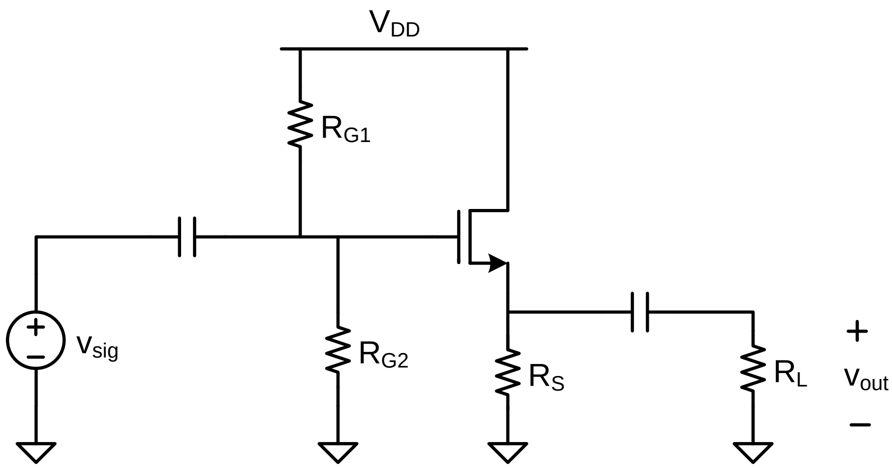
10 Source follower amplifier

The MOSFET amplifier comparable to the BJT emitter follower is the source follower or common drain amplifier. One configuration is shown below.



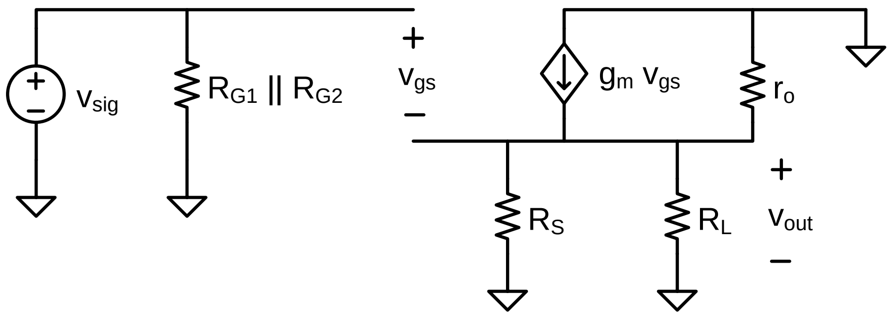
The DC drain current is found from

$$I_D = \mu_n C_{ox} (W / L) \tfrac{1}{2} (V_{GS} - V_{th})^2$$
$$V_S = I_D R_S$$
$$V_G = V_{DD} R_{G2} / (R_{G1} + R_{G2})$$

where, as long as the gate voltage is sufficient to turn on the transistor, we are assured the transistor will be in saturation mode because of the drain connection to V_{DD}. And like the case of the common source amplifier with source degeneration, we can solve these equations to obtain two solutions for I_D and V_S, only one of which will correspond to the transistor turned on in saturation mode.

For the transistor to be turned on, the voltage divider on the gate must provide $V_G \geq V_{th}$. Below that level the MOSFET is not conducting. With this configuration, the MOSFET cannot be in linear mode which would require $V_G > V_D + V_{th} = V_{DD} + V_{th}$.

The small signal circuit is shown below.



Although the emitter follower is not unilateral, the source follower is unilateral because the insulated gate prevents signals applied at the output from getting to the input.

From the small signal circuit, the open circuit voltage gain is

$$A_v = v_{out} / v_{sig}$$

$$v_{sig} = v_{gs} + v_{out}$$

$$v_{out} = g_m v_{gs} (R_S \| r_o) \qquad \text{with } R_L \text{ removed}$$

$$= g_m (v_{sig} - v_{out}) (R_S \| r_o)$$

$$v_{out} / v_{sig} = g_m (v_{sig} - v_{out}) (R_S \| r_o) / v_{sig}$$

$$= g_m (R_S \| r_o) - g_m (v_{out} / v_{sig}) (R_S \| r_o)$$

Then we get

$$A_v = \frac{g_m (R_S \| r_o)}{1 + g_m (R_S \| r_o)}$$

This can be put in an even simpler form as follows.

$$A_v = \frac{g_m (R_S \| r_o)}{1 + g_m (R_S \| r_o)}$$

$$= \frac{g_m}{1 / (R_S \| r_o) + g_m}$$

$$= \frac{g_m}{1 / R_S + 1 / r_o + 1 / (1/g_m)}$$

$$= g_m (R_S \| r_o \| 1/g_m)$$

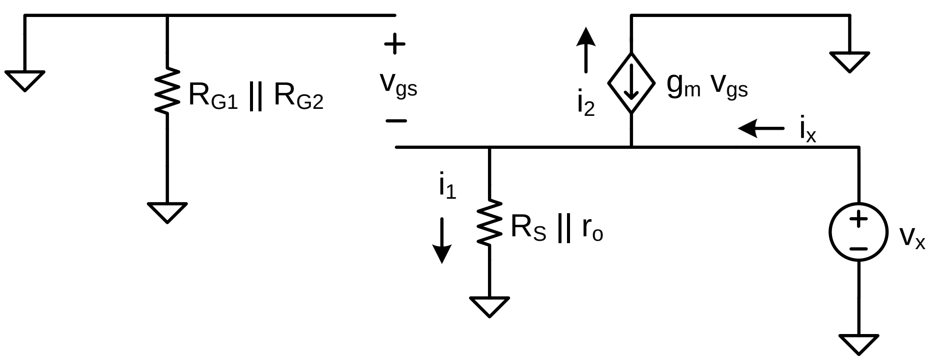
This open circuit gain is clearly less than one but can approach one for typical values of R_S, r_o, and g_m where $1/g_m$ dominates the parallel combination of resistors. $A_v \leq 1$ is just what we found for the BJT case of the emitter follower.

The input resistance is found directly.

$$R_{in} = R_{G1} \parallel R_{G2}$$

which can, again, be very large because there is no gate current.

The output resistance is found from the following.



$$R_{out} = v_x / i_x = v_x / (i_1 + i_2)$$
$$i_1 = v_x / (R_S \parallel r_o)$$
$$i_2 = -g_m v_{gs} = -g_m (-v_x) = g_m v_x$$

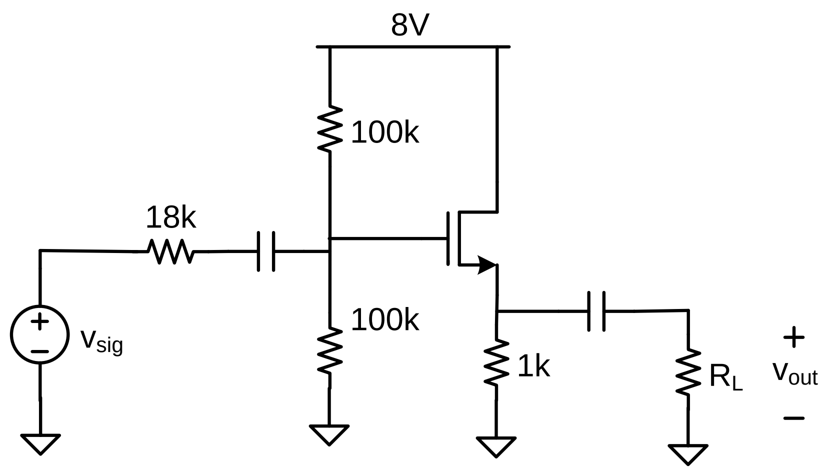
Combining these we get

$$\begin{aligned} R_{out} &= v_x / [v_x / (R_S \parallel r_o) + g_m v_x] \\ &= 1 / [1 / (R_S \parallel r_o) + g_m] \\ &= R_S \parallel r_o \parallel 1/g_m \end{aligned}$$

Note that the current source, $g_m v_{gs}$, with a voltage across it equal to its controlling voltage, $v_x = |v_{gs}|$, looks just like a resistor with resistance $1/g_m$. So v_x sees three parallel paths to ground and we get directly that $R_{out} = R_S \,||\, r_o \,||\, 1/g_m$. R_{out} is typically on the order of 1 kΩ or less.

The primary advantage of the source follower is that it can provide a low output resistance to drive low resistance loads. The high input resistance is also important but this is not unique to the source follower. MOSFET amplifiers with inputs at the gate (common source and source follower) usually have high input resistance due to the insulated MOSFET gate.

Example 10-1



This source follower amplifier uses a transistor with $\mu_n C_{ox}$ = 100 μA/V², W / L = 50, V_{th} = 0.7 V, and V_A = 95 V. Draw the small signal circuit for this amplifier. Find the open circuit voltage gain, R_{in} and R_{out}, and the overall gain for a load resistor of 200 Ω.

Solution:

$$V_G = 8\text{ V}\,(100\text{ k}\Omega / 200\text{ k}\Omega) = 4\text{ V}$$

$$V_S = I_D R_S = I_D \cdot 1\text{ k}\Omega$$

$$I_D = \mu_n C_{ox} (W/L)\, \tfrac{1}{2}\, (V_{GS} - V_{th})^2$$

$$= 100 \times 10^{-3}\text{ mA/V}^2\; 50 \cdot \tfrac{1}{2}\, (4\text{ V} - I_D\, 1\text{ k}\Omega - 0.7\text{ V})^2$$

$$= 2.5\text{ mA/V}^2\, (3.3\text{ V} - I_D\, 1\text{ k}\Omega)^2$$

Solving the quadratic

$$I_D = 2.34 \text{ mA and } 4.66 \text{ mA}$$

The second solution is incorrect because we get a source voltage that is greater than the gate voltage, $V_{GS} < 0$. The transistor is in cutoff.

For the first solution,

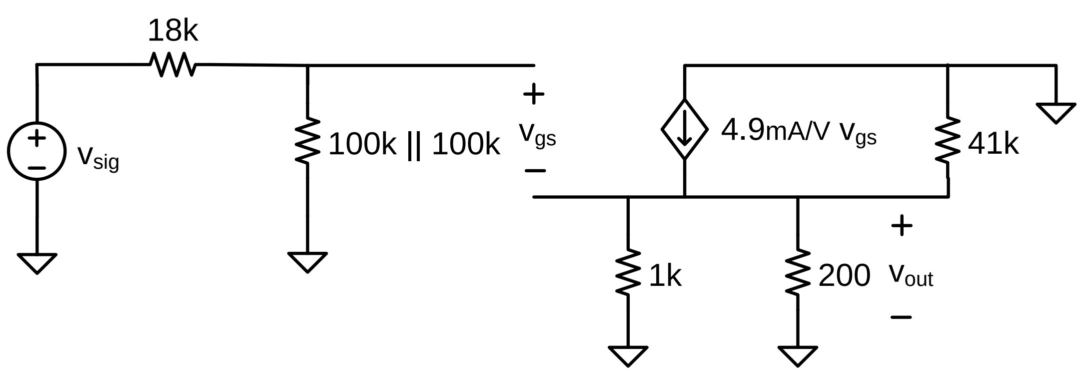
$$I_D = 2.34 \text{ mA}$$

$$V_S = I_D R_S = 2.34 \text{ V}$$

$$g_m = 2 I_D / (V_{GS} – V_{th}) = 4.9 \text{ mA/V}$$

$$r_o = V_A / I_D = 41 \text{ k}\Omega$$

The small signal circuit is



Then we get

$$A_v = g_m (R_S \| r_o \| 1/g_m) = 0.83$$

$$R_{in} = R_{G1} \| R_{G2} = 50 \text{ k}\Omega$$

$$R_{out} = R_S \| r_o \| 1/g_m = 170\ \Omega$$

$$A_{overall} = A_v [R_{in} / (R_{sig} + R_{in})] [R_L / (R_{out} + R_L)]$$

$$= 0.83 (50 \text{ k}\Omega / 68 \text{ k}\Omega) (200\ \Omega / 370\ \Omega) = 0.33$$