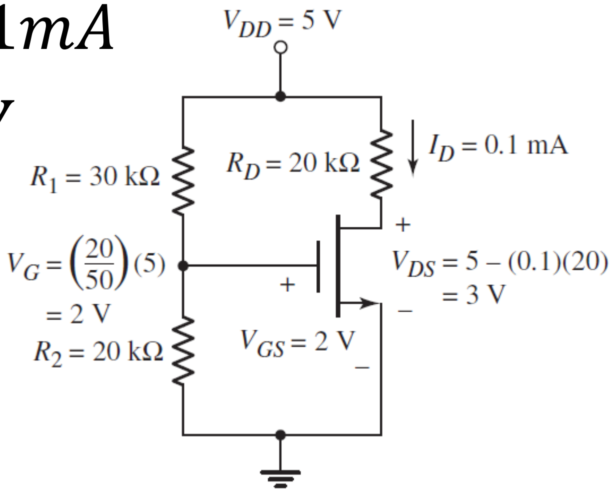
Numerical Problems

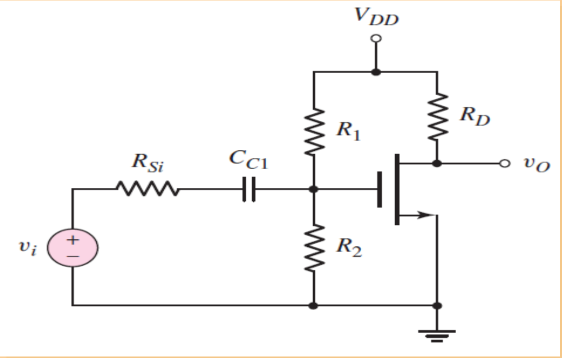
Problem: Calculate the drain current and drain-to-source voltage of a common source circuit with an n-channel enhancement-mode MOSFET. Find the power dissipated in the transistor

Large Signal analysis or DC analysis

$Given\ values: V_{TN} = 1V, K_n = 0.1mA/V^2$, λ=0.05 V^{-1}

- $V_G = V_{GS} = \left(\frac{R_2}{R_1+R_2}\right)V_{DD} = \left(\frac{20k}{30k+20k}\right)5 = 2V$
- $I_D = K_n(V_{GS} - V_{TN})^2 = 0.1m(2-1)^2 = 0.1mA$
- $\boldsymbol{V_{DS} = V_{DD} - I_D R_D} = 5 - 0.1m(20k) = 3V$
- Power dissipated:
  $P_T = I_D V_{DS} = 0.1m(3) = 0.3mW$
- To check if in saturation:
  $V_{DS(sat)} = V_{GS} - V_{TN} = 2 - 1 = 1V$
  $V_{DS} = 3V > V_{DS(sat)}$ Hence solution is valid.





Large Signal analysis or DC analysis

Solution (dc calculations): The dc or quiescent gate-to-source voltage is

$$V_{GSQ} = \left(\frac{R_2}{R_1 + R_2}\right)(V_{DD}) = \left(\frac{60}{140 + 60}\right)(3.3) = 0.99\ \text{V}$$

The quiescent drain current is

$$I_{DQ} = K_n(V_{GSQ} - V_{TN})^2 = (0.5)(0.99 - 0.4)^2 = 0.174\ \text{mA}$$

and the quiescent drain-to-source voltage is

$$V_{DSQ} = V_{DD} - I_{DQ}R_D = 3.3 - (0.174)(10) = 1.56\ \text{V}$$

Since $V_{DSQ} > V_{GSQ} - V_{TN}$, the transistor is biased in the saturation region.

Small-signal Voltage Gain: The small-signal transconductance g_m is then

$$g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{(0.5)(0.174)} = 0.590 \text{ mA/V}$$

and the small-signal output resistance is

$$r_o = \frac{1}{\lambda I_Q} = \frac{1}{(0.02)(0.174)} = 287 \text{ k}\Omega$$

The input resistance to the amplifier is

$$R_i = R_1 \| R_2 = 140 \| 60 = 42 \text{ k}\Omega$$

From Figure 4.15 and Equation (4.29), the small-signal voltage gain is

$$A_v = -g_m (r_o \| R_D)\left(\frac{R_i}{R_i + R_{Si}}\right) = -(0.59)(287\|10)\left(\frac{42}{42+4}\right)$$

$$A_v = -5.21$$

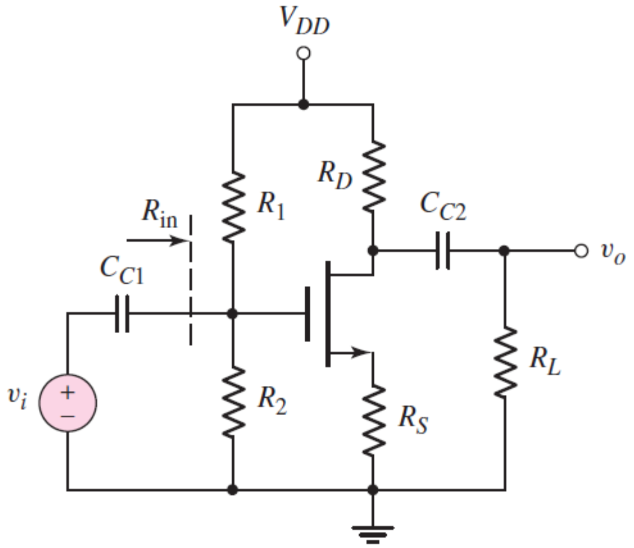
Input and Output Resistances: As already calculated, the amplifier input resistance is

$$R_i = R_1 \| R_2 = 140 \| 60 = 42 \text{ k}\Omega$$

and the amplifier output resistance is

$$R_o = R_D \| r_o = 10 \| 287 = 9.66 \text{ k}\Omega$$

For the NMOS common-source amplifier in Figure P4.15, the transistor parameters are: $V_{TN} = 0.8$ V, $K_n = 1$ mA/V^2, and $\lambda = 0$. The circuit parameters are $V_{DD} = 5$ V, $R_S = 1$ kΩ, $R_D = 4$ kΩ, $R_1 = 225$ kΩ, and $R_2 = 175$ kΩ. (a) Calculate the quiescent values I_{DQ} and V_{DSQ}. (b) Determine the small-signal voltage gain for $R_L = \infty$. (c) Determine the value of R_L that will reduce the small-signal voltage gain to 75 percent of the value found in part (b).



(a) $V_G = \left(\frac{R_2}{R_1 + R_2}\right) \cdot V_{DD} = \left(\frac{175}{175 + 225}\right)(5) = 2.1875 \text{ V}$

$$2.1875 = V_{GS} + I_D R_S = V_{GS} + K_n R_S (V_{GS} - V_{TN})^2$$

$$2.1875 = V_{GS} + (1)(1)\left(V_{GS}^2 - 1.6V_{GS} + 0.64\right)$$

or $V_{GS}^2 - 0.6V_{GS} - 1.5475 = 0 \Rightarrow V_{GS} = 1.58 \text{ V}$

$$I_{DQ} = K_n (V_{GS} - V_{TN})^2 = (1)(1.58 - 0.8)^2 = 0.608 \text{ mA}$$

$$V_{DSQ} = V_{DD} - I_{DQ}(R_S + R_D) = 5 - (0.608)(1 + 4) = 1.96 \text{ V}$$

(b) $A_\upsilon = \frac{-g_m R_D}{1 + g_m R_S}$

$$g_m = 2\sqrt{(1)(0.608)} = 1.56 \text{ mA/V}$$

$$A_\upsilon = \frac{-(1.56)(4)}{1 + (1.56)(1)} = -2.44$$

(c) $A_\upsilon = \frac{-g_m \left(R_D \| R_L\right)}{1 + g_m R_S} = \frac{-(1.56)\left(R_D \| R_L\right)}{1 + (1.56)(1)} = -0.6094\left(R_D \| R_L\right)$

$$-(0.75)(2.44) = -(0.6094)\left(R_D \| R_L\right) \Rightarrow R_D \| R_L = 3.0 \text{ k}\Omega$$

$$4 \| R_L = 3 \Rightarrow R_L = 12 \text{ k}\Omega$$

$$V_O = -g_m V_{gs} R_D$$

$$V_i = V_{gs} + g_m V_{gs} R_S = V_{gs}(1 + g_m R_S)$$

$$Av = \frac{V_O}{V_i} = \frac{-g_m V_{gs} R_D}{V_{gs}(1 + g_m R_S)} = \frac{-g_m R_D}{(1 + g_m R_S)}$$

$$g_m R_S >> 1$$

$$Av = \frac{V_O}{V_i} \simeq \frac{R_D}{R_S}$$

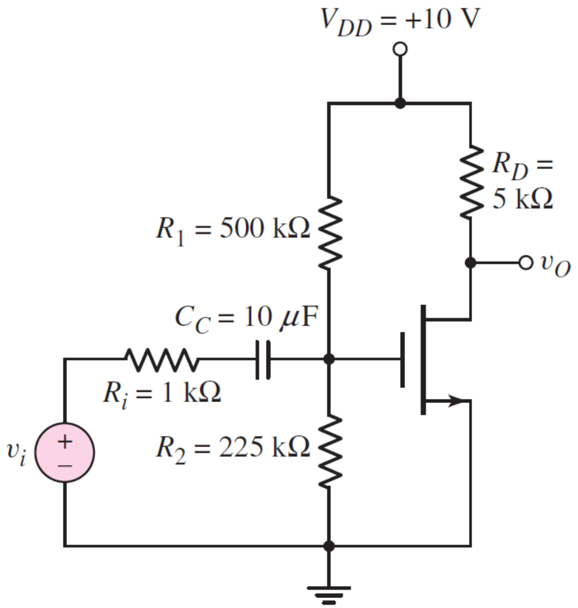
For the FET circuit in Figure ,

the transistor parameters are: $Kn = 1\ mA/V2, VT\ N = 2\ V, \lambda = 0, Cgs = 50\ fF$, and$Cgd = 8\ fF$.

(a) Draw thesimplified high – frequency equivalent circuit.

(b) Calculate the equivalentMiller capacitance.

(c) Determine the upper 3 dB frequency for thesmallsignalvoltage gain and find themidbandvoltage gain.



(b) $V_{GS} = \left(\dfrac{225}{225+500}\right)(10) = 3.103\text{ V}$

$$I_{DQ} = (1)(3.103-2)^2 = 1.218\text{ mA}$$

$$g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{(1)(1.218)} = 2.207\ \text{mA/V}$$

$$C_M = C_{gd}(1+g_m R_D) = (8)[1+(2.207)(5)] = 96.28\text{ fF}$$

(c) $f_{3-dB} = \dfrac{1}{2\pi\tau}$, $\tau = (R_i \| R_1 \| R_2)(C_{gs}+C_M)$

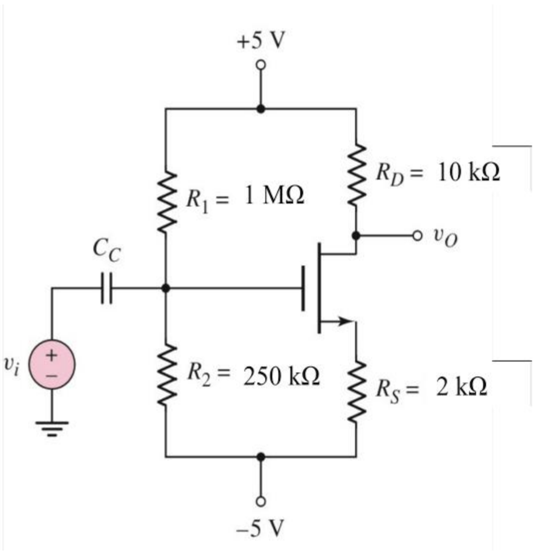
Now $R_i \| R_1 \| R_2 = 1 \| 500 \| 225 = 0.9936\text{ k}\Omega$

$$\tau = (0.9936\times10^3)(50+96.28)\times10^{-15} = 1.453\times10^{-10}\text{ s}$$

$$f_{3-dB} = \frac{1}{2\pi(1.453\times10^{-10})} \Rightarrow f_{3-dB} = 1.095\text{ GHz}$$

$$A_\upsilon = -g_m R_D\left(\frac{R_1\|R_2}{R_1\|R_2+R_i}\right) = -(2.207)(5)\left(\frac{155.2}{155.2+1}\right) = -10.96$$

The parameters for the transistor in the circuit shown in Figure Q3 are V_{TN} = 0.6 V, K_n =0.5 mA/V2, and λ= 0. (a) Determine the quiescent values of I_{DQ} and V_{DSQ} ,(b) Find the small signal voltage gain vo/vi.



$$V_G = \left(\frac{R_2}{R_1+R_2}\right)(10)-5 = \left(\frac{250}{250+1000}\right)(10)-5 = -3\text{ V}$$

$$I_D = \frac{(V_G - V_{GS})-(-5)}{2} = K_n\left(V_{GS}-V_{TN}\right)^2$$

$$-3 - V_{GS} + 5 = 2(0.5)(V_{GS}-0.6)^2$$

$$2 - V_{GS} = V_{GS}^2 - 1.2V_{GS} + 0.36$$

$$V_{GS}^2 - 0.2V_{GS} - 1.64 = 0$$

$$V_{GS} = \frac{0.2 \pm \sqrt{(0.04) + 4(1.64)}}{2} = 1.385 \text{ V}$$

$$I_{DQ} = (0.5)(1.385 - 0.6)^2 \Rightarrow I_{DQ} = 0.308 \text{ mA}$$

$$V_{DSQ} = 10 - (0.308)(10 + 2) \Rightarrow V_{DSQ} = 6.30 \text{ V}$$

Small signal voltage gain

$$A_v = \frac{-g_m R_D}{1 + g_m R_S}$$

$$g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{(0.5)(0.308)}$$

$$g_m = 0.7849 \text{ mA/V}$$

$$A_v = \frac{-(0.7849)(10)}{1 + (0.7849)(2)} \Rightarrow \underline{A_v = -3.05}$$

$$V_O = -g_m V_{gs} R_D$$

$$V_i = V_{gs} + g_m V_{gs} R_S = V_{gs}(1 + g_m R_S)$$

$$Av = \frac{V_O}{V_i} = \frac{-g_m V_{gs} R_D}{V_{gs}(1 + g_m R_S)} = \frac{-g_m R_D}{(1 + g_m R_S)}$$

$$g_m R_S >> 1$$

$$Av = \frac{V_O}{V_i} \simeq \frac{R_D}{R_S}$$