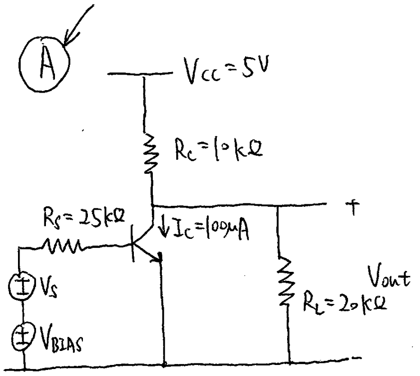
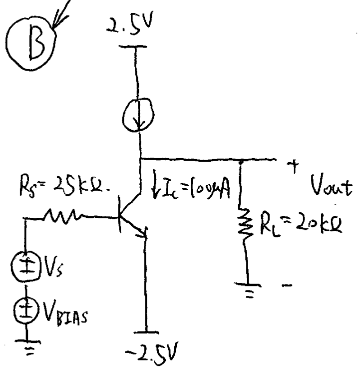
Homework #10 Solution EE105 (Spring 2001) by Xuesong Jiang

8.12). Circuit in the 2nd midterm | Improved circuit





(a). In both circuits

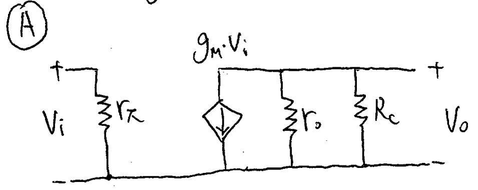
$$V_{BE}=\frac{kT}{q}\cdot\ln\frac{I_c}{I_s}=26mV\cdot\ln\frac{10^{-4}A}{10^{-16}A}=718.4\,mV$$

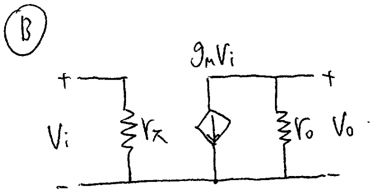
$$I_B=\frac{I_c}{\beta}=\frac{100\mu A}{100}=1\mu A$$

In Ⓐ, $V_{BIAS}=I_B\cdot R_s+V_{BE}=1\mu A\cdot 25k\Omega+718.4mV=\boxed{743.4\,mV}$

In Ⓑ, $V_{BIAS}=I_B\cdot R_s+V_{BE}-2.5V=\boxed{-1.757\,V}$

(b). Small signal model





$$r_\pi=\frac{\beta}{g_m}=\frac{100}{3.846mS}=26k\Omega$$

$$g_m=\frac{q\cdot I_c}{kT}=\frac{100\mu A}{26mV}=3.846\,mS$$

$$r_o=\frac{V_A}{I_c}=\frac{20V}{100\mu A}=200\,k\Omega$$

For both circuits

$R_{in} = r_\pi = \boxed{26\,k\Omega}$

$G_m = g_m = \boxed{3.846\,mS}$

In Ⓐ,

$$R_{out} = r_o \| R_c = \frac{10k\Omega \cdot 200k\Omega}{10k\Omega + 200k\Omega} = \boxed{9.524\,k\Omega}$$

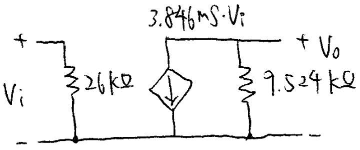
$$A_v = -g_m \cdot R_{out} = -3.846\,mS \cdot 9.524\,k\Omega = \boxed{-36.63}$$

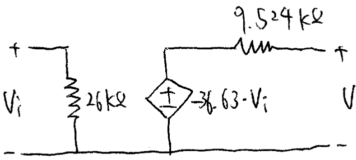
In Ⓑ,

$$R_{out} = r_o = \boxed{200\,k\Omega}$$

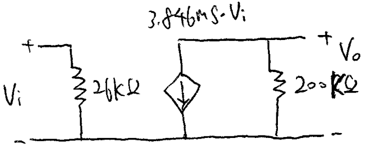
$$A_v = -g_m \cdot R_{out} = -3.846\,mS \cdot 200\,k\Omega = \boxed{-769.2}$$

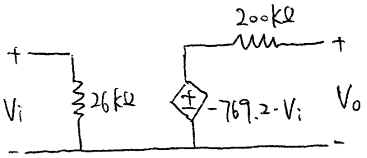
Two port model for Ⓐ





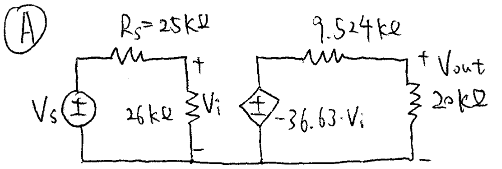
Two port model for Ⓑ



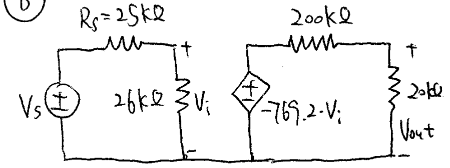


(C). Overall circuit small signal model

Ⓐ



Ⓑ



For Ⓐ,

Overall voltage gain $= \frac{V_{out}}{V_s} = \frac{26k\Omega}{25k\Omega+26k\Omega} \cdot (-36.63) \cdot \frac{20k\Omega}{20k\Omega+9.524k\Omega}$

$= \boxed{-12.65}$

For Ⓑ,

Overall voltage gain $= \frac{V_{out}}{V_s} = \frac{26k\Omega}{25k\Omega+26k\Omega} \cdot (-769.2) \cdot \frac{20k\Omega}{200k\Omega+20k\Omega}$

$= \boxed{-35.65}$

(d).(i) If $V_{CE} > V_{CE\text{-}sat}$, the bipolar transistor is in forward active region, $I_C = \beta \cdot I_B$ and small signal $i_c = \beta \cdot i_b$

For Ⓐ $V_o = -i_c \cdot (R_L \| R_c \| r_o) = -\beta \cdot i_b (R_L \| R_c \| r_o) = -\beta \cdot \frac{V_s}{R_s + r_\pi} (R_L \| R_c \| r_o)$

For Ⓑ $V_o = -i_c \cdot (R_L \| r_o) = -\beta \cdot i_b \cdot (R_L \| r_o) = -\beta \cdot \frac{V_s}{R_s + r_\pi} (R_L \| r_o)$

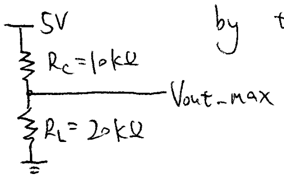
V_o is a linear function of V_i

(ii) If $V_{CE} = V_{CE\text{-}sat}$, $i_c \neq \beta \cdot i_b$, the overall voltage gain of both circuit will drop, the input signal is cliped

For Ⓐ, the negative output swing will be 0.1V,

For Ⓑ, the negative output swing will be -2.4V

(iii) For Ⓐ, the maximum positive output swing can be reached when I_c of the bipolar transistor becomes zero, it is determined by the voltage divider.



$$V_{out-max} = 5V \cdot \frac{20k\Omega}{10k\Omega + 20k\Omega} = 3.333V$$

For Ⓑ, the maximum positive output swing can be reached when I_c of the bipolar transistor becomes zero, all current from the current source will flow through R_L

$$V_{out-max} = 100\mu A \cdot 20k\Omega = 2V$$

∴ For Ⓐ $V_{out} \in (0.1V, 3.333V)$

For Ⓑ $V_{out} \in (-2.4V, 2V)$