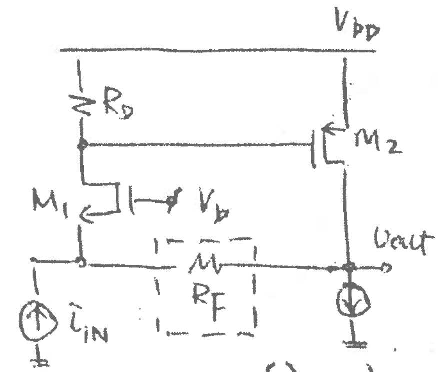
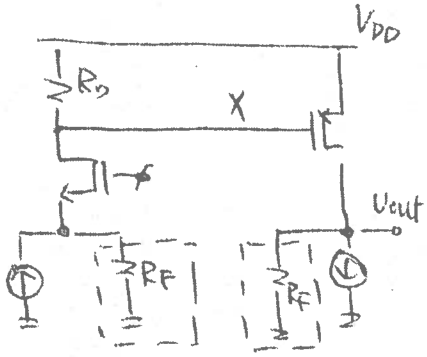
~~52~~ 51.

(a) Breaking the feedback loop results in the following circuit:



$(\lambda = 0)$

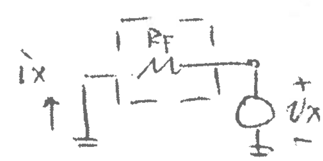


$$R_{O.L.} = \frac{v_x}{i_{IN}} \cdot \frac{v_{out}}{v_x}$$

$$= g_{m1} R_D \left(\frac{1}{g_{m1}} \| R_F\right) \times (-g_{m2} R_F)$$

$$R_{in,OPEN} = \frac{1}{g_{m1}} \| R_F \qquad R_{out,OPEN} = R_F$$

- Feedback factor k:



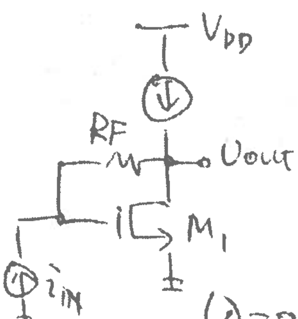
$$k = \frac{v_x}{i_x} = -\frac{1}{R_F}$$

$$\Rightarrow R_{C.L.} = \frac{R_{O.L.}}{1 + R_{O.L.} \times k} = \frac{-g_{m1} g_{m2} R_D R_F \left(\frac{1}{g_{m1}} \| R_F\right)}{1 + g_{m1} g_{m2} R_D \left(\frac{1}{g_{m1}} \| R_F\right)}$$

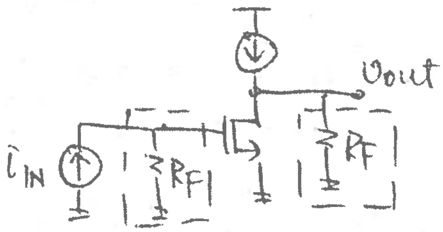
$$R_{in,CLOSED} = \frac{\left(\frac{1}{g_{m1}} \| R_F\right)}{1 + g_{m1} g_{m2} R_D \left(\frac{1}{g_{m1}} \| R_F\right)}$$

$$R_{out,CLOSED} = \frac{R_F}{1 + g_{m1} g_{m2} R_D \left(\frac{1}{g_{m1}} \| R_F\right)}$$

(b) Breaking the feedback loop results in the following circuit:



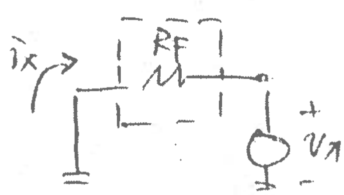
$(\lambda = 0)$



$$R_{O.L.} = \frac{v_{out}}{i_{IN}} = -g_m R_F R_F = -g_m R_F^2$$

$$R_{in,OPEN} = R_F \qquad R_{out,OPEN} = R_F$$

- Feedback factor K:



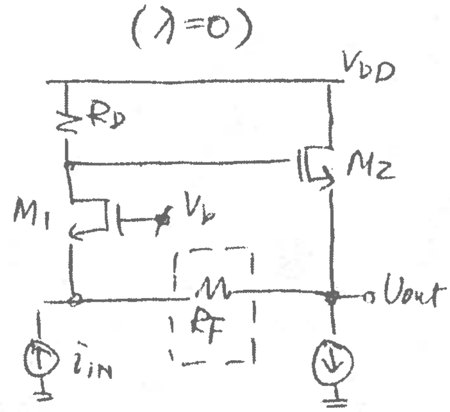
$$K = \frac{v_x}{i_x} = -\frac{1}{R_F}$$

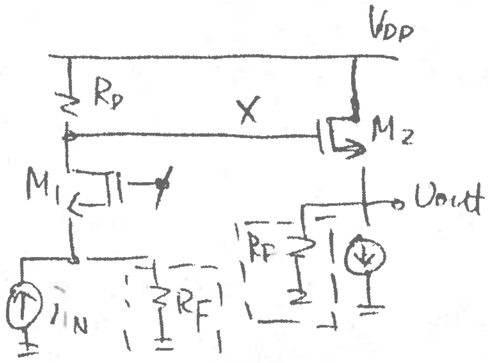
$$\Rightarrow R_{C.L.} = \frac{-g_m R_F^2}{1 + g_m R_F}$$

$$R_{in,CLOSED} = \frac{R_F}{1 + g_m R_F}$$

$$R_{out,CLOSED} = \frac{R_F}{1 + g_m R_F}$$

(c) Breaking the feedback loop results in the following circuit:





$$R_{O.L.} = \frac{v_{out}}{i_{IN}} = \frac{v_x}{i_{IN}} \cdot \frac{v_{out}}{v_x}$$

$$= g_{m1} R_D \left(\frac{1}{g_{m1}} \| R_F\right) \times g_{m2}\left(R_F \| \frac{1}{g_{m2}}\right)$$

$$R_{in,OPEN} = \left(\frac{1}{g_{m1}} \| R_F\right) \qquad R_{out,OPEN} = \left(R_F \| \frac{1}{g_{m2}}\right)$$

- Feedback factor K:

$$K = \frac{v_x}{i_x} = -\frac{1}{R_F}$$

(Note: Feedback is positive.)

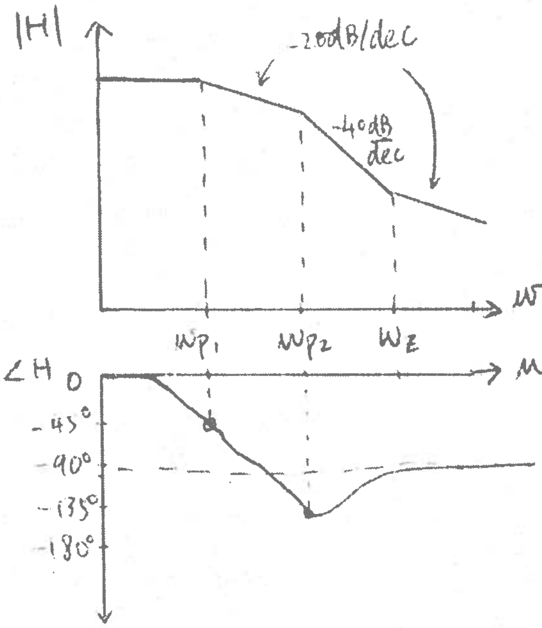
$$\Rightarrow R_{C.L.} = \frac{R_{O.L.}}{1 + R_{O.L.} \times K}$$

$$= \frac{g_{m1} g_{m2} R_D (1/g_{m1} \| R_F)(1/g_{m2} \| R_F)}{1 - g_{m1} g_{m2} \left(\frac{R_D}{R_F}\right)\left(\frac{1}{g_{m1}} \| R_F\right)\left(1/g_{m2} \| R_F\right)}$$

$$R_{IN,CLOSED} = \frac{(1/g_{m1} \| R_F)}{1 - \frac{R_{O.L.}}{R_F}} \qquad R_{out,CLOSED} = \frac{(1/g_{m2} \| R_F)}{1 - \frac{R_{O.L.}}{R_F}}$$

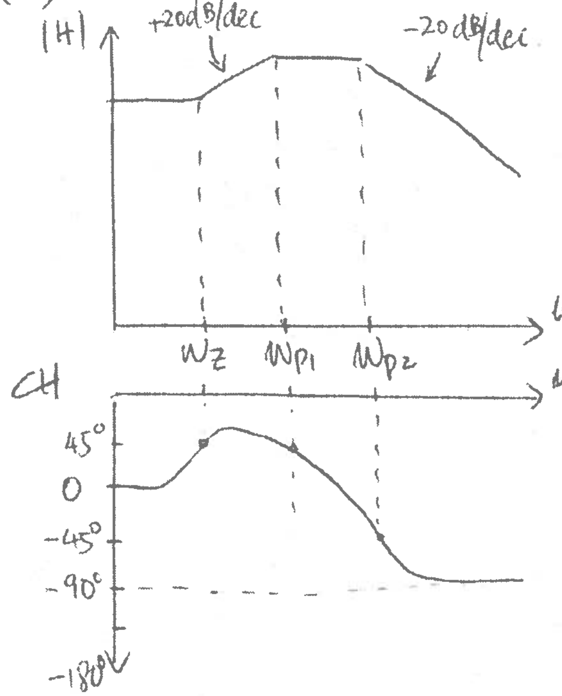
~~20~~. 57.

(a)



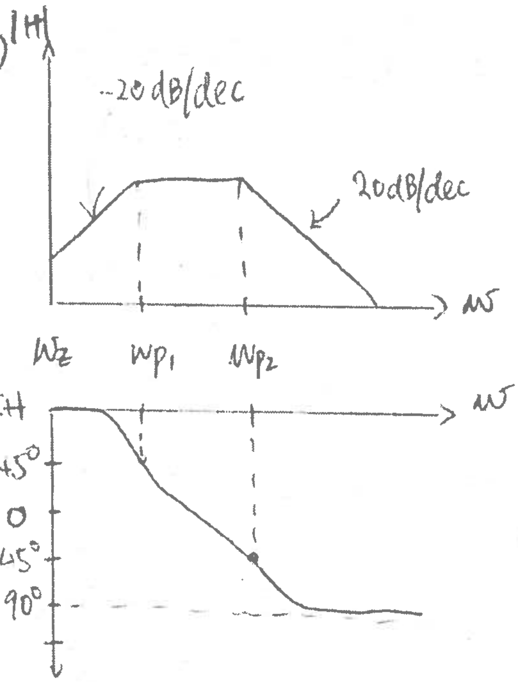
|H|
-20dB/dec
-40dB/dec
ω
ωp1
ωp2
ωz
∠H
0
-45°
-90°
-135°
-180°
ω

(b)



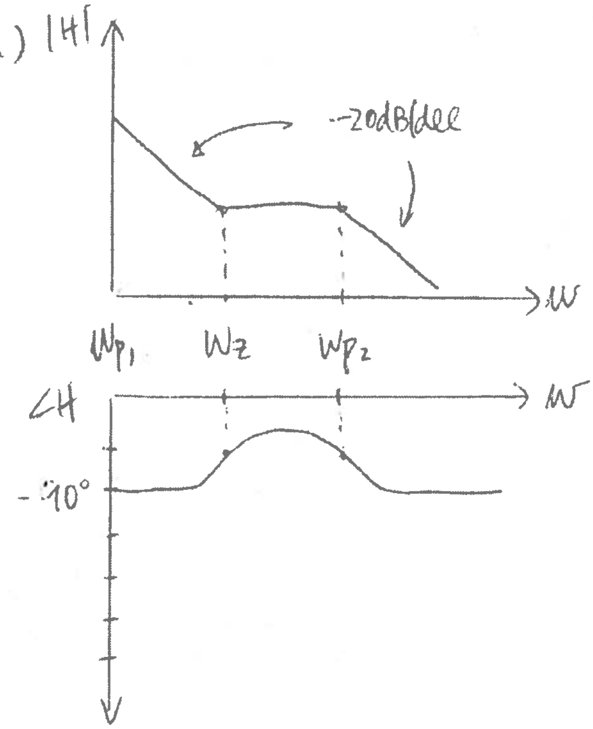
|H|
+20dB/dec
-20dB/dec
ω
ωz
ωp1
ωp2
∠H
45°
0
-45°
-90°
-180°
ω

(c)



|H|
-20dB/dec
20dB/dec
ω
ωz
ωp1
ωp2
∠H
45°
0
-45°
-90°
ω

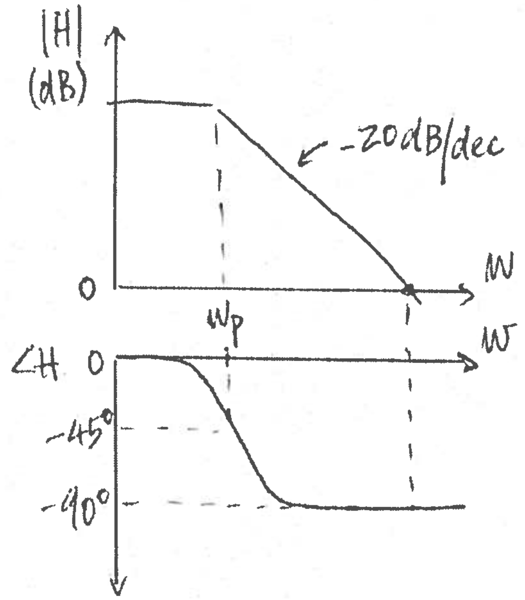
(d)



|H|
-20dB/dec
ω
ωp1
ωz
ωp2
∠H
-90°
ω

~~68~~. 65.

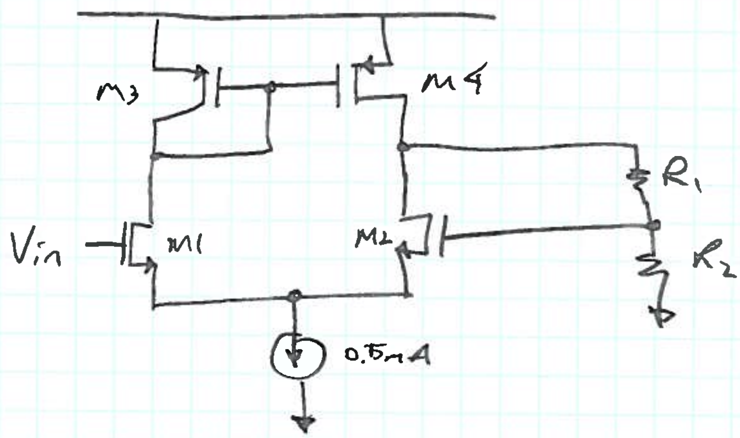
$$H(s) = \frac{A_o}{1 + \frac{s}{\omega_p}} \qquad k = 1.$$



$\therefore$ Phase margin
$= 180° - 90° = 90°$

(i.e. system is stable)

71.



Specs: $A_{OL} = 50$

$A_{CL} = 4$

$R_L + R_2 \simeq 10(r_{o2} \| r_{o4})$

As $R_L + R_2 \simeq 10(r_{o2}\|r_{o4})$ we can neglect the output loading

$$A_{OL} = g_{m1}\left(r_{o2} \| r_{o4}\right) = 50$$

$$r_{o2} = \frac{1}{\lambda_N \, I_{SS}/2} = \frac{1}{(0.1V^{-1})(0.25mA)} = 40k\Omega$$

$$r_{o4} = \frac{1}{\lambda_P \, I_{SS}/2} = \frac{1}{(0.2V^{-1})(0.25mA)} = 20k\Omega$$

$$r_{o2} \| r_{o4} = 13.3k\Omega$$

$$\boxed{g_{m1} = \frac{50}{13.3k\Omega} = 3.75\ mA/V}$$

This can be achieved with

$$\frac{W}{L}_{1,2} = \frac{g_m^2}{\mu C_{ox} 2 I_D} = \frac{(3.75\ mA/V)^2}{(100\ \mu A/V^2)(2)(0.25mA)} = 281$$

$$A_{CL} = \frac{A_{OL}}{1 + K A_{OL}}$$

$$K = \frac{A_{OL} - A_{CL}}{A_{OL} A_{CL}} = \frac{50 - 4}{(50)(4)} = 0.23$$

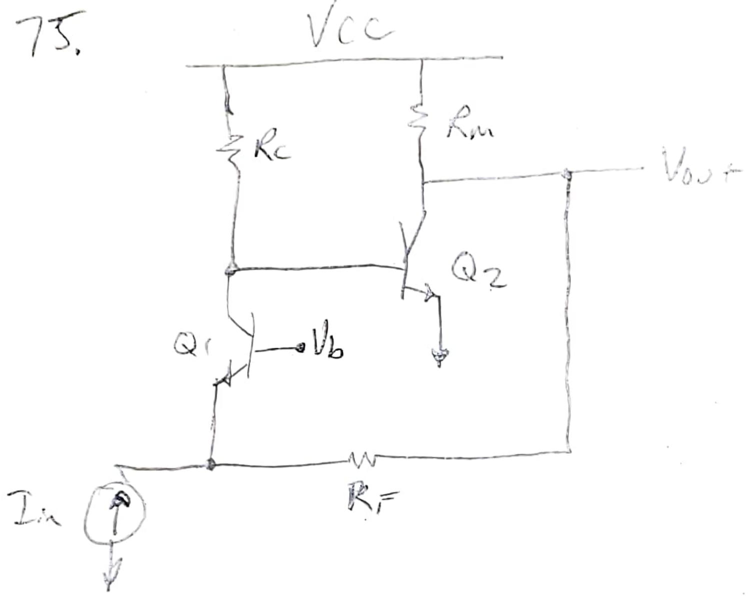
Need: $K = \frac{R_2}{R_1 + R_2} = 0.23$ and $R_1 + R_2 = 10(13.3k\Omega)$

$$R_2 = 0.23(133k\Omega) = 30.6k\Omega$$

$R_1 = 133k\Omega - 30.6k\Omega = 102.4k\Omega$

$$\boxed{\begin{aligned} R_1 &= 102.4k\Omega \\ R_2 &= 30.6k\Omega \end{aligned}}$$

75.



$|R_{CL}| = 1k\Omega$

$I_{C1} = I_{C2} = 1mA$

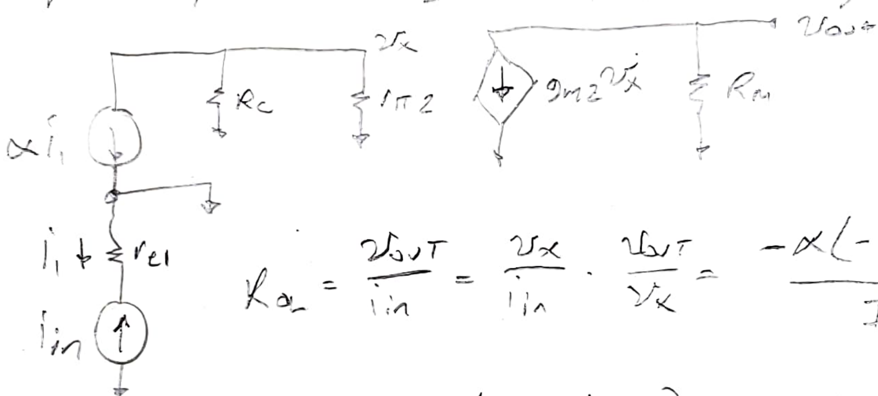
$\beta = 100$

$V_A = \infty$

R_F is large

a. Need $|R_{OL}| = 20k\Omega$ $\quad R_{OUT,OL} = 500\Omega$

Open-loop small-signal model w/ large R_F (ignored)



T-model for Q_1

π-model for Q_2

$$R_{OL} = \frac{v_{OUT}}{i_{in}} = \frac{v_x}{i_{in}} \cdot \frac{v_{OUT}}{v_x} = \frac{-\alpha(-I_{in})(R_c \| r_{\pi 2})}{I_{in}} \cdot (-g_{m2} R_m)$$

$$R_{OL} = -\alpha(R_c \| r_{\pi 2})\, g_{m2} R_m$$

$$R_{OUT,OL} = \boxed{R_M = 500\Omega}$$

$$|R_{OL}| = \frac{\alpha g_{m2} R_M}{\frac{1}{R_c} + \frac{1}{r_{\pi 2}}} \Rightarrow \frac{1}{R_c} = \frac{\alpha g_{m2} R_m}{|R_{OL}|} - \frac{1}{r_{\pi 2}}$$

$$\frac{1}{R_c} = \frac{\left(\frac{100}{101}\right)\left(\frac{1mA}{25.9mV}\right)(500)}{20k\Omega} - \frac{1mA}{100(25.9mV)} = 570\ \mu A/V$$

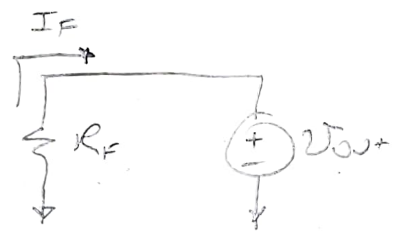
$$\boxed{R_c = 1.76k\Omega}$$

b. Find R_F for $R_{CL} = -1k\Omega$

$$R_{CL} = \frac{R_{OL}}{1 + K R_{OL}} \implies K = \frac{\frac{R_{OL}}{R_{CL}} - 1}{R_{OL}}$$

$$K = \frac{\frac{-20k\Omega}{-1k\Omega} - 1}{-20k\Omega} = -950 \, {}^{\mu A}/_{V}$$

For K



$$K = \frac{I_F}{V_{OUT}} = \frac{-V_{OUT}/R_F}{V_{OUT}}$$

$$K = -\frac{1}{R_F}$$

$$R_F = -\frac{1}{K} = -\frac{1}{(-950 \, {}^{\mu A}/_{V})} = 1.05k\Omega$$

$$\boxed{R_F = 1.05k\Omega}$$

c. $R_{IN,CL}$, $R_{OUT,CL}$

$$R_{IN,CL} = \frac{R_{IN,OL}}{1 + K R_{OL}} = \frac{r_{\pi 1}}{1 + K R_{OL}} = \frac{\frac{25.9mV}{1mA\left(\frac{101}{100}\right)}}{1 + (-950 \, {}^{\mu A}/_{V})(-20k\Omega)}$$

$$\boxed{R_{IN,CL} = 1.28\Omega}$$

$$R_{OUT,CL} = \frac{R_{OUT,OL}}{1 + K R_{OL}} = \frac{R_M}{1 + K R_{OL}} = \frac{500\Omega}{1 + (-950 \, {}^{\mu A}/_{V})(-20k\Omega)}$$

$$\boxed{R_{OUT,CL} = 25\Omega}$$