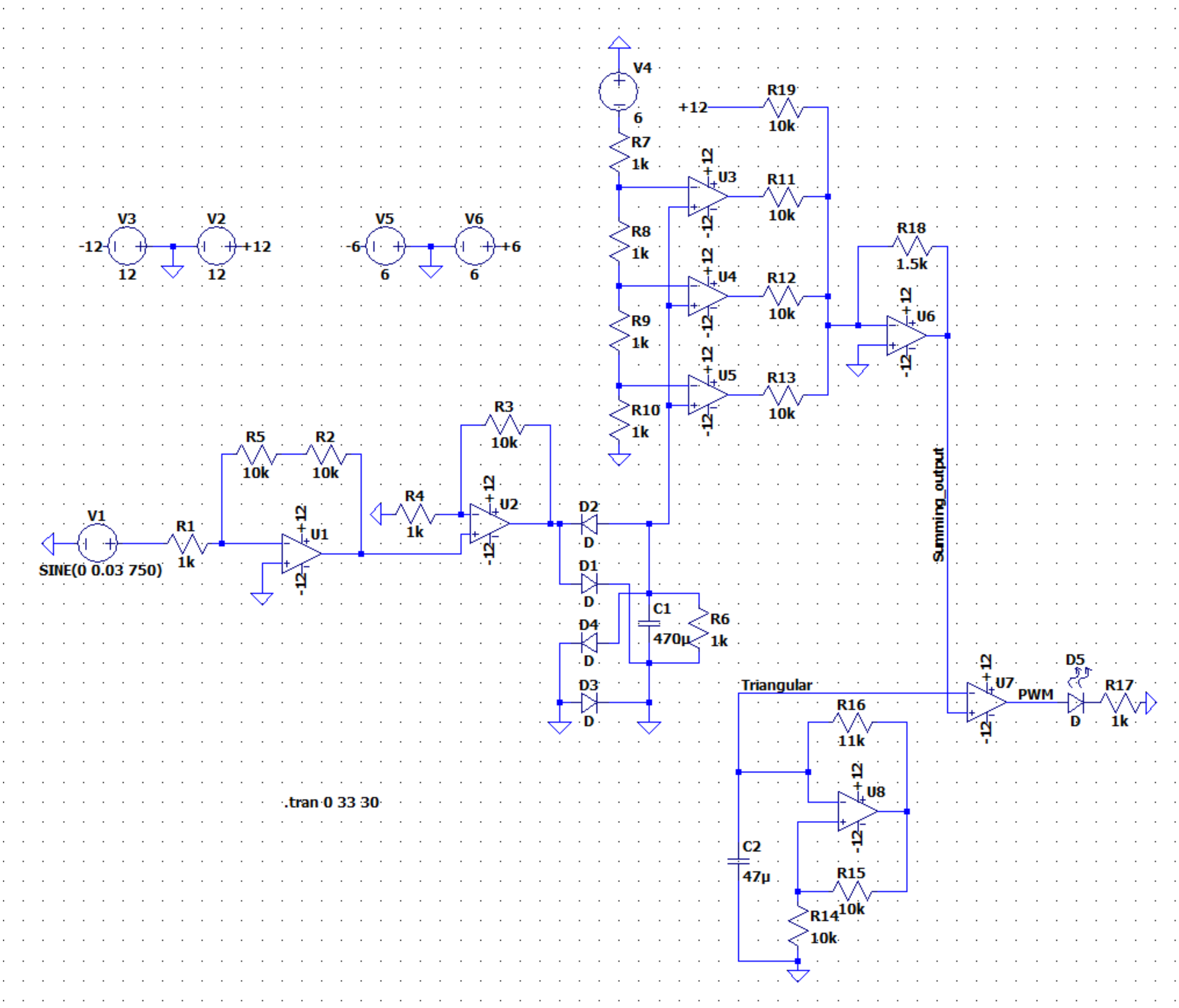

Figure 2: Overall Circuit Design (We used an AC voltage source instead of microphone in simulation)

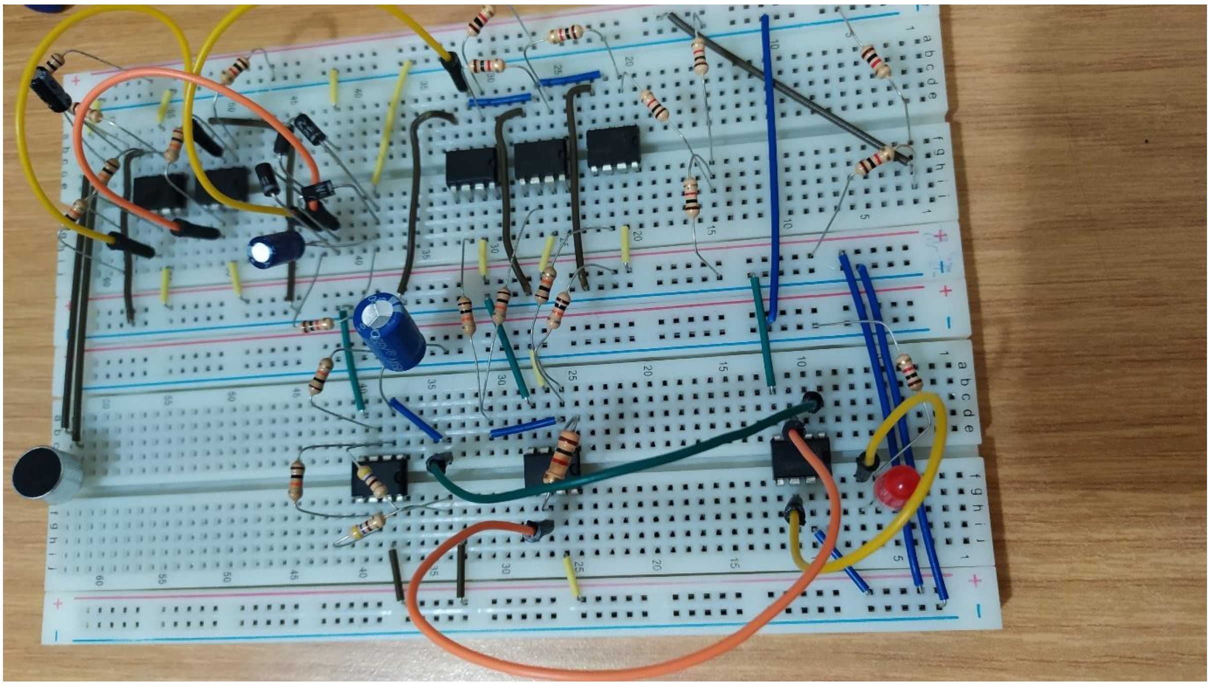

Figure 3: Our Project on Breadboard

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In this part, we will examine our project mentioned above in detail.

Input Unit

a) Electret Microphone Circuit

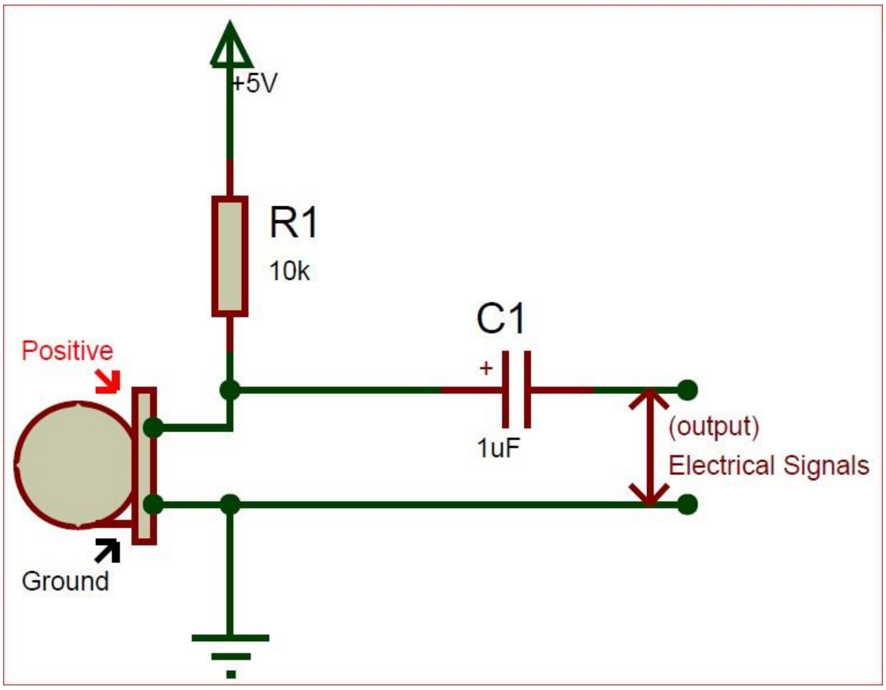

Figure 4: Microphone Circuit

Since we can only use analog components, we decided to use an electret microphone to detect environmental sounds as our input. An electret microphone is a type of electrostatic capacitor-based microphone. Here, we fed the microphone with 6V DC source to charge the capacitor-based microphone, so that it can produce voltage differences according to sound level changes. Also, we measured some offset voltage value from pure microphone. To avoid this offset voltage of the microphone, we used a drive circuit constructed by a resistor and a capacitor as given in Figure 4. We picked the resistor and the capacitor values as suggested by the manufacturer. Since microphone is not included in the LTspice program which we used for the simulation, we replaced the microphone circuit with an AC voltage source when creating the overall circuit block diagram.

Decision Unit

b) Two Stage Amplifier Circuit

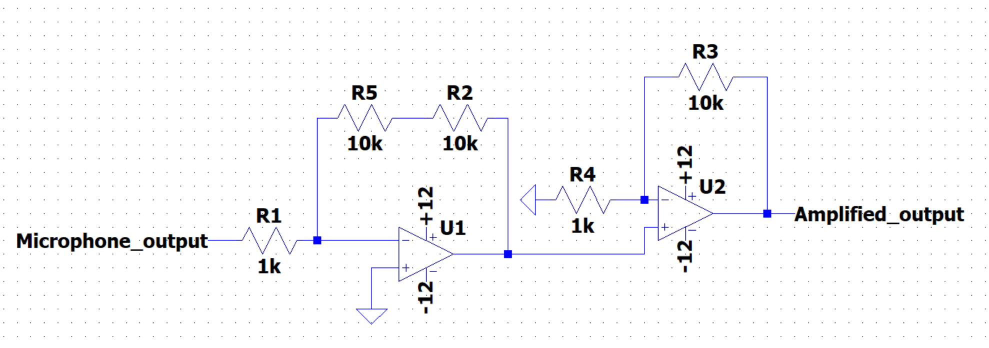

Figure 5: Two Stage Amplifier Circuit

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Since the voltage obtained from the microphone is not enough to observe, we used a two-stage amplifier system which is consists of a non-inverting and an inverting amplifier to increase the voltage. Since it is not possible to achieve 220 times gain at a time using op-amp in real life, we decided to amplify it in two steps. The schematic representation of this subcircuit is given in Figure 5. In order to make a comparison with -6 volts in the comparator circuit which is the other part of our circuit, and according to our research and observations, we have increased the maximum voltage value to about -6 volts by increasing the voltage by around -220 times since the maximum voltage obtained from the microphone is approximately 0.03 volts.

c) Full-Wave Rectifier

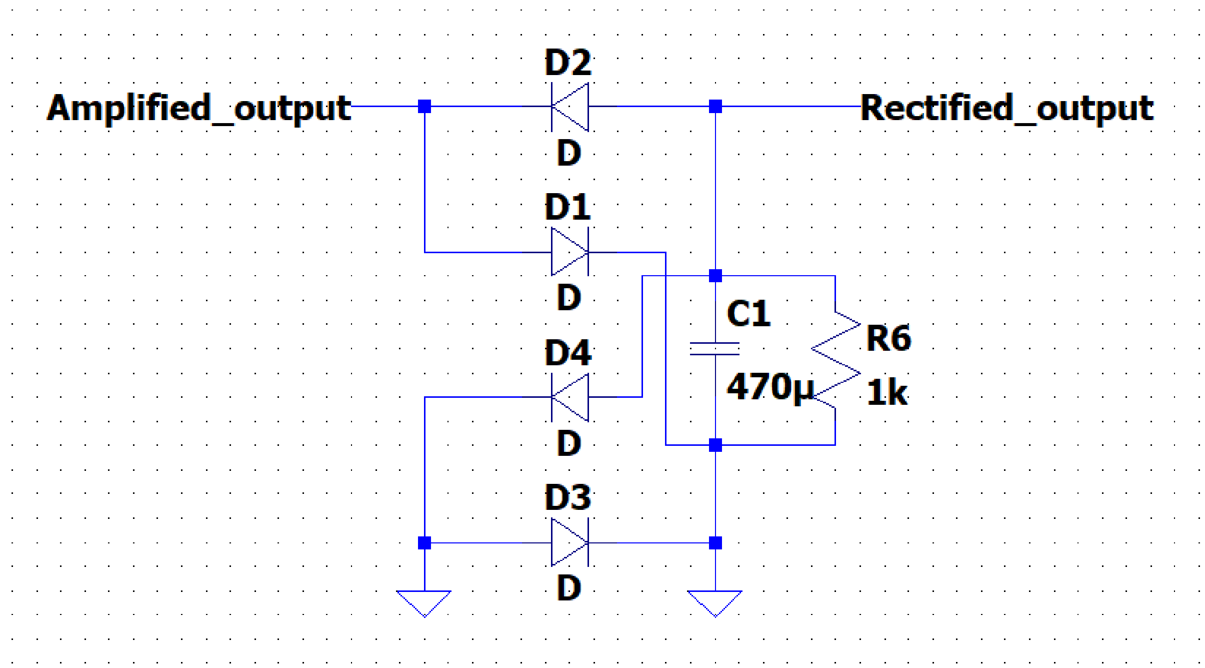

Figure 6: Full Wave Rectifier Circuit

In order to make a comparison with a DC source in the comparator circuit, we converted the voltage value in Amplified_output of Figure 6 to DC by connecting it to the full wave rectifier. This rectifier subcircuit is given in Figure 6.

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d) Comparators and Summing Amplifier

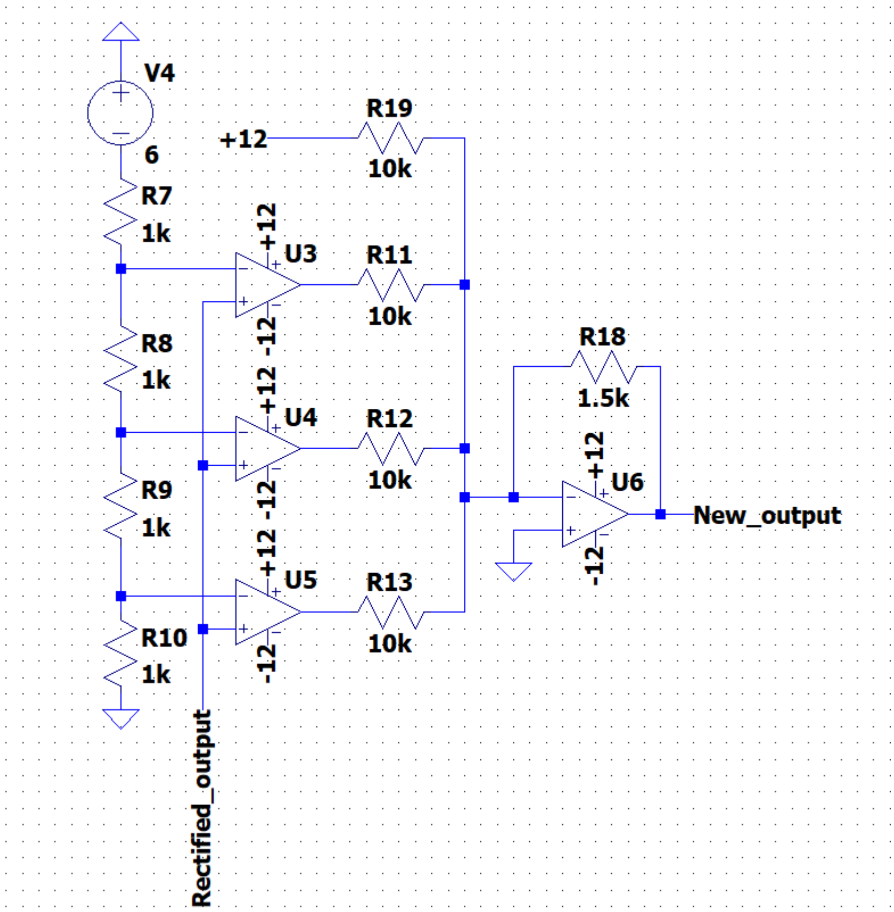

Figure 7: Comparator and Summing Amplifier Circuits

Since the PWM signal is requested according to 4 different sound levels, before the PWM signal is generated, we have compared our DC voltage value of rectified output with 3 different voltage values. Then, we summed the outputs of the comparators using summing amplifier to obtain 4 different voltage levels (with 0 level). Since our rectified output has a negative value, we made a comparison with the negative DC voltage value in the comparator system. The subcircuit described above is illustrated in Figure 7.

When the rectified output value is in the range of negative 3 – negative 4.5 volts, output from the summing amplifier must be zero in order to achieve a 50% duty cycle. So, we connected a 12 volts DC voltage source to the summing amplifier as fourth source. In this way, we had the opportunity to obtain the duty cycles (%0, %20, %50, %80).

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e) Triangular Waveform Generator

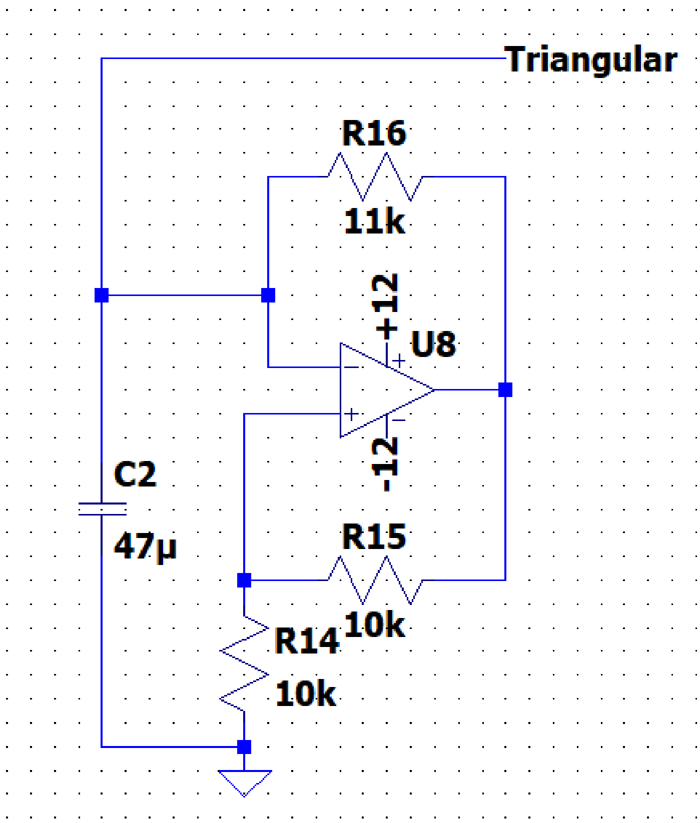

Figure 8: Triangular waveform generator

The circuit schematics used for generating triangular waveform is given in Figure 8.This subcircuit is a negative resistive converter to produce a triangular wave for PWM. As we know from experiment 6 part 3, a triangular wave can be obtained by connecting a capacitor to a negative resistive converter. The final circuit is often called astable multivibrator. This opamp circuit consists of a positive feedback, therefore V_+ is equal to $\pm V_{sat}.R14/(R14+R15)$. For simplicity, we will assign $B=R14/(R14+R15)$. Assume that at time t=0, the capacitor has no initial charge and V_{out} is equal to $+V_{sat}$. Then, current flows on R16 and charges the capacitor. Since $V_-=V_c$ and $V_+=B.V_{sat}$ $V_+>V_-$ for $V_{out}=+V_{sat}$. When the capacitor voltage exceeds $B.V_{sat}$, i.e. $V_->V_+$, V_{out} becomes $-V_{sat}$ and the capacitor discharges on R16. At discharging time interval, V_+ is equal to $-B.V_{sat}$. Therefore, the capacitor discharges until $V_c=-B.V_{sat}$. When V_c exceeds this limit, i.e. $V_+>V_-$, V_{out} becomes V_{sat} and so on. This charging and discharging cycle produce a triangular waveform on V_- and a square waveform on V_{out}. The triangular waveform is enough for our purposes therefore we use it in PWM production.

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e) PWM Generator

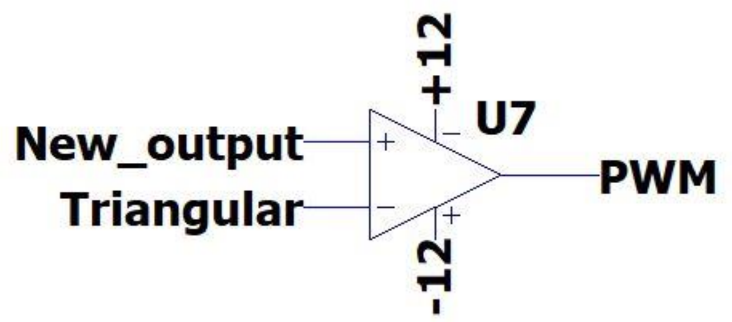


Figure 9: Comparator as a PWM generator

The final subcircuit of the decision unit is given in the Figure 9. This subcircuit is a simple comparator. Triangular waveform and DC voltage from part d was compared using a comparator. The comparator gives an output of $+V_{sat}$ when $V_+>V_-$ and $-V_{sat}$ when $V_->V_+$. So, to get a PWM as output, a triangular wave is connected to inverting input of the comparator opamp and a DC voltage to noninverting input of the comparator opamp. Resulting voltage is a PWM signal. The duty cycle of the PWM is decided by the DC voltage connected to noninverting input of the opamp with respect to the triangular waveform connected to inverting input. In this case, triangular waveform is between -6V and 6V. When the DC voltage is lower than -6V, then $V_->V_+$ all the time and $V_{out}=-V_{sat}$ all the time. This case is PWM with %0 duty cycle. When the DC voltage is higher than -6V but lower than 0V, then $V_->V_+$ most of the time and $V_{out}=-V_{sat}$ most of the time. If this DC voltage is happens to be -3V, this case is PWM with %25 duty cycle. When the DC voltage is exactly 0V, then $V_->V_+$ is exactly half of the period, therefore $V_{out}=-V_{sat}$ for the half of the period and $V_{out}=V_{sat}$ for the other half of the period. This case is PWM with %50 duty cycle. And lastly when the DC voltage is higher than 0V but lower than 6V, then $V_+>V_-$ most of the time and $V_{out}=V_{sat}$ most of the time. If this DC voltage is 3V, the resulting output is PWM with %75 duty cycle. The main calculation made to figure out the duty cycle is the following.

$$Duty\ cycle = \frac{\mathrm{Vdc} - \mathrm{Vlow}}{\mathrm{Vhigh\text{-}Vlow}}.\%100 \quad (1)$$

Display Unit

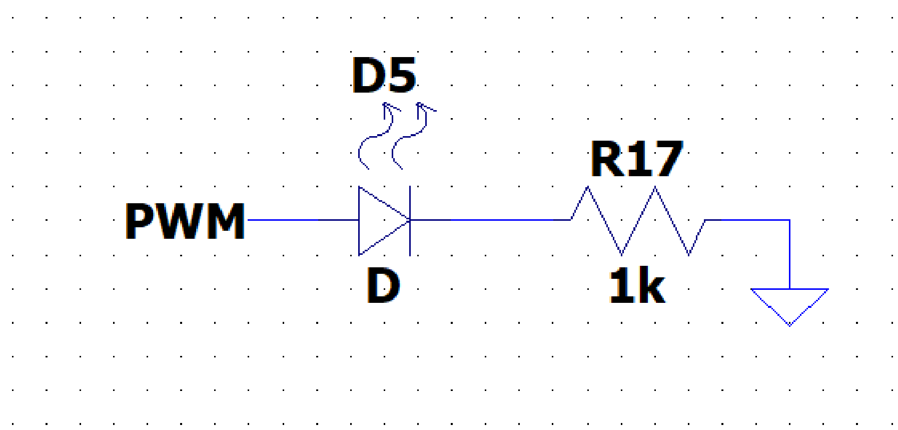
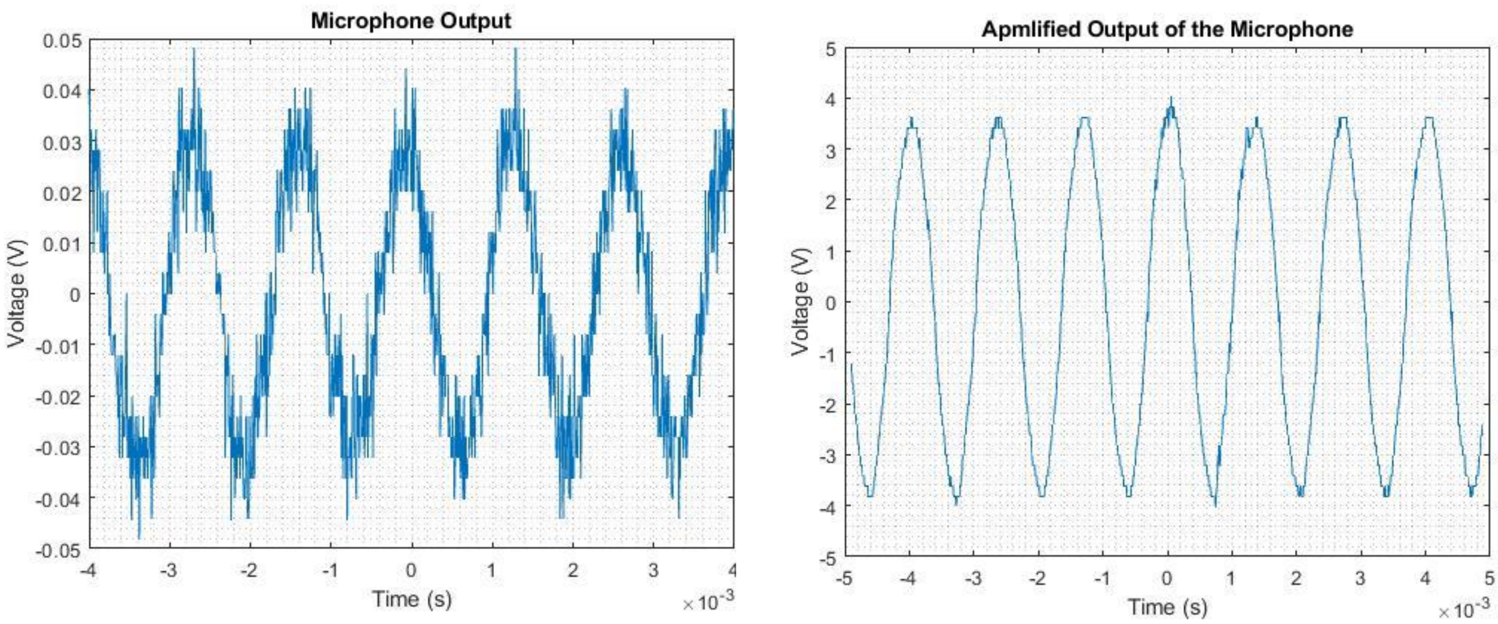


Figure 10: A LED and a Resistor as the Display Unit

By connecting a LED and a resistor to the output of the comparator in part e of decision unit, all the required specimens for the project are satisfied. LED blinks same as the duty cycle of the resulting PWM. The resistance value of the resistor is picked high enough to protect the LED from burning due to the high currents.

Simulation and Setup Results

Microphone Output and Amplified Output



Figures 11: Setup Results of microphone output and amplified output

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Triangular Signal Generator

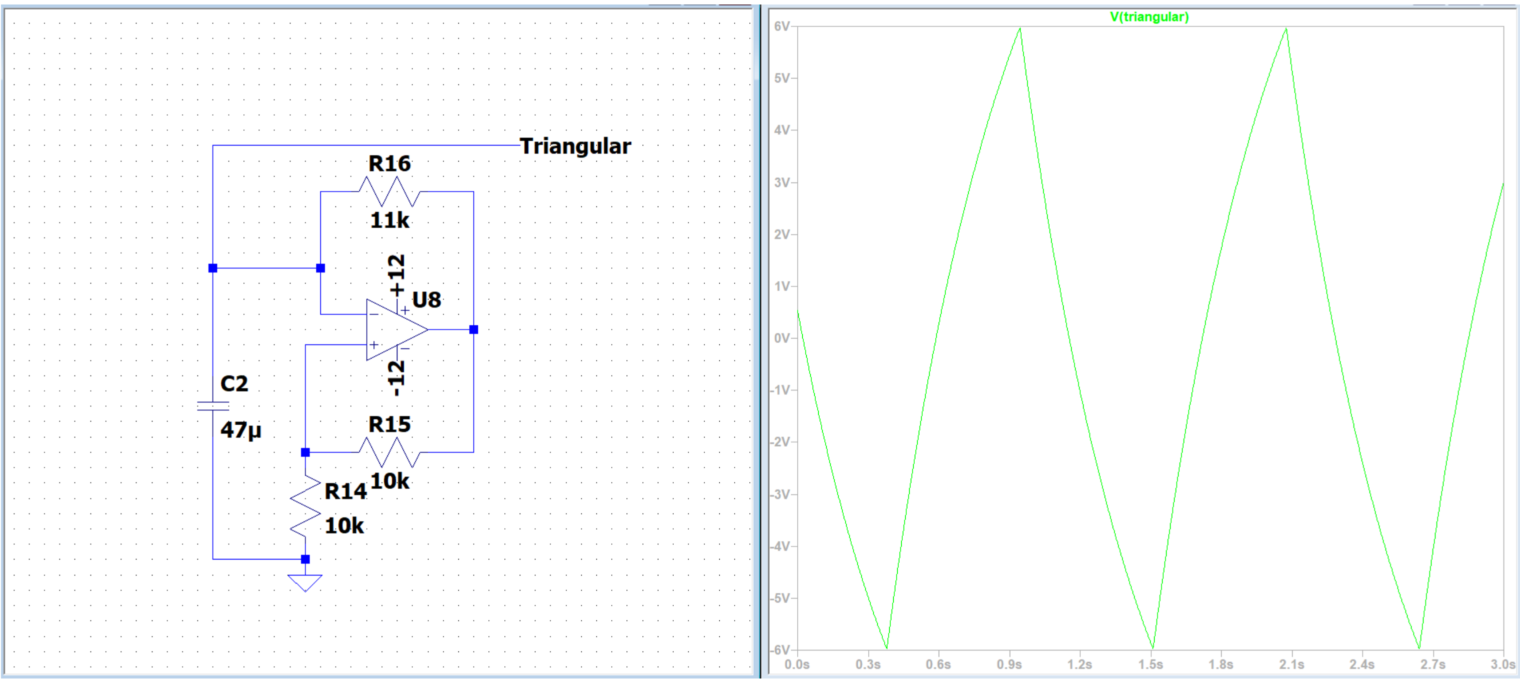

Figure 12:Simulation result of triangular signal generator

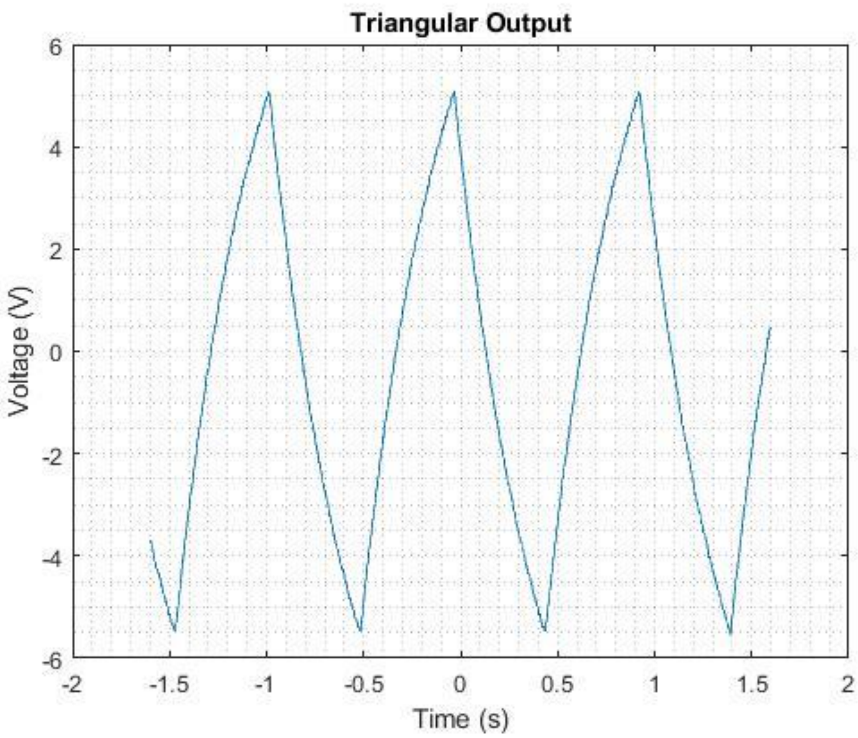

Figure 13: Setup result of triangular signal generator

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%0 Duty Cycle Case

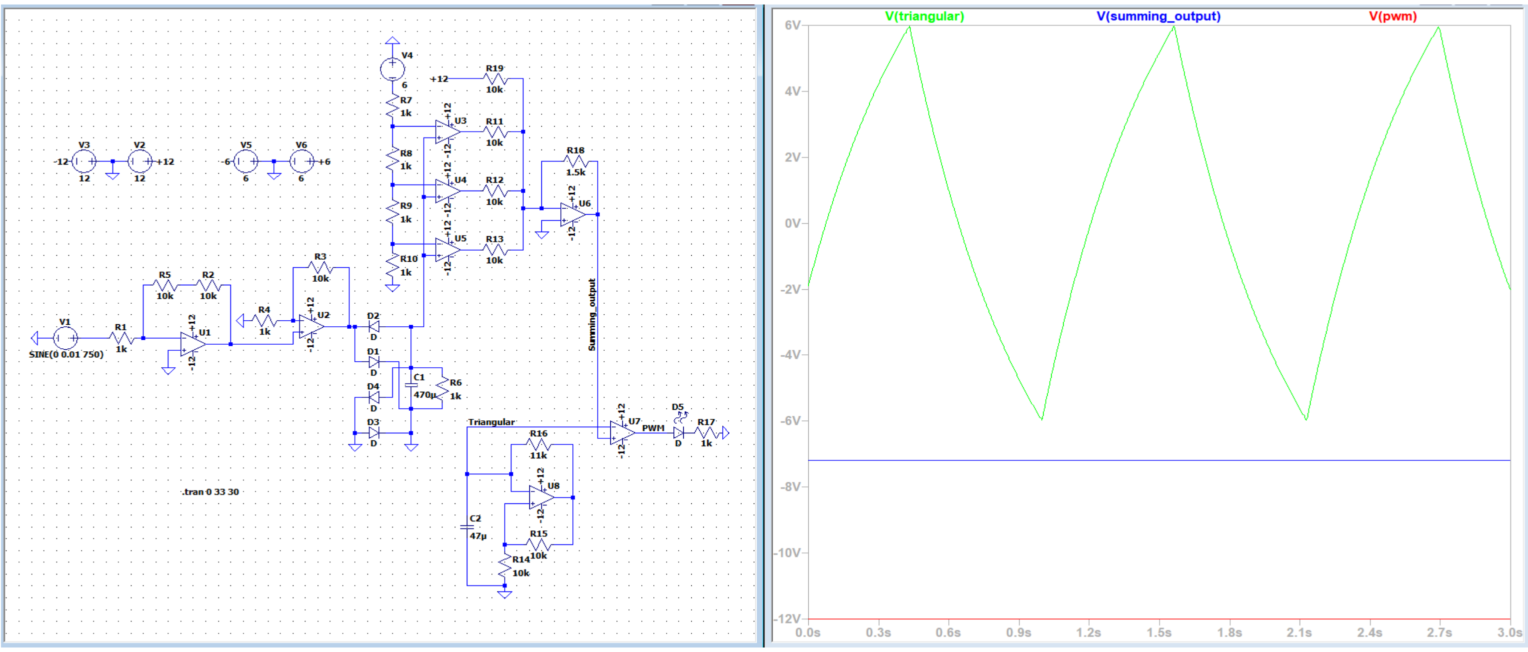

Figure 14: Simulation result for %0 duty cycle

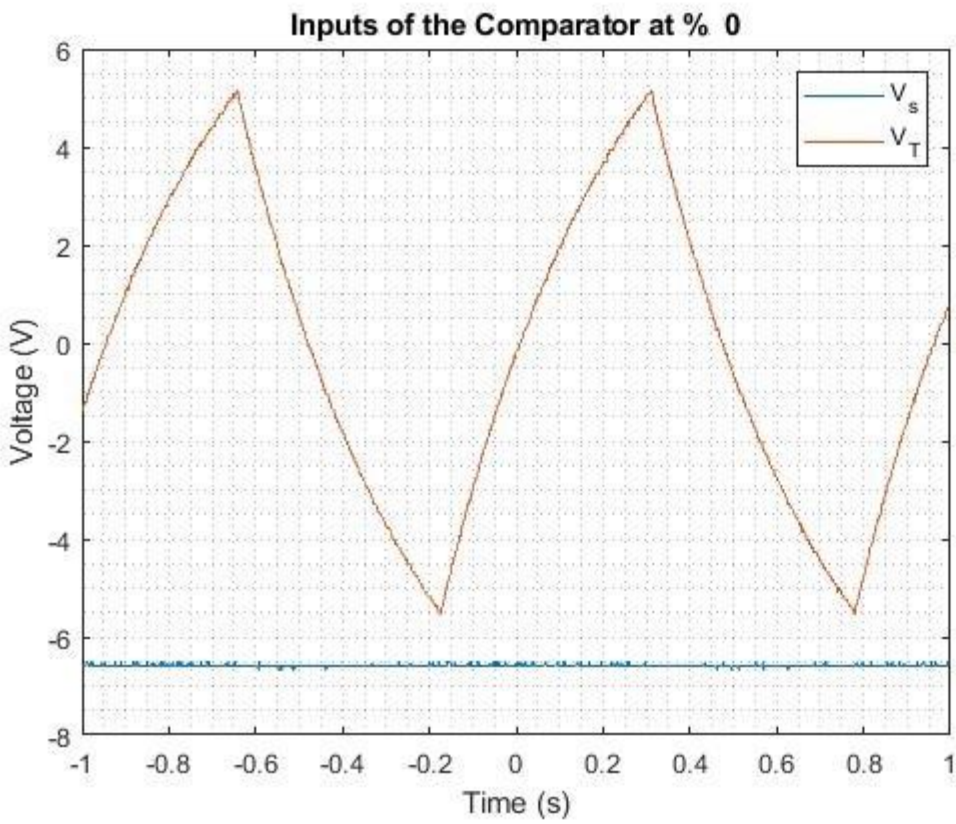

Figure 15: Setup result for %0 duty cycle

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%20 Duty Cycle Case

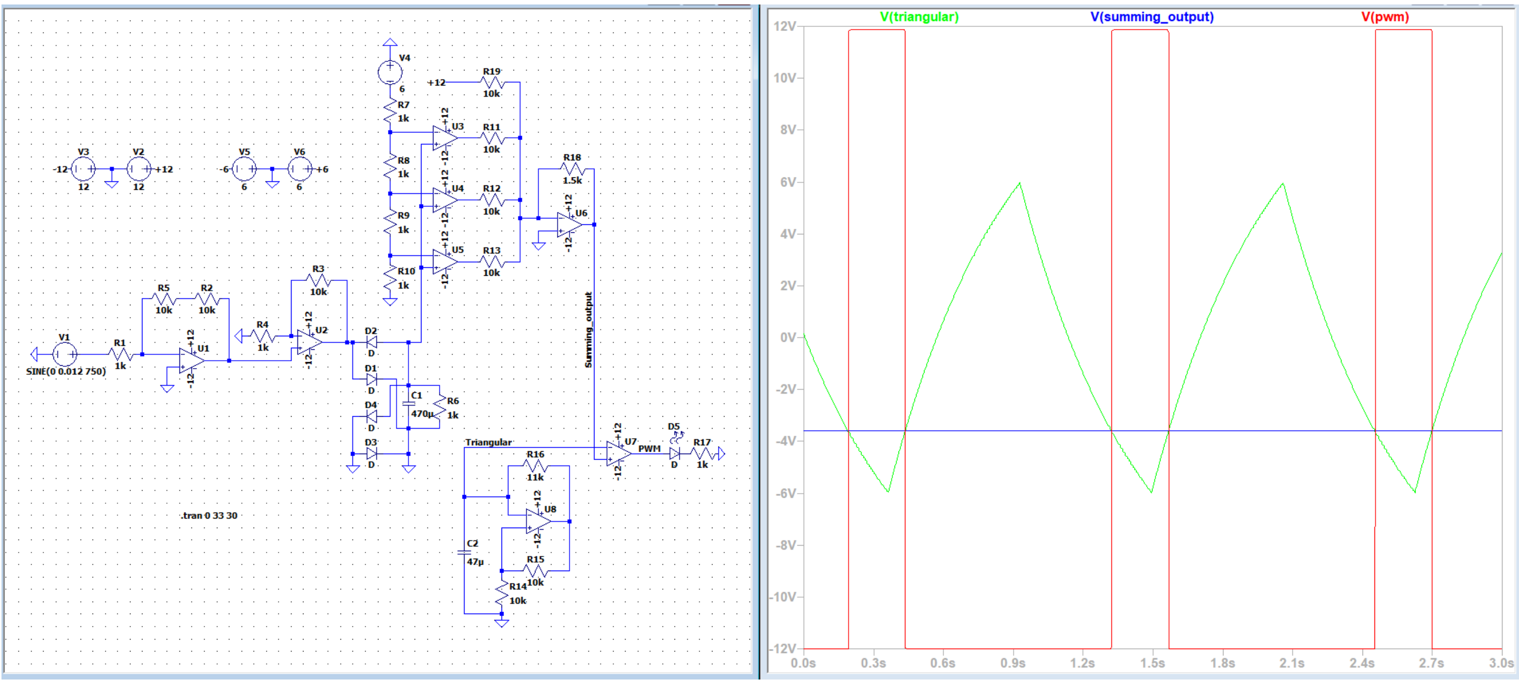
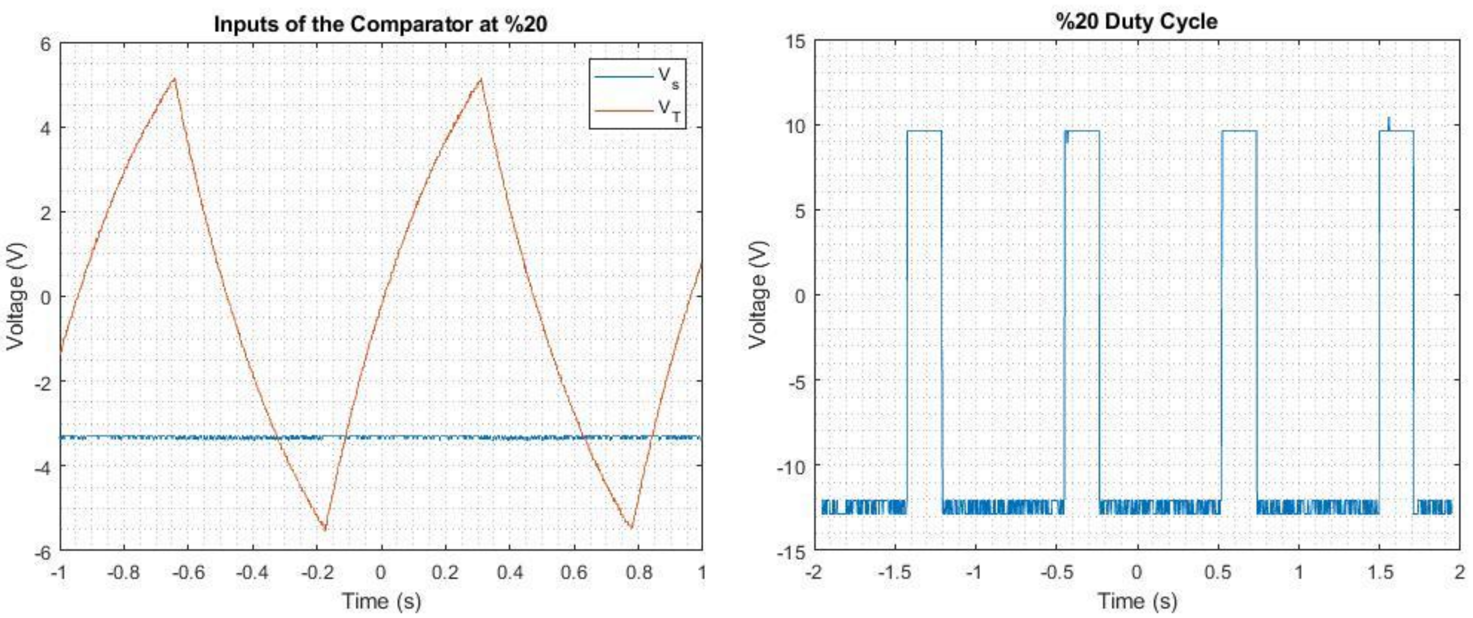


Figure 16: Simulation result for %20 duty cycle



Figures 17: Setup results for %20 duty cycle

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%50 Duty Cycle Case

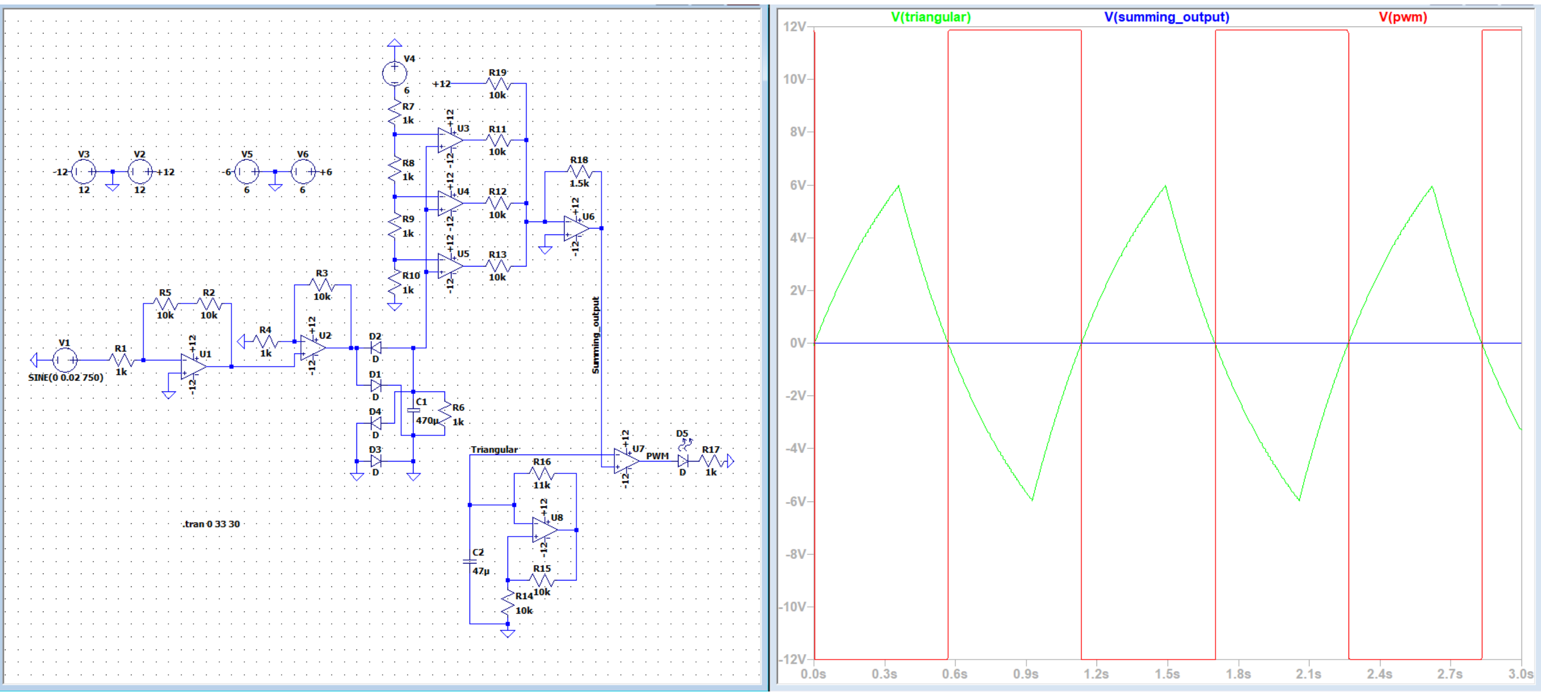
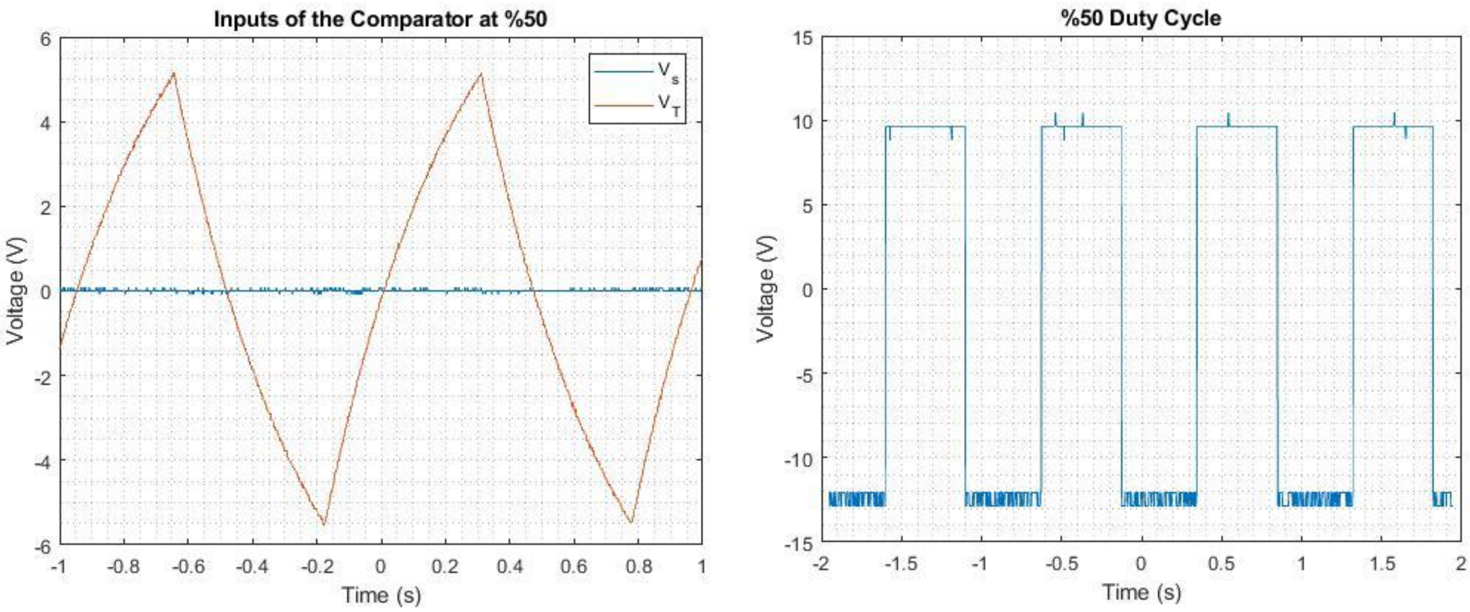


Figure 18: Simulation result for %50 duty cycle



Figures 19: Setup results for %50 duty cycle

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%80 Duty Cycle Case

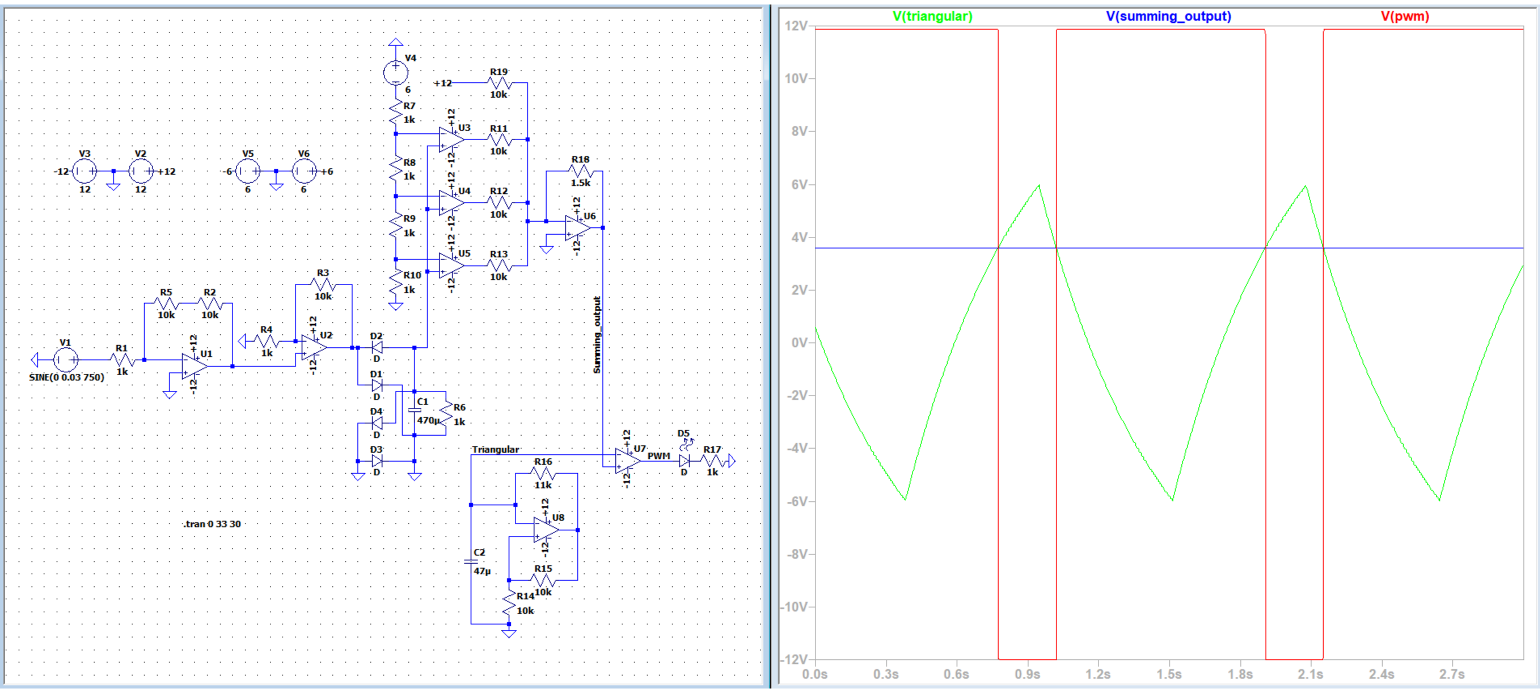
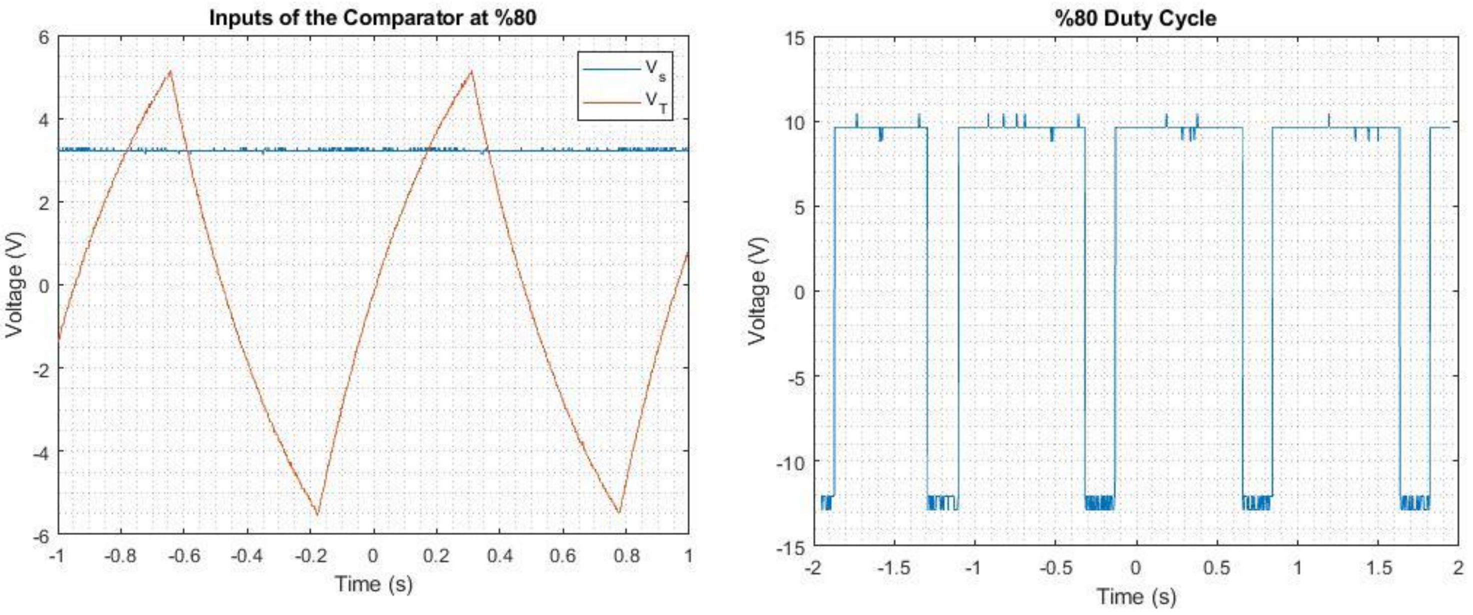


Figure 20: Simulation result for %80 duty cycle



Figures 21: Setup results for %80 duty cycle

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Design Formulations

Two-stage amplifier

In the calculations we will assume that both opamps are in linear region and ideal. Since the noninverting terminal of the first opamp (U1) is grounded and the opamp is in the linear region, inverting terminal of the first opamp would be a virtual ground. No current flows through the input terminals of the opamp, therefore all the current passing on R1, also passes through R2 and R5. Similarly, no current flows through the input terminals of the second opamp (U2), therefore current passing through R4 also passes through R3. Using node analysis, we get these equations:

$$\frac{Vmic - 0}{R1} = \frac{0 - V1out}{R2 + R5} \quad (1)$$

$$\frac{0 - V1out}{R4} = \frac{V1out - V2out}{R3} \quad (2)$$

$$R1 = R4 = 1k\Omega$$
$$R2 = R3 = R5 = 10k\Omega$$

From equation (1), we get

$$Vmic = \frac{-V1out}{20} \quad (3)$$

From equation (2), we get

$$11V1out = V2out \quad (4)$$

By combining equations (3) and (4), we get

$$V2out = -220Vmic \quad (5)$$

So, from these calculations, we can conclude that the microphone is amplified 220 times and inverted.

Summing amplifier

In the calculations we will assume that both opamps are in linear region and ideal. Since the noninverting terminal of the summing opamp (U6) is grounded, V_- becomes a virtual ground. No current flows through the input terminals of the opamp, hence the sum of the currents flowing through R19, R11, R12, and R13 must be equal to current flowing through R18. Using node analysis, we get these equations:

$$\frac{12 - 0}{R19} + \frac{V3out - 0}{R11} + \frac{V4out - 0}{R12} + \frac{V5out - 0}{R13} = \frac{0 - V6out}{R18} \quad (6)$$

$$\mathrm{R19 = R11 = R12 = R13 = 10k\Omega}$$

$$R18 = 1.5k\Omega$$

So, we get

$$-\frac{3}{20}(12 + V3out + V4out + V5out) = V6out \quad (7)$$

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Triangular waveform generator

In the calculations of this subcircuit, we will assume that capacitor has some initial charge, causing V_c=V_- to be negative (could also be positive as well). Just before the capacitor is connected to the rest of the subcircuit, V_{out} and V_+ is both zero. When the capacitor is connected, since V_+>V_-, V_{out}=V_{sat} and the capacitor starts to charge up to a point as explained in part e of the decision unit. After a while, when capacitor charges up such that V_c exceeds V_+, V_{out} becomes -V_{sat} and causes to capacitor discharge to -V_{sat} until V_c=V_+ and this process goes on. The period of this triangular waveform generated by V_c should be 1 seconds in order to obtain PWM with 1hz frequency. Any point in other than near the starting point is suitable to make the calculations. But for convenience, we will pick a starting point when V_c=B.V_{sat} and ending point when V_c=-B.V_{sat}. This time interval is the half of the period due to the symmetry. This time period is shown as t in the equations. The calculations made to determine a formula for the period is following:

$$Vc(t) = V_{final} + [V_{initial} - V_{final}]e^{-\frac{t}{RC}} \qquad (8)$$

$$V_{initial} = B.V_{sat}$$

$$V_{final} = -V_{sat}$$

$$-B.V_{sat} = -V_{sat} + V_{sat}(B+1)e^{-\frac{t}{RC}} \qquad (9)$$

$$\frac{1+B}{1-B} = e^{-\frac{t}{RC}} \qquad (10)$$

$$t = RCln\left[\frac{1+B}{1-B}\right] \qquad (11)$$

So, by equation (11), we can say that the frequency of the triangular waveform is

$$f = \frac{1}{2RCln\left[\frac{1+B}{1-B}\right]} \qquad (12)$$

If we pick our positive feedback resistors as the same, B becomes ½ and the formula becomes

$$f = \frac{1}{2RCln(3)} \qquad (13)$$

Using the equation (13), we picked C=47μF and R=11kΩ so that our frequency is approximately 1Hz.

Selection of Equipment and Cost Analysis

While picking the equipment, we prioritized safety. We knew about LM741 opamp from the laboratory experiments, so we used this model as our opamp. Additionally, microphone model picked was suitable to use on a breadboard and produced voltage differences rather than current differences which makes us easier to build a decision unit. The other components were picked as the design of the circuit requires.The list of the prices of the equipment are given in Table 1.

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Equipment Name	Price Per Component	Amount Bought	Amount Used	Total Price (used)	Total Price (paid)
LM741 opamp	1.15	28	8	9.2	32.2
1µF capacitor	0.24	2	1	0.24	0.48
47µF capacitor	0.24	3	1	0.24	0.72
470µF capacitor	0.24	2	1	0.24	0.48
1kΩ resistor	0.06	20	8	0.48	1.2
10kΩ resistor	0.06	10	9	0.54	0.6
11kΩ resistor	0.06	5	1	0.06	0.3
1.5kΩ resistor	0.14	3	1	0.14	0.42
Breadboard	9.00	2	2	18.00	18
1N4007 diode	0.09	5	4	0.36	0.45
Electret microphone	1	3	1	1	3
Jumper cable set	15	1	1	15	15
				45.5	72.85

Table 1: Cost of the project in Turkish Liras

Power Analysis

In this part, we will calculate the power consumption of our circuit by a simple power relation, P=VI. Since we supply power by a single voltage generator, we can use the readings we got from the screen of the voltage generator which is I=93mA. Since we fed the circuit with 12V, instantaneous power consumption of the circuit is 1.116 W.

Conclusion

In the beginning of the end, we would like to rephrase our purpose of the project. Detection and classification of the sound levels of an environment is a vital necessity both in everyday and work life. Even some working sectors depend on that fact. Since we re-mentioned the importance of building such circuit, we can now point out our main findings. Firstly, almost no design or simulation can be perfect fit to the reality. Many features of our first design did not match the real world. This problem takes us to our next finding. Secondly, when plans do not work out as they ought to work, you should be looking for a new way of solving the problem or designing the circuit rather than panicking. Of course, to be able to do this, you should be competent in this craft. Thirdly, making use of any kind of sources to bypass a problem. The design of the project must be tentative due to our first finding. And lastly, punctuality, being a team player and patient person has great importance in team-based projects. Arguments along the team members does nothing but waste some valuable time. We learned technical information too, other than the skills mentioned above. The main concept learned in this project was the pulse width modulation, how to produce and use it. Of course, there are a lot more fields that PWM is used, like representing AC waveforms in DC voltage, but here we only used it in 4 different duty cycles with very low frequency to make it observable. We produced the PWM signal by simply using a comparator with a DC voltage input and a triangular waveform input. We arranged the DC voltages to represent the sound levels of the room. To cluster continuously changing DC input, we constructed a comparator system with 3 opamps. The microphone gives an AC voltage with very low values; therefore, we amplified and rectified the input. These last 4 sentences summarize our thought process on approaching such problem. The resulting circuit was polished by real world experiences, concluding the project. It can be further developed by gathering data from different environments and arranging proper amplification values.

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Appendix I

Total time spent on/during

- Pre-Design Report : 6 hours
- Pre-Report : 20 hours
- Project Implementation: 8 hours
- Final Report: : 30 hours
- Demo. Video: : 3 hours