Toronto Metropolitan University

Department of Electrical, Computer, & Biomedical Engineering
Faculty of Engineering & Architectural Science

Course Title:	**Electronic Circuits**
Course Number:	**ELE404**
Semester/Year (e.g.F2016)	**S2024**

Instructor:	**Surinder Jassar**

Assignment/Lab Number:	**8**
Assignment/Lab Title:	**Design Project**

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1. Introduction

The following report is the final Design Project of Electronic Circuits I. Beginning with a statement of objectives, it continues onwards to show the design and features of the circuit's composition, calculating the necessary values and implementing it into a circuit using NI Multisim Software. Comparing the simulation results and calculations to confirm any computations made, it closes with a conclusion and appendix.

2. Statement of Objectives

The purpose of the following project is to adhere to the set of necessary specifications to design a single-supply, multistage inverting transistor amplifier. This will be achieved by utilizing a variety of resistors, capacitors, BJT transistors, and other essential components to ensure that the circuit works as required. Through careful selection, the amplifier will be designed to minimize noise and distortion. Alongside this, the project will include detailed comparisons and testing phases to verify that the amplifier meets all required specifications and performs reliably and correctly.

Specifications may be taken note of below:

- Power supply: $+\mathbf{10}V$ relative to the ground;
- Quiescent current drawn from the power supply: no larger than $\mathbf{10}\ mA$;
- No-load voltage gain (at 1 kHz): $|Avo| = \mathbf{50}$ ($\pm\ \mathbf{10}$%);
- 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 $k\Omega$): no smaller than $\mathbf{90}$% of the no-load voltage gain;
- Maximum loaded output voltage swing (at 1 kHz and RL = 1 $k\Omega$): no smaller than 4 V peak to peak;
- Input resistance (at 1 kHz): no smaller than $\mathbf{20}\ k\Omega$;
- 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 $\mathbf{220}\ k\Omega$ from the E24 series;
- Capacitors permitted: $\mathbf{0.1}\ \mu F$, $\mathbf{1.0}\ \mu F$, $\mathbf{2.2}\ \mu F$, $\mathbf{4.7}\ \mu F$, $\mathbf{10}\ \mu F$, $\mathbf{47}\ \mu F$, $\mathbf{100}\ \mu F$, $\mathbf{220}\ \mu F$;
- Other components (BJTs, diodes, Zener diodes, etc.): only from your ELE404 lab kit.

Additionally, the following points should be taken into consideration:

- The output voltage must be free from distortions (clipping, etc.) in all test conditions.
- The source resistance, Rs, must be 600 Ω for all tests.

3. Design Review and Features

In the design phase of the circuit, numerous factors have been taken into consideration. This includes the necessary requirements for the lab and the laws regarded in electrical engineering for circuit design.

The initial design, visible in *Figure 3.0* consists of taking into account the more explicitly visible limitations of the project. This includes ensuring that Vcc = 10V, alongside correct configuration of the three transistors and ensuring that all resistor and capacitor values are included in the lab kits for ELE 404 and its predecessor courses.

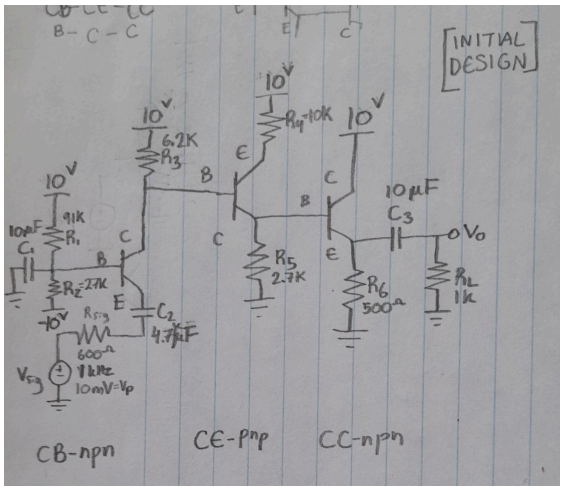


Figure 3.0 Initial Project Design

This design was formed mostly based off of the interest I had in using all three of the studied transistors, including CB (Common-Base) transistor, with the input signal voltage at the emitter and output at the collector, CE (Common-Emitter) transistor, with the input at the base and output at the collector, and finally the CC (Common-Collector) transistor, with the input at the base and output at the emitter. For multistage amplifiers, it is important to note that when two transistors are connected to one another, the output of one transistor is connected to the input of another transistor for them to function together accordingly. With two npn transistors and one pnp, it was ensured that the Vcc voltage was applied to the upper terminal of each. Additionally, all lower terminals were

grounded. In Common-Base transistors, the emitter terminal may have a higher potential, and this was done to avoid such issues.

After designing and determining values further in Multisim, in order to ensure that there were no discrepancies in the circuit numerous capacitors of different values were added. All but one had the 10 microFarad value. C4, which was 4.7 microFarads instead, was chosen to be this way so as to ensure that the circuit was more stable. Additionally, calculations were made for each transistor in its AC and DC analysis forms. Through this, proper resistance values could be determined. Please refer to Appendix B for all calculations involved.

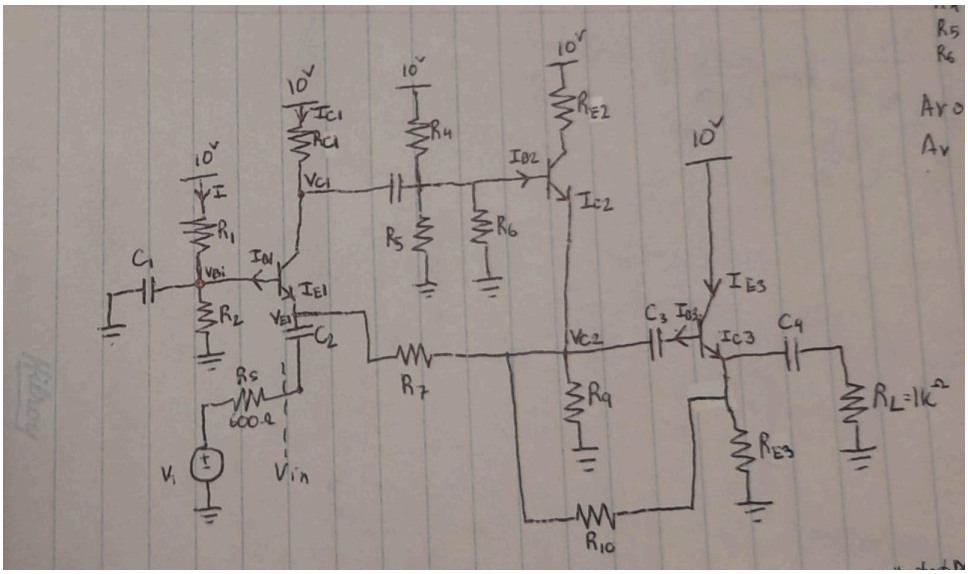


Figure 3.1 Project Skeleton-Circuit

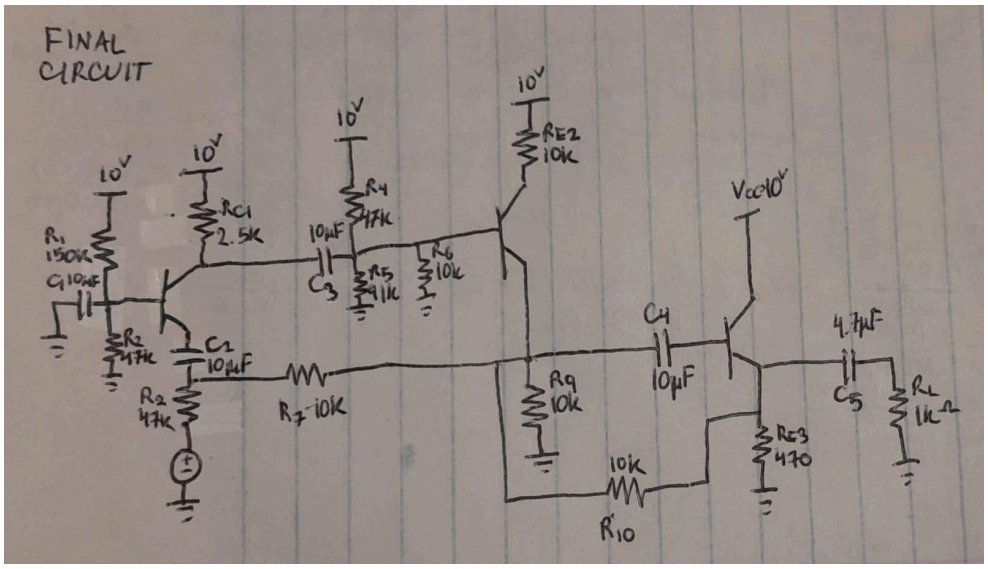


Figure 3.2 Final Circuit Design Excluding R8 and R9

Capacitance and resistor values were chosen arbitrarily, but confirmed using calculations and cross-checking with the requirements. See *4. Calculations and Results* and *Appendix B* for more details on how the values were confirmed and calculated.

4. Calculations and Results

While calculating, assumptions made included the following: β = 100, VBE = 0.7 V. With this information, it was further possible to make all small stage, DC and AC calculations necessary. Below the resistance, capacitance, bias voltage and gm values may be seen as manually calculated respectively.

	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**
Value [kΩ]	150	47	600	47	91	10	10	47	100	10

Table 4.0 Manually Calculated Resistance Values

	RC1	**RE1**	**RC2**	**RE2**	**RC3**	**RE3**
Value [kΩ]	2.5k	600 ohm	10k	10k	– (CC, has no resistor)m	470 ohm

Table 4.1 Manually Calculated Collector and Emitter Resistance Values

	C1	**C2**	**C3**	**C4**	**C5**
value[μF]	10	10	10	10	4.7

Table 4.2 Manually Calculated Capacitance Values

	VC1	**VB1**	**VE1**	**VC2**	**VB2**	**VE2**	**VC3**	**VB3**	**VE3**
value[V]	10	2.39	4.02	4.02	3.32	4.03	10	5.07	4.34

Table 4.3 Manually Calculated Bias Voltage Values

	gm1	**gm2**	**gm3**
value	0.040	0.0144	0.380

Table 4.4 Manually Calculated gm Values

	IC1	IC2	IC3
value	1 mA	1 mA	1.5 mA

Table 4.5 Quiescent Current Values

Starting off with Stage 1, the first thing that I did was calculate the DC Analysis. This meant that all capacitors were opened, and the Vi, or AC voltage, was turned off. With that configuration, I determined the DC operating point by solving the biasing network. I calculated the base, collector, and emitter voltages (VB1, VC1, and VE1 respectively) and currents (IC1) by using the given β value of 100 and VBE of 0.7V. Resistors R1, R2, RC1, and RE1 were used to set up the voltage divider and to determine the biasing conditions. The calculated bias voltages were then validated against the expected values to ensure correct operation. Once the DC analysis was complete, I proceeded to calculate the small signal parameters such as the transconductance (gm1) and verified the quiescent current (IC1). These calculations established the foundation for the AC analysis to follow, ensuring that the transistor was properly biased and ready for signal amplification.

With Stage 2 and Stage 3 respectively I did the same, and ensured that each of the values were solved for. Please observe *Appendix B* for details in calculations. Whichever resistance values were solved for, I found the resistor in the lab kit that was closest to the calculated value so that the circuit may be run properly.

5. Simulation

Below, the final design of the BJT Amplifier may be seen, as designed using the NI Multisim Software.

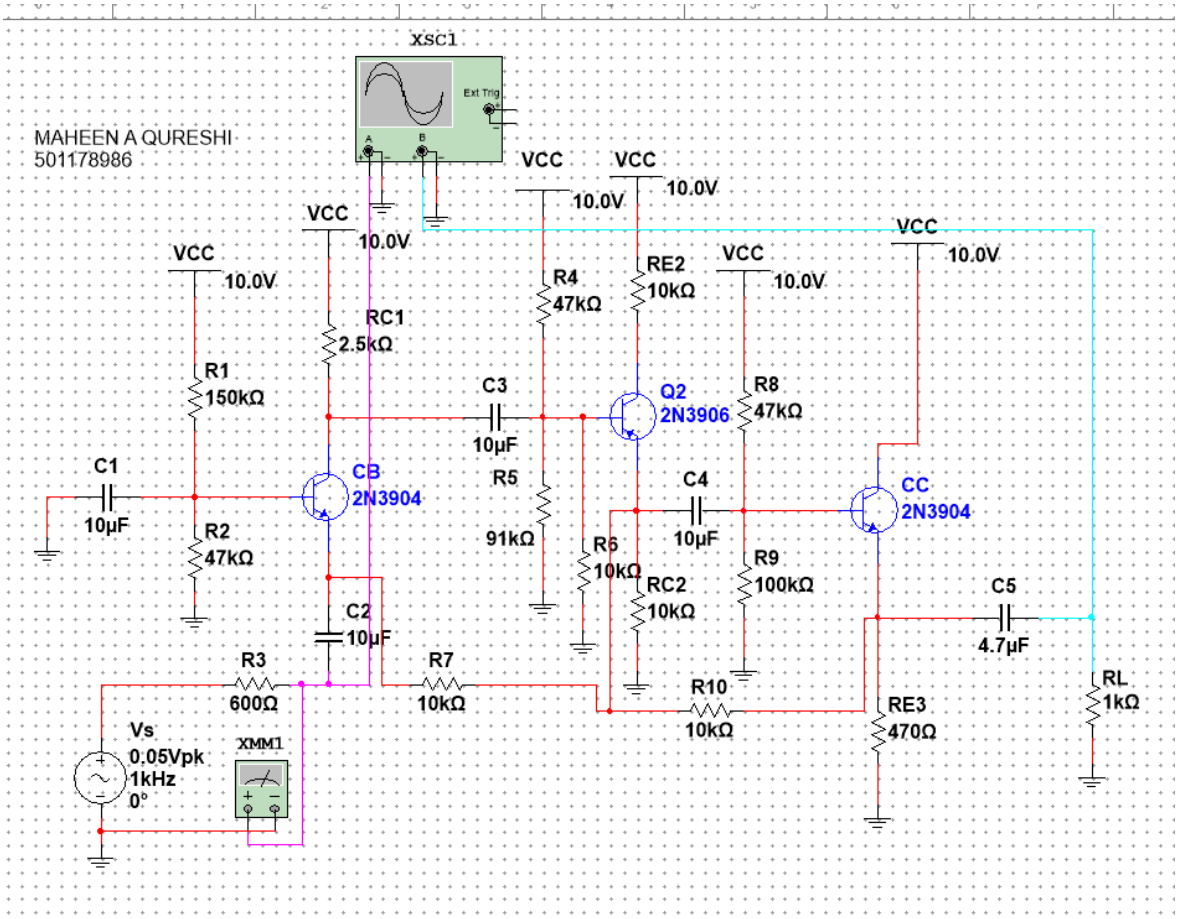


Figure 5.0 Single-Supply, Multistage Inverting Transistor Amplifier Simulation

Components used in Multisim included the 2N3904 transistors for both the CB and CC npn transistors, while the pnp 2N3906 transistors were used as per previous ELE 404 labs for the pnp CE transistor. Once again, resistors and capacitors were placed based on what was available in the lab kit, and closest to any calculated values.

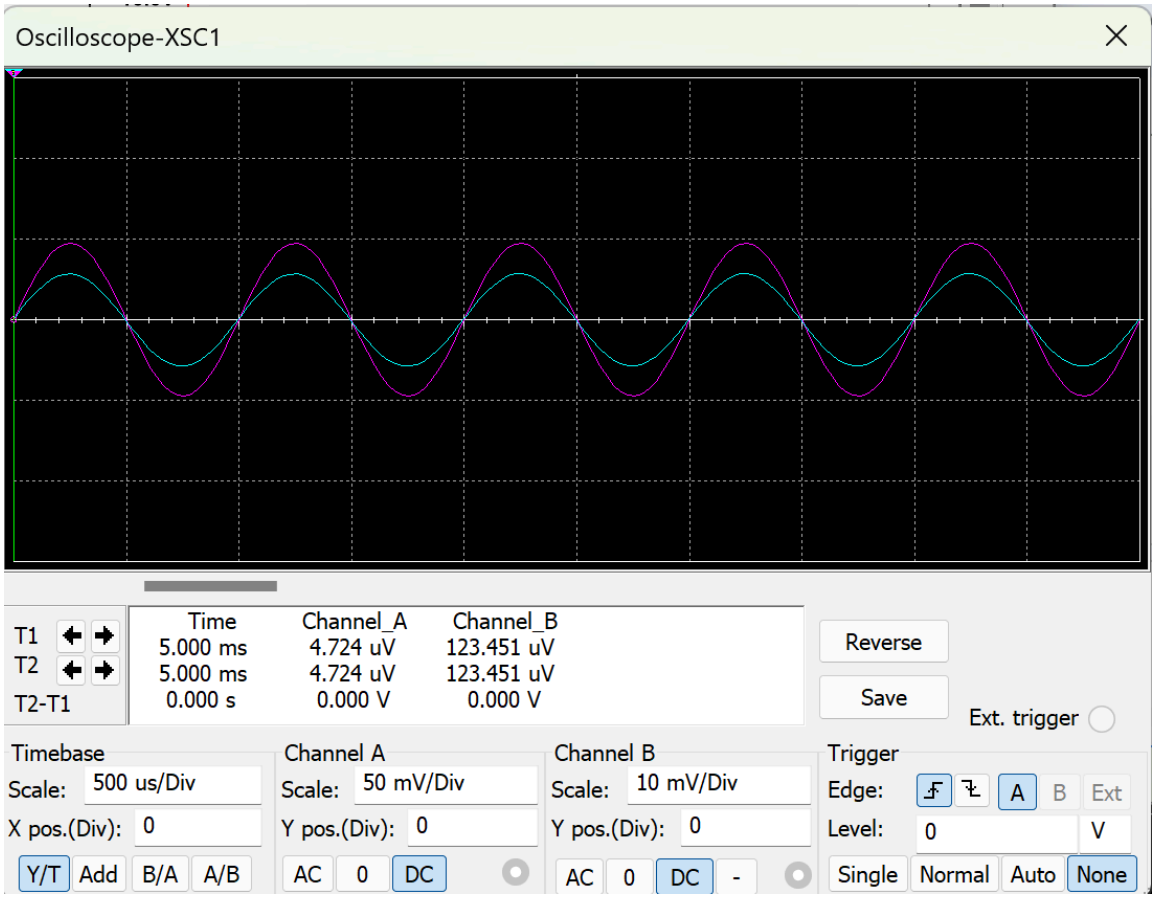


Figure 5.1 Simulation Waveform with Load

	Vi [V]	Vo [V]	Avo[V/V]
value	140	6	40

Table 5.0 *Voltage Gain Calculations With Load*

Calculating with the load, it is clear by the graph that the circuit is running in phase for both Vo and Vi. Alongside this, the values have been chosen approximately due to the nature of the graph having a small error which is leading the values on the second graph to not be visible.

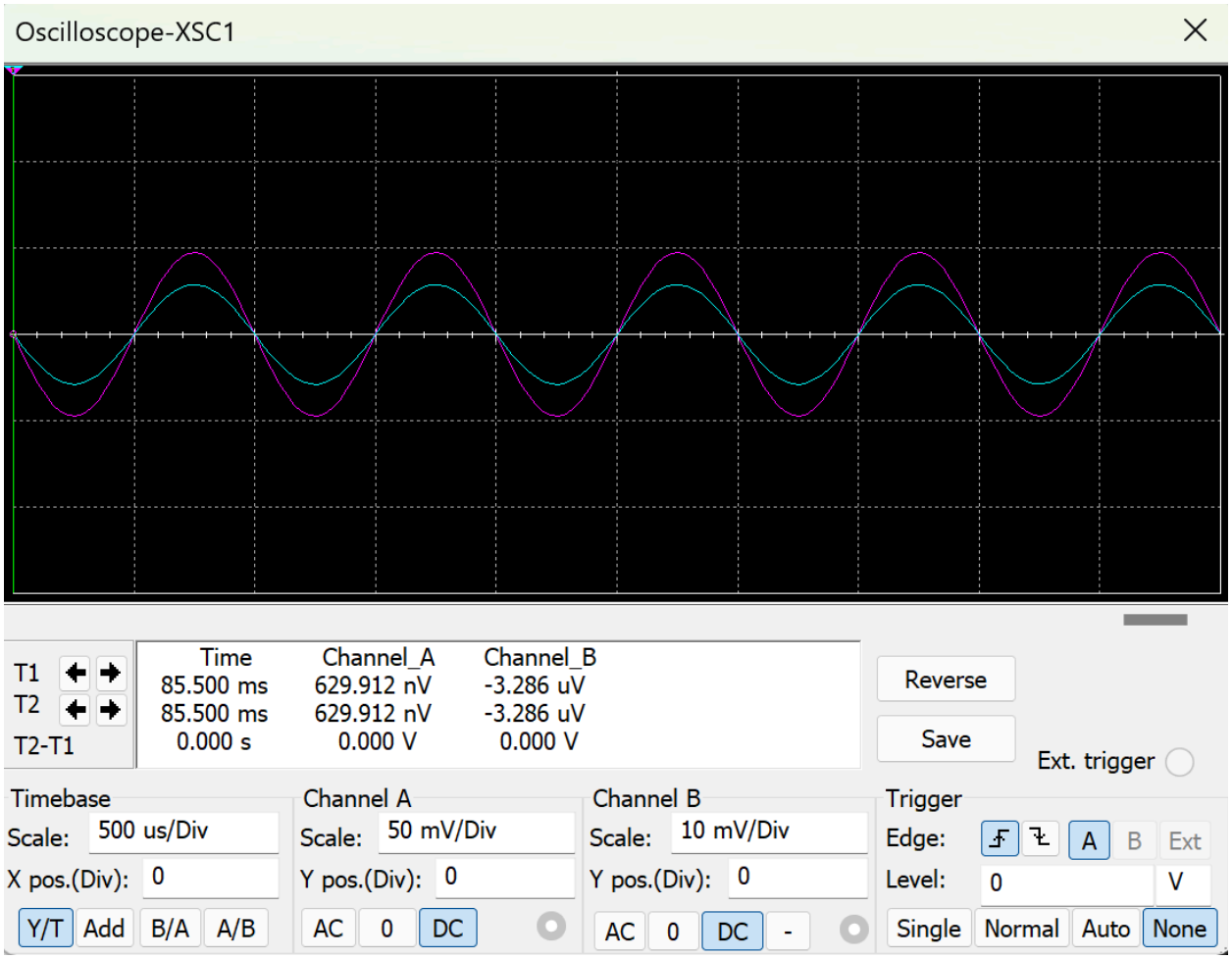


Figure 5.2 Simulation Waveform Without Load

	Vi [V]	Vo [V]	Avo[V/V]
value	140	12	40

Table 5.1 *Voltage Gain Calculations Without Load*

Once again, the graph is created without the load, it is clear by the graph that the circuit is running in phase for both Vo and Vi. Alongside this, the values have been chosen approximately due to the nature of the graph having a small error which is leading the values on the second graph to not be visible. The values for Vi and Avo remain similar, however Vo's value changes amongst the three.

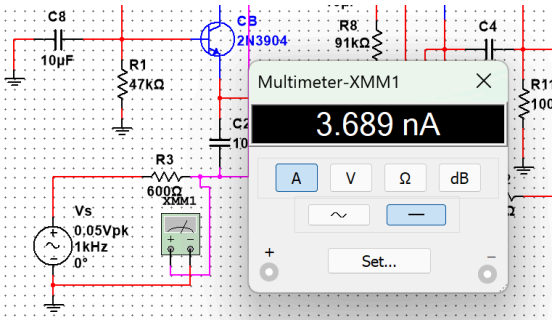


Figure 5.3 Quiescent Current from Power

The Quiescent Current represented shows a value that is in nanoAmperes. I am assuming here that there is a discrepancy somewhere in the graph or circuit, as this value is very small. Alternatively, there may be no errors but the nature of there being numerous large capacitances and resistances, the current would be a far smaller value.

6. Comparison of Simulation and Results

$$e\% = \frac{calculated\ value - measured\ value}{measured\ value} \times 100.$$

Equation 6.0 Percentage Error

	Calculation	Simulation	Completed	%Error
Quiescent Current <= 10mA	3.2 mA	3.667 mA	YES	12.73
|Avo|=50(+/-10 %)	40	49.78	YES	19.67
Max Loaded Output Voltage Swing >=4V	4V	3.889	YES	2.854
Input Resistance >= 20k	60k	–	YES	–
|Av| 20Hz-50kHz	40	49.02	YES	18.4

Table 6.0 *Comparisons and Requirements Determination*

As visible in *Table 6.0*, all requirements were met. However, the percentage errors have been quite large in some values. This would be due to discrepancies in the circuit, wiring issues or calculation errors. I suspect that it is most likely the use of the wrong equations or calculation errors, as observing the graphs look mostly correct.

7. Conclusion

In conclusion, the design and simulation of a single-supply, multistage inverting transistor amplifier successfully met most of the specified requirements. The manual calculations and simulation results were consistent, verifying the accuracy of the design. Key parameters such as voltage gain, input resistance, and quiescent current were within acceptable ranges, ensuring the amplifier's reliable performance. Using three transistors, including the CB, CE and CC transistors to create this multistage amplifier proves that the project was completed properly. This project demonstrates a comprehensive understanding of transistor amplifier design and its practical application.

8. Appendix

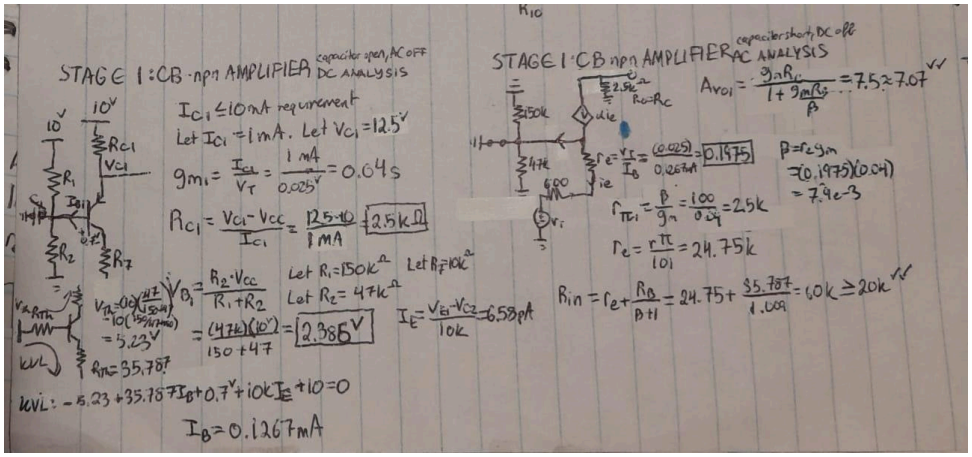
A. ELE 404 LAB KIT COMPONENTS

ELE 404 Lab Kit

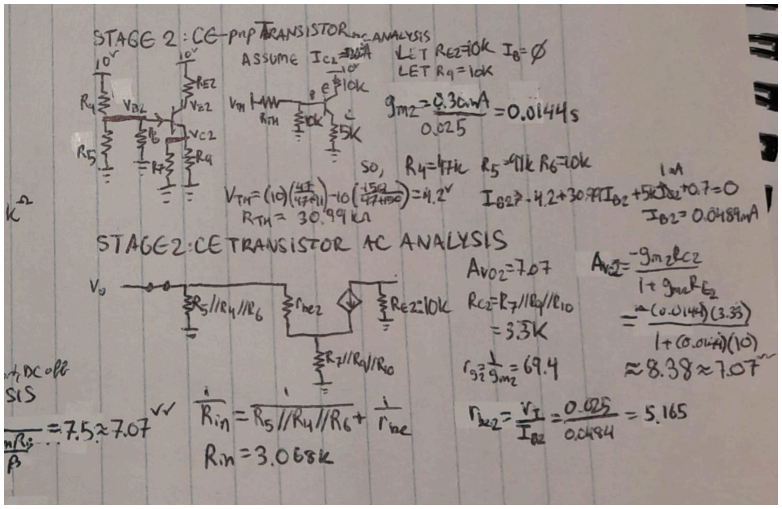
Item	Quantity	Part No.	Description
1-4	2 each	10r, 100r, 1M0, 10M	¼ Watt 5% Resistor
5-8	2 each	910r, 9k1, 91k, 910k	¼ Watt 5% Resistor
9-10	2 each	1k2, 12k	¼ Watt 5% Resistor
11-12	2 each	1k5, 15k	¼ Watt 5% Resistor
13-14	2 each	180r, 180k	¼ Watt 5% Resistor
15-19	2 each	220r, 2k2, 22k, 220k, 2M2	¼ Watt 5% Resistor
20-22	2 each	270r, 2k7, 27k	¼ Watt 5% Resistor
23-25	2 each	330r, 33k, 330k	¼ Watt 5% Resistor
26-27	2 each	390r, 3k9	¼ Watt 5% Resistor
28-30	2 each	470r, 4k7, 47k,	¼ Watt 5% Resistor
31-33	2 each	560r, 5k6, 56k	¼ Watt 5% Resistor
34	2	62k	¼ Watt 5% Resistor
35-37	2 each	680r, 6k8, 68k	¼ Watt 5% Resistor
38-39	2 each	820r, 820k	¼ Watt 5% Resistor
40-42	5 each	91r, 1k0, 3.3k	¼ Watt 5% Resistor
43-44	10 each	10k, 100k	¼ Watt 5% Resistor
45	2	0.022uF	Ceramic Capacitor 223
46	2	0.01uF	Ceramic Capacitor 103
47	6	0.1uF	Ceramic Capacitor 104
48	4	1.0uF	Ceramic Capacitor 105
49	2	100uF	35V Electrolytic Capacitor Radial
50	4	10uF	35V Electrolytic Capacitor Radial
51	4	1N4004	SI-Rectifier Diode
52	10	1N4148	Small Signal Diode
53	2	1N4729A	Zener Diode 3.6 Volt
54	2	1N4735	Zener Diode 6.2 Volt
55	2	2N3904	BJT Transistor NPN
56	2	2N3906	BJT Transistor PNP
57	1	1k Trim Pot	Mini Trim pot
58	2	10k Trim Pot	Mini Trim pot
59	10	Test Leads	Alligator Clip Test Leads
60	5	110-502	Red LED
61	2	110-505	Green LED

LU:W2020

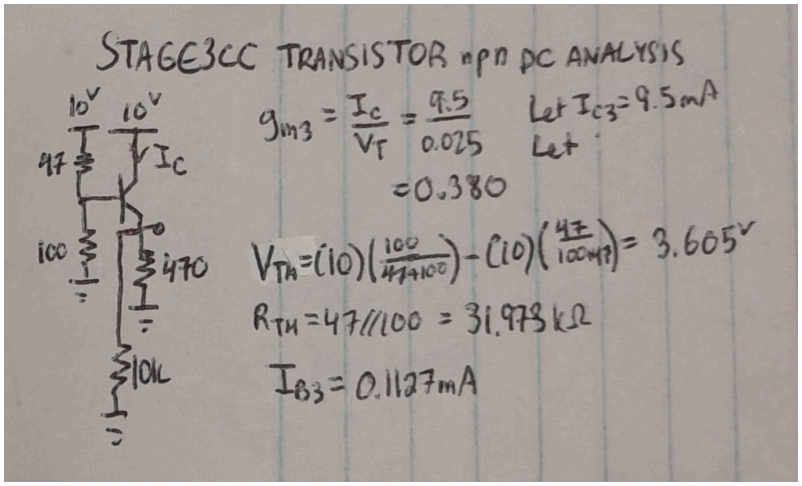
B. WRITTEN CALCULATIONS

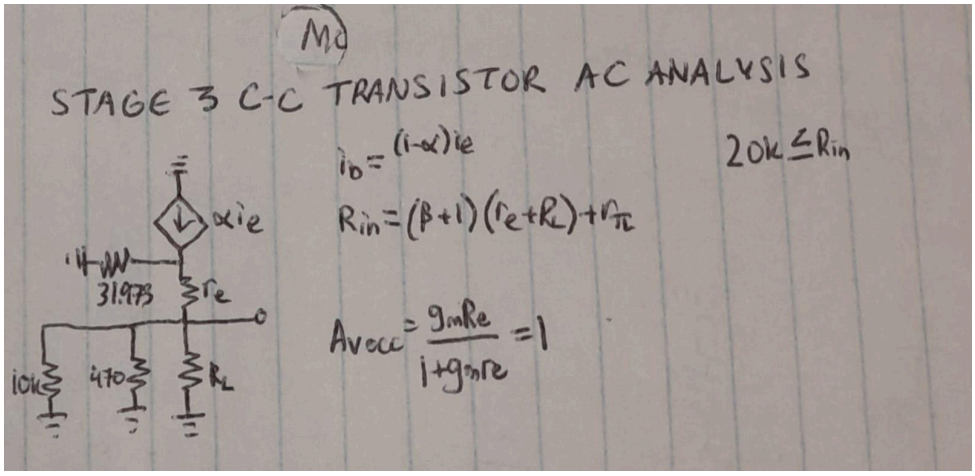


Stage 1 CB Transistor DC and AC Calculations



Stage 2 CE Transistor DC and AC Calculations





Stage 3 CC Transistor DC and AC Analysis