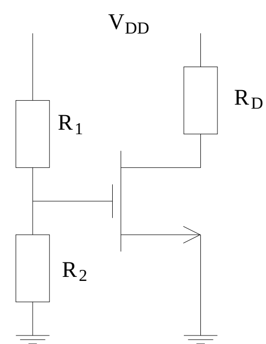
EE 321 Analog Electronics, Fall 2009
Exam 3 November 18, 2009

Rules: This is a open book test. You may use the textbook as well as your notes. The exam will last 50 minutes. Each problem counts equally toward your grade. None of the problems require long calculations.

Use the following parameters in this exam, unless otherwise stated: $k_n' \frac{W}{L} = 1\,\text{mA/V}^2$, $|V_t| = 1\,\text{V}$, and $V_{DD} = +5\,\text{V}$.



MOSFETs at DC

1. **In the circuit above, select R_1, R_2, and R_D such that $I_D = 1\,\text{mA}$ and $V_D = 3\,\text{V}$.**

$$R_D = \frac{V_{DD} - V_D}{I_D} = \frac{5-3}{1} = 2\,\text{k}\Omega$$

$$I_D = \frac{k_n'}{2}\frac{W}{L}(V_{GS} - V_t)^2$$

$$V_{GS} = \sqrt{\frac{I_D}{\frac{k_n'}{2}\frac{W}{L}}} + V_t$$
$$= \sqrt{\frac{1}{0.5}} + 1 = 2.41\,\text{V}$$

And we see that the circuit is in saturation mode as we assumed. Next choose $R_2 = 1\,\text{M}\Omega$, and

$$\frac{R_2}{R_1 + R_2} = \frac{V_{GS}}{V_{DD}}$$

$$R_1 = R_2\left(\frac{V_{DD}}{V_{GS}} - 1\right) = 1 \times 10^6 \left(\frac{5}{2.41} - 1\right) = 1.07\,\text{M}\Omega$$

2. **For the same circuit, if we set $\boldsymbol{V_G = 2\,\mathrm{V}}$ and $\boldsymbol{V_D = 0.1\,\mathrm{V}}$, what is the operating region, and what should be $\boldsymbol{R_D}$? (Be sure to make the reasonable simplification which makes the math much quicker). What is the effective drain to source resistance?**

   This circuit is in the triode region because $V_{DS} < V_{GS} - V_t$. First find the current

$$\begin{aligned} I_D =& k_n' \frac{W}{L} \left[(V_{GS} - V_t)\, V_{DS} - \frac{V_{DS}}{2} \right] \\ =& 1 \times \left[(2-1) \times 0.1 - \frac{0.1^2}{2} \right] \\ =& 0.095\,\mathrm{mA} = 95\,\mu\mathrm{A} \end{aligned}$$

   Then,

$$R_D = \frac{V_{DD} - V_D}{I_D} = \frac{5 - 0.1}{95 \times 10^{-6}} = 51.6\,\mathrm{k\Omega}$$

   Effective drain to source resistance is

$$R_{DS} = \frac{V_{DS}}{I_D} = \frac{0.1}{95 \times 10^{-6}} = 1.05\,\mathrm{k\Omega}$$

MOSFET amplifier

3. **Still for the same circuit, but now $\boldsymbol{V_{DD} = 10\,\mathrm{V}}$, determine the values of $\boldsymbol{V_G}$ and $\boldsymbol{R_D}$ to make it a common-source amplifier with a voltage gain of -10 and a maximum negative output swing of $1\,\mathrm{V}$ before entering saturation.**

   Hint: Because the swing in $\boldsymbol{v_g}$ is much smaller than the swing in $\boldsymbol{v_d}$ we ignore the former, and thus the bias point is simply $\boldsymbol{V_D = V_G - V_t + 1\,\mathrm{V} = V_G}$. Begin with the expression for the voltage gain in terms of bias values and find $\boldsymbol{V_D}$ directly from it. Then find $\boldsymbol{I_D}$, and then $\boldsymbol{R_D}$. This is the longest calculation of the exam, but still not long.

   Following the hint we write the voltage gain as

$$A_v = -\frac{2\,(V_{DD} - V_D)}{V_{GS} - V_t}$$

   But since $V_D = V_{GS}$ we can write

$$A_v = -\frac{2\,(V_{DD} - V_D)}{V_D - V_t}$$

$$A_v V_D - A_v V_t = -2V_{DD} + 2V_D$$

$$V_D\left(A_v-2\right)=-2V_{DD}+A_vV_t$$

$$V_D=\frac{-2V_{DD}+A_vV_t}{A_v-2}=\frac{-2\times 10-10\times 1}{-12}=2.5\,\mathrm{V}$$

Because $V_{GS}=V_{DS}$ the MOSFET is in saturation and we have

$$\begin{aligned}
I_D=&\frac{k_n'}{2}\frac{W}{L}\left(V_{GS}-V_t\right)^2\\
=&\frac{1}{2}\left(2.5-1.\right)^2\\
=&1.13\,\mathrm{mA}
\end{aligned}$$

Finally, the drain resistor is

$$R_D=\frac{V_{DD}-V_D}{I_D}=\frac{10-2.5}{1.13}=6.64\,\mathrm{k\Omega}$$

Amplifier input and output resistances

4. **A common source amplifier is biased such that $g_m=1\,\mathrm{mA/V}$, $R_G=1\,\mathrm{M\Omega}$ and $R_D=10\,\mathrm{k\Omega}$. Ignore channel-length modulation. What are the input and output resistances? What is the open-circuit voltage gain? What is the overall gain (source to load) if the input signal source has a output resistance of $100\,\mathrm{k\Omega}$ and the load is $R_L=5\,\mathrm{k\Omega}$.**

   This problem can be solved by examining Table 4.2 in the text book.

$$R_{\mathrm{in}}=R_G=1\,\mathrm{M\Omega}$$

$$R_{\mathrm{out}}=R_D=10\,\mathrm{k\Omega}$$

$$A_{vo}=-g_mR_D=-10^{-3}\times 10^4=10$$

$$\begin{aligned}
G_v=&-\frac{R_{\mathrm{in}}}{R_{\mathrm{in}}+R_{\mathrm{source}}}g_m\left(R_D||R_L\right)\\
=&-\frac{10^6}{10^6+10^5}10^{-3}\frac{1}{\frac{1}{10^4}+\frac{1}{5\times 10^3}}\\
=&-3.03
\end{aligned}$$