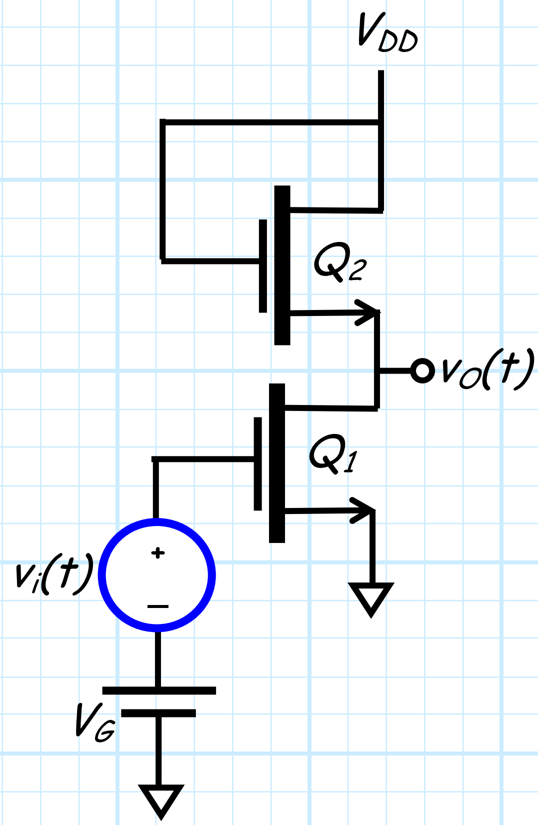
The Common Source Amp with Enhancement Load

Consider this **NMOS amplifier** using an **enhancement load**.



* Note **no** resistors or capacitors are present!

* This is a **common source** amplifier.

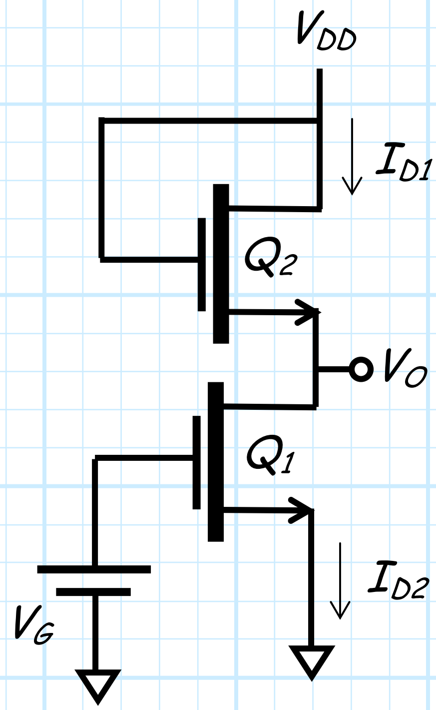
* I_D stability **could** be a problem

Q: *What is the small-signal open-circuit voltage gain, input resistance, and output resistance of this amplifier?*

A: The values that we will determine when we follow precisely the same steps as before!!

Step 1 – *DC Analysis*

The DC circuit of this amplifier is:



Note that:

$$I_{D1} = I_{D2} \doteq I_D$$

and that:

$$V_{GS1} = V_G - 0 = V_G$$

and also that:

$$V_{DS2} = V_{GS2}$$

and finally that:

$$V_{DS1} = V_{DD} - V_{DS2}$$

Let's of course **ASSUME** that both Q_1 and Q_2 are in saturation. Therefore we **ENFORCE**:

$$\begin{aligned} I_{D1} &= K_1 (V_{GS1} - V_{t1})^2 \\ &= K_1 (V_G - V_{t1})^2 \end{aligned}$$

Note that there are no unknowns in the previous equation. The drain current is explicitly determined from K_1 , V_G, and V_{t1}!

Continuing with the **ANALYSIS**, we can find the drain current through the enhancement load (I_{D2}), since it is equal to the current through Q_1:

$$I_{D2} = I_{D1} = K_1 (V_G - V_{t1})^2$$

Yet we also know that V_{GS2} must be related to this drain current as:

$$I_{D2} = K_2 (V_{GS2} - V_{t2})^2$$

and therefore combining the above equations:

$$I_{D1} = I_{D2}$$

$$K_1 (V_G - V_{t1})^2 = K_2 (V_{GS2} - V_{t2})^2$$

Note this last equation has only one unknown (V_{GS2}) ! Rearranging, we find that:

$$V_{GS2} = \sqrt{\frac{K_1}{K_2}} (V_G - V_{t1}) + V_{t2}$$

Since $V_{DS2} = V_{GS2}$ and $V_{DS1} = V_{DD} - V_{DS2}$, we can likewise state that:

$$V_{DS2} = \sqrt{\frac{K_1}{K_2}} (V_G - V_{t1}) + V_{t2}$$

and:

$$V_{DS1} = V_{DD} - V_{t2} - \sqrt{\frac{K_1}{K_2}} (V_G - V_{t1})$$

Now, we must **CHECK** to see if our assumption is correct.

The saturation assumption will be correct if:

$$\begin{aligned} V_{DS1} &> V_{GS1} - V_{t1} \\ &> V_G - V_{t1} \end{aligned}$$

and:

$$V_{GS1} > V_{t1} \quad \therefore \quad \text{if} \quad V_G > V_{t1}$$

Step 2 - *Calculate small-signal parameters*

We require the small-signal parameters for each of the transistors Q_1 and Q_2. Therefore:

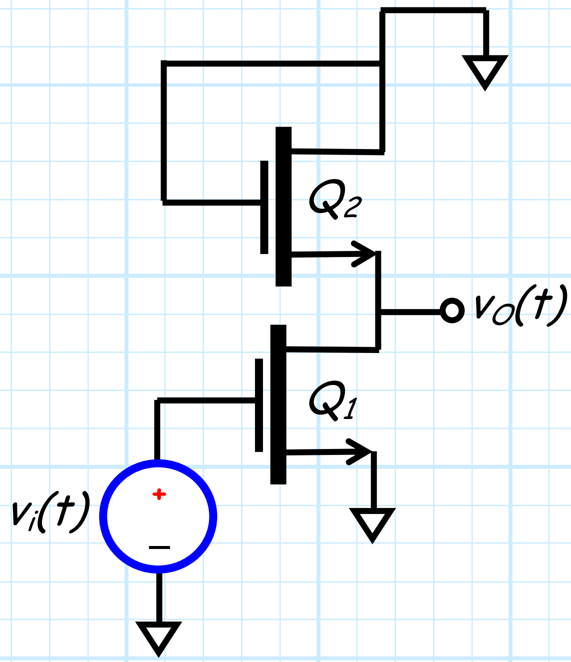
$$g_{m1} = 2K_1\left(V_G - V_{t1}\right) \qquad \text{and} \qquad g_{m2} = 2K_1\left(V_{GS2} - V_{t2}\right)$$

and:

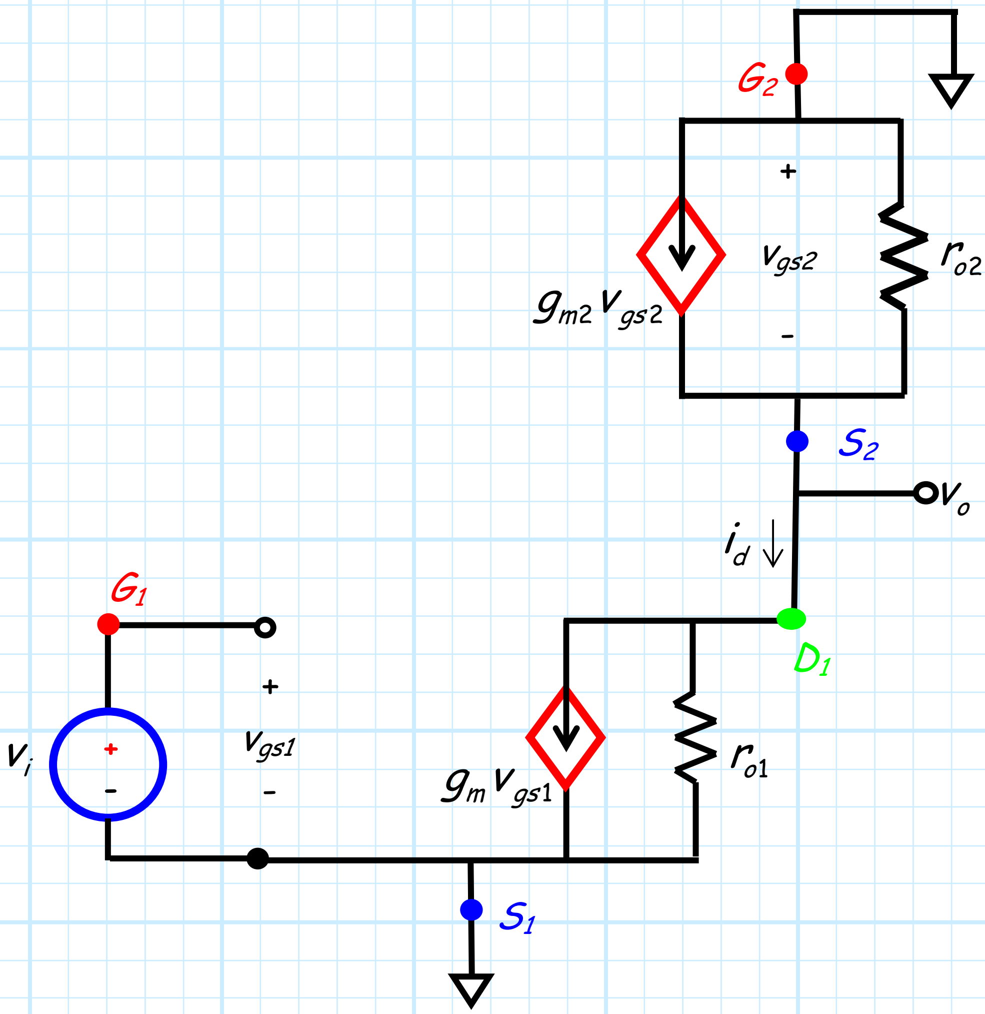
$$r_{o1} = \frac{1}{\lambda_1 \, I_D} \qquad \text{and} \qquad r_{o2} = \frac{1}{\lambda_2 \, I_D}$$

Step 3 – *Determine the small-signal circuit*

First, let's turn off the DC sources:

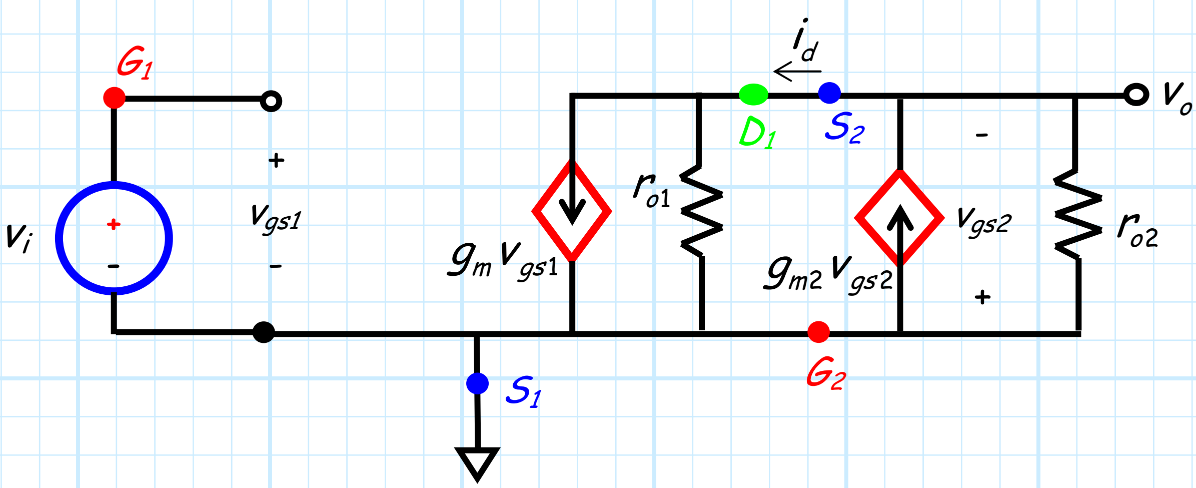


We now replace **MOSFET** Q_1 with its equivalent small-signal model, **and** replace the **enhancement load** with its equivalent small-signal model.

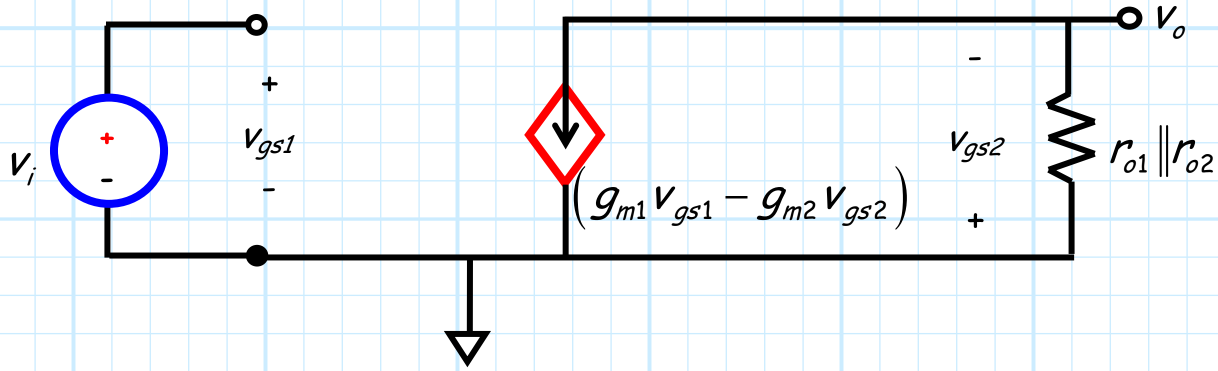


Note S_1 and G_2 are at **small-signal ground**!

Therefore, we can rewrite this circuit as:



Simplifying further, we find:



Therefore, we find that:

$$v_{gs1} = v_i$$

and that:

$$v_{gs2} = -v_o$$

as well as that:

$$\begin{aligned} v_o &= -\left(g_{m1}\, v_{gs1} - g_{m2}\, v_{gs2}\right)\left(r_{o1} \| r_{o2}\right) \\ &= -\left(g_{m1}\, v_i + g_{m2}\, v_o\right)\left(r_{o1} \| r_{o2}\right) \end{aligned}$$

Rearranging, we find:

$$A_{vo} = \frac{v_o}{v_i} = \frac{-\left(r_{o1} \| r_{o2}\right) g_{m1}}{1 + \left(r_{o1} \| r_{o2}\right) g_{m2}} \approx \frac{-g_{m1}}{g_{m2}}$$

But recall that:

$$\begin{aligned} g_m &= 2K\left(V_{GS} - V_t\right) \\ &= 2\sqrt{K}\sqrt{I_D} \end{aligned}$$

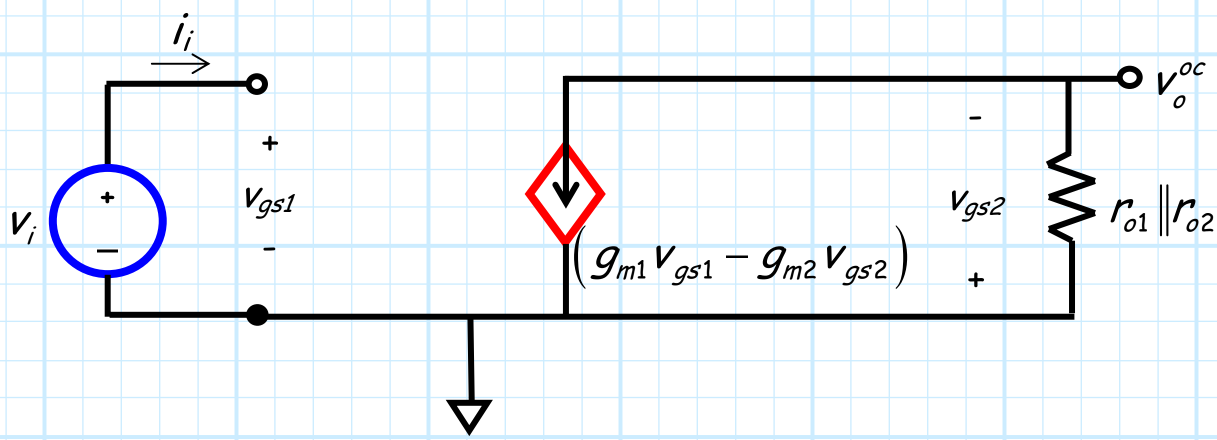
where we have used the fact that $I_D = K\left(V_{GS} - V_t\right)^2$ to determine that $\left(V_{GS} - V_t\right) = \sqrt{I_D / K}$.

Therefore:

$$A_{vo} = \frac{-g_{m1}}{g_{m2}} = \frac{2\sqrt{K_1}\sqrt{I_D}}{2\sqrt{K_2}\sqrt{I_D}} = \sqrt{\frac{K_1}{K_2}} = \frac{\sqrt{\left(W/L\right)_1}}{\sqrt{\left(W/L\right)_2}}$$

In other words, we adjust the MOSFET channel geometry to set the small-signal gain of this amplifier!

Now let's determine the small-signal input and output resistances of this amplifier!

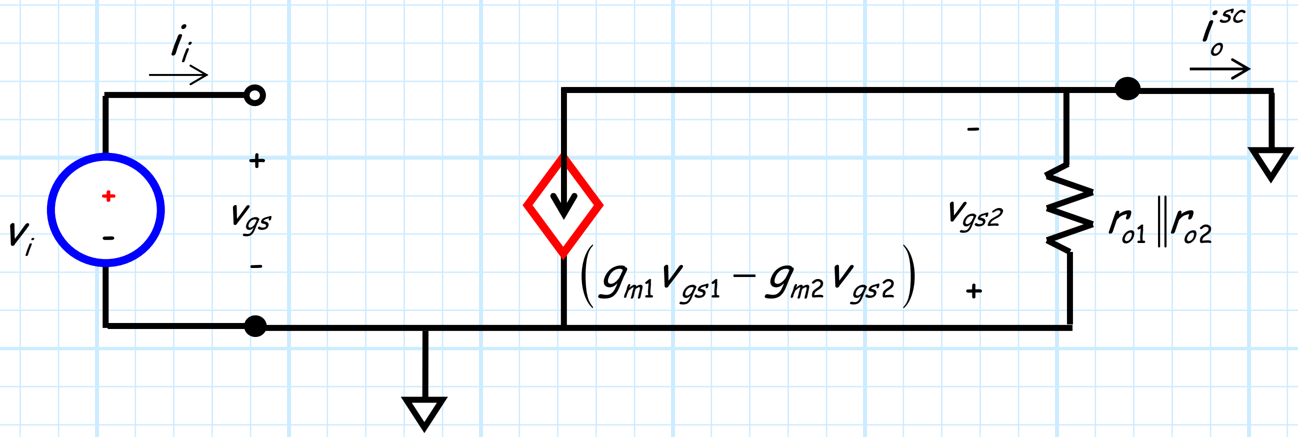


It is evident that since $i_i = i_g = 0$:

$$R_i = \frac{v_i}{i_i} = \infty \qquad \text{(Great!!!)}$$

Now for the output resistance, we know that the open-circuit output voltage is:

$$v_o^{oc} = -\left(g_{m1} v_{gs1} - g_{m2} v_{gs2}\right)\left(r_{o1} \| r_{o2}\right)$$



Likewise, the short-circuit output current i_o^{sc} is:

$$i_{os} = -(g_{m1} v_{gs1} - g_{m2} v_{gs2})$$

Thus, the small-signal output resistance of this amplifier is equal to:

$$R_o = \frac{v_o^{oc}}{i_o^{sc}} = \frac{-(g_{m1} v_{gs1} - g_{m2} v_{gs2})(r_{o1} \| r_{o2})}{-(g_{m1} v_{gs1} - g_{m2} v_{gs2})} = (r_{o1} \| r_{o2}) \quad \textbf{(Doh!!!)}$$

*The input resistance and open-circuit voltage gain of this **common source** amplifier are **good**, but the **output resistance stinks**!!*

Smells like a common emitter amplifier!