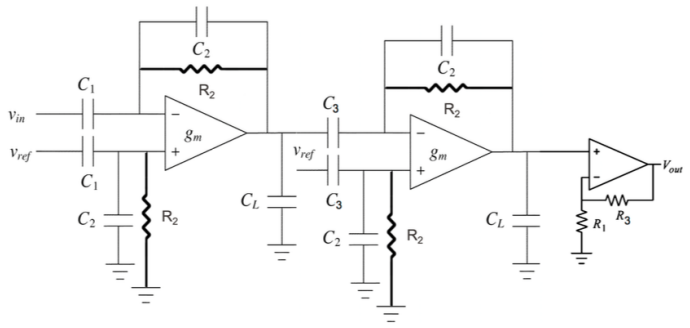
NX-422 EXERCISE 3 – Implantable Electronics
Solutions

1. Let's check the details of the three-stage neural amplifier.



(a) The equation for the overall mid-band gain:

$$|\mathbf{A_V}|_{\mathbf{3-Stage}} = |\mathbf{A_{V1}} \times \mathbf{A_{V2}} \times \mathbf{A_{V3}}| = \left(\frac{\mathbf{C_1}}{\mathbf{C_2}}\right) \times \left(\frac{\mathbf{C_3}}{\mathbf{C_2}}\right) \times \left(\frac{\mathbf{R_1 + R_3}}{\mathbf{R_1}}\right)$$

(b) Assuming $\mathrm{C_2 = C_u}$, we will find the values of $\mathrm{C_1}$ and $\mathrm{C_3}$ in terms of $\mathrm{C_u}$. Ignore $\mathrm{C_L}$, and assume $\mathrm{R_1}$=40kΩ and $\mathrm{R_3}$=60kΩ. For our calculations, we are asked to have a total mid-band gain of 1000 and minimize the chip area by minimizing the total capacitance.

Let's start:

$\mathbf{C_2 = C_u}$ assume $\mathbf{C_1 = M \times C_u}$ and $\mathbf{C_3 = N \times C_u}$

We know that R_1=40kΩ and R_3=60kΩ. Hence, $\frac{\mathbf{R_1+R_3}}{\mathbf{R_1}} = \frac{\mathbf{100k\Omega}}{\mathbf{40k\Omega.}} = \mathbf{2.5}$.

$$|\mathbf{A_V}|_{\mathbf{3-Stage}} = \mathbf{1000} \rightarrow \left(\frac{\mathbf{C_1}}{\mathbf{C_2}}\right) \times \left(\frac{\mathbf{C_3}}{\mathbf{C_2}}\right) = \frac{\mathbf{1000}}{\mathbf{2.5}} = \mathbf{400 = M \times N}$$

Total capacitance excluding $\mathrm{C_L}$ is

$$\mathbf{= 2C_1 + 2C_2 + 2C_3 + 2C_2 = 2 \times (M + N + 2) \times C_u}$$

Area $\propto \mathbf{2 \times (M + N + 2) \times C_u}$

$$\mathbf{2 \times (M + N + 2) \times C_u = 2 \times \left(M + \frac{400}{M} + 2\right) \times C_u = f(M)}$$

To minimize the total capacitance and area $\frac{df}{dM} = \mathbf{0} \rightarrow \mathbf{1 - \frac{400}{M^2} = 0}$
$\rightarrow \mathbf{M_{opt} = 20}$

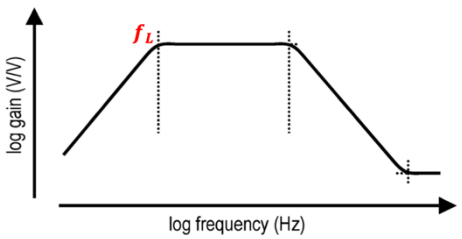
$\rightarrow \mathbf{C_1 = 20C_u}$ and $\mathbf{C_3 = \frac{400}{20} C_u = 20C_u}$

(c) The amplifier's bandwidth is set by the first stage and $C_2 = 400\text{fF}$.

$$\mathbf{f_L = \frac{1}{2 \times \pi \times R_2 \times C_2} = 1\ Hz}$$

$$\mathbf{C_2 = C_u = 400\ fF}$$

$$\mathbf{R_2 = \frac{1}{2 \times \pi \times 400 \times 10^{-15}} = 3.98 \times 10^{11}}$$
$$\mathbf{= 0.398\ T\Omega}$$



2. We will draw the drain current of an NMOS (I_D) as a function of V_{GS} where V_{GS} varies from $0 \rightarrow 3V$.

- $\frac{W}{L} = \frac{50}{0.5}, V_{DS} = 3\ V, V_{TH} = 0.7\ V,\ \mu_n C_{ox} = 50\ \mu A/V^2$ and $\lambda = 0$.

Saturation condition: $\mathbf{V_{DS} > V_{GS} - V_{TH}}$

$3V > (0 \rightarrow 3V) - 0.7V$, which means that the assumption is correct. The transistor is in saturation.

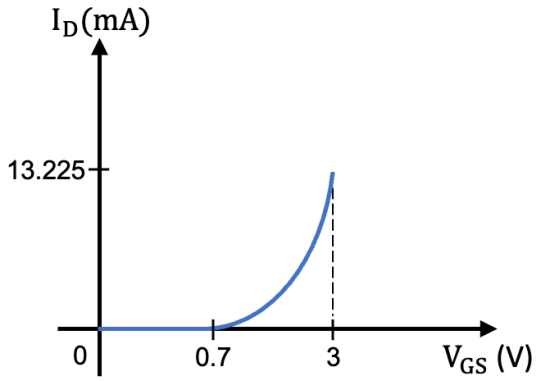
The drain current equation for the saturation ($\lambda = 0$):

$$\mathbf{I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2}$$

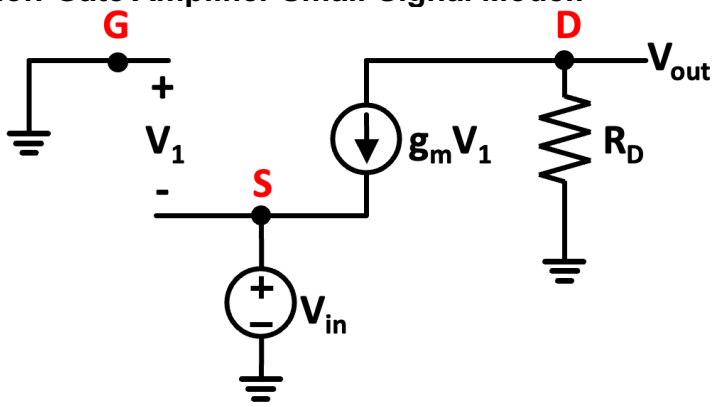
$$I_D = \frac{1}{2} \times (50\frac{\mu A}{V^2}) \times \frac{50}{0.5} \times (V_{GS} - 0.7)^2$$

$$I_D = 2.5\frac{mA}{V^2}(V_{GS} - 0.7)^2$$

At $\mathbf{V_{GS} = 3V \rightarrow I_D = 13.225mA}$



3. **(a) Common-Gate Amplifier Small-Signal Model:**



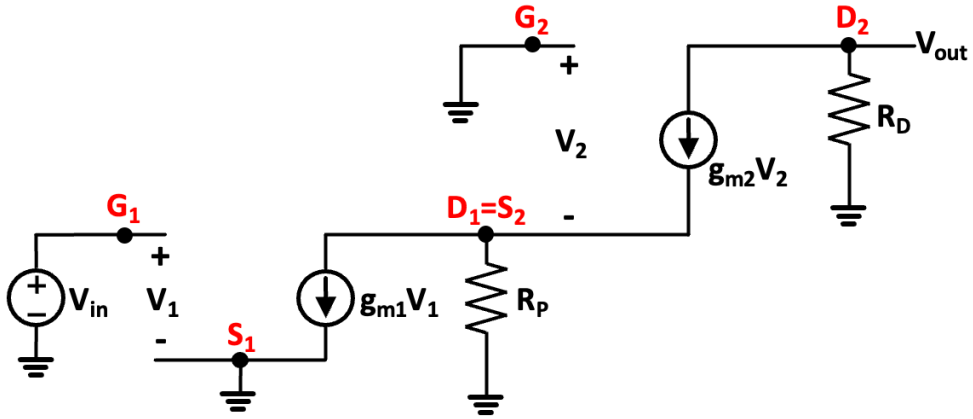
$$V_{GS} = V_1 = -V_{in}$$

$$V_{out} = -g_m V_1 \times R_D$$

$$V_{out} = -g_m \times (-V_{in}) \times R_D$$

$$\boldsymbol{A_V = \frac{V_{out}}{V_{in}} = g_m \times R_D}$$

(b) Cascode Amplifier Small-Signal Model:



$$-V_2 = (g_{m2}V_2 - g_{m1}V_1) \times R_P$$

$$V_2 \times (g_{m2}R_P + 1) = g_{m1}V_1 \times R_P$$

$$V_2 = V_1 \times \left(\frac{g_{m1}R_P}{g_{m2}R_P + 1}\right)$$

$$V_{out} = -g_{m2}V_2 \times R_D$$

$$V_{out} = -g_{m2}R_D \times V_1 \times \left(\frac{g_{m1}R_P}{g_{m2}R_P + 1}\right)$$

$$\boldsymbol{V_{in} = V_1}$$

$$\boldsymbol{A_V = \frac{V_{out}}{V_{in}} = -\frac{g_{m1}g_{m2}R_P R_D}{g_{m2}R_P + 1}}$$