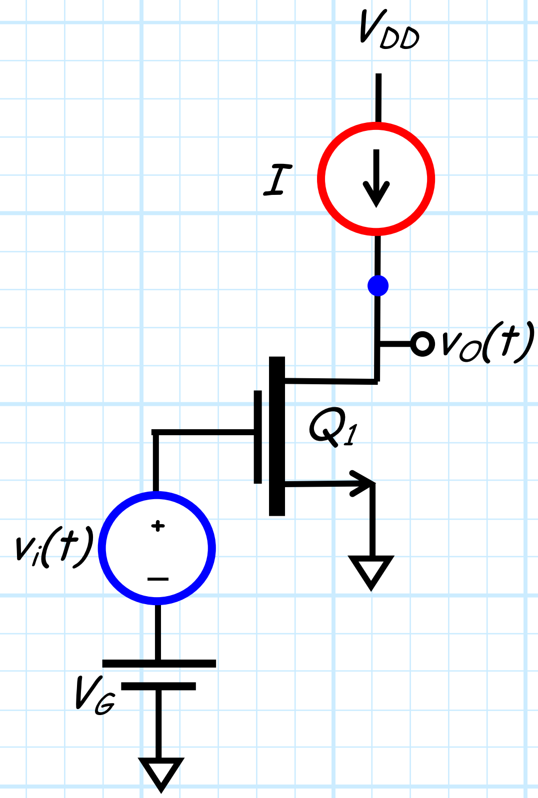
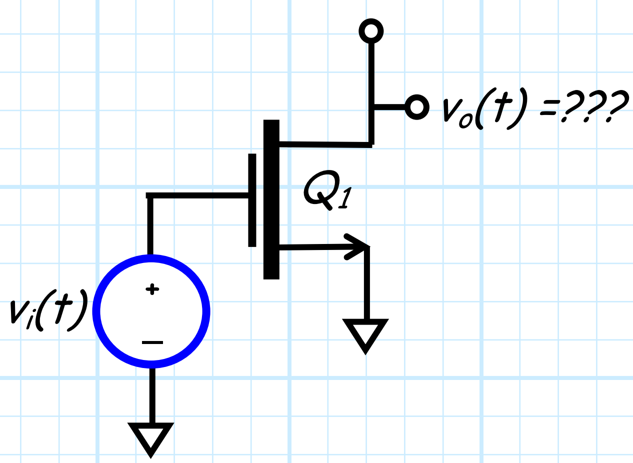
The Common Source Amp with a Current Source

Now consider this NMOS amplifier using a **current source**.

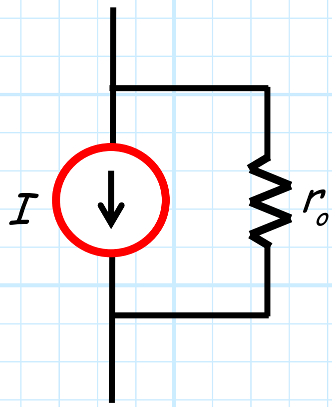


- Note **no** resistors or capacitors are present!
- This is a **common source** amplifier.
- I_D stability **is not a problem!**

Q: *I don't understand! Wouldn't the small-signal circuit be:*



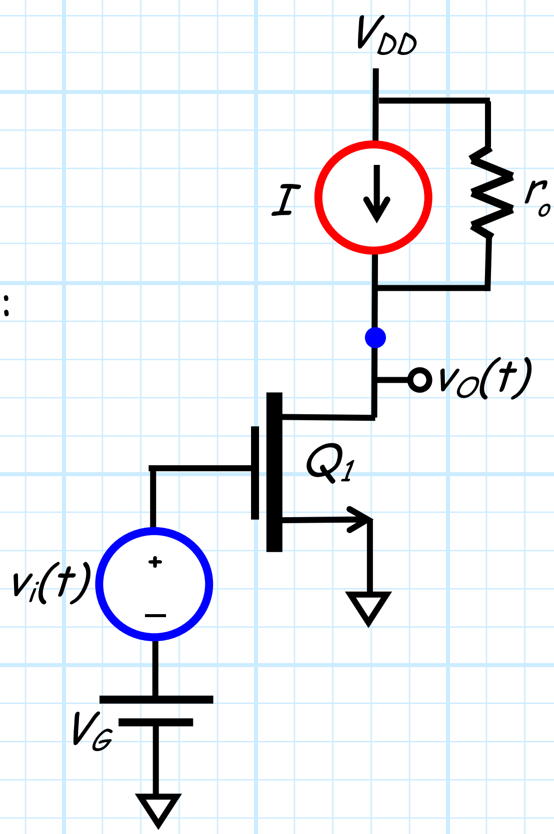
A: Remember, every **real** current source (as with every voltage source) has a **source resistance** r_o. A more **accurate** current source model is therefore:



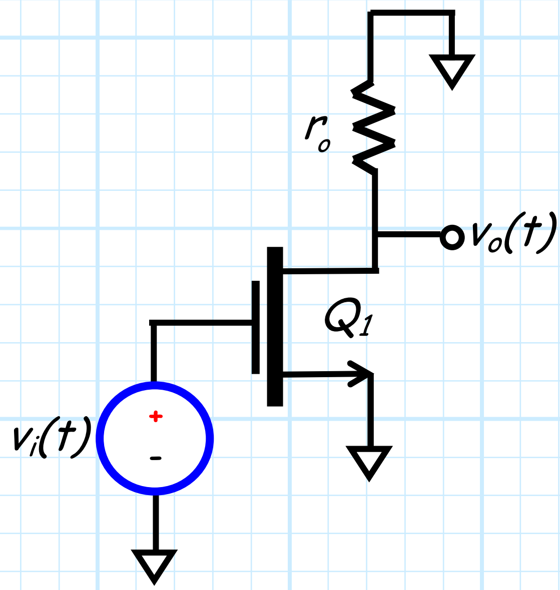
Ideally, $r_o = \infty$. However, for good current sources, this output resistance is large (e.g., $r_o = 100\ K\Omega$). Thus, we mostly **ignore** this value (i.e., approximate it as $r_o = \infty$), but there are some circuits where this resistance makes quite a **difference**.

This is one of those circuits!

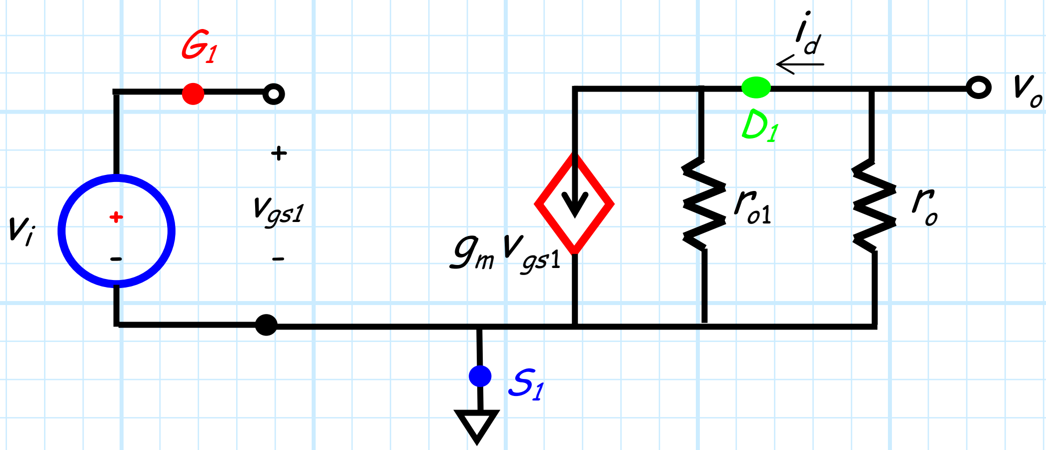
Therefore, a more **accurate** amplifier circuit schematic is:



And so the **small-signal circuit** becomes the familiar:

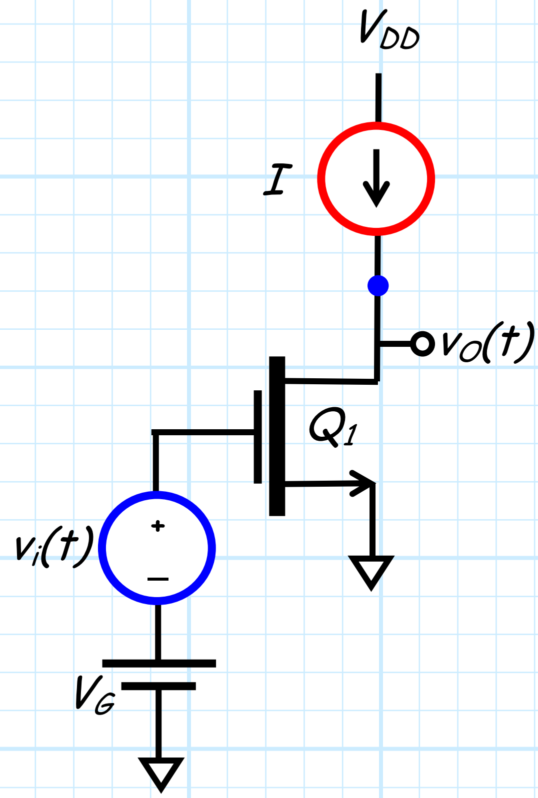


Therefore, with the hybrid-pi model:

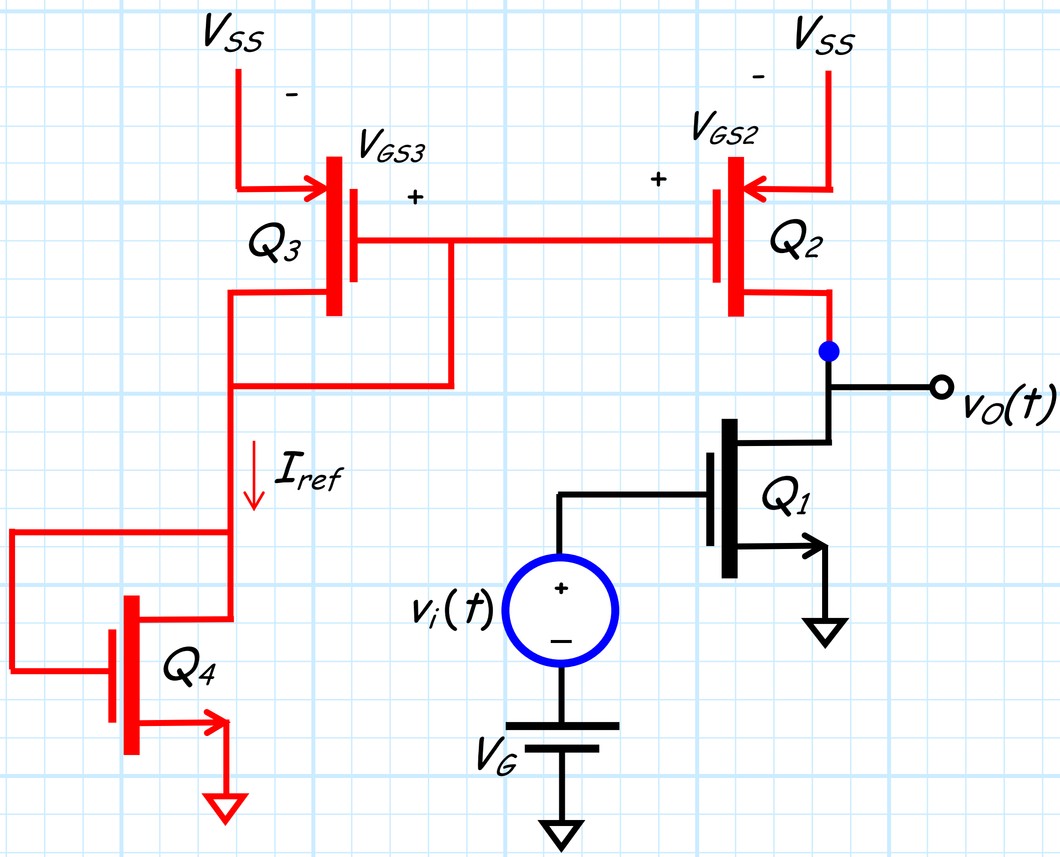


Q: *But, we implement a current source using a **current mirror**. What is the **output resistance** r_o of a current mirror?*

A: Implementing a **PMOS** current mirror, we find that our amplifier circuit:



is specifically:



Q: *Yikes! Where did all those **transistors** come from? What is it that they **do**?*

A: Transistors Q_2, Q_3, and Q_4 form the **current mirror** that acts as the **current source**. Note that transistor Q_4 is an **enhancement load**—it acts as the **resistor** in the current mirror circuit.

Note this amplifier circuit is **entirely** made of NMOS and PMOS **transistors**—we can "easily" implement this amplifier as an **integrated circuit**!

Q: *So again, what **is** the source resistance r_o of this current source?*

A: Let's determine the **small-signal circuit** for this integrated circuit amplifier and find out!

Q: *But there are **four** (count em') transistors in this circuit, determining the small-signal circuit must **take forever**!*

A: Actually **no**.

The important thing to realize when analyzing **this** circuit is that the gate-to-source voltage for transistors Q_2, Q_3, and Q_4 are **DC values**!

Q: *??*

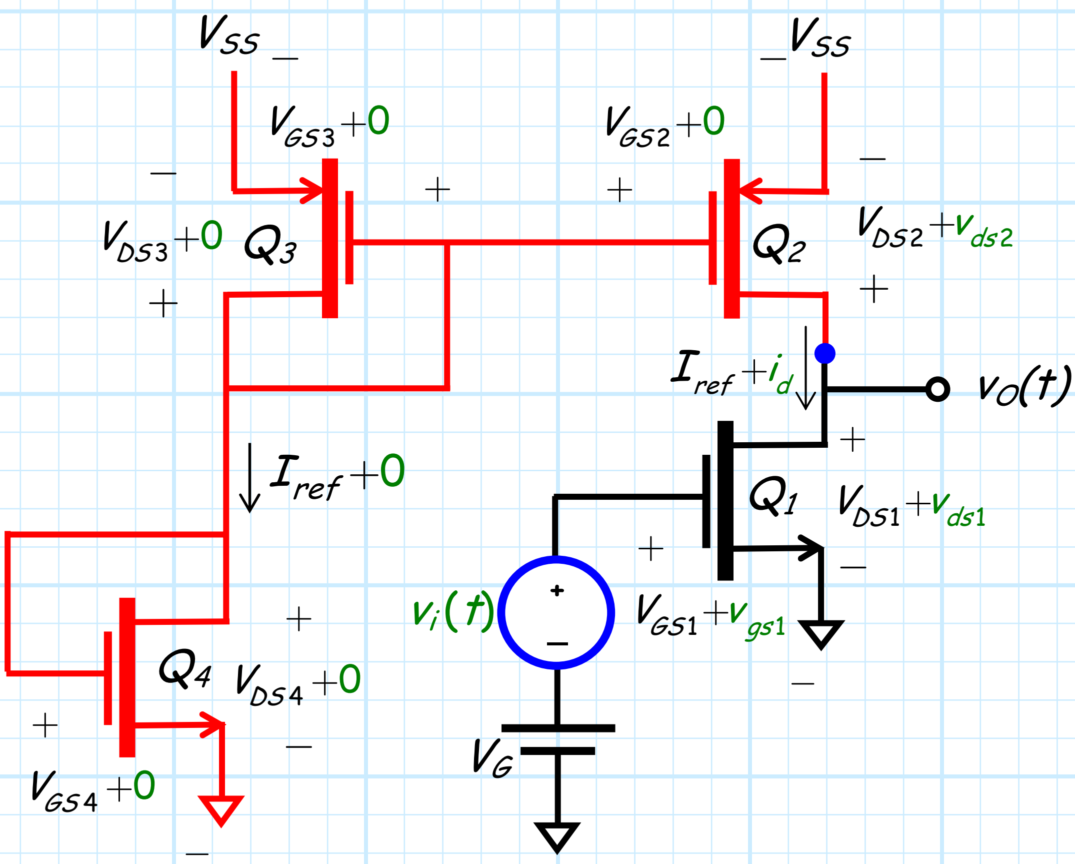
A: In other words, the small signal voltages v_{gs} for each transistor are equal to **zero**:

$$v_{gs2} = v_{gs3} = v_{gs4} = 0$$

Q: *But doesn't the small-signal source $v_i(t)$* ***create*** *small-signal voltages and currents* ***throughout*** *the amplifier?*

A: For **some** of the circuit yes, but for **most** of the circuit no!

Note that for transistor Q_1 there will be small-signal voltages $v_{gs1}(t)$ and $v_{ds1}(t)$, along with $i_{d1}(t)$. Likewise for transistor Q_2, a small-signal voltage $v_{ds2}(t)$ and current $i_{d2}(t)$ will occur.



But, for the remainder of the voltages and currents in this circuit (e.g., V_{DS4}, V_{GS2}, I_{D3}), the small-signal component is zero!

Q: *But wait!* ***How*** *can there be a small-signal* ***drain current*** $i_{d2}(t)$ *through transistor* Q_2*,* ***without*** *a corresponding small-signal* ***gate-to-source voltage*** $v_{gs2}(t)$*?*

A: Transistor Q_2, is **the** important device in this analysis.

Note its gate-to-source voltage is a **DC value** (no small-signal component!), yet there **must** be (by KCL) a **small-signal** drain current $i_{d2}(t)$!

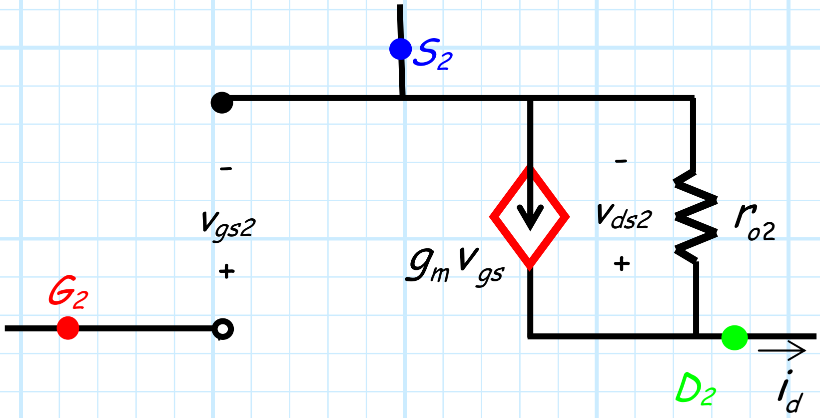
This is a case where we **must** consider the **MOSFET output resistance** r_{o2}. The small-signal drain current for a **PMOS** device is:

$$i_{d2} = g_{m2}\, v_{gs2} - \frac{v_{ds2}}{r_{o2}}$$

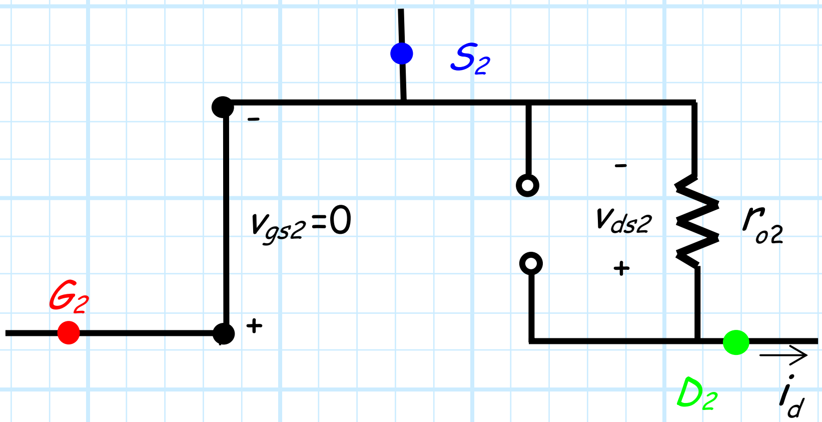
Since $v_{gs2}=0$, this equation **simplifies** to:

$$i_{d2} = -\frac{v_{ds2}}{r_{o2}}$$

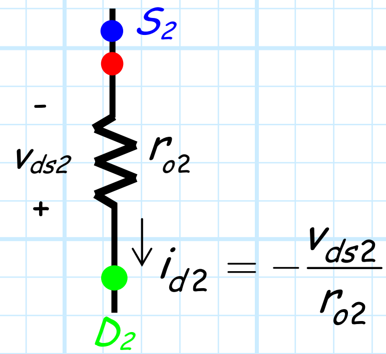
Equivalently, the **small-signal PMOS model** is:



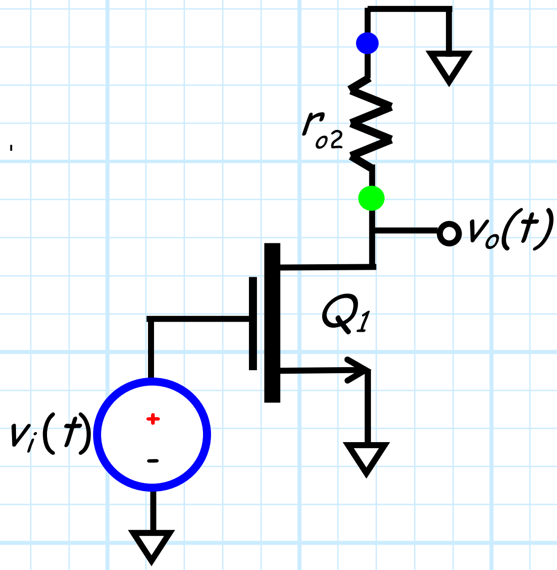
Thus for $v_{gs2}=0$, the small-signal model becomes:



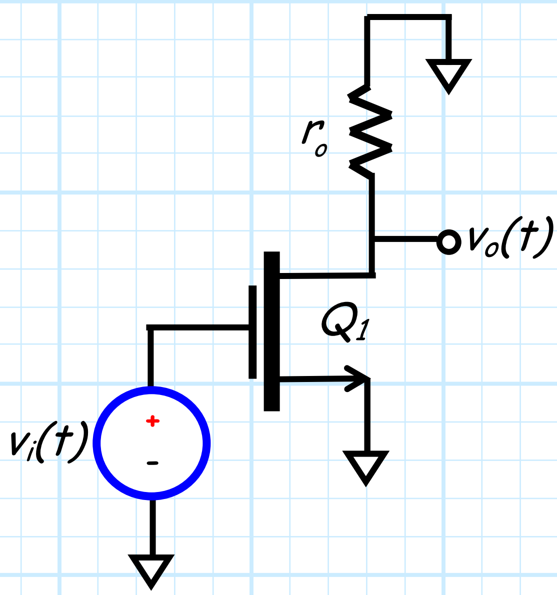
Or, simplifying further:



Thus, the small-signal model of the entire current mirror is simply the output resistance of the MOSFET $\boldsymbol{Q_2}$!



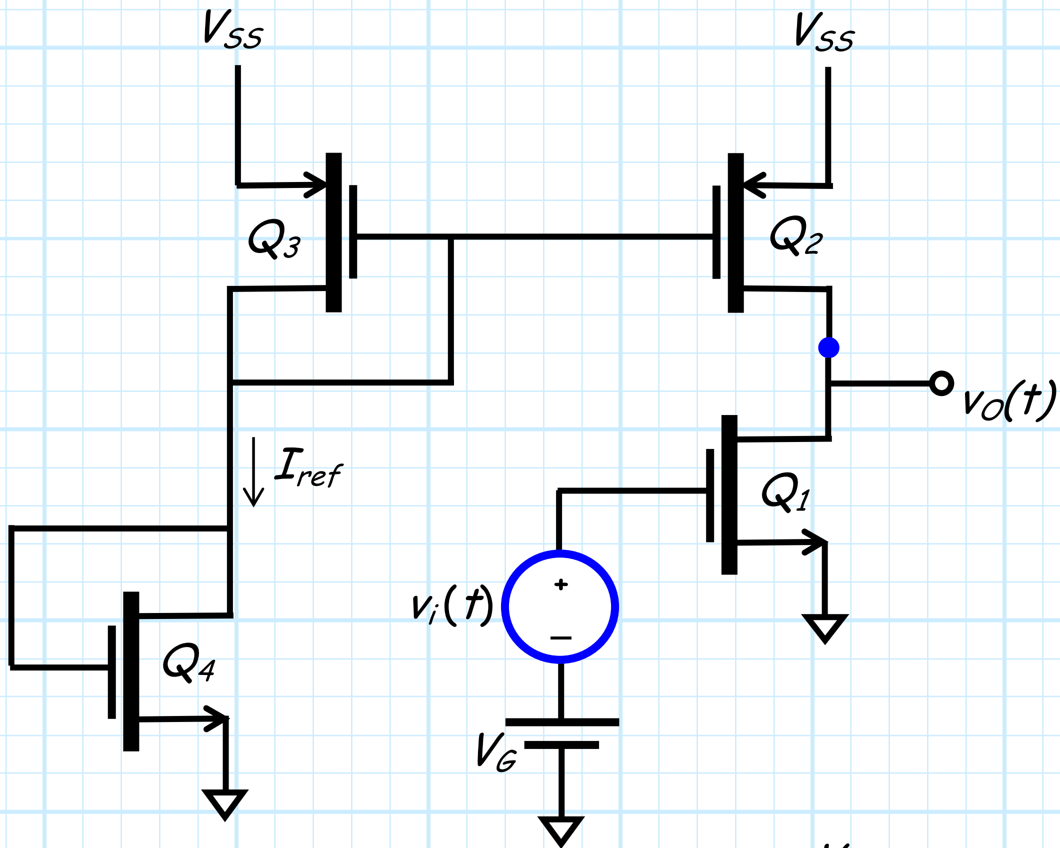
Comparing this to the earlier analysis--with a current source of output resistance r_o:



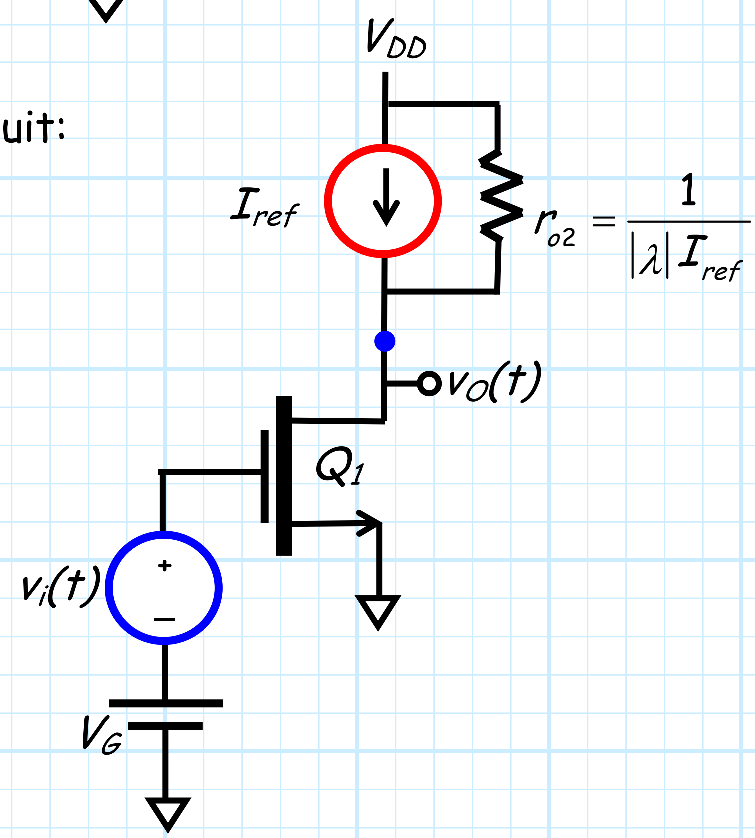
It is evident that the output resistance of the current mirror is simply equal to the output resistance of MOSFET Q_2 !!!!

$$r_o = r_{o2}$$

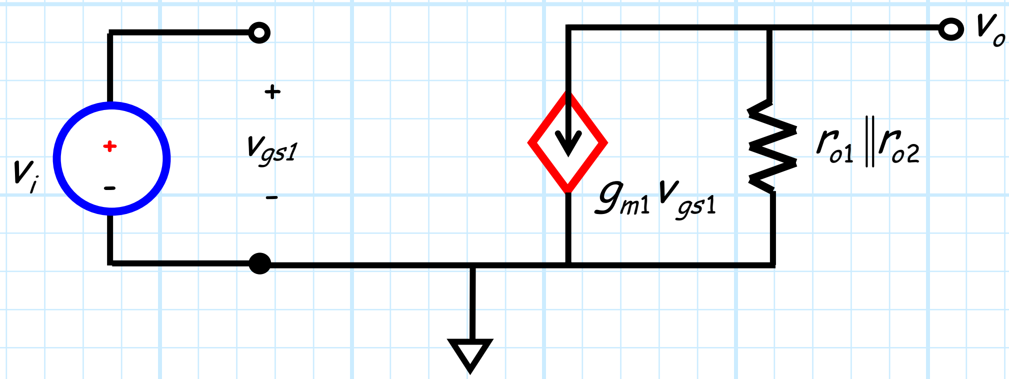
And so **this** circuit:



is equivalent to **this** circuit:



The resulting small-signal circuit of this amp is:



And so the **open-circuit voltage gain** is:

$$A_{vo} = -g_{m1}\left(r_{o1} \| r_{o2}\right) = 2\sqrt{K_1}\sqrt{I_{ref}}\left(r_{o1} \| r_{o2}\right)$$

Note **this** result is **far different** (i.e., larger) than the result when using the **enhancement load** for R_D:

$$A_{vo} = -\sqrt{\frac{K_1}{K_2}}$$

However, we find that the **output** and **input** resistances of this amplifier are the **same** as with the enhancement load:

$$R_i = \infty \qquad\qquad R_o = r_{o1} \| r_{o2}$$