Toronto Metropolitan University
Department of Electrical, Computer, & Biomedical Engineering
Faculty of Engineering & Architectural Science

Course Title:	Electronic Circuits
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Assignment/Lab Number:	Design Project
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Introduction:
This is the final report for the ELE 404 Amplifier Design Project. This design project, which examines a multi-stage amplifier that can comply with a set of specifications, cultivates all of the course material related to Bipolar Junction Transistors (BJT).

Objectives:
Below, the objectives and specifications are listed:

- Power supply: +10 V relative to the ground;
- Quiescent current drawn from the power supply: no larger than 10 mA;
- No-load voltage gain (at 1 kHz): |Avo| = 50 (± 10%);
- Maximum no-load output voltage swing (at 1 kHz): no smaller than 8 V peak to peak;
- Loaded voltage gain (at 1 kHz and with RL = 1 kΩ): no smaller than 90% of the no-load voltage gain;
- Maximum loaded output voltage swing (at 1 kHz and RL = 1 kΩ): no smaller than 4 V peak to peak;
- Input resistance (at 1 kHz): no smaller than 20 kΩ;
- Amplifier type: inverting or non-inverting;
- Frequency response: 20 Hz to 50 kHz (−3dB response);
- Type of transistors: BJT;
- Number of transistors (stages): no more than 3;
- Resistances permitted: values smaller than 220 kΩ from the E24 series;
- Capacitors permitted: 0. 1 μF, 1. 0 μF, 2. 2 μF, 4. 7 μF, 10 μF, 47 μF, 100 μF, 220 μF;
- Other components (BJTs, diodes, Zener diodes, etc.): only from your ELE404 lab kit.

Graphs:
Below are the characteristic Graphs for the BJT:

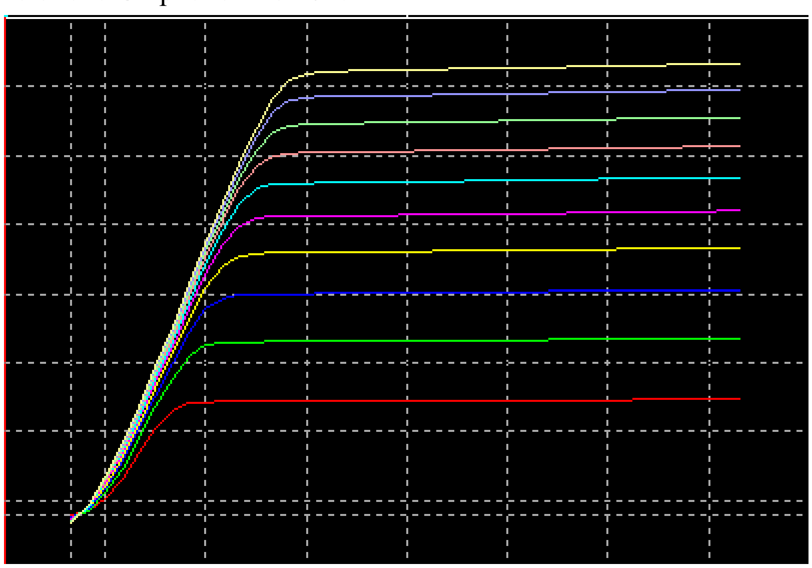


Figure 1. Characteristics Graph for Transistor 1 (CE Amplifier)

Summary of Calculations:
These are the values used in the circuit:

C1	C2	C3
10μF	10μF	220μF

Table 1. Capacitor Values

R1	R2
$90k\Omega$	$62k\Omega$

Table 2. Resistor Values

RE1	RE2	RE3	RC
180Ω	$27k\Omega$	$1k\Omega$	$24k\Omega$

Table 3. Emitter and Collector Resistor Values

I_c	β	V_{cc}	g_m
0.083 mA	100	10 V	3.19×10^{-6} ms

Table 4. Useful Values from Stage 1

Overall Process:

A 2 stage amplifier chosen to get the specifications given in this project. Those specifications being a voltage gain of 50 and Rin of greater than 20 kOhms. The design I presented consists of 2 stages. The first stage is a CE amplifier and the second stage is a CC amplifier. I set the gain to be 50 for the first stage. Since CC stage is the last one the gain would be close to unity which is approximately 1. When calculating overall gain, you take the gain at both stages and multiply them. Multiplying 50 and 1 would give you a gain of 50 as the overall value. To begin the calculations, Rc was first assumed to be 24 kOhms because I found that it worked best on multisim and was an accepted resistor. Then, Vc was found to be 8V and these values were used to calculate Ic. From this, all of the resistor values were calculated. Each of the calculated values were rounded to the nearest accepted resistor. The only assumed resistor value was $R_C = 24k\Omega$. The capacitors were all assumed. When simulating on multisim, the capacitors had a minimal effect on the gain. The capacitors are used to block the AC signal. Since the capacitor didn't affect the resistor calculations, whilst simulating the capacitor values were chosen to better fit the specifications.

Circuit Under Test:

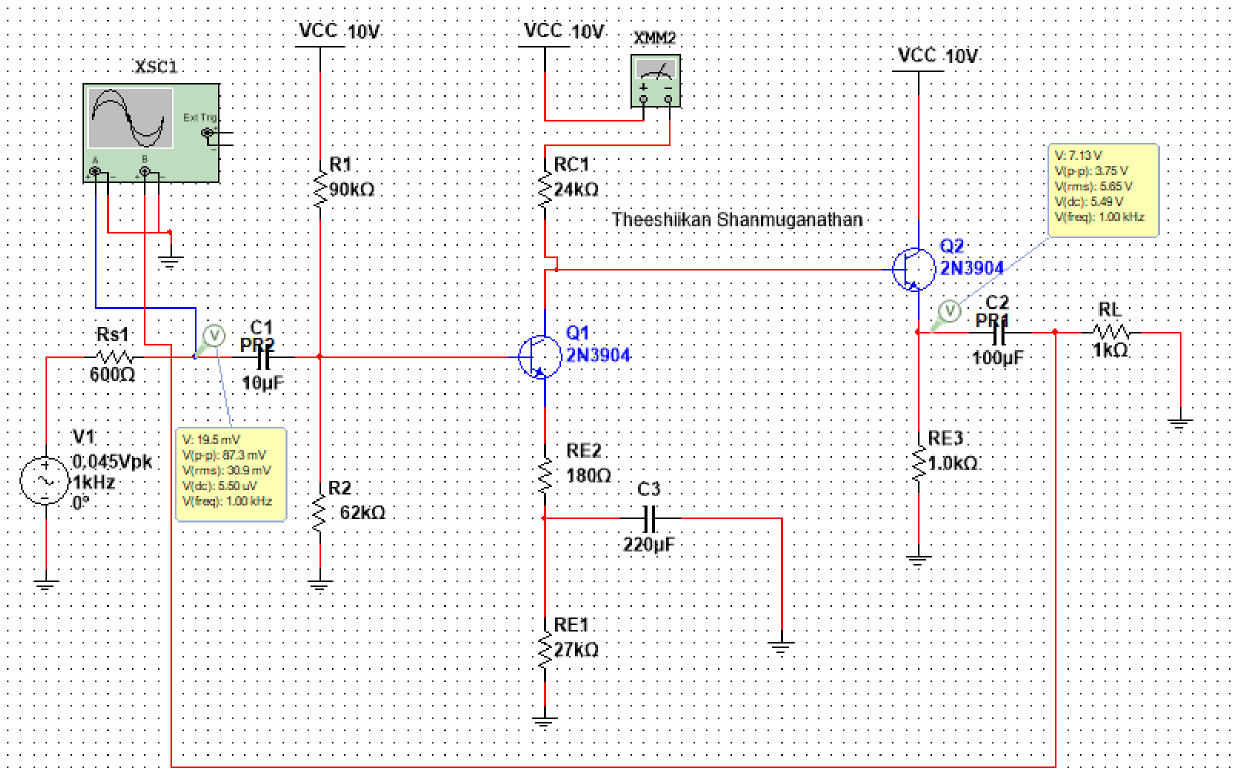


Figure 2. The Multisim Circuit

Figure 2 is the multisim circuit used to test the specifications given. All of the resistor and capacitor values are accepted from the E24 list.

Experimental Results:

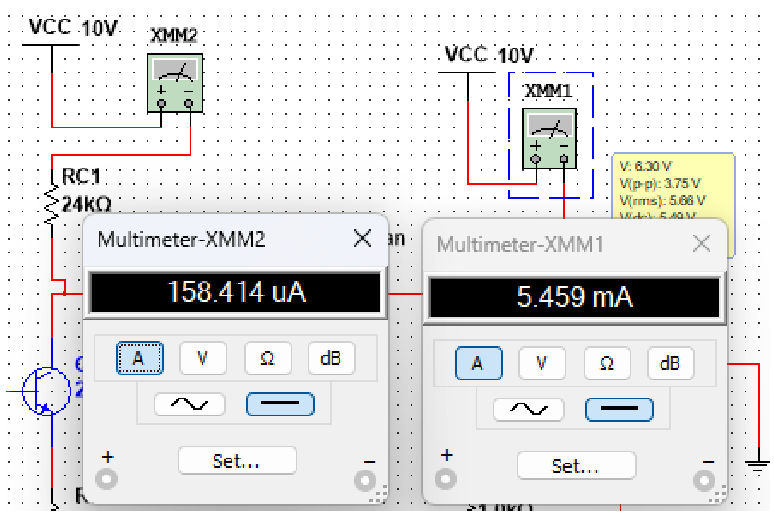


Figure 3. The quiescent Current < 10 mA

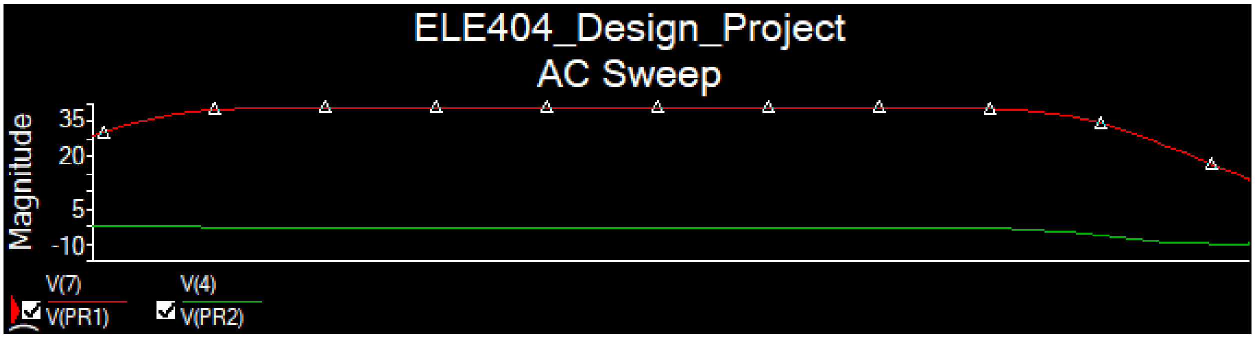


Figure 4. Frequency Response Graph

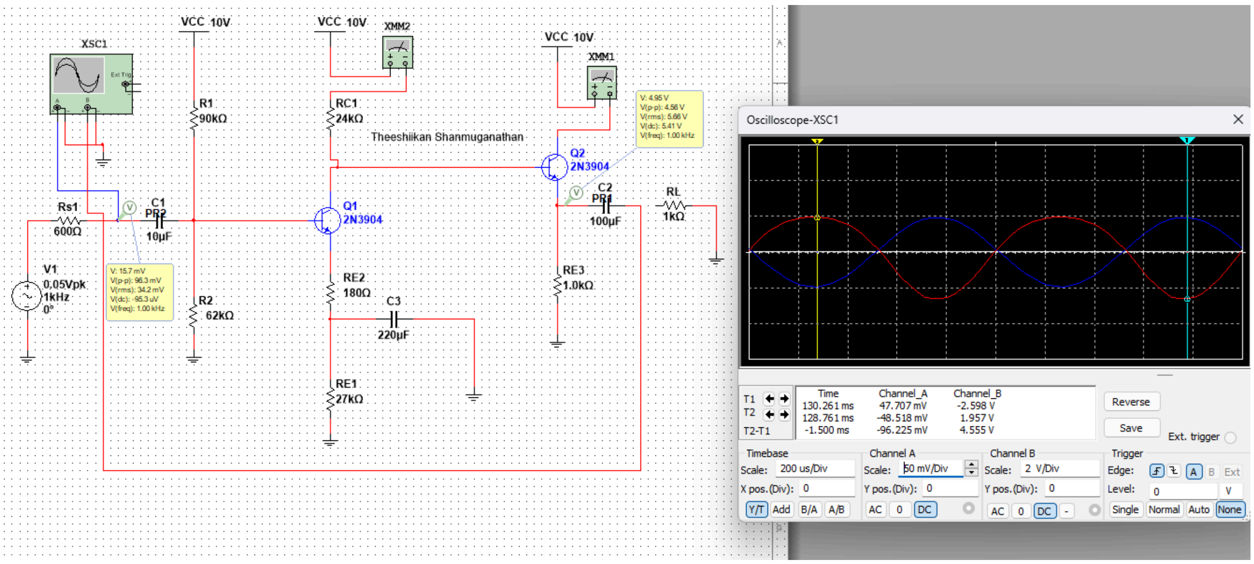


Figure 5. The input and output voltages without load

$$\text{Gain} = \frac{4.56\ V}{0.0963\ V} \approx 47.35$$

$$\text{Maximum not loaded output voltage swing} = 4.555\ V_{p-p}$$

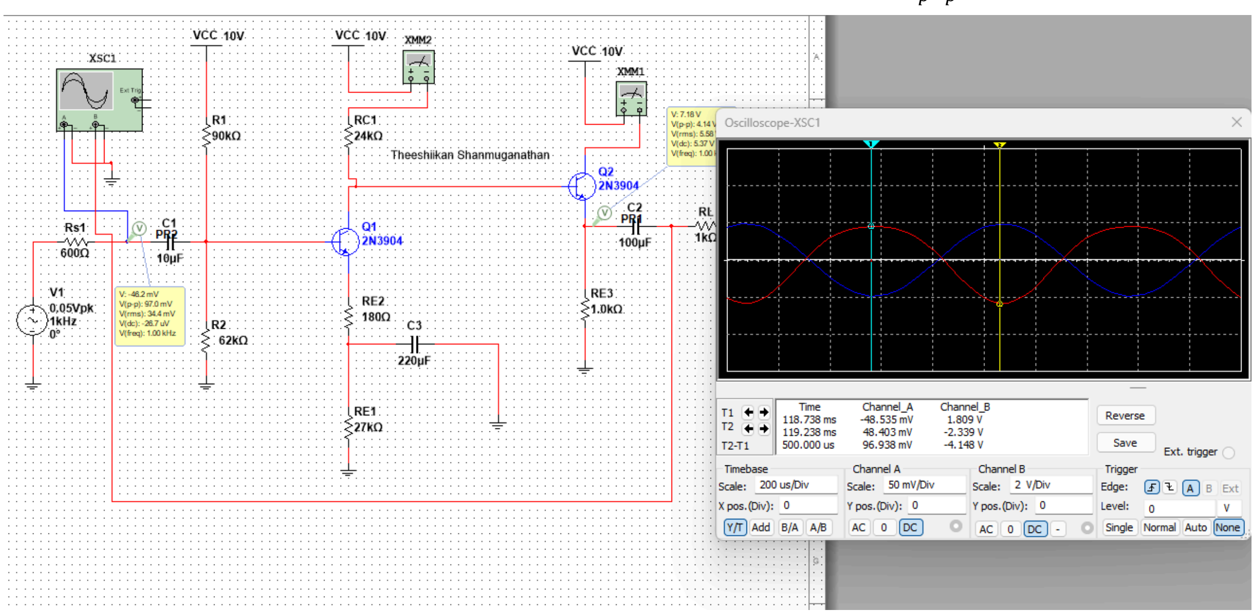


Figure 6. The input and output voltage with load

Gain = $\frac{4.14}{0.0970} \approx 42.68$

Maximum loaded output voltage swing = 4.184 V_{p-p}

Input Resistance = $R1//R2//Ri = \frac{1}{\frac{1}{90}+\frac{1}{62}+\frac{1}{48}} \approx 20.8 > 20\,k\Omega$

Conclusion and Remarks:

All of the specifications were achieved except for the output voltage swing with no load. The value simulated was around 4.555V which is 3.445V aways from the specified 8V. The percent error is around 75.63%. Also the frequency response part is seen through the graph. All of the other requirements are met. Therefore, the CE-CC Amplifier was an effective design choice to meet the specifications. Overall, the project can be seen as a success. The manual calculations are added below in the Appendix.

Appendix:

$V_{cc}: 10V$

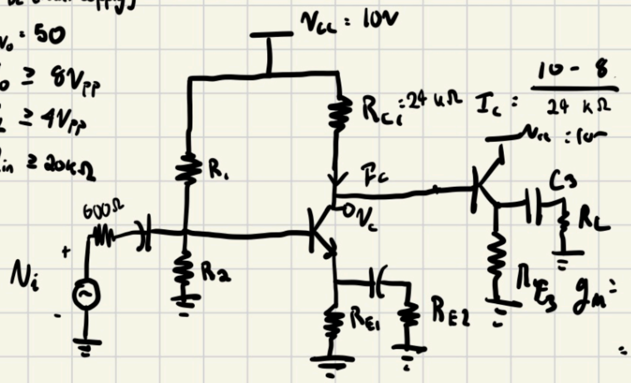
I_{DC} (Power Supply) $< 10mA$

$A_{v_o}: 50$

$V_o \geq 8V_{pp}$

$V_L \geq 4V_{pp}$

$R_{in} \geq 20k\Omega$



$I_c: \frac{10-8}{24\ k\Omega} : 0.083mA$

$g_m: \frac{I_c}{V_t}$

$= \frac{0.083mA}{26mV} : 3.19 \times 10^{-6}\ mS$

In CE Amp $R_o: R_c$

$R_c: 0.1\ k\Omega$

No load Gain: $|A_{vo}| : \left| \frac{-g_m R_c}{1+g_m R_{E1}} \right|$

$A_{vo}(1+g_m R_{E1}) : g_m R_c$

$1+g_m R_{E1} = \frac{g_m R_c}{A_{vo}}$

$g_m R_{E1} : \frac{g_m R_c}{A_{vo}} - 1$

$R_{E1} : \left(\frac{g_m R_c}{A_{vo}} - 1\right) \div g_m$

$50 : \frac{3.19 \times 10^{-6} (24\ k\Omega)}{1 + 3.19 \times 10^{-6} (R_{E1})}$

$\boxed{R_{E1} : 166.52\ \Omega}$

$V_c : \frac{1}{2}(V_{cc} + V_E + 0.3V)$

$8 = \frac{1}{2}(10 + V_E + 0.3)$

$16 : 10 + V_E + 0.3$

$16 - 10 - 0.3 : V_E$

$V_E : 5.7V$

$R_{E1} + R_{E2} = \frac{V_E}{I_E}$

$R_{E1} + R_{E2} : \frac{5.7V}{0.2mA}$

$69.99987 + R_{E2} = 28500\ \Omega$

$R_{E2} = 28500\Omega - 69.99987$

$\boxed{R_{E2} : 28430.00013}$

Input Resistance:

$r_e = \frac{26}{0.083}$

$= 313.25\ \Omega$

$R_i = R_1 // R_2 // R_i'$

$20k\Omega : R_1 // R_2 // r_i'$

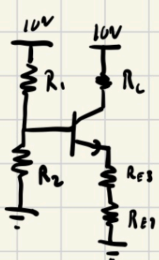
$20000 : R_1 // R_2 // 47977\Omega$

$r_i' : \beta(r_e + R_{E1})$

$= 47977$

$\frac{1}{20000} \leq \frac{1}{R_1} // \frac{1}{R_2} // \frac{1}{47977}$

$\left(\frac{1}{20000} - \frac{1}{47977}\right)^{-1} \leq R_1 // R_2$



$V_B : V_{cc} \cdot \frac{R_2}{R_1 + R_2} \approx 27k\Omega$

$6.4 : 10V \cdot \frac{R_2}{R_1 + R_2}$

$\frac{R_1 + R_2}{R_2} : \frac{10}{6.4} : 1.5625$

$\frac{R_1 + R_2}{R_2} : 1.5625$

$\frac{R_1}{R_2} + 1 : 1.5625 \Rightarrow R_1 : 0.5625 R_2$

$V_{BE} : V_B - V_E$

$0.7 : V_B - 5.7V$

$V_B : 6.4V$

$34297.46 = \frac{R_1 R_2}{R_1 + R_2}$

$34297.46 : \frac{0.5625 R_2^2}{0.5625 R_2 + R_2}$

$34297.46\ (1.5625\ \cancel{R_2}) = 0.5625\ R_2^{\cancel{2}}$

$53589.779 = 0.5625\ R_2$

$R_2 : 95270.71\ \Omega$

$\boxed{R_2 = 95.27\ k\Omega}$

$R_L : R_{o,...} // R_{E3}$

$1 = \frac{24 \cdot R_{E3}}{24 + R_{E3}}$

$24 + R_{E3} : 24 \cdot R_{E3}$

$\frac{24}{23} : \frac{23 R_{E3}}{23}$

$\boxed{R_{E3} : 1.04\ k\Omega}$

$R_1 : 0.5625\ (95.27k\Omega)$

$R_1 : 53589.779\ \Omega$

$\boxed{R_1 : 53.59\ k\Omega}$