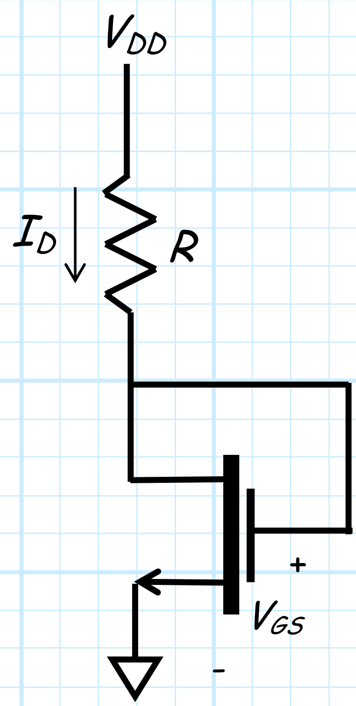
The MOSFET Current Mirror

Consider the following MOSFET circuit:



Note $V_D = V_G$, therefore:

$$V_{DS} = V_{GS}$$

and thus:

$$V_{DS} > V_{GS} - V_t$$

So, **if** $V_{GS} > V_t$, then the MOSFET is in **saturation**!

We know that for a MOSFET in saturation, the drain current is equal to:

$$I_D = K\left(V_{GS} - V_t\right)^2$$

Say we want this current I_D to be a **specific** value—call it I_{ref}.

Since $V_s = 0$, we find that from the above equation, the drain voltage must be:

$$V_D = \sqrt{\frac{I_{ref}}{K}} + V_t$$

Likewise, from KVL we find that:

$$I_{ref} = \frac{V_{DD} - V_D}{R}$$

And thus the **resistor** value to achieve the desired drain current I_{ref} is:

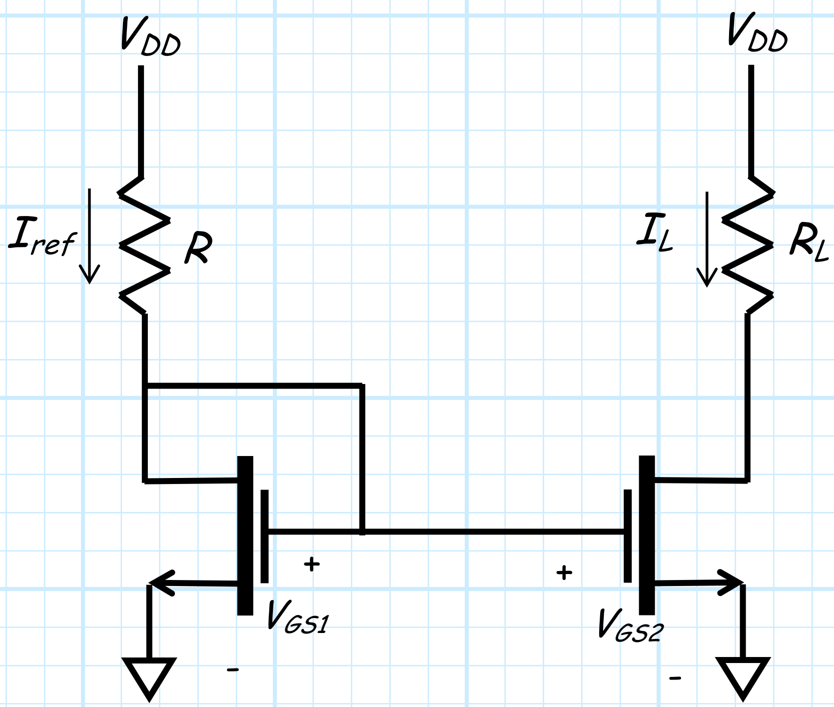
$$R = \frac{V_{DD} - V_D}{I_{ref}}$$

where:

$$V_D = \sqrt{\frac{I_{ref}}{K}} + V_t$$

Q: *Why are we doing this?*

A: Say we now add another component to the circuit, with a second MOSFET that is **identical** to the first :



Q: *So what is current I_L ?*

A: Note that the gate voltage of each MOSFET is the **same** (i.e., $V_{GS1} = V_{GS2}$), and if the MOSFETS are the **same** (i.e., $K_1 = K_2,\ V_{t1} = V_{t2}$), and if the second MOSFET is likewise in **saturation**, its drain current I_L is:

$$
\begin{aligned}
I_L &= K_2 \left(V_{GS2} - V_{t2}\right)^2 \\
&= K_1 \left(V_{GS1} - V_{t1}\right)^2 = I_{ref}
\end{aligned}
$$

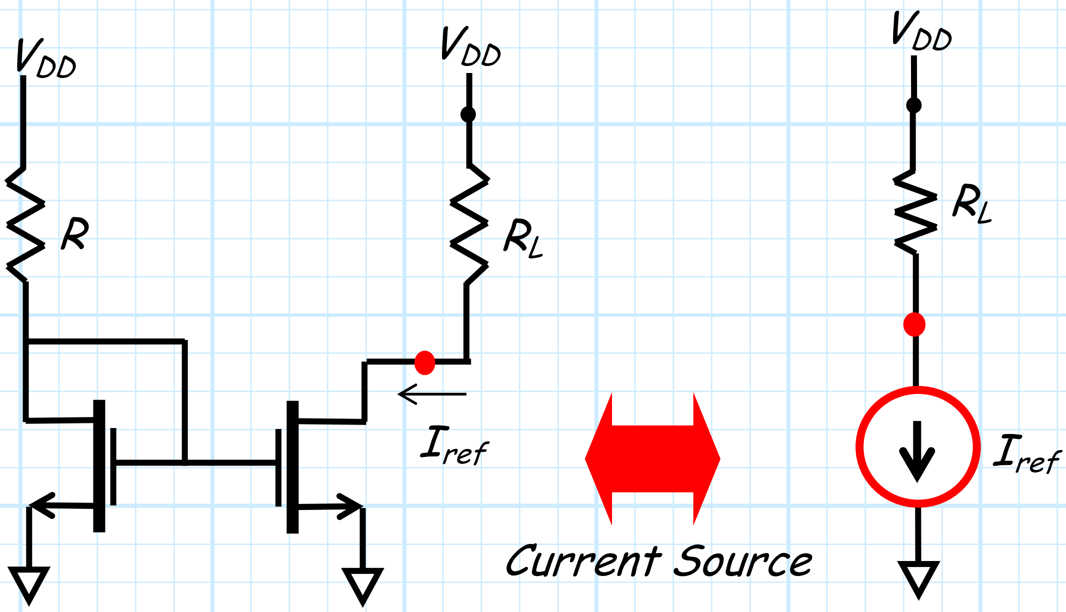
Therefore, the drain current of the **second** MOSFET is **equal** to the current of the **first**!

$$
I_{ref} = I_L
$$

Q: *Wait a minute! You mean to say that the current through the resistor R_L is **independent** of the value of resistor R_L ?*

A: Absolutely! As long as the second MOSFET is in **saturation**, the current through R_L is equal to I_{ref}—**period**.

The current through R_L is independent on the value of R_L (provided that the MOSFET remains in saturation). Think about what this means—this device is a **current source** !



Remember, the second MOSFET **must** be in saturation for the current through R_L to be a constant value I_{ref}. As a result, we find that:

$$V_{DS2} > V_{GS2} - V_{t2}$$

or for this example, since $V_s = 0$:

$$V_{D2} > V_{G2} - V_{t2}$$

Since $V_{D2} = V_{DD} - R_L I_{ref}$, we find that in order for the MOSFET to be in saturation:

$$V_{DD} - R_L I_{ref} > V_{G2} - V_{t2} = V_{G1} - V_{t1}$$

Or, sated another way, we find that the load resistor R_L can be **no larger** than:

$$R_L < \frac{V_{DD} - V_{G1} + V_{t1}}{I_{ref}}$$

Where we know that:

$$V_{G1} = V_{DD} - R\, I_{ref}$$

and thus we can alternatively write the above equation as:

$$R_L < R + \frac{V_{t1}}{I_{ref}}$$

If the **load** resistor becomes **larger** than $R + V_{t1}/I_{ref}$, the voltage V_{DS2} will drop **below** the excess gate voltage $V_{GS2} - V_{t2}$, and thus the second MOSFET will enter the **triode** region. As a result, the drain current will **not** equal I_{ref}—the current source will **stop working**!

Although the circuit presented here is sometimes referred to as a current **sink**, understand that the circuit is clearly a way of designing a **current source**.

We can also use **PMOS** devices to construct a current mirror!