

The MOSFET Current Mirror

Consider the following MOSFET circuit:

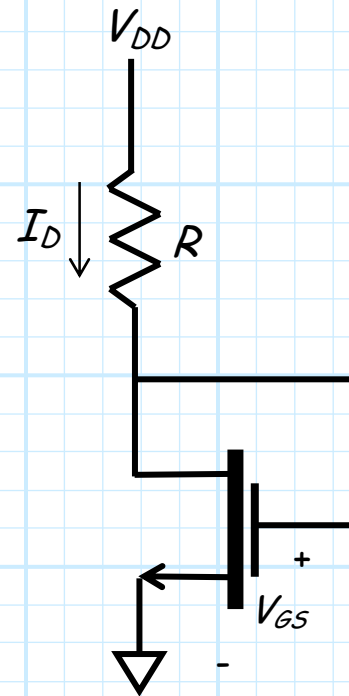
Note $V_D = V_G$, therefore:

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

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:

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

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:

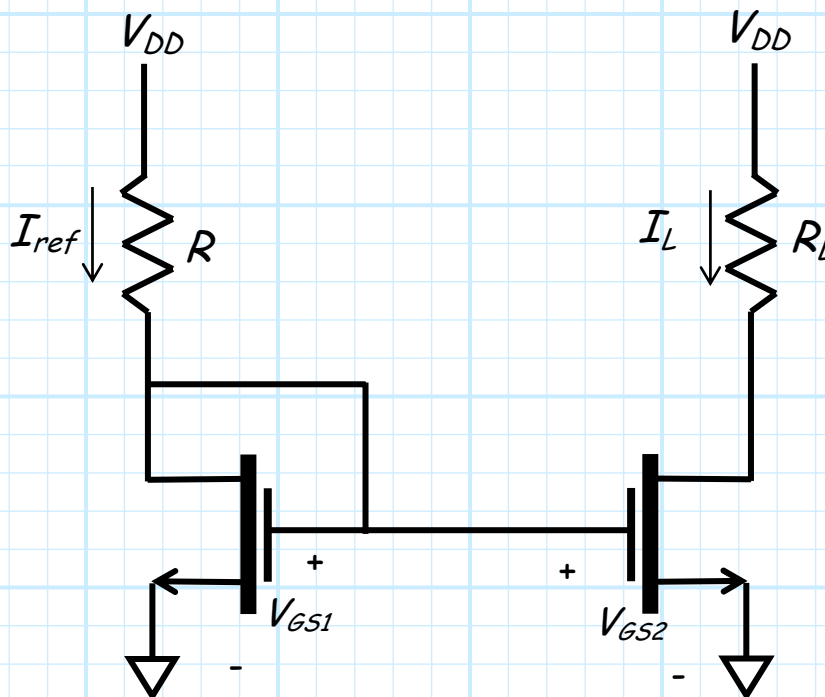
$$R = \frac{V_{DD} - V_D}{I_{ref}}$$

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:

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

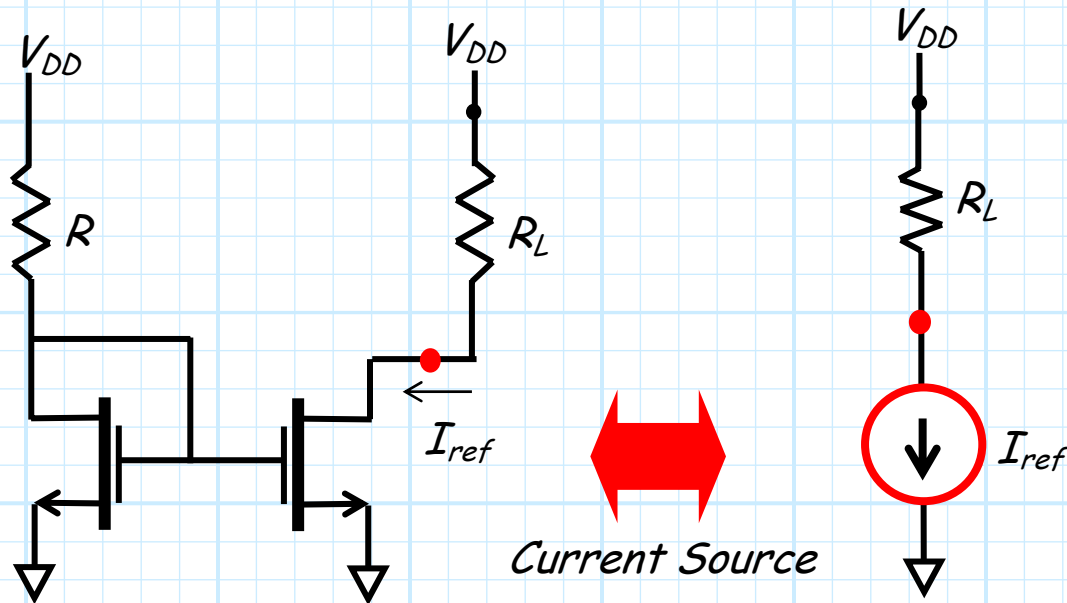
Therefore, the drain current of the **second** MOSFET is **equal** to the current of the **first**!

$$I_{ref} = I_L$$

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:

$$V_{D_{S2}} > V_{G_{S2}} - V_{t2}$$

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, stated 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!

