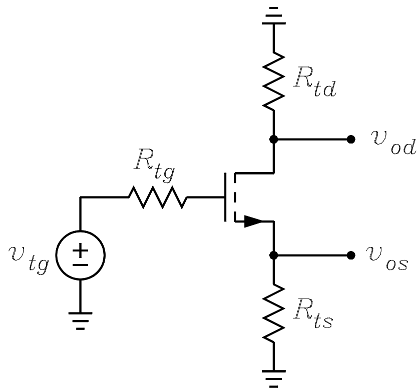
ECE3040 – Assignment 5

1. The figure shows the ac signal circuit for a combination common-source and common-drain amplifier.



   (a) Replace the MOSFET with its pi model. Assume that $r_0 = \infty$. Show that

$$\frac{v_{os}}{v_{tg}} = \frac{g_m R_{ts}}{1 + g_m R_{ts}} \qquad \frac{v_{od}}{v_{tg}} = \frac{-g_m R_{td}}{1 + g_m R_{ts}}$$

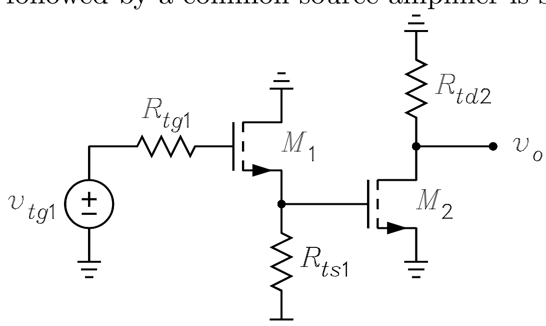
   Note that one gain is positive and the other is negative. If $R_{ts} = R_{td}$, the gains are equal but of opposite signs. In this case, the circuit is called a "phase inverter."

   (b) Replace the MOSFET with its T model. Assume $r_0 = \infty$. Show that

$$\frac{v_{os}}{v_{tg}} = \frac{R_{td}}{r_s + R_{ts}} \qquad \frac{v_{od}}{v_{tg}} = \frac{-R_{ts}}{r_s + R_{ts}}$$

   (c) Show that the answers are equivalent.

2. A common-drain amplifier followed by a common-source amplifier is shown.



   (a) Replace the MOSFETs with the pi models and show that

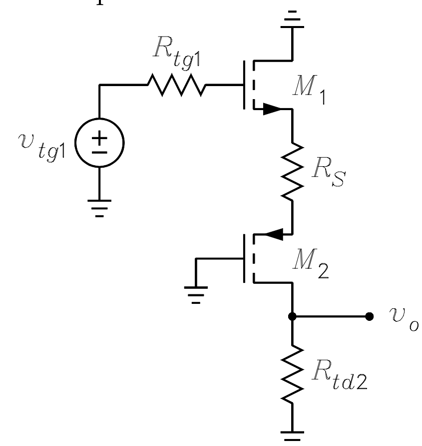
$$\frac{v_o}{v_{tg1}} = \frac{g_{m1}\left(r_{01} \| R_{ts1}\right)}{1 + g_{m1}\left(r_{01} \| R_{ts1}\right)} \times g_{m2} \times \left[-\left(r_{02} \| R_{td2}\right)\right]$$

   (b) Replace the MOSFETs with the T models and show that

$$\frac{v_o}{v_{tg1}} = \frac{r_{01} \| R_{ts1}}{r_{s1} + r_{01} \| R_{ts1}} \times \frac{1}{r_{s2}} \times \left[-\left(r_{02} \| R_{td2}\right)\right]$$

(c) Show that the two answers are equivalent.

3. The figure shows a common-drain amplifier followed by a common-gate amplifier. The small-signal models of the n-channel and the p-channel devices are identical.



(a) Assume that $r_0 = \infty$. Replace the MOSFETs with the pi models and show that $g_{m1}v_{gs1} = -g_{m2}v_{gs2}$, $v_{tg1} = v_{gs1} + g_{m1}v_{gs1}R_S - v_{gs2}$, and $v_o = -g_{m2}v_{gs2}R_{td2}$. Solve these equations to obtain

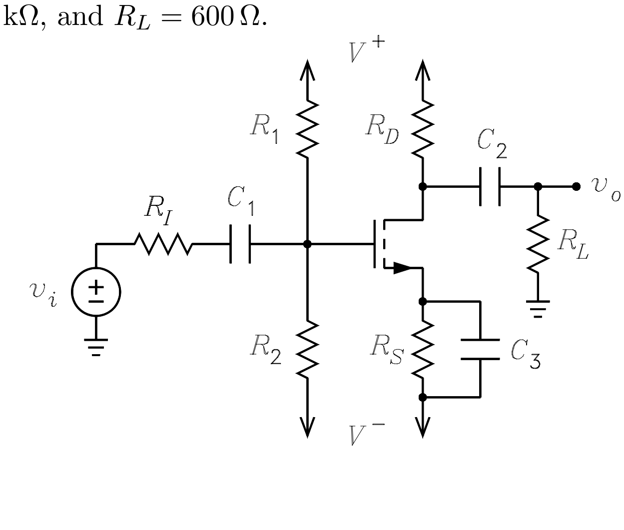
$$\frac{v_o}{v_{tg1}} = \frac{g_{m1}}{1 + g_{m1}R_S + g_{m1}/g_{m2}} \times R_{td2}$$

(b) Assume that $r_0 = \infty$. Replace the MOSFETs with the T models and show by inspection that

$$\frac{v_o}{v_{tg1}} = \frac{1}{r_{s1} + R_S + r_{s2}} \times R_{td2}$$

(c) Show that the answers are identical and explain which model makes this problem the simplest to solve.

4. The figure shows a common-source amplifier. It is given that $V^+ = +20\,\mathrm{V}$, $V^- = -20\,\mathrm{V}$, $K = 0.0015\,\mathrm{A/V}$, $V_{TH} = 1.75\,\mathrm{V}$, $r_0 = 40\,\mathrm{k\Omega}$, $R_I = 200\,\Omega$, $R_1 = 1\,\mathrm{M\Omega}$, $R_2 = 213.7\,\mathrm{k\Omega}$, $R_D = 7.2\,\mathrm{k\Omega}$, $R_S = 1.6\,\mathrm{k\Omega}$, and $R_L = 600\,\Omega$.



(a) Show that $I_D = 2.5\,\mathrm{mA}$ and $V_{DS} = 18\,\mathrm{V}$.

(b) Show that $A_v = v_o/v_i = -2.11$.

(c) Show that $r_{in} = 176.1\,\mathrm{M\Omega}$ and $r_{out} = 6.102\,\mathrm{k\Omega}$.

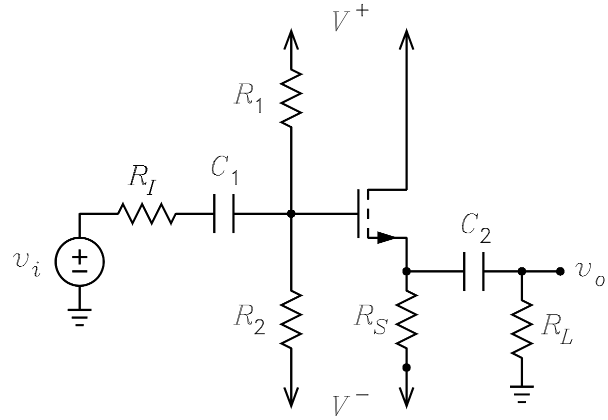
5. Let a common-drain stage be added between the drain of the MOSFET and the load as was done in the class notes. Assume that the second MOSFET is biased at the same current.

   (a) Show that $R_{S2} = 7.584\,\mathrm{k\Omega}$.

   (b) Show that the new voltage gain is $A_v = -16.02$.

   (c) Show that the new output resistance is $r_{out} = 248.1\,\Omega$.

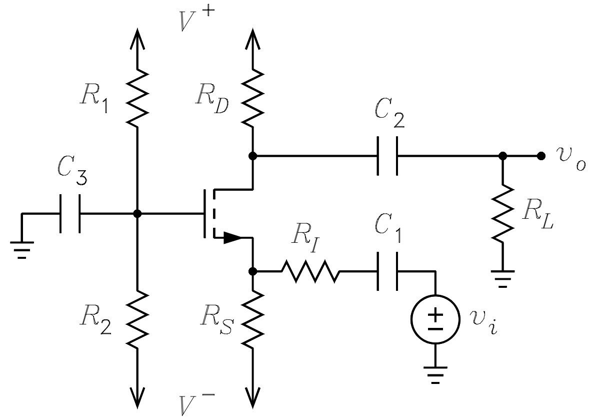
6. A common-drain amplifier is shown. It is given that $V^+ = +20\,\mathrm{V}$, $V^- = -20\,\mathrm{V}$, $K = 0.0015\,\mathrm{A/V}$, $V_{TH} = 1.75\,\mathrm{V}$, $r_0 = 40\,\mathrm{k\Omega}$, $R_I = 200\,\Omega$, $R_1 = 1\,\mathrm{M\Omega}$, $R_2 = 213.7\,\mathrm{k\Omega}$, $R_S = 1.6\,\mathrm{k\Omega}$, and $R_L = 600\,\Omega$. Note that I_D is the same as for problem 4.



   (a) Show that $A_v = v_o/v_i = 0.625$.

   (b) Show that $r_{in} = 176.1\,\mathrm{M\Omega}$ and $r_{out} = 221.1\,\Omega$.

7. A common-gate amplifier is shown. It is given that $V^+ = +20\,\mathrm{V}$, $V^- = -20\,\mathrm{V}$, $K = 0.0015\,\mathrm{A/V}$, $V_{TH} = 1.75\,\mathrm{V}$, $r_0 = \infty$, $R_I = 1\,\mathrm{k\Omega}$, $R_1 = 1\,\mathrm{M\Omega}$, $R_2 = 213.7\,\mathrm{k\Omega}$, $R_D = 7.2\,\mathrm{k\Omega}$, $R_S = 1.6\,\mathrm{k\Omega}$, and $R_L = 10\,\mathrm{k\Omega}$. Note that I_D is the same as for problem 4.

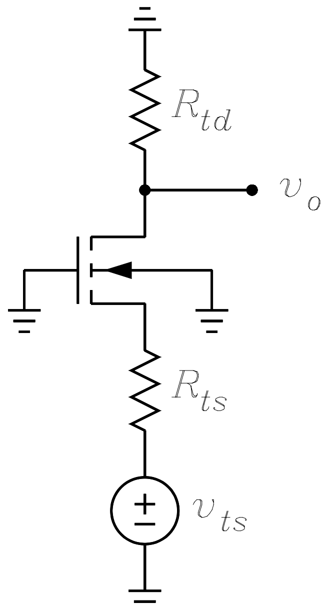


   (a) Show that $A_v = v_o/v_i = 2.949$.

   (b) Show that $r_{in} = 222.3\,\Omega$ and $r_{out} = 7.2\,\mathrm{k\Omega}$.

(c) If $R_I = 50\,\Omega$, show that the new gain is $A_v = 13.24$.

8. The figure shows the ac signal circuit of a common-gate amplifier with body effect. Assume that $r_0 = \infty$.



(a) Replace the MOSFET with its pi model and show that

$$\frac{v_o}{v_{ts}} = \frac{(g_m + g_{mb})\,R_D}{1 + (g_m + g_{mb})\,R_{ts}}$$

To show this, first show that $v_{gs} = -v_s$, $v_{bs} = -v_s$, $v_s = (g_m + g_{mb})\,v_{gs}R_{ts} + v_{ts}$ and that $i'_d = (g_m + g_{mb})\,v_{gs}$.

(b) Replace the MOSFET with its T model and show that

$$\frac{v_o}{v_{ts}} = \frac{R_D}{r_s \| r_{sb} + R_{ts}}$$

where $r_s = 1/g_m$ and $r_{sb} = 1/g_{mb}$.

(c) Show that the two answers are identical.