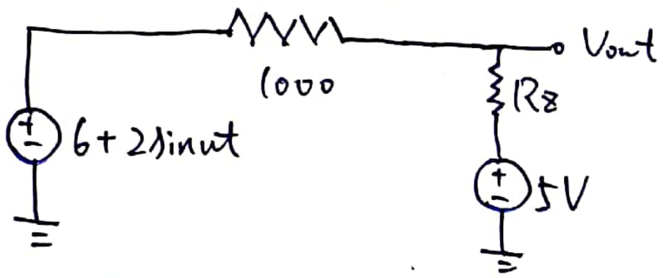
Prob # 1

(1) Circuit # 1

The diode is Zener breakdown when $|V_{in}| > 5$

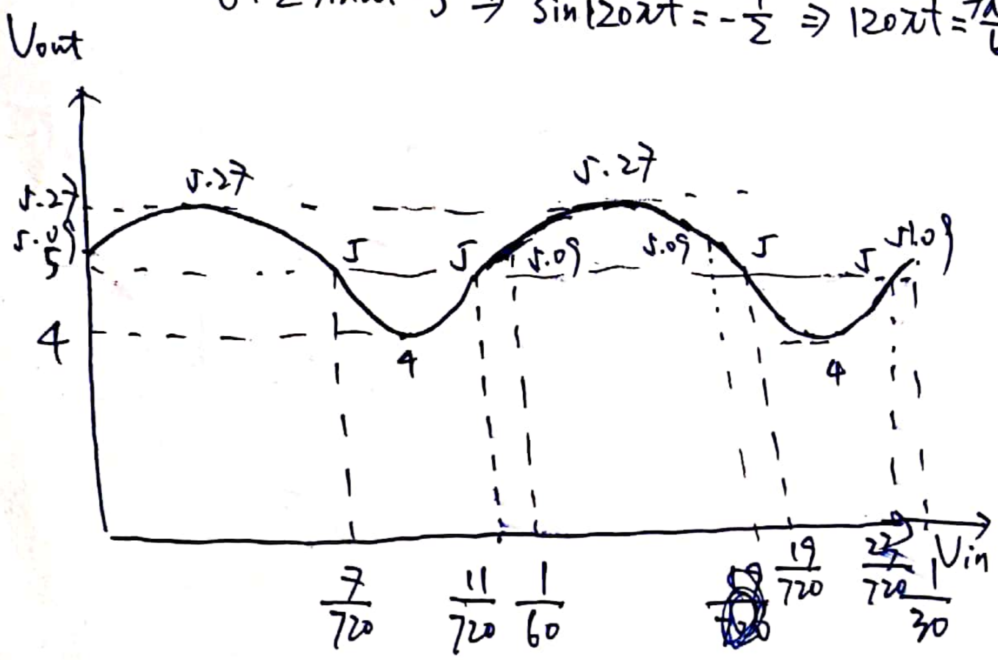
$$\begin{cases} \text{when } V_{in} \le 5 \text{ ; } V_{out} = V_{in} \\ \text{when } V_{in} > 5 \text{ ; The equlivant circuit} \end{cases}$$



$R_z = \frac{1}{k_z} = 100\,\Omega$ $\quad V_{out} = \frac{R_z}{R + R_z} \cdot (6 + 2\sin\omega t - 5) + 5$

$= 5.09 + 0.182\sin\omega t$

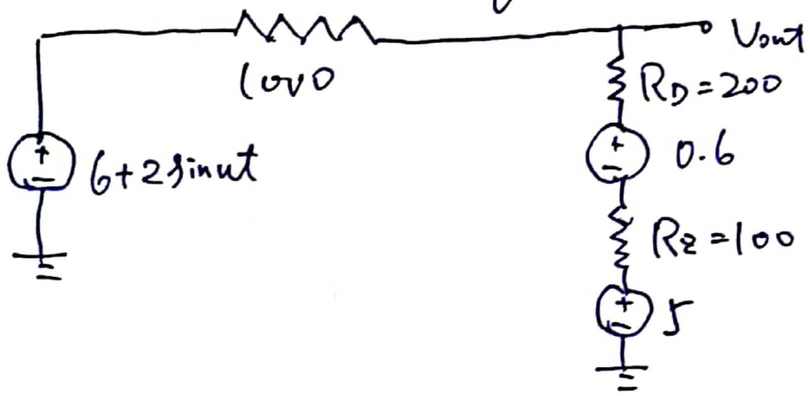
$6 + 2\sin\omega t = 5 \Rightarrow \sin 120\pi t = -\frac{1}{2} \Rightarrow 120\pi t = \frac{7\pi}{6} \Rightarrow t = \frac{7}{720}$



(2) Circuit # 2

The ~~two~~ current can pass through the diode when $|V_{in}| > 5.6$

$$\begin{cases} |V_{in}| \leq 5.6 \Rightarrow V_{out} = 6 + 2\sin 120\pi t \\ |V_{in}| > 5.6 \Rightarrow \text{The equivalent circuit:} \end{cases}$$

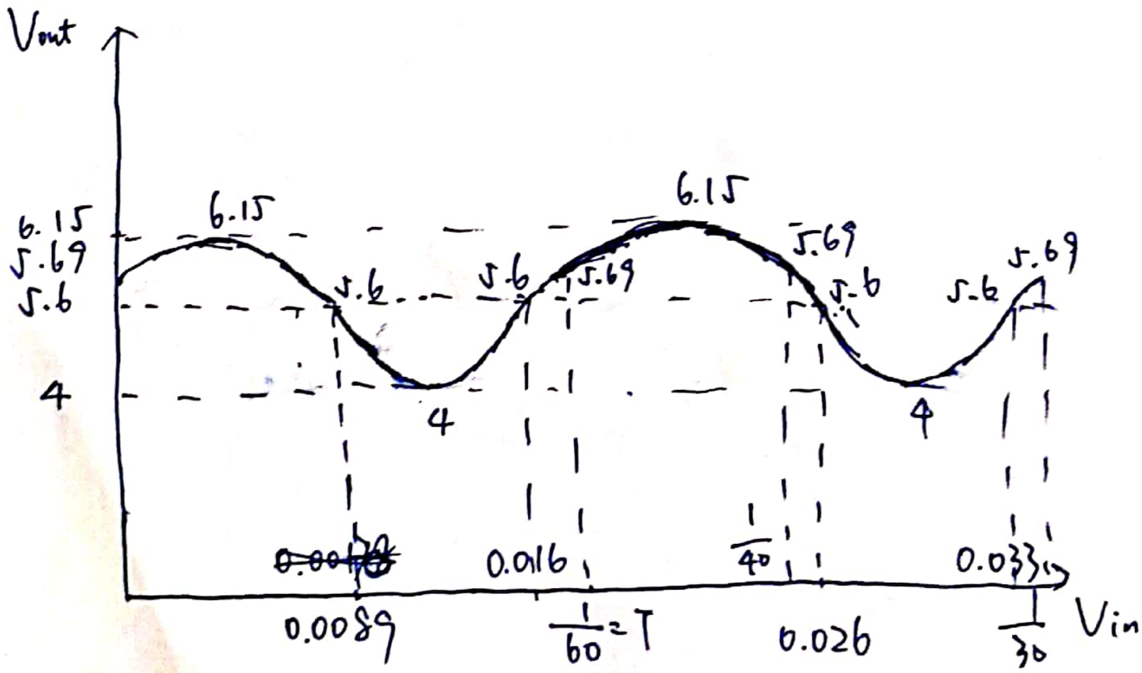


$$V_{out} = \frac{R_D + R_Z}{R_D + R_Z + R} \cdot (6 + 2\sin\omega t - 0.6 - 5) + 0.6 + 5$$

$$= \frac{3}{13}(0.4 + 2\sin\omega t) + 5.6$$

$$= 5.69 + 0.46\sin\omega t$$

$6 + 2\sin\omega t = 5.6 \Rightarrow \sin 120\pi t = -0.2 \Rightarrow t = \cdots$



Prob (2)

(1). $\tilde{\bar{V}}_{in} = 1 + 0.01 \sin 60\pi t$

For DC: $\overline{V_{OUT}} = (\overline{V_{IN}} - 2)^2 = 1$

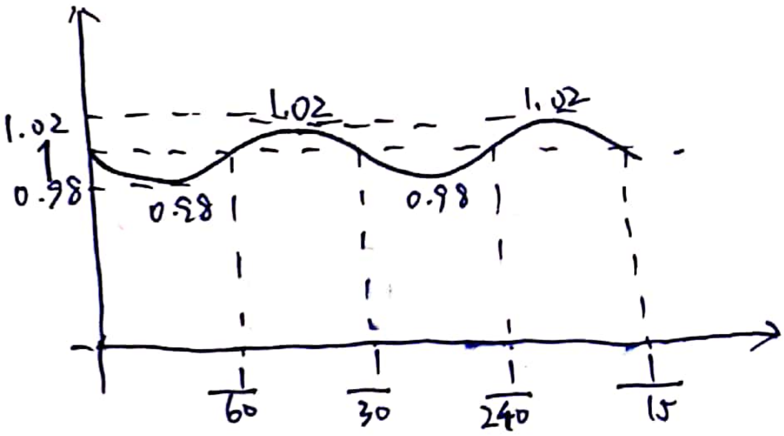
For AC: $\tilde{v}_{out} = \left.\frac{dV_{out}}{dV_{in}}\right|_{\overline{V_{IN}}} \cdot \tilde{v}_{in}$

$= 2(\overline{V_{IN}} - 2) \cdot \tilde{v}_{in}$

$= -2 \cdot \tilde{v}_{in}$

$= -0.02 \sin 60\pi t$

$T = \frac{2\pi}{w} = \frac{1}{30} s$



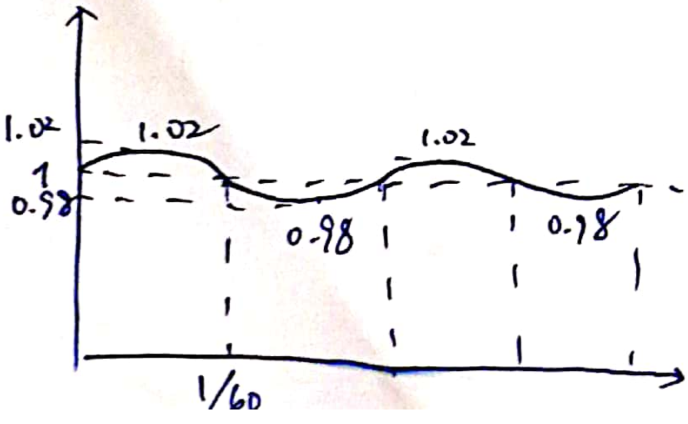
(2) $\tilde{\bar{V}}_{in} = 3 + 0.01 \sin 60\pi t$

For DC: $\overline{V_{out}} = (\overline{V_{IN}} - 2)^2 = 1$

For AC: $\tilde{v}_{out} = \left.\frac{dV_{out}}{dV_{in}}\right|_{\overline{V_{in}}} \cdot \tilde{v}_{in}$

$= 2(\overline{V_{IN}} - 2) \cdot \tilde{v}_{in}$

$= 0.02 \sin 60\pi t$



Prob #3.

(1) $I_{dc} = \dfrac{V_s - 2V_{on} - 2V_{on}}{R \parallel R} = 2 \cdot \dfrac{V_s - 4V_{on}}{R} = \dfrac{2V_s - 8V_{on}}{R}$

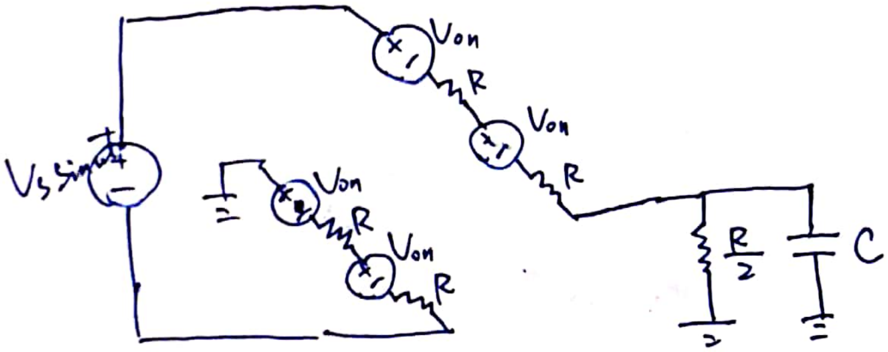
$\Delta T = \dfrac{1}{w} \cdot \sqrt{\dfrac{2V_r}{V_s}}$ $\quad V_r = (V_s - 2V_{on} - 2V_{on})\dfrac{T}{2R\frac{C}{2}} = (V_s - 4V_{on})\dfrac{T}{2R\frac{C}{2}} = (V_s - 4V_{on})\dfrac{T}{RC}$

$\Rightarrow \Delta T = \dfrac{1}{w} \cdot \sqrt{\dfrac{2(V_s - 4V_{on})T}{V_s RC}} = \sqrt{\dfrac{2(V_s - 4V_{on})T}{V_s RC}}$

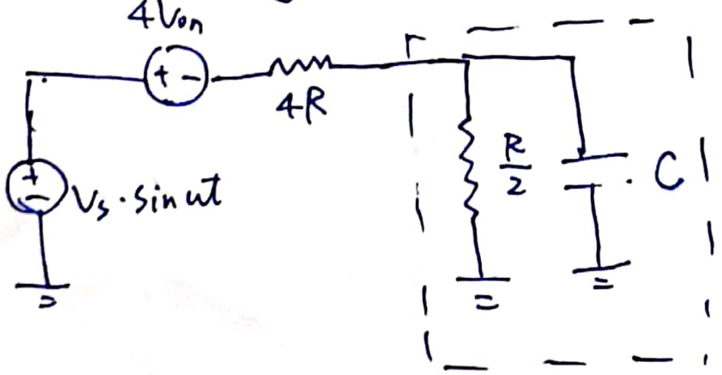
$PIV = V_{dc} + 2V_{on} = V_s - 4V_{on} + 2V_{on} = V_s - 2V_{on}$

(2) The circuit will not work.

if we transform the diodes into ideal models: (Assume first charge)



$\Downarrow$



$(Z_{load} \ll 4R$

load $\Rightarrow V_{load} = \dfrac{Z_{load}}{Z_{load} + 4R} \cdot V_s \approx 0.$

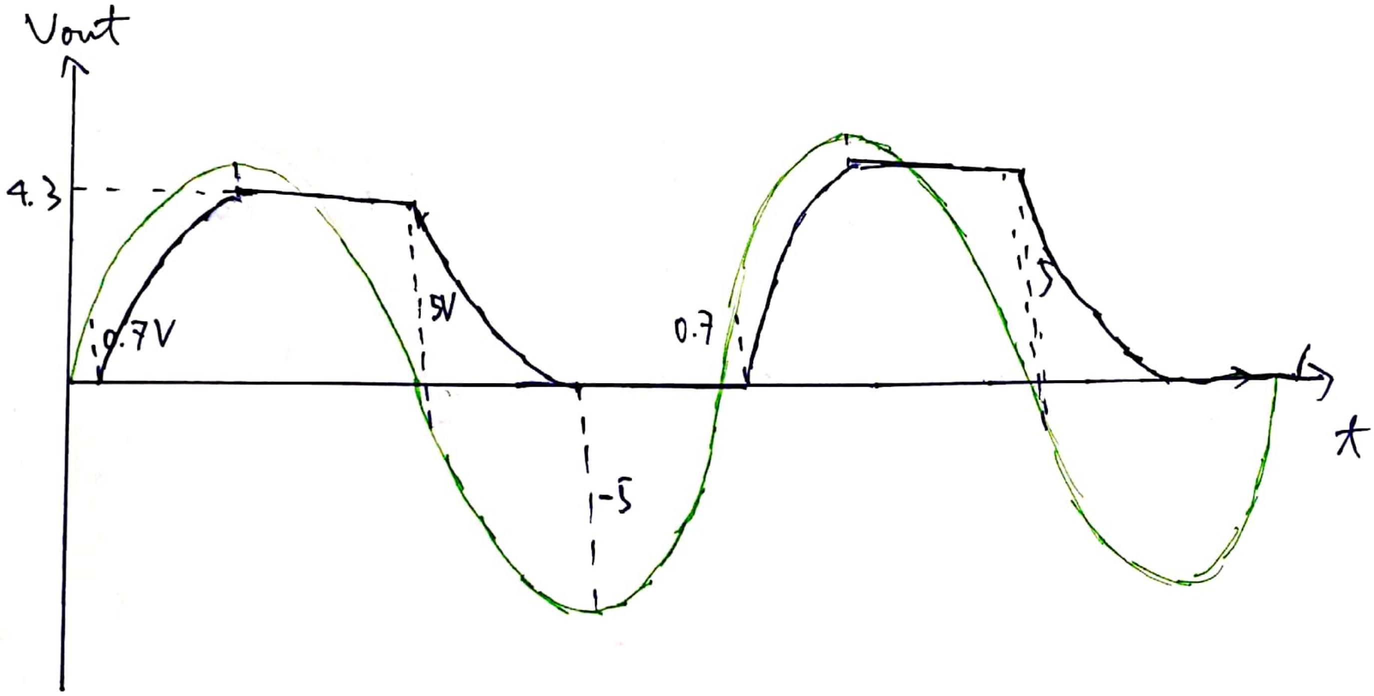
$Z_{eq}(load) = \left|\dfrac{1}{jwC}\right| \parallel \dfrac{R}{2} < \left|\dfrac{1}{jwC}\right| = \left|\dfrac{1}{j\frac{2\pi}{T}C}\right| = \left|\dfrac{T}{j2\pi C}\right| = \dfrac{T}{2\pi C}$

since $RC \gg T \Rightarrow \dfrac{T}{C} \ll R \Rightarrow \dfrac{T}{2\pi C} \ll R < 4R$

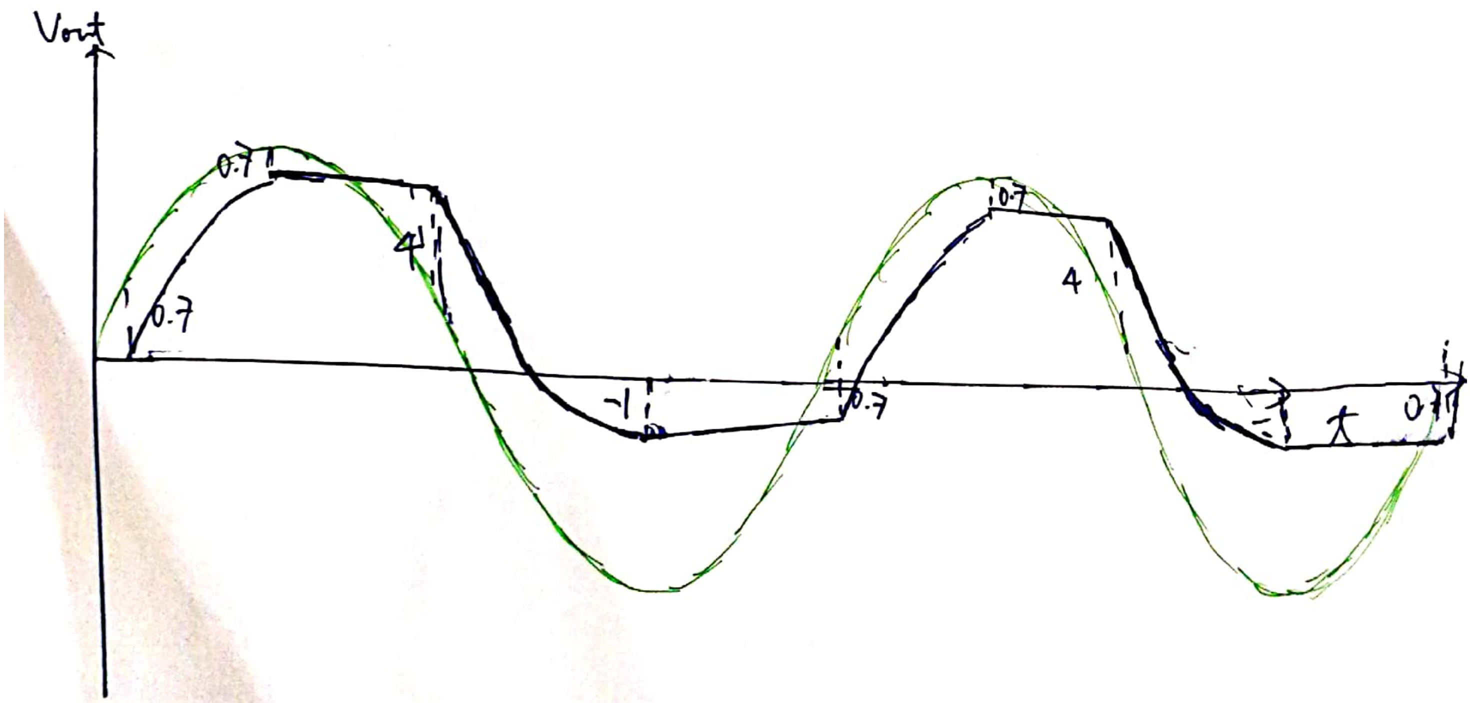
Thus, the load resistance is quite small compared with the diode's inner resistance, so the output voltage is almost equal to zero

Prob #4

(1). When $v_{in} - v_{out} \geq 0.7$, the diode is turned on.
When $v_{in} - v_{out} \leq 5$, the diode is Zener breakdown

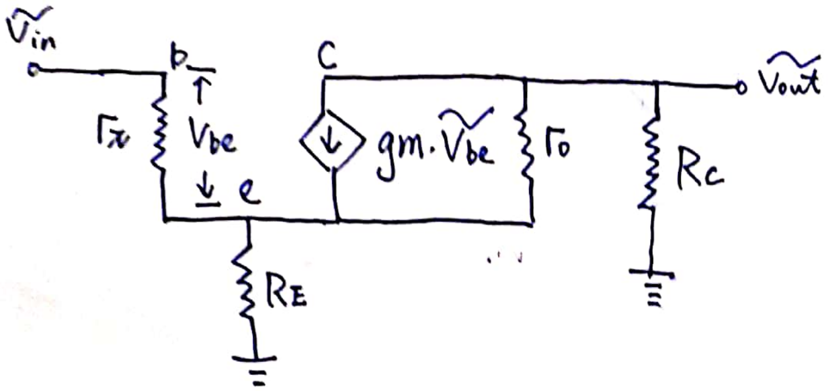


(2). When $v_{in} - v_{out} \leq 4$, the diode is Zener breakdown.



Prob #5

(1) Plot the small signal model ($r_\pi, r_o \neq +\infty$)



Suppose in the e port, the small signal voltage is $\tilde{V}_e$

at node e : using KCL

$$\frac{\tilde{V}_{in} - \tilde{V}_e}{r_\pi} + g_m \cdot \tilde{V}_{be} + \frac{\tilde{V}_{out} - \tilde{V}_e}{r_o} = \frac{\tilde{V}_e - 0}{R_e} \quad ①$$

at node c : using KCL :

$$g_m \cdot \tilde{V}_{be} = \frac{\tilde{V}_e - \tilde{V}_{out}}{r_o} + \frac{0 - \tilde{V}_{out}}{R_c} \quad ②$$

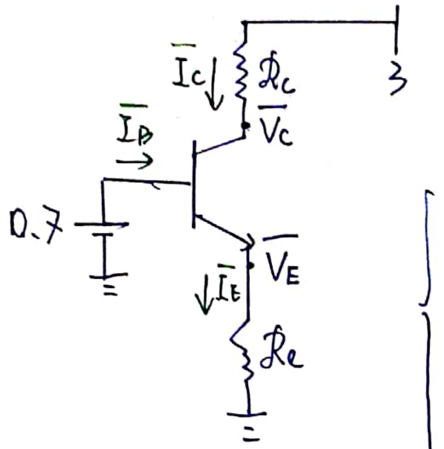
$$\tilde{V}_{be} = \tilde{V}_{in} - \tilde{V}_e \quad ③$$

combine ①, ②, ③, we get $\tilde{V}_e = \dfrac{r_o r_c g_m \tilde{V}_{in} + \tilde{V}_{out} r_c + \tilde{V}_{out} r_o}{r_o r_c g_m + r_c}$

(in your exam, the intermidia calculation process will not count for marks)

$$A_v = \frac{\tilde{V}_{out}}{\tilde{V}_{in}} = \frac{r_e r_c - g_m r_o r_c r_\pi}{r_o r_\pi + r_c r_\pi + r_e r_c + r_o r_e + r_e r_\pi + g_m r_o r_\pi r_e}$$

(2) (DC Analysis)



Do a dc analysis:

$$\begin{cases} \overline{I_C} = \dfrac{\overline{V_{cc}} - \overline{V_C}}{R_C} \\ \overline{I_E} = \dfrac{\overline{V_E} - 0}{R_E} \\ \overline{I_C} = I_S\left(e^{\frac{q(\overline{V_B} - \overline{V_E})}{kT}} - 1\right)\left(1 + \dfrac{\overline{V_C} - \overline{V_E}}{V_{AF}}\right) \quad * \\ \overline{I_C} = \beta \overline{I_B} \\ \overline{I_E} = \overline{I_C} + \overline{I_B} \end{cases}$$

$$\begin{cases} \overline{I_C} = \beta \overline{I_B} \\ \overline{I_E} = \overline{I_C} + \overline{I_B} \end{cases} \Rightarrow \overline{I_E} = \frac{\overline{I_C}}{10} + \overline{I_C} \Rightarrow \overline{I_C} = \frac{10}{11}\overline{I_E}\ ;\ \overline{I_E} = 1.1\overline{I_C}$$

Thus, we have $\overline{V_E} = 1.1\overline{I_C} \cdot R_E = 5500\overline{I_C}$ ①

$\overline{I_C} = \dfrac{\overline{V_{cc}} - \overline{V_C}}{R_C} \Rightarrow \overline{V_C} = \overline{V_{cc}} - \overline{I_C}R_C = 3 - 5000\overline{I_C}$ ②

According to $*$, ①, ②, we have

$$\overline{I_C} = 1\times10^{-16} \times \left(e^{\frac{1.6\times10^{-19}\times(0.7 - 5500\overline{I_C})}{1.38\times10^{-23}\times300}} - 1\right)\left(1 + \frac{3 - 5000\overline{I_C} - 5500\overline{I_C}}{100}\right)$$

Solve the equation, we can get $\overline{I_C} = 8.8\times10^{-6}$ A (by Casio 991 Calculator)

$$g_m = \frac{dI_C}{dV_{BE}} \approx \frac{\overline{I_C}}{kT/q} = \frac{8.8\times10^{-6}\times1.6\times10^{-19}}{1.38\times10^{-23}\times300} = 3.4\times10^{-4}\ S$$

$$r_\pi = 1/\frac{dI_B}{dV_{BE}} = \frac{\beta}{g_m} = \frac{10}{3.4\times10^{-4}} = 2.94\times10^4\ \Omega$$

$$r_o = 1/\frac{dI_C}{dV_{CE}} \approx \frac{V_{AF}}{\overline{I_C}} = \frac{100}{8.8\times10^{-6}} = 1.14\times10^7\ \Omega$$

$R_C = R_E = 5000$

Thus,

$$A_v = \frac{5000^2 - 3.4\times10^{-4}\times1.14\times10^7\times2.94\times10^4\times5000}{2.94\times10^4\times1.14\times10^7 + 5000\times2.94\times10^4 + 5000^2 + 1.14\times10^7\times5000 + 2.94\times10^4\times5000 + 3.4\times10^{-4}\times1.14\times10^7\times2.94\times10^4\times5000}$$

$= -0.592.$