EEC 210 | Solution to HW #7

(7.1) ① Similar to GHLom 7.1 but replace BJTs with MOS Transistors

$g_m = \sqrt{2(60)\left(\frac{100}{1.6}\right)(500\,\mu A)} = 1.9\,mA/V$; $A_v \simeq -g_m R_L = -g_m(5k) = \boxed{-9.7}$

$f_T = g_m/[2\pi(C_{gs}+C_{gd})]$; $C_{gsi} = 2/3\, W\cdot L_{eff}\, C_{ox}' = 2/3(100)(1.6)\,C_{ox}'$

$C_{gsOL} = C_{gdOL} = W\cdot L_d \cdot C_{ox}' = 100(0.2)\,C_{ox}'$

$$C_{ox}' = \frac{1.9\,mA/V}{2\pi(106.7+20+20)\,3GHz} = 0.7\,fF/\mu^2$$

$C_{gs} = (106.7+20)\,0.7 = 89\,fF$; $C_{gd} = 20(0.7) = 14\,fF$

(a) Use Miller Effect for $|p_1| = \dfrac{1}{2\pi(R_S)[C_{gs}+C_{gd}(1-A_v)]} = \dfrac{1}{2\pi(10k)[89+14(10.7)]}$

$= \boxed{67\,MHz}$

(b) DO NOT use Miller Effect to calculate 2nd POLE!

From EQ 7.26, $|p_2| = \dfrac{1}{2\pi p_1}\,\dfrac{1}{R_L R_S C_{gd} C_{gs}} = \dfrac{1}{2\pi(2\pi\times 67meg)(5k)(10k)(14f)(89f)}$

$= \boxed{6\,GHz}$

SPICE gives 63 MHz and 4.5 GHz, (It doesn't zero Cdb, as I did above)

(7.14) ② The given Cox' here is the same as that calculated in ①.

So the result here is the same as in ① except that Cdb is included here

$V_O = 10 - 0.5(5k) = 7.5V$; $C_{db0} = 5(100)(0.4) + 100(0.4) = 240\,fF$

$C_{db} = 240/\sqrt{1+7.5/0.6} = 65\,fF$

So the output time constant $= 5K(65fF) = 0.3\,ns$

The time constant in ① $= 1/2\pi(67\,MHz) = 2.4\,ns$

$f_{-3dB} = \dfrac{1}{2\pi(2.7ns)} = \boxed{59\,MHz}$

(7.26) ③ Iterate to find bias current, Start w/ $V_{ov3} = 0$

Then $I_3 \simeq (10-V_t)/30K = 9/30K = 300\,\mu A$; $V_{ov3} = \sqrt{\dfrac{2(300)}{60\cdot 100/(2-0.4-1)}} = 0.24V$

Then $I_3 \simeq (10-1-0.24)/30k \simeq 290\,\mu A$

V_{ov3} still $= 0.24V$ so this is close enough

Now $V_{DS2} = 10V$, $V_{DS3} = 1.24V \rightarrow \Delta V_{DS} = 8.8V \rightarrow I_1 = I_2 = 290\left(1+\frac{8.8}{100}\right) = 315\,\mu A$

$g_{m1} = \sqrt{2(20)(200/0.6)\,315} = 2.0\,mA/V$; $r_{o1} = 50/315 = 160\,K\Omega$

$g_{m2} = \sqrt{2(60)(100/0.6)\,315} = 2.5\,mA/V$; $r_{o2} = 100/315 = 320\,K\Omega$

$g_{m3} = \sqrt{2(60)(100/0.6)\,290} = 2.4\,mA/V$; $r_{o3} = 100/290 = 340\,K\Omega$

(a) $A = -(1/g_{m1})\,g_{m1}(r_{o1}\|r_{o2}) = -160K\|320K \simeq \boxed{-110\,K\Omega}$

$C_{gs1} = 2/3(200)(0.6)(0.7) + 200(0.2)(0.7) = 84\,fF$

$R(C_{gs1}) = 1/g_{m1} = 500\,\Omega$; $T_{gs1} = (0.084)(0.5) = 0.04\,ns$ (very small)

$C_{db01} = 5(200)(0.2) + 200(0.2) = 240\,fF$

$C_{db02} = 5(100)\,0.4 + 100(0.4) = 240\,fF$

So $C_{db1} = C_{db2} = \dfrac{240}{\sqrt{1+10/0.6}} \simeq 57\,fF$

Also $R(C_{db1}) = R(C_{db2}) = r_{o1}\|r_{o2} = 110\,K\Omega$

$T_{db1-2} = 2(0.057)\,110K = 12.5\,ns$

See EQ 7.117

$C_{gd2} = W L_d C_{ox}' = 100(0.2)(0.7) = 14\,fF$

$R(C_{gd2}) = (1/g_{m3})\|r_{o3}\|30K + r_{o1}\|r_{o2} + g_{m2}\left[\frac{1}{g_{m3}}\|r_{o3}\|30K\right][r_{o1}\|r_{o2}]$

$\simeq 2(r_{o1}\|r_{o2}) = 220\,K\Omega$; $T_{gd2} = 0.014(220) = 3\,ns$

$C_{gd1} = W L_d C_{ox} = 200(0.2)(0.7) = 28\,fF$

$R(C_{gd1}) = 1/g_{m1} + r_{o1}\|r_{o2} + (1/g_{m1})\,g_{m1}(r_{o1}\|r_{o2})$

$\simeq 2(r_{o1}\|r_{o2}) = 220\,K\Omega$; $T_{gd1} = 0.028(220) = 6.2\,ns$

So $f_{-3dB} \simeq 1/(2\pi\,\Sigma T) = 1/(2\pi(6.2+12.5+3)) = \boxed{7.3\,MHz}$

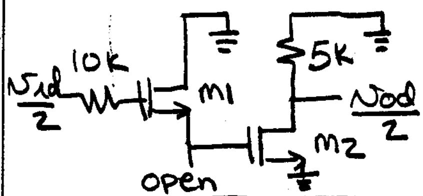
Note that none of the time constants dominates here

(3b) $C_{gd1} = 20pF + 28fF \simeq 20pF$; $R(C_{gd1})$ still $= 220k$ } $\tau = 20(220) = 4400$ ns (dominant!)

$f_{-3dB} \simeq \frac{1}{2\pi(4400\,ns)} = \boxed{36\ KHz}$

(7.31) (4) Similar to GHLM 7.31 except replace all BJT with NMOS. Current source in tail of M2 & M3 is ideal; therefore, cm gain = 0 → use differential half ckt

(a)



M1 = source follower with perfect current source, $\lambda = 0$, and no body effect. → Gain = 1

M2 = CS Amp

$\frac{V_{od}}{V_{id}} = -g_{m2}(5K) = \boxed{-9.6}$

$g_{m1} = \sqrt{2(60)(100/1.6)(10)} = 270\,\mu A/V$

$g_{m2} = \sqrt{2(60)(100/1.6)(500)} = 1.9\,mA/V$

(b) Since M1 is an ideal source follower, its gain = 1. Therefore, the voltage across C_{gs1} doesn't change. So ignore C_{gs1}. Note that if you include C_{gs1}, ZVTC only predicts the pole. (It ignores the zero.)

$C_{gd1} = W L_d C_{ox}' = 100(0.2)(0.7) = 14fF$
$R(C_{gd1}) = 10K\Omega$; $\tau_{gd1} = 0.014(10) = 0.14$ ns

$C_{sbo1} = 5(100)(0.4) + 100(0.4) = 240fF$; Need DC voltage at source of M1
$V_{S1} = 0 - V_{t1} - V_{ov1}$; $V_{ov1} = \sqrt{2(10)/(60 \cdot 100/1.6)} = 0.07$ V
$V_{S1} = 0 - 1 - 0.07 = -1.07$ V
$C_{sb1} = 240/\sqrt{1 + (-1.07 - (-6))/0.6} = 80fF$
$R(C_{sb1}) = 1/g_{m1} = 3.7K\Omega$; $\tau_{csb1} = 0.08(3.7) = 0.30$ ns

$C_{gs2} = 2/3(100)(1.6)(0.7) + 100(0.2)(0.7) \simeq 90fF$
$R(C_{gs2}) = 1/g_{m1} = 3.7K\Omega$; $\tau_{cgs2} = 0.09(3.7) = 0.33$ ns

$C_{dbo2} = 5(100)(0.4) + 100(0.4) = 240fF$; Need DC V_{D2}
$V_{D2} = 6 - 5K(0.5mA) = 3.5$ V
$C_{db2} = 240/\sqrt{1 + (3.5+6)/0.6} \simeq 60fF$
$R(C_{db2}) = 5K\Omega$; $\tau_{db2} = 0.06(5K) = 0.30$ ns

$C_{gd2} = W L_d C_{ox}' = 100(0.2)(0.7) = 14fF$
$R(C_{gd2}) = 1/g_{m1} + 5K + g_{m2}(1/g_{m1})5K = 44K\Omega$; $\tau_{gd2} = 0.014(44) = 0.62$ ns

$f_{-3dB} \simeq 1/[2\pi(0.14 + 0.30 + 0.33 + 0.30 + 0.62)] = \boxed{94\ MHz}$

COMMENT: In working ZVTC problems, it pays to be careful, organized, & neat.