Solutions to Selected Problems (Problem Set 8)

Chapter 8: 8.4, 8.10, 8.28, 8.34, 8.35, Ex. 8.5 (with R_2=0), 8.39, 8.50, 8.55, 8.61, 8.64, 8.70

8.4

All output voltage is fed back $\therefore \beta = 1$

$$A_f = \frac{100}{1 + 100 \times 1} = 0.99$$

$1 + A\beta = 1 + 100 \times 1 = 101 \equiv 40.1\,dB$

$V_o = 0.99 V_s = 0.99V$

$V_i = V_s - V_o\beta = 1 - 0.99 = 10mV$

$$A = 90 \Rightarrow A_f = \frac{90}{1 + 90 \times 1} \approx 0.989$$

$$\frac{\Delta A_f}{A_f} = \frac{0.989 - 0.99}{0.99} \equiv -0.1\%$$

8.10

$A_0 \equiv 1000 \pm 30\%$ want $A_f = 100 \pm 1\%$

To reduce % change in A_0 we need

$$\frac{1}{1+A\beta} = \frac{1}{30} \Rightarrow A_f = \frac{1000}{30} < 100$$

For single stage $A_F = \frac{A}{1+A\beta_1} \Rightarrow \frac{1}{1+A\beta_1} = \frac{100}{1000} = \frac{1}{10}$

For two stages (identical) $A_2 = \frac{A}{1+A\beta_2} = 10$

$\Rightarrow (1 + A\beta_2) = 1000/10 = 100$

Thus each stage has $\pm 30/100\,\% = \pm 0.3\%$

But two such stages may give $\pm 0.6\%$ OK

[3 stages $A_3 = A_f^{1/3} = 100^{1/3}$

$(1 + A_0\beta_3) = 1000/100^{1/3} \doteq 215$

Now each stage has $\pm 0.14\%$]

8.28

Here R_o is lowered by amount of feedback

i.e. $(1 + A\beta) = 80$

$\Rightarrow A\beta = 79$

$R_o = R_{of}(1 + A\beta) = 100 \times 80 = 8K\Omega$

8.34

Since $V_{G1} = 0 = V_{G2}$

$\Rightarrow V_{E3} = V_o = 0$ and $V_{B3} = +0.7V$

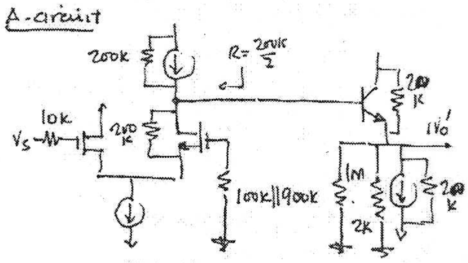
$g_{m1} = g_{m2} = 2\sqrt{\tfrac{1}{2}k'(W/L)I}$

$= 2\sqrt{\tfrac{1}{2}\,1\,(0.5)} = 1mA/V$

$r_{e3} = V_T/5mA = 5\Omega$

$r_o = V_A/I = 100/0.5 = 200K$

A-circuit



$R_i = \infty$

$R_o = 1M \| 2K \| \frac{200K}{2} \| \left(r_{e3} + \frac{200K/2}{\beta+1}\right) = 622.2\Omega$

$$A = \frac{100 \| (\beta+1)(r_{e3} + 1M \| 10K \| 2K)}{2/g_m} \times \frac{1.66K}{r_{e3} + 1.66K} = 31.3\,V/V$$

$$\beta = \frac{100}{100 + 900} = 0.1\,V/V$$

$$A_F = \frac{A}{1 + A\beta} = \frac{31.3}{1 + 31.3 \times 0.1} = 7.58\,V/V$$

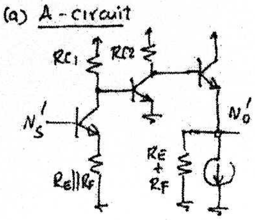
$R_{if} = \infty \quad \therefore R_{IN} = \infty$

$$R_{of} = \frac{R_o}{1 + A\beta} = \frac{622.2}{1 + 3.13} = 150.6\,\Omega$$

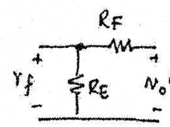
$R_{of} = R_{OUT} \| R_L \Rightarrow R_{out} = 163\,\Omega$

8.35

(a) A-circuit



B-circuit



(b) For $A\beta \gg 1$: $A_F = \dfrac{A}{1+A\beta} \Rightarrow \dfrac{1}{\beta}$

$\beta = \dfrac{R_E}{R_E+R_F} \Rightarrow A_f \approx \dfrac{R_E+R_F}{R_E} = 1 + \dfrac{R_F}{R_E}$

(c) $R_E = 50\Omega$

$\Rightarrow A_F = 1 + R_F/R_E = 25\,V/V$

$\Rightarrow R_F/R_E = 24$ and $R_F = 24R_E = 1.2k\Omega$

(d) $I_{Q1} = 1mA$, $I_{Q2} = 2mA$, $I_3 = 5mA$

$\beta = 100$

$r_{e1} = \dfrac{25mV}{1mA} = 25\Omega$, $r_{e2} = 12.5\Omega$, $r_{e3} = 5\Omega$

$A_1 = \dfrac{-R_{C1} \| r_{\pi 2}}{r_{e1} + R_E \| R_F} = -10$

$\Rightarrow R_{C1} \| r_{\pi 2} = 10(25 + 50 \| 1.2k) = 730\Omega$

$\Rightarrow R_{C1} = 1.75k\Omega$

$A_2 = \dfrac{-R_{C2} \| [(\beta+1)(r_{e3} + R_E + R_F)]}{r_{e2}} = -5$

$\Rightarrow R_{C2} \| 125.5K = 5 \times 12.5 = 625\Omega$

$\Rightarrow R_{C2} = 628.1\Omega$

$A_3 = \dfrac{R_E + R_F}{r_{e3} + R_E + R_F} = \dfrac{1.25}{1.255} = 0.996\,V/V$

(e) $\therefore A_1A_2A_3 = 10 \times 50 \times 0.996 = 498\,V/V$

$A\beta = 498(50/1250) = 19.92$

$A_F = \dfrac{A}{1+A\beta} = 23.8\,V/V$

(f) $R_i = (\beta+1)(r_e + R_E \| R_F)$

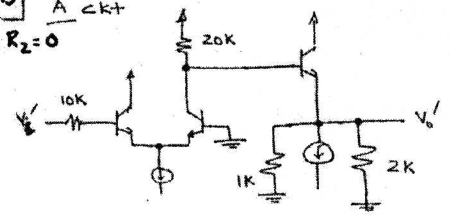
$\therefore R_i = 101(25 + 4.8) = 7.37k\Omega$

$R_{if} = R_i(1 + 19.92) = 154\,k\Omega$

$R_o = 1.25K \| (r_{e3} + R_{C2} \| 101) = 11.12\Omega$

$R_{OF} = \dfrac{R_o}{1 + 19.92} = 0.53\Omega$

Ex.8.5 A ckt with $R_2 = 0$



$r_{e1} = r_{e2} = 50\Omega$, $r_{e3} = 5\Omega$

8

$R_i = (\beta+1)2r_{e1} + 10K = 20.1k\Omega$

$R_o = 1k \| 2k \| (r_{e3} + \dfrac{20K}{\beta+1}) = 156.8\,\Omega$

$A = A_1 A_2$

$= \dfrac{20K \| (\beta+1)(r_{e3} + 1k \| 2k)}{2r_{e1} + \dfrac{10K}{\beta+1}} \cdot \dfrac{1k \| 2k}{1k \| 2k + r_{e3}}$

$= 77(0.993) = 76.5\,V/V$

$\beta = 1$

$A_f = \dfrac{76.5}{1 + 76.5} = 0.987\,V/V$

$R_{if} = (1 + A\beta)R_i = (1+A)R_i$

$= (1 + 76.5)\,20.1k\Omega = 1.56M\Omega$

$R_{in} = R_{if} - R_s = 1.55M\Omega$

$R_{of} = \dfrac{R_o}{1+A} = \dfrac{156.8}{1 + 76.5} = 2.02\Omega$

$R_{of} = R_{out} \| R_L$

$\Rightarrow R_{out} = 2.03\Omega$

Prob. 8.39

Series – Series feedback amplifier

input: VOLTAGE   output: CURRENT

$\Rightarrow$ Transconductance amplifier
(i.e., a voltage-to-current converter)

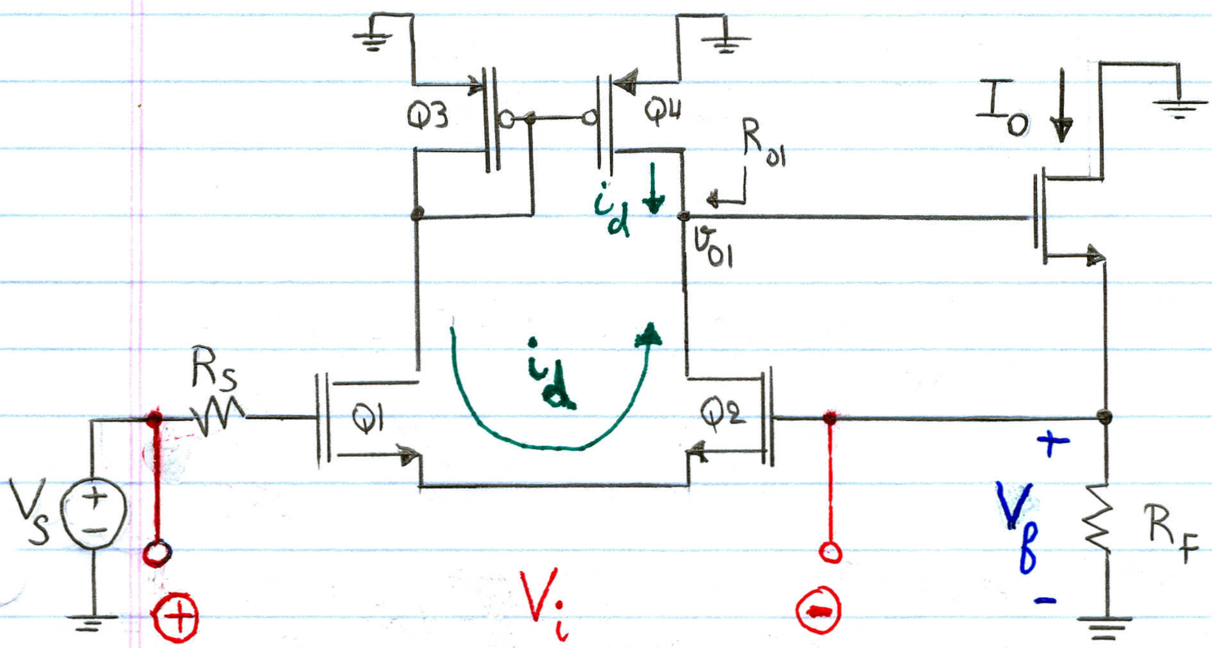
- DC analysis:

$$I_{D1} = I_{D2} = I_{D3} = I_{D4} = 0.1\ mA$$

$$I_{D5} = 0.8\ mA$$

$\longrightarrow\!\!\!>$

AC analysis: $\Rightarrow$ open-circuit the ideal current sources
short-circuit the ideal voltage sources



Define: $V_f = V_{g2}$

$V_i = V_s - V_f$

Then: @ Input: KVL $\Rightarrow V_i = V_s - V_f \Rightarrow$ SERIES mixing

@ Output: sample I_o $\Rightarrow$ SERIES sampling

$\longrightarrow\!\!\!\!\!>$

a) $V_f = I_o R_F \Rightarrow \underline{\underline{B}} \triangleq \dfrac{V_f}{I_o} = R_f = \underline{\underline{10k\Omega}}$

For large loop gain $(AB \gg 1)$:

$$A_f \triangleq \frac{I_o}{V_s} = \frac{A}{1+AB} \simeq \frac{1}{B} = \frac{1}{R_f} = \underline{\underline{0.1\ mA/V}}$$

b) $i_d = \dfrac{V_i}{2/g_{m1}}$ (see circuit diagram)

$R_{01} = r_{02} \| r_{04}$

$$\Rightarrow V_{01} = 2\, i_d R_{01} = g_{m1} (r_{02} \| r_{04})\, V_i$$

Assume $r_{05} = \infty$:

$$I_o = \frac{V_{o1}}{\frac{1}{g_{m5}} + R_F}$$

$$\therefore\ A \triangleq \frac{I_o}{V_i} = g_{m1} \frac{(r_{02} \| r_{04})}{\frac{1}{g_{m5}} + R_F}$$

$\longrightarrow\!\!\!\!\!\gg$

$$r_{o2} = r_{o4} = \frac{V_A}{I_{D2}} = 1\,M\Omega$$

$$g_{m1} = \sqrt{2\mu_n C_{ox}\left(\frac{W}{L}\right)_1 I_{D1}} = 0.12\ mA|V$$

$$g_{m5} = \sqrt{2\mu_n C_{ox}\left(\frac{W}{L}\right)_5 I_{D5}} = 0.8\ mA|V$$

$$\Rightarrow A = 5.33\ mA|V$$

$$\Rightarrow AB = (5.33\ mA|V)(10\,k\Omega) = 53.3$$

$$\Rightarrow A_f \triangleq \frac{I_o}{V_s} = \frac{A}{1+AB} = \underline{\underline{0.0982\ mA|V}}$$

c) Assume $r_{o5} = \infty$:

at source of Q_5 : $V_o = I_o R_F$

$$\Rightarrow \frac{V_o}{V_s} = \frac{I_o}{V_s} R_F = A_f R_F = \underline{\underline{0.982\ V/V}}$$

8.50

$I_o/I_s = 100\,A/A$, $R_{in} = 1K$, $R_{out} = 10K$

$\beta = 0.1$ shunt-series topology

$$A_P = \frac{I_o'}{I_s'} = 100$$

$$A_F = \frac{A_o}{1+A_o\beta} = \frac{100}{1+100(0.1)} = 9.09\ A/A$$

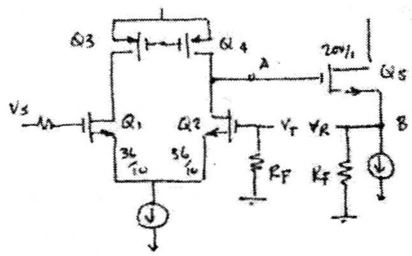
$R_i = 1K\Omega$

$\Rightarrow R_{if} = R_i/(1+A\beta) = 90.9\Omega$

$R_o = 10K\Omega$

$\Rightarrow R_{of} = R_o(1+A\beta) = 110K\Omega$

8.55



$V_f = V_{G2}$ and $V_S \to 0$

$V_A = -g_{m2}(r_{o2} \| r_{o4})$

$$V_B = V_A \frac{(R_F \| r_{o5})}{(R_F\|r_{o5}) + 1/g_{m5}}$$

$$A\beta = -\frac{V_f}{V_R} = +\frac{g_{m2}(r_{o2}\|r_{o4})(R_F\|r_{o5})}{(R_F\|r_{o5})+1/g_{m5}}$$

QED

8.61

$$A(s) = \frac{10^5}{1+s/100}$$

$$\text{Ang}(A) = -\tan^{-1}\frac{\omega}{100} - 2\tan^{-1}\frac{\omega}{10^4}$$

at ω_{180}: $\text{Ang}(A) = -180°$ for $\omega_{180} \gg 100$

$$\Rightarrow 180° = 90° + 2\tan^{-1}\left[\frac{\omega_{180}}{10^4}\right]$$

hence $\tan^{-1}\frac{\omega_{180}}{10^4} = \frac{90°}{2}$

i.e. $\frac{\omega_{180}}{10^4} = \tan(45°) = 1$

$\therefore \omega_{180} = 10^4$ rad/s

$$|A\beta| = \frac{10^5\beta}{\sqrt{1+(10^4/10^2)^2}}\cdot\frac{1}{(\sqrt{1+1})^2} = 1$$

$\Rightarrow \beta = 0.002$

$$A_f(0) = \frac{10^5}{1+10^5(0.002)} \approx 500\,V/V$$

8.64

$$A(s) = \frac{1000}{(1+s/10^4)(1+s/10^5)^2}$$

and β is independent of frequency

$$\text{Ang}(A) = -\tan^{-1}\frac{\omega}{10^4} - 2\tan^{-1}\frac{\omega}{10^5}$$

try $\omega = 10^4$: $\theta = 45° + 2\times 5.7 = 56.4°$

try $\omega = 10^5$: $\theta = 84.2° + 2\times 45 = 174.2°$

Iteration yields $\omega \approx 1.1\times 10^5$ rad/s

For oscillations: $|A\beta(\omega_{180})| \geq 1$

$$\frac{\beta\, 10^3}{(\sqrt{1+11^2})(\sqrt{1+1.1^2})} \geq 1$$

$\Rightarrow \beta \geq 0.0244$

8.70

$$A(f) = \frac{10^5}{1+jf/10}$$

for $\beta = 1$: $A(f)\beta = \frac{10^5}{1+jf/10}$

for $f \gg 10$: $|A\beta| \approx 10^5 \cdot \frac{10}{f_1}$

$\Rightarrow f_1 = 1\,MHz$

at f_1: phase margin $= 180° - \tan^{-1}\frac{10^6}{10}$

$= 90°$