EE 3124 Project #2

Design a two-stage BJT class-A amplifier to provide the following characteristics.

Jaeha Huh

EE project 2

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Design a two-stage BJT class-A amp.

1) Hand Calculations:

A)

Vcc	R_{in} *	A_i *
20V	103.66Ω	63.99

$\beta = 200$

From project #1

B)

I_{CQ}	V_{BEQ}	V_{CEQ}	P_D
180.2mA	0.808V	3.03V	547.4mW

Project #1 power-amp stage

I_{CQ}	V_{BEQ}	V_{CEQ}	P_D
2.5mA	0.7V	7.3V	18.25mW

Project #2 driver stage

C) Power rating for each resistors

R1	R2	RC	R_{E1}	R_{E2}
10.9mW	13.21mW	6.25mW	7.245mW	18.35mW

D) I_{ps1} (Project #1) = 182.298 mA

I_{ps2} (Project #2) $= I_{R1} + I_{CQ} = 1.205mA + 2.5mA$

$= 3.705 mA$

$\therefore \boxed{I_{ps}(\text{Total}) = I_{ps1} + I_{ps2} = 186.003 mA \cong 186 mA}$

E)

A_i (driver stage)	A_i (power amp stage)	A_i (Total)
3.139	63.99	200.86

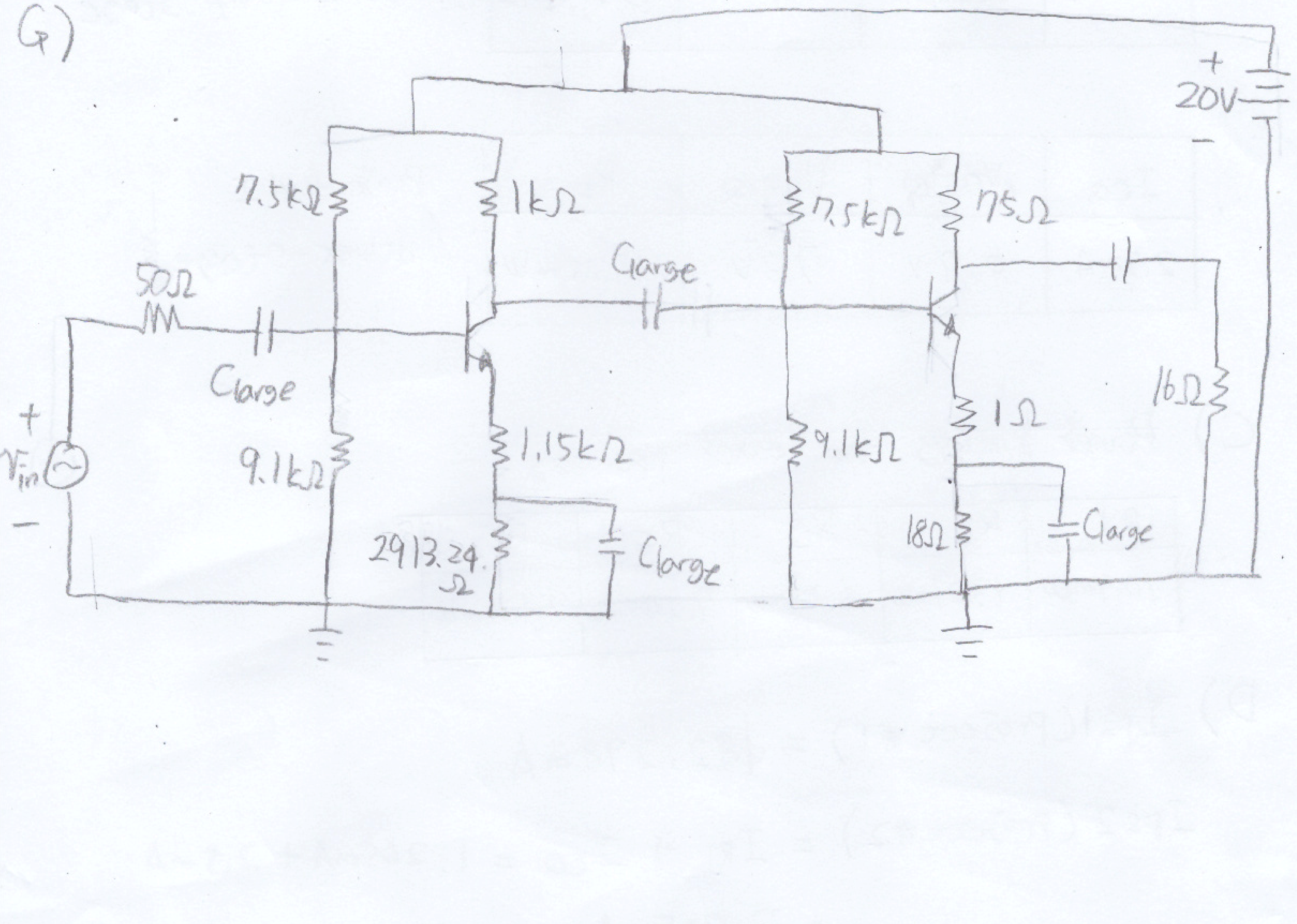
$A_i(\text{Total}) = A_i(\text{driver}) \times A_i(\text{power amp}) = 3.139 \times 63.99$

$\boxed{A_i(\text{total}) = 200.86 \cong 201}$

F) $\boxed{R_{in} = 4040.23\,\Omega}$

It is less than $10\,k\Omega$.

G)



H) Hand Calculation for Driver stage.

Given: From project 1, we know $A_i^* = 63.99$

$\Rightarrow$ Max (Peak) current swing of Driver Amp $= 125mA / (A_i^*)$

$= \frac{125mA}{63.99} = 1.9534\ mA$.

So, let $I_{C,peak} = 3.5\ mA$ and $R_L = R_{in}^* = 103.66\ \Omega$ (given)

$\Rightarrow I_{L,peak} = I_{C,pk} \frac{R_C}{R_C + R_L}$, let $R_C = 1k$.

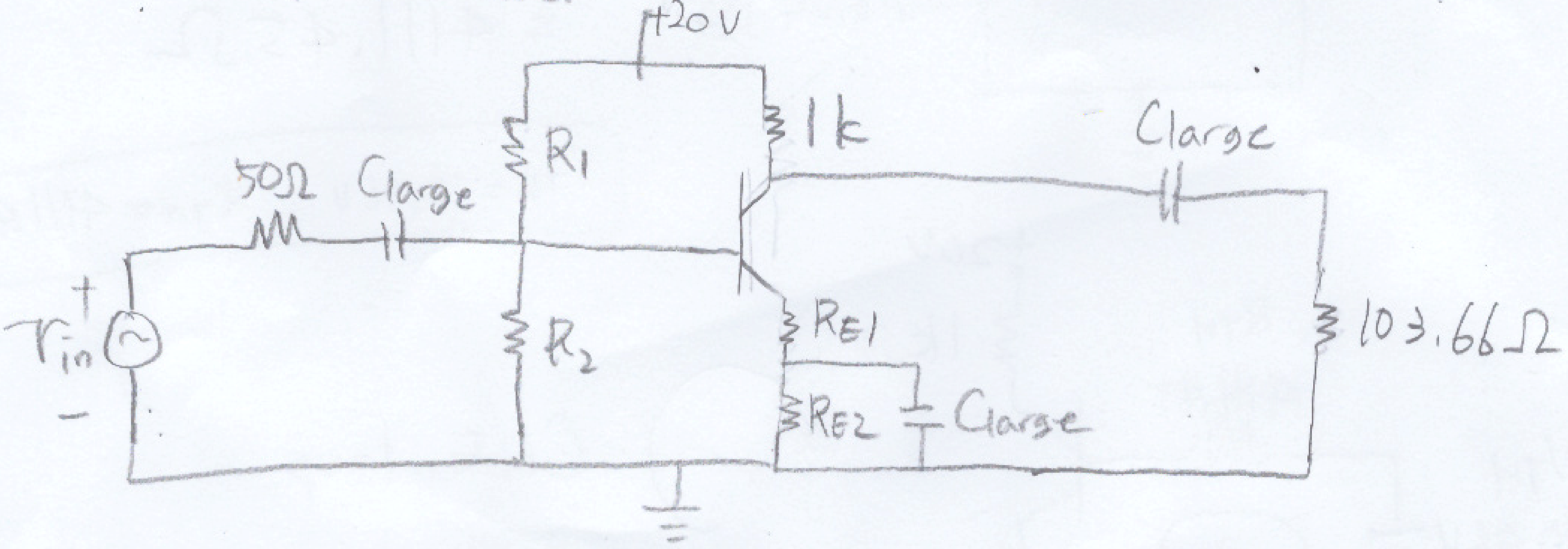
$I_{L,pk} = 3.5\ mA \cdot \frac{1k}{1k + 103.66} = 3.171\ mA$

So, $I_{L,pk} = 3.171\ mA$ (my assumption) $>$ $1.9534\ mA$ (calculation)

$\Rightarrow$ let $I_{CQ} = 3.171\ mA = 0.003171\ A$

by formula of I_{CQ} with Max swing

$I_{CQ} = \frac{V_{CC}}{R_{DC} + R_{AC}}$ $V_{CC} = 20V$ (given)



$0.003171 = \frac{20}{R_{DC} + R_{AC}} \Rightarrow R_{DC} + R_{AC} = \frac{20}{0.003171}$

$\Rightarrow R_{DC} + R_{AC} = 6307.16\ \Omega$

$R_{DC} = R_C + R_{E1} + R_{E2}$, $R_{AC} = (R_C \| R_L) + R_{E1}$

$R_{DC} + R_{AC} = R_C + 2R_{E1} + R_{E2} + R_C \| R_L = 6307.16$

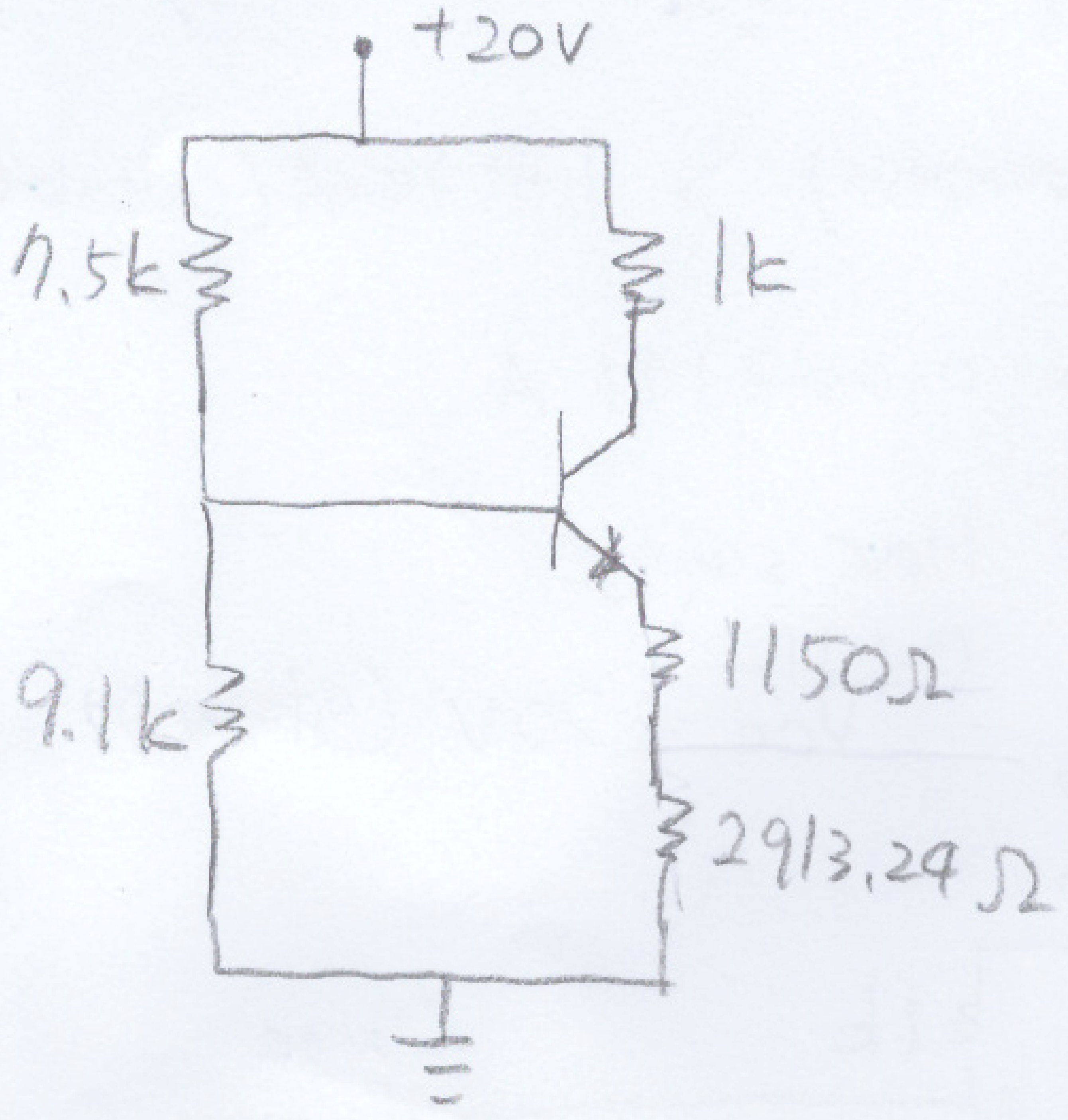
$2R_{E1} + R_{E2} = 5213.24$

Let $R_{E1} = 1.15k\Omega$, then $R_{E2} = 2913.24\Omega$

$\Rightarrow \boxed{R_C = 1k\Omega, \ R_{E1} = 1.15k\Omega, \ R_{E2} = 2913.24\Omega}$

Pick $R_1 = 7.5k$ and $R_2 = 9.1k$ (from standard resistance value)

DC Analysis



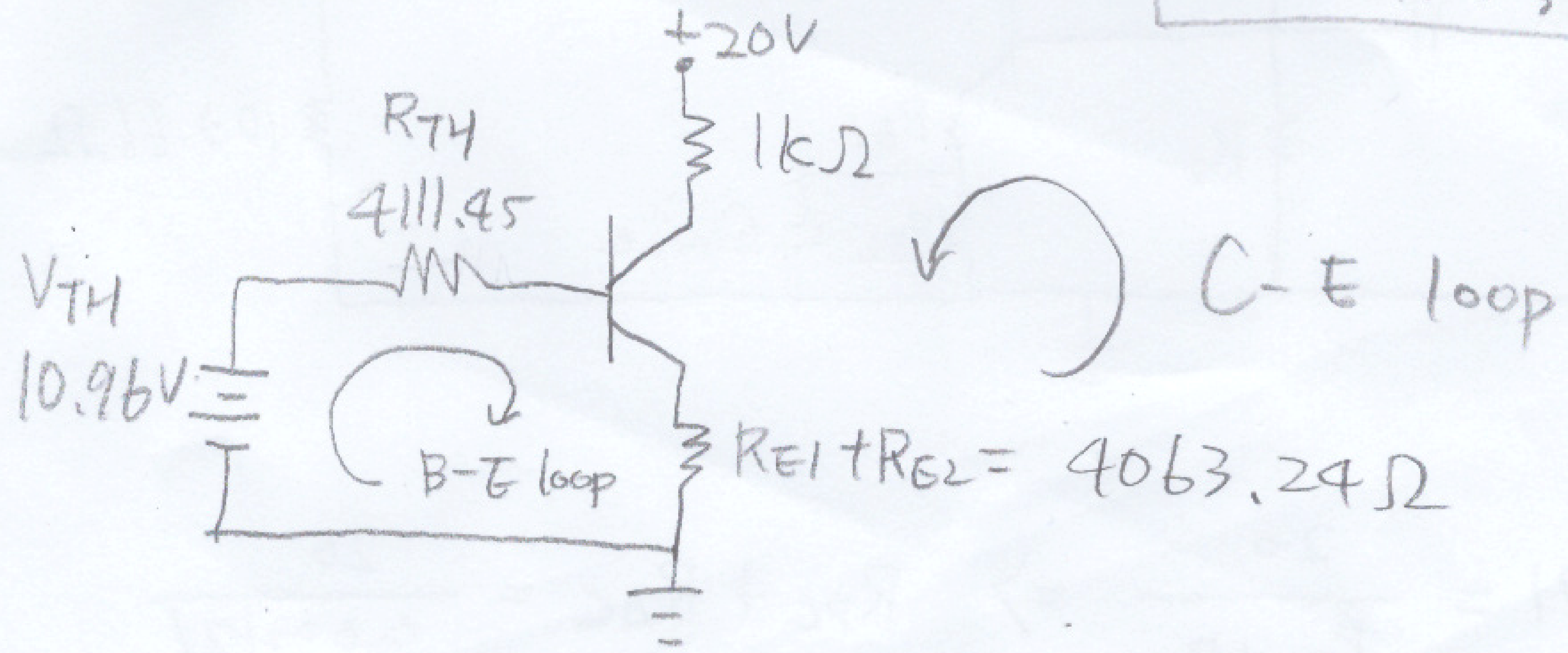
$V_{TH} = 20V\left(\frac{9.1k}{16.6k}\right) = 10.96V$

$R_{TH} = R_1 \| R_2$

$= \frac{9.1k \times 7.5k}{16.6k}$

$= 4111.45\Omega$

$\boxed{V_{TH} = 10.96V, \ R_{TH} = 4111.45\Omega}$



① KVL: B−E Loop

$0 = -V_{TH} + R_{TH}(I_{BQ}) + V_{BEQ} + (4063.24)(I_{EQ})$

$I_{EQ} = (\beta + 1) I_{BQ}$ $\beta = 200$ (given)

$0 = -V_{TH} + R_{TH}(I_{BQ}) + V_{BEQ} + (4063.24)(\beta+1) I_{BQ}$

$0 = -10.96 + (4111.45)(I_{BQ}) + 0.7 + (4063.24)(201) I_{BQ}$

$I_{BQ} = \frac{10.96 - 0.7}{820822.7} = \frac{10.26}{820822.7} = 0.0000125 = 12.5\,\mu A$

$I_{CQ} = \beta I_{BQ} = 200(12.5\,\mu A) = 2.5\,mA$

$I_{EQ} = (\beta+1) I_{BQ} = 201(12.5\,\mu A) = 2.51\,mA$

$\Rightarrow \boxed{I_{BQ} = 12.5\,\mu A, \quad I_{CQ} = 2.5\,mA, \quad I_{EQ} = 2.51\,mA}$

② KVL: C−E Loop

$0 = -V_{CC} + R_C(I_{CQ}) + V_{CE} + R_E(I_{EQ})$

$V_{CE} = V_{CC} - R_C(I_{CQ}) - R_E(I_{EQ})$

$= 20 - 1k(2.5\,mA) - (4063.24)(2.51\,mA)$

$= 20 - 2.5 - 10.2 = 7.3\,V$

$V_{CEQ} = 7.3\,V > V_{CE,Sat} = 0.3\,V$ ✓

$\therefore$ $V_{CEQ} = 7.3\,V$

Foward Active

③ $P_D \cong (V_{CEQ})(I_{CQ}) = (7.3V)(2.5mA)$

$= 0.01825 = \underline{18.25mW}$

$\therefore \boxed{P_D = 18.25mW}$

$P_{RC} = I^2R = (I_{CQ})^2(R_C) = (2.5mA)^2(1k\Omega) = 6.25mW$

$P_{RE1} = (R_{E1})(I_{EQ})^2 = (1.15k)(2.51mA)^2 = 7.245mW$

$P_{RE2} = (R_{E2})(I_{EQ})^2 = (2913.24)(2.51mA)^2 = 18.35mW.$

④ $V_{R1} = V_{CC} - V_B = 20 - 10.96 = 9.04$

$I_{R1} = \frac{V_{R1}}{R_1} = \frac{9.04}{7.5k} = 1.205mA$ $\boxed{I_{R1} = 1.205mA}$

$\Rightarrow P_{R1} = (R_1)(I_{R1})^2 = 10.9mW$

$I_{R1} = I_{R2}$

$\Rightarrow P_{R2} = (R_2)(I_{R2})^2 = 13.21mW$

$\therefore$ Power dissipation of resistors

$\Rightarrow \boxed{R_1 = 10.9mW \quad R_2 = 13.21mW \quad R_C = 6.25mW \quad R_{E1} = 7.245mW \quad R_{E2} = 18.35mW}$

④ $r_o = \infty$

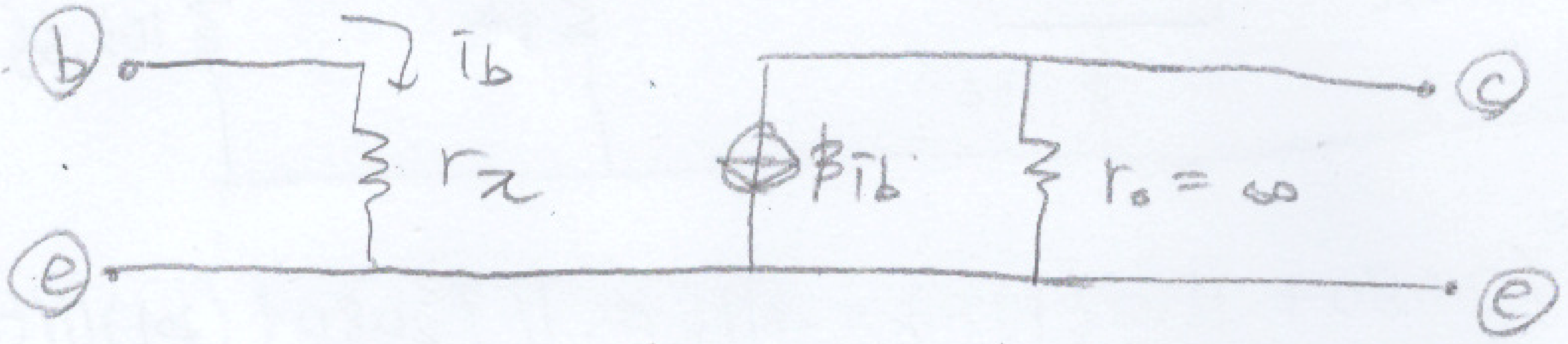
$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{200\,(26mA)}{(2.5mA)} = 2080$$

$$g_m = \frac{\beta}{r_\pi} = \frac{200}{2080} = 0.096$$

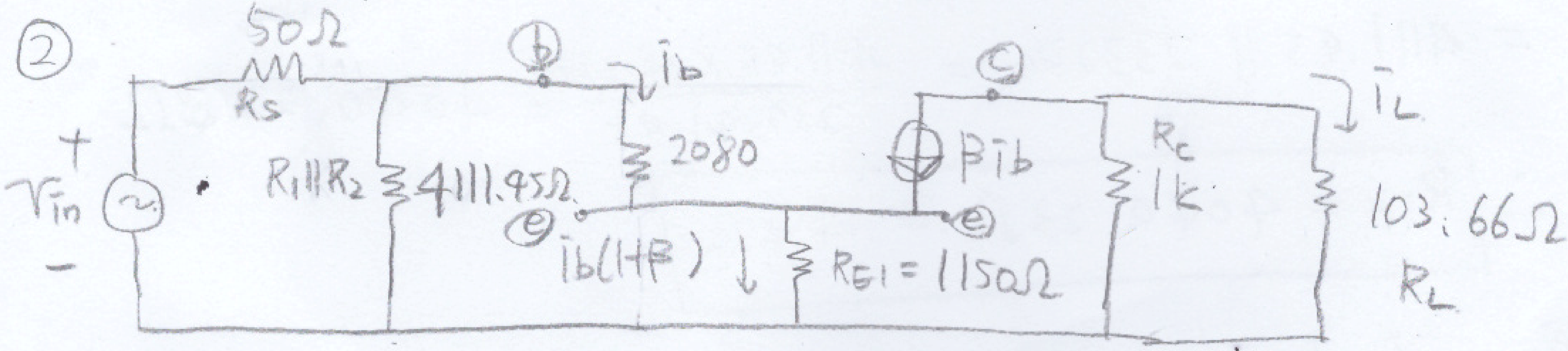
$\therefore \boxed{r_\pi = 2080\ ,\ g_m = 0.096}$

Ac Analysis

① Small signal



②



Current gain of Driver Amp $= 200 / A_i^* = \frac{200}{63.99} = 3.1255$
(This is primary goal). $\therefore A_i(\text{goal}) = 3.1255$

Hand Calculation:

$2080 + (201)\,1150 = 233230\Omega$

$$i_b = i_{in}\left(\frac{4111.45}{4111.45 + 233230}\right) \Rightarrow i_{in} = \frac{237341.45}{4111.45}\, i_b$$

$\Rightarrow i_b = 57.727$

$$i_o = -\beta i_b \left(\frac{1k}{1k + 103.66} \right) = -200 \left(\frac{1k}{1k+103.66} \right) i_b$$

$$i_o = -181.215$$

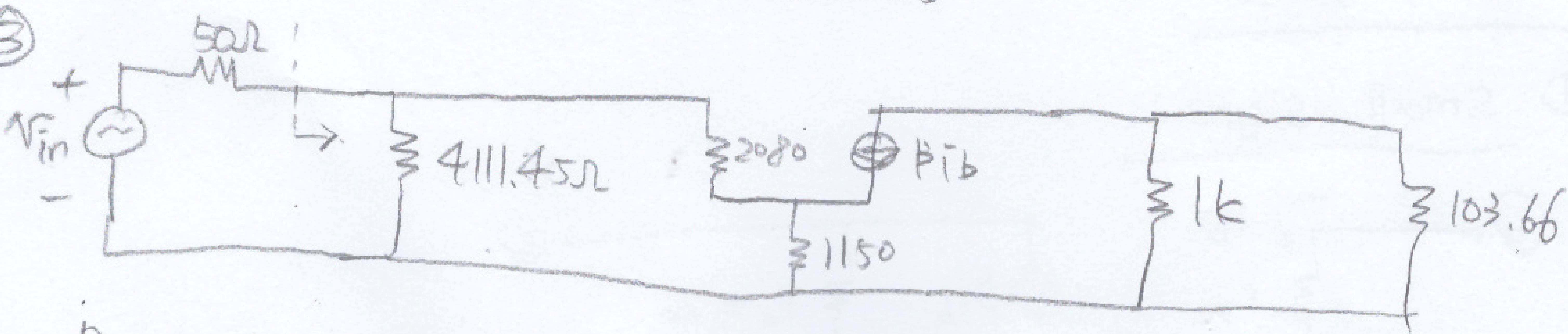
$$\therefore A_i = \left| \frac{i_o}{i_{in}} \right| = \left| \frac{-181.215}{57.727} \right| = 3.139$$

$$\therefore \boxed{A_i = 3.139}$$

$\Rightarrow A_i$ (by hand calculation) $\cong A_i$ (goal).

$3.139 \cong 3.1255.$

③

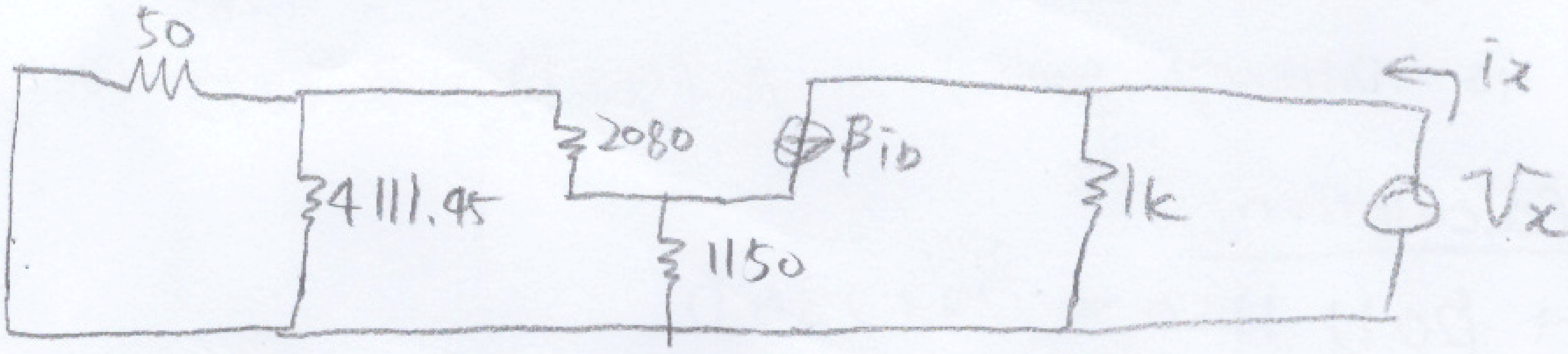


$$R_{in} = 4111.45 \parallel (2080 + 1150(1+\beta)) = 4111.45 \parallel (2080 + (201)(1150))$$

$$= 4111.45 \parallel 233230 = \frac{4111.45 \times 233230}{237341.45} = 4040.228\Omega$$

$$\therefore \boxed{R_{in} = 4040.23\Omega \cong 4k\Omega}$$

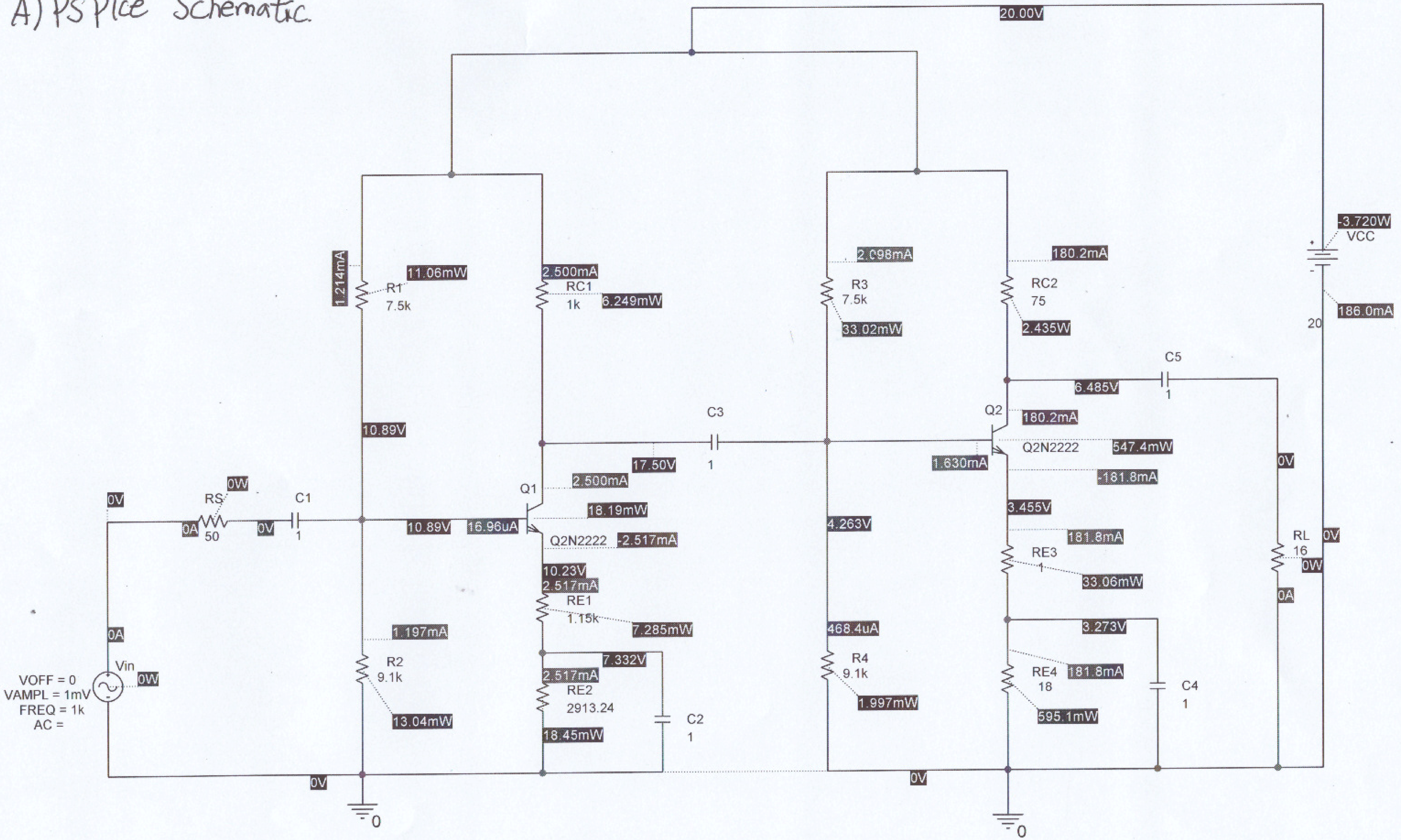
④ $R_o = \left. \frac{v_x}{i_x} \right|_{v_{in}=0}$



$i_b = 0$, $\beta i_b = 0$ $\Rightarrow v_x = i_x \, 1k$

$$\boxed{R_{out} = 1k\,\Omega}$$

A) PSpice Schematic



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PSpice part

B) SIMLATED DC BIAS

Power amp stage (Project#1)

Simulated value	
ICQ	180.2mA
VCEQ	3.03V
VBEQ	0.808V
P_D,transistor	547.4mW

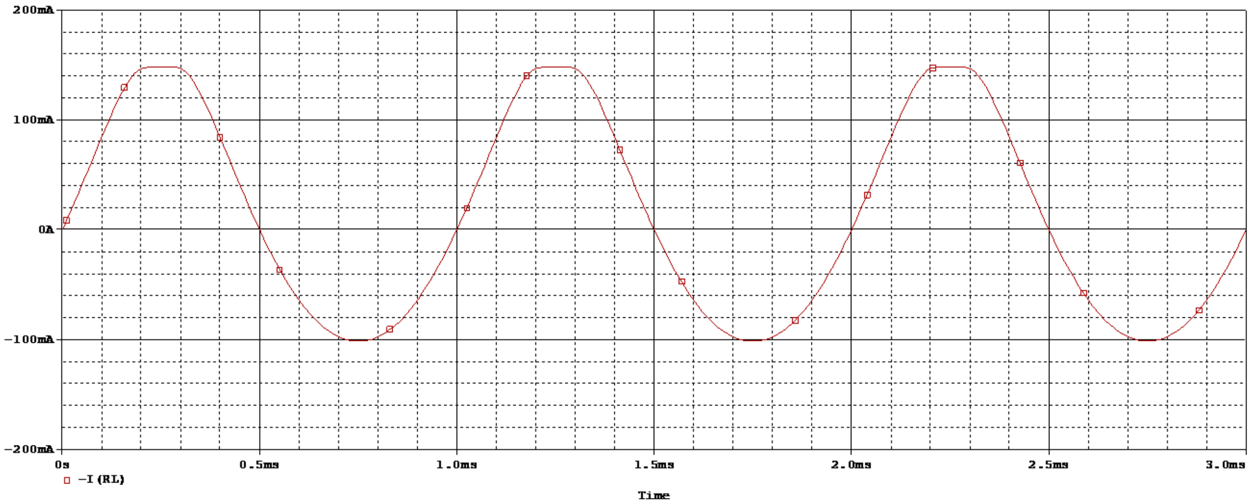
Simulated value		Hand-calculated value	
ICQ	2.5mA	ICQ	2.5mA
VCEQ	7.27V	VCEQ	7.3V
VBEQ	0.66V	VBEQ	0.7V
P_D,transistor	18.19mW	$P_D s$,transistor	18.25mW

C) SIMLATED POWER SUPPLY BIAS

DC power Supply Current (Ips) = 186mA.

It is less than 225mA. Thus, my circuit operate below the specification for maximum current, 225mA.

D) SIMULATED CURRENT SWING (β=200)



It is clipping to 148 mA at the top. The small value of two value is 102mA.

The peak-to-peak swing in the output current, i_L = 204mA. So, my design does not achieve the 250mA peak-peak swing.

E) SIMULATED CURRENT SWING (β=100 and β=300)

Table for peak-to-peak swing in the output current, i_L

β=100	β=200	β=300
168mA	204mA	60mA

Thus, my design does not achieve 125mA peak-to-peak swing under all conditions.

F) SIMULATED EFFICIENCY

$$PS = (Vcc)(Ips) = 20V * 0.186mA = 3.72\text{W}$$

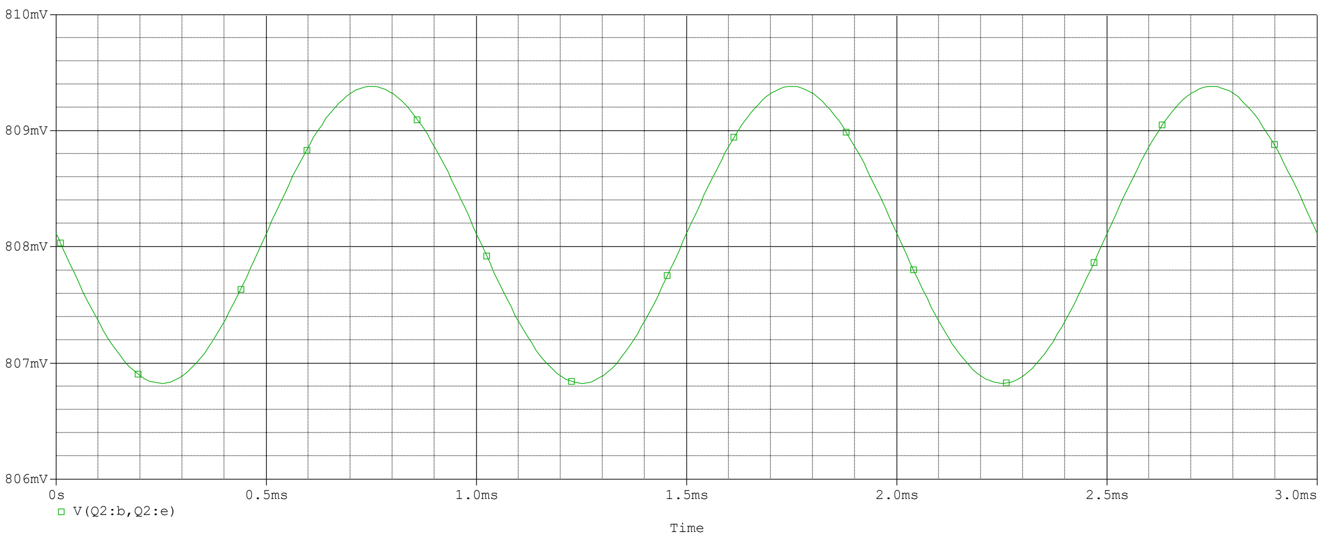
$$PL = \left(\frac{iL}{\sqrt{2}}\right)^2 (RL) = (0.0884)^2(16) = 0.125W$$

$$\eta = \frac{PL}{PS} = \frac{0.125W}{3.72W} = 0.0336 = 3.36\%$$

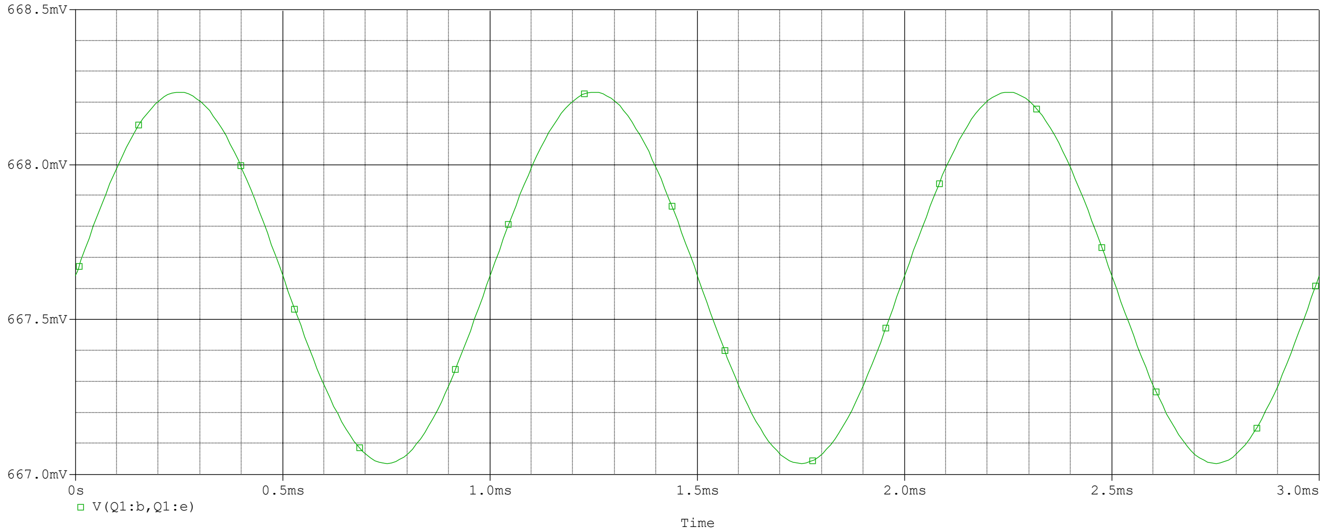
G) SIMULATED SMALL SIGNAL OPERATION

The amplitude value of the source voltage for small signal operation is 65mV for both transistors.

Power-amp stage transistor ($\beta = 200$)

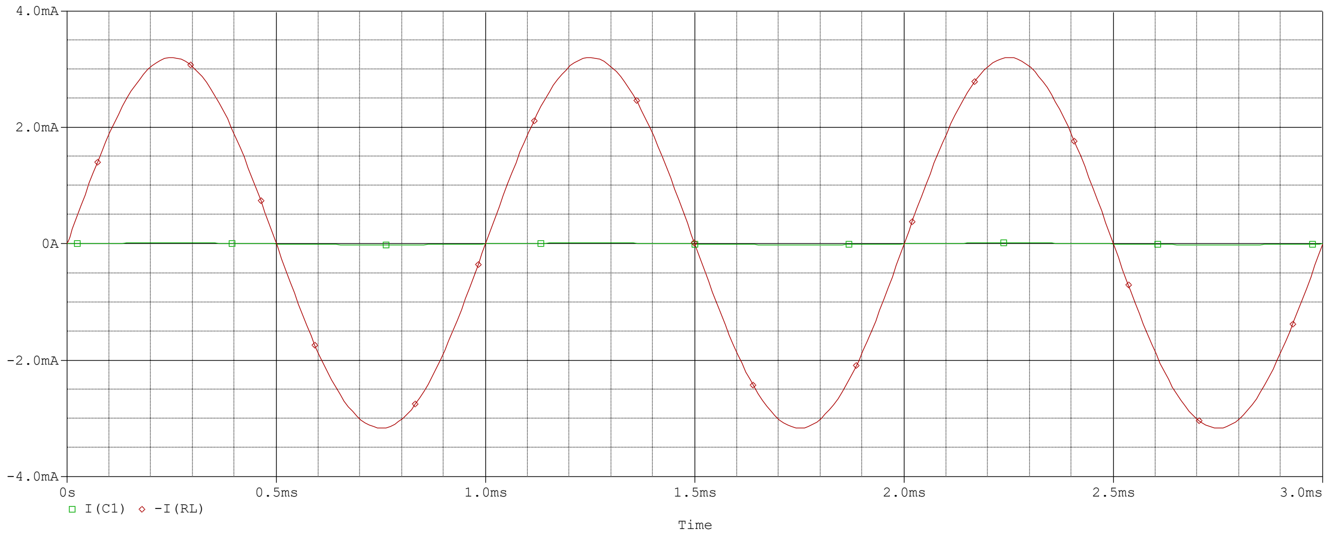


Driver stage transistor ($\beta = 200$)



H) SIMULATED TWO-STAGE CURRENT GAIN

$$\beta = 200, Ai = \frac{3.2036mA}{15.975uA} = 200.54$$



Thus, I achieve a current gain, 200.

I) SIMULATED GAIN VARIATION WITH β

$$\beta = 100, Ai = \frac{2.2307mA}{16.234uA} = 137.41$$

$$\beta = 300, Ai = \frac{2.3346mA}{15.886uA} = 146.96$$

Table (Current gain)

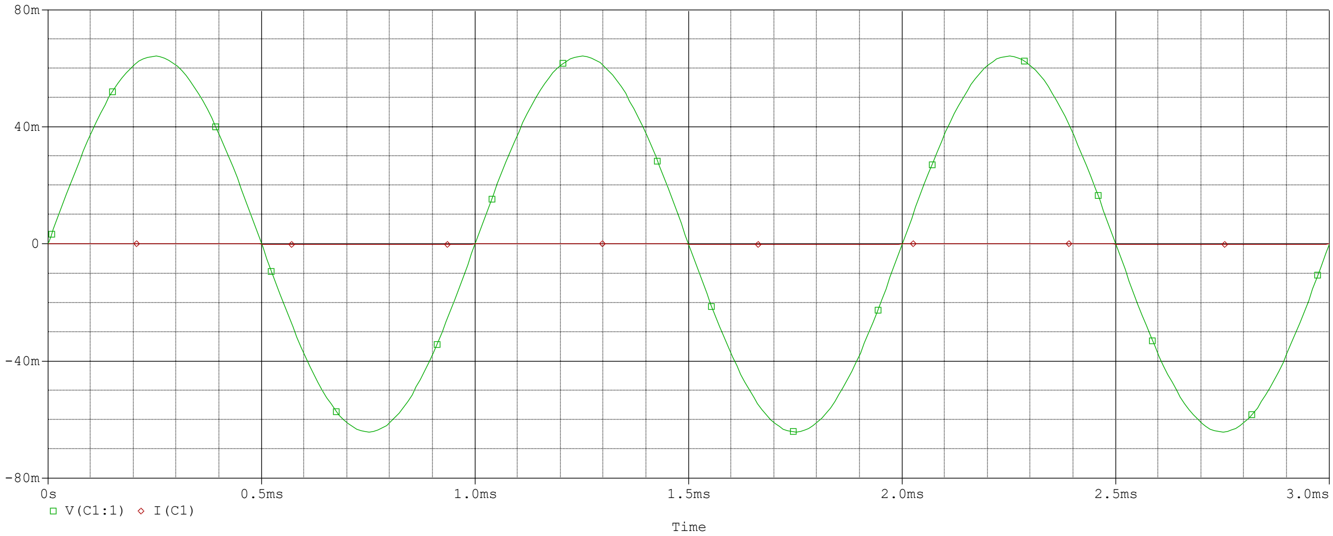
β=100	β=200	β=300
137.41	200.54	146.96

$$Percent\ gain\ variation = \frac{200.54 - 200}{200} * 100 = 0.27\%$$

I achieve a current gain variation 15% about the nominal value of $\beta = 200$.

J) SIMULATED INPUT RESISTANCE

$$\beta = 200, Rin = \frac{64.198mV}{15.975uA} = 4018.65\Omega$$



$$\beta = 100, Rin = \frac{64.186mV}{16.234uA} = 3953.80\Omega$$

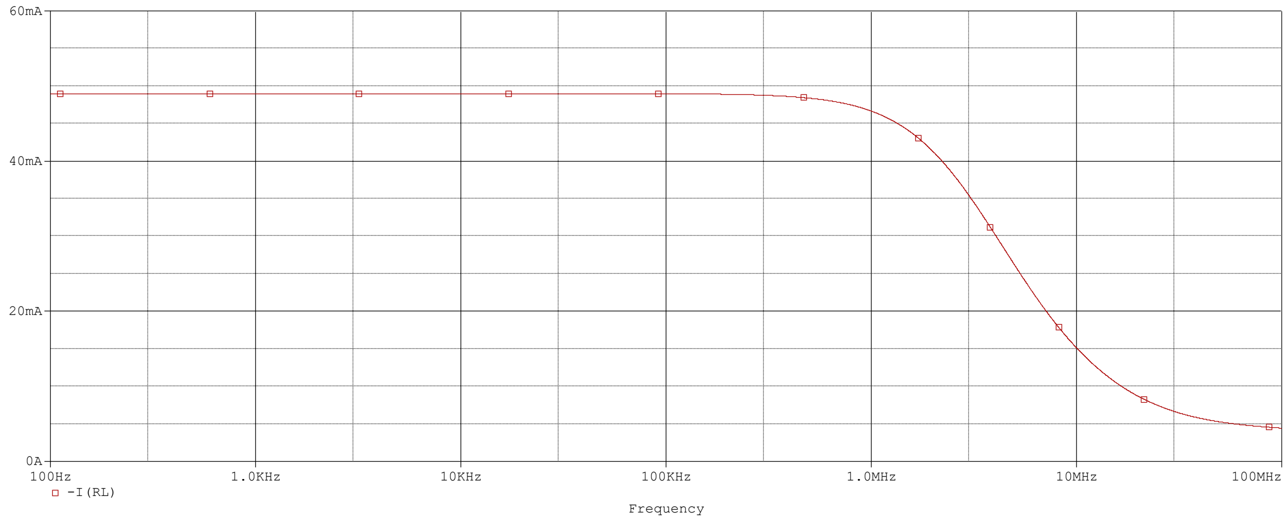
$$\beta = 300, Rin = \frac{64.202mV}{15.887uA} = 4041.17\Omega$$

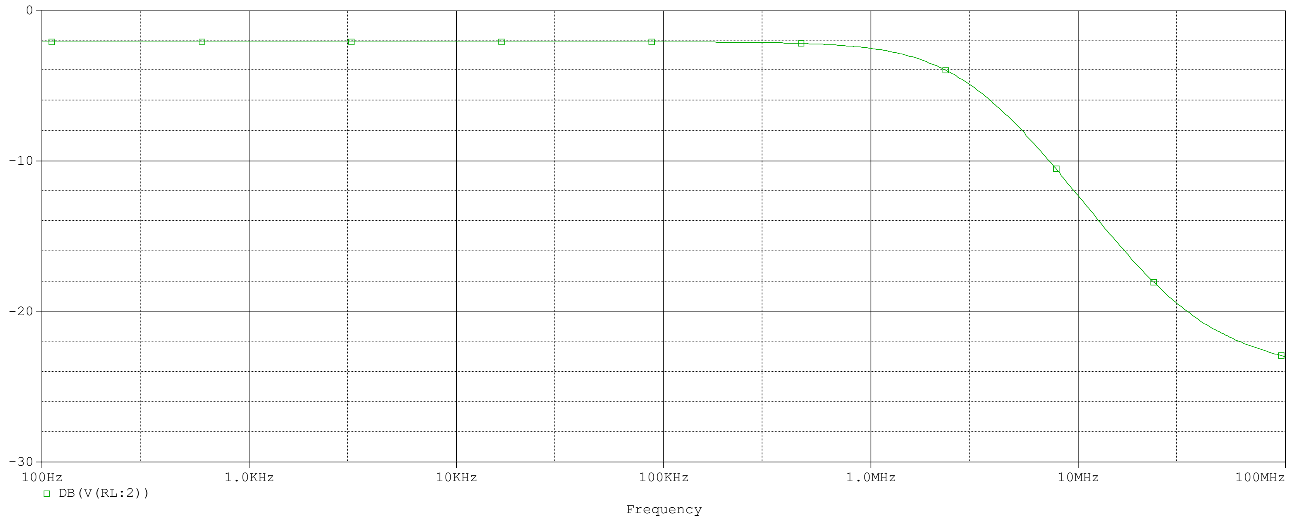
$\beta = 100$	$\beta = 200$	$\beta = 300$
3953.80Ω	4018.65Ω	4041.17Ω

I achieve an input resistance of less than $10k\Omega$.

I) SIMULATED FREQUENCY RESPONSE

The 3dB bandwidth of the current gain $= 20\log_{10}|\frac{i_L}{I_s}| = 20\log_{10}|200.54| = 46.04$

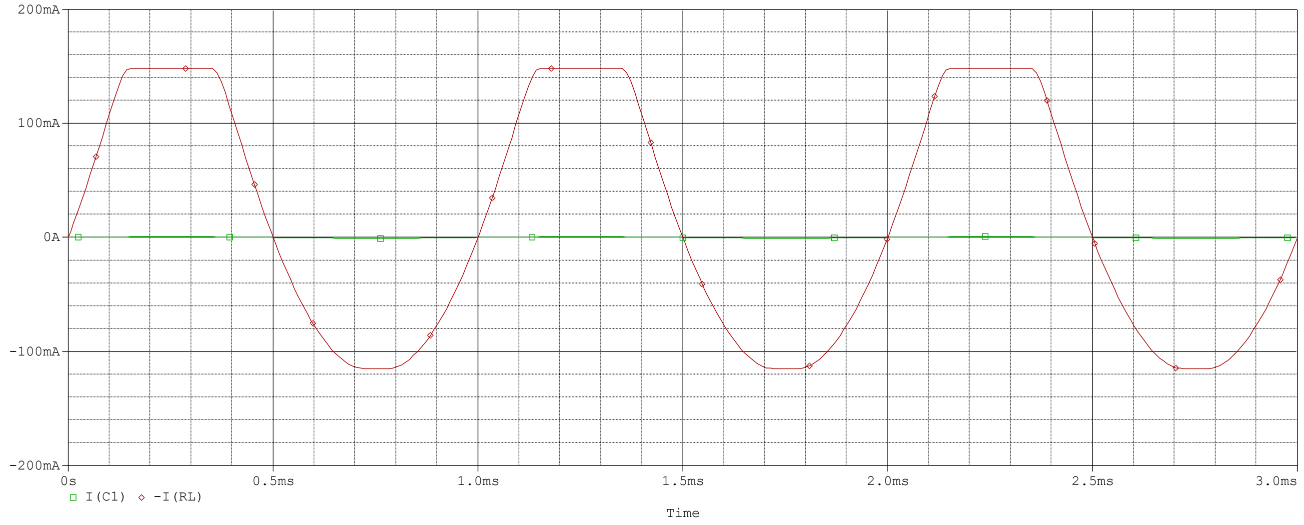




According to the graphs, it can be seen that -3dB is the cutoff frequency. Furthermore, this value is the point where the input voltage and current decrease by 0.707 times when delivered to the output.

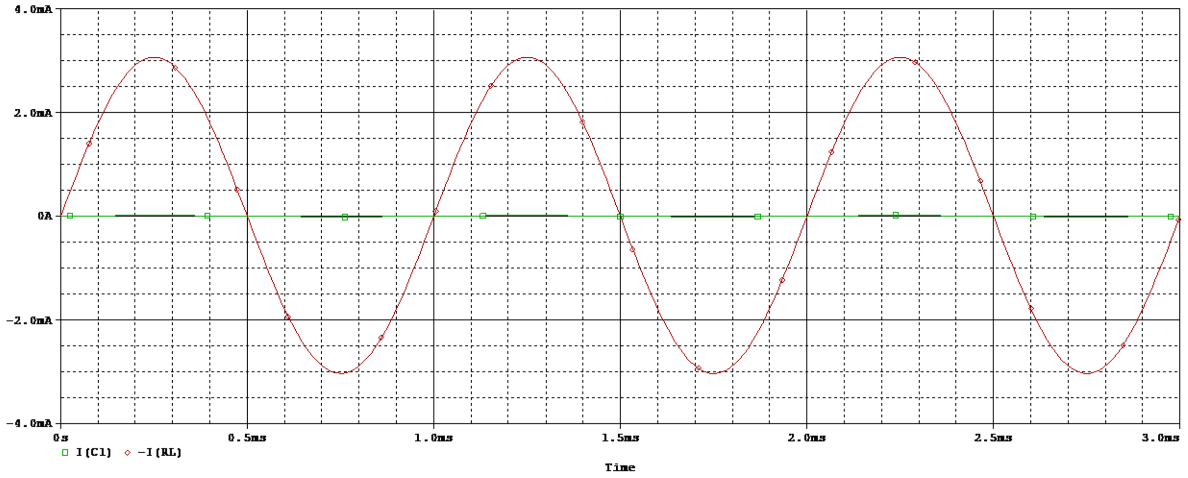
J) SIMULATION USING STANDARD RESISTOR VALUES

The plot of i_L with clipping at both the positive and negative peaks using a β = 200.



The small value of two value is 115mA. The peak-to-peak swing in the output current, i_L = 230mA.

The plots of is and i_L under small signal conditions



$$\beta = 200, Ai = \frac{3.0689mA}{15.959uA} = 192.28$$

$$Percent\ gain\ variation = |\frac{192.28 - 200}{200} * 100| = 3.86\%$$

My design still achieves normal gain specifications when the resistors are changed. The total peak to peak swing exceeds 250, but the bottom swing of the graph does not exceed 125mA. It seems that the offset is wrong.

Table (comparing the simulated peak swing, the simulated small signal gain and input resistance)

Original resistor

Peak swing	Small signal gain	Input resistance
204mA	200.54	4018.65Ω

Standard resistor

Peak swing	Small signal gain	Input resistance
230mA	192.28	4017.23Ω

BJT Power Amp and Driver Design: BOM (Project#1 and Project#2)

Name: ______________Jaeha Huh______________________

Lab Section: ___________ C1LB______

Note 1 – Resistor values, and power ratings should be chosen from standard resistor list.

Note 2 – Enter the quantity of capacitors

Note 3 – Enter resistor values in ascending order.

Note 4 – Do not include RS, RL, 1Ω precision resistors.

Note 5 –Email this list to your lab TA.

Capacitor Value	Voltage Rating	Quantity
100 μF	50V	5
Resistor Value	Resistor Power Rating	Quantity
1	3	1
16	3	1
18	3	1
50	3	1
75	3	1
1k	1/2	1
1.2k	1/2	1
3k	1/2	1
7.5k	1/2	2
9k	1/2	2
15	3	2