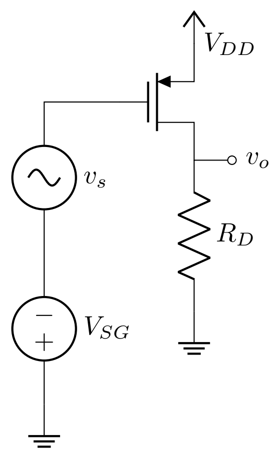
EE 105 HW 08

1

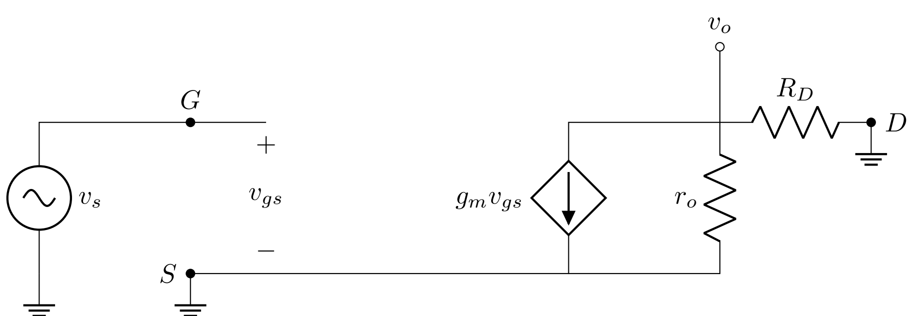


(a) We have that $V_{SG} - |V_{TP}| = V_0$ and that $\mu_0 C_{ox}\frac{W}{L} = k$. For the PMOS to be in saturation mode, we want

$$V_{SD} \leqslant V_0 = V_{DD} - I_D R_D \tag{1}$$

$$\implies R_D = \frac{V_{DD} - V_0}{I_D} = \frac{2(V_{DD} - V_0)}{kV_0^2} \tag{2}$$

(b) Converting to an NMOS common-source amplifier, the small-signal equivalent is



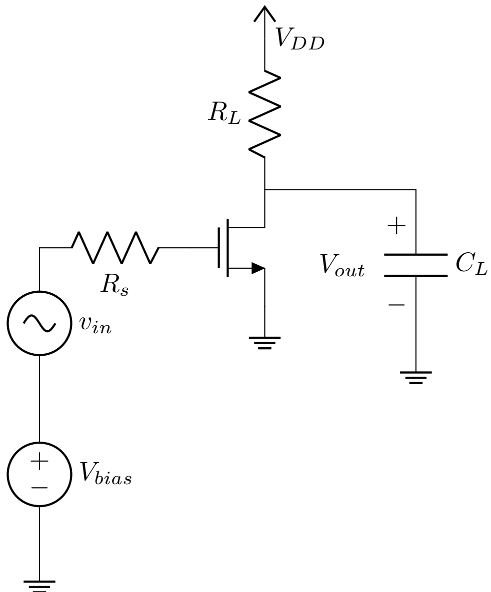
We then have

$$g_m v_s = \frac{-v_o}{r_o \parallel R_D} \tag{3}$$

$$g_m(r_0 \parallel R_D)v_s = -v_0 \tag{4}$$

$$\implies A = \frac{v_o}{v_s} = -g_m \frac{r_o R_D}{r_0 + R_D} \tag{5}$$

2



$$I_{DS} = k(V_{GS} - V_{TH})^2 \tag{6}$$
$$V_{TH} = 0.65\,\mathrm{V} \tag{7}$$
$$k = 20\,\mathrm{mA\,V^{-2}} \tag{8}$$

(a)

$$V_{DD} = 1.8\,\mathrm{V} \tag{9}$$
$$R_s = 10\,\mathrm{k\Omega} \tag{10}$$
$$R_L = 1\,\mathrm{k\Omega} \tag{11}$$
$$C_L = 1\,\mathrm{pF} \tag{12}$$
$$V_{bias} = 0.85\,\mathrm{V} \tag{13}$$

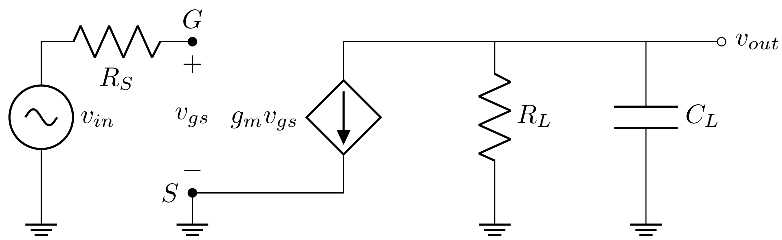
At the DC operating point, we have $v_s = 0$, so we have

$$V_{GS} = V_{bias} = 0.85\,\mathrm{V} \tag{14}$$
$$I_{DS} = k(V_{bias} - 0.65\,\mathrm{V})^2 = 0.8\,\mathrm{mA} \tag{15}$$
$$V_{out} = V_{DD} - I_{DS}R_L = 1\,\mathrm{V} \tag{16}$$

(b)

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}} = 2k(V_{GS} - V_{TH}) = 8\,\mathrm{mS} \tag{17}$$

(c) The small-signal model of the circuit is



The transfer function is

$$g_m v_{in} + \frac{v_{out}}{R_L} + sC_L v_{out} = 0 \tag{18}$$

$$g_m v_{in} = -v_{out}\left(\frac{1}{R_L} + sC_L\right) \tag{19}$$

$$\implies \frac{v_{out}}{v_{in}} = -\frac{g_m R_L}{1 + sR_L C_L} \tag{20}$$

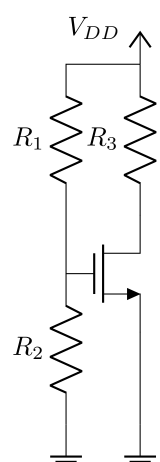
(d)

$$\lim_{\omega \to 0} |H(j\omega)| = g_m R_L = 8 \tag{21}$$

$$|H(j\omega)| = \frac{g_m R_L}{\sqrt{1 + (R_L C_L)^2}} \tag{22}$$

$$\implies \omega_c = \frac{g_m \cancel{R_L}}{2\pi \cancel{R_L} C_L} = 1.27\,\text{GHz} \tag{23}$$

3



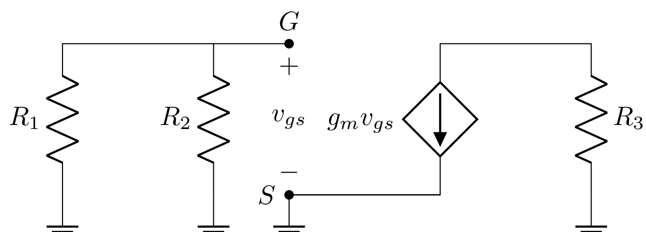
$$V_{DD} = 3.3\,\mathrm{V} \tag{24}$$
$$R_1 = 2.3\,\mathrm{k\Omega} \tag{25}$$
$$R_2 = 1.2\,\mathrm{k\Omega} \tag{26}$$
$$R_3 = 1.2\,\mathrm{k\Omega} \tag{27}$$
$$V_{TH} = 0.5\,\mathrm{V} \tag{28}$$
$$\lambda = 0\,\mathrm{V}^{-1} \tag{29}$$
$$\mu_n C_{ox} = 2 \times 10^{-4}\,\mathrm{A\,V^2} \tag{30}$$
$$\frac{W}{L} = 20 \tag{31}$$
$$L = 0.5\,\mathrm{\mu m} \tag{32}$$

(a) The gate voltage forms a resistive divider, so we have $V_{GS} = 1.13\,\mathrm{V}$. Since $V_{GS} > V_{TH}$, the NMOS is either in the linear/triode or saturation region. We can test the saturation condition for an NMOS:

$$V_{DS} = V_{DD} - I_D R_D \geqslant V_{GS} - V_{TH} \tag{33}$$
$$\implies R_D \leqslant \frac{V_{DD} + V_{TH} - V_{GS}}{I_D} = \frac{2(V_{DD} + V_{TH} - V_{GS})}{\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})^2} = 3.3\,\mathrm{k\Omega} > R_3 \tag{34}$$

Since the condition is satisfied, the NMOS is in saturation mode. Thus, $V_{DS} = V_{DD} - I_D R_D = 2.34\,\mathrm{V}$. This confirms the operating region.

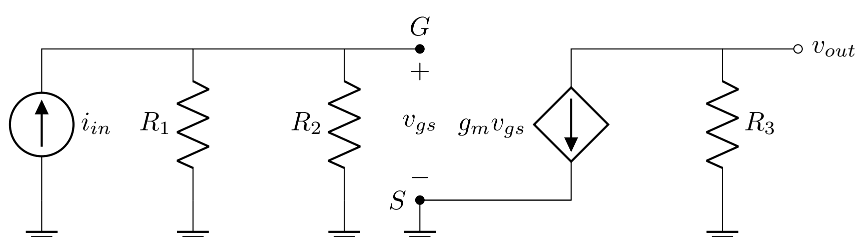
(b) Since $\lambda = 0\,\mathrm{V}^{-1}$, there is no channel-length modulation, so $r_o = \infty$. The small-signal model is



We can find g_m as

$$g_m = \frac{\partial I_D}{\partial V_{DS}} = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH}) = 2.52\,\mathrm{mS} \tag{35}$$

(c) The small-signal model is now



We have the equation

$$-v_{out} = g_m i_{in}(R_1 \parallel R_2)R_3 \implies A = \frac{v_{out}}{i_{in}} = -g_m(R_1 \parallel R_2)R_3 = -2.39\,\mathrm{k\Omega} \tag{36}$$

4

$$\begin{aligned}
V_{GS} &= 1\,\mathrm{V} \\
V_{DS} &= 1\,\mathrm{V} \\
V_{SB} &= 0.2\,\mathrm{V} \\
V_{TN} &= 0.5\,\mathrm{V} \\
W &= 5\,\mathrm{\mu m} \\
L &= 1\,\mathrm{\mu m} \\
t_{ox} &= 10\,\mathrm{nm} \\
\epsilon_{ox} &= 3.9\epsilon_0 \\
L_j &= 2\,\mathrm{\mu m} \\
L_{ov} &= 0.05\,\mathrm{\mu m} \\
C_{j0} &= 1\,\mathrm{mF\,m^{-2}} \\
C_{j,sw0} &= 4 \times 10^{-10}\,\mathrm{F\,m^{-1}} \\
\phi_b &= 1\,\mathrm{V} \\
C_{\text{fringe}} &= 1\,\mathrm{fF}
\end{aligned}$$

$$C_{gs} = \frac{2}{3}WLC_{ox} + C_{ov} = \frac{2}{3}WL\frac{\epsilon_{ox}}{t_{ox}} + L_{ov}W\frac{\epsilon_{ox}}{t_{ox}} = 1.24 \times 10^{-14}\,\mathrm{F} \tag{37}$$

$$C_{gd} = C_{ov} + C_{\text{fringe}} = L_{ov}WC_{ox} + C_{\text{fringe}} = 1.86 \times 10^{-15}\,\mathrm{F} \tag{38}$$

$$A_{d,j} = A_{s,j} = L_jW = 1 \times 10^{-11}\,\mathrm{m^2} \tag{39}$$

$$P_{d,j} = P_{s,j} = 2L_j + W = 9\,\mathrm{\mu m} \tag{40}$$

$$C_{db} = \frac{C_{j0}}{\sqrt{1 + \frac{V_{DB}}{\phi_B}}}A_{d,j} + \frac{C_{j,sw0}}{\sqrt{1 + \frac{V_{DB}}{\phi_B}}}P_{d,j} = 1.01 \times 10^{-14}\,\mathrm{F} \tag{41}$$

$$C_{sb} = \frac{C_{j0}}{\sqrt{1 + \frac{V_{SB}}{\phi_B}}}A_{s,j} + \frac{C_{j,sw0}}{\sqrt{1 + \frac{V_{SB}}{\phi_B}}}P_{s,j} = 1.24 \times 10^{-14}\,\mathrm{F} \tag{42}$$