# **Noise-to-Color Visualizer (NCV) Device**


Team 41

Han Young Kim

Hyun Soo Kim


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TA: Kexin Hui

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# 1. Introduction

## 1.1. Objective

We are exposed to various intensity of sound daily. Constructions, sound bar, café and streets are all filled with noise generated by many different sources such as cars, animals, and human conversation. However, according to American Academy of Otolaryngology, one in 10 Americans has a hearing loss that affects his or her ability to understand normal speech [1]. Moreover, as the audio technologies advance, the demands for High-Fidelity headphones are skyrocketing, which also affects our hearing as the headphones and earphones greatly stimulate eardrums. Today, 1 in 5 teens has some form of hearing loss, which many experts believe is due to the increased use of headphones, as presented in American Osteopathic Association [2]. Clearly, the exposure to excessive noise may damage hearing, and we have to avoid such situation as much as we can.

Our project is to design a device that visualizes the noise level by classifying the noise levels into six different color: Red, Yellow, Green, Blue, Pink, and White. We will scale red being the loudest and pink being the quietest. By interpreting the decibel into a simple color, we can clearly observe how noisy the surrounding is. Moreover, with this device, people cannot be selfish and subjective about the noise level because the device would indicate the level of sound at a glance.

## 1.2. Background

Often, we are very subjective about the noise level around us. Some people desire listening to music with booming sound while some just want the music to be controlled at certain level. Or, when we are involved in conversation, we often ignore that the fact we are making noise that disturbs the people around us. There are cases like even in crowded space, some people say it's manageable while some say the place is very noisy. Considering these facts, we believe it's just too difficult to be neutral at judging the level of noise. Plus, numeric display of noise level does not actually make sense to children or those who are not familiar in the area. For them and in general, it would be much easier to visualize the noise level with a color so that when we tell our friends about the noise level at certain place, it would give them clear image of how quiet/noisy the place is. Additionally, we would be able to avoid unwanted exposure for loud and disturbing level of noise for several hours.

## 1.3. High-Level Requirements

1. The device must take in the human hearing range of noise generated from everyday items and human speech.
2. The device must possess noise level perception technique that resembles human ear

perception of noise.

3. Device must be portable and time-varying.
4. The device should be able to provide simple way to interpret the noise level.

# 2. Design

## 2-1. Physical Design

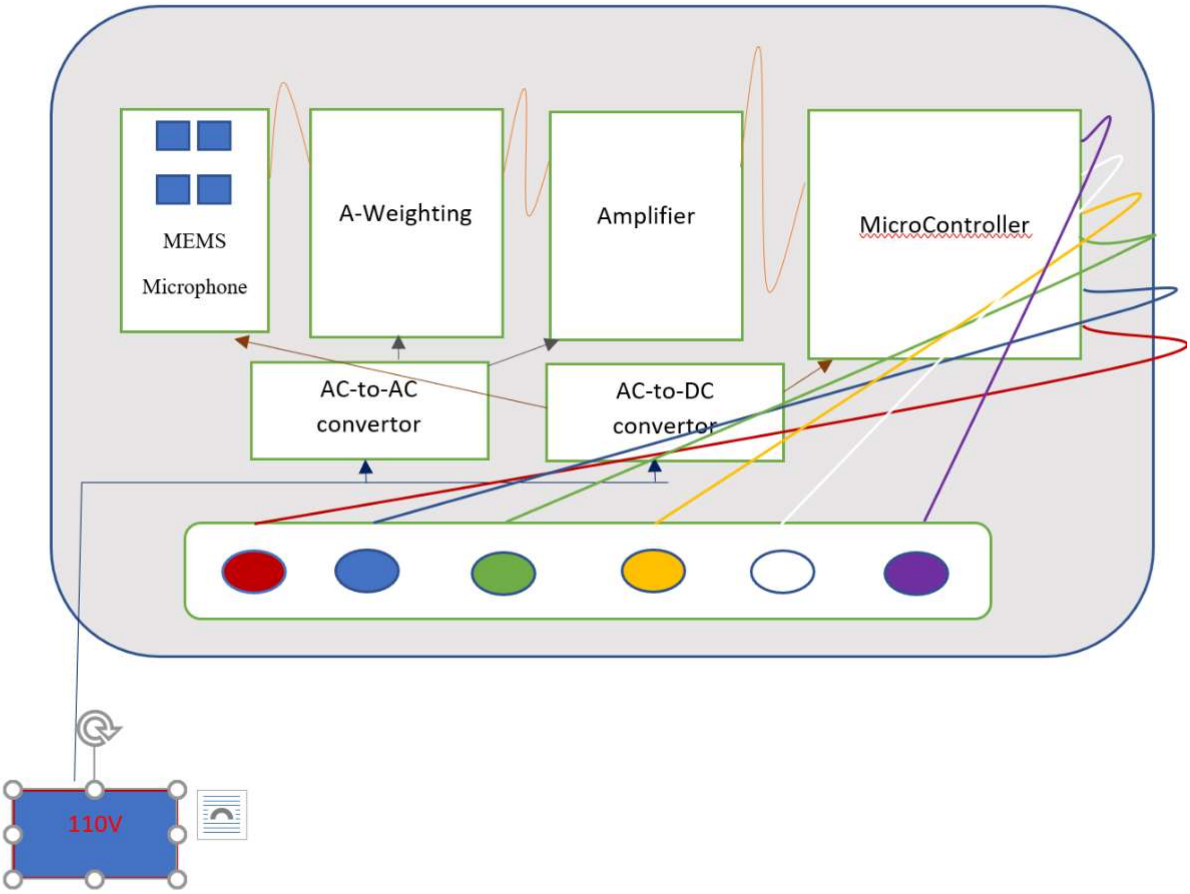


**Figure 1. Physical Design**

## 2-2. Device Block Diagram

We would divide the device into sections: Power Supply, Input-to-Output (I/O) system Circuit, and control system.

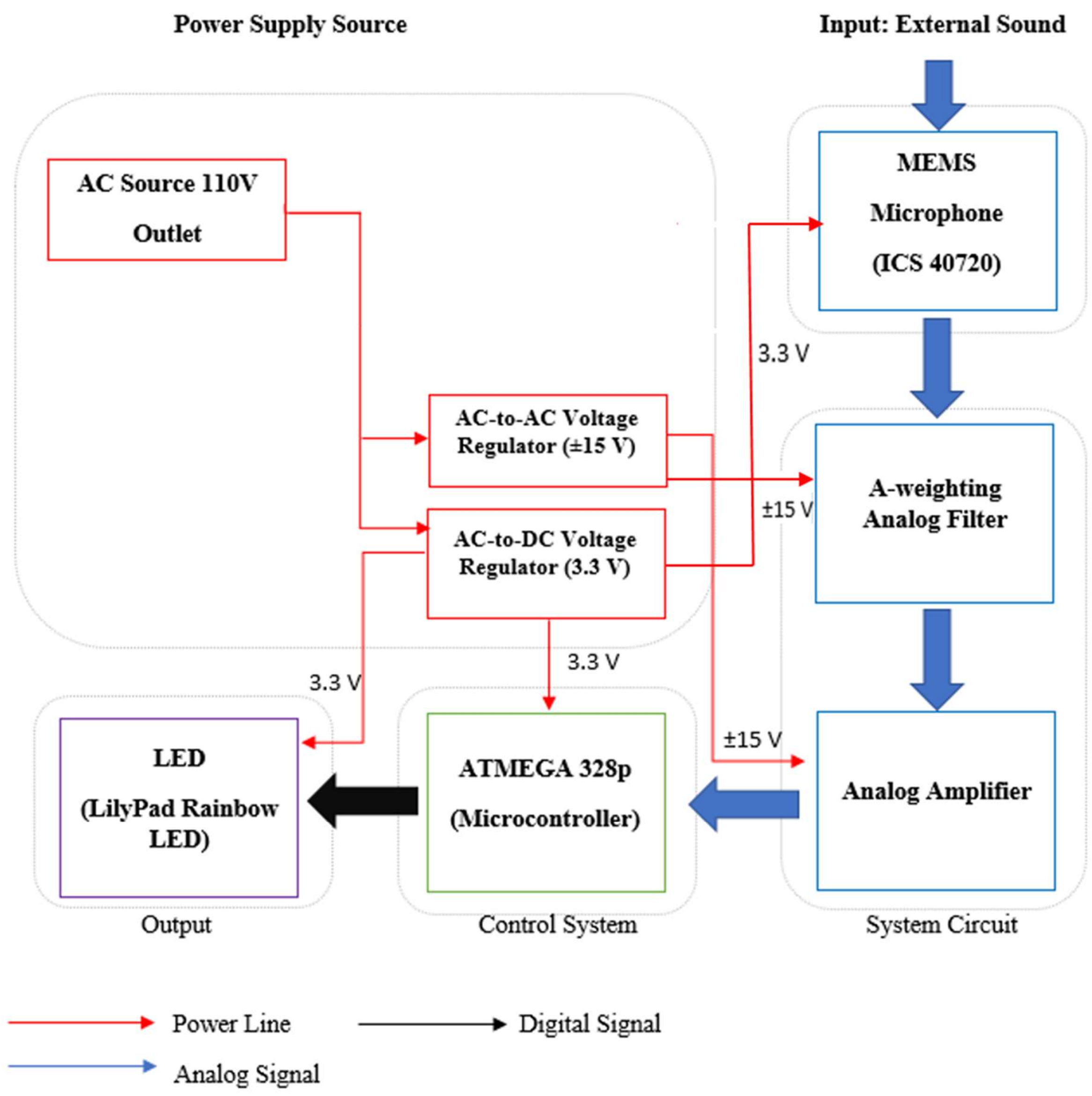


**Figure 2. Block Diagram**

## 2-3. Power Supply

To supply power into the device, we will use 110 V outlet from the wall or any adaptors. We will then use voltage regulator by implementing AC-to-DC converter to supply voltage into the microcontroller, which operates within 1.8 ~ 5.5 V and we are looking to provide 3.3 V. MEMS microphones and LilyPad LEDs also has operating voltage of 3.7 and 3.3 V respectively.

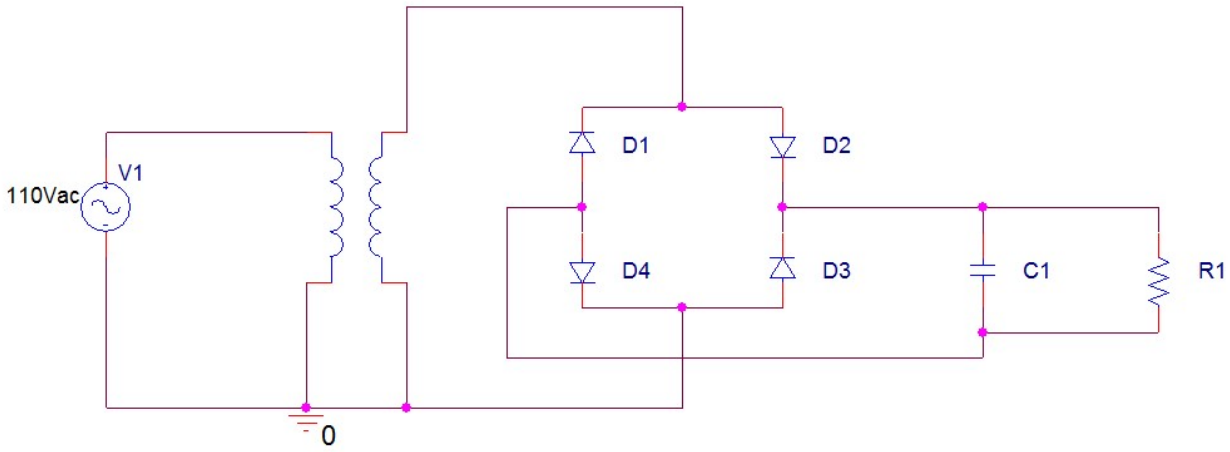


**Figure 3. AC-to-DC Full Wave Rectifier**

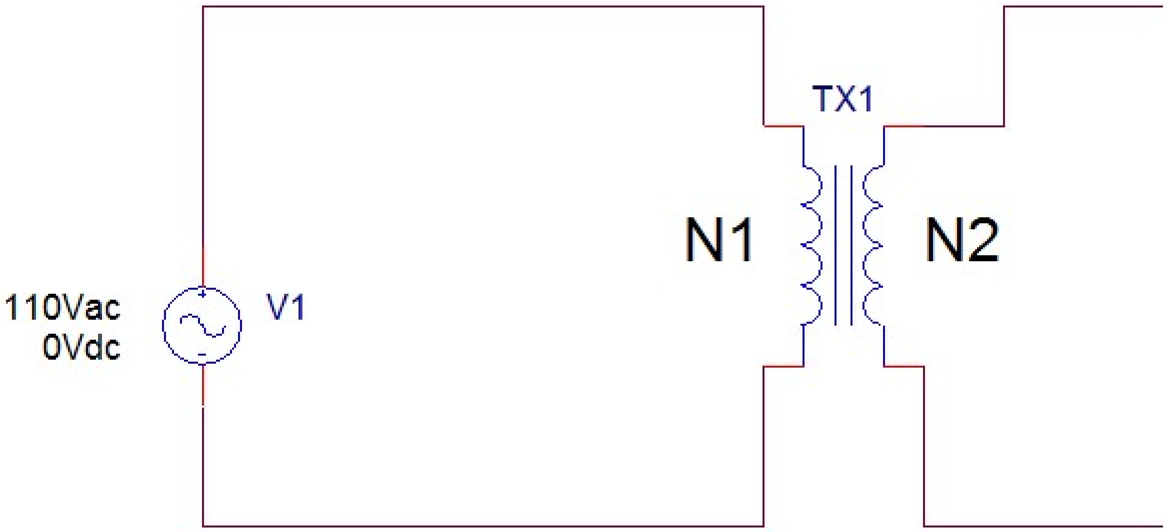


**Figure 4. AC-to-AC Transformer**

### 2.3.1. Calculation for AC-to-DC converter (3.3 V)

$$R_{load} = R_1 = \frac{V^2}{P} \tag{1}$$

The parts that use 3.3 DC voltage are MEMS Microphone, LED Pad, and Microcontroller Chip. To obtain P, we have to calculate all power dissipated or consumed by these three elements.

1. ATmega328P, when used with 16 MHz Oscillator, would spend approximately 0.0262 Watts.
2. ICS 40720, MEMS microphone mode, uses approximately 0.00124 Watts.
3. LilyPad LEDs use 0.078 Watts.

Then, sum up all values and then the total power (P) is

$$P = 0.10544\,W \tag{2}$$

Plugging in to the equation 1, we get

$$R_{load} = R_1 = \frac{(3.3)^2}{0.10544} = 103.281\,\Omega \tag{3}$$

**2.3.2. Calculation for AC-to-AC converter**

For the A-weighting analog Filter and Analog Amplifier, we need 15 AC voltage from 110 AC voltage to give power to operate systems. When 110 AC voltage enters to AC converter, it needs to be converted to RMS value according the following equation.

$$V_{\text{rms}} = \frac{V_{\text{peak}}}{\sqrt{2}} \tag{4}$$

Then, as it goes through transformer and load resistor, it is changed to 15 AC voltage. According to the following equation, we can get AC converter from simple transformer.

$\mathrm{V_{AC,out}} = \pm 15$ V and $\mathrm{V_{AC,in}} = \pm 110$ V. We need the ratio of $\frac{\mathrm{N1}}{\mathrm{N2}} = \frac{22}{3}$

Using the transformer equation

$$\mathrm{V_{AC,out}} = \frac{N1}{N2} * V_{ACin} \tag{5}$$

**2.4 I/O System Circuit**

**2.4.1 MEMS(Microelectromechanical Systems) Microphones (Model: ICS 40720)**

**Operating Voltage :** 1.8 ~ 5 V

**Input:** Collected sound and noise from surroundings

**Output:** Analog signal of the collected sound and noise

MEMS microphone will collect the noise level of the surrounding. To be accurate, we will use omni-directional MEMS microphones to collect noise samples from different directions in respective to the user. Another fact about microphone is that it is already Band Pass filter because it detects the sound between the range 75 Hz to 20 kHz, according to the specification.

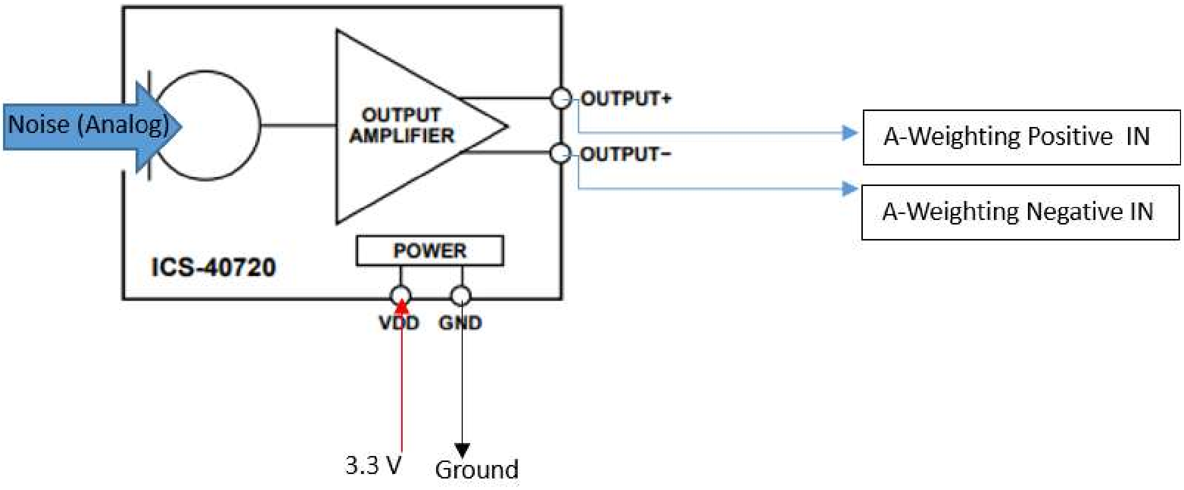


**Figure 5. MEMS Microphone Pin Description**

| PIN Name | Decription |
|---|---|
| VDD | Supply Voltage |
| GND | Ground |
| Output+ | Positive Analog Output Voltage |
| Output- | Negative Analog Output Voltage |

**Table 1. PIN Specifics**

**2.4.2. A-Weighting Filter**

**Operating Voltage :** ± 15 V for Op-Amp <AC>

**Input:** Collected analog noise signal from MEMS microphone

**Output:** Filtered analog signal

By definition, A-Weighting Filter took model human ear perception because human ears are unable to sense certain high frequency sound levels as supported with the graph below.

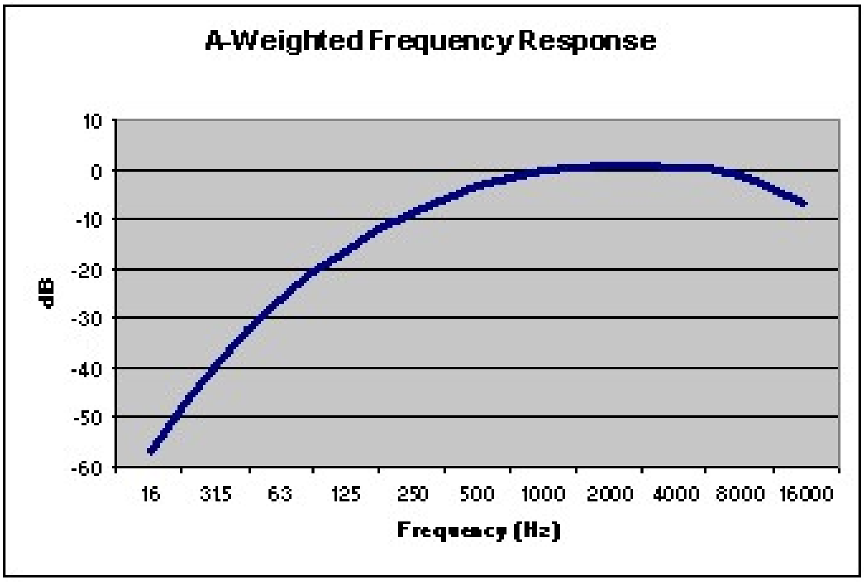


**Figure 6. Ideal Frequency Response of A weighting Filter [3]**

When we measure the sound level through machine, this is not very accurate description of what we perceive because machines and human ears have different sensitivity. Human ear responds more to frequencies between 500 Hz and 1 kHz and less sensitive at certain range of 1 kHz to around 8 kHz [3]. This means that at the peak of the graph shown above, there is a matching point that intersects 0 dB. Therefore, weighting filters are used to help converting instrument-measured sound level to relative human-hearing loudness. Typically, A Weighting Filter is most commonly used filter for measuring the sound level because it effectively cuts off lower and higher frequencies that average person cannot hear, which resembles human ear.

As implementing the schematics for the A-Weighted filter, we set the Op-Amps within the filter to be operated at 15V, using the model LM324 [4], with Unity gain for U3 for fully compensated internal frequency.

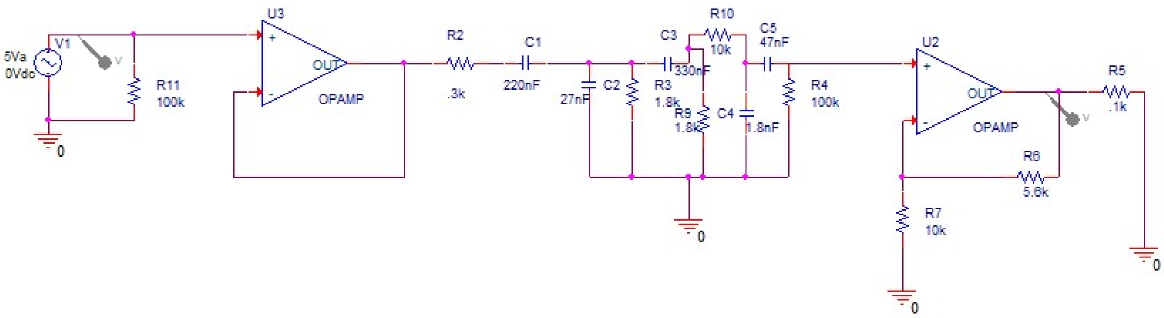


**Figure 7. Schematics for A-Weighting Filter [5]**

Second non-inverting Op-Amp, denoted U2, has the gain coefficient as

$$A_v = 1 + \frac{R_6}{R_7} = 1 + \frac{5.6}{10} = 1.56 \quad (6)$$

to adjust the decibel level of around 1kHz (1000Hz) to 8 kHz to possess near 0 dB, as ideal A-weighted filter indicates that the humans are generally not aware of the noise with frequency range approximately between 1 kHz to 8kHz. The simulation of the above circuit through OrCAD is shown below. Note that the first graph shows the voltage response in non-log scale and the second graph shows the voltage response in log-scale, which is basically the decibel range as referring to the following equation [6].

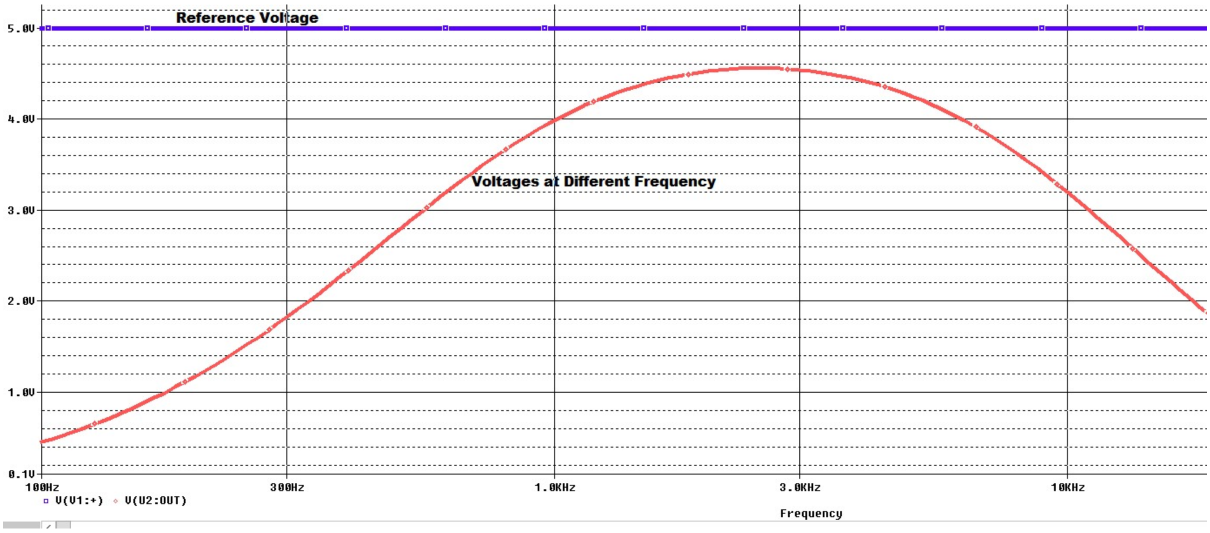


**Figure 8. Voltage Response from 100 Hz to 20kHz**

From the graph above, we would not observe the range below 100 Hz. This phenomena can be explained by the low frequencies under 100 Hz demonstrates slow curvature in the area of speech processing. The most important frequencies for speech fall between the 250 and 6000 Hz [7], so this would mean that the noise generated by human falls between that range.

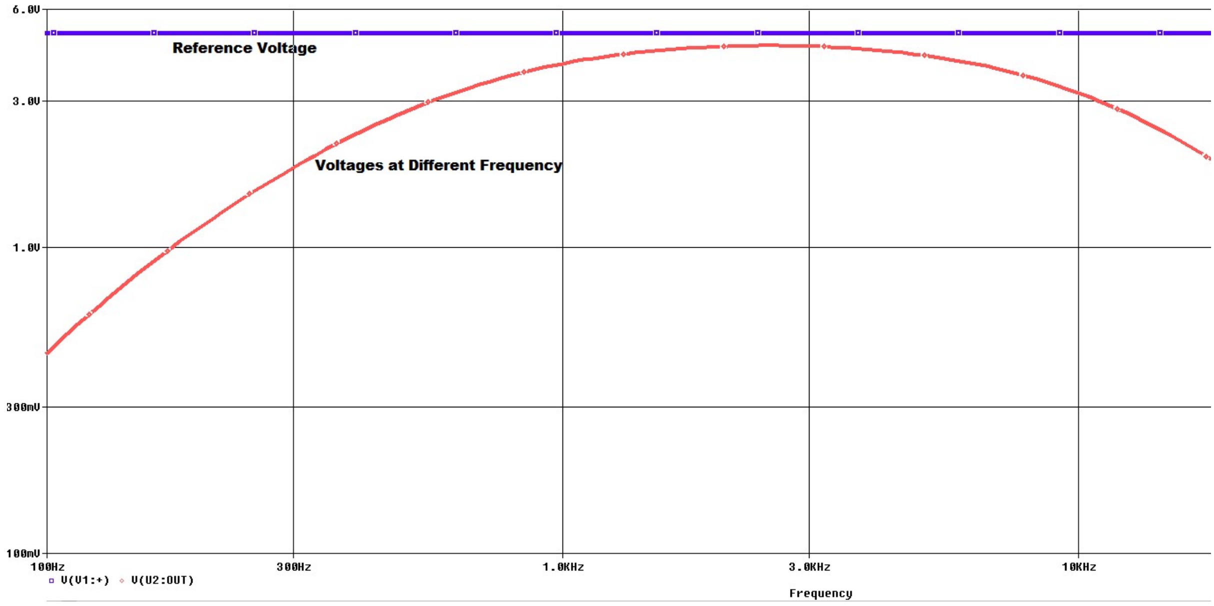


**Figure 9. Log Scaled version of Voltage Response when generated with AC ±5V source**

**2.4.3. Amplifier**

**Operating voltage Range:** ±15 V for Op-Amp <AC>

**Input:** A-Weighting Filter output analog signal

**Output:** Amplified signal of the input

**Problem**: Since the input signal amplitude is varying depending on the loudness, the specific value of gain coefficient is yet determined.

**Plan**: Collect noise samples of different environments using the MEMS microphone and derive out relationship between

Since all hardware circuits may possess loss in the amplitude of signal as it processes through all different elements of circuit, we would like to implement circuit for an amplifier to restore back to the original amplitude of signal. The gain of the amplifier depends on how much voltage level is achieved by the A Weighting filter. For example, when the original signal has amplitude of 5V and post-A Weighting filter amplitude was observed as 4.5, the gain of the amplifier would be $A_v = \frac{5}{4.5} \cong 1.111$, using equation **(4)**.

While we won't be dealing with the stable source of AC signal, it is a dilemma to use time-invariant gain constant. Thus, since the noise and sound level of the surroundings may vary depending on how loud and quiet the inputting noises are, the gain coefficient of this amplifier has to be flexible or derive relationship between voltage level and the amount of gain logically deduced after sufficient number of calculations and measurements with different amplitudes of the noise signals. Our original plan of schematics for the amplifier is the following

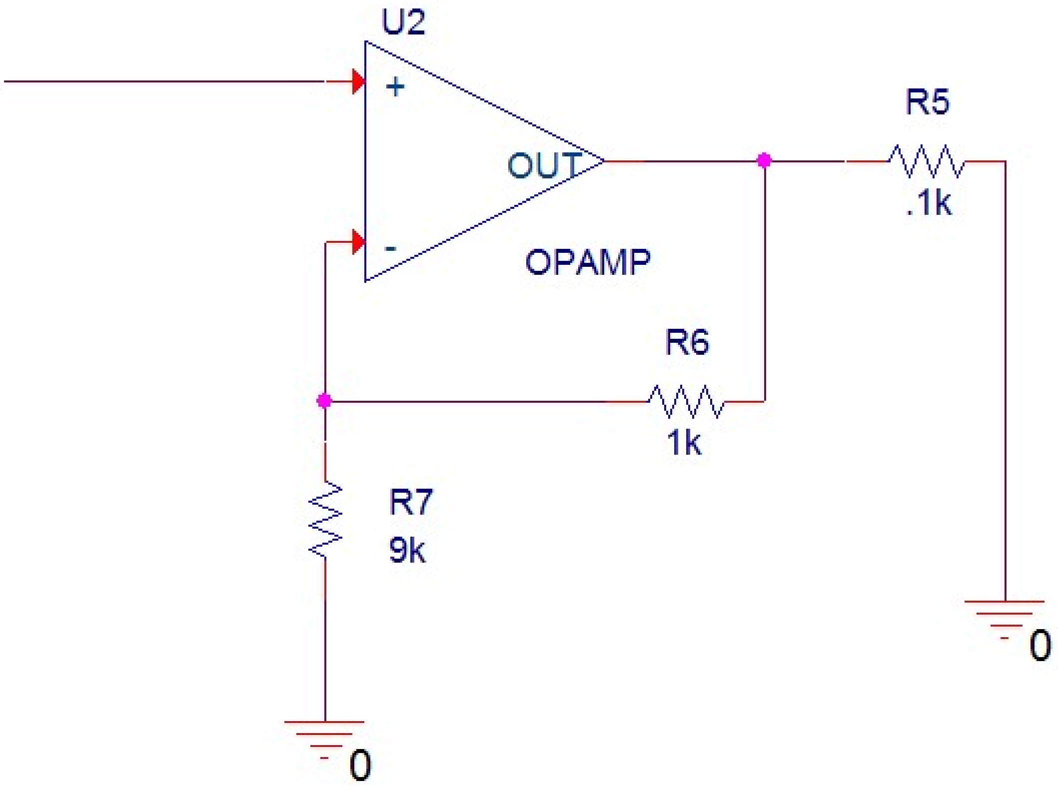


**Figure 10. Original option of Amplifier Circuit with gain coefficient of 1.11**

First, we will collect data using the MEMS microphone from various environments and surroundings and then draw correlation between the maximum input signal (voltage) amplitude and amount of gain needed for the peak voltage level to reach exact 0 dB in log scale.

Second, we will derive out the best correlation coefficient level that adjust the peak voltage level to the 0 dB. Then, the amount of coefficient that we need to scale the amplitude of signal would be the gain coefficient of the amplifier circuit.

For the Op-Amp chip we will be using is the LM324 shown below. This chip would also be used in the A-Weighting filter.

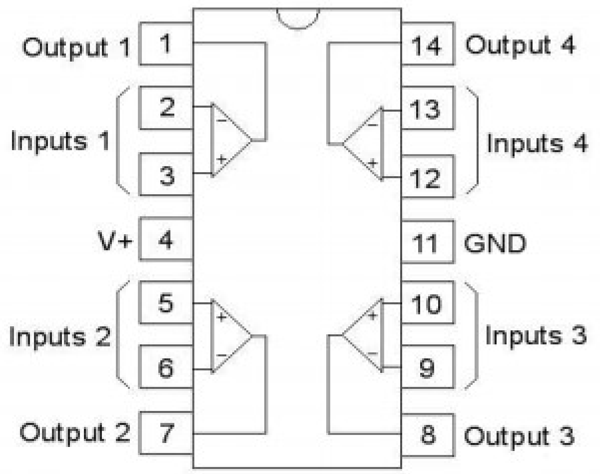


**Figure 11. Pin Description of LM324**

### 2.4.4 LED – LilyPad Rainbow LEDs

**Operating voltage Range** : 2.0 ~ 5 V <DC>

**Input:** Digital Signal from Microcontroller

**Output:** LED light

As the microcontroller makes instruction, the command signal would pass to LED panel to light up certain color. There are total six colors of LEDs, each with different colors, and depending on the sound level, one of the LEDs would light up. Lilypad Rainbow LED has 6 colors (Red, Blue, Green, Yellow, pink, and White) and furthermore can be customize the color as customer's sate.

## 2.5. Control System

**Microcontroller Model**: ATMEGA 328P

**Operating Voltage Range**: 1.8 – 5.5 V.  Allow ± 5% tolerance range

**Input**: Analog Signal from amplifier circuit.

**Output**: Digital Signal that control LED light up.

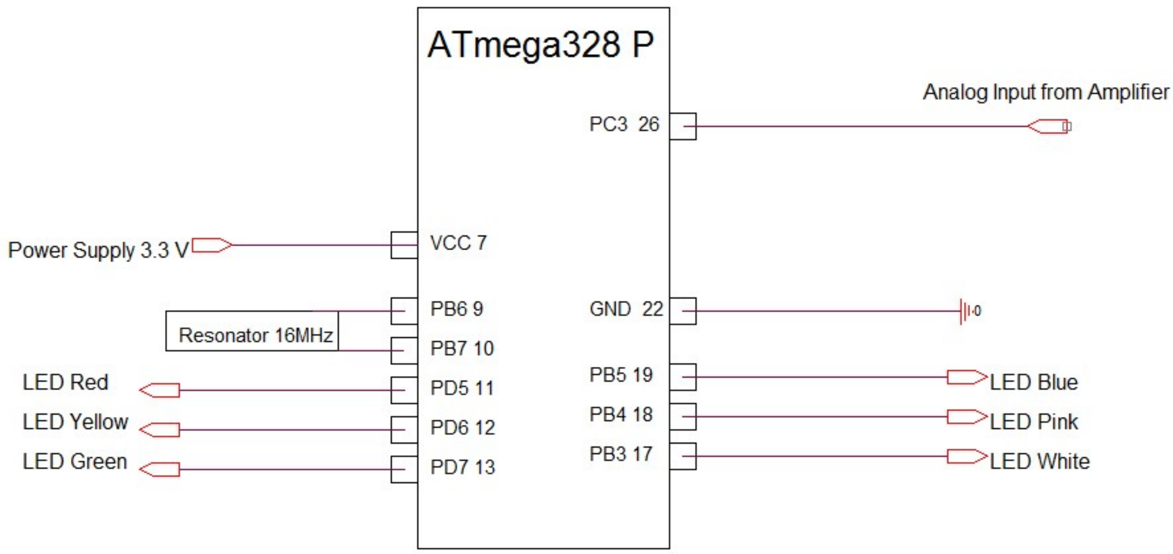


**Figure 12. Pin Description of ATmega328P**

The ideal microcontroller for our project should be able to support Analog-to-Digital Converter (ADC) embedded and the functionality of FFT as well as programmable. Considering these qualifications, we decided to use ATEMGA 328P, which possesses the desired functionalities.

As microcontroller receive the analog signal from amplifier circuit, it converts the voltages into decibel scale using the logarithm.

$$P_o(Watts) = 2 * 10^{-6}\ Pascals$$

$$L(dB) = 10\log\left(\frac{P}{P_o}\right)^2 = 20\log\left(\frac{P}{P_o}\right) \tag{7}$$

The equation for the power is

$$P = VI = \frac{V^2}{R} \tag{8}$$

Note that since the signal went through the analog circuits, the resistance is same for $P_o$ and $P$ can be cancelled off.

Thus the calculation of noise level is now just

$$L\ (dB) = 10\log\left(\frac{V}{V_o}\right)^2 = 20\log\left(\frac{V}{V_o}\right) \tag{9}$$

Here, $V_o$ is the peak voltage amplitude of the signal and $V$ is the varying voltage amplitude of signal. This would mean if $V$ is close to $V_o$, it would return lower sound intensity (level). Thus, this means that a person is not likely to hear this frequency very well.

After getting the range of frequency to analyze, we will be implementing the following algorithm written in pseudo-code:

```
Color_Select(x){
Switch(x = noise level)

Case1 (x >= 110 dB) return Color Red;
Case2 (x >= 95 dB && x < 110 dB) return Color Yellow;
Case3 (x >= 80 dB && x < 95 dB) return Color Green;
Case4 (x > =65 dB && x < 80 dB) return Color Blue;
Case5 (x > =50 dB && x < 65 dB) return Color White;
Case6 (x < 50 dB) return Color Purple;

}
```

**Code 1. Pseudo-code for color selection**

## 2.6. Risk Analysis

The block of greatest risk to be successful completion of the project is the filter. As seen, we will be using analog designed A-weighting filter, which require in-depth research in the area of sound perception techniques. We also have to take human ear perception into consideration because machine-detected sound level is not equivalent to the level of human hearings. Therefore, the accuracy would not be precisely satisfying because human ears are very complicated and differ from person to person. There are many options of weighting filters as B-type, C-type, and Z-type yet A-type is most commonly used and demonstrate closest proximity to human ear sensitivity. Errors may exist and our task is to minimize the error for this block, which is the biggest concern.

# 3. Requirements and Verification

**3-1. Power Supply**

| Requirements | Verification | Points : 15 |
|---|---|---|
| A) AC-to-DC converter<br>1. 3.3 V DC voltage: LEDs, Microcontroller, MEMS Microphone<br>2. Devices must have corresponding or operating voltage level for Microcontroller and MEMS microphone to perform its functions. | 1. For AC-to-AC converter, use Oscilloscope to verify whether the correct amplitude of waveform is generated. | 1. AC-to-AC Voltage Regulator design **[5]**<br>➔ The output is converted to ± 15V and within 5% of tolerance range. **[3]**<br>➔ A Weighting Filter functions **[2]**<br><br>2. AC-to-DC Voltage Regulator design **[10]**<br>➔ The output is converted to DC 3.3V with 5% of tolerance range. **[3]**<br>➔ The output is converted to DC 9 V with 5% of tolerance range. **[3]**<br>➔ The following connected elements operates with supplied voltages<br>⇨ LED **[1]**<br>⇨ Amplifier **[1]**<br>⇨ Mic **[1]**<br>⇨ MCU **[1]** |
| B) AC-to AC converter.<br>1. ±15 V AC voltage: A-Weighting analog filter, Analog Amplifier<br>2. Devices must have corresponding or operating voltage level for A-Weighting analog filter and Analog Amplifier to perform its functions. | 1. For AC-to-DC converter, set up a digital multimeter to verify whether the corresponding DC voltage value has been generated. | |

**Table 2. Power Supply Table**

**3-2. MEMS Microphone**

| Requirements | Verification | Points:2 |
|---|---|---|
| 1. The Microphone must generate analog signal from input noise signal. | 1. Test with building a simple circuit to confirm whether it's outputting the analog signal and | 1. 2 **points total**<br>➔ Build a simple circuit that can be used to test |

| | | |
|---|---|---|
| 2. The microphone should be placed in an optimal place of the device where the output amplitude is maximized. | observe this using the oscilloscope.<br><br>2.<br>a). Prepare a beep impulse sound with frequency of 5000 Hz and generate through cellphone speaker at range of 3m.<br>b). Use the oscilloscope while adjusting the position of MEMS microphone and find the position that approximately the amplitude reaches maximum. | analog signal output of MEMS microphone. **[1]**<br><br>➔ Prepare 5000 Hz or an impulse sound for testing MEMS microphone optimal condition. **[1]** |

**Table 3. MEMS Microphone Table**

**3-3. A-Weighting Filter**

| Requirements | Verification | Points: 12 |
|---|---|---|
| 1. The sound signal should be adjusted to human-ear-like perception range by modulating the collected signal using a filter.<br><br>2. There must be an ensuring experiment that confirms that the filter is outputting desired behavior. | 1. a). Place an arbitrary AC voltage source.<br>b). Test the behavior of signal in log-scale and verify whether the output is similar to **Figure 6.**<br><br>2. a). To test its validity, use PSPICE software to place an arbitrary AC source of ±5 V.<br>b). Use SPICE simulator to check its output.<br>c). After PCB model is fabricated as schematics in **Figure 8**, use oscilloscope to test its output. | 10 points Total<br>1. Correctness **[5]**<br>➔ The filter returns an output within frequencies of human-hearing range (20 to 20kHz). **[3]**<br>➔ As converted to log scale, at the range between 1 kHz to 8 kHz is close to 0 dB. **[2]**<br><br>2. Completeness **[7]**<br>➔ The analog design is complete and generates output similar to the ideal |

| | | |
|---|---|---|
| 3. MEMS Microphone output signal should be compatible as it becomes input of A-Weighting Filter. | | behavior of A Weighting Filter. |

**Table 4. A-Weighting Filter Table**

## 3-4. Amplifier

| Requirements | Verification | Points: 5 |
|---|---|---|
| 1. Amplifier should produce a gain that would return closest to 0 dB in log scale from 1 kHz to 8 kHz approximately with realistically implementable value of resistance. | 1. a). Use the plot obtained from simulating the A-Weighted Filter to calculate the gain needed.<br>b). Manipulate the indicated resistor value (R5) in **Figure 8** and observe behavior of the log-scaled graph.<br>c). Conduct tolerance analysis along with A-Weighting Filter to find the closest the resistance of Op-Amp could obtain realistically. | 5 points total<br>➔ The designed amplifier demonstrates some sort of amplified signal **[3]**<br>➔ The Gain of amplifier generates a signal that meets the requirement of 0 dB in the range 1kHz to 8kHz when represented with log scale graph. **[2]** |

**Table 5. Amplifier Table**

## 3-5. LED Pads

| Requirements | Verification | Points: 5 |
|---|---|---|
| 1. LEDs should be lit up based on LED control logic in **Code 1** that is implemented in the microcontroller. | 1. Set the digital output of Microcontroller to tentatively to test whether LEDs are turned on as Microcontroller outputs 1 and turned off as output of 0. | 5 points total<br>➔ Different LED is lighted up as the sound level changes. **[3]**<br><br>➔ LED is lighted up by |

| | | |
|---|---|---|
| 2. No more than 1 LED should be lit up simultaneously. | 2. Implement 'switch' logic to Microcontroller chip that assigns each LED with corresponding value according to Figure ****<br><br>3. Connect 1k Resistor in series with each LEDs.<br><br>4. Test each LEDs to verify only one LED is lit up by the programming code | connecting correct input voltage and circuit elements. **[2]** |

**Table 6. LED Pads Table**

**<u>3-6. Microcontroller</u>**

| Requirements | Verification | Points: 10 |
|---|---|---|
| 1. The Microcontroller should contain a code that controls the turn on/off mode of LED.<br>2. The microcontroller should pass the analog signal to Analog-to-Digital Converter in order to process the analog sampled sound profile and analyze its characteristics (noise level in dB).<br><br>3. The output of the microcontroller should be digital command of turn on or turn off (1 and 0) for each digital pin connected to each of the LEDs. | 1.<br>a). Use Arduino ISP (In System Programming) to upload a code or sketch.<br>b). Build a circuit that connects Arduino Uno board and ATmega328P.<br>c). Change the setting of Arduino IDE to be Arduino ISP mode, indicating that Arduino would be used to program the connected chip<br>d). Connect 16 MHz Resonator at Pin 9 and Pin 10 (XTL) at ATmega328P to enhance the clock signal.<br>2. | <u>10 points total</u><br>➔ The test code for functional check successfully compiles to run and lighted up LED with logical flow **[2]**<br>➔ Analog Signal has successfully been processed to be represented with an arbitrary variable within the microcontroller. **[3]**<br>➔ The output of Microcontroller successfully turns on a single LED non-simultaneously. **[4]**<br>➔ Microcontroller |

| | | |
|---|---|---|
| | a). Implement in following order: decibel calculation using the algorithms.<br>b). Test it with arbitrary value of signal generated by the A-Weighted filter and read off the value through simulation by the microcontroller.<br>3. Only one of the digital outputs would be True(1) and the others be False(0) since there could not be overlapping sound level. | produces a command that lights up correct LED. **[1]** |

**Table 7. Microcontroller Table**

**3-7. Tolerance Analysis**

The main output of this entire device is the LED, taking a noise signal as the input. However, the most crucial part of the device is the A-Weighting Filter and the amplifier that follows up. As A-Weighting filter draw a connection to the machine calculated to human perceptible range of hearing, there is not many related journals nor researches conducted on the weighting filter but rather conceptual. Therefore, we will conduct the tolerance analysis on the A-Weighting Filter in that it demonstrates the minimal aperture from 0 dB by manipulating the circuit elements.

Suppose we have the following schematics with arbitrary ac source voltage of 5 V and unity gain for U3 and 1.11 gain on U2. We simulated this schematics on figure 2.

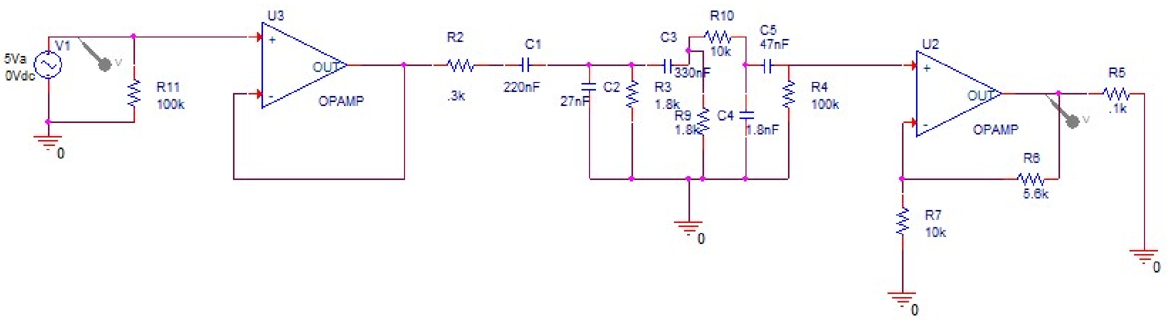


**Figure 13. A-Weighting Filter**

Then, using the Trace option, we obtained the maximum voltage level of the graph.

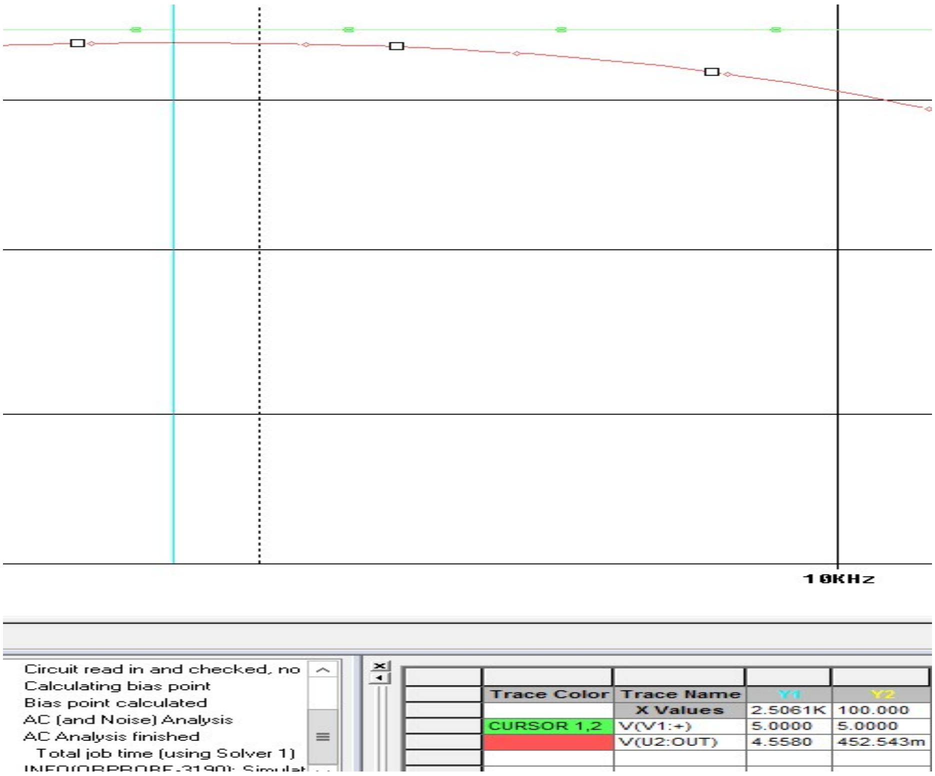


**Figure 14. Traced Graph**

We can clearly see that the distance between the peak voltages of output and input is

$$5 - 4.5580 = 0.442 \text{ V}$$

which is clearly not the ideal behavior we desire, since the ideal A-Weighting Filter Curve demonstrates 0 dB at some point from 1 kHz to 8 kHz. We assumed it to be the non-inverting Op-Amp amplifier attached on the rightmost side of the weighted filter.

We manipulated gains of the amplifier and obtained the following data.

| R5 value | Input Voltage Peak |
|---|---|
| 5.6k (Original) | 4.5580 V |
| 6.2 kΩ | 4.73 V |
| 6.26 kΩ | 4.7508 V |
| 7 kΩ | 4.9670 V |
| 7.1 kΩ | 4.9963 V |
| 7.11 kΩ | 4.9981 V |
| 7.115 kΩ | 5.006 V |

**Table 8. Obtained data from experiment**

Since we don't want the voltage level go beyond the maximum input voltage, we would have to narrow

down our R5 value to be adjusted between 7.11 kΩ and 7.115 kΩ.
To guarantee the circuit would work, we would set the maximum R5 resistance to be 7.11, which would be the error percentage of

$$\frac{5 - 4.9981}{5} = 0.00038 = 0.038\ \%$$

Acknowledging that the voltage input may differ, we allowed up to 5% error so that

$$V_{inpeak} = 4.75\ V$$

is allowed, which would enable us to use the minimum resistance of R5 be

$$R_{5,min} = 6.26\ k\Omega$$

To sum up R5 would be between the values of

$$6.26\ k\Omega < R_5 < 7.11\ k\Omega$$

**<u>3-8. Safety and Ethical Issues</u>**

First, we will put our best effort for keeping our project ethical in accordance with IEEE code of Ethics #1, 2,4, and 8 [7]. We believe that the best way to solve the conflict is the frequent conversation to each other, enabling us to understand and aid each other whenever possible. Thus, there will be no discrimination on any types of background. All individual opinions will be valued and put into consideration. From beginning to the end, we will make sure the design engineering process is clearly visible to ensure reliable and trustworthy product as IEEE code of ethics #3 [8] states.
Since our project involves complexity in hardware design as well as human ear response, sufficient amount of background research would be required to optimize the quality. Abiding IEEE Code Ethics #5 [8], we are looking to use best possible technology with appropriate functionality to better the quality. Under IEEE code of ethics #9 [8], the priority will be placed on the safety of users. Our primary and only safety concern lies on the AC-to-DC conversion circuits, which would involve manipulating a high voltage that could cause accidents. Although we may keep ourselves away from potential dangers, we acknowledge that there could be unexpected dangers of using the power, and do our best to optimize the circuit and hardware design that minimizes the potential power and circuit failure with in accordance with IEEE code of ethics #1 [8]. Along with the rising role of Social Network Service as well as caution notes, we will be providing how to avoid and prevent dangerous circumstances.
Moreover, as IEEE code of ethics #7 [8] states, we will accept the designated TA's advice in order to focus on the purpose of the ECE445 course as well as crediting the contributions of others by citing their works. Additionally, to correct errors in timely manner, the frequent debugging process would be recorded as we proceed in hardware and software designs.

# 4 Cost and Schedule

## 4.1. Cost Analysis

| Name | Description | Manufacturer | Quantity | Cost |
|---|---|---|---|---|
| ICS-40720 | MEMS microphone | TDK Invensense | 2 | 7.96dollars ($ 3.98 each) |
| ATMEGA 328p | Microcontroller | ATMEL | 1 | $ 4.81 |
| Lily Pad Rainbow LED | LED | SparkFun Electronics | 1 | $ 4.95 |
| A-weighting Filter | System Circuit | PCBs(4hours) | 1 | - |
| Voltage Regulator | System Circuit | PCBs(3hours) | 4 | - |
| Bread Board for Device | Circuit board, and part of device | All Electronics Corp | 1 | $ 7.65 |
| Amplifier (LM324) | Op-Amp | Bonanza - bpelectronic's booth | 1 | $ 1 |
| Arduino UNO | Microcontroller ISP | Arduino | 1 | $24.90 |
| Labor Cost | Han Young Kim | | $35 / hour | $ 5250 |
| | Hyun Soo Kim | | $ 35 / hour | $ 5250 |
| Total | | | | $ 10551.3 |

**Table 9. Cost Analysis**

## 4.2. Schedule

<table>
<tr><th>Week</th><th colspan="2">Description of Construction.</th></tr>
<tr><td>Members</td><td>Han Young Kim</td><td>Hyun Soo Kim</td></tr>
<tr><td>10/16</td><td>Soldering Assignment(ECE445)<br><br>➔ Final design A-weighting Filter and configure how to connect it to Op-Amp.<br><br>➔ Final reviewing products to order and buying Mems Microphone (ICS 40720), Op-Amp(324).</td><td>Soldering Assignment(ECE445)<br><br>➔ Final design Voltage regulator and find out how to connect to other elements.<br><br>➔ Final reviewing products to order and buying Microcontroller (Atmega 328p from ATMEL), Lily pad rainbow LED</td></tr>
<tr><td>10/23</td><td colspan="2">Review each circuit design (Voltage Regulator, A-weighting Filter, Amplifier) to order first PCBway</td></tr>
<tr><td rowspan="2">10/30</td><td>Assemble Mems Microphone, A-weighting Filter, and Op-Amp.</td><td>Assemble Voltage Regulator, Microcontroller, and LEDs.</td></tr>
<tr><td colspan="2">Combine all elements to construct prototype device and test them and find out what error is.</td></tr>
<tr><td>11/6</td><td colspan="2">Final orders PCBway</td></tr>
<tr><td>11/13</td><td>Integrate prototype on the breadboard including Mems Microphone, Microcontroller, and LEDs and test them.</td><td>Build an outer cover and integrate it with the system circuits, the breadboard, and Lily rainbow LED.</td></tr>
<tr><td>11/20</td><td colspan="2">Refine prototype by testing and reviewing device at the proper environment where the device would be possibly used by customer.<br><br>Final test for Mock demo.</td></tr>
<tr><td>11/27</td><td colspan="2">Mock demo.<br><br>Final review for the demonstration such as checking stability and reliability of the device and embellish device appearance.</td></tr>
</table>

**Table 10. Schedule**

# 5 References

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