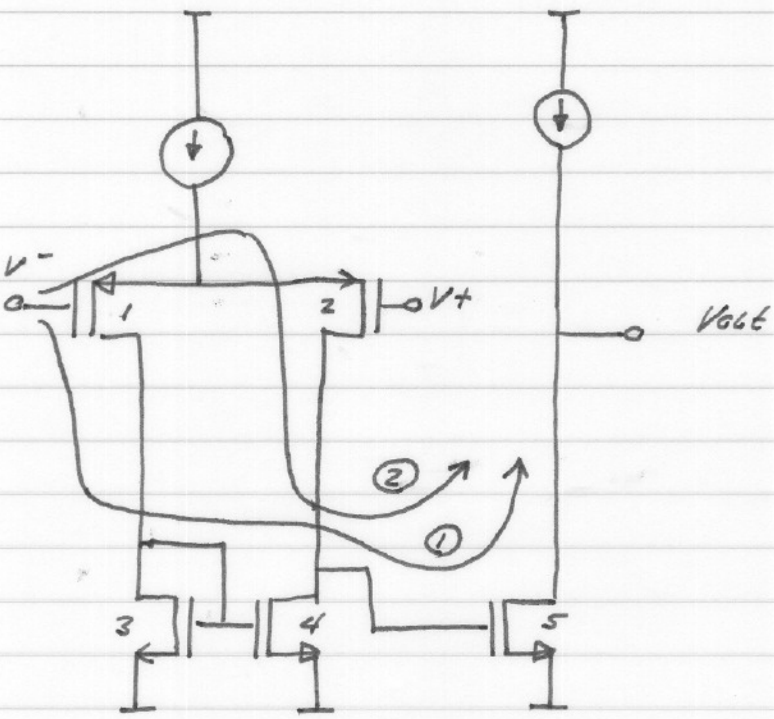
ECE137B Multistage example: Notes set 9



This is a simplified MOSFET op-Amp.

There are 2 paths, 1 & 2, from V^- to output.

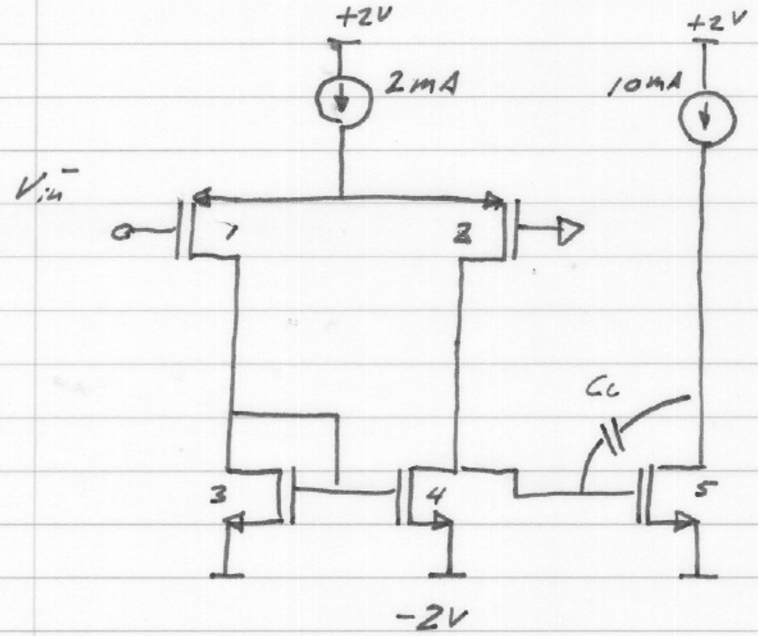
If there are 2 such paths, then

$$\frac{V_{out}}{V^-} = A_{dc1} \left.\frac{1 + b_1' s + b_2' s^2 + \cdots}{1 + a_1' s + a_2' s^2 + \cdots}\right|_{path\,1}$$

$$+ A_{dc2} \left.\frac{1 + \tilde{b}_1 s + \tilde{b}_2 s^2}{1 + \tilde{a}_1 s + \tilde{a}_2 s^2}\right|_{path\,2}$$

lets solve both these paths.

Recall: op-amps are analyzed assuming $v_{out} = 0\,V$.



$1/\lambda = 10V$
$V_{th} = 1/4V$
$C_{ox}v_{sat} = 1\,mS/\mu m$ $L_g = 200nm$

$Q1, 2:$ $g_m = 2mS$
$W_g = 2\mu m$
$C_{gs} = C_{gd} = 0$

$R_{ds} = 1/\lambda I_D = 10\,K\Omega$

$Q3, Q4:$ $g_m = 2mS$, $W_g = 2\mu m$, $C_{gs} = 4fF$, $C_{gd} = 0.4fF$
$R_{ds} = 1/\lambda I_D = 10K\Omega$

<u>$Q5:$</u> $g_m = 20\,mS$, $W_g = 20\mu m$ $C_{gs} = 40fF$, $C_{gd} = 4fF$
$R_{ds} = 1/\lambda I_D = 1K\Omega$

<u>Mid-band gain</u>

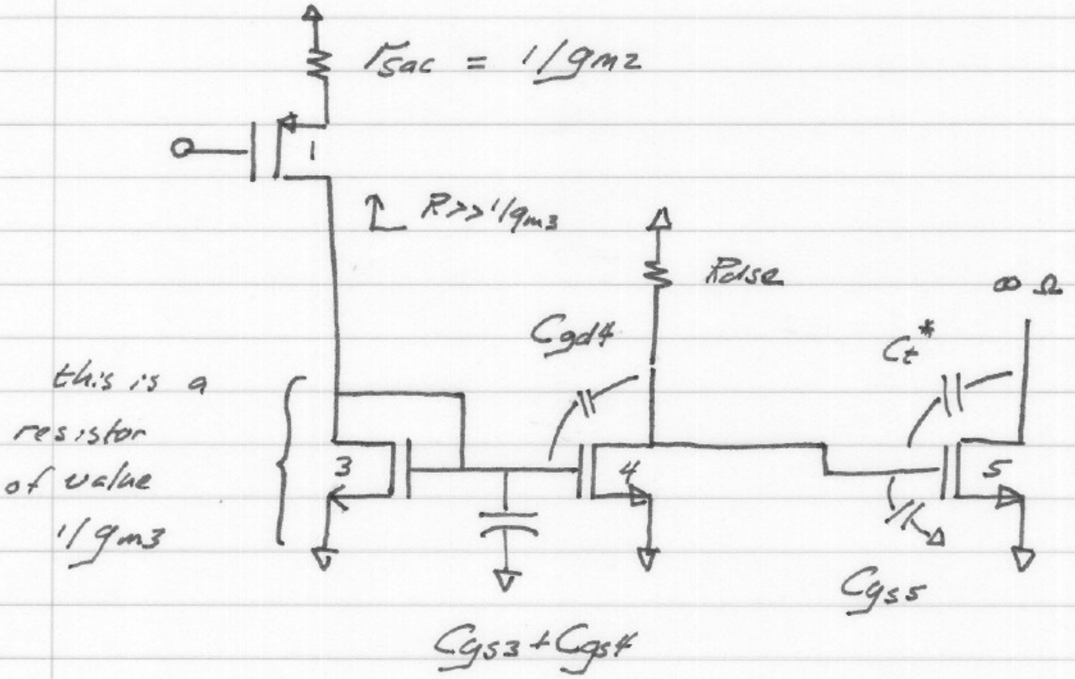
$Q5:$ $A_v = -g_m R_{Leq} = -g_{m5} R_{ds5} = 20$

<u>$Q1-4:$</u> $A_v = g_{m1}(R_{ds4} \| R_{ds2}) = 10$

note that the overall gain is low.

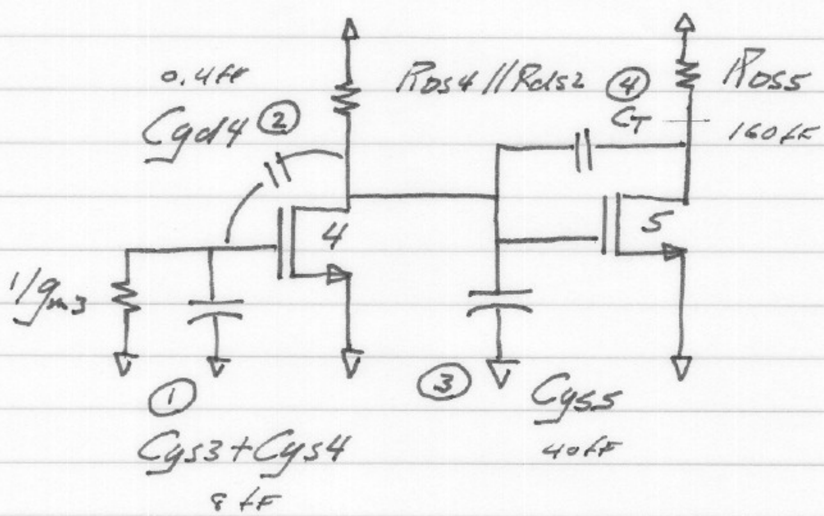
Getting large gain with MOSFETS requires effort.

HF analysis; path I



$C_t = C_{gs5} + C_c \Rightarrow$ pick C_c so that $C_t = 160\,fF$

160



first calculate $a_1 = R_{11}^0 C_1 + R_{22}^0 C_2 + R_{33}^0 C_3 + R_{44}^0 C_4$

$R_{11}^0 C_1$

$R_{11}^0 = 1/g_{m3}$, $C_1 = C_{gs3} + C_{gs4} \rightarrow R_{11}^0 C_1 = 4\,ps$

$R_{22}^0 C_2$

$C_2 = C_{gd4} = 0.4\,fF \quad R_{22}^0 = (1/g_{m3})(1 + g_{m4} \cdot R_{ds4} \| R_{ds2}) + R_{ds4} \| R_{ds2}$

$= 5.5\,k\Omega + 5\,k\Omega = 10.5\,k\Omega$

$R_{22}^0 C_2 = 4.2\,ps$

$R_{33}^0 C_3$

$R_{33}^0 = R_{DS4} \| R_{ds2} = 5\,k\Omega$, $C_3 = C_{gs5} = 40\,fF$

$\rightarrow R_{33}^0 C_3 = 200\,ps$

$R_{44}^0 C_4$

$R_{44}^0 = (R_{ds4} \| R_{DS2})(1 + A_{v5}) + R_{DS5}$

$= 5\,k\Omega(1 + 20) + 1\,k\Omega = 106\,k\Omega$

$C_4 = 160\,fF$

$\rightarrow R_{44}^0 C_4 = 17.0\,ns$

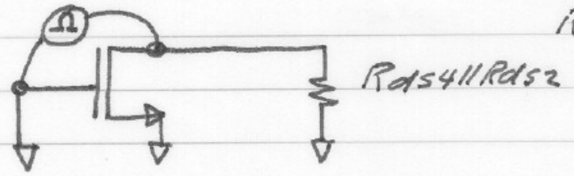
a_1 = sum of those terms = $17.2\,ns$

$f_{p1} = 1/2\pi a_1 = 9.2\,MHz$ assuming SPA will hold

Now calculate a_2

$R_{11}^{0} C_1 C_2 R_{22}' = 500\Omega \cdot 8fF \cdot 0.4fF \cdot 5K\Omega = 8 \cdot 10^{-24}\ \text{Sec}^2$

R_{22}':

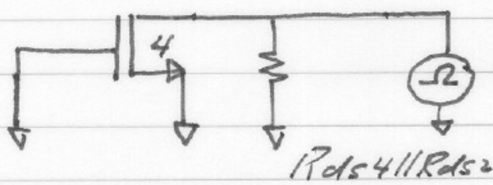


$R_{22}' = R_{ds4} \| R_{ds2}!$

$= 5K\Omega$

$R_{11}^{0} C_1 C_3 R_{33}' = 500\Omega \cdot 8fF \cdot 40fF \cdot 5K\Omega = 8 \cdot 10^{-22}\ \text{Sec}^2$

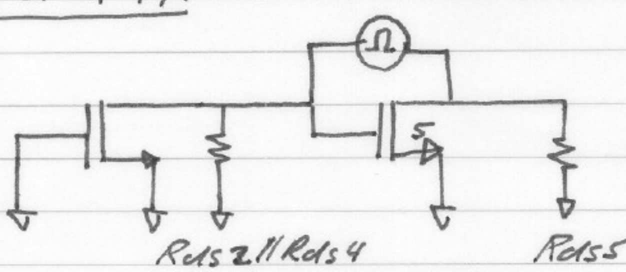
R_{33}'



$R_{33}' = R_{ds4} \| R_{ds2}!$

$= 5K\Omega$

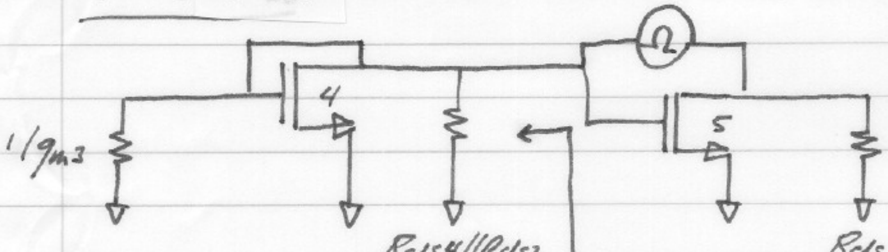
$R_{11}^{0} C_1 C_4 R_{44}' = 500\Omega \cdot 8fF \cdot 160fF \cdot 55K\Omega = 3.52 \cdot 10^{-20}\ \text{Sec}^2$



$R_{44}' = (R_{ds2} \| R_{ds4})(1 + A_{v5}) + R_{ds5}$

$= R_{44}^{0} = 55K\Omega$

$R_{22}^{0} C_2 C_4 R_{44}^{2} = 10.5K\Omega \cdot 0.4fF \cdot 160fF \cdot 6K\Omega = 4.03 \cdot 10^{-21}\ \text{Sec}^2$



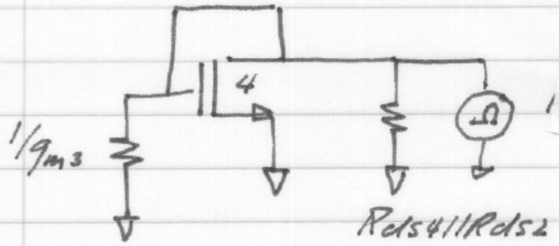
$R_{44}^{2} = R_X(1 + g_{m5} R_{ds5}) + R_{ds5}$

$= 5k + 1k = 6k$

$R_X = (1/g_{m3}) \| (1/g_{m4}) \| R_{ds4} \| R_{ds2}$

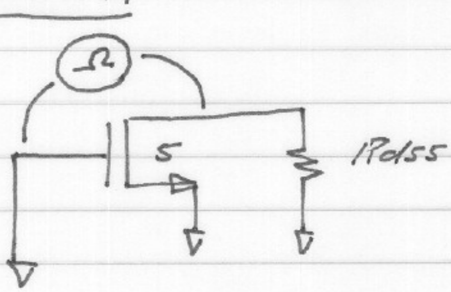
$= 238\Omega$

$\underline{R_{22}^{\circ} C_2 C_3 R_{33}^{2}} = 10.5k\Omega \cdot 0.4fF \cdot 40fF \cdot 238\Omega = 4.0 \cdot 10^{-23} \sec^2$



$R_{33}^{2} = \frac{1}{g_{m3}} \,||\, \frac{1}{g_{m4}} \,||\, R_{ds4} \,||\, R_{ds2} = 238\Omega$

$\underline{R_{33}^{\circ} C_3 C_4 R_{44}^{3}} = 5k\Omega \cdot 40fF \cdot 160fF \cdot 1k\Omega = 3.2 \cdot 10^{-20} \sec^2$



$R_{44}^{3} = R_{ds5} = 1k\Omega$

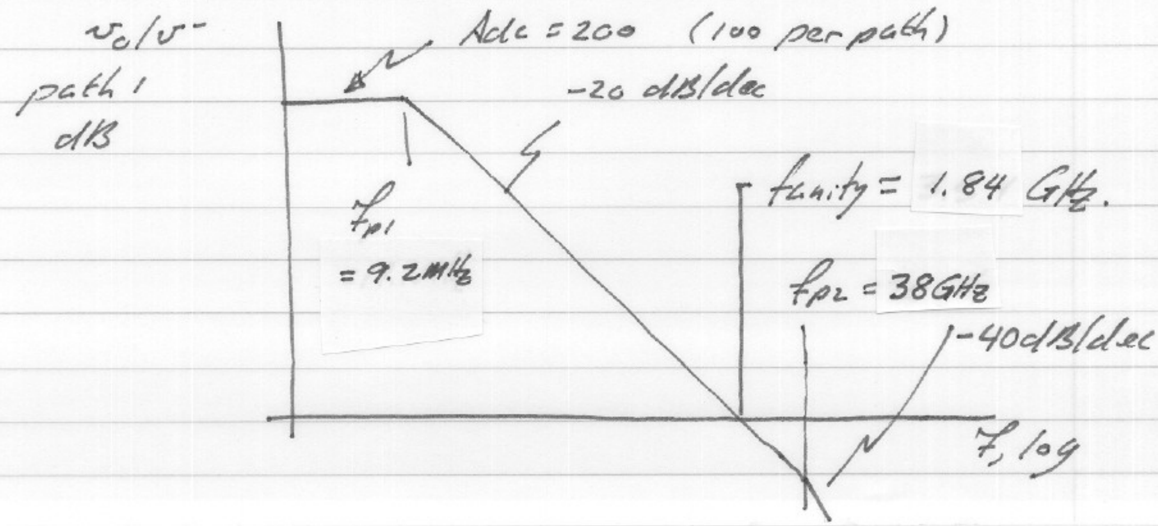
$\underline{a_2 = \text{sum of terms} = 7.26 \cdot 10^{-20} \sec^2 = (0.27ns)^2}$

SPA:

$f_{p1} \simeq 1/2\pi a_1 = 1/2\pi(17ns) = 9.2\ MHz$

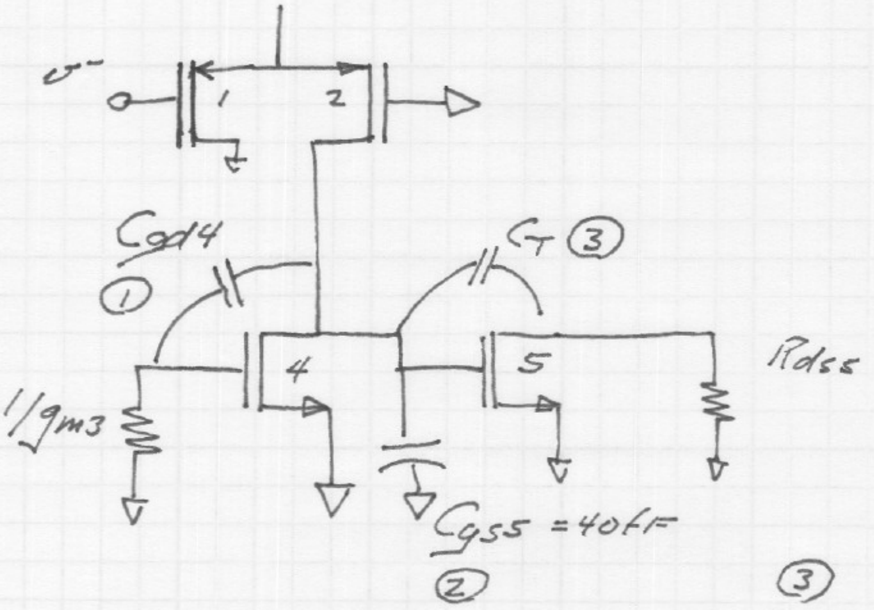
SPA works.

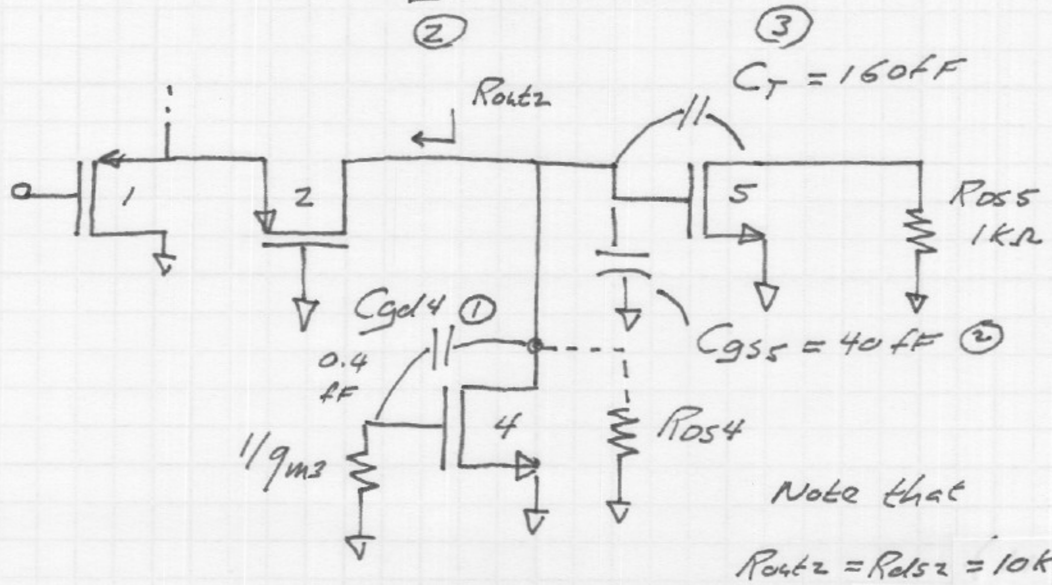
$f_{p2} \cong a_1/2\pi a_2 = 37.5\ GHz$



HF Analysis; path 2

$C_T = 160fF$



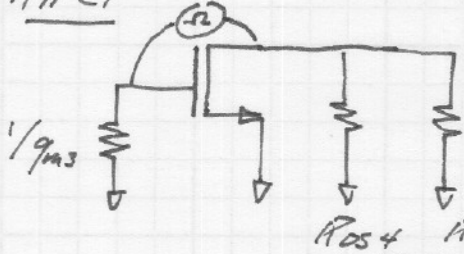


Note that

$R_{out2} = R_{ds2} = 10k\Omega$

now find $a_1 = R_{11}^0 C_1 + R_{22}^0 C_2 + R_{33}^0 C_3$

$\underline{R_{11}^0 C_1}$



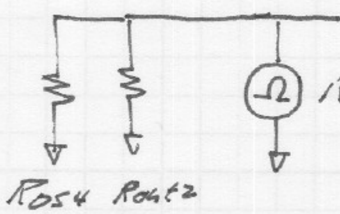
$\underbrace{\quad}_{R_x = 5k\Omega}$

$R_{11}^0 C_1 = 0.4 fF \cdot 10.5 k\Omega = 4.2 ps$

$R_{11}^0 = (1/g_{m3})(1 + g_{m4} R_x) + R_x$

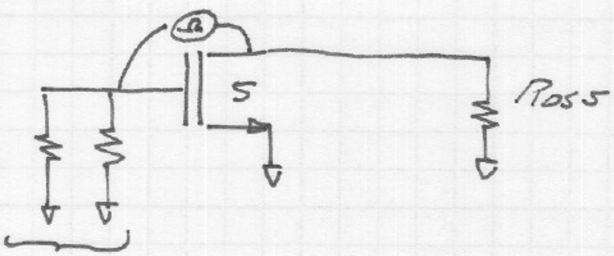
$= 10.5 k\Omega$

$\underline{R_{22}^0 C_2} = 5k\Omega \cdot 40 fF = 200ps$



$R_{22}^0 = R_{os4} \,//\, R_{out2} = 5k\Omega$

$\underline{R_{33}^0 C_3} = 106 k\Omega \cdot 160 fF = 17 ns$



$R_x = R_{os2} \,//\, R_{os4}$

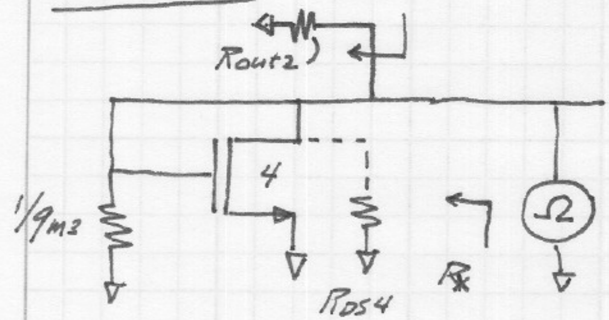
$R_{33}^0 = R_x (1 + A_{v5}) + R_{os5}$

$= 106 k\Omega$

a_1 = sum of these = 17.2 ns $\Leftarrow$ same as for other path.

$$a_2 = R_{11}^{o} C_1 C_2 R_{22}' + R_{11}^{o} C_1 C_3 R_{33}' + R_{22}^{o} C_2 C_3 R_{33}^{2}$$

$$\underline{R_{11}^{o} C_1 C_2 R_{22}'} = 10.5\,k\Omega \cdot 0.4\,fF \cdot 40\,fF \cdot 238\,\Omega = 4.0 \cdot 10^{-23}\ sec^2$$



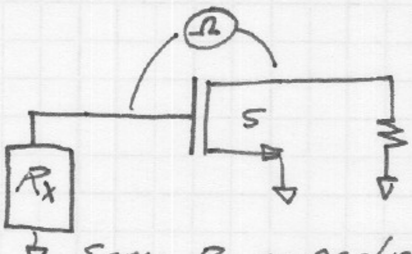
$$R_{22}' = R_x = R_{out2} \,\|\, \frac{1}{g_{m3}} \,\|\, \frac{1}{g_{m4}} \,\|\, R_{DS4}$$

$$= 238\,\Omega$$

$$\underline{R_{11}^{o} C_1 C_3 R_{33}'} = 10.5\,k\Omega \cdot 0.4\,fF \cdot 160\,fF \cdot 6\,k\Omega = 4.03 \cdot 10^{-21}\ sec^2$$

$$R_{33}' = R_x(1 + g_{m5} R_{DS5}) + R_{DS5}$$

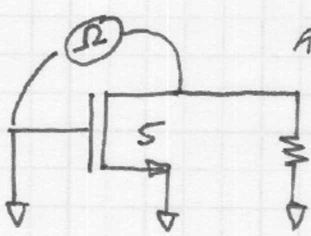
$$= 6\,k\Omega$$



Same R_x as earlier

$$\underline{R_{22}^{o} C_2 C_3 R_{33}^{2}} = 5\,k\Omega \cdot 40\,fF \cdot 160\,fF \cdot 1\,k\Omega = 3.2 \cdot 10^{-20}\ sec^2$$

$$R_{33}^{2} = R_{DS5} = 1\,k\Omega$$



$$\underline{a_2 = \text{sum of terms} = 3.6(10^{-20})\ sec^2 = (190\,ps)^2}$$

$f_{p1} \cong 1/2\pi a_1 = 9.2\ MHz$

$f_{p2} \cong a_1/2\pi a_2 = 76\ GHz.$

assuming SPA

Note that both paths have the same dominant pole, but secondary pole is at higher frequency in path 2.