Final Project Report

CSCE 325-511: Electronics | Fall 2021 | Dr. Silva

1. Introduction

The purpose of this report is to show the developmental process and final results of the lab. The requirement of the project was to build a multi-stage amplifier with the gain 30dB assuming that the load impedance is 20Ω, with maximum peak-to-peak input voltage of 20mV. The Bipolar Junction diode that will be used in this project is 2N3904. The input impedance of the configurations should be more than 20kΩ, and result in amplification of the input.

2. Design & Calculations

In the advanced report we recognized the given values and analysis of the circuit. Furthermore, the three stages of amplification are used, since the gain is in dB, it needs to be changed in voltage, the formula gain = 20 log(Av) is used to find out the voltage gain in Av . Since gain = 30dB we have the following value:

$30 = 20\log(Av)$

$1.5 = \log(Av)$

$Av = 10^{1.5}$

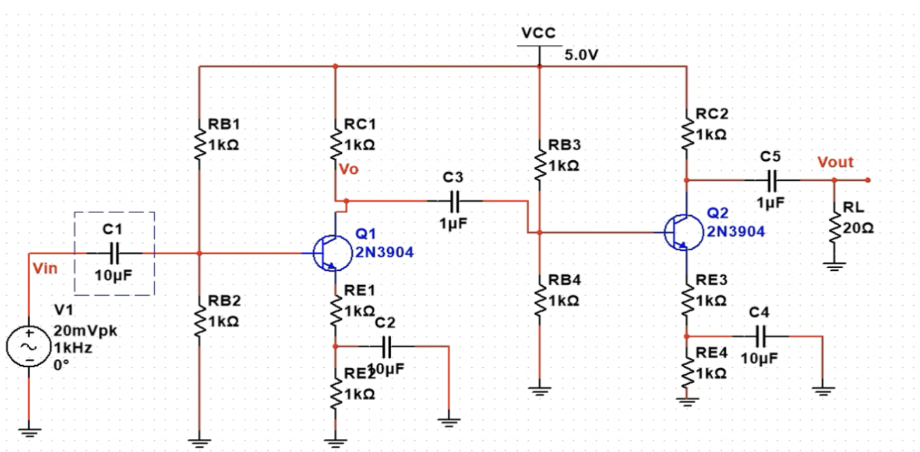
$Av = 31.63$

$Av \approx 32$

From the above calculation of the voltage gain Av should be around 32. So to get that, our team has decided to use first stage amplification voltage gain (Av1) = 16, second stage amplification voltage gain (Av2) = 2, hence getting components values of:

Voltage gain $\lvert Av \rvert$	32
Input Impedance Ri	>= 20kohm
Load Impedance R_L	= 20 ohm
β	=100
Vo,pk	600mApK

Our original design looked like:



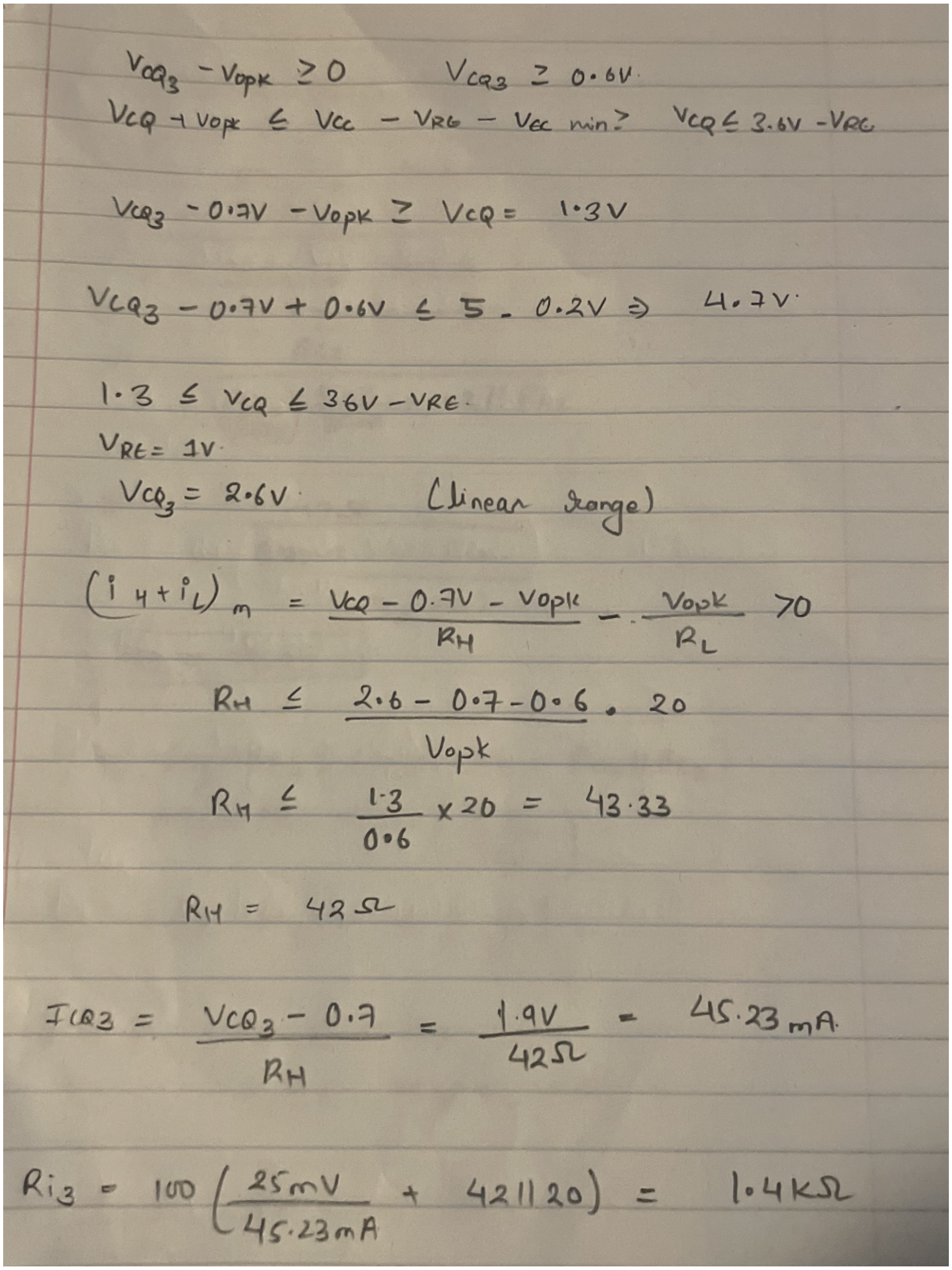
Following similar formulas from the advanced report, which were

$A_{V2} = (R_{C2} \| R_L) / (R_{E3} + r_{e2})$

$A_{V1} = (R_{C1} \| Z_{in}) / (R_{E1} + r_{e1})$

Z_{in} is the input impedance of the second stage and $A_V = A_{V1} \times A_{V2}$.

For the final report in the multistage circuit for audio amplification we implemented 3 BJT's instead of 2, so our first attempt for calculations are attached below:



$V_{CQ_3} - V_{opk} \geq 0 \qquad V_{CQ3} \geq 0.6V$

$V_{CQ} + V_{opk} \leq V_{CC} - V_{RE} - V_{EC\,min}? \qquad V_{CQ} \leq 3.6V - V_{RE}$

$V_{CQ_3} - 0.7V - V_{opk} \geq V_{CQ} = 1.3V$

$V_{CQ3} - 0.7V + 0.6V \leq 5 - 0.2V \Rightarrow 4.7V$

$1.3 \leq V_{CQ} \leq 3.6V - V_{RE}$

$V_{RE} = 1V$

$V_{CQ_3} = 2.6V$ (Linear range)

$(i_H + i_L)_m = \frac{V_{CQ} - 0.7V - V_{opk}}{R_H} - \frac{V_{opk}}{R_L} > 0$

$R_H \leq \frac{2.6 - 0.7 - 0.6}{V_{opk}} \cdot 20$

$R_H \leq \frac{1.3}{0.6} \times 20 = 43.33$

$R_H = 42\Omega$

$I_{CQ3} = \frac{V_{CQ_3} - 0.7}{R_H} = \frac{1.9V}{42\Omega} = 45.23\,mA$

$R_{i3} = 100\left(\frac{25mV}{45.23mA} + 42 \| 20\right) = 1.4k\Omega$

$R_L << R_{i2} \Rightarrow R_{C_2} \leq 140\Omega$

$$I_{C2} = \frac{5V}{140\Omega} = 35mA.$$

$$\boxed{R_{H2} = \frac{V_{RE2}}{I_E} = 142\Omega}$$

$$8 = \frac{R_{C2}}{\left(\frac{V_T}{I_{CQ2}}\right)\frac{25mV}{35mA} + 142 \,||\, R_{L2}}$$

$$8 = \frac{140\Omega}{0.71 + \frac{142\ R_{L2}}{R_{L_2} + 142}}$$

$$\boxed{R_{L_2} = 19.04\Omega}$$

$$R_{i_2} = R_{B_3} \,||\, R_{B_4} \,||\, (1+\beta)(r_{e_2} + R_{H2} \,||\, R_{L_2})$$

$$R_{i_2} = R_{B_3} \,||\, R_{B_4} \,||\, 100\left(\frac{R_{C_2}}{A_{V_2}}\right)$$

$$R_{i_2} = R_{B_3} \,||\, R_{B_4} \,||\, 100\left(\frac{140}{8}\right)$$

$$R_{i_2} = R_{B_3} \,||\, R_{B_4} \,||\, 1.75K\Omega$$

Suppose $R_{B_3} = 2K\Omega$

Now

$$\frac{R_{B\cancel{3}4}}{R_{B_3} + R_{B_4}} \cdot 5V = V_{CC} - V_{RE_2} - 0.7$$

$$\frac{R_{B_4}}{1k\Omega + R_{B_4}} \times 5V = 3.3V.$$

$$\frac{RB_4}{1K\Omega + RB_4} = 0.66$$

$$RB_4 = 660\Omega + 0.66 RB_4$$

$$RB_4 = 1.9K\Omega$$

$$Ri_2 = RB_3 \parallel RB_4 \parallel 3.5K\Omega$$

$$Ri_2 = \left(\frac{1K\Omega \cdot 1.9K\Omega}{1K\Omega + 1.9K\Omega}\right) \parallel 3.5K\Omega$$

$$Ri_2 = (0.655K\Omega) \parallel 3.5K\Omega$$

$$Ri_2 = 551\Omega$$

$$\boxed{RC_1 = 300\Omega}$$

$$IC_1 = \frac{5V}{300\Omega} = 16mA$$

$$RH_1 = \frac{VRE}{IE} = \frac{1}{16.\,mA} = 59.99\Omega = \boxed{60}$$

$$4 = \frac{RC_2}{\frac{25mV}{16.67mA} + 60\Omega \parallel RL_1}$$

$$4 = \frac{300\Omega}{1.5 + \frac{60 \times RL_1}{RL_1 + 60}}$$

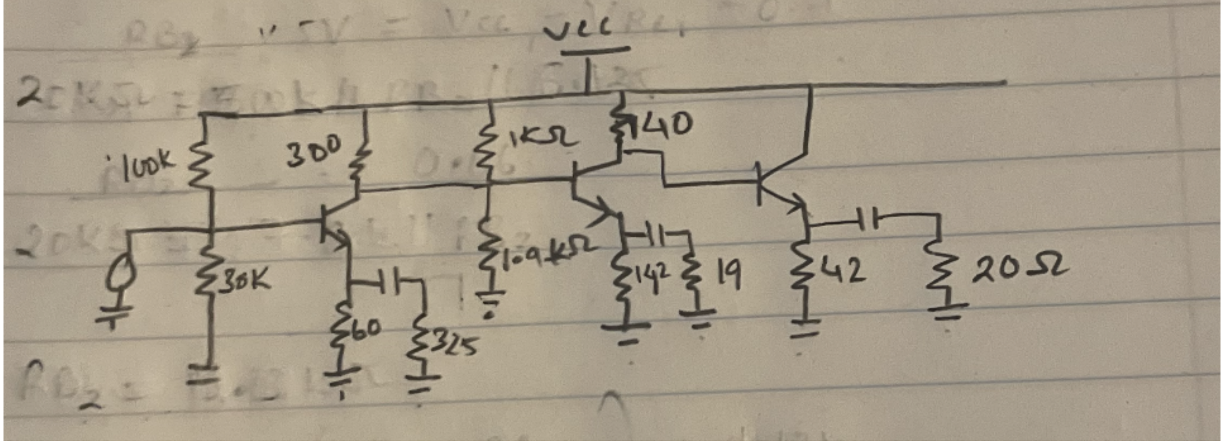
$$R_L = 326.66 \simeq 325$$

$$R_i = R_{B1} \parallel R_{B2} \parallel (1+\beta)(r_{e2} + R_{H1} \parallel R_{L2})$$

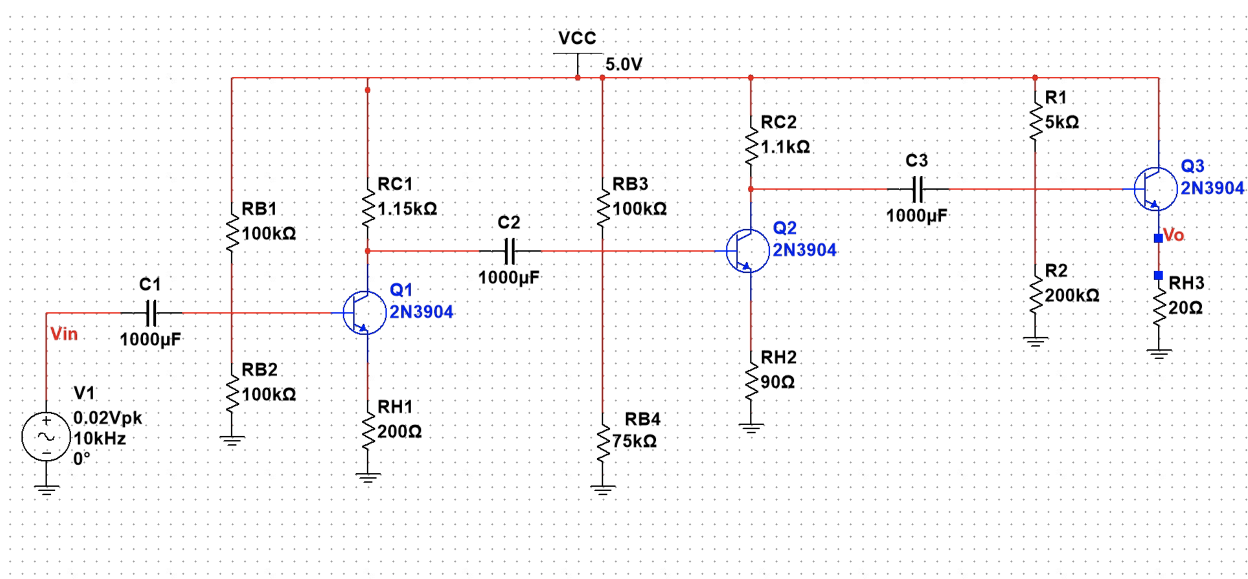
$$R_i = R_{B1} \parallel R_{B2} \parallel (100)\left(\frac{325}{4}\right)$$

$$20\text{k}\Omega = R_{B1} \parallel R_{B2} \parallel 8.125$$

Suppose $R_{B1} = 100\text{k}$ and $R_{B2} = 30\text{k}\Omega$.

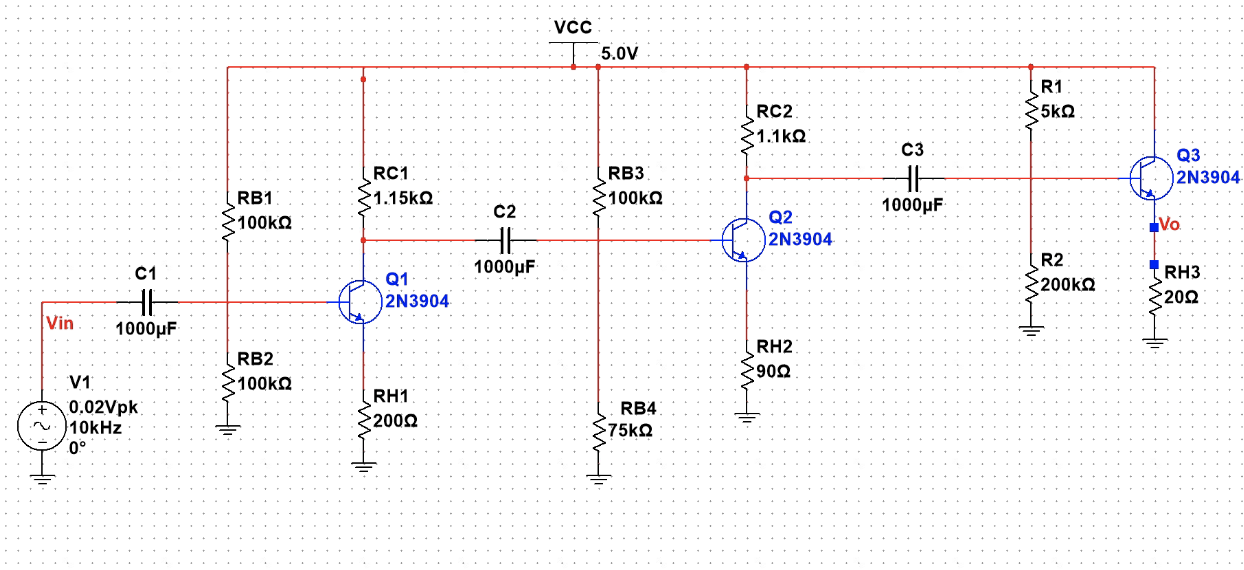


However, with few more alterations of components to get reasonable simulation results our final design was the following:

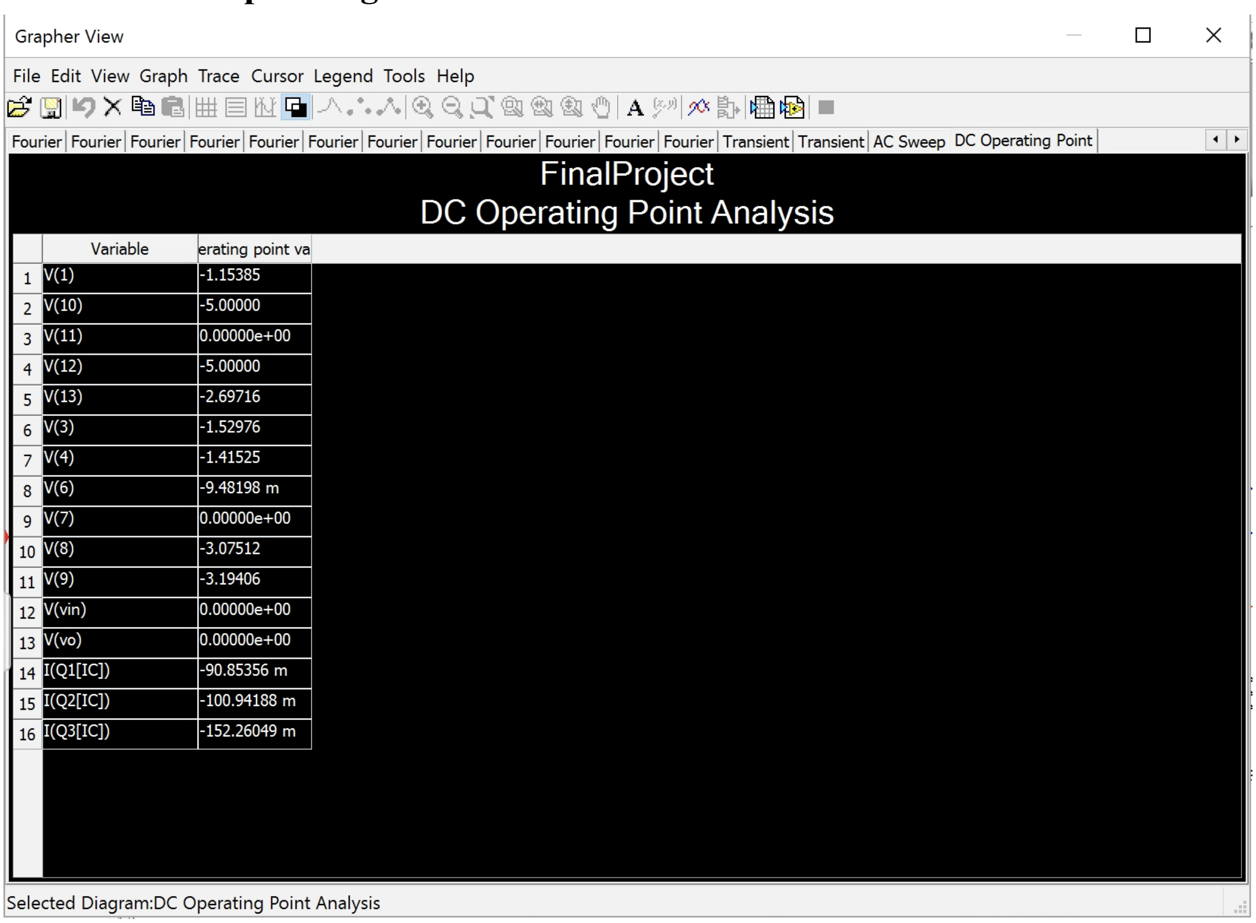


Simulations

3.1 Schematic

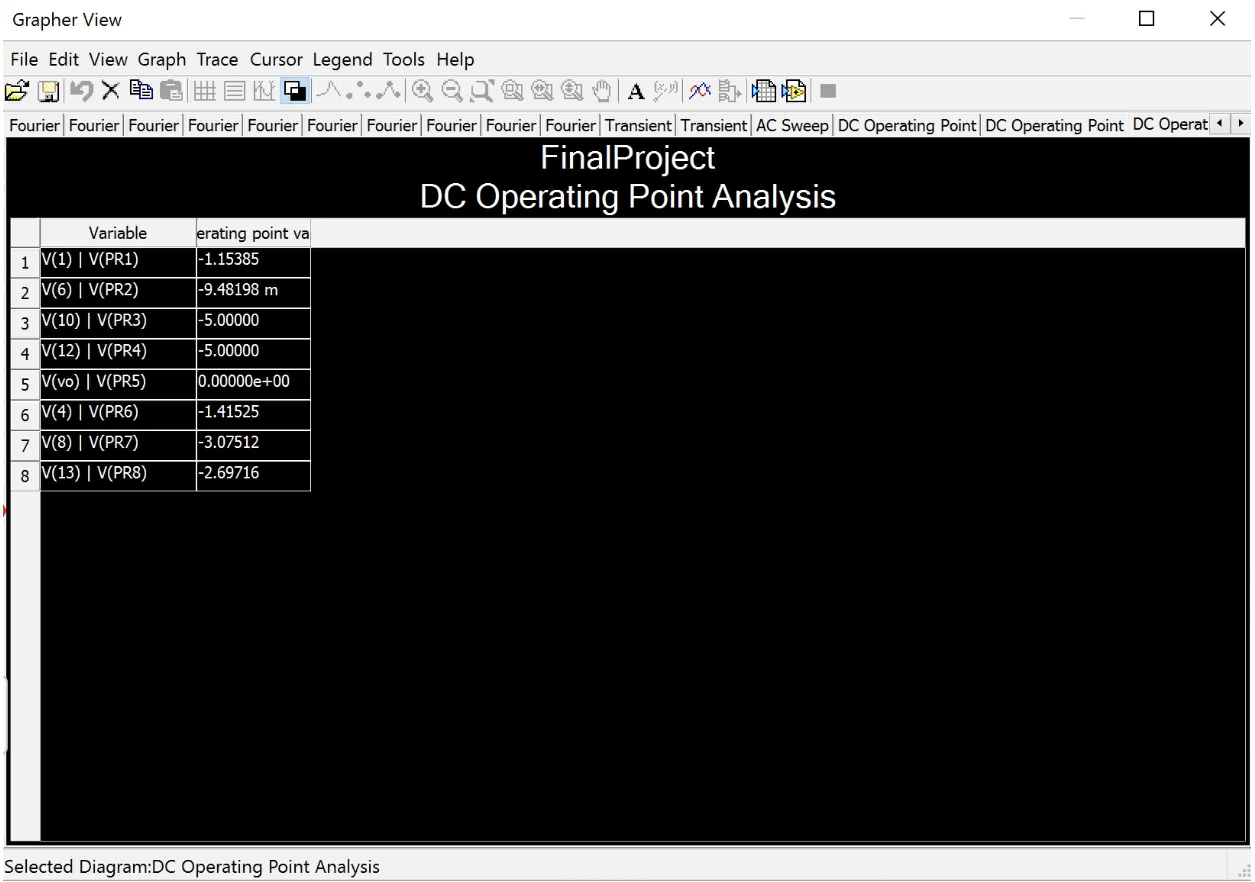


3.2 DC Operating Point



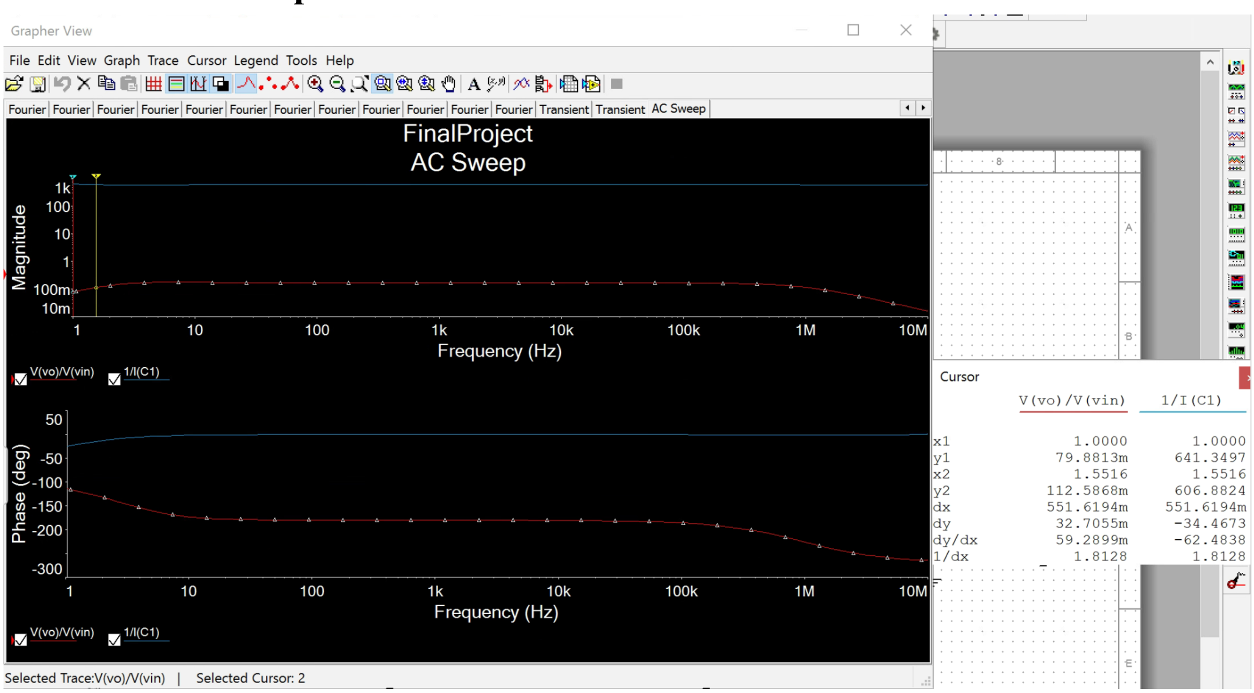
FinalProject
DC Operating Point Analysis

	Variable	erating point va
1	V(1)	-1.15385
2	V(10)	-5.00000
3	V(11)	0.00000e+00
4	V(12)	-5.00000
5	V(13)	-2.69716
6	V(3)	-1.52976
7	V(4)	-1.41525
8	V(6)	-9.48198 m
9	V(7)	0.00000e+00
10	V(8)	-3.07512
11	V(9)	-3.19406
12	V(vin)	0.00000e+00
13	V(vo)	0.00000e+00
14	I(Q1[IC])	-90.85356 m
15	I(Q2[IC])	-100.94188 m
16	I(Q3[IC])	-152.26049 m

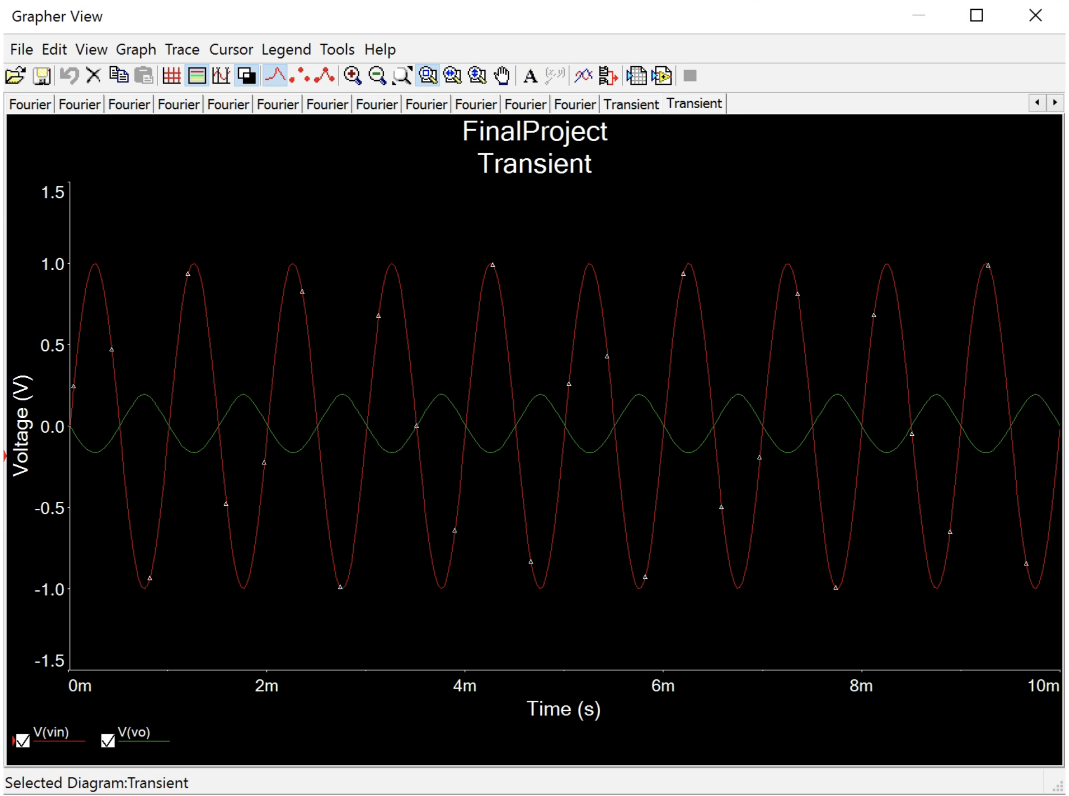


	Variable	erating point va
1	V(1) | V(PR1)	-1.15385
2	V(6) | V(PR2)	-9.48198 m
3	V(10) | V(PR3)	-5.00000
4	V(12) | V(PR4)	-5.00000
5	V(vo) | V(PR5)	0.00000e+00
6	V(4) | V(PR6)	-1.41525
7	V(8) | V(PR7)	-3.07512
8	V(13) | V(PR8)	-2.69716

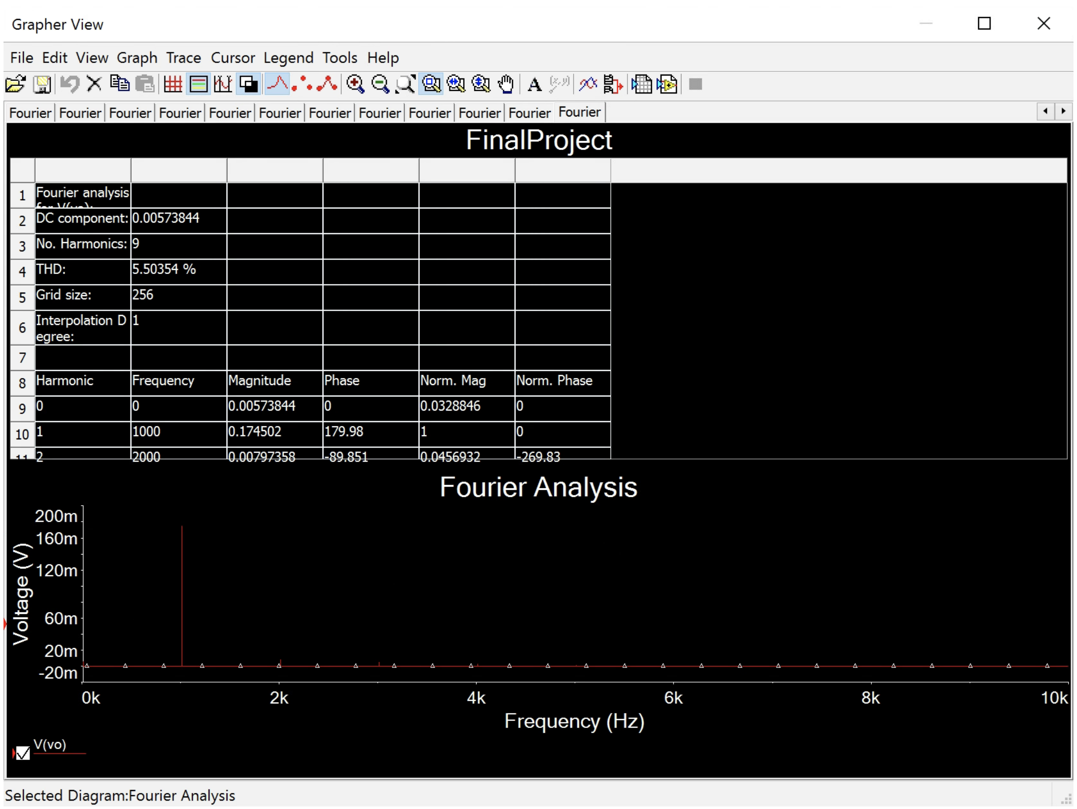
3.3 AC Sweep



3.4 Transient



3.5 Fourier



1	Fourier analysis					
2	DC component:	0.00573844				
3	No. Harmonics:	9				
4	THD:	5.50354 %				
5	Grid size:	256				
6	Interpolation Degree:	1				
7						
8	Harmonic	Frequency	Magnitude	Phase	Norm. Mag	Norm. Phase
9	0	0	0.00573844	0	0.0328846	0
10	1	1000	0.174502	179.98	1	0
11	2	2000	0.00797358	-89.851	0.0456932	-269.83

3. Measurements / Demo

4.1 DC Values

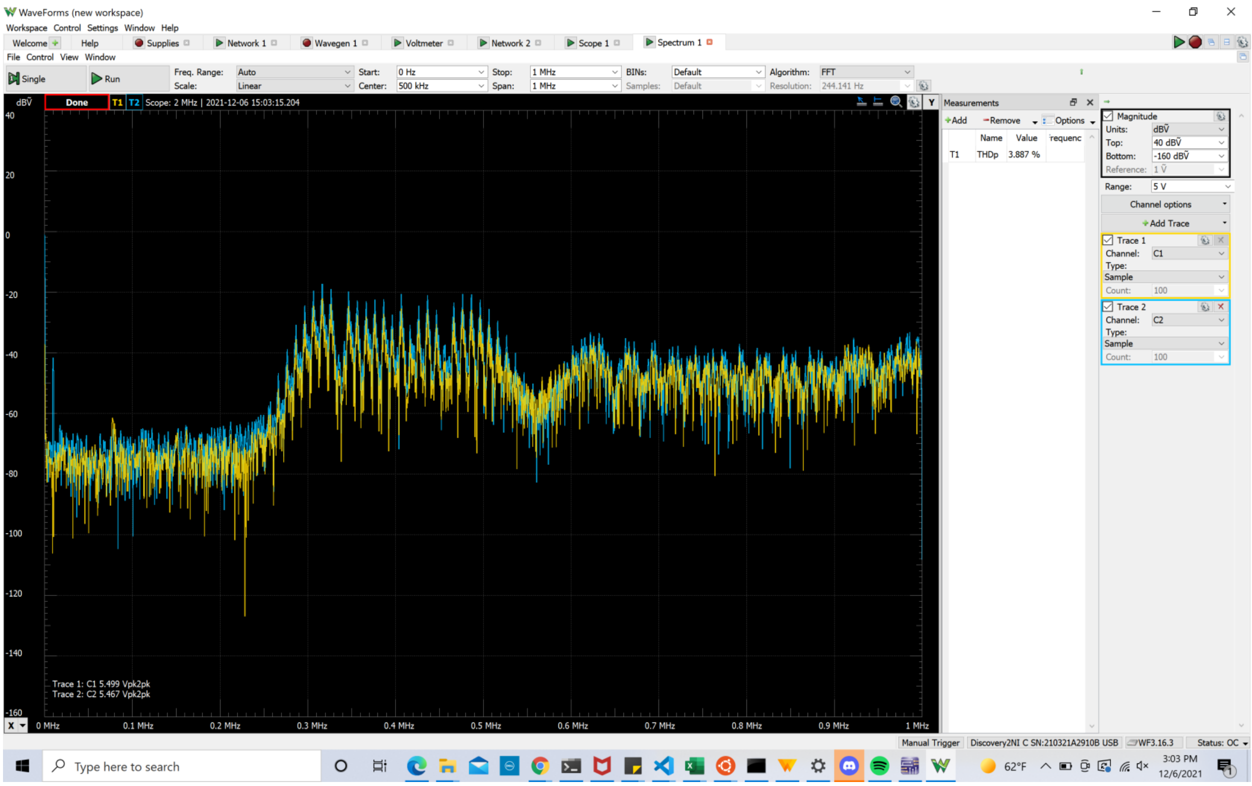
	DC Values
V_{RB2}	1.01 V
V_{RE1}	1.175V
V_{RE2}	3.13 V
V_{RE3}	2.531 V
V_{RC}	4.34 V
V_o	.213 V
I_{C1}	97.34 mA
I_{C2}	114.23 mA
I_{C3}	167.16 mA

4.2 Network Analyzer

4.3 Scope

The scope is shown in the demo video where channel 2 is amplified as it receives an input. We can see the changes in amplification as the volume is increased or decreased in the input.

4.4 THD



4. Data Tables

5.1 Calculations / Simulations / Measurements

	Calculations	**Simulations**	**Measurements**
Gain	30 dB	19.98 dB	7.4285
R_i	-	606.88 m	510.12 m
Transient	-	4.053k	Demo video
THD	-	5.50354%	3.887%

5.2 DC values

DC Values	**Simulations**	**Measurements**
V_{RB2}	1.15 V	1.01 V

V_{RE1}	1.41 V	1.175V
V_{RE2}	3.07 V	3.13 V
V_{RE3}	2.73 V	2.531 V
V_{RC}	5 V	4.34 V
V_o	180 mV	.213 V
I_{C1}	90.85 mA	97.34 mA
I_{C2}	100.94 mA	114.23 mA
I_{C3}	152.26 mA	167.16 mA

5. Conclusion

For this project most of the values between the simulations and measurements were pretty consistent for the circuits. If there were any minor differences, that's probably because of component differences, since we did not use exact values for resistors and capacitors. Despite these differences, we were able to get clear sound using the speaker, which was connected to a MacBook Pro as the input sound. As seen in the demo video, changing the volume on the input changed the amplification on the output, hence making the speaker louder, and showing more fluctuations on the scope (channel 2).