EEE232 Project

A 3-Stage 5W Audio Amplifier

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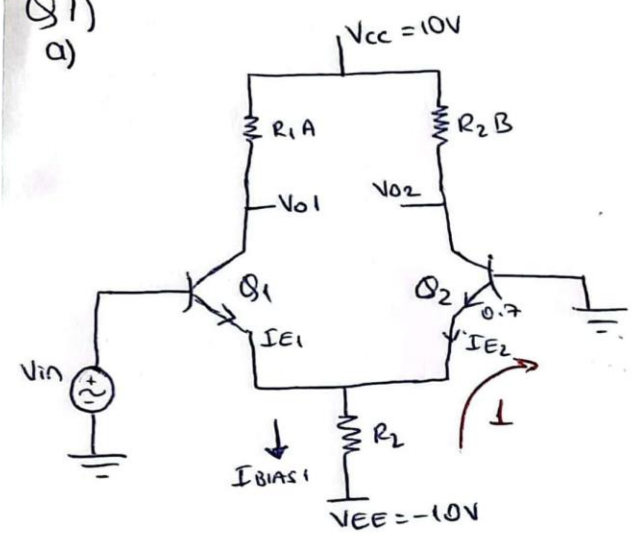
Electrical & Electronics Engineering

Q1. Determine values for the resistances R1A, R1B, and R2 to achieve the following bias voltages and currents (assume β = 100 for each transistor). (Hints: Apply superposition and symmetry).

Q1)
a)



$I_{E1}+I_{E2}=500\mu A$

$I_{E1}=I_{E2}$

$I_{E1}=I_{E2}=\frac{500}{2}\mu=250\mu A$

$V_{O1}=10-R_{1}A\,I_{E1}$

$9.3=10-R_{1}A(250\mu)$

$R_{1}A=2.8\ k\Omega$

$V_{O2}=10-R_{1}B\,I_{E2}$

$9.3=10-R_{1}B(250\mu)$

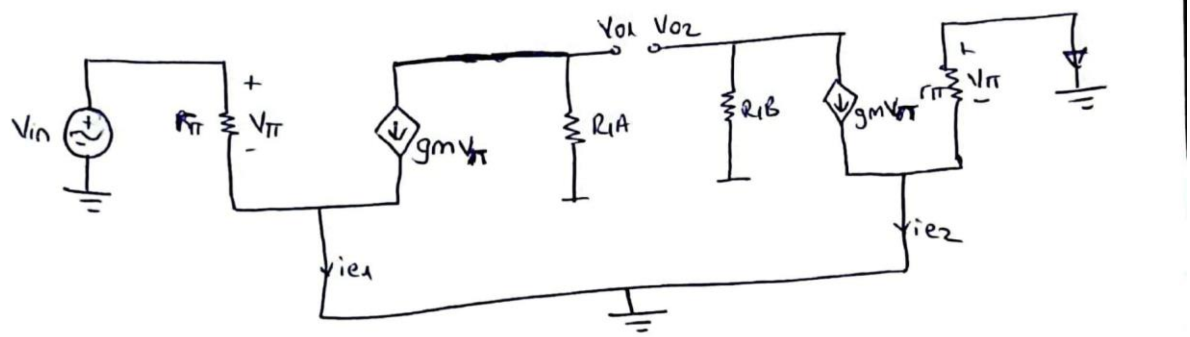
$R_{1}B=2.8k\Omega$

KVL at 1

$-10+R_2(500\mu)+0.7=0$

$R_2=18.6\ k\Omega$

Q2. Now, by performing small-signal analysis find the following: i. Small-signal voltage gains VO1/Vin and VO2/Vin. ii. Differential output gain (VO1-VO2)/Vin. iii. Small-signal input resistance Rin at the input to the amplifier.



$I_{BIAS} = 500\mu A$

$V_T = 26mV$

$i_{e1} = i_{e2} = 250\mu A = \frac{I_{BIAS}}{2}$

$I_B = \frac{2.5 \times 10^{-4}}{100} = \frac{i_{e1}}{\beta}$

$I_B = 2.5 \times 10^{-6} A$

$r_\pi = \frac{V_T}{I_B} = \frac{26mV}{25 \times 10^{-6}} = 10.4 k\Omega$

$g_m = \frac{\beta}{r_\pi} = \frac{100}{10.4}$

$g_m = 9.62 \times 10^{-3}$

$V_{o1} = -R_1A \cdot g_m \cdot V_\pi$

$\frac{V_{o1}}{V_{in}} = -R_1A \cdot g_m$

$= -26.9$

$\leftarrow V_\pi = V_{in} \rightarrow$

$V_{o2} = -R_1B \cdot g_m V_\pi$

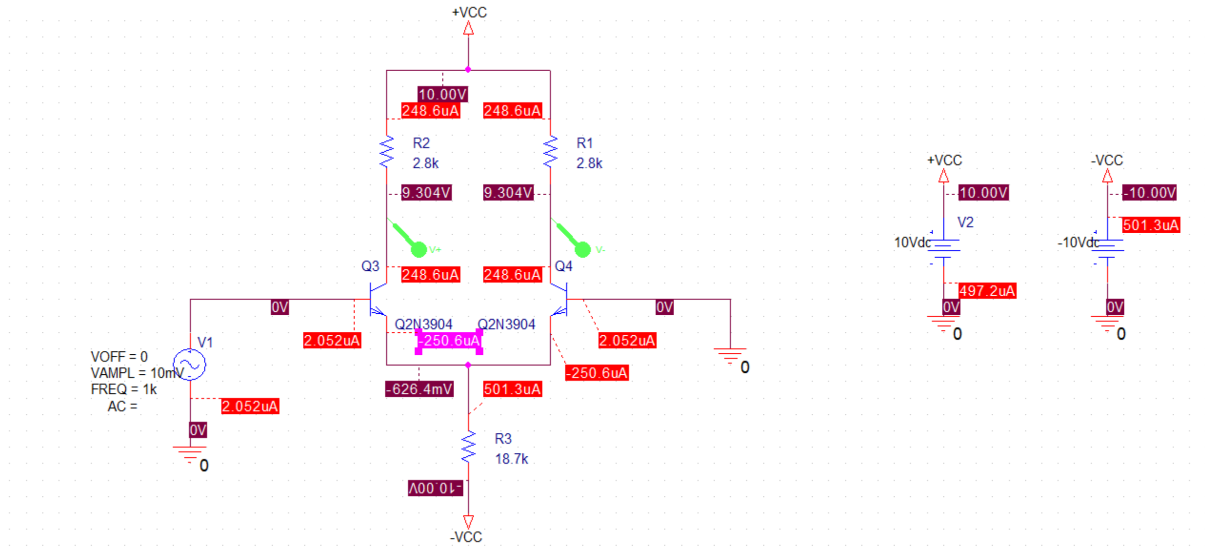
$\frac{V_{o2}}{V_{in}} = -R_1B \, g_m$

$= -26.9$

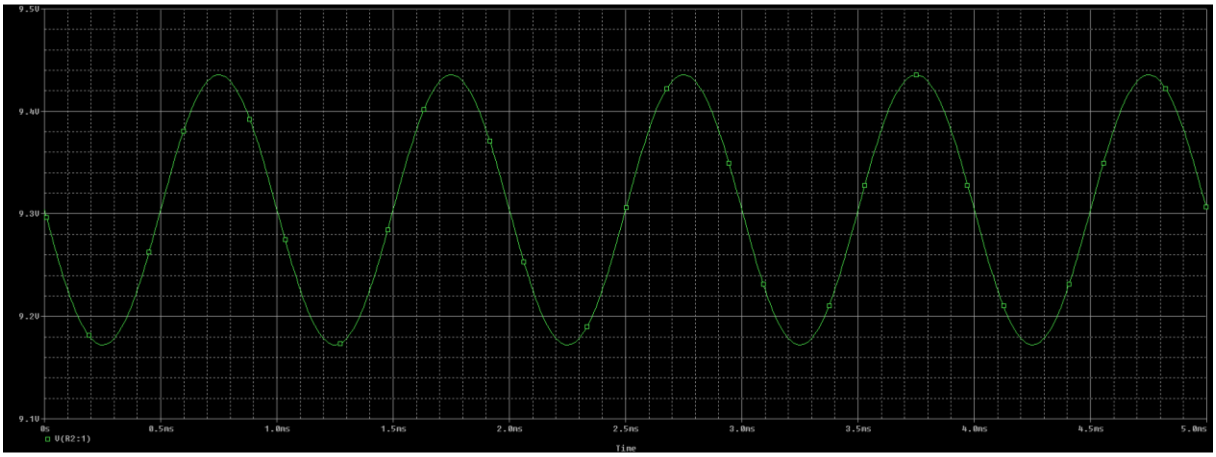
$\frac{V_{o1} - V_{o2}}{V_{in}} = 0$

$R_{in} = 2r_\pi = 20.8 k\Omega$

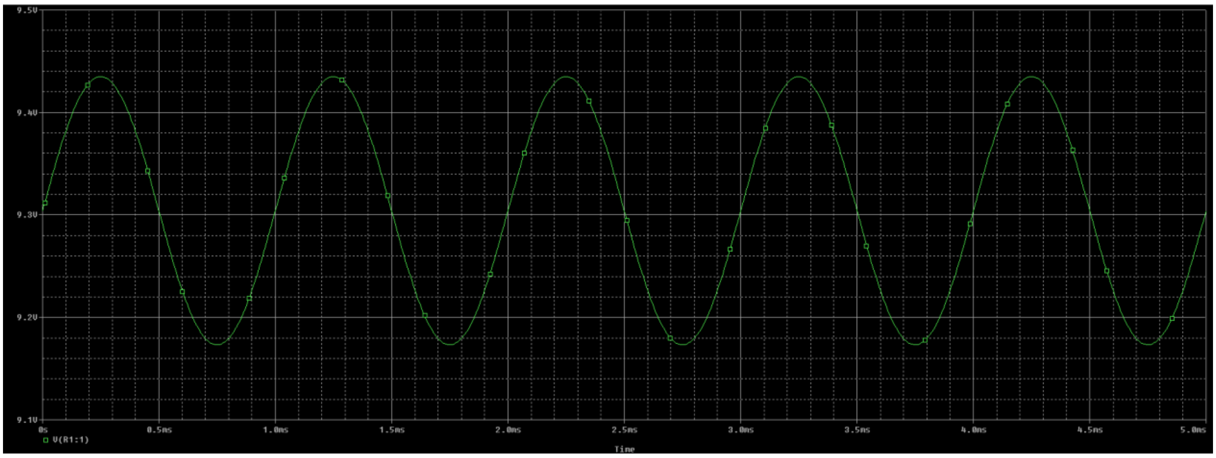
Q3. Produce graphs of VO1(t), VO2(t) and VO1(t) – VO2(t) for an input signal of Vin being a 10mVpk 1kHz sine wave signal.



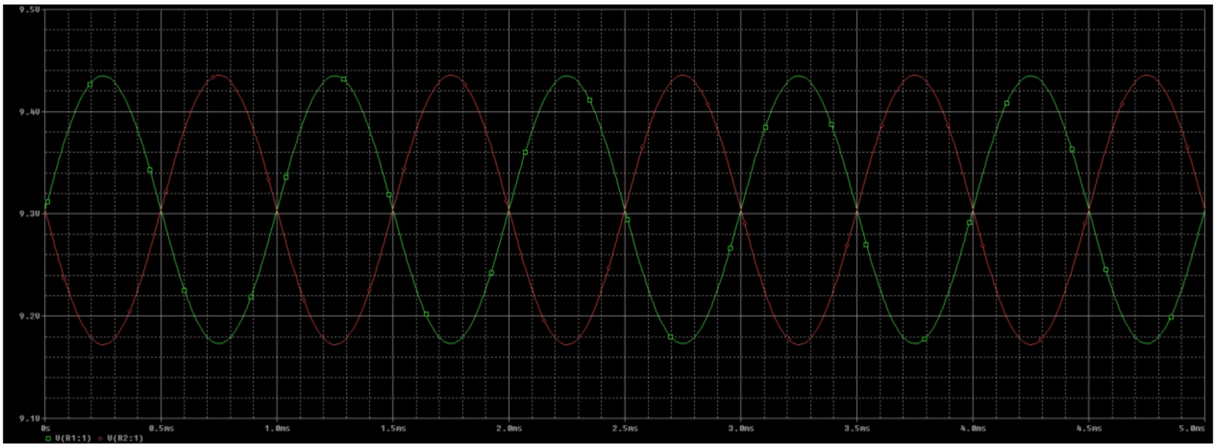
V01:



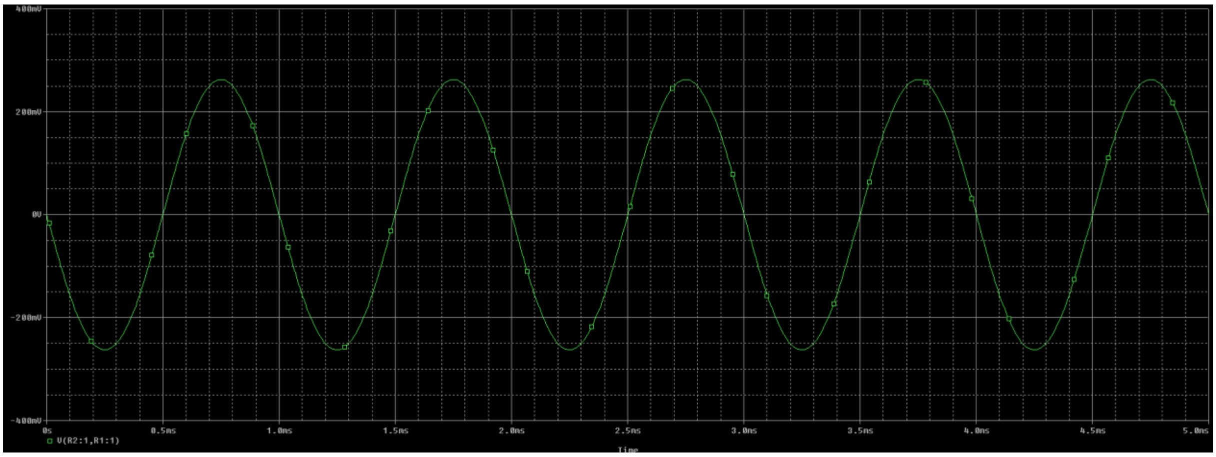
V02:



V01 (Red) and V02 (Green):



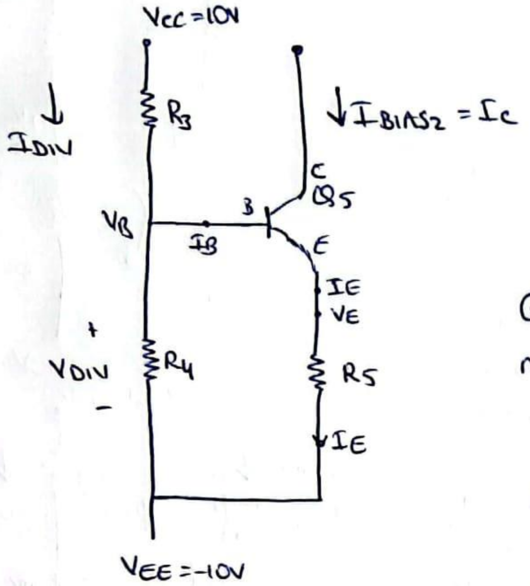
V01-V02:



Q4. The actual current source circuit is comprised of a NPN BJT and a voltage divider network (oval insert). Choose values for the resistors R3, R4 and R5 to achieve the following specifications (assuming β = 100):

Stage 2

Q4)



$I_{BIAS2} = 20mA$

$I_{DIV} = 1.8 mA$

$V_{DIV} = 1.7V$

$V_{CC} = 10V$

$V_{EE} = -10V$

$\beta = 100$

Given that $\beta = 100$ a huge number. Hence I_B is insignificant

$I_C \cong I_E$

$I_{BIAS2} = I_C$

$I_C \cong 20mA$

so, $I_E \cong 20mA$

$$V_B = V_{DIV} + V_{EE} = 1.7 - 10V = -8.3$$

$$I_{DIV} = \frac{V_{CC} - V_B}{R_3} = \frac{10-(-8.3)}{R_3}$$

$$R_3 = \frac{10-(-8.3)}{1.8} = 10.2\ k\Omega$$

$R_3 = 10.2\ k\Omega$

$$R_3 + R_4 = \frac{V_{CC} + V_{EE}}{I_{DIV}} = \frac{20}{1.8} = 11.1$$

$10.2 + 0.9 = 11.1$

$$R_4 = \frac{V_{DIV}}{I_{DIV}} = \frac{1.7}{1.8} = 0.9\ k\Omega$$

$R_4 = 0.9\ k\Omega$

Applying KVL at loop 1

$$-1.7 + V_{BE} + I_{BIAS2} \cdot R_5 = 0$$

$$-1.7 + 0.7 + I_{BIAS2} \cdot R_5 = 0$$

$$\underset{20mA}{I_{BIAS2}} \cdot R_5 = 1.00$$

$$R_5 = \frac{1}{20mA} = \frac{1}{20 \times 10^{-3}} = 50\Omega \qquad R_5 = 50\Omega$$

$$I_B = \frac{I_C}{\beta} = \frac{20}{100} = 0.2mA$$

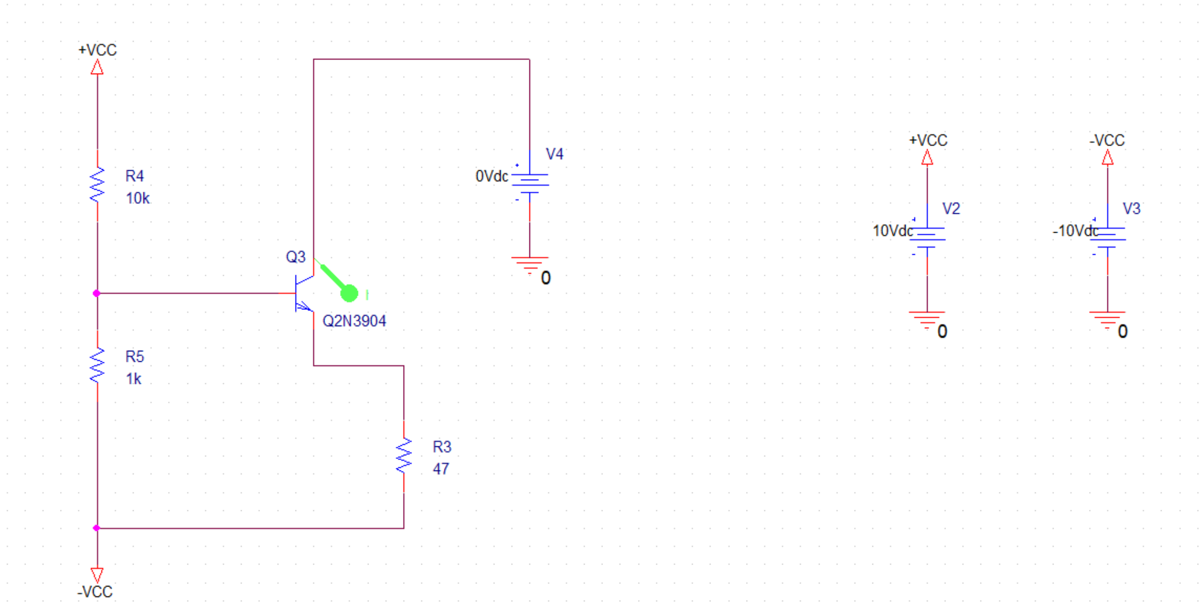
$$I_{DIV} = I_B + I_{R_4}$$

$$1.8 = 0.2 + I_{R_4}$$

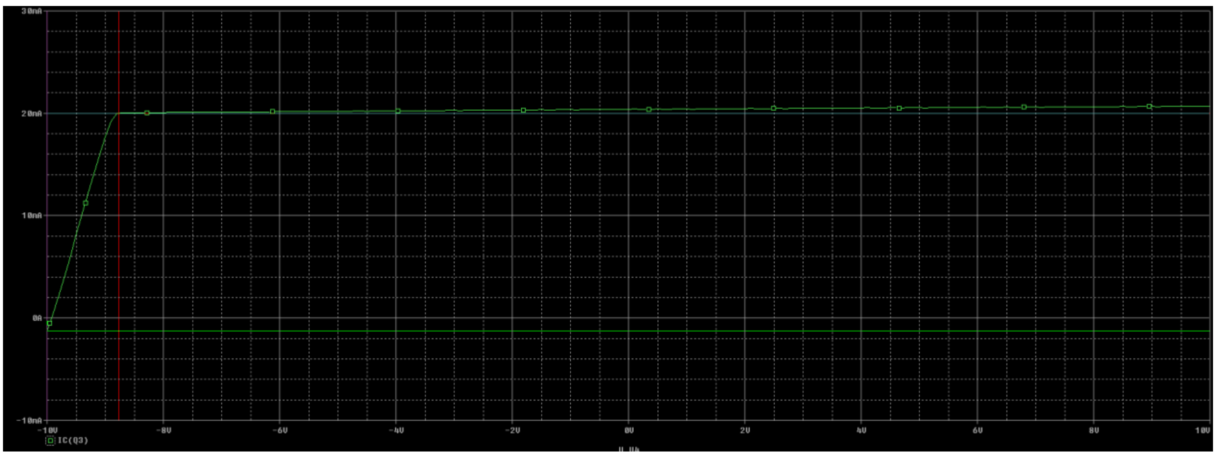
$$I_{R_4} = 1.6$$

Q5. Using DC ANALYSIS in simulation, verify the values of IBIAS2, IDIV and VDIV. Connect the output of the current source to a separate DC supply (VS) and use DC SWEEP analysis to vary the voltage from -10 to +10 Volts. Produce a plot of IBIAS2 as a function of VS. What is the dynamic voltage range of the output?

Sketch:

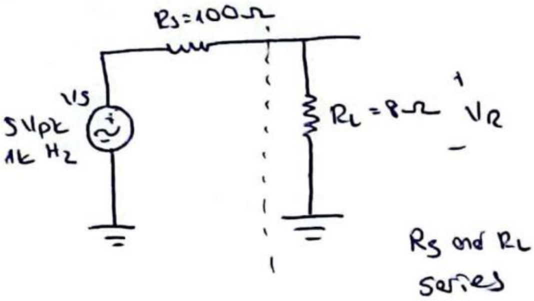


Simulation:

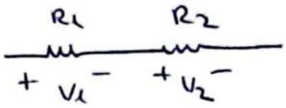


Q6. What is the maximum voltage that this circuit can deliver to the load? What percentage of the signal is this value?

Q6-



R_S and R_L series



$V_1 = V \dfrac{R_1}{R_1+R_2}$ $\quad V_2 = V \dfrac{R_2}{R_1+R_2}$

The voltage across the load R_L using the voltage division rule

$$V_R = V_{pk} \frac{R_L}{R_S+R_L}$$

$$5 \cdot \frac{8}{108} = 0.370$$

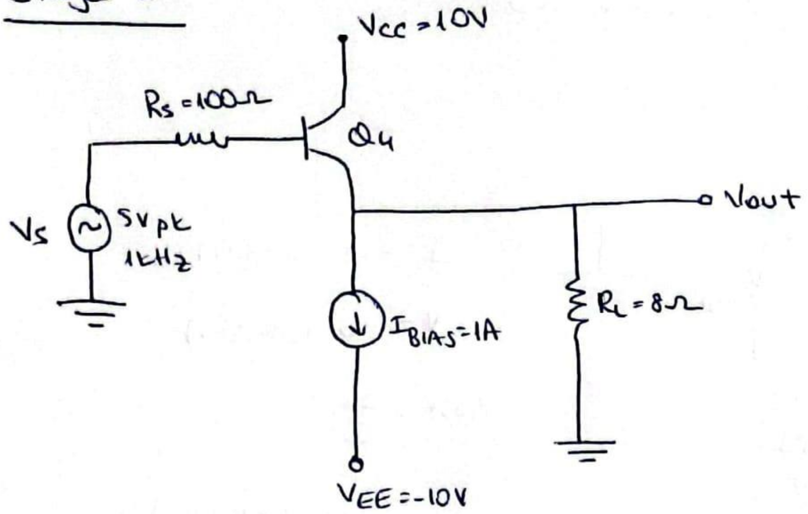
$V_R = 0.37V$ ↗ The circuit's maximum voltage delivery to a load is

$R_S + R_L \rightarrow$ minimum

$\dfrac{V_S}{R_S+R_L} \rightarrow$ maximum

Q7. Using the small-signal model for this amplifier, determine the effective output impedance Rout of this stage (assume β = 50 for the power transistor Q4).

Stage 3



$I_E = 1A \quad \beta = 50$

$I_c = \left(\frac{\beta}{\beta+1}\right) I_E = \left(\frac{50}{50+1}\right) \times 1$

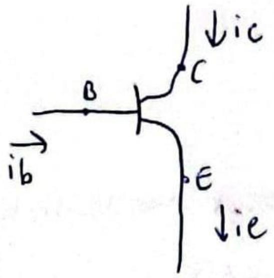
$I_c = 0.980\,A$

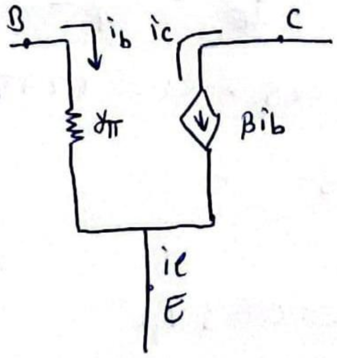
Transconductance $\quad g_M = \frac{I_c}{V_T}$

$V_T = 26mV$

$g_M = \frac{0.980}{0.026} = 37.7\ A/V$

$r_\pi = \frac{\beta}{g_m} = \frac{50}{37.7} = 1.326$





$i_e = i_b + i_c$

$i_e = i_b + \beta i_b$

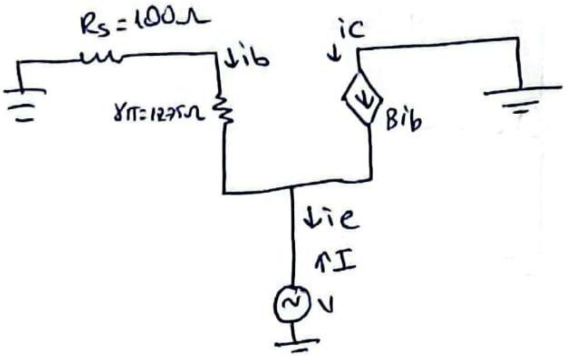
$i_e = (\beta+1)\, i_b$

Turn off all of the DC source

Transistor should be replaced with AC comparable model. $V_s = 0V$

$R_{out} = \left(\frac{V}{I}\right) \Omega$ This is output resistance without load

$R'_{out} = R_{out} \parallel R_L$



$I = -i_e = -(\beta+1)\, i_b$

$V = -i_b\,(r_\pi + R_s)$

$R_{out} = \frac{V}{I}$

$= \frac{\cancel{-i_b}\,(r_\pi + R_s)}{\cancel{-i_b}\,(\beta+1)}$

$= \frac{r_\pi + R_s}{\beta+1} = \frac{1.326 + 100}{50+1}$

$R_{out} = 1.987\,\Omega$

$R'_{out} = (R_{out} \parallel R_L)$

$= \frac{(1.987)\cdot(8)}{(1.987+8)}$

$R'_{out} = 1.59\,\Omega$ This is output resistance with load

Q8. What is the peak voltage delivered to the load using the Emitter Follower.

Q9. How does this output compare to the circuit without the transistor?

8) $V_s = 5V_p$

$$Re = \frac{V_T}{I_E} = \frac{0.026}{1} = 0.026$$

$$R_\pi = Re(\beta+1) = 0.026 \times 51 = 1.326\Omega$$

$$V_{out} = \frac{R_\pi}{R_S + R_\pi} \times V_S$$

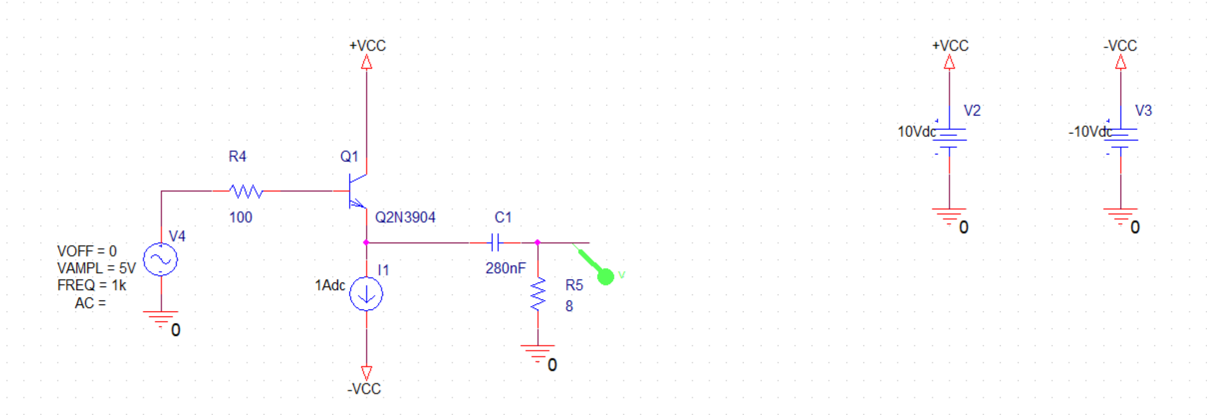
$$\frac{1.326 \times 5}{100 + 1.326} = 0.065V_p$$

9) without the transistor

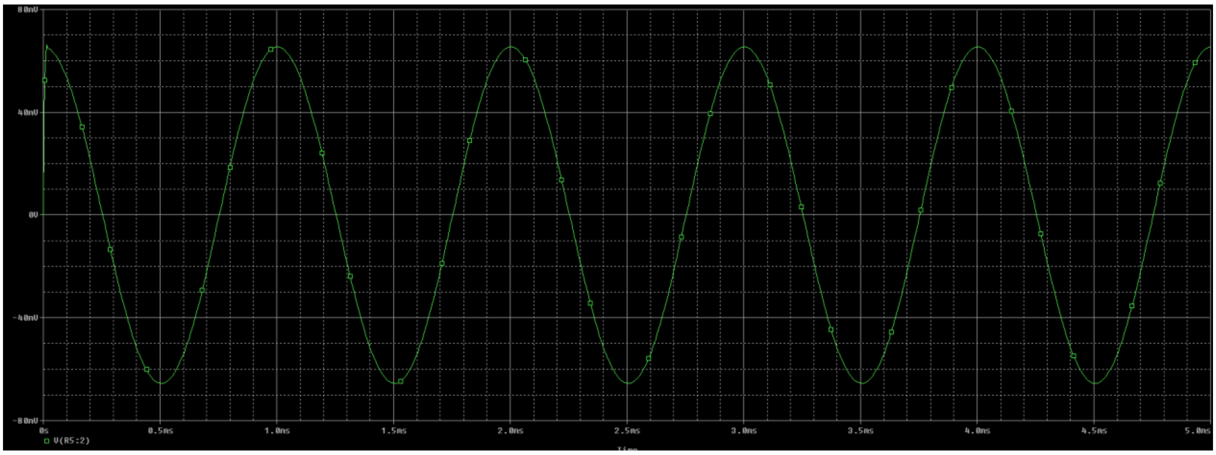
$$V_{out} = \frac{8 \times 5}{100+8} = 0.370$$

Q10. Using TRANSIENT ANALYSIS, verify these results in simulation.

Sketch:



Simulation:



Q11. Measure the DC Bias values before injecting the input signal and include them in your report.

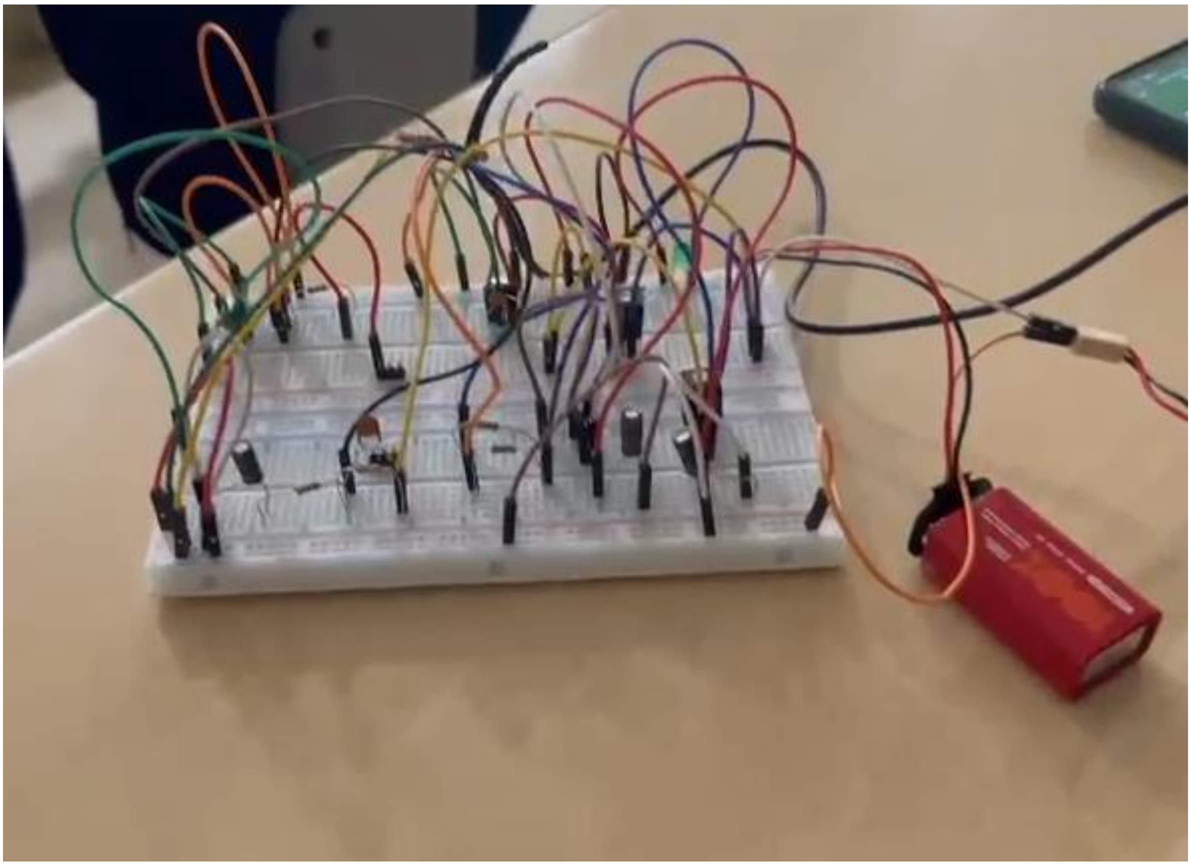
IBIAS1:

IBIAS2:

IBIAS3:

Q12. Test the amplifier with a real input signal (mp3 player, iPod, guitar pick-up, etc.), and demonstrate the working audio amplifier circuit to your TA.

Breadboard:

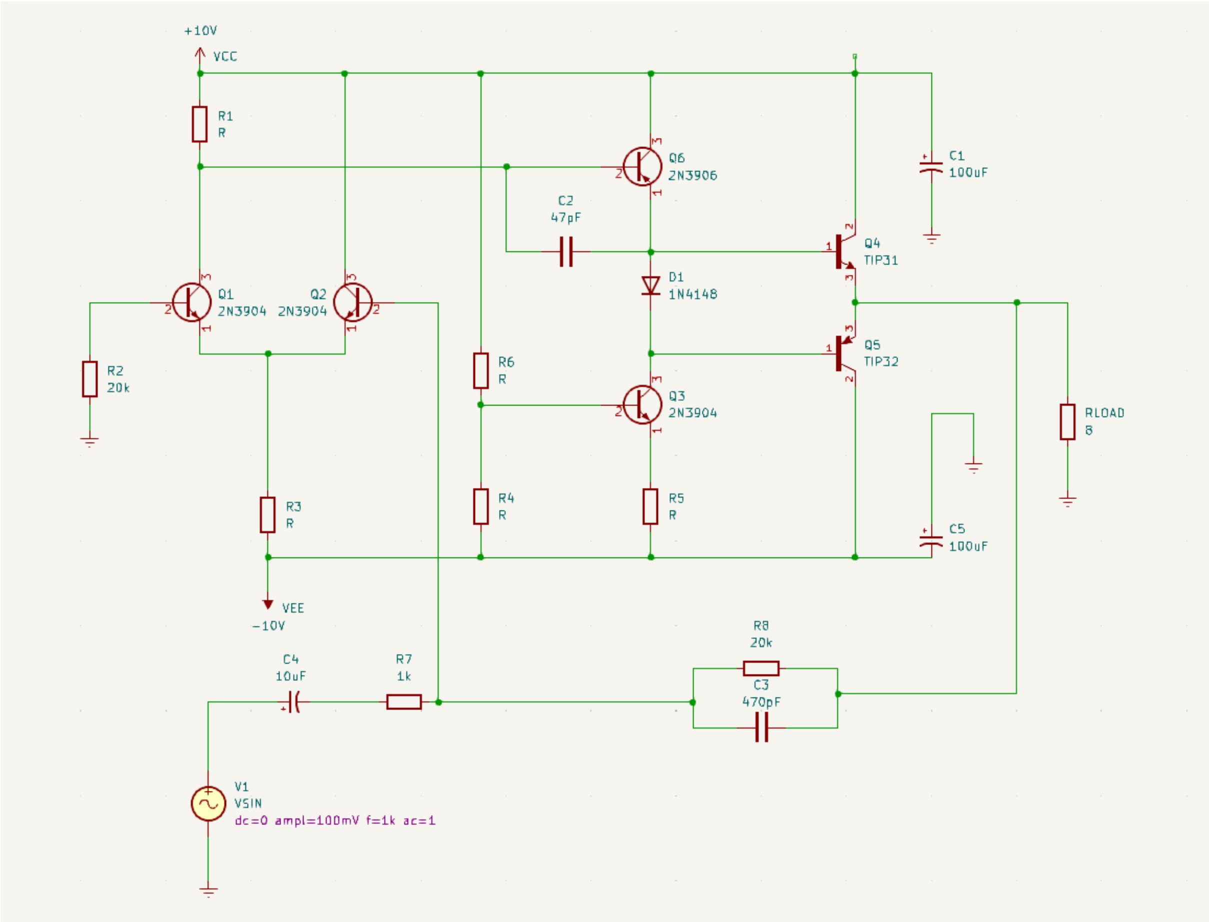


Test Video:

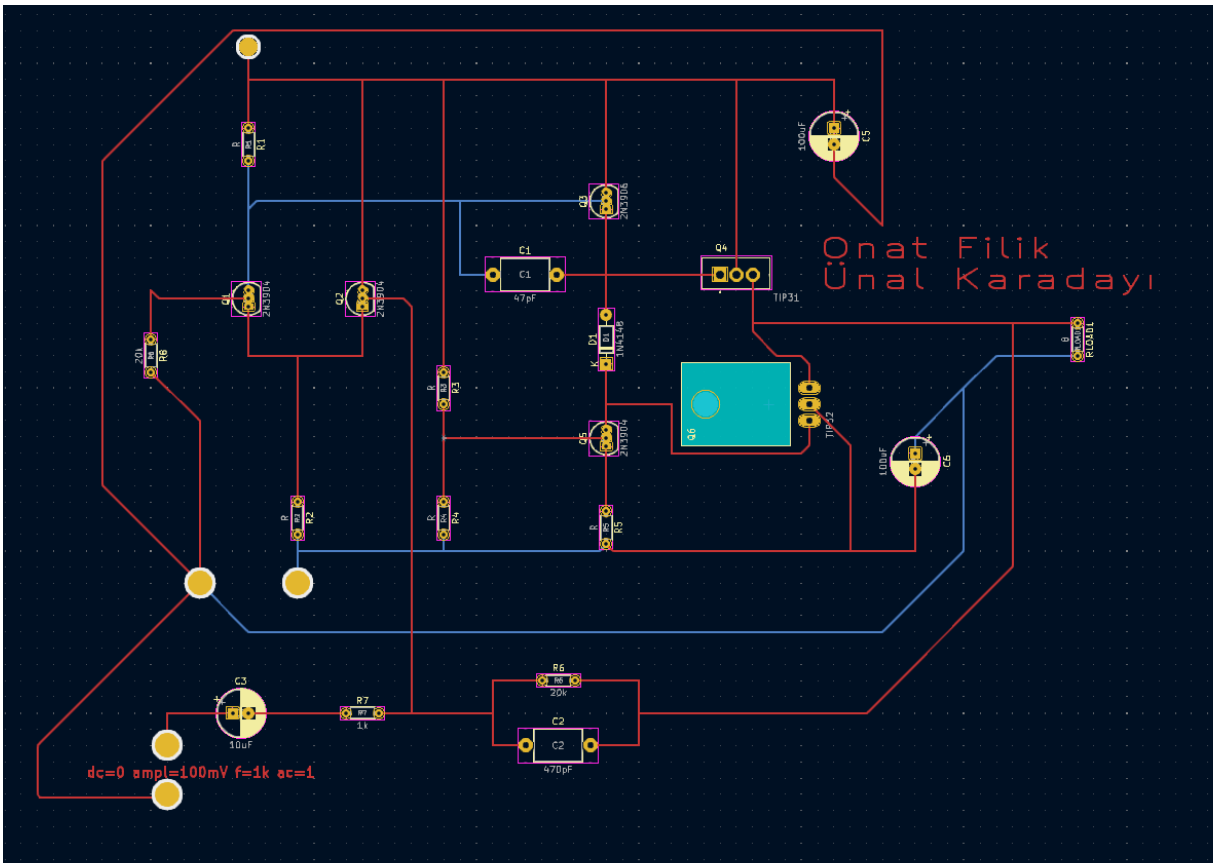
232ONATUNAL.mp4

Q13. Discuss the steps of PCB (Printed Circuit Board) design and manufacturing process, and provide your schematic diagram and PCB layout for the complete audio amplifier circuit.

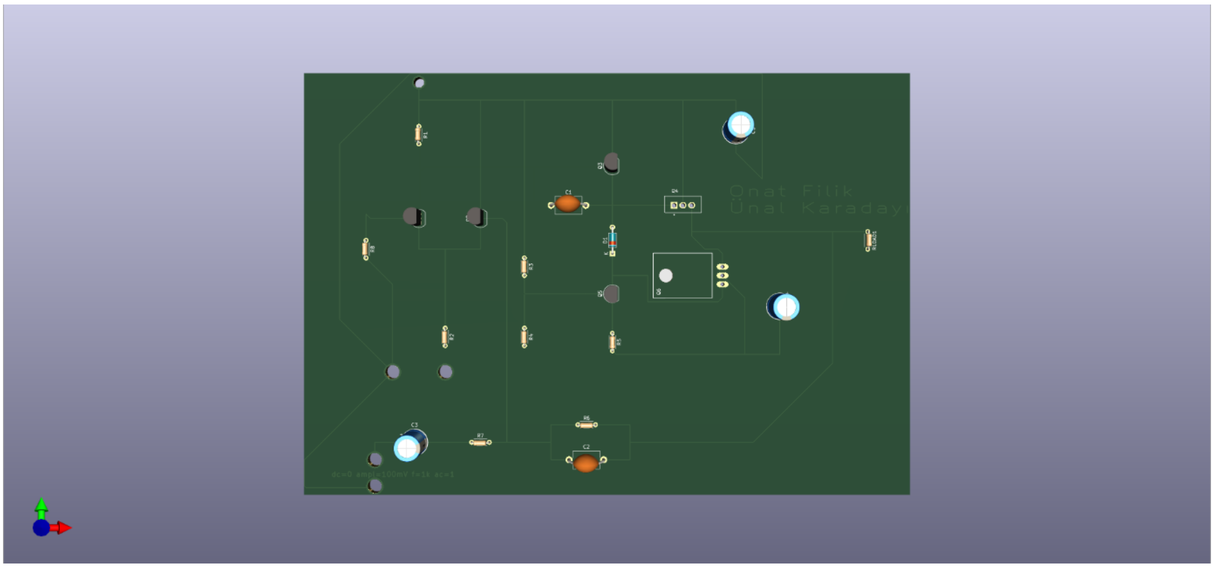
Sketch:



PCB:


Onat Filik
Ünal Karadayı
dc=0 ampl=100mV f=1k ac=1
C1
47pF
C2
470pF
C3
10uF
C5
100uF
C6
100uF
R6
20k
R7
1k
Q4
TIP31
TIP32
2N3904
2N3906
1N4148
RLOAD1

PCB 3D Front:



PCB 3D Rear: