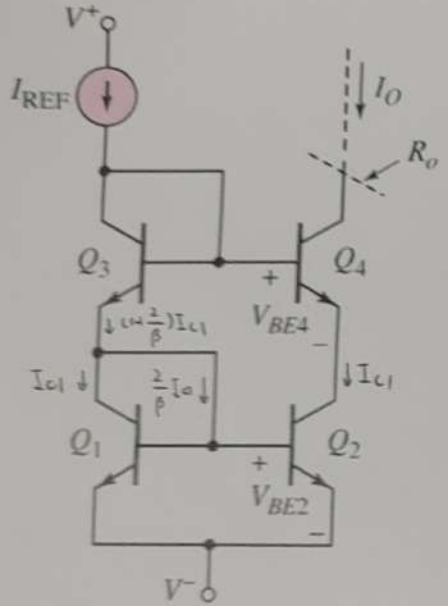
1. (10%)



(a) (5%)

$\beta = 40,\ I_o = 0.1\,mA$

$$I_o = \frac{\beta}{1+\beta} I_{c1}$$

$$I_{REF} = (1+\frac{2}{\beta})I_{c1} + \frac{1}{1+\beta} I_{c1}$$

$$= \frac{\beta(1+\beta)+2(1+\beta)+\beta}{\beta(1+\beta)} \times I_{c1}$$

$$= \frac{\beta^2+4\beta+2}{\beta(1+\beta)} \times I_{c1}$$

$$\frac{I_o}{I_{REF}} = \frac{\beta^2}{\beta^2+4\beta+2} \quad (3\%)$$

$$\Rightarrow I_{REF} = \frac{\beta^2+4\beta+2}{\beta^2} \times I_o = \frac{40^2+4\times 40+2}{40^2} \times I_o$$

$$= \frac{1762}{1600} \times 0.1 = 0.11\ mA$$

這邊如果直接寫 $I_{REF} = I_o = 0.1\ mA$
只給2分

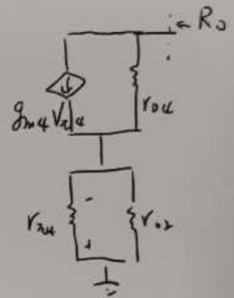
(b) (5%)

$$r_{o2} = \frac{V_A}{I_{c2}} = \frac{80}{0.1 \times \frac{41}{40}} = 780.5\,k\Omega$$

$$r_{o4} = \frac{V_A}{I_{c4}} = \frac{80}{0.1} = 800\,k\Omega$$

$$r_{\pi 4} = \frac{\beta V_T}{I_{c4}} = \frac{40\times 26}{0.1} = 10.4\,k\Omega$$

$r_{\pi 4} /\!/ r_{o2} = 10.26\,k\Omega$, $g_{m4} = 3.846\,mA/V$



$$R_o = (r_{\pi 4} /\!/ r_{o2}) + r_{o4} + g_{m4} r_{o4} (r_{\pi 4} /\!/ r_{o2})$$

$$\approx \left(1 + g_{m4}(r_{\pi 4} /\!/ r_{o2})\right) \times r_{o4}$$

$$\approx (1+\beta) r_{o4} \quad (3\%)$$

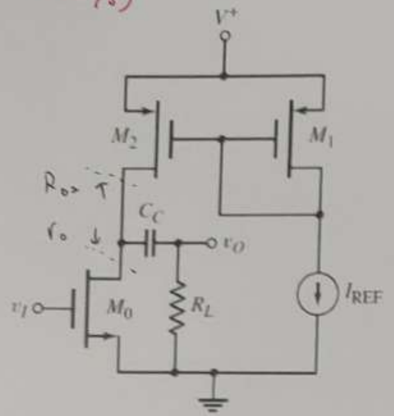
公式解依近似程度，3種寫法都可

$$R_o = 10.26 + 800 + 3.846 \times 10.26 \times 800$$

$$= 32.38\ M\Omega$$

or $R_o \approx 41 \times 800 = 32.8\,M\Omega$

2. (10%)



(a) (5%)

$$A_v = -g_m (r_o \parallel R_{o2} \parallel R_L) \quad (3\%)$$

$$r_o = r_{on} = \frac{1}{\lambda_n I_D} = \frac{1}{0.01 \times 0.25}$$

$$= 400\,k\Omega$$

$$R_{o2} = r_{op} = \frac{1}{\lambda_p I_D} = \frac{1}{0.02 \times 0.25}$$

$$= 200\,k\Omega$$

$$g_m = 2\sqrt{K_n I_D} = 2 \times \sqrt{0.25 \times 0.25}$$

$$= 0.5\ mA/V$$

$$A_v = -0.5(400 \parallel 200 \parallel 500)$$

$$= -0.5 \times 105.26$$

$$= -52.63$$

(b) (5%) cascode active load

$$R_{o2} = r_{op} + r_{op} + g_{mp} r_{op} r_{op} \quad (2\%)$$

或说 R_{o2} 大到可忽略

$$g_{mp} = 2\sqrt{K_p I_D} = 2\sqrt{0.1 \times 0.25} = 0.316\ mA/V$$

$$R_{o2} = 200 + 200 + 0.316 \times 200^2$$

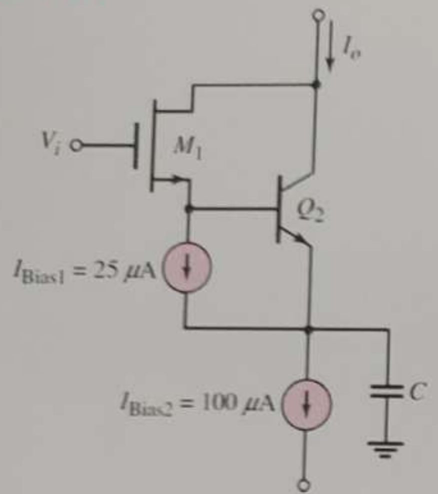
$$= 13.05\,M\Omega$$

$$A_v = -g_m (r_o \parallel R_{o2} \parallel R_L) \quad (1\%)$$

$$= -0.5 \times (400 \parallel 13050 \parallel 500)$$

$$= -109.25$$

3. (12%)



$I_{E2} = I_{Bias2} - I_{Bias1}$

$= 100 - 25 = 75\ \mu A$

$I_{C2} = \frac{\beta}{1+\beta} I_{E2} = \frac{150}{151} \times 75$

$= 74.5\ \mu A$

$I_{B2} = \frac{1}{1+\beta} I_{E2} = 0.5\ \mu A$

$I_{D1} = I_{Bias1} + I_{B2} = 25.5\ \mu A$

(a) (4%)

$g_{m1} = 2\sqrt{K_n I_{D1}}$ (1%)

$= 2\sqrt{50\mu \times 25.5\mu}$

$= 71.41\ \mu A/V$ (2%)

注意單位

$g_{m2} = \frac{I_{C2}}{V_T} = \frac{74.5\mu}{26m}$ (1%)

$= 2.865\ mA/V$

(2%)

$r_{\pi 2} = \frac{\beta V_T}{I_{C2}} = \frac{150 \times 26}{74.5\mu}$

$= 52.35\ k\Omega$

(b) (5%)

$g_m^c = \frac{g_{m1}(1 + g_{m2} r_{\pi 2})}{1 + g_{m1} r_{\pi 2}}$ (3%)

$g_m^c = \frac{71.41\mu \times (1 + 2.865 \times 52.35)}{(1 + 71.41 \times 10^{-3} \times 52.35)}$

$= 2.275\ mA/V$

(c)

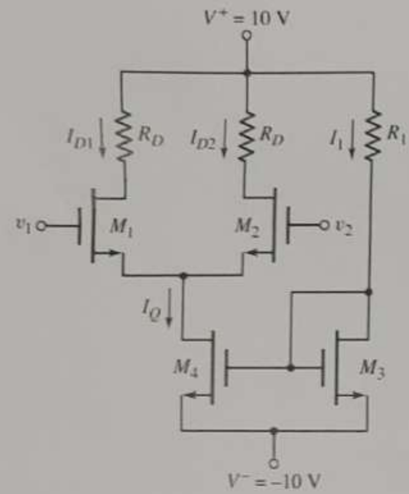
Have larger g_m ($g_m^c > g_{m1}$)

while still have infinite input resistance (3%)

(有寫出 g_m^c 大就可以)

(又寫到 $R_i = \infty$ 时給 1%)

4. (20%)



$R_1 = 50 k\Omega$

$R_D = 24 k\Omega$

$K_n = 0.25 \ mA/V$

$V_{TN} = 2V$

(a) (4%)

$$\begin{cases} I_1 R_1 + V_{GS3} = V^+ - V^- \\ I_1 = K_n (V_{GS3} - V_{TN})^2 \end{cases} \quad (2\%)$$

$$\begin{cases} 50 I_1 + V_{GS3} = 20 \\ I_1 = 0.25 (V_{GS3} - 2)^2 \end{cases}$$

$12.5 (V_{GS3} - 2)^2 + V_{GS3} = 20$

$12.5 V_{GS3}^2 - 49 V_{GS3} + 30 = 0$

$\Rightarrow V_{GS3} = 3.16V$

$I_1 = 0.337 mA$

$I_Q = I_1 = 0.337 mA$ (4%)

(b) $I_{D1} = I_Q/2 = 0.168 mA$

(6%) $V_{GS1} = V_{TN} + \sqrt{I_{D1}/K_n}$

$= 2 + \sqrt{0.168/0.25} = 2.82V$

$V_{D1} = V^+ - I_{D1} R_D = 10 - 0.168 \times 24$

$= 5.968 V$

$V_{DS1} = V_{D1} - V_{S1} = V_{D1} - (V_{cm} - V_{GS1}) \geq V_{DS1(sat)}$

$V_{cm} \leq V_{D1} + V_{TN} = 7.968 V$ (2%)

maximum of $V_{cm} = 7.968V$ (3%)

$V_{DS4} = V_{D4} - V^- = (V_{cm} - V_{GS1}) - V^- \geq V_{DS4(sat)}$

$V_{cm} \geq V^- + V_{GS1} + V_{GS4} - V_{TN}$ (2%)

$\Rightarrow V_{cm} \geq -10 + 2.82 + 3.16 - 2 = -6.02V$

minimum of $V_{cm} = -6.02 V$ (3%)

(c)
(5%) $g_{m2} = 2\sqrt{K_n I_{D2}} = 2\sqrt{0.25 \times 0.168} = 0.41 mA/V$

$A_d = \frac{1}{2} g_{m2} R_D = \frac{1}{2} \times 0.41 \times 24 = 4.92$ (5%)

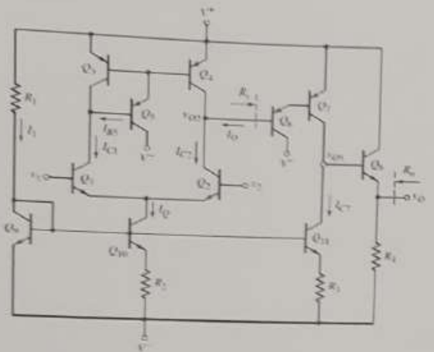
(3%)

(d) $R_o = \frac{1}{\lambda I_Q} = \frac{1}{0.02 \times 0.337} = 148.37 k\Omega$

(5%) $A_{cm} = -g_{m2} R_D \times \frac{1}{1 + 2 g_{m2} R_o}$ (3%)

$= -\frac{0.41 \times 24}{1 + 2 \times 0.41 \times 148.37} = -0.0802$ (5%)

5. (25%)



$I_{C7} = I_Q = 0.5\,mA$, $I_{C8} = 2.5\,mA$

$R_2 = R_3 = 0.1\,k\Omega$

$\beta = 100$

$V_A = 80\,V$

(a)

$$R_i = r_{\pi 6} + (1+\beta) r_{\pi 7} = \frac{2(1+\beta)\beta V_T}{I_{C7}}$$

$$= 2 r_{\pi 6}$$ (3%) (任意一種都可以)

$$r_{\pi 6} = \frac{\beta V_T}{I_{C6}} = \frac{\beta(1+\beta) V_T}{I_{C7}}$$

$$= \frac{100 \times 101 \times 26}{0.5} = 525.2\,k\Omega$$

$$R_i = 2 r_{\pi 6} = 1.05\,M\Omega$$ (5%)

(b)

$$R_{C11} = r_{o11}(1 + g_{m11}(r_{\pi 11} /\!/ R_3))$$ (3%)

$$g_{m11} = \frac{I_{C11}}{V_T} = \frac{0.5}{26} = 19.23\,mA/V$$

$$r_{o11} = \frac{V_A}{I_{C11}} = \frac{80}{0.5} = 160\,k\Omega$$

$$r_{\pi 11} = \frac{\beta V_T}{I_{C11}} = \frac{100 \times 26}{0.5} = 5.2\,k\Omega$$

$$R_{C11} = 160(1 + 19.23 \times (5.2 /\!/ 0.1))$$

$$= 461.87\,k\Omega$$ (5%)

(c)

$$A_{v1} = \frac{v_{o2}}{v_d} = g_{m2}(r_{o2} /\!/ r_{o4} /\!/ R_i)$$ (3%)

$$g_{m2} = \frac{I_{C2}}{V_T} = \frac{0.5/2}{26} = 9.615\,mA/V$$

$$r_{o2} = r_{o4} = \frac{V_A}{I_{C2}} = \frac{80}{0.5/2} = 320\,k\Omega$$

$$A_{v1} = 9.615(320 /\!/ 320 /\!/ 1050)$$

$$= 1335.0$$ (5%)

(d)

$$A_{v2} = \frac{v_{o3}}{v_{o2}} = -\frac{\beta(1+\beta)}{R_i} \times (R_{C11} /\!/ R_{b8})$$ (3%)

$$R_{b8} = r_{\pi 8} + (1+\beta) R_4 = \frac{100 \times 26}{2.5} + 101 \times 5$$

$$= 506.04\,k\Omega$$

$$A_{v2} = -\frac{100 \times 101 \times (461.87 /\!/ 506.04)}{1050}$$

$$= -2434.8$$ (5%) (負號有沒有都可以)

(e)

$$R_o = R_4 /\!/ \frac{r_{\pi 8} + R_{C11}}{1+\beta}$$ (3%)

$$= 5 /\!/ \frac{1.04 + 461.87}{101} = 5 /\!/ 4.583$$

$$= 2.39\,k\Omega$$ (5%)

$R_o = R_4 /\!/ (\frac{r_{\pi 8} + R_{C11}}{1+\beta}) = 5k /\!/ (\frac{1.04 + \ldots}{101})$

$= 5k /\!/ 4.58\,k$ $\quad$ $19.23\,m$ $\quad$ $= -9.615 \cdot 241.406$

6. (10%)

(a) (4%)

input : parallel

output : series

$\Rightarrow$ shunt-series feedback system

(b) $R_{if} = \dfrac{R_i}{1+\beta A}$ (3%)

$R_{of} = R_o \times (1+\beta A)$ (3%)

7. (13%)

(a) $R_{i2} = r_{\pi 16} + (1+\beta_n)\left[R_9 /\!/ \left(r_{\pi 17} + (1+\beta_n) R_8 \right) \right]$ (5%)

(b) Q_{18}. Q_{19} and R_{10} create a voltage drop V_{BB} 至少提到其中一項

between Q_{14} and Q_{20}, and $V_{BB} = V_{BE(on)} + V_{EB(on)}$.

Make Q_{14} and Q_{20} as class-AB output stage. (4%)

(c) short-circuit protection 至少寫到其中一項

Q_{15} turn on when current of Q_{14} exceed its limit

$\Rightarrow Q_{15} + R_6$: protect Q_{14}

Q_{21} turn on when current of Q_{20} exceed its limit

$\Rightarrow Q_{21} + R_7$: protect Q_{20}