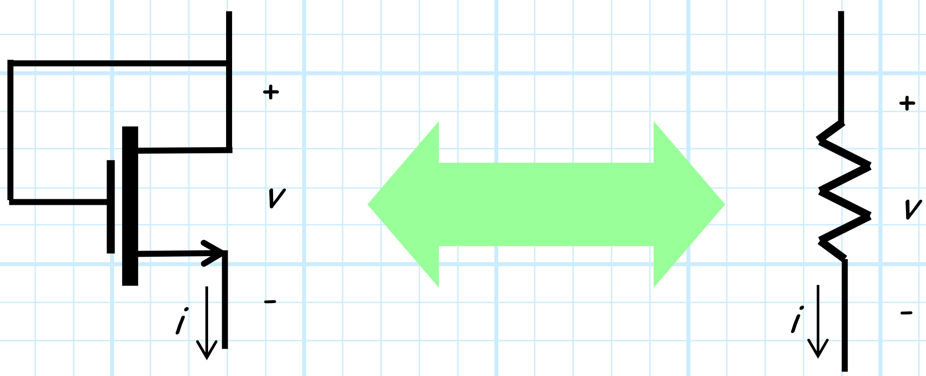
Enhancement Loads

Resistors take up far too much **space** on integrated circuit substrates.

Therefore, we need to make a **resistor** out of a **transistor**!

Q: *How can we do that!? After all, a resistor is a **two** terminal device, whereas a transistor is a **three** terminal device.*

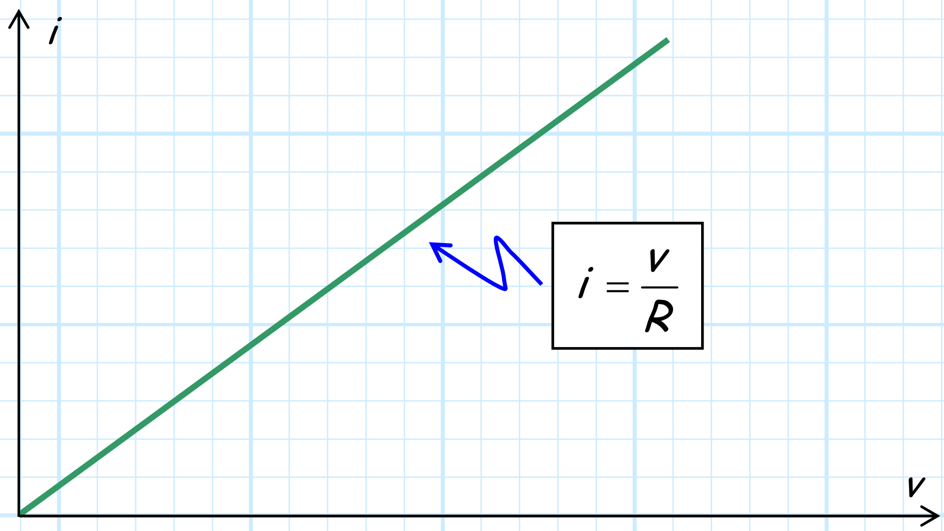
A: We can make a two terminal device from a MOSFET by **connecting** the gate and the drain!



Enhancement Load *Resistor Load*

Q: *How does this "**enhancement load**" resemble a resistor?*

A: Consider the *i-v* curve for a **resistor**:



Now consider the same curve for an **enhancement load**.

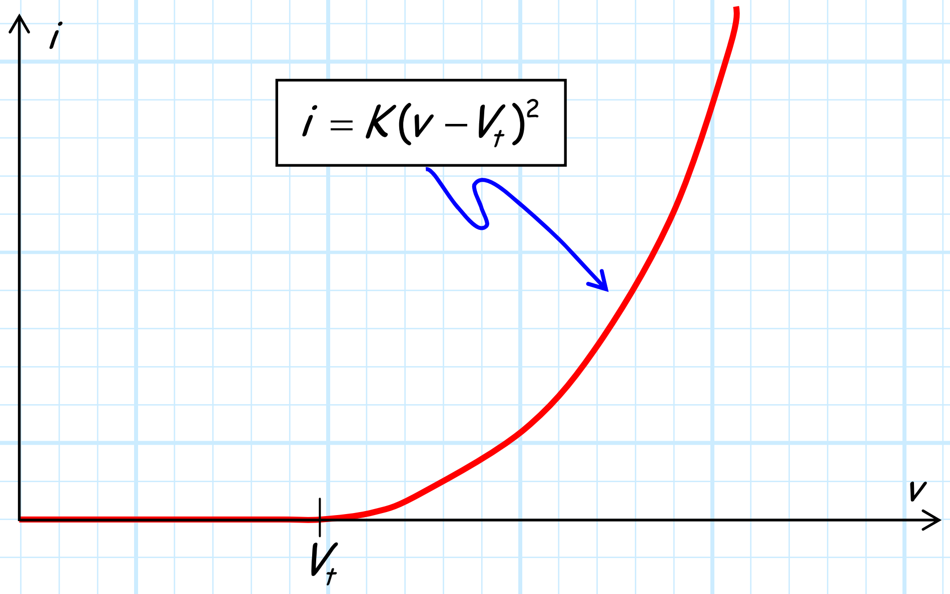
Since the gate is tied to the drain, we find $v_G = v_D$, and thus $v_{GS} = v_{DS}$. As a result, we find that $v_{DS} > v_{GS} - V_t$ **always**.

Therefore, we find that if $v_{GS} > V_t$, the MOSFET will be in **saturation** ($i_D = K(v_{GS} - V_t)^2$), whereas if $v_{GS} < V_t$, the MOSFET is in **cutoff** ($i_D = 0$).

Since for enhancement load $i = i_D$ and $v = v_{GS}$, we can describe the enhancement load as:

$$i = \begin{cases} 0 & \text{for } v < V_t \\ K(v - V_t)^2 & \text{for } v > V_t \end{cases}$$

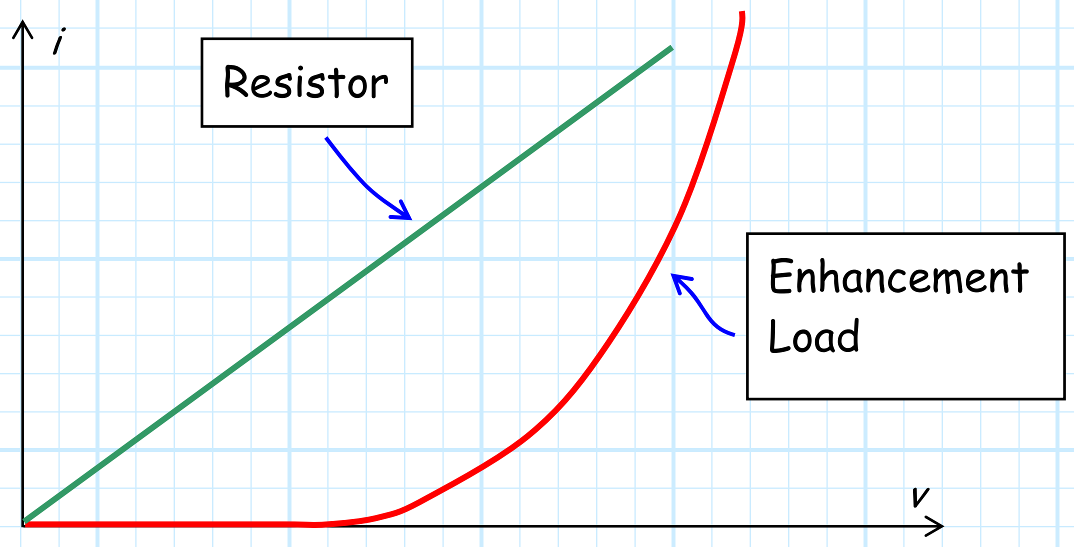
Plotting this equation:



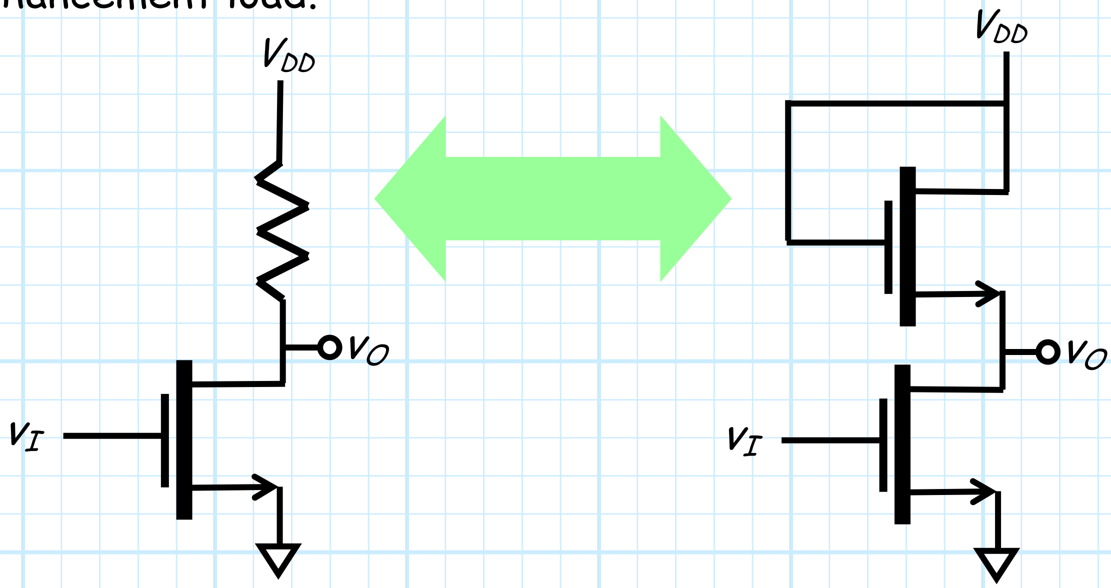
So, resistors and enhancement loads are far from **exactly** the same, but:

1) They **both** have $i = 0$ when $v = 0$.

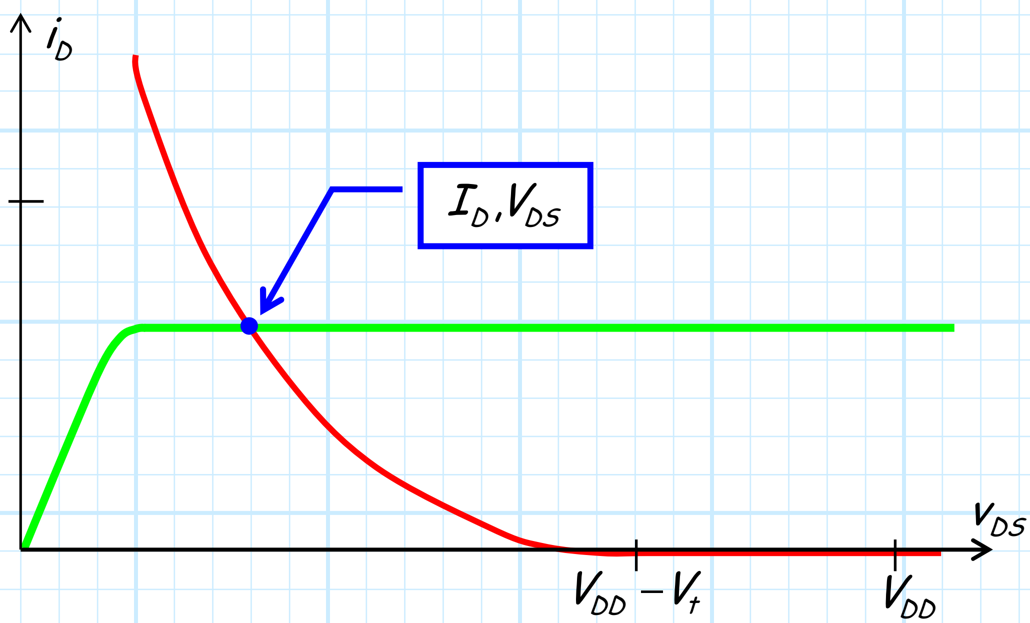
2) They **both** have increasing current i with increasing voltage v.



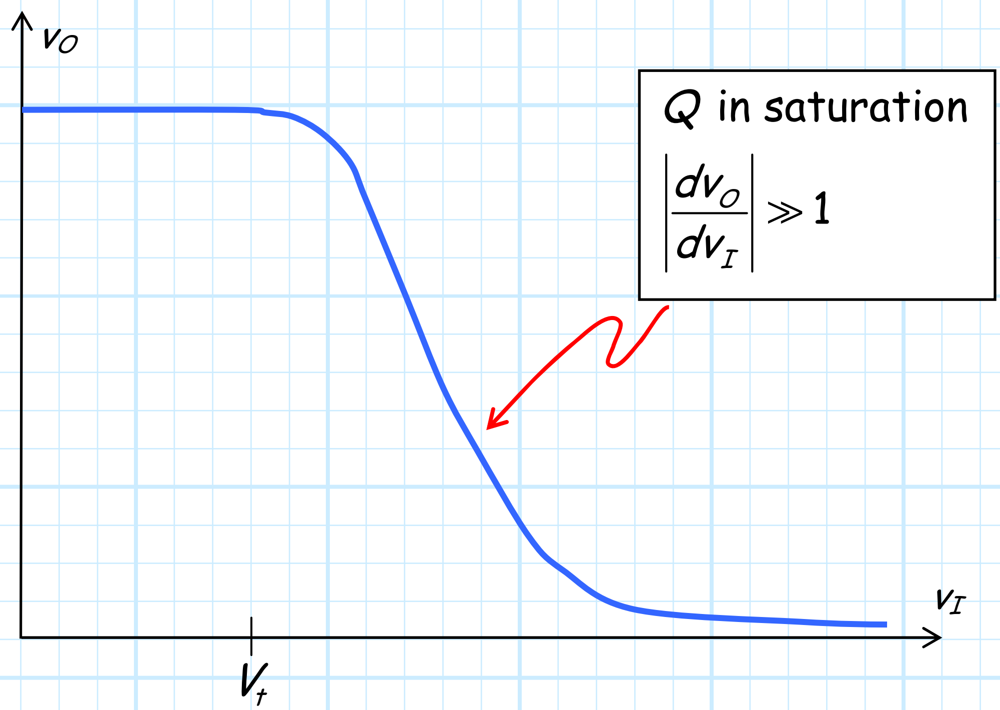
Therefore, we can build a **common source** amplifier with either a resistor, or in the case of an **integrated circuit**, an enhancement load.



For the enhancement load amplifier, the **load line** is replaced with a **load curve** ($v = V_{DD} - v_{DS}$)!



And the **transfer function** of this circuit is:



Q: *What is the **small signal** behavior of an enhancement load?*

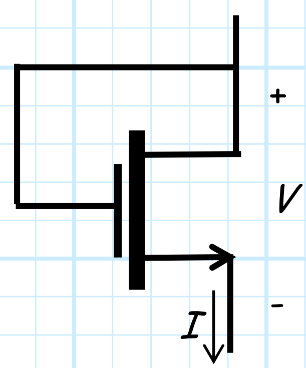
A: The enhancement load is made of a MOSFET device, and we **understand** the small-signal behavior for a MOSFET!

Step 1 - DC Analysis

If $V > V_t$, then $I = K\left(V - V_t\right)^2$

or:

$$V = \sqrt{\frac{I}{K}} + V_t$$



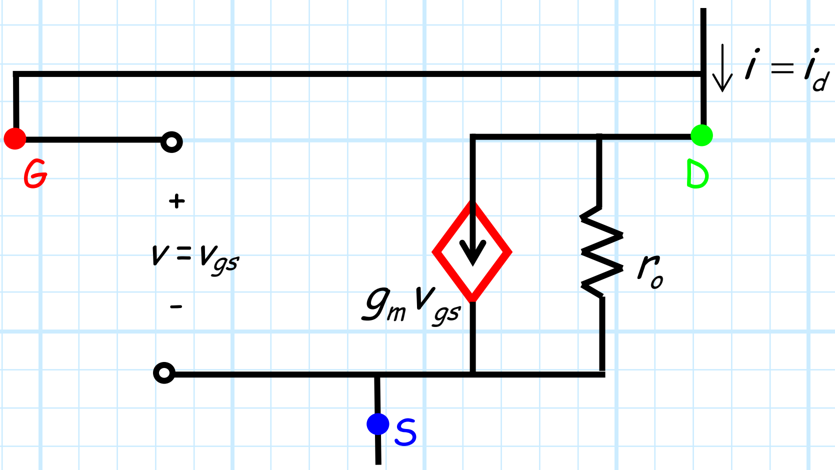
Step 2 – Determine g_m and r_o

$$g_m = 2K\left(V_{GS} - V_t\right) = 2K\left(V - V_t\right)$$

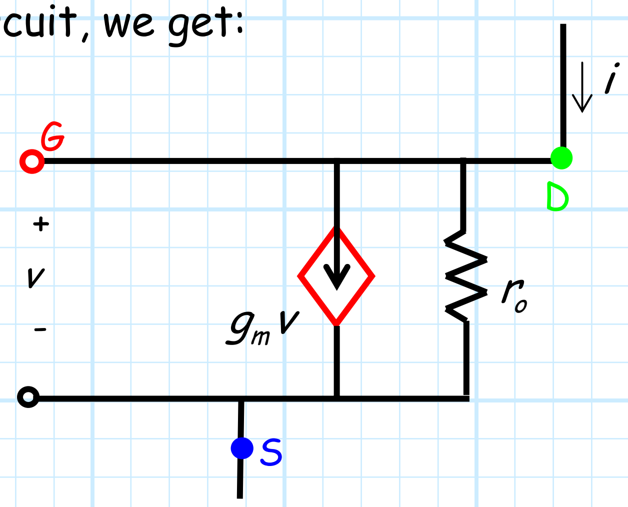
$$r_o = \frac{1}{\lambda I_D} = \frac{1}{\lambda I} = \frac{1}{\lambda K\left(V - V_t\right)^2}$$

Step 3 – Determine the small-signal circuit

Inserting the MOSFET **small-signal model**, we get:



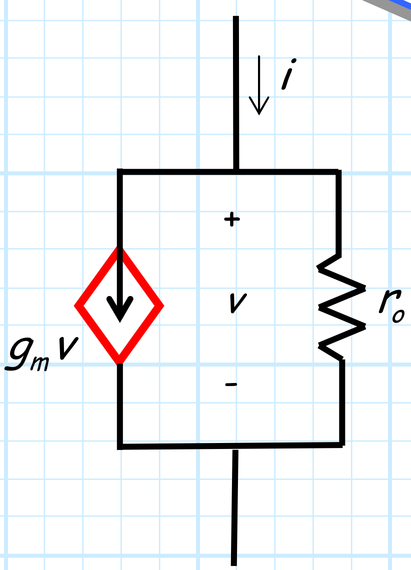
Redrawing this circuit, we get:

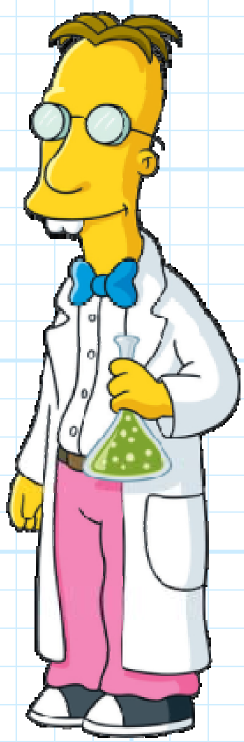


Or, simplifying further, we have the small-signal equivalent circuit for an enhancement load:

*It is imperative that **you** understand that the circuit to my right is the **small-signal equivalent circuit** for an enhancement load.*

*Please replace all **enhancement loads** with this small-signal model whenever you are attempting to find the **small-signal circuit** of any MOSFET amplifier.*





Enhancement Load Small-Signal Model