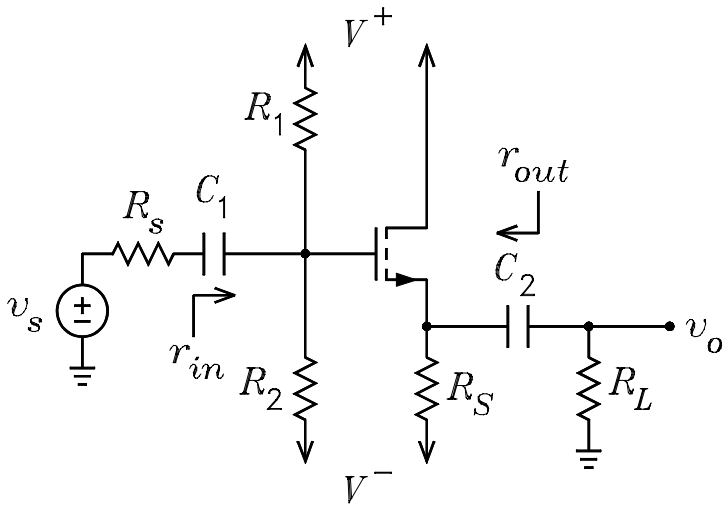Common-Drain Amplifier Example - Spring 2002
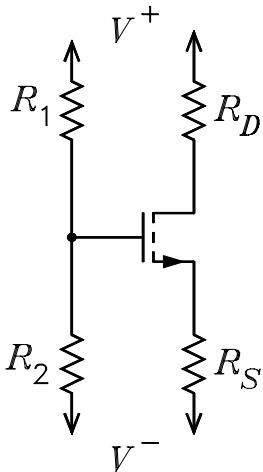
$K' := 0.002$ $W := 1$ $L := 1$ $V_{TO} := 1.75$ $\lambda := 0.016$ $\chi := 0$

$V_{plus} := 24$ $V_{minus} := -24$ $R_1 := 5 \cdot 10^6$ $R_2 := 1 \cdot 10^6$ Jaeger's notation

$R_S := 3 \cdot 10^3$ $R_L := 20 \cdot 10^3$ $R_s := 5 \cdot 10^3$ $R_p(x, y) := \dfrac{x \cdot y}{x + y}$

DC Bias Solution

$$V_{GG} := \frac{V_{plus} \cdot R_2 + V_{minus} \cdot R_1}{R_1 + R_2} \qquad V_{GG} = -16 \qquad V_{SS} := V_{minus} \qquad R_{SS} := R_S$$

$$V_1 := V_{GG} - V_{SS} - V_{TO} \qquad V_1 = 6.25$$

We neglect the Early effect, i.e. set $\lambda = 0$, to solve for the drain bias current.

$$K_0 := K' \cdot \frac{W}{L}$$

$$I_D := \frac{1}{2 \cdot K_0 \cdot R_S^2} \cdot \left(\sqrt{1 + 2 \cdot K_0 \cdot V_1 \cdot R_S} - 1 \right)^2 \qquad I_D = 1.655 \bullet 10^{-3}$$

$$V_D := V_{plus} \qquad\qquad V_D = 24 \qquad V_S := V_{minus} + I_D \cdot R_S \qquad V_S = -19.036$$

$$V_{DS} := V_D - V_S \qquad\qquad V_{DS} = 43.036$$

$$V_{GS} := V_{GG} - V_S \qquad V_{GS} = 3.036 \qquad\qquad V_{GS} - V_{TO} = 1.286$$

Because $V_{DS} > V_{GS} - V_{TO}$, the MOSFET is in the active or saturated state.

Here is an exact solution for the drain current. Note that MathCad requires numbers for everything except the variable being solved for. The drain-source voltage in the equation is $48 - I_D \cdot 13 \cdot 10^3$

$$I_D = \frac{1}{4 \cdot 10^{-3} \cdot \left[1 + 0.016 \cdot \left(48 - I_D \cdot 3 \cdot 10^3 \right) \right] \cdot 3000^2} \cdot \left[\sqrt{1 + 4 \cdot 10^{-3} \cdot \left[1 + \left[0.016 \cdot \left(48 - I_D \cdot 3 \cdot 10^3 \right) \right] \right] \cdot 6.25 \cdot 3000} - 1 \right]^2$$

.0017441295129196544703   This is the exact solution for I_D including the Early effect. We will use
                          the approximate solution for the ac analysis below.

$$\frac{I_D - .0017441295129196544703}{.0017441295129196544703} \cdot 100 = -5.135$$ This is the percentage error in neglecting the Early effect in
   solving for the drain current.

Now for the ac solution.
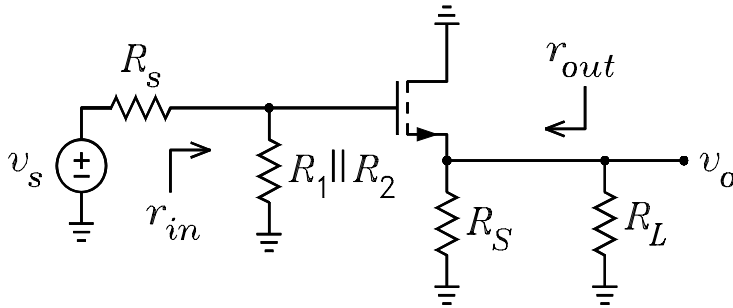
$$K := K_0 \cdot \left(1 + \lambda \cdot V_{DS}\right)$$

$$K = 3.377 \bullet 10^{-3}$$

$$g_m := \sqrt{2 \cdot K \cdot I_D}$$

$$g_m = 3.343 \bullet 10^{-3}$$

$$r_s := \frac{1}{g_m}$$

$$r_s = 299.135$$
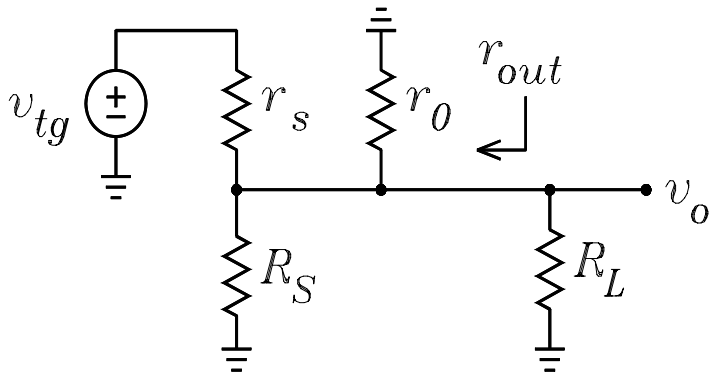
$$r'_s := \frac{r_s}{1 + \chi}$$

$$r'_s = 299.135$$

No body effect because the body lead is connected to the source lead. Thus $\chi = 0$ in the equations.

$$r_0 := \frac{\lambda^{-1} + V_{DS}}{I_D}$$

$$r_0 = 6.378 \bullet 10^4$$

$$v_s := 1$$

This makes the gain equal to v_o.

$$v_{tg} := v_s \cdot \frac{R_p\left(R_1, R_2\right)}{R_s + R_p\left(R_1, R_2\right)}$$

$$v_{tg} = 0.994$$

$$R_{tg} := R_p\left(R_s, R_p\left(R_1, R_2\right)\right)$$

$$R_{tg} = 4.97 \bullet 10^3$$

$$v_o := v_{tg} \cdot \frac{R_p\left(r_0, R_p\left(R_S, R_L\right)\right)}{r'_s + R_p\left(r_0, R_p\left(R_S, R_L\right)\right)}$$

$v_o = 0.888$ This is the voltage gain.

$$r_{out} := R_p\left(R_S, R_p\left(r'_s, r_0\right)\right)$$

$r_{out} = 270.857$

$$r_{in} := R_p\left(R_1, R_2\right)$$

$r_{in} = 8.333 \cdot 10^5$

An Alternate Solution using the Thevenin equivalent circuit looking into the source.
Note that $R_{td} = 0$ in the formulas for v_{soc} and r_{iso}.

$$v_{soc} := v_{tg} \cdot \frac{r_0}{r'_s + r_0}$$

$v_{soc} = 0.989$

$$r_{is} := R_p\left(r'_s, r_0\right)$$

$r_{is} = 297.738$

$$v_o := v_{soc} \cdot \frac{R_p\left(R_S, R_L\right)}{r_{is} + R_p\left(R_S, R_L\right)}$$

$v_o = 0.888$

$$r_{out} := R_p\left(r_{is}, R_S\right)$$

$r_{out} = 270.857$