1. (a) $I_{REF} = \frac{V^+ - V^- - V_{BE1(on)}}{R_1} = \frac{5+5-0.7}{20} = 0.465\,mA$

(b) $I_{O2} R_{E2} = V_T \ln\left(\frac{I_{REF}}{I_{O2}}\right)$

$20\times10^{-6} \times R_{E2} = 26\times10^{-3} \times \ln\left(\frac{465\mu}{20\mu}\right)$

$\Rightarrow R_{E2} = 4.09\,k\Omega$

(c) $I_{O3} R_{E3} = V_T \ln\left(\frac{I_{REF}}{I_{O3}}\right)$

$I_{O3} \times 2.2\times10^{3} = 26\times10^{-3} \times \ln\left(\frac{0.465}{I_{O3}}\right)$

$\Rightarrow I_{O3} = 34\,\mu A$

(d) For Q_3, $I_{O3} = 34\mu A$.

$r_{\pi3} = \frac{\beta V_T}{I_{O3}} = \frac{120\times0.026}{34\times10^{-6}} = 91.77\,k\Omega$, $g_{m3} = 1.308\,mA/V$

$r_{O3} = \frac{V_A}{I_{O3}} = \frac{100}{34\times10^{-6}} = 2.94\,M\Omega$

$R_o = r_{O3}(1 + g_{m3}(r_{\pi3} \parallel R_{E3})) = 2.94\times(1 + 1.308\times(91.77 \parallel 2.2))$

$= 10.47\,M\Omega$

2. (a) $r_{O1} = r_{O2} = r_{O4} = r_{O4} = \frac{1}{\lambda I_{D81}} = \frac{1}{0.02\times0.8} = 62.5\,k\Omega$

$g_{m3} = 2\sqrt{K_{p3} I_{D3}} = 2\sqrt{\frac{1}{2}\times40\times10^{-6}\times100 \times 80\times10^{-6}} = 0.8\,mA/V$

$R_{O3} \approx g_{m3} r_{O1} r_{O4} = 0.8\times10^{-3} \times 62.5\times10^{3} \times 6M\times10^{3} = 312.5\,M\Omega$

5

(b) $g_{m2} = 2\sqrt{K_{n2} I_{D2}} = 2\sqrt{\frac{1}{2}\times80\times10^{-6}\times50\times80\times10^{-6}} = 0.8\,mA/V$

$R_{O2} \approx g_{m2} r_{O2} r_{O1} = 312.5\,M\Omega$

$A_V = -g_{m1}(R_{O2} \parallel R_{O3}) = -0.8\times10^{-3} \times \frac{312.5}{2}\times10^{6}$

$= -125000$

5

(c) $V_{O(max)} = V^+ - V_{SG} - V_{SD(min)}$

$I_D = K_p(V_{SG} + V_{TP})^2 \Rightarrow 80\times10^{-6} = 2\times10^{-3}(V_{SG} - 0.6)^2$

$\Rightarrow V_{SG} = 0.8\,V$

$V_{SD(min)} = V_{SG} + V_{TP} = 0.8 - 0.6 = 0.2\,V$

$\Rightarrow V_{O(max)} = 9 - 0.8 - 0.2 = 8\,V$

5

3. (a) $I_Q = I_1 = \dfrac{V^+ - V^- - V_{GSQ}}{R_1} = K_n (V_{GSQ} - V_{TN})^2$

$\dfrac{12+12-V_{GSQ}}{50} = 0.2 (V_{GSQ} - 2)^2$

$10 V_{GSQ}^2 - 39 V_{GSQ} + 16 = 0 \quad \Rightarrow V_{GSQ} = 1.434\ V$

$\Rightarrow I_Q = \underline{0.411\ mA}$

$R_O = r_{ds} = \dfrac{1}{\lambda I_Q} = \dfrac{1}{0.02 \times 0.411} = \underline{121.65\ k\Omega}$

(b) $I_{D1} = I_{D2} = \dfrac{I_Q}{2} = 0.206\ mA$

$g_{m2} = 2\sqrt{K_n I_{D2}} = 2\sqrt{0.2 \times 0.206} = 0.406\ mA/V$

$A_d = \dfrac{v_{o2}}{v_d} = \dfrac{1}{2} g_{m2} R_D = \dfrac{1}{2} \times 0.406 \times 40 = \underline{8.12}$

(c) $A_{cm} = -g_{m2} R_D \times \dfrac{1}{1 + 2 g_{m2} R_O} = -\dfrac{0.406 \times 40}{1 + 2 \times 0.406 \times 121.65}$

$= \underline{-0.163}$

4. (a) $R_{id} = 2 [r_{\pi 1} + (1+\beta_n) \times \dfrac{r_{\pi 3}}{1+\beta_p}]$

$= (r_{\pi 1} + r_{\pi 2}) + (1+\beta_n) \times \dfrac{r_{\pi 3} + r_{\pi 4}}{1+\beta_p}$

(b) If $V^+, V^- \downarrow \Rightarrow I_{REF} \downarrow \Rightarrow I_{C1}, I_{C2} \downarrow$

$r_\pi \propto \dfrac{1}{I_C} \Rightarrow r_\pi \uparrow \Rightarrow R_{id} \uparrow$

R_{id} 變大

5. (a)

5

$$A_{V1} = \frac{v_{o2}}{v_d} = g_{m2}(r_{o2} \parallel r_{o4} \parallel R_i)$$

$$g_{m2} = \frac{I_{C2}}{V_T} = \frac{I_B}{2V_T} = \frac{0.4}{2\times 26} = 7.692\ mA/V$$

$$r_{o2} = r_{o4} = \frac{V_A}{I_{C2}} = \frac{80\times 2}{0.4} = 400\ k\Omega$$

$$A_{V1} = 7.692 \times (400 \parallel 400 \parallel 1313) = \underline{1335.0}$$

(b)

5

$$R_i = r_{\pi 6} + (1+\beta) r_{\pi 7}$$

$$r_{\pi 7} = \frac{\beta V_T}{I_{C7}} = \frac{100\times 26}{0.4} = 6.5\ k\Omega$$

$$r_{\pi 6} = \frac{\beta V_T}{I_{C6}} = \frac{100\times 26}{0.4/(1+\beta)} = 656.5\ k\Omega$$

$$R_i = r_{\pi 6} + (1+\beta) r_{\pi 7} = 656.5 + 101\times 6.5 = \underline{1.313\ M\Omega}$$

(c)

5

$$A_{V2} = \frac{v_{o3}}{v_{o2}} = -\frac{\beta(1+\beta) R_L}{R_i} = -\frac{I_B \cdot R_L}{2V_T}$$

$$R_L = R_{b8} \parallel R_{c7} \parallel R_{c11}$$

$$R_{b8} = r_{\pi 8} + (1+\beta) R_4 = \frac{100\times 26}{2} + 101\times 5 = 506.3\ k\Omega$$

$$R_{c7} = r_{o7} = \frac{V_A}{I_{C7}} = \frac{80}{0.4} = 200\ k\Omega$$

$$R_{c11} = r_{o11} \times (1 + g_{m11}(r_{\pi 11} \parallel R_3))$$

$$= \frac{80}{0.4} \times \left(1 + \frac{0.4}{26} \times \left(\frac{100\times 26}{0.4} \parallel 0.1\right)\right) = 200\times(1 + 15.38 \times 0.0985)$$

$$= 503.03\ k\Omega$$

$$R_L = 506.3 \parallel 200 \parallel 503.03 = 111.57\ k\Omega$$

$$A_{V2} = -\frac{0.4\times 111.57}{2\times 0.026} = \underline{-858.23}$$

(d)

5

$$R_o = R_4 \parallel \frac{r_{\pi 8} + R}{1+\beta} = R_4 \parallel \frac{r_{\pi 8} + R_{c7} \parallel R_{c11}}{1+\beta}$$

$$= 5 \parallel \frac{1.3 + 200 \parallel 503.03}{101} = \underline{1.12\ k\Omega}$$

6. (a)

6

$$A_{vf} = \frac{V_o}{V_i} = \frac{A_1}{1+A_1\beta_1} \times \frac{A_2}{1+A_2\beta_1} = 20$$

$$\frac{200}{1+200\beta_1} \times \frac{10}{1+10\beta_1} = 20 \Rightarrow (1+200\beta_1)(1+10\beta_1) = 100$$

$$\Rightarrow \beta_1 = \underline{0.1761}$$

$$A_{vf} = \frac{A_1 A_2}{1+A_1A_2\beta_2} = 20$$

$$\frac{2000}{1+2000\beta_2} = 20 \Rightarrow \beta_2 = \underline{0.0495}$$

6

(b) For configuration (a):

$$A_{vf_1} = \frac{200}{1+200\times0.1761} \times \frac{9}{1+9\times0.1761} = 19.2256$$

$$\text{percent change} = \frac{19.2256-20}{20} \times 100\%$$

$$= \underline{-3.872\%}$$

For configuration (b):

$$A_{vf_2} = \frac{200\times9}{1+200\times9\times0.495} = 19.9778$$

$$\text{percent change} = \frac{19.9778-20}{20} \times 100\%$$

$$= \underline{-0.111\%}$$

7. Shunt-series

因為輸入端為並聯減去 feedback 電流.

輸出端傳入 feedback 電路為串聯.