EE2073 Project Report

Automatic Volume Control for Audio Amplifier System

Student Name: Zhong Zhenlin
Matric No.: U1923080J
Project Group: EJ08 group 14

School of Electrical and Electronic Engineering
Academic Year 2020/21
Semester 2

Table of Contents

Chapter 1 Introduction

The main purpose of EE2073 is to construct, test and evaluate three subsystems of audio amplifier system which includes Voltage Controlled Amplifier (VCA), Power Amplifier (PA) and Volume Unit Meter (VU Meter) subsystems. And to integrate all hardware and software to develop an Automatic Volume Control for audio amplifier system. Software tools including LabVIEW and NI ELVIS II are used for circuit designing, output testing and data acquisition etc.

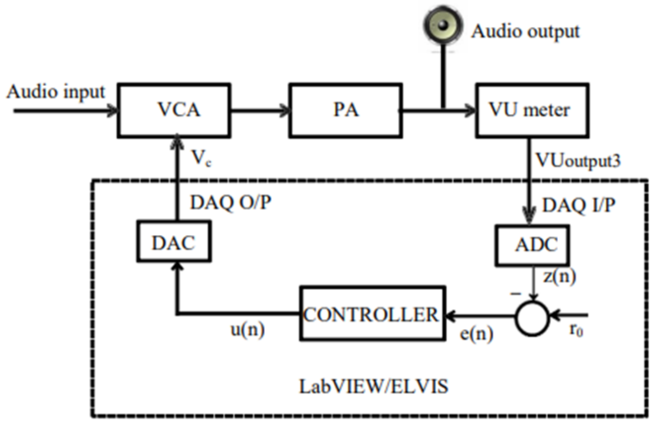


Figure 1. Block Diagram of Closed-loop System

Chapter 2 Voltage Controlled Amplifier Subsystem

The Voltage Controlled Amplifier (VCA) subsystem is the first of the subsystems of the audio amplifier system. The VCA subsystem is constructed using THAT 2180C (THAT Corporation) and OP 275 (Analog Devices).

Figure 2: VCA Circuit Configuration and Gain Measurement Setup

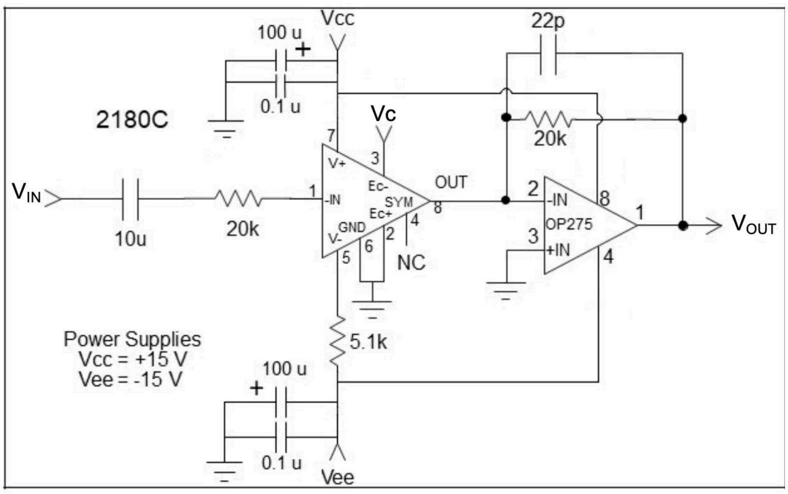
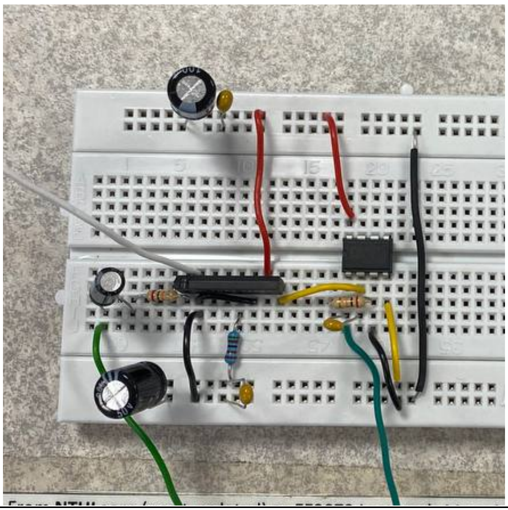


Figure 3: VCA circuit setup



During the setup process, firstly, I finished the circuit setup and cleared a short circuit test to make sure there is no short circuit in the connection. After short circuit test, connect V_C of the VCA to pin AO 1 of NIELVIS II and connect V_{IN} to the NI ELVIS function generator. Set FGEN to generate a 1 kHz sinusoidal waveform.

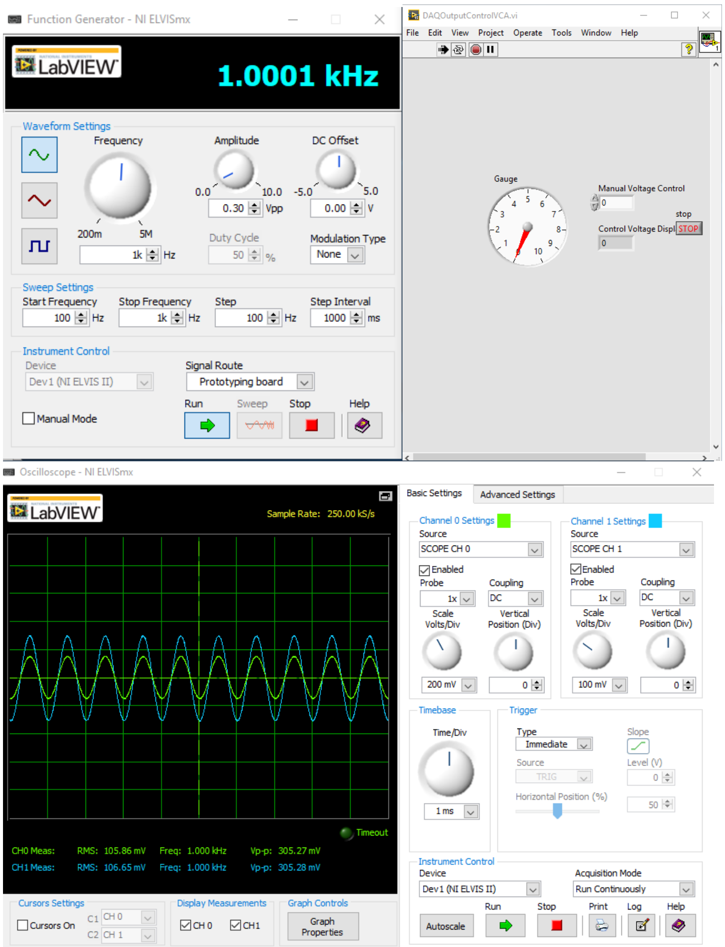


Figure 4. Waveform output with 1kHz sinusoidal waveform

I then vary the peak-to-peak amplitude (V_{pp}) of the sinusoidal waveform with the values given in Table 1 and record down the V_{pp} of the VCA output as well as Measured Gain (dB)
(Theoretical Gain (dB) = 20 $\log_{10}(V_{OUT} / V_{IN})$)

V_{IN} (Vpp)	V_C(V)	V_{OUT}(Vpp)	Measured Gain = V_{OUT}/V_{IN}	Measured Gain (dB)	Theoretical Gain (dB)
1.1	0.5	0.00121	0.0011	-59.1721463	-81.96721311
0.59	0.36	0.00155	0.002627119	-51.61040627	-59.01639344
0.52	0.18	0.0177	0.034038462	-29.36060155	-29.50819672
0.33	0.06	0.10632	0.322181818	-9.837979439	-9.836065574
0.3	0	0.305	1.016666667	0.143571693	0
0.18	0.06	0.553	3.072222222	9.749052524	9.836065574
0.1	0.12	0.989	9.89	19.90392583	19.67213115
0.1	0.15	1.73	17.3	24.76092206	24.59016393

Table 1: Gain Measurement

Using the data we obtained from Table1, I plot the graph of both Measured Gain (dB) and Theoretical Gain (dB) versus V_C on Microsoft Excel. Can observe a decrease of both Measured Gain and Theoretical Gain as V_C increases. And the decrease of Measured Gain gets smaller compared to Theoretical Gain which might be due to heat the circuit produced during the operation.

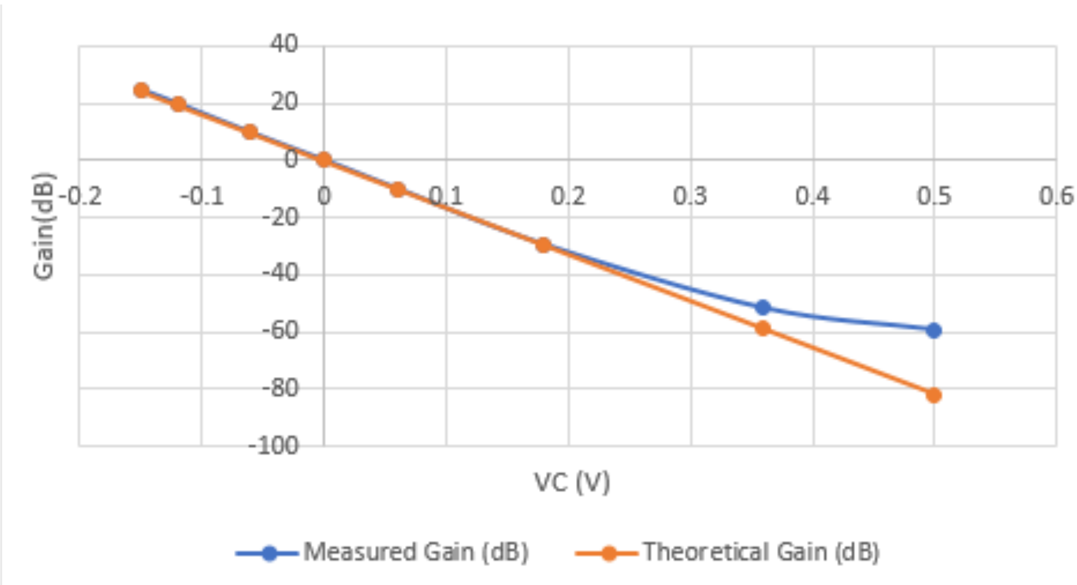


Figure 5. Graph of Gain(dB)(Measured and Theoretical) vs V_C

Chapter 3 Power Amplifier Subsystem

The Power Amplifier (PA) is the second of the subsystems of the overall audio amplifier. The purpose of the PA is to provide power amplification to drive the load (speaker). It requires integrated circuit (IC) LM380N. It is strongly suggested to ground the pin7 separately to reduce any unwanted errors.

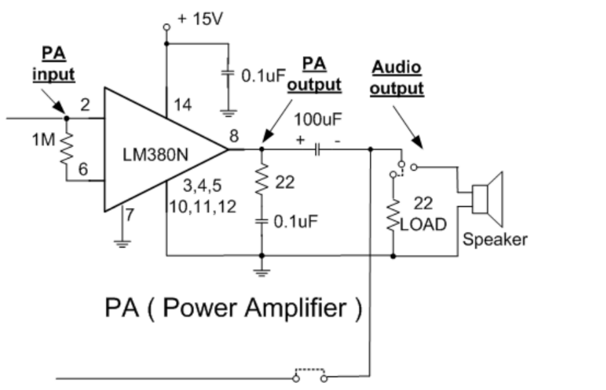


Figure 6. Schematic Diagram of Power Amplifier circuit

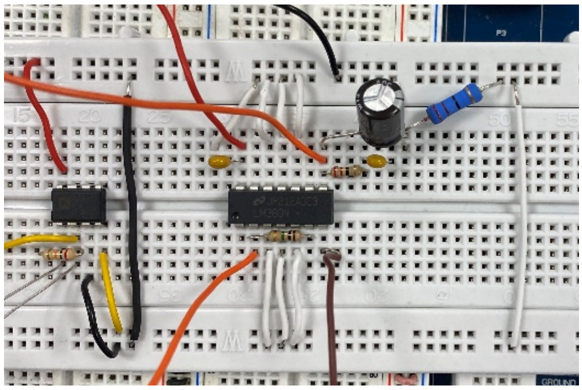


Figure 7. Power Amplifier circuit setup

I then launched FGEN (1kHz sinusoidal waveform with peak-to -peak amplitude of V_{PP} = 0.1V) and Scope from NI ELVIS. Connect the FGEN to PA input and connect Scope CH0 to the input of PA and CH1 to the output of PA respectively. Below is the capture of the peak-to-peak (V_{PP}) waveform.

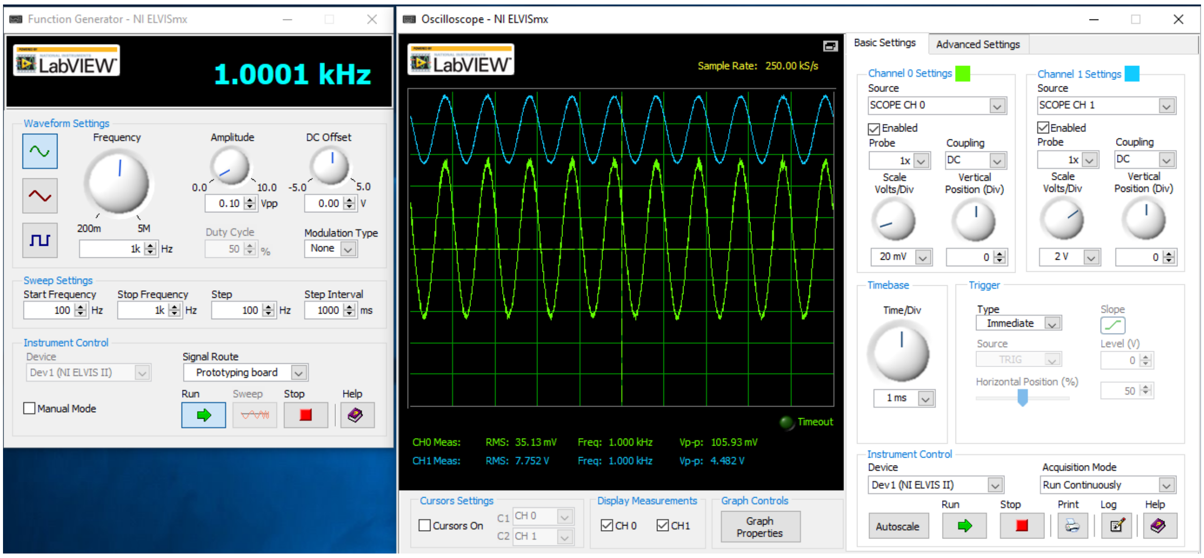
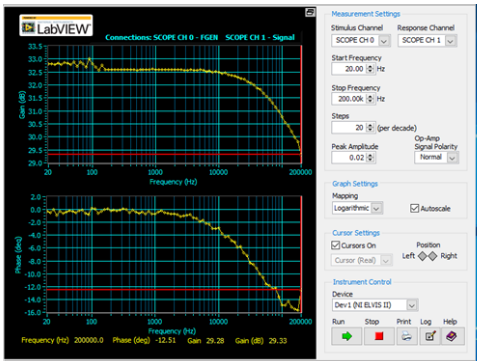
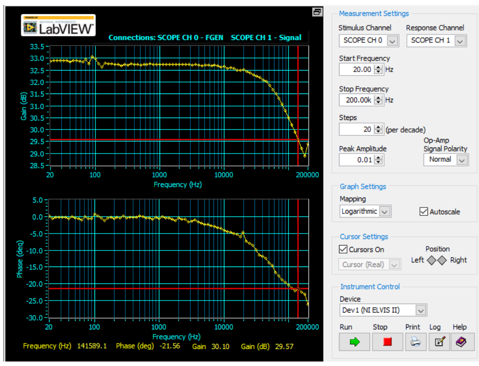


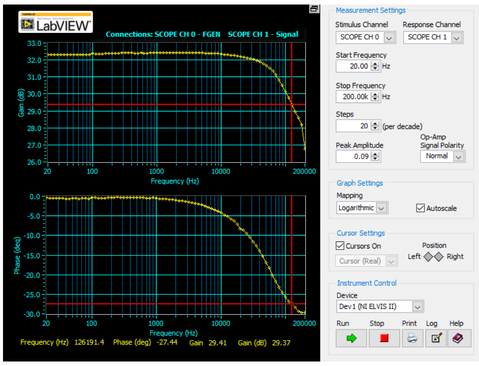
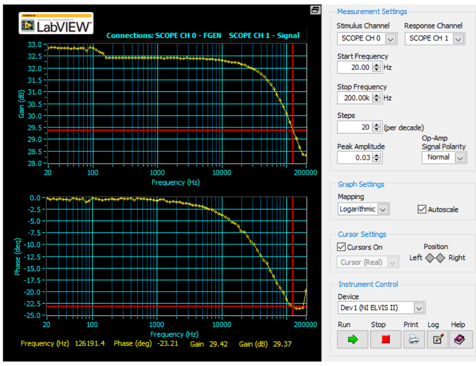
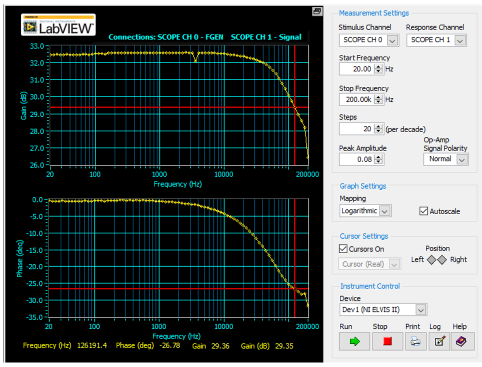
Figure 8. FGEN 1kHz sinusoidal waveform

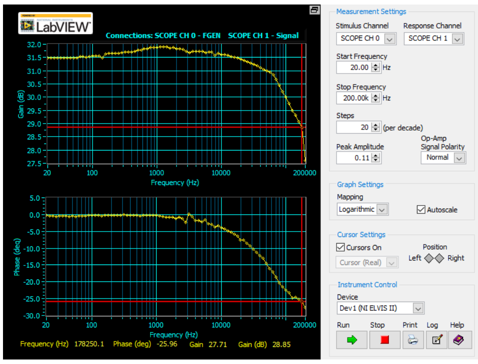
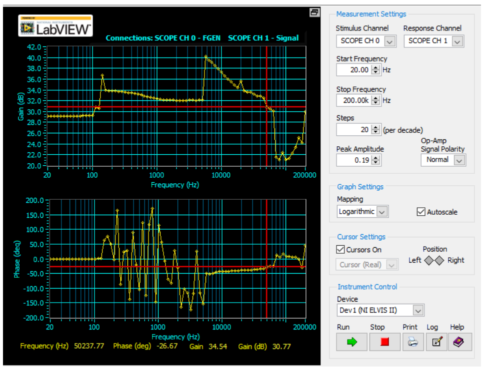
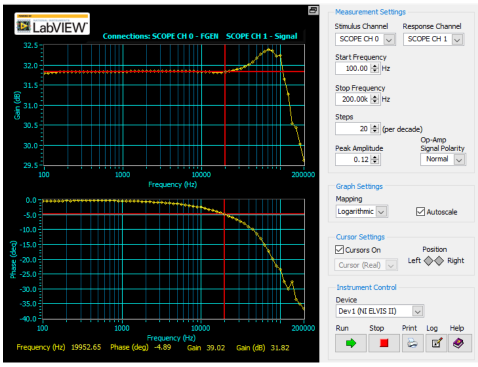
Closed the Scope and launched the Bode Analyzer to return the frequency response of Bode plot of the PA circuit, which is able to characterize the PA. Connect the FGEN and Scope CH0 to the PA input as the Stimulus Channel for the Bode Analyzer and connect Scope CH1 to the PA output as the Response Channel for the Bode Analyzer. (Start/Stop Frequency: 100Hz/200Hz, Steps: 20 per decade, Peak Amplitude: V_P=0.02V). The window capture is shown below.

Figure 9. Bode Plot with peak-to-peak amplitude v_{pp}=0.02V

I then repeat the procedure with different amplitude of VPP according to my matriculation number. Below are window captures of the results.

VP(v)	Bode Analyzer Window Capture
0.02	
0.01	

<table>
<tr><td>0.09</td><td>
</td></tr>
<tr><td>0.03</td><td>
</td></tr>
<tr><td>0.08</td><td>
</td></tr>
<tr><td>0.10</td><td>
</td></tr>
</table>

0.11	
0.19	
0.12	

I have observed that values of frequency response increase with input peak amplitude V_P and image of *Frequency-Gain* became distorted when peak amplitude reached 0.19V. Also, the Bode Analyzer shows "low-pass" filter since Gain decrease drastically with the increase of frequency. During the measurements of frequency response on Bode Analyzer, the temperature of IC LM380N increased, which might be due to the connection instability. Hence, I changed wires that are too short with longer wires to make sure all wires are fully inserted into the circuit board.

Chapter 4 Volume Unit Meter Subsystem

The Volume Unit Meter (VU Meter) is the third of the subsystems of the overall audio amplifier system. The purpose of the VU Meter is to measure the output signal amplitude from the PA subsystem and feedback to control the input of the PA subsystem. It is constructed using operational amplifier (op-amp) integrated circuit (IC) CA3140.

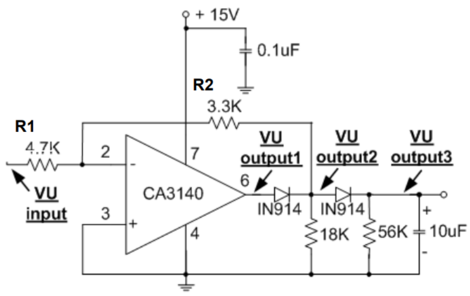


Figure 10. Schematic Diagram of VU Meter Subsystem

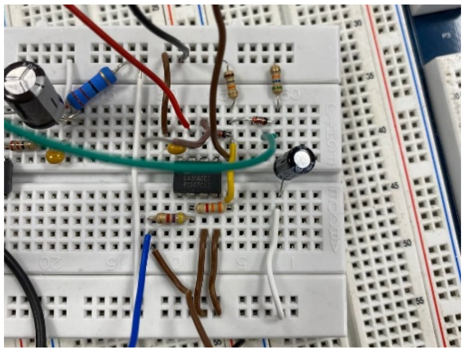


Figure 11. VU Meter circuit setup

Connect the FGEN to the VU Meter input VU_{input}. Connect Scope CH0 to VU_{input} and Scope CH1 to $VU_{output1}$, $VU_{output2}$, $VU_{output3}$ respectively. Capture signal waveform from each output as shown below.

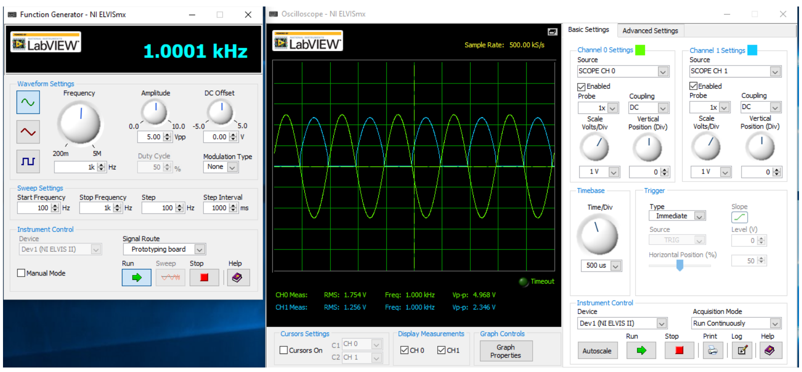


Figure 12. $VU_{output1}$

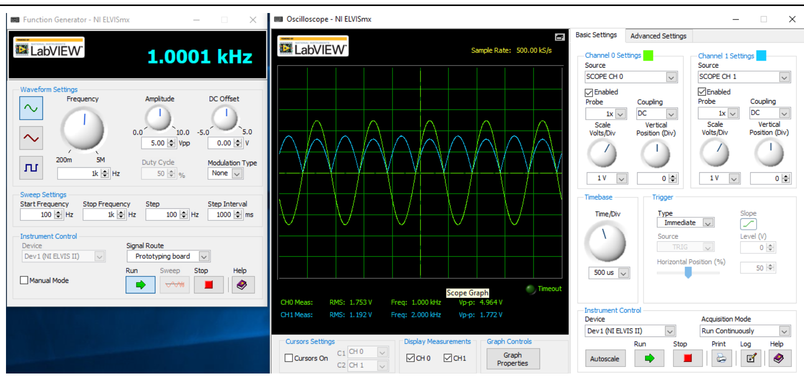


Figure 12. $VU_{output2}$

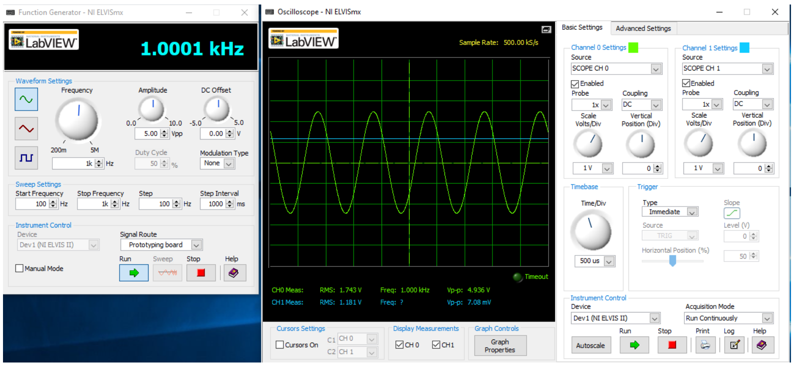


Figure 13. $VU_{output3}$

It is observed that VU_{outpu1} displays a positive half-wave rectified waveform which only appears when input voltage is negative and the frequency of the input and output waveform is the same. $VU_{output2}$ displays a positive full-wave rectified waveform and the frequency of the input and output waveform is the same. $VU_{output3}$ displays a constant output waveform.

I repeated the procedure with different peak-to-peak amplitude of VU_{input} provided in Table 2 and obtained $VU_{output1}$, $VU_{output2}$ and $VU_{output3}$ and computed the Measured Gain. Shown in the table below.

$VU_{input}(V_{pp})$	$VU_{ouput1}(V_{pk})$	$VU_{ouput2}(V_{pk})$	$VU_{ouput3}(V_{RMS})$	Measured Gain = $2VU_{output2}/VU_{input}$
5	2.351	1.772	1.81	0.7088
9.1	3.818	3.183	2.563	0.6996
4.59	2.204	1.623	1.055	0.7072
3.52	1.815	1.246	0.712	0.7080
2.53	1.45	0.898	0.406	0.7099
1.5	1.059	0.534	0.127	0.7120
0.58	0.685	0.208	0.007	0.7172
0.2	0.506	0.0766	0.0018	0.7660

Table 2: Gain Measurement

Used the obtained value and plotted the graph of Measured Gain versus VU_{input} using Microsoft Excel.

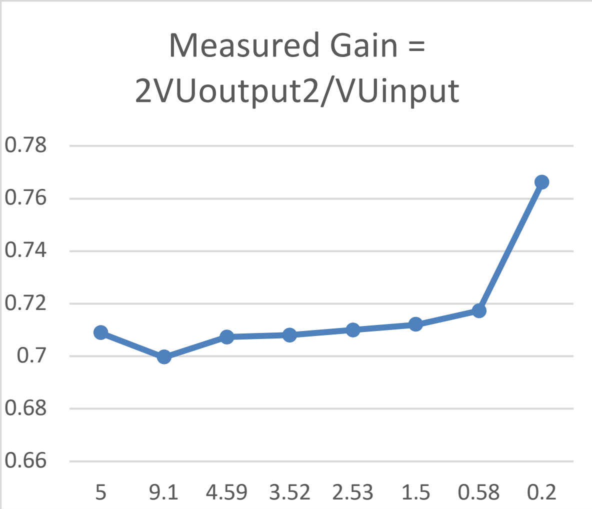


Figure 14. Measured Gain vs VU_{input}

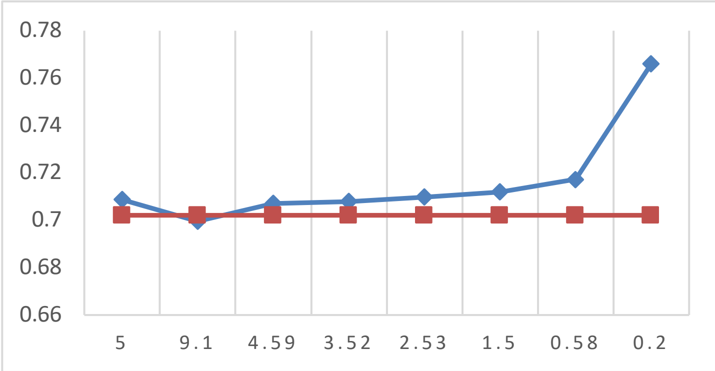


Figure15. Theoretical Gain and Measured Gain

Theoretically, output gain will not change with the change of input value($|-R_2/R_1| = -3.3k/4.7k = 0.7021$). Output voltage gain is independent from input voltage and its only depends on the value of R_1 and R_2. Compared measured gain and theoretical gain, the result aligns when input voltage has bigger peak-to-peak value. The difference between measured gain value and theoretical gain increase as input voltage decrease.

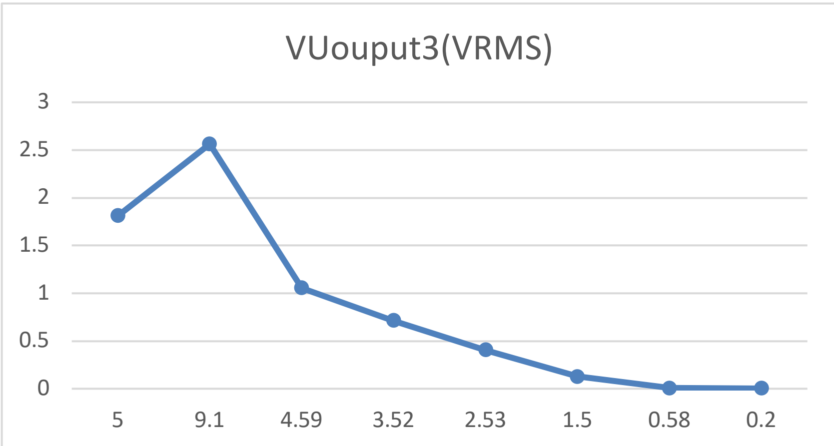


Figure 16. $VU_{output3}$ vs VU_{input}

It is observed that $VU_{ouptut3}$ increase smoothly as the amplitude of VU_{input} increases except for the outliner when $VU_{input} = 5V$. The functionality of VU meter could be meet since value of $VU_{output3}$ can reflect the change of VU_{input}. Hence it can feedback to the controller to control the input amplitude to the PA.

Chapter 5 Integration for Audio Amplifier System

The Audio Amplifier System includes all three subsystems VCA, PA and VU Meter constructed together. It is so far an open system without feedback.

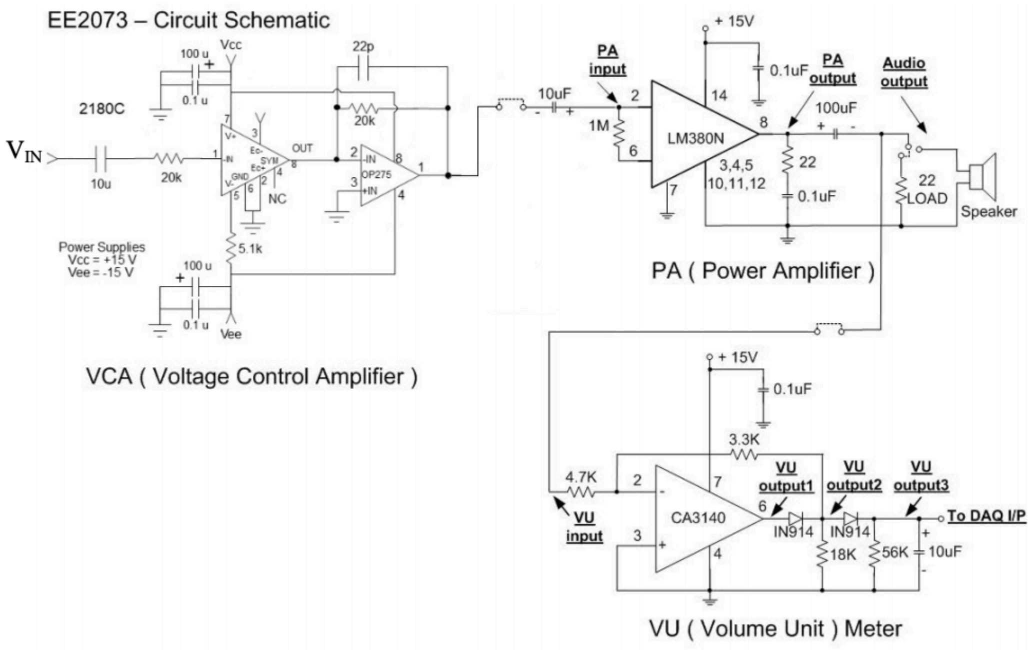


Figure 16. Schematic Diagram of Audio Amplifier System

Connect +15V and -15V of the IC to the corresponding DC power supply of NI ELVIS II. Connect FGEN of NI ELVIS II to the Audio input of the VCA. Connect Scope to the Audio input of the VCA and the Audio output respectively. Set FGEN to generate a 300 Hz sinusoidal waveform.

Repeating the procedure with different peak-to-peak amplitude of the sinusoidal waveform according to *table 3*, we can obtain the following values as shown in the table below.

Audio Input (V_{pp})	V_C (V)	Audio Output (V_{pp})	Gain (dB)	$VU_{output3}$ (V_{RMS})
1.1	0.50	0.02462	-35.95841118	0.00377
0.59	0.36	0.03744	-23.26592402	0.00206
0.52	0.18	0.75267	2.91814506	0.01278
0.33	0.06	4.557	22.52439975	1.019
0.3	0.00	12.678	31.90725186	3.918
0.18	-0.06	14.754	37.35759567	4.476
0.1	-0.12	16.075	42.53939471	4.97
0.11	-0.15	0.00148	-24.97185155	6.04(Ignored)

Table 3. Audio Amplifier System Testing

Using the obtained values, we plotted a graph of Gain (dB) versus V_C using Microsoft Excel as shown below.

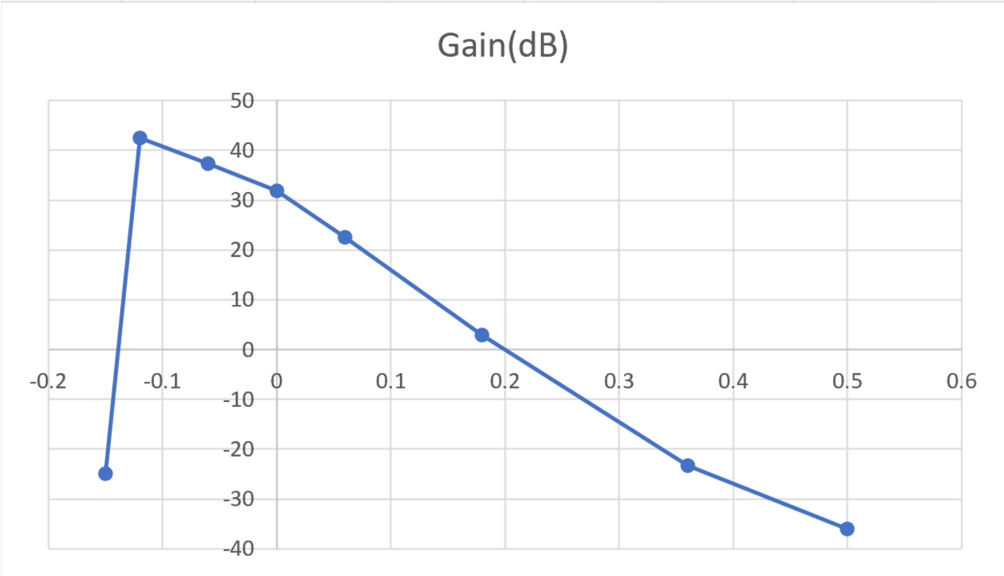


Figure 17. Gain (dB) vs V_C

When set the frequency of the FGEN to 100kHz, the waveform will be distorted due to saturation (It exceeds the characteristics of the audio amplifier). A problem I faced during the integration operation was that the IC THAT 2180C of the VCA was inserted unstably which resulted in distorted output. So I changed to another IC for more stable connection.

Chapter 6 Manual Volume Control for Audio Amplifier System

The manual volume control for audio amplifier system provides the necessary adjustment of the volume control based of the indicator, the reading of VU meter. It is considered as open-loop system without feedback path in the system. The 22Ω load resistor is replaced by a speaker as Audio output.

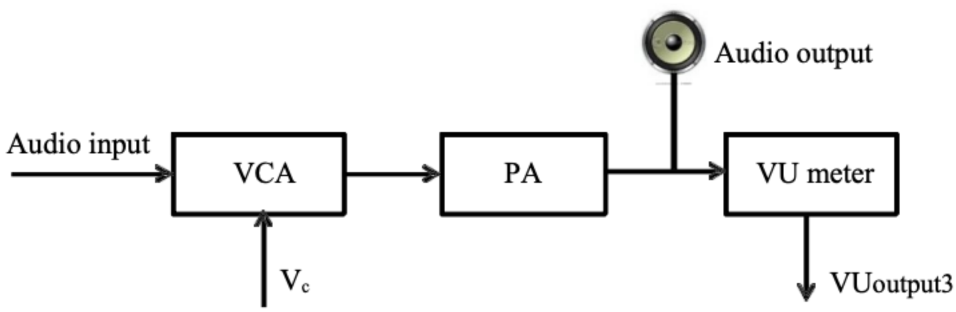


Figure 18. Block Diagram Representation of open-loop System

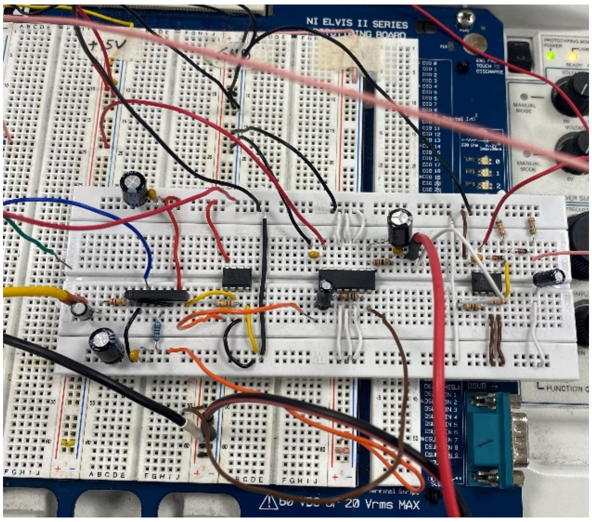


Figure 19. Manual Volume Control Audio Amplifier System setup

The manual volume control for audio amplifier system is implemented in LabVIEW. The control voltage range of the VCA should be -0.18V to +0.54V. Connect FGEN of NI ELVIS II to the Audio input of the VCA and connect the Audio output from the PA to a speaker. Generate the FGEN with a 300Hz sinusoidal waveform. Below are window captures.

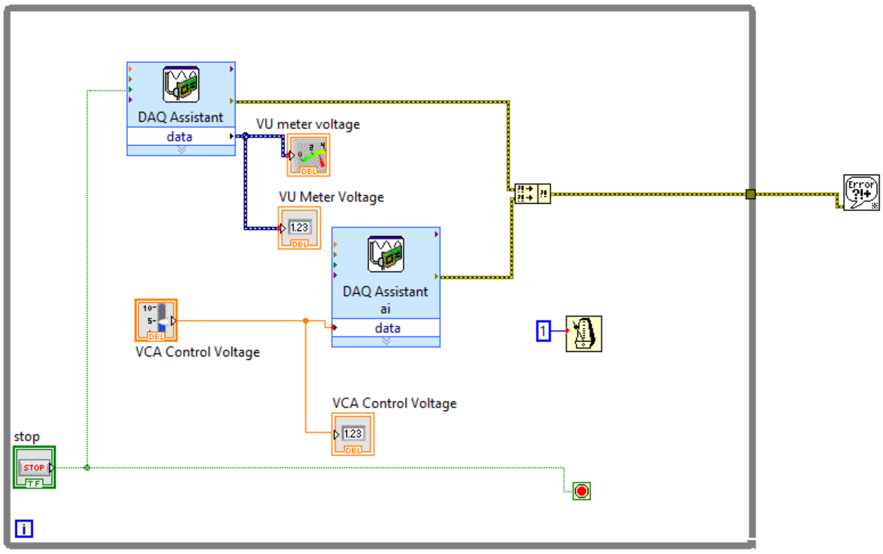


Figure 20. Manual Volume Control Block Diagram

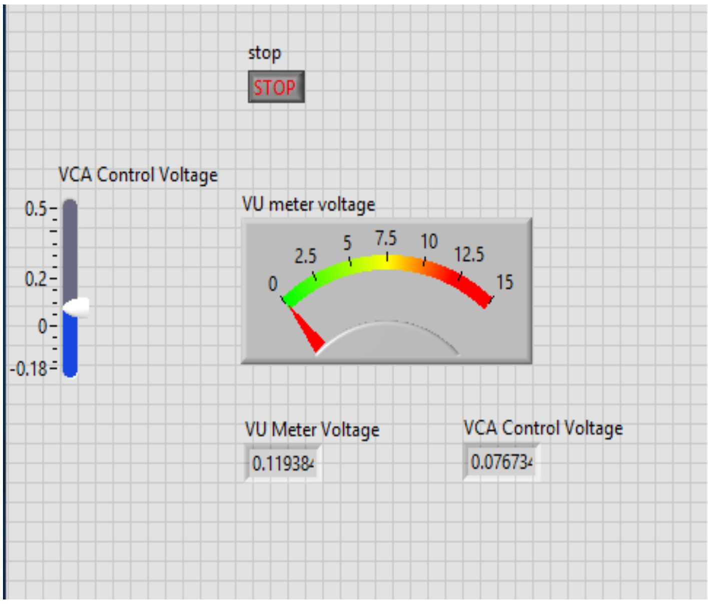


Figure 21. Front Panel Diagram of Manual Volume Control

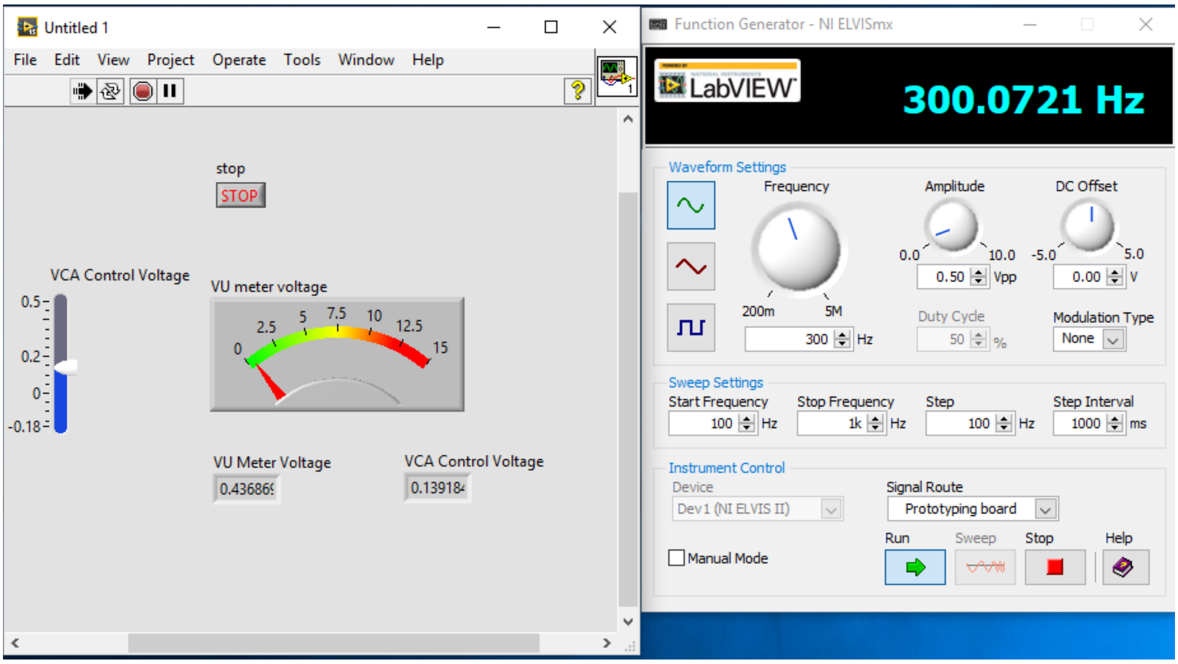


Figure 22. Output with FGEN: sinusoidal waveform (f = 300Hz)

When using FGEN as circuit input, a clear sound was produced when VCA Control Voltage was around 1V. The volume of the audio output varies with different VCA Control Voltage. At certain value of VCA Control Voltage, audio will disappear as it exceeds the range of the output. When computer is connected as circuit input, different levels of distortion happen with different types of songs. Distortion of the audio (noise) gets more obvious with the increase of volume.

A problem encountered during the operation was that Audio output was unstable from time to time while there is no change at input. Thus I checked the connection of each component and wires of the circuit to ensure more stable connection.

Chapter 7 Automatic Volume Control for Audio Amplifier System

The automatic volume control for audio amplifier system can be considered as a closed-loop system with a feedback path which passes through a suitable control algorithm to be executed by the computer. The control algorithm is implemented in the LabVIEW. In ideal condition, the audio output should remain constant under the automatic volume control.

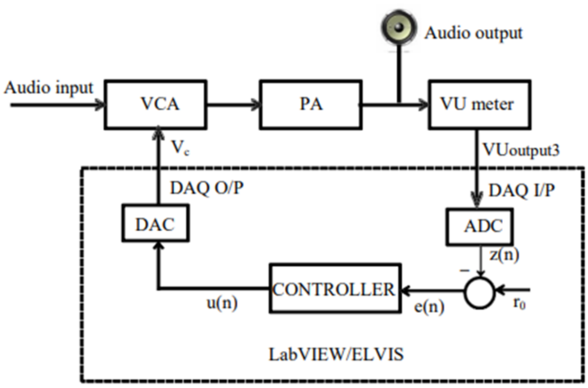


Figure 23. Block Diagram of Closed-loop System

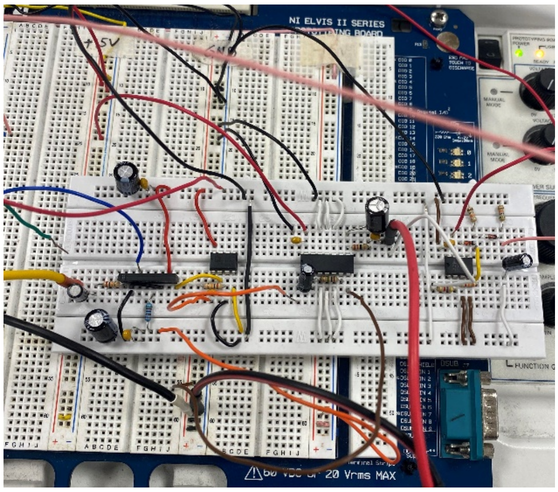


Figure 24. Automatic Volume Control setup

The window captures of the LabVIEW setup are shown below.

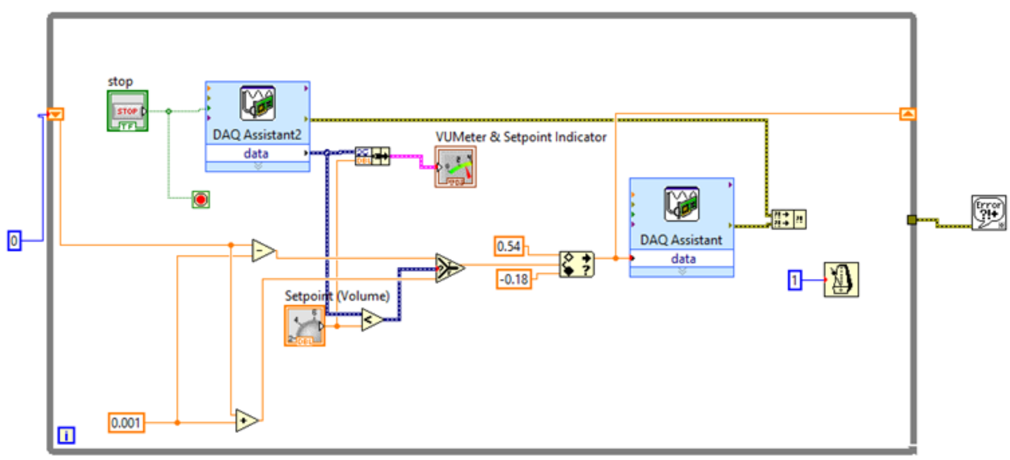


Figure 25. Automatic Volume Control Block Diagram

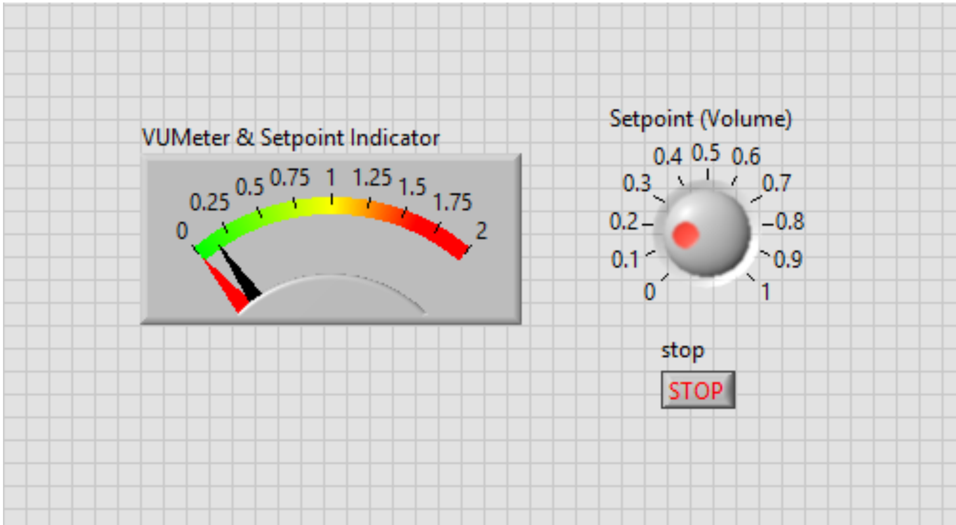


Figure 26. Diagram of Front Panel

(Black needle: Set point value r_0; Red needle: Value of z(n))

As observed during the operation, as r_0 of VU Meter increase, the volume of the sound will increase as well. Sound quality of the output is not consistent with distortion that cannot be tolerated, which is probably due to the connection stability or grounding condition of the circuit. And there exists fluctuation in the sound output as well(might due to the feedback loop of the system).

Chip OP275 – Operational Amplifier (in VCA section) will get heated up during the operation. Large amount of current is needed to for amplification purpose. It will produce more heat in the circuit during operation. Possible solutions for overheating problem.

(1) Add another Power Amplifier (LM380N) in the circuit.
(2) Ground all the GRD pins of the circuit individually instead of sharing a common ground.
(3) Use a heat sink for the IC chips.

Chapter 8 Conclusion

In general, I've gained more hands-on experience through EE2073 *Introduction to EEE Design and Project.* I have had better idea on how to connect a circuit better and come up with better solutions when I encountered problems in real life. I am also more familiar with using LabVIEW and NI ELVIS II. I believe this will definitely be helpful when it comes to more complicated projects in the near future.

References

[1] EE2073 EE2073 *Introduction to EEE Design and Project* Lab Manaul_AY19-20 Sem2