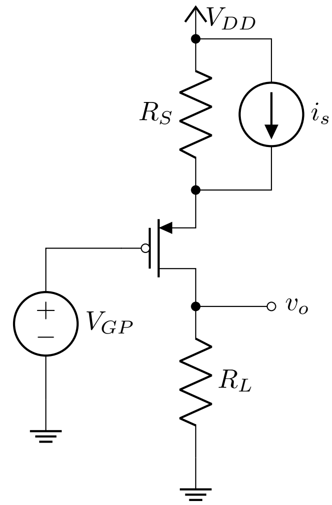
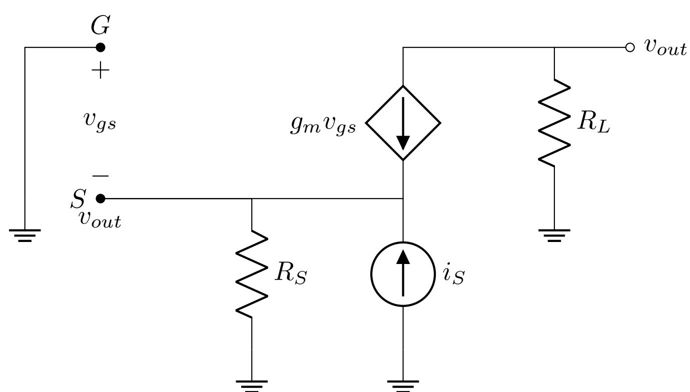
EE 105 HW 10

1



(a) This is a *common-gate* amplifier.

(b) The small-signal model is



The node equations governing the circuit are

$$g_m(-v_S) + i_s = \frac{v_s}{R_S} \tag{1}$$

$$\frac{v_{out}}{R_L} + g_m(-v_S) = 0 \tag{2}$$

$$\implies v_S = \frac{i_S}{\frac{1}{R_S} + g_m} \tag{3}$$

$$\implies \frac{v_{out}}{i_S} = \frac{g_m R_L}{\frac{1}{R_S} + g_m} \tag{4}$$

(c)

$$
\begin{aligned}
V_{GP} &= 0\,\mathrm{V} && (5)\\
R_S &= 2\,\mathrm{k\Omega} && (6)\\
V_{DD} &= 12\,\mathrm{V} && (7)\\
k_p &= 1\,\mathrm{mA\,V^{-1}} && (8)\\
V_{TP} &= -3\,\mathrm{V} && (9)
\end{aligned}
$$

To maximize the small-signal gain, we would want R_L to be as large as possible while remaining in the saturation region. In order to remain in the saturation region, we want

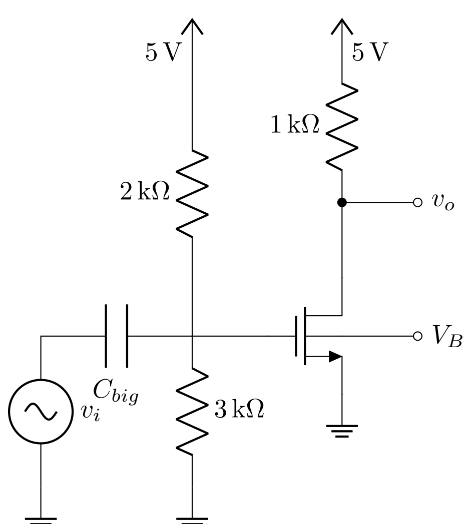
$$
\begin{aligned}
V_{SD} &\geqslant V_{DD} - I_{DS}R_S - |V_{TP}| && (10)\\
\cancel{V_{DD} - I_{DS}R_S} - I_{DS}R_L &\geqslant \cancel{V_{DD} - I_{DS}R_S} - |V_{TP}| && (11)\\
\implies R_L &\leqslant \frac{|V_{TP}|}{I_{DS}} && (12)
\end{aligned}
$$

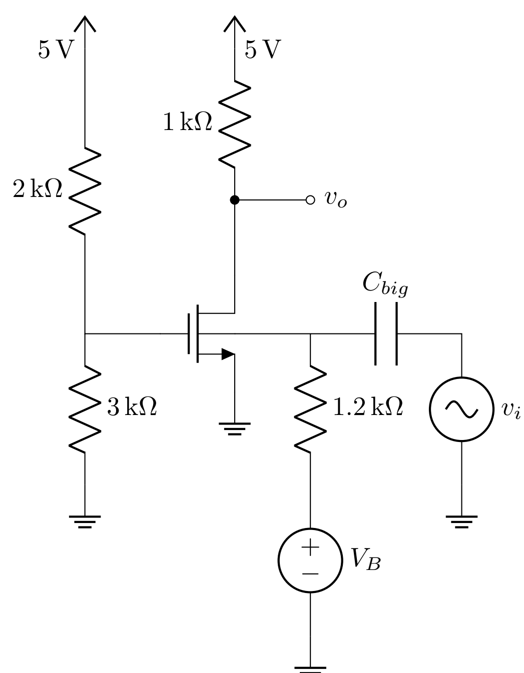
The current given the MOSFET parameters is

$$
\begin{aligned}
I_{DS} &= \frac{k_p}{2}(v_S - |V_{TP}|)^2 && (13)\\
&= \frac{k_p}{2}(v_{DD} - I_{DS}R_S - |V_{TP}|)^2 && (14)\\
\implies I_{DS} &= 3.23\,\mathrm{mA}, 6.27\,\mathrm{mA} && (15)
\end{aligned}
$$

Picking the smaller value of I_{DS}, we get $R_L = 928.8\,\Omega$.

2 Impact of Body Effect on Amplifiers

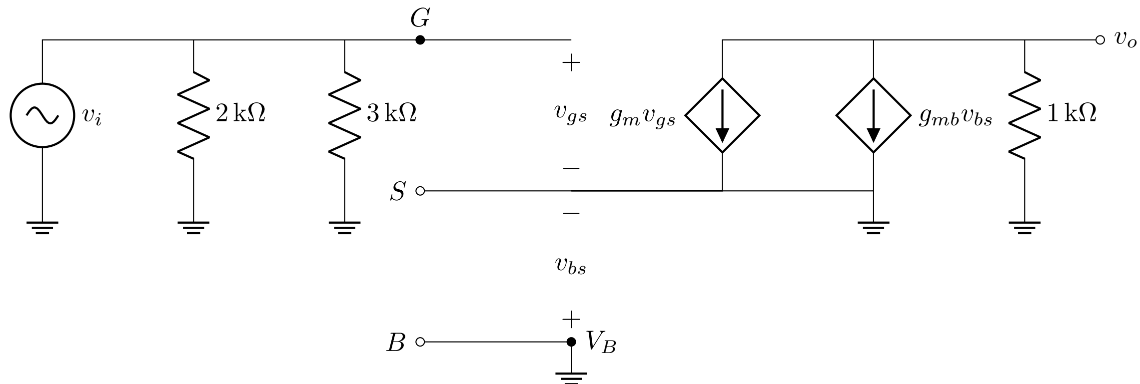


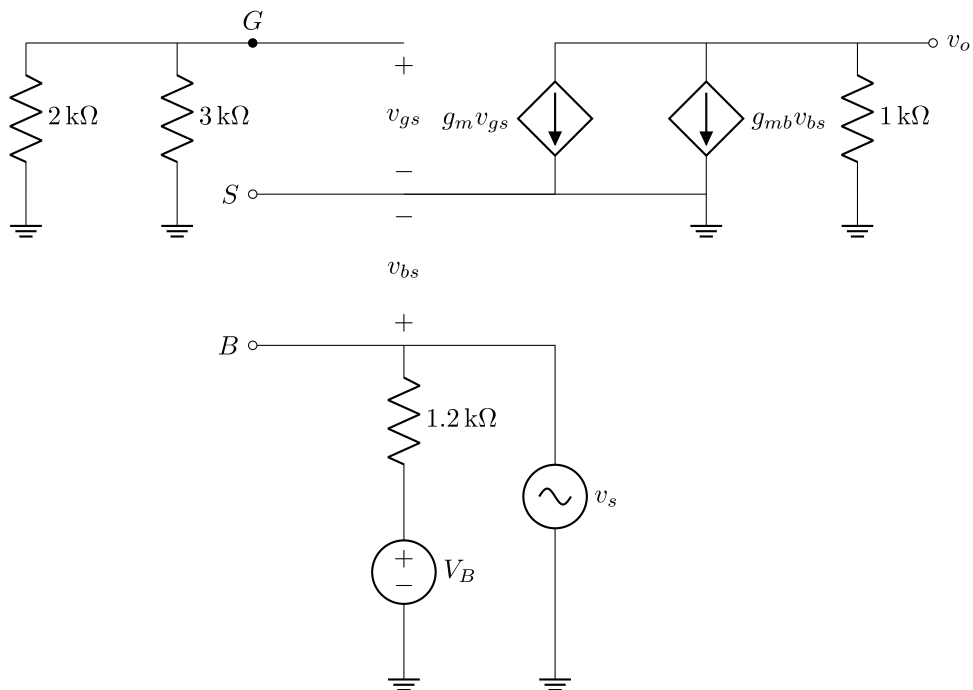


$$V_{TN} = 1\,\mathrm{V} \tag{16}$$
$$k_n = 2\,\mathrm{mA\,V^{-1}} \tag{17}$$
$$\lambda = 0\,\mathrm{V^{-1}} \tag{18}$$
$$\gamma = 0.5\,\mathrm{V^{1/2}} \tag{19}$$
$$\phi_p = -200\,\mathrm{mV} \tag{20}$$
$$V_T = V_{T0} + \gamma\left(\sqrt{V_{SB} - 2\phi_p} - \sqrt{-2\phi_p}\right) \tag{21}$$

(a) Amplifier A is a *common-source* amplifier, and amplifier B is a *common-gate* amplifier.

(b) The small-signal model for both amplifiers when we reduce C_{big} to a short-circuit is





Analyzing amplifier A,

$$g_m v_i + \frac{v_o}{1\,\mathrm{k\Omega}} = 0 \implies \frac{v_0}{v_i} = -g_m(1\,\mathrm{k\Omega}) \tag{22}$$

Calulating g_m,

$$g_m = k_n \left(v_{gs} - \left(V_{T0} + \gamma \left(\sqrt{V_{SB} - 2\phi_p} - \sqrt{-2\phi_p}\right)\right)\right) = k_n \left(V_g - 1.27\,\mathrm{V}\right) = 3.45\,\mathrm{mS} \tag{23}$$

This means that our gain is -3.45.
For amplifier B,

$$g_{mb} v_s + \frac{v_o}{1\,\mathrm{k\Omega}} = 0 \implies \frac{v_o}{v_i} = -g_{mb}(1\,\mathrm{k\Omega}) \tag{24}$$

Calculating g_{mb},

$$g_{mb} = \frac{\gamma g_m}{2\sqrt{-v_{bs} - 2\phi_p}} \tag{25}$$

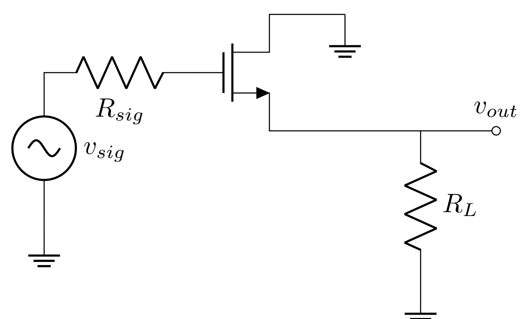
$$g_m = 3.45\,\mathrm{mS} \tag{26}$$

$$\implies g_{mb} = 7.29 \times 10^{-4}\,\mathrm{S} \tag{27}$$

This means that our gain is -0.729.

(c) In amplifier A, an increased V_B would decrease V_{SB}, which would decrease v_T, which would increase g_m, which would *increase* our absolute gain. In amplifier B, an increased V_B would decrease V_{SB}, which would increase g_{mb}, which would *increase* our absolute gain.

3



$$\mu_n C_{ox} = 0.5\,\mathrm{mA\,V^{-2}} \tag{28}$$

$$V_{GS} - V_T = 0.2\,\mathrm{V} \tag{29}$$

$$\tag{30}$$

The output resistance of a source follower is

$$R_{out} \approx \frac{1}{g_m} \implies g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T) = 3.33\,\mathrm{mS} \tag{31}$$

$$\implies \frac{W}{L} = \frac{3.33\,\mathrm{mS}}{\mu_n C_{ox}(V_{GS} - V_T)} = 33.33 \tag{32}$$

The DC bias current is

$$I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_T)^2 = 33.33\,\mathrm{\mu A} \tag{33}$$

The range of gains based on R_L is

$$\frac{v_{out}}{v_{sig}} = \left. \frac{g_m}{\frac{1}{R_L} + g_m} \right|_{1\,\mathrm{k\Omega}}^{10\,\mathrm{k\Omega}} = [0.77, 0.97] \tag{34}$$

4

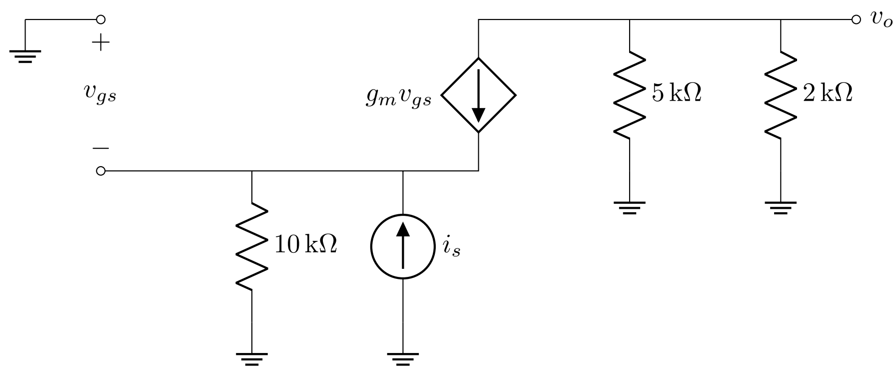
$$g_m = 10\,\mathrm{mA\,V^{-1}} \tag{35}$$

(a) For the source follower, the gain and output resistance are

$$\frac{v_o}{v_i} = \frac{g_m}{\frac{1}{R_L} + g_m} = 0.99 \tag{36}$$

$$R_o = \frac{1}{g_m} = 100\,\Omega \tag{37}$$

(b) Analyzing the small-signal model of a common-gate amplifier,



We can find the gain as

$$\frac{v_o}{5\,\mathrm{k\Omega}} + \frac{v_o}{2\,\mathrm{k\Omega}} + g_m(-V_s) = 0 \tag{38}$$

$$\frac{V_s}{10\,\mathrm{k\Omega}} = i_s + g_m(-V_s) \implies V_s = \frac{i_s}{\frac{1}{10\,\mathrm{k\Omega}} + g_m} \tag{39}$$

$$\implies \frac{v_o}{i_s} = \left(\frac{1}{10\,\mathrm{k\Omega}} + g_m\right) \frac{g_m(10\,\mathrm{k\Omega})}{\frac{1}{5\,\mathrm{k\Omega}} + \frac{1}{2\,\mathrm{k\Omega}}} = 1.44\,\mathrm{k\Omega} \tag{40}$$

For the common-gate amplifier, the input resistance is $R_i = \frac{1}{g_m} = 100\,\Omega$.