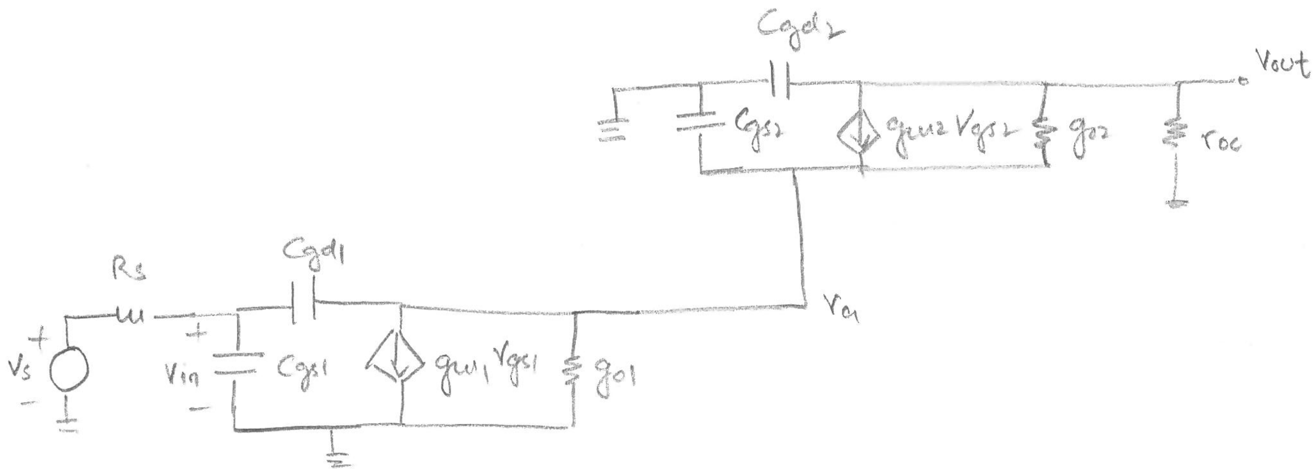
ECE Homework #11 Solutions
(Farhan Rana)

11.1

a)



b) $g_m \cong \sqrt{2 k_n I_D} = .0057 \text{ S}$ $\qquad g_o \cong \lambda_n I_D = 8\times 10^{-5} \text{ S}$

g_m is $\sim$ 70 times larger than g_o

c) $$\frac{V_{out}}{r_{oc}} + (V_{out} - V_a) g_{o2} - g_{m2} V_a + V_{out}\, j\omega C_{gd2} = 0$$

$$\Rightarrow \frac{V_{out}}{V_a} = \frac{g_{m2} + g_{o2}}{\frac{1}{r_{oc}} + g_{o2} + j\omega C_{gd2}} \approx \frac{g_{m2}}{\frac{1}{r_{oc}} + g_{o2} + j\omega C_{gd2}} = \frac{g_{m2}(r_{oc} \| r_{o2})}{1 + j\omega C_{gd2}(r_{oc} \| r_{o2})} = H_2(\omega)$$

d) see attached plot.

e) $$V_a g_{o1} + g_{m1} V_{in} + j\omega C_{gd1}(V_a - V_{in}) + V_a j\omega C_{gs2} + g_{m2} V_a + (V_a - V_{out}) g_{o2} = 0$$

$$\Rightarrow \frac{V_a}{V_{in}} = \frac{-g_{m1} + j\omega C_{gd1}}{g_{o1} + g_{o2} + g_{m2} + j\omega (C_{gd1} + C_{gs2}) - g_{o2} H_2(\omega)} = H_1(\omega).$$

f) See attached plot.

g) $$\frac{V_{in} - V_s}{R_s} + V_{in} j\omega C_{gs1} + (V_{in} - V_a) j\omega C_{gd1} = 0.$$

$$\frac{V_{in}}{V_s} = \frac{1}{1 + j\omega (C_{gs1} + C_{gd1}) R_s - j\omega C_{gd1} R_s H_1(\omega)} = H_0(\omega).$$

h) See the attached plot

i). $|H_2(\omega)|^2$ has a 3dB freq of ~ 2.5 GHz.

$|H_1(\omega)|^2$ has a 3dB freq of ~ 1.58 GHz.

$|H_0(\omega)|^2$ has a 3dB freq of ~ 1.29 GHz.

So the first and the second stage limit the freq. bandwidth of the amplifier.

j) $$\frac{V_{out}}{V_s} = \frac{V_{out}}{V_a} \cdot \frac{V_a}{V_{in}} \cdot \frac{V_{in}}{V_s} = H_2(\omega) H_1(\omega) H_0(\omega) = H_T(\omega)$$

See the attached plot. The 3dB frequency for $|H_T(\omega)|^2$ is ~ 0.80 GHz.

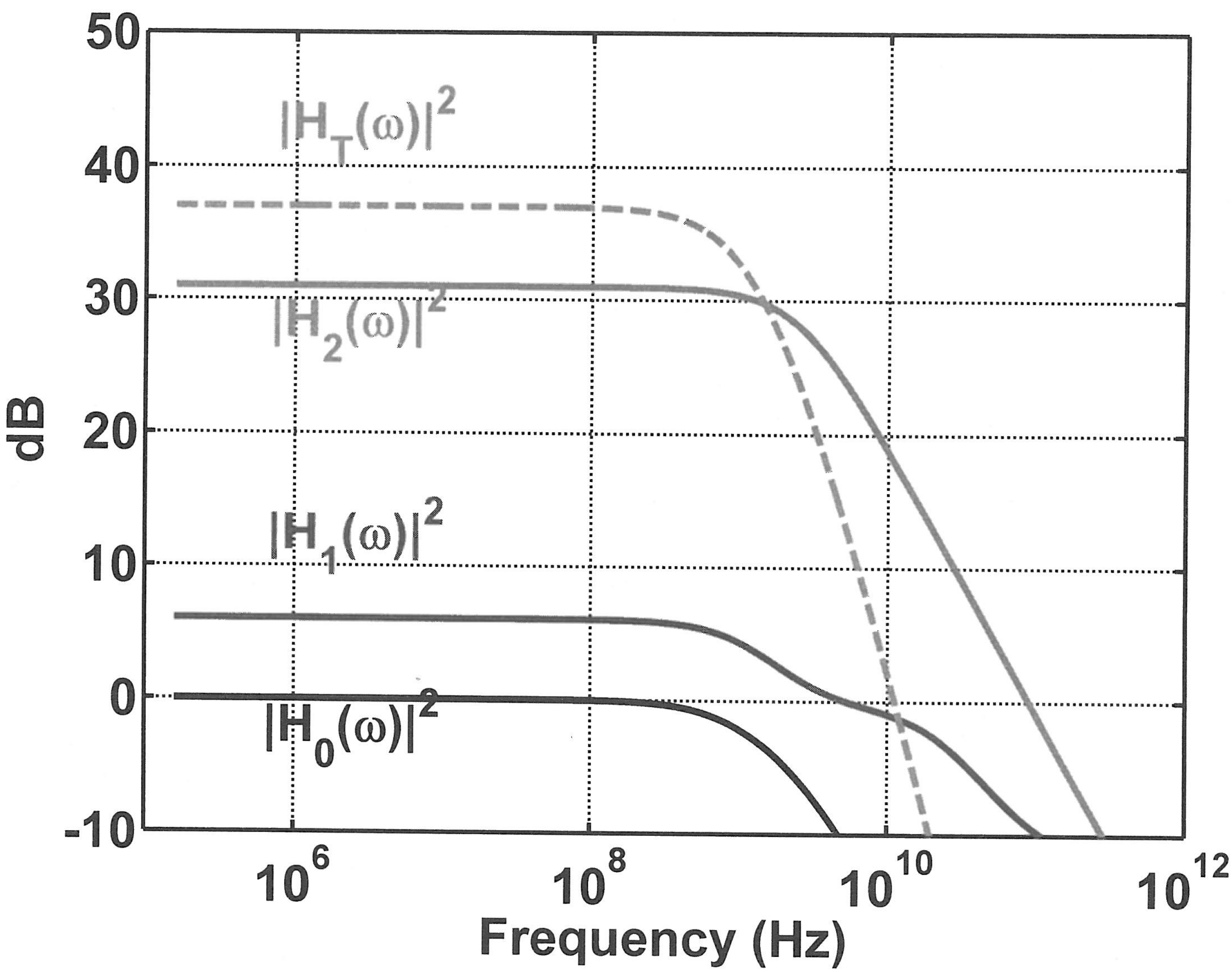
k) See the attached plot.

The 3dB freq. of the Common Source amp is ~ 0.18 GHz.

The Cascode has ~ 4.4 times larger 3dB frequency compared to the Common Source.

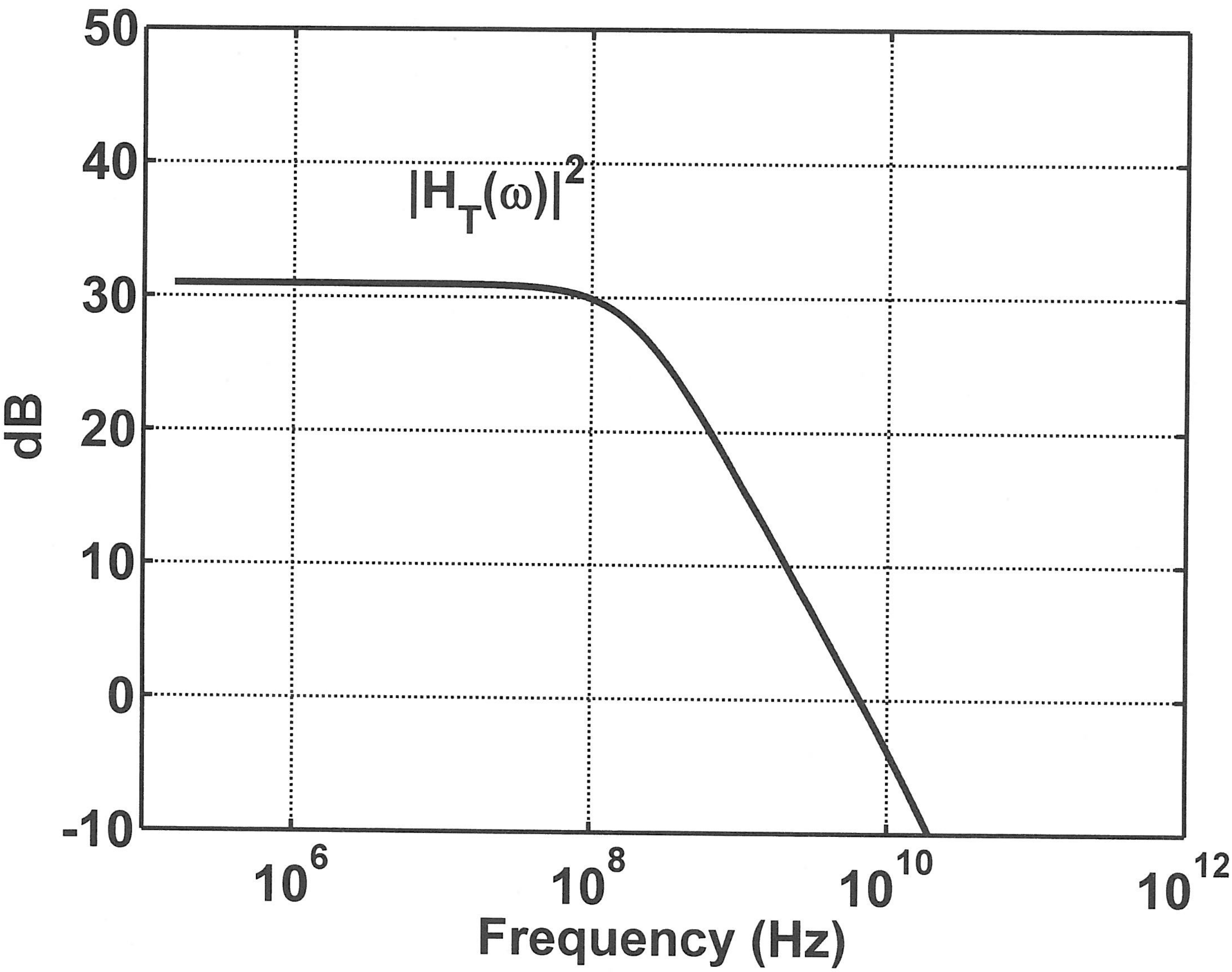
e) Common drain does not suffer from the Miller effect as there is no gain provided by this stage.

{ Cascode }



see (i)(j) for the 3dB frequencies of each curve

(Common Source)



11.2

a). As long as $V_{DS} > V_{GS} - V_{TN}$ for the NFET, or $V_{OUT} > V_{DD} - V_{TN}$, the NFET will be in saturation. In saturation,

$$C_L \frac{dV_{OUT}}{dt} = -I_D = -\frac{k_n}{2}\left(V_{DD} - V_{TN}\right)^2$$

$$\Rightarrow V_{OUT}(t) = V_{OUT}(t=0) - \frac{k_n}{2C_L}\left(V_{DD} - V_{TN}\right)^2 t$$

$$= V_{DD} - \frac{k_n}{2C_L}\left(V_{DD} - V_{TN}\right)^2 t$$

The time it takes for the output to reach $V_{DD} - V_{TN}$

is $t_1 = \frac{2C_L}{k_n} \frac{V_{TN}}{\left(V_{DD} - V_{TN}\right)^2}$

For $t > t_1$, NFET will be in the linear region, where,

$$C_L \frac{dV_{OUT}}{dt} = I_D = -k_n\left(V_{DD} - V_{TN} - \frac{V_{OUT}}{2}\right)V_{OUT}$$

$\left\{ \begin{array}{l} \text{boundary condition} \\ V_{OUT}(t=0) = V_{DD} - V_{TN}. \end{array} \right.$

$$\int_{V_{DD}-V_{TN}}^{0.1V_{DD}} \frac{dV_{OUT}}{\left(2\left(V_{DD}-V_{TN}\right) - V_{OUT}\right)V_{OUT}} = -\frac{k_n t}{2C_L}$$

$$\frac{1}{2\left(V_{DD}-V_{TN}\right)} \log\left[\frac{0.1V_{DD}}{2\left(V_{DD}-V_{TN}\right) - 0.1V_{DD}}\right] = -\frac{k_n t}{2C_L}$$

$$t = -\frac{2C_L}{k_n\left(V_{DD}-V_{TN}\right)} \times \frac{1}{2}\log\left[\frac{0.1V_{DD}}{2\left(V_{DD}-V_{TN}\right) - 0.1V_{DD}}\right].$$

$$\text{Total time} = \frac{2C_L}{k_n\left(V_{DD}-V_{TN}\right)}\left\{\frac{V_{TN}}{V_{DD}-V_{TN}} - \frac{1}{2}\log\left[\frac{0.1V_{DD}}{2\left(V_{DD}-V_{TN}\right) - 0.1V_{DD}}\right]\right\}.$$

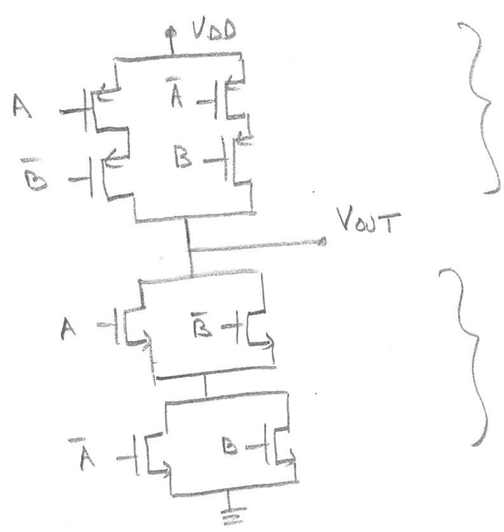
b) The expression for fall time will be the same as in part (a) if we replace k_n in there by $\frac{k_n}{2}$ because two NFETS in series with the same gate voltage is like one longer NFET that is twice as long.

c) If we consider two NFETS as one longe FET then the bottom FET never operates in saturation. It always operates in the linear region.

d) Yes. The top FET goes from saturation into the linear region when $V_{OUT} < V_{DD} - V_{TN}$.

11.3.

$A \oplus B = A\bar{B} + \bar{A}B$. So the pull-up network could be:



The pull-down network is just the duel of it.

We will need to generate $\bar{A}$ and $\bar{B}$ using inverters. So we will need total of 12 FETs.