EE 3124 Project #1

Class A Power Amplifier Design

Jaeha Huh

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Hand Calculation

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A) Given = Peak to Peak current swing at R_L,

$i_{L,pk\text{-}to\text{-}pk} = 250mA$.

So, $I_{L,pk} = 125mA$

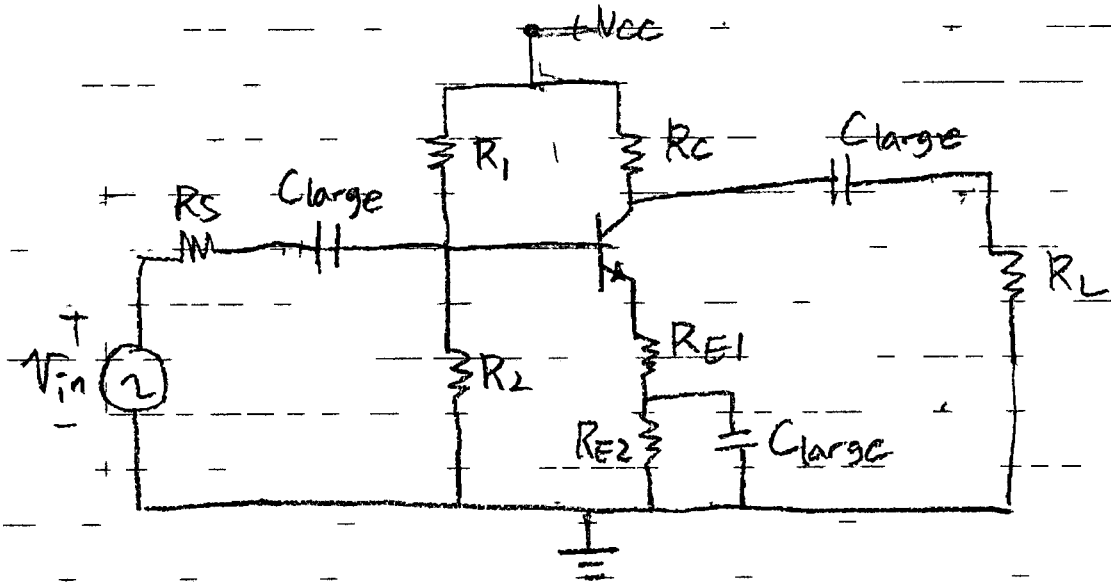
$I_{L,pk} = I_{C,pk}\left(\frac{RC}{RC+R_L}\right) \Rightarrow 125mA = I_{C,pk}\left(\frac{RC}{RC+165\Omega}\right)$

Let, $I_{C,pk} = 150mA$ then $125mA = 150mA\left[\frac{RC}{RC+165\Omega}\right]$

$\Rightarrow \boxed{RC = 80\Omega}$

- I_{CQ} with Max swing

$$I_{CQ} = \frac{V_{CC}}{R_{DC} + R_{AC}}$$



$R_{DC} = R_C + R_{E1} + R_{E2}$

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

$I_{CQ} = 125mA$ Let: $\boxed{V_{CC} = 18V}$, then

$$0.125A = \frac{18V}{R_{DC}+R_{AC}}$$

So, $R_{DC} + R_{AC} = 144$

$(R_C + R_{E1} + R_{E2}) + ((R_C \| R_L) + R_{E1}) = 144$

$(80 + R_{E1} + R_{E2}) + ((80 \| 16) + R_{E1})$

$= 80 + R_{E1} + R_{E2} + (13.33333) + R_{E1} = 144$

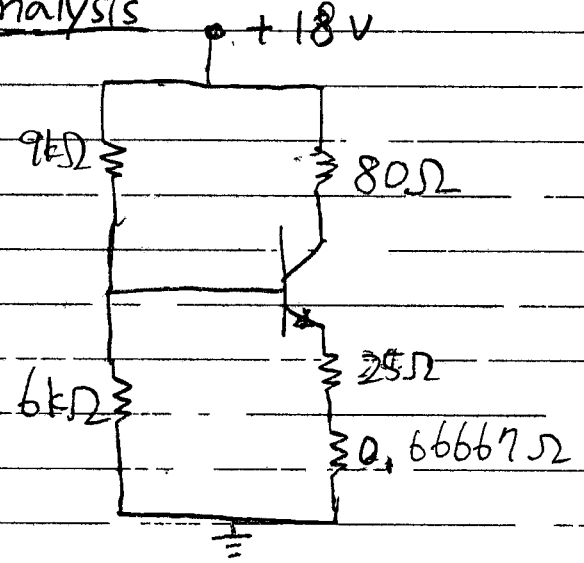
$2R_{E1} + R_{E2} = 144 - 93.33333 = 50.66667$

$\Rightarrow$ Let $2R_{E1} = 50$ $\Rightarrow$ $R_{E1} = 25\,\Omega$

$R_{E2} = 50.6667 - 50$ $R_{E2} = 0.66667\,\Omega$

- Pick $R_1 = 9k\Omega$ $R_2 = 6k\Omega$

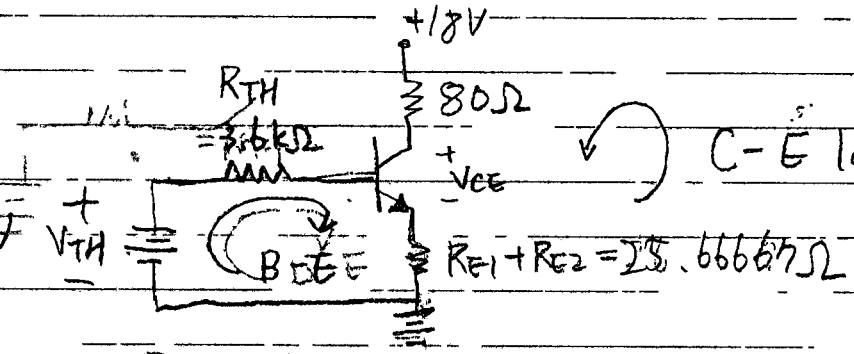
- DC Analysis



$V_{TH} = 18V\left(\frac{6k\Omega}{15k\Omega}\right) = 7.2V$

$R_{TH} = R_1 \| R_2 = \frac{9k \times 6k}{15k}$

$= 3.6k\Omega$



① KVL: B-E loop

$0 = -V_{TH} + R_{TH}(I_{BQ}) + V_{BEQ} + (25.66667)(I_{EQ})$

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

$0 = -V_{TH} + R_{TH}(I_{BQ}) + V_{BEQ} + (25.66667)(\beta + 1) I_{BQ}$

$0 = -7.2 + (3.6k)(I_{BQ}) + 0.7 + (25.66667)(201) I_{BQ}$

$I_{BQ} = \frac{7.2 - 0.7}{3600 + 5159} = \frac{6.5}{8759} = 0.000742A \approx 0.742mA$

$I_{CQ} = \beta(I_{BQ}) = (200)(0.742mA) = 0.148A$

$I_{EQ} = (\beta+1)(I_{BQ}) = (201)(0.725mA) = 0.149$

② KVL: C-E loop

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

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

$= 18 - 80(0.148) - 25.66667(0.149)$

$= 18 - 11.84 - 3.824$

$= 2.336$

$\therefore \boxed{V_{CEQ} = 2.336V}$ $V_{CEQ} > V_{CE,sat}$ ✓

$2.336V > 0.3V$

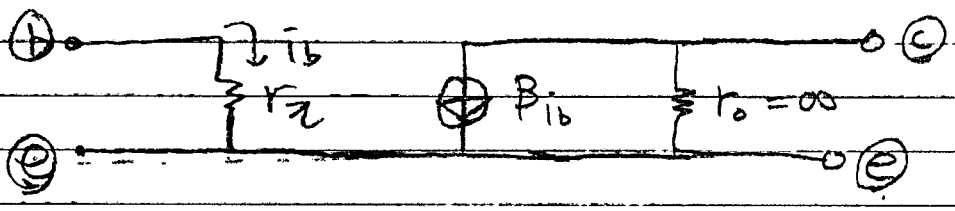
$\Rightarrow$ Fouard Active

③ $r_o \doteq \infty$

$r_\pi \doteq \frac{\beta V_T}{I_{CQ}} = \frac{200(26mA)}{(148mA)} = 35.14$

$g_m = \frac{\beta}{r_\pi} = \frac{200}{35.14} = 5.692$

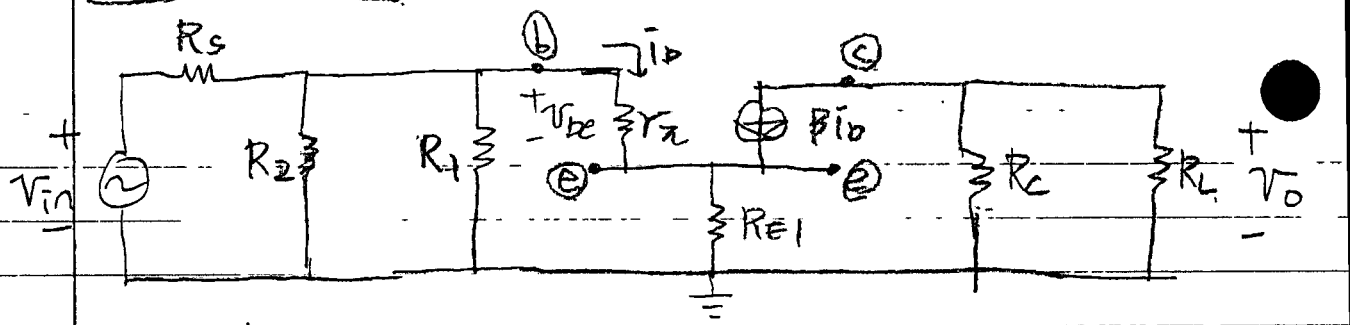
④ Small Signal

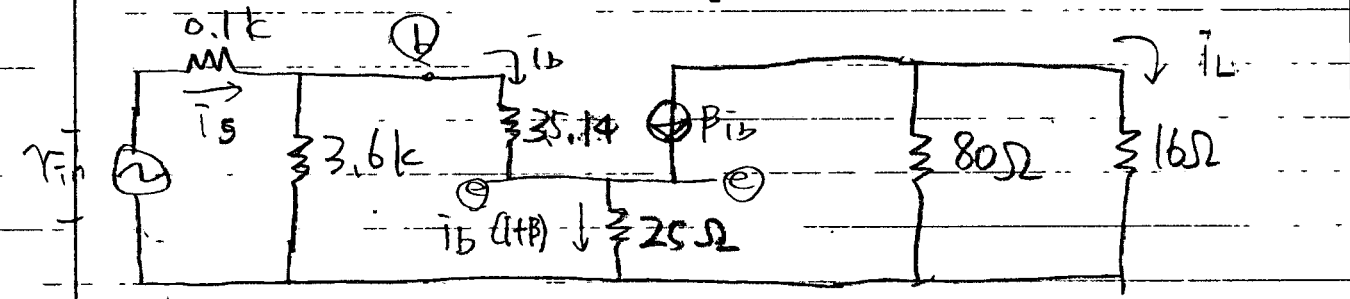


transistor model

Plug transistor model into circuit

⑤ AC Analysis





$35.14 + 25\,(201) = 4859.86\,\Omega$

$i_b = i_s \left(\frac{3600}{3600 + 5060.14}\right) i_s = 0.4157\, i_s$

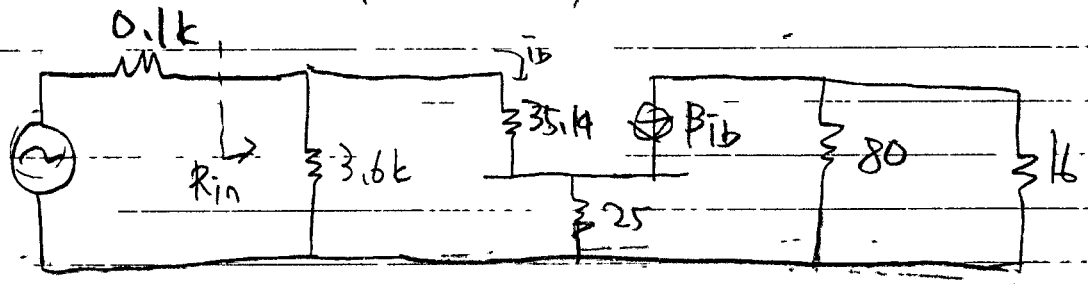
$i_s = \frac{1}{0.4157}\, i_b = 2.4056\, i_b$

$i_o = -\beta i_b \left(\frac{80}{80+16}\right) = -200\left(\frac{80}{80+16}\right) i_b$

$i_o = -166.6666\, i_b$

$\therefore A_i = \left|\frac{i_o}{i_s}\right| = \left|\frac{-166.6666\, i_b}{2.4056\, i_b}\right| = \boxed{69.28}$

⑥

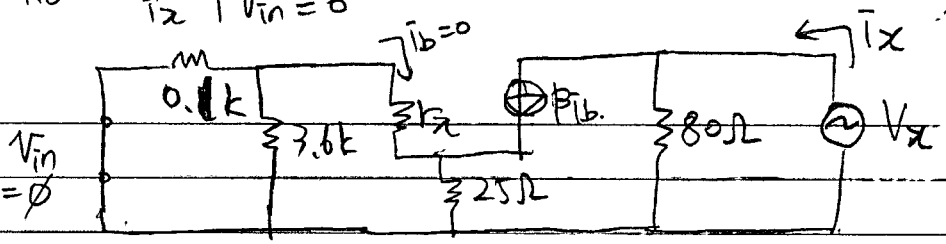


$R_{in} = 3.6k \,||\, (35.14 + 25) = 3600 \,||\, 60.14$

$R_{in} = \frac{3600 \times 60.14}{3660.14} = 59.15$

$\therefore \boxed{R_{in} = 59.15\,\Omega}$

$$R_o = \frac{V_x}{i_x}\Big|_{V_{in}=0}$$



$i_b = 0$, $\beta i_b = 0$

$\Rightarrow V_x = i_x\, 80\Omega$

$\therefore \boxed{R_{out} = 80\Omega}$

B) $\overline{P_S} = V_{CC}(I_{CQ}) = 18\,V \times 0.148\,A = 2.664\,w$

$$\overline{P_L} = \left(\frac{V_{pk}}{\sqrt{2}}\right)\left(\frac{i_{pk}}{\sqrt{2}}\right) = \left(\frac{V_{CEQ}}{\sqrt{2}}\right)\left(\frac{I_{CQ}}{\sqrt{2}}\right)$$

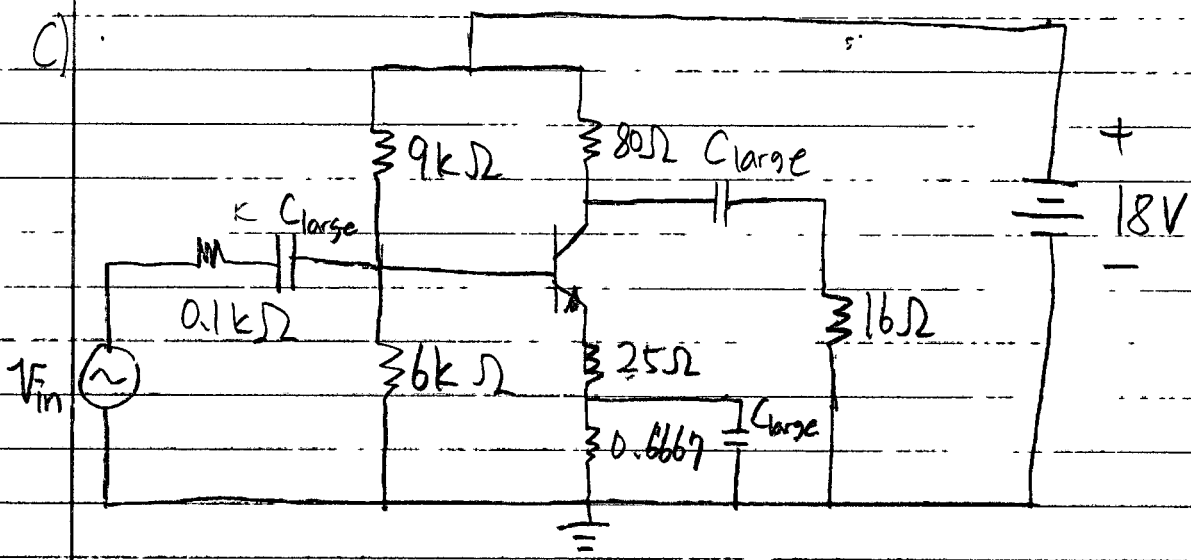
$$= \left(\frac{2.336}{\sqrt{2}}\right)\left(\frac{0.148}{\sqrt{2}}\right) = 0.172864\,w$$

$$\eta\ (\text{power conversion efficiency}) = \frac{\overline{P_L}}{\overline{P_S}} = \frac{0.172864}{2.664}$$

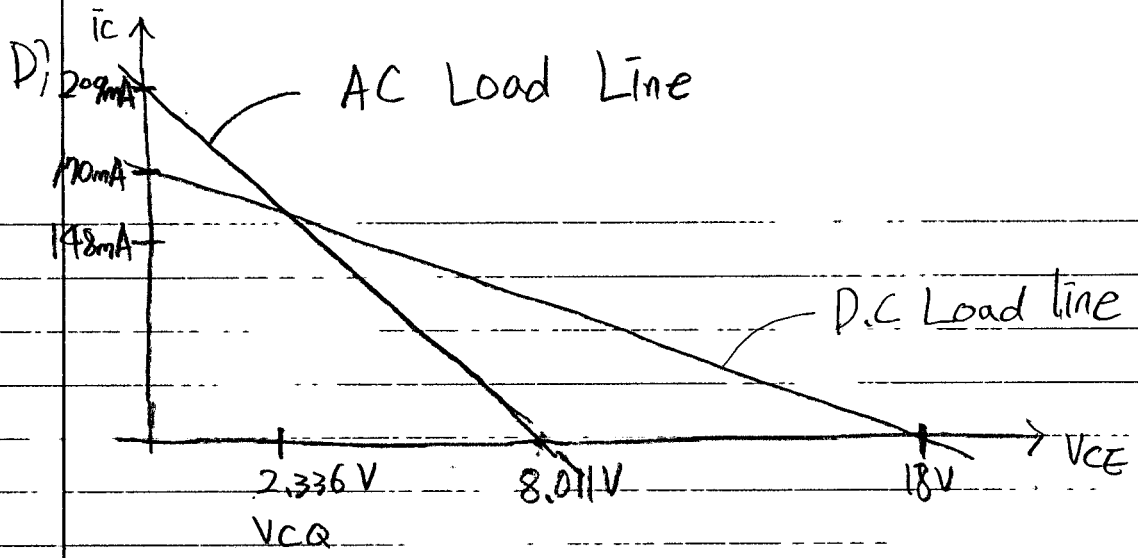
$= 0.06488 \cong 0.065$

$\therefore \boxed{\eta = 6.5\,\%}$

C)



D)



Slope of AC Load line $= -\frac{1}{R_{AC}} = -\frac{1}{38.3333}$

Slope of DC Load line $= -\frac{1}{R_{DC}} = -\frac{1}{105.66667}$

E)

V_{CC}	I_{CQ}	V_{CQ}	P_D
18V	148 mA	2.336 V	346 mW

$P_D \cong (V_{CEQ})(I_{CQ}) = (2.336)(0.148) = 0.346W$

F)

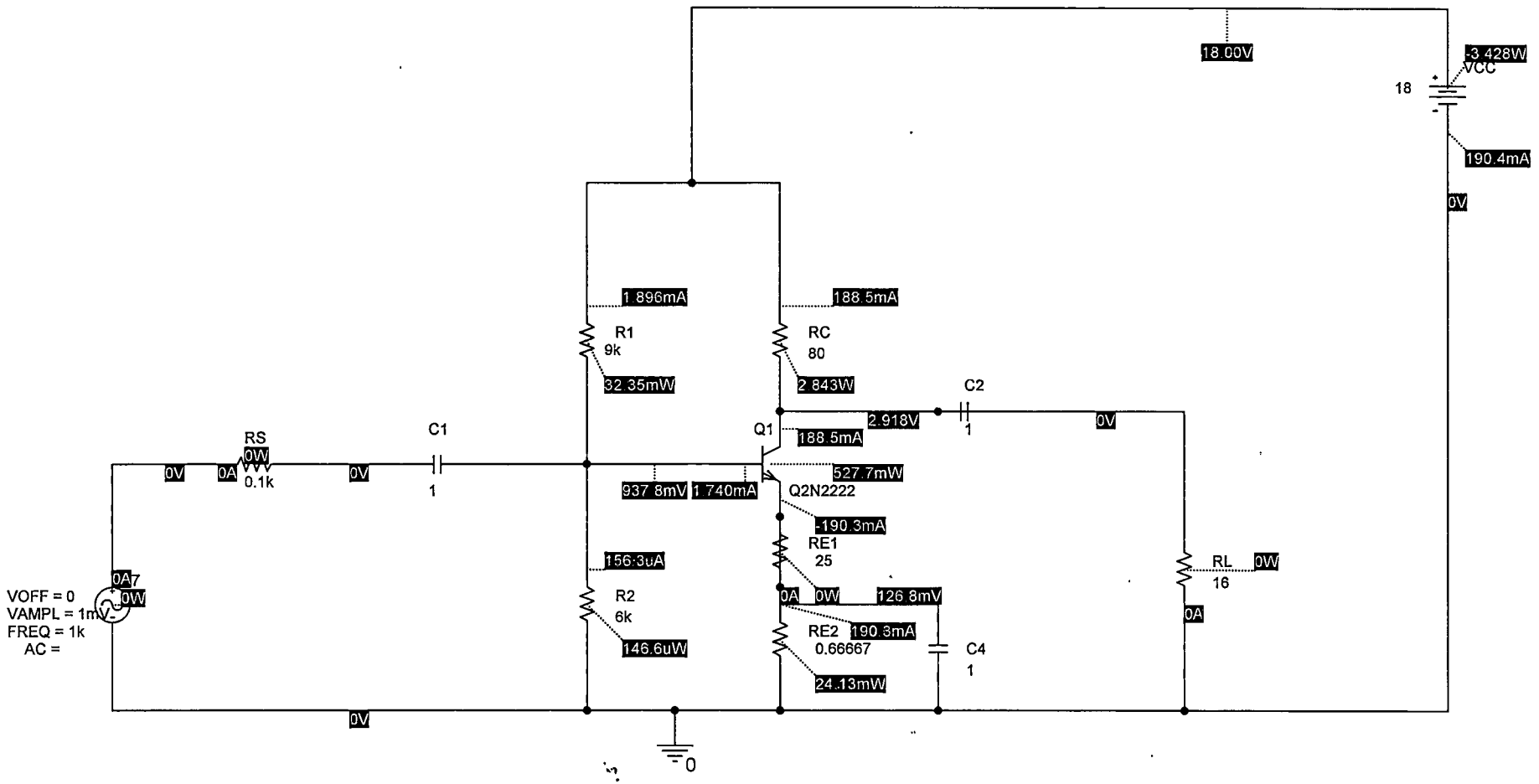
A_i	R_{in}	R_{out}
69.28	59.15Ω	80Ω

G) $P_{RC} = [I_{CQ}]^2 R_C = (0.148)^2 (80) = 1.75 W$

$P_{RE1} = 0.5476 W$

$P_{RE2} = 0.0146 W = 14.6 mW$

A) PSpice Schematic



PSpice part

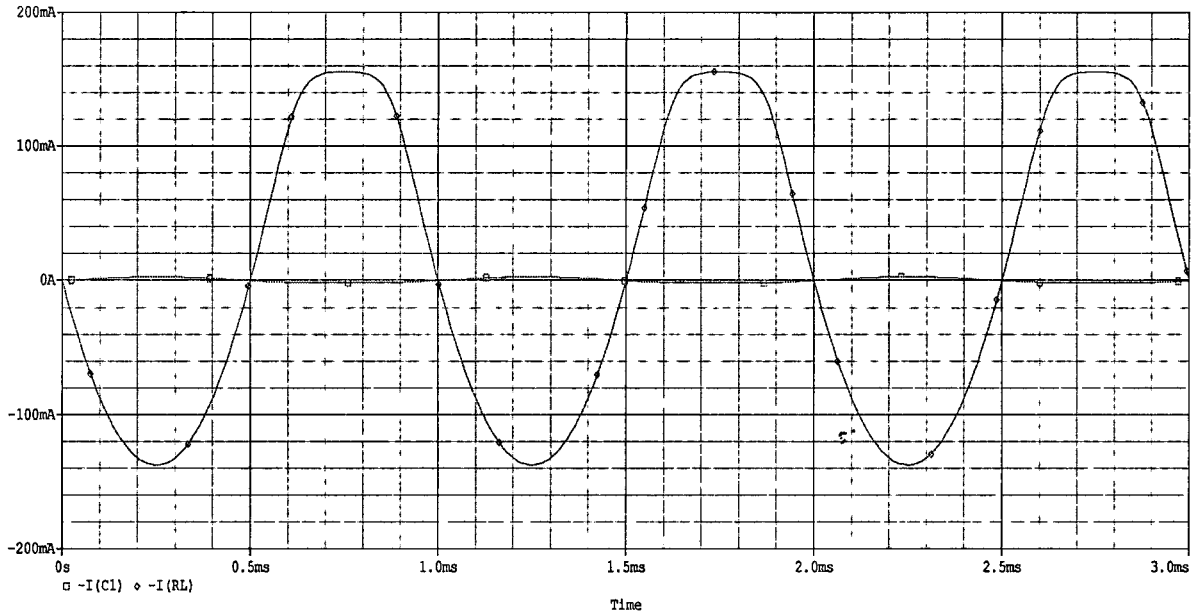
B) SIMLATED DC BIAS

Simulated value		Hand-calculated value	
ICQ	188.5mA	ICQ	148mA
VCEQ	2.918V	VCEQ	2.336V
VBEQ	0.94V	VBEQ	0.7V
PD,transistor	527.7mW	PD,transistor	346mW

C) SIMLATED POWER SUPPLY BIAS

DC power Supply Current (Ips) = 190.4mA. It is less than 200mA. Thus, I achieve the specification for maximum current

D) SIMULATED CURRENT SWING



It is clipping to 125 mA at the top. Therefore, my design achieves the 250mA peak-to-peak swing.

E) SIMULATED EFFICIENCY

$PS = (Vcc)(Ips) = 18 * 0.1904 = 3.4272\text{W}$

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

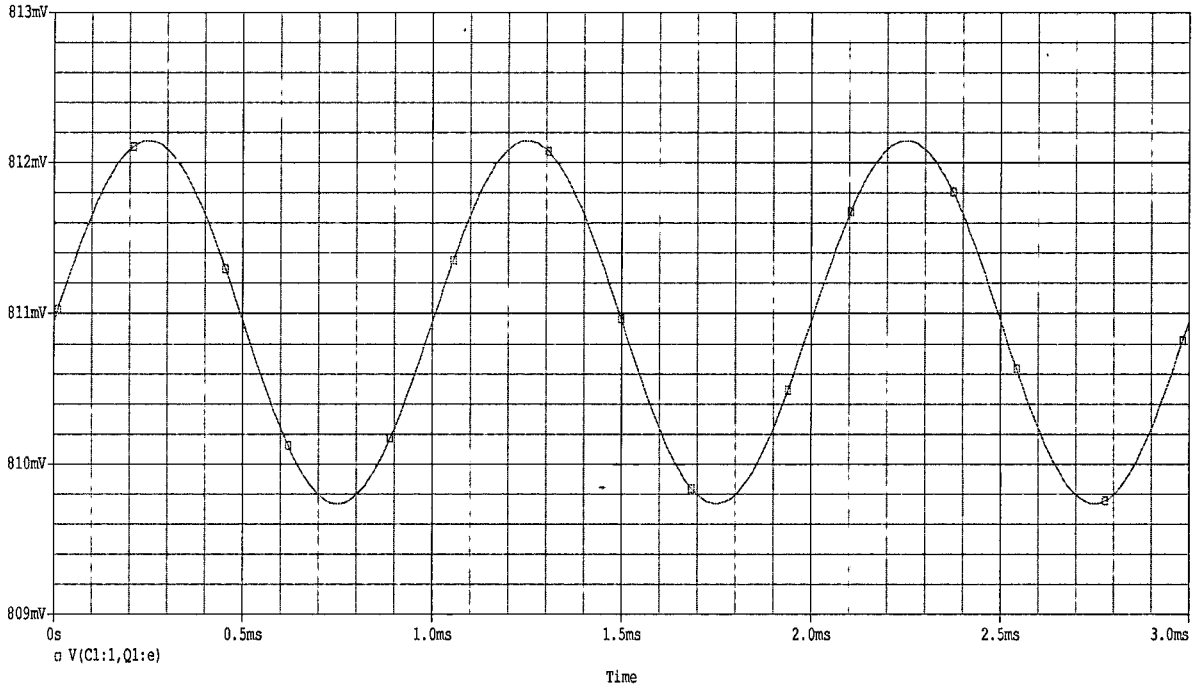
$$\eta = \frac{PL}{PS} = \frac{0.125}{3.4272} = 0.03647 = 3.65\%$$

$\eta, simulated$	η, hand-calculated
3.65%	6.5%

F) SIMULATED SMALL SIGNAL OPERATION

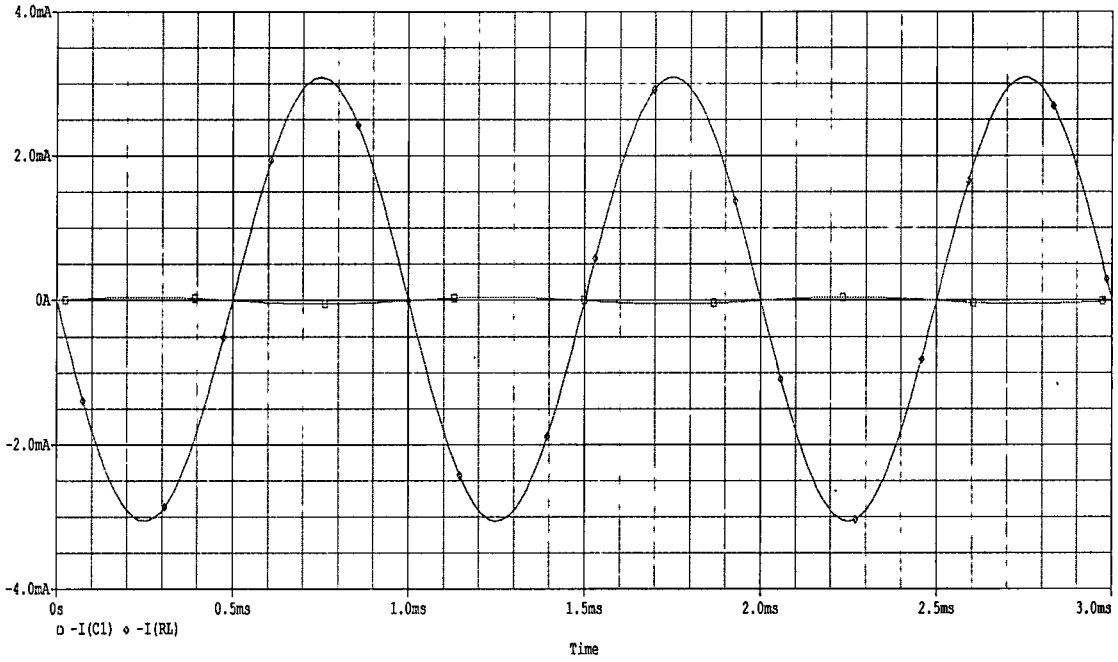
The amplitude value of the source voltage for small signal operation is 6mV.

Plot (Vbe for $\beta = 200$)

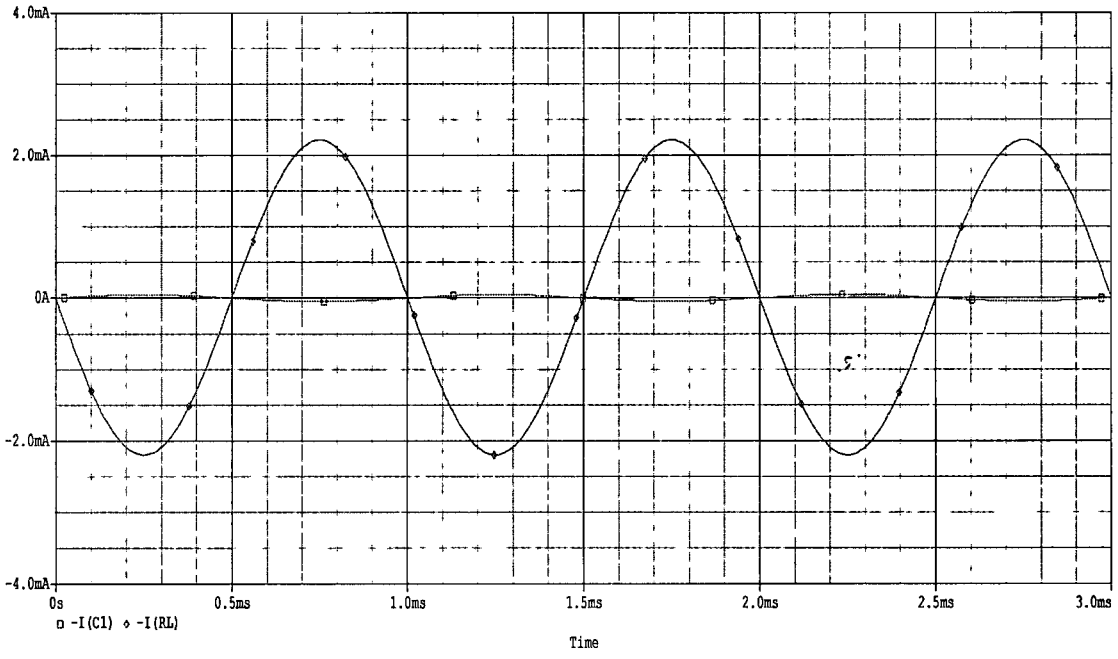


G) SIMULATED GAIN

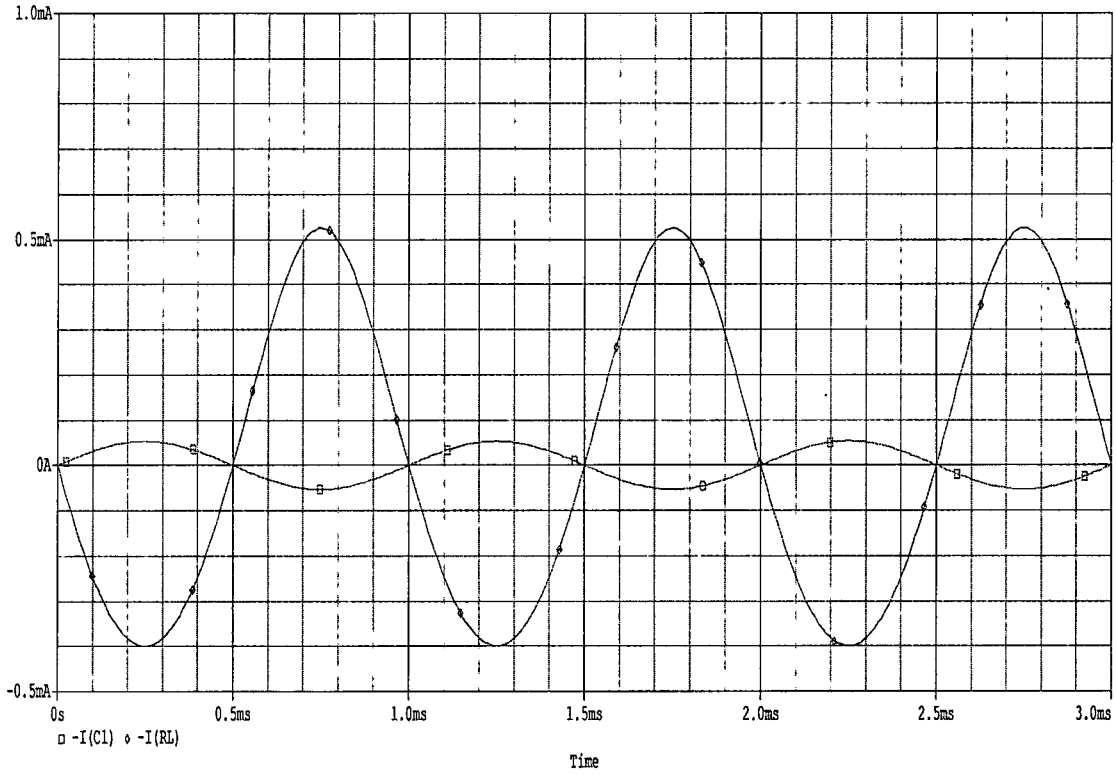
$$\beta = 200, Ai = \frac{3.0868mA}{48uA} = 64.31$$



$$\beta = 100, Ai = \frac{2.2145mA}{48.123uA} = 46.02$$

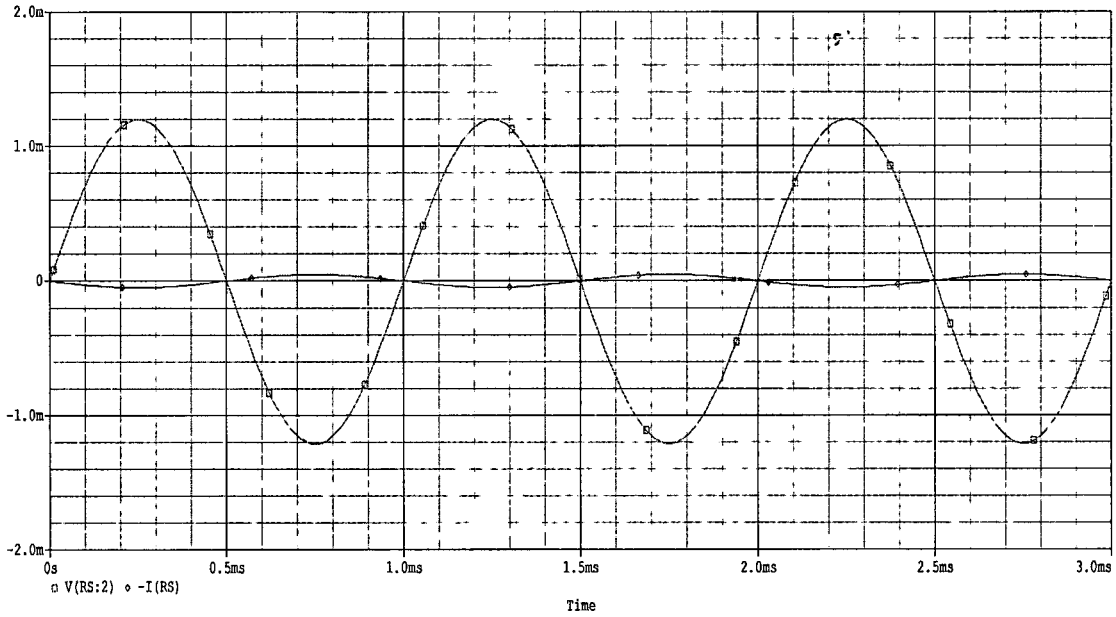


$$\beta = 300, Ai = \frac{526.211uA}{53.469uA} = 9.84$$



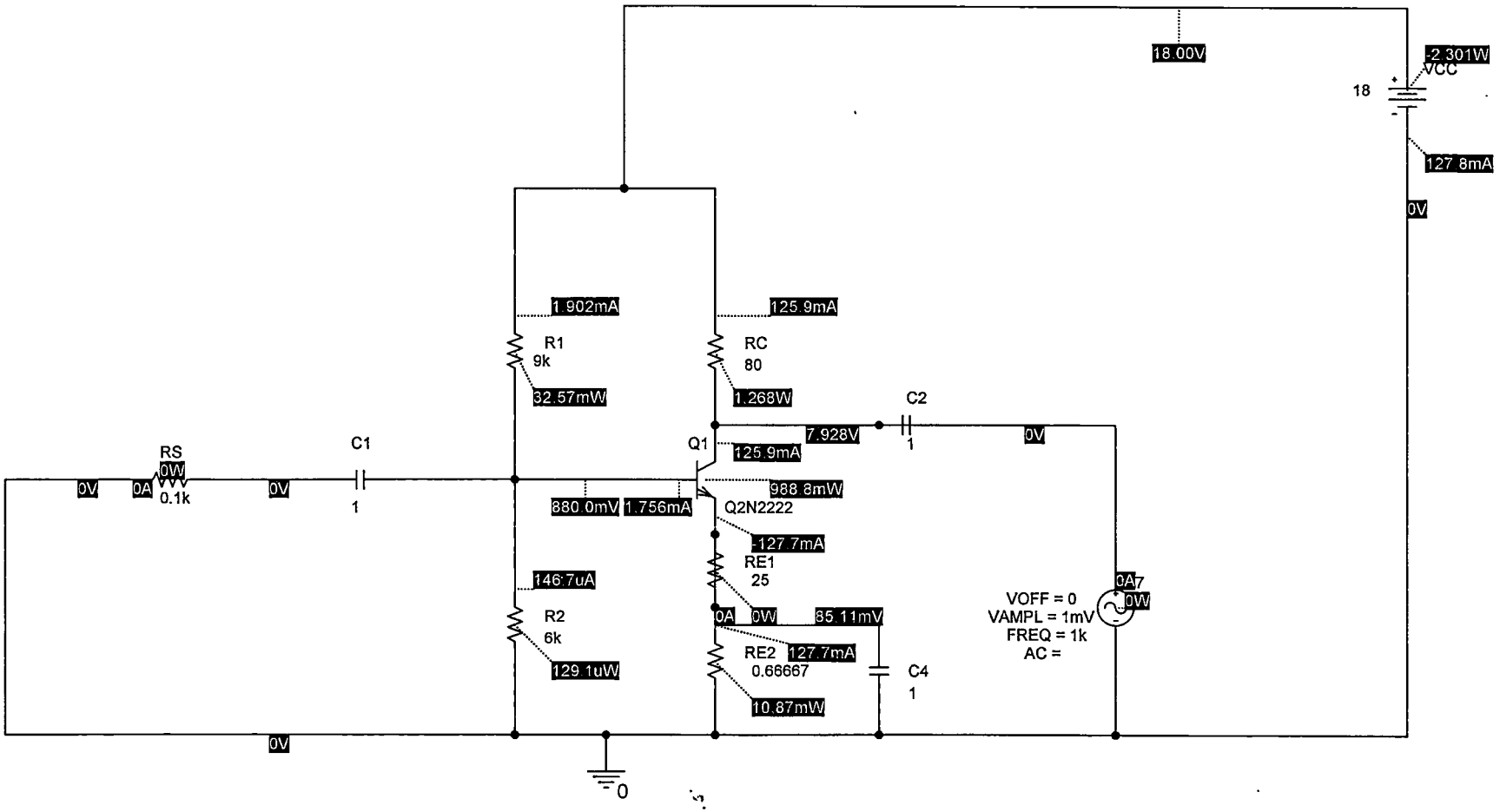
H) SIMULATED INPUT RESISTANCE

$$\beta = 200, Rin = \frac{1.1983mV}{47.841uA} = 25.05\Omega$$



$\beta = 100$	$\beta = 200$	$\beta = 300$
24.72Ω	25.05Ω	12.3Ω

I) Pspice schematic, R out



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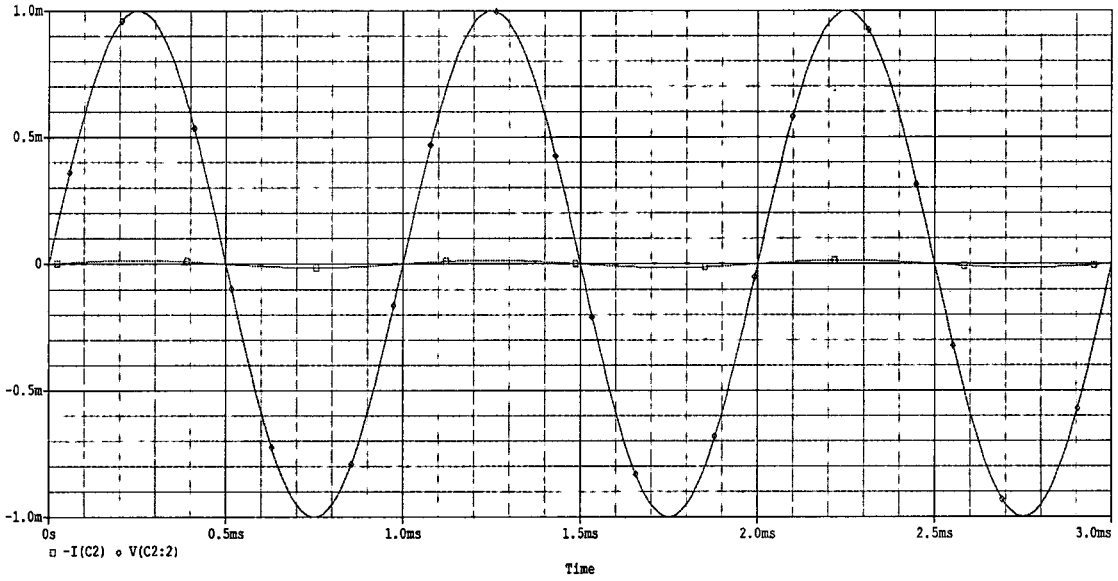
I) SIMULATED OUTPUT RESISTANCE

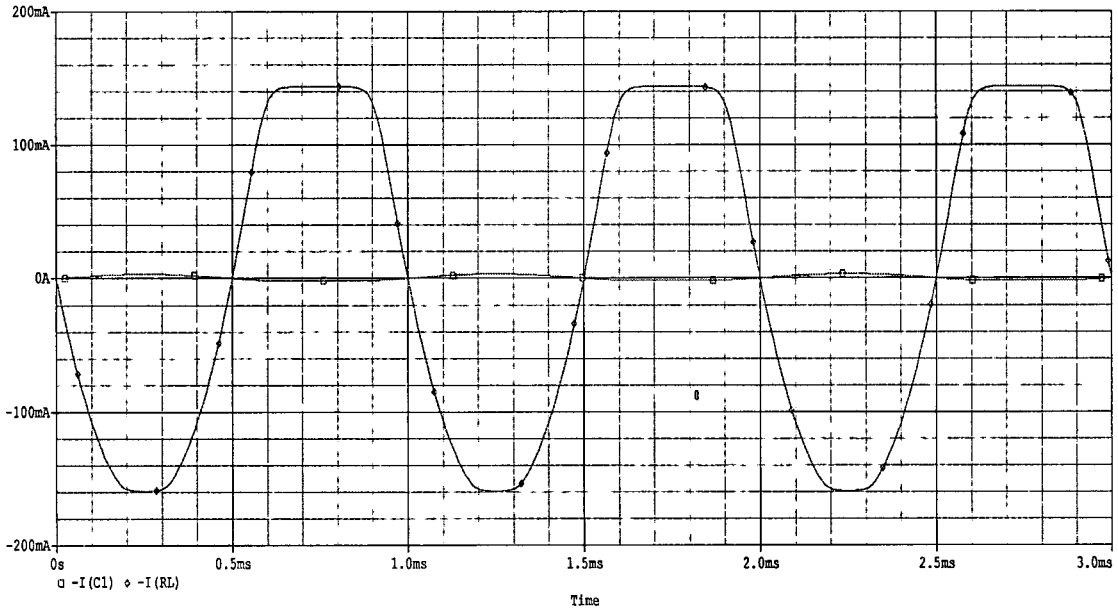
$$\beta = 200, Rout = \frac{0.9997mV}{15.097uA} = 66.22\Omega$$



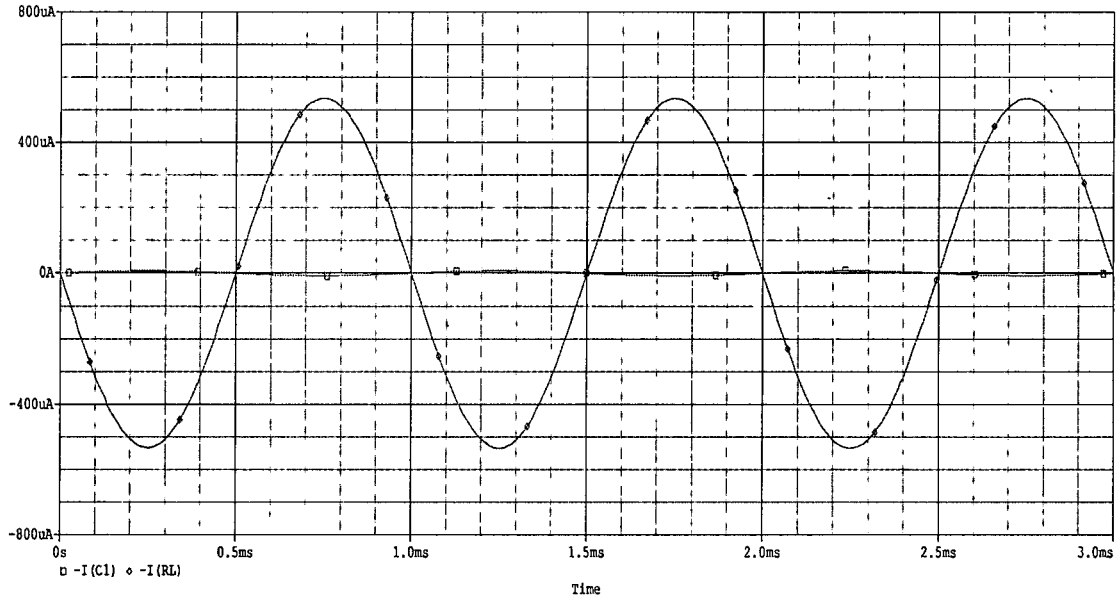
$\beta = 100$	$\beta = 200$	$\beta = 300$
71.02Ω	66.22Ω	2.93Ω

J) SIMULATION USING STANDARD RESISTOR VALUES

The plot of iL with clipping at both the positive and negative peaks using a $\beta = 200$.

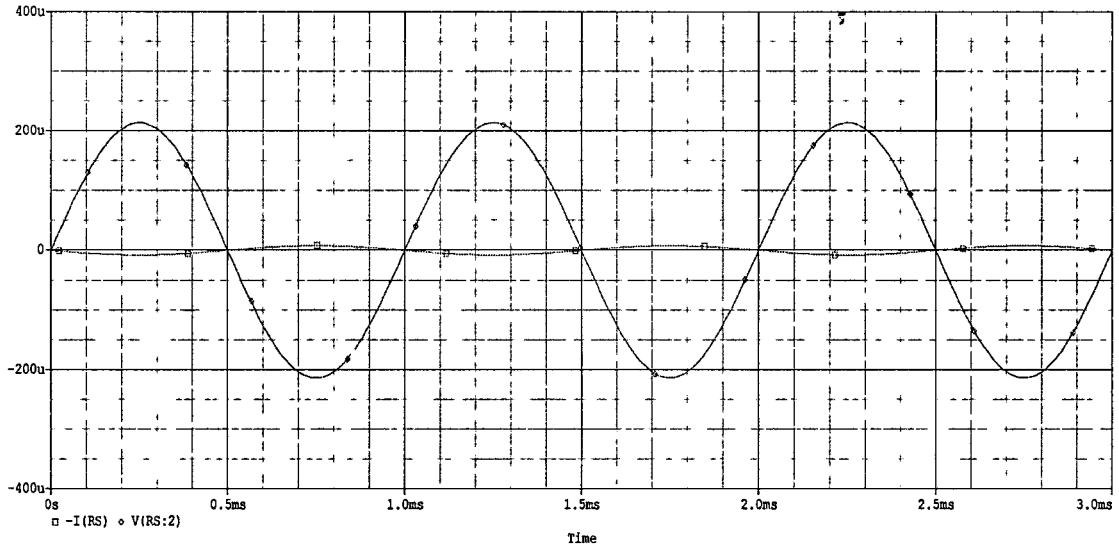


The plots of is and iL under small signal conditions



$$\beta = 200, Ai = \frac{535.492uA}{7.8581uA} = 68.15$$

The plots of is and vs for calculate the Rin

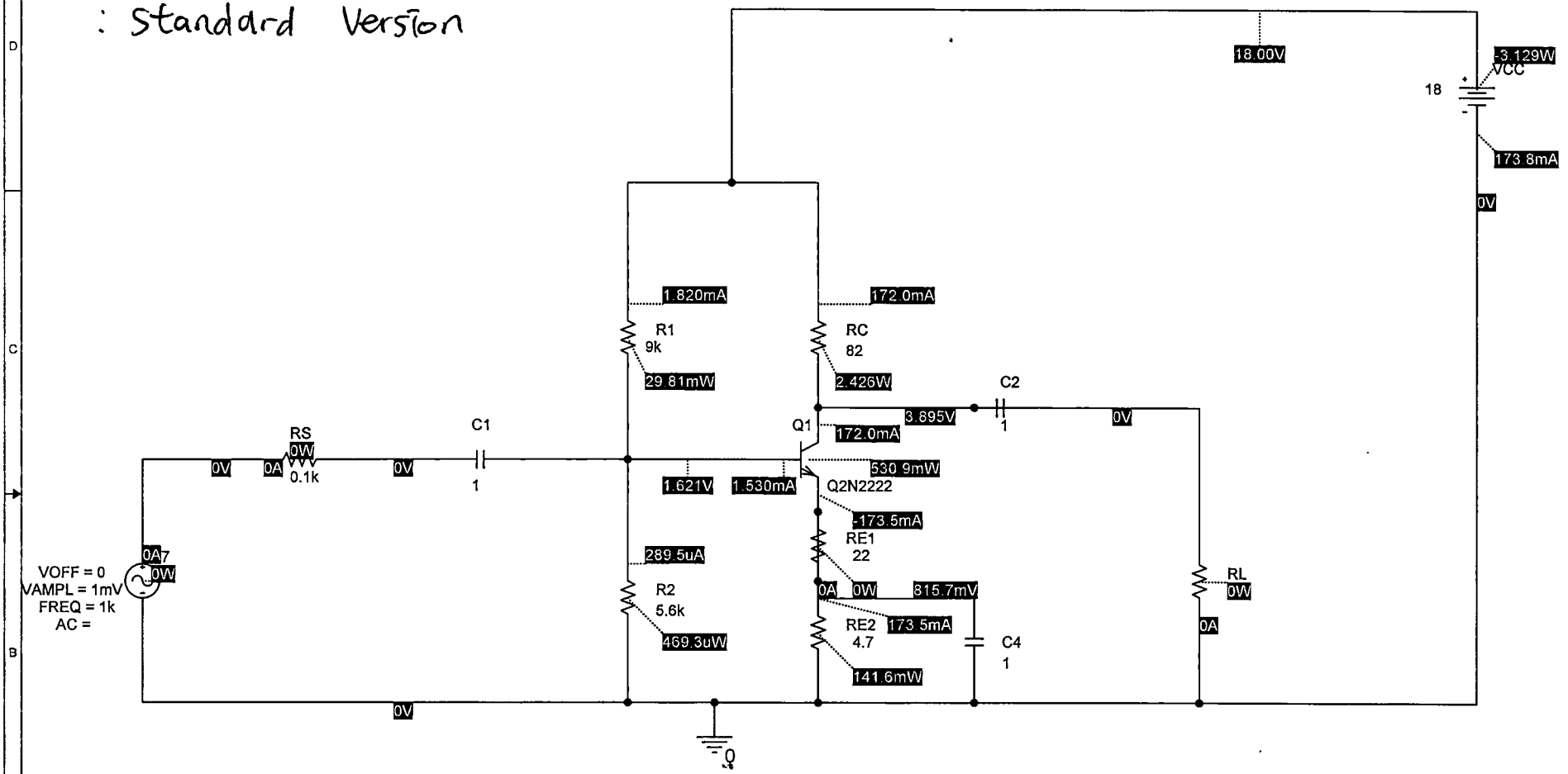


$$\beta = 200, Rin = \frac{213.982uV}{7.8529uA} = 27.25\Omega$$

Original design (Rin)	Standard design (Rin)
25.05Ω	27.25Ω

J) Pspice Schematic

: Standard Version



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