6.002 CIRCUITS AND ELECTRONICS

Dependent Sources and Amplifiers

Review

- Nonlinear circuits — can use the node method
- Small signal trick resulted in linear response

Today

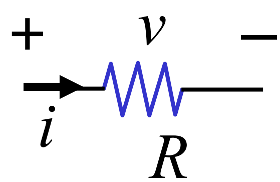
- Dependent sources
- Amplifiers

Reading: Chapter 7.1, 7.2

Dependent sources

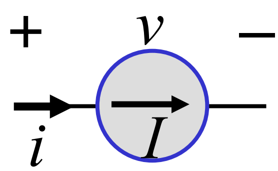
Seen previously

Resistor



$$i = \frac{v}{R}$$

Independent
Current source

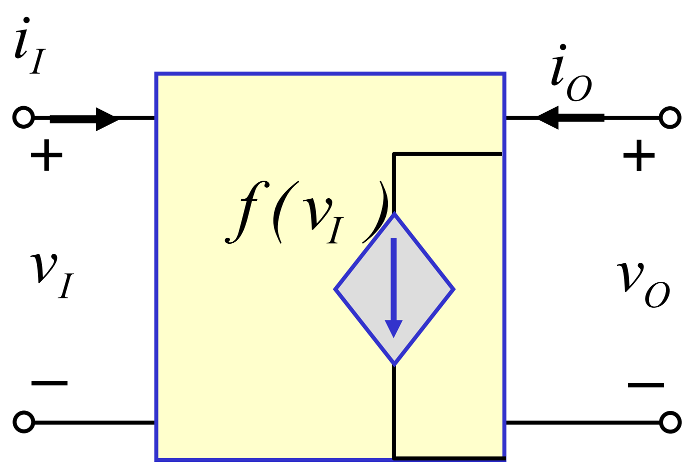


$$i = I$$

2-terminal 1-port devices

New type of device: Dependent source

control
port



output
port

2-port device

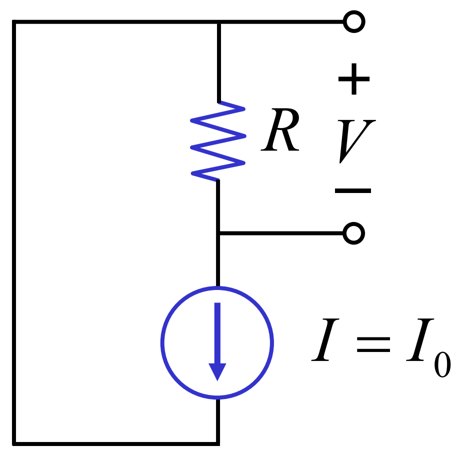
E.g., Voltage Controlled Current Source

Current at output port is a function of voltage at the input port

Dependent Sources: Examples

Example 1: Find V

independent
current
source

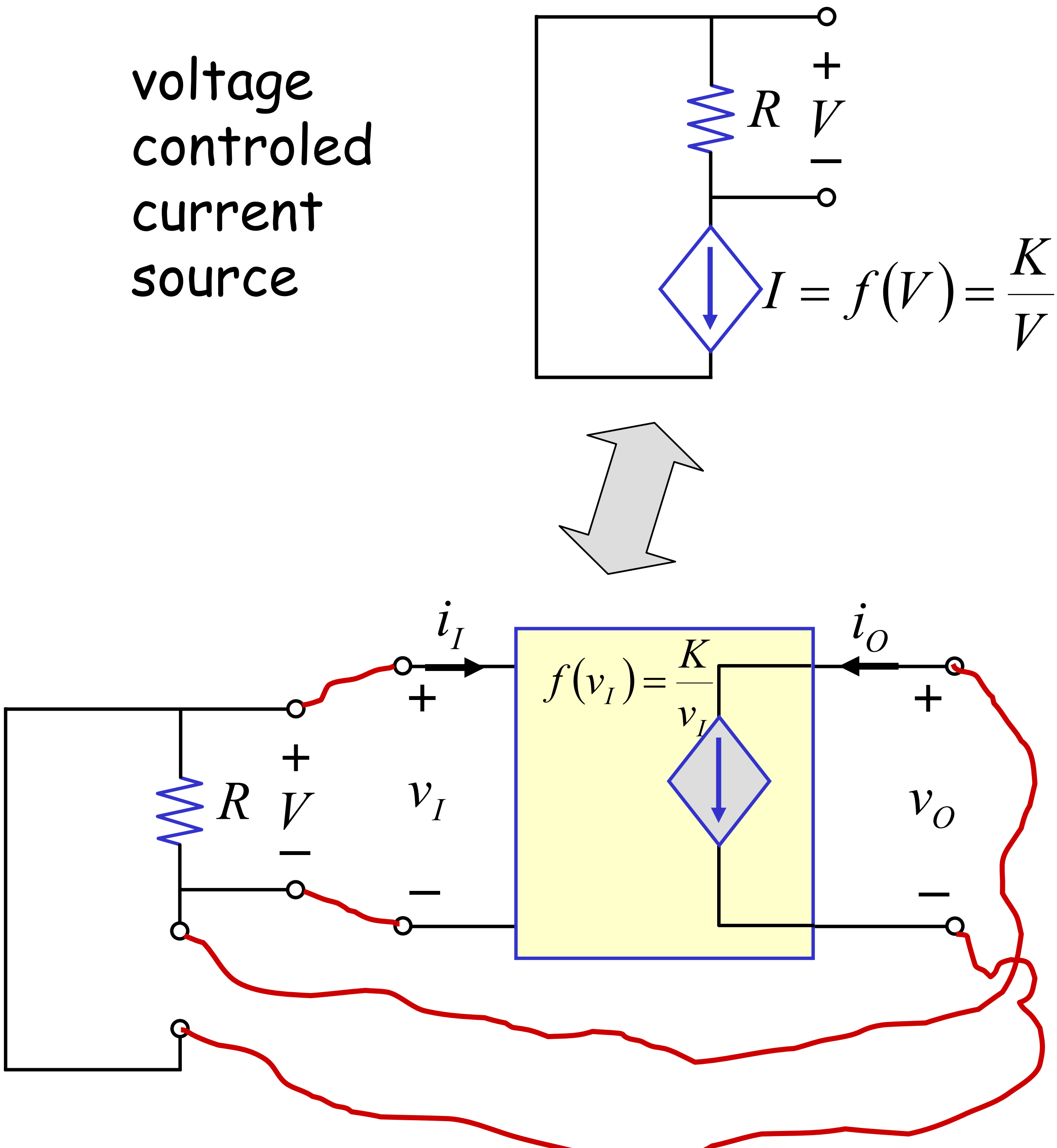


$$V = I_0 R$$

Dependent Sources: Examples

Example 2: Find V

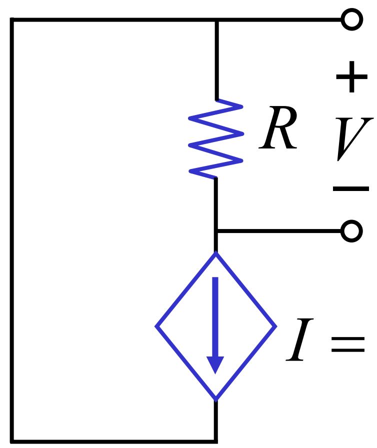
voltage
controled
current
source



Dependent Sources: Examples

Example 2: Find V

voltage
controled
current
source



e.g. $K = 10^{-3}\ Amp \cdot Volt$

$R = 1k\Omega$

$$V = IR = \frac{K}{V} R$$

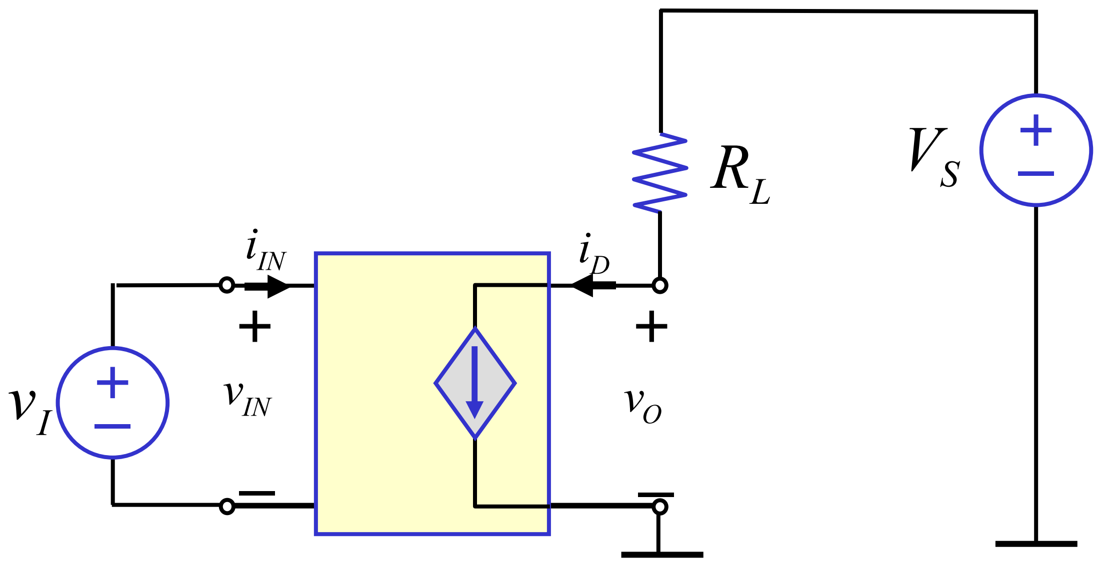
or $V^2 = KR$

or $V = \sqrt{KR}$

$$= \sqrt{10^{-3} \cdot 10^{3}}$$

$$= 1\ Volt$$

Another dependent source example



$$i_D = f(v_{IN})$$

e.g.

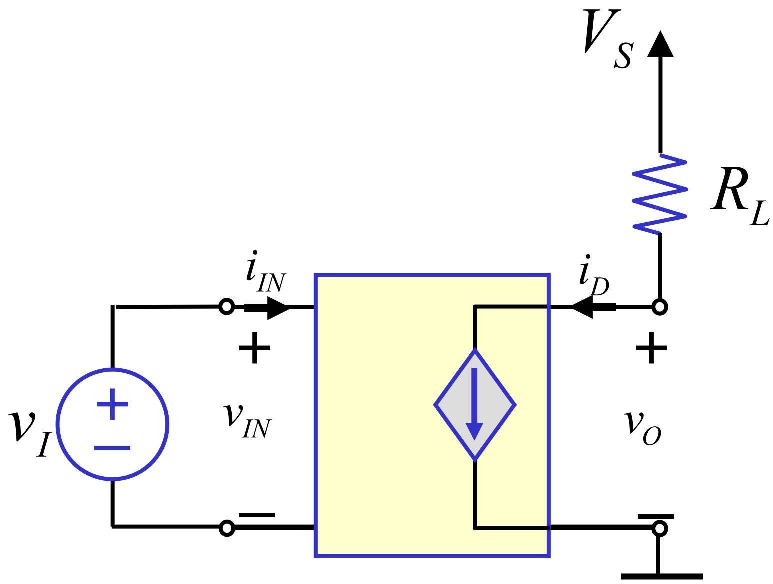
$$i_D = f(v_{IN})$$

$$= \frac{K}{2}(v_{IN} - 1)^2 \quad \text{for} \quad v_{IN} \geq 1$$

$$i_D = 0 \qquad \text{otherwise}$$

Find v_O as a function of v_I.

Another dependent source example



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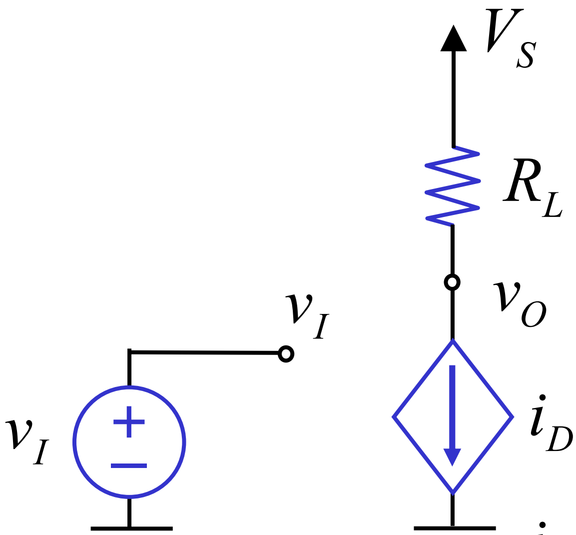

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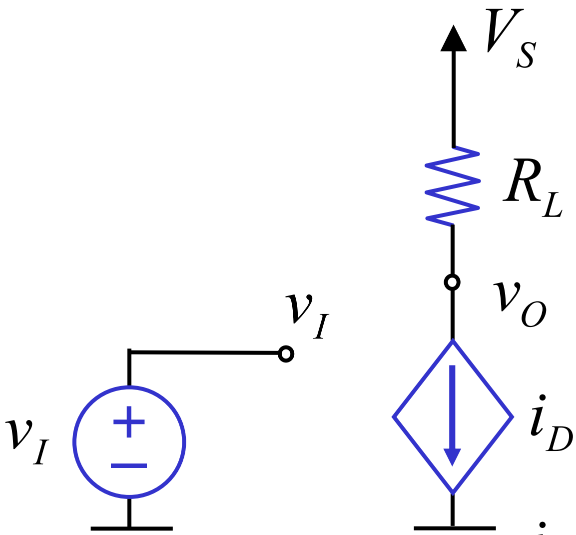


$$i_D = \frac{K}{2}(v_{IN} - 1)^2 \quad \text{for } v_{IN} \geq 1$$

$$i_D = 0 \quad \text{otherwise}$$

KVL

$$-V_S + i_D R_L + v_O = 0$$

$$v_O = V_S - i_D R_L$$

$$\boxed{v_O = V_S - \frac{K}{2}(v_I - 1)^2 R_L \quad \text{for } v_I \geq 1}$$

$$v_O = V_S \quad \text{for } v_I < 1$$

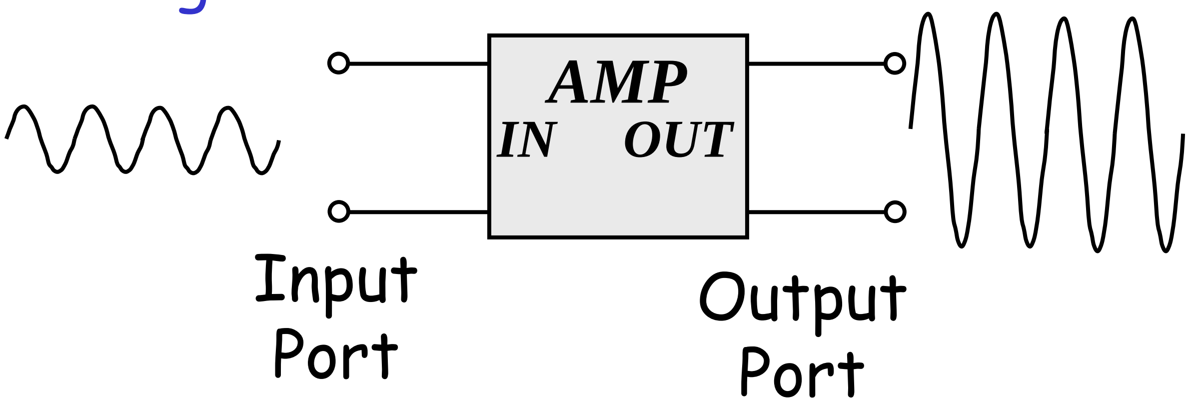
Hold that thought

Next, Amplifiers

Why amplify?

Signal amplification key to both analog and digital processing.

Analog:

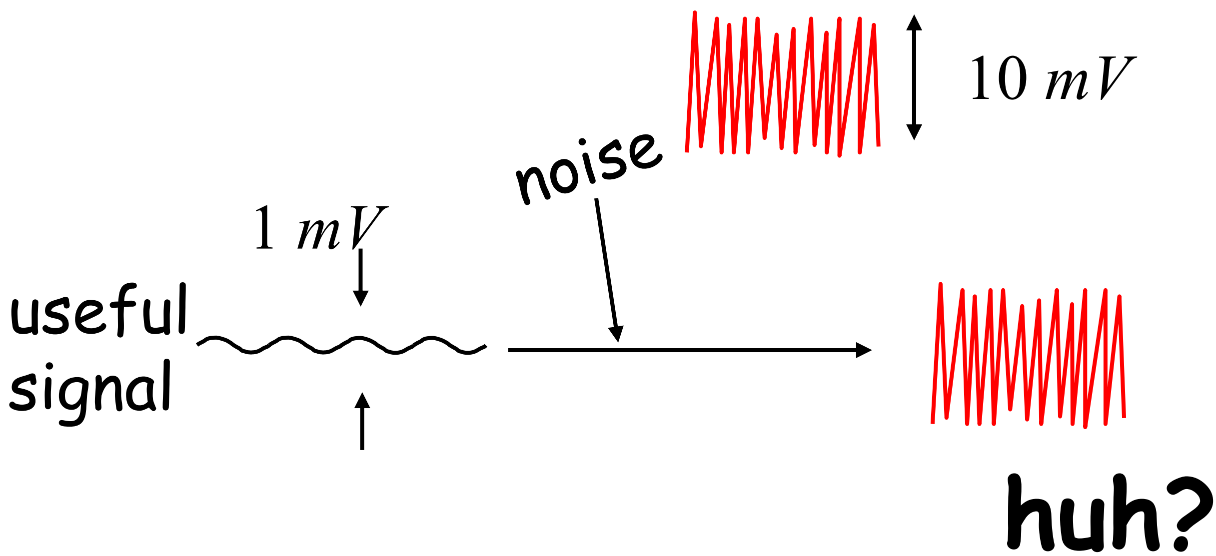


Besides the obvious advantages of being heard farther away, amplification is key to noise tolerance during communcation

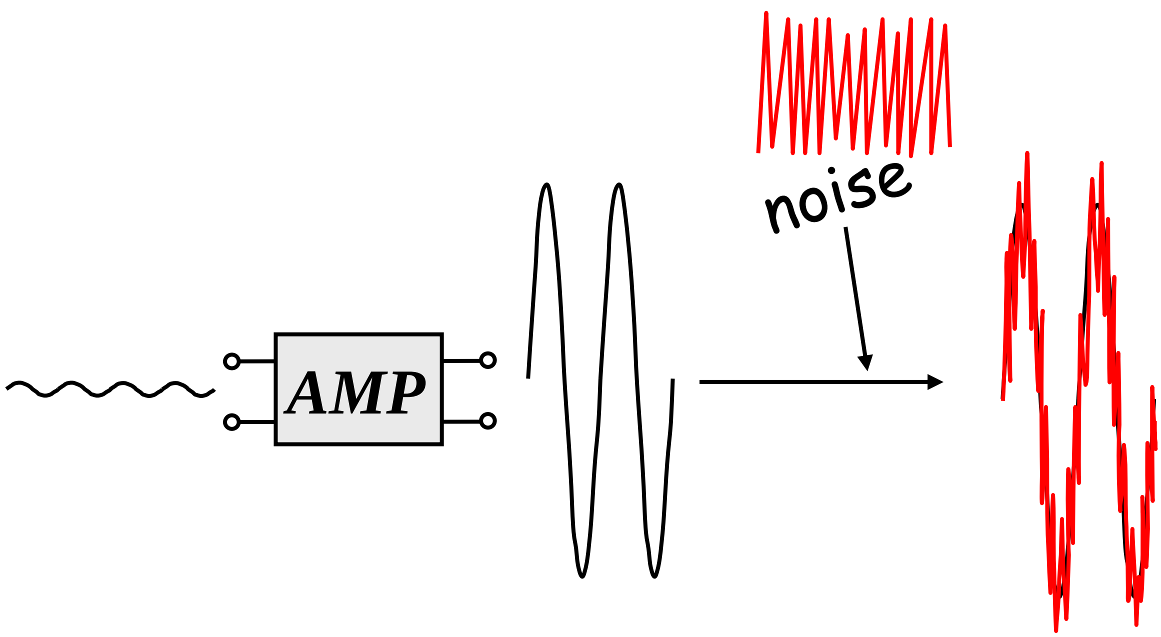
Why amplify?

Amplification is key to noise tolerance during communcation

No amplification



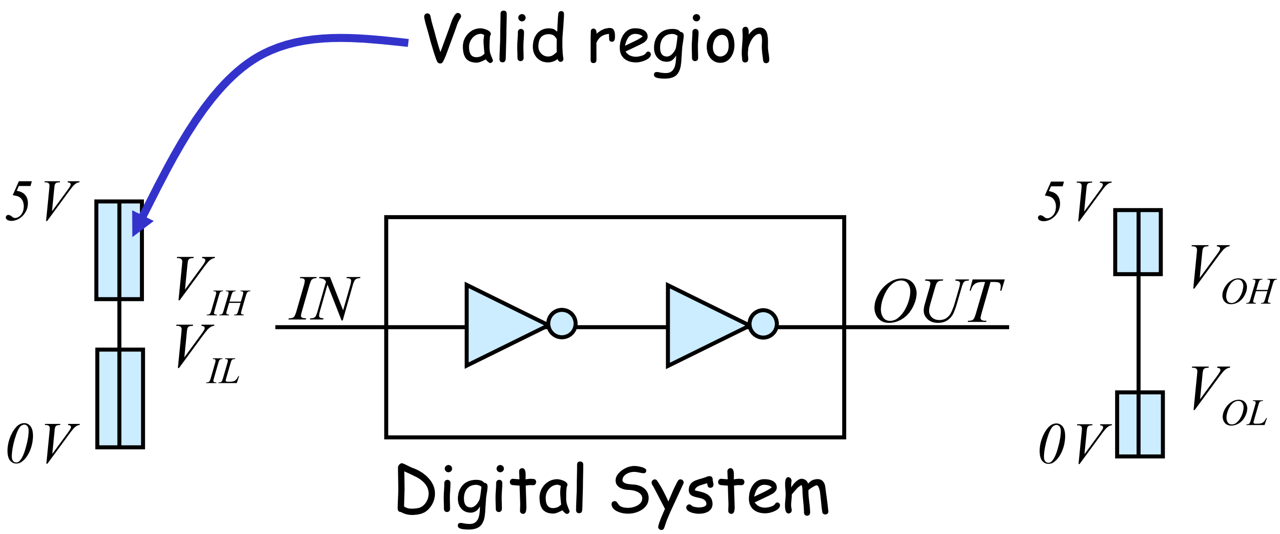
Try amplification

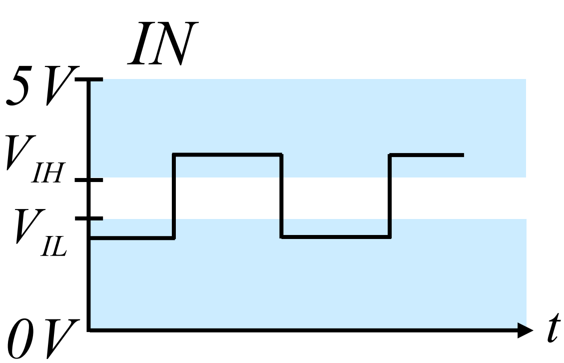


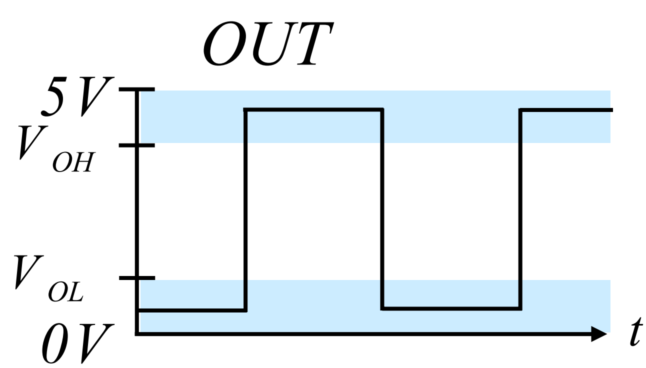
not bad!

Why amplify?

Digital:





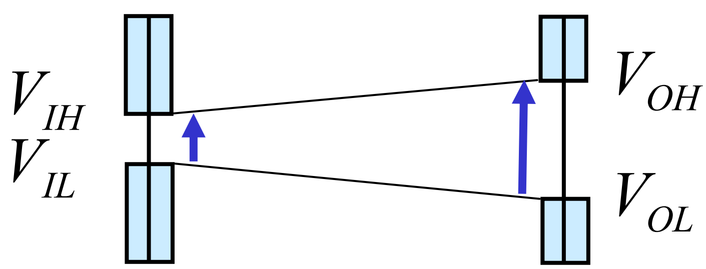


Why amplify?

Digital:

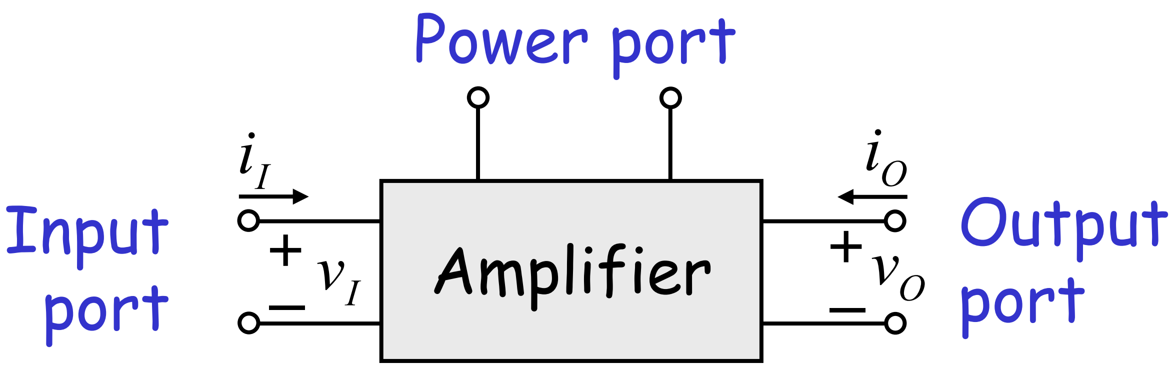
Static discipline requires amplification!

Minimum amplification needed:



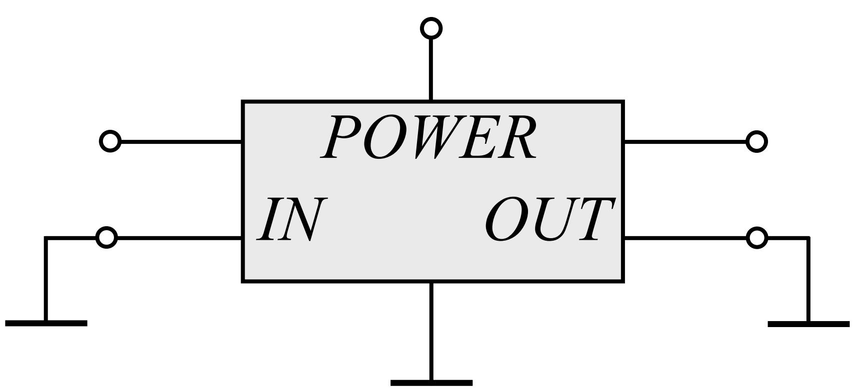
$$\frac{V_{OH} - V_{OL}}{V_{IH} - V_{IL}}$$

An amplifier is a 3-ported device, actually



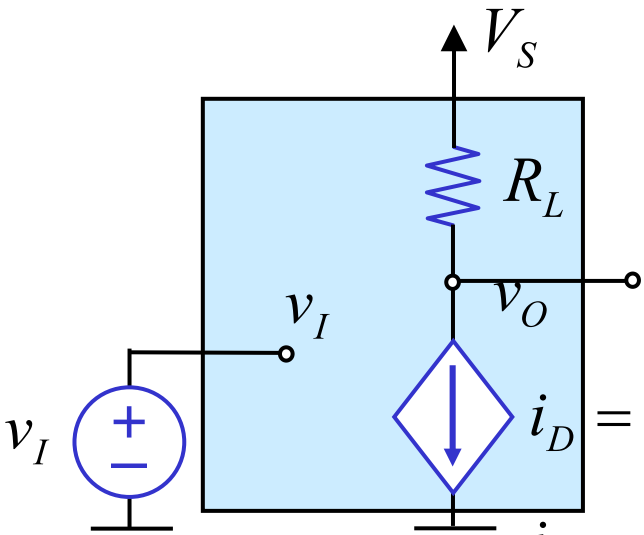
We often don't show the power port.

Also, for convenience we commonly observe "the common ground discipline."
In other words, all ports often share a common reference point called "ground."



How do we build one?

Remember?



$$i_D = \frac{K}{2}(v_{IN} - 1)^2 \quad \text{for } v_{IN} \geq 1$$

$$i_D = 0 \quad \text{otherwise}$$

KVL

$$-V_S + i_D R_L + v_O = 0$$

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$$v_O = V_S \quad \text{for } v_I < 1$$

Claim: This is an amplifier

So, where's the amplification?

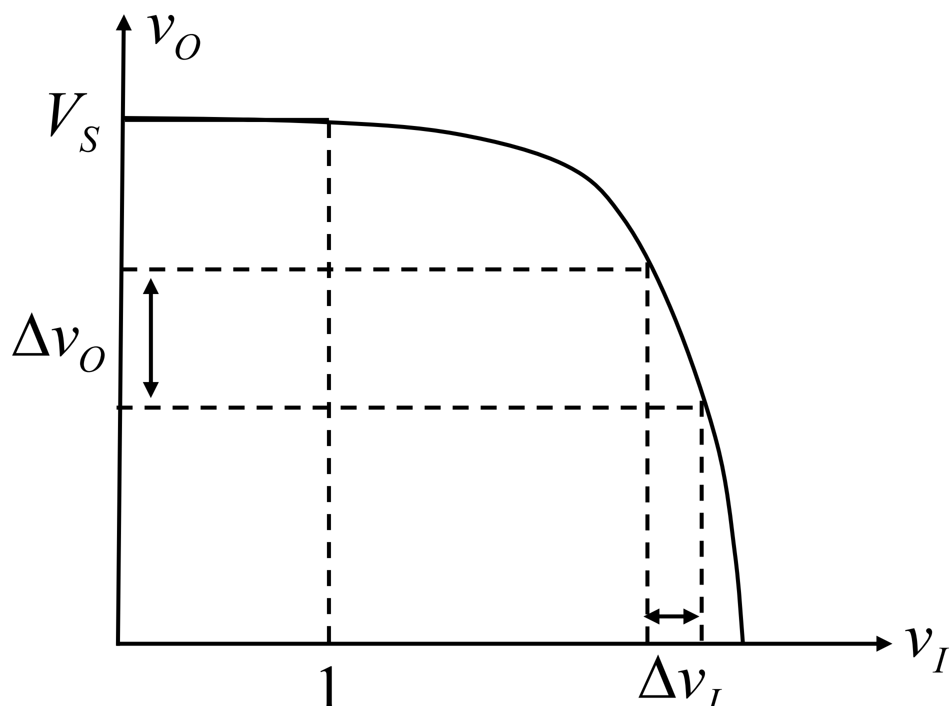
Let's look at the v_O versus v_I curve.

e.g. $\quad V_S = 10V, \quad K = 2\frac{mA}{V^2}, \quad R_L = 5k\Omega$

$$v_O = V_S - \frac{K}{2} R_L \left(v_I - 1\right)^2$$

$$= 10 - \frac{\cancel{2}}{\cancel{2}} \cdot \cancel{10}^{-3} \cdot 5 \cdot \cancel{10}^{3} \left(v_I - 1\right)^2$$

$$v_O = 10 - 5\left(v_I - 1\right)^2$$



$\frac{\Delta v_O}{\Delta v_I} > 1 \longrightarrow$ amplification

Plot v_O versus v_I

$$v_O = 10 - 5\,(v_I - 1)^2$$

v_I	v_O
0.0	10.00
1.0	10.00
1.5	8.75
2.0	5.00
2.1	4.00
2.2	2.80
2.3	1.50
2.4	$\sim$ 0.00

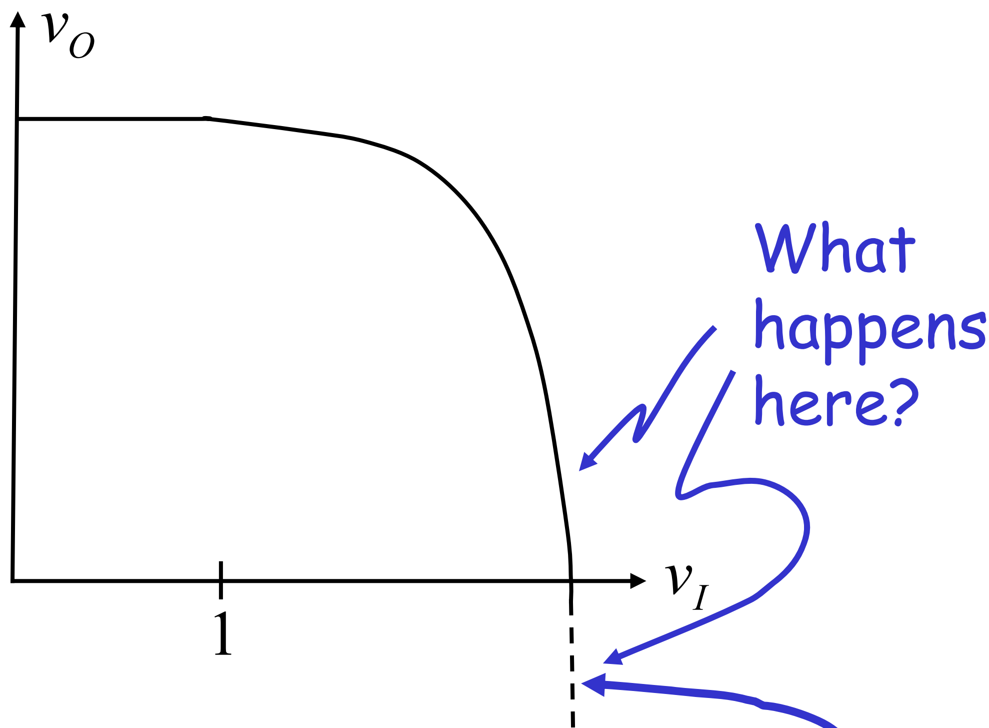
0.1 change in v_I

1V change in v_O

Gain!

Measure v_O.

One nit …

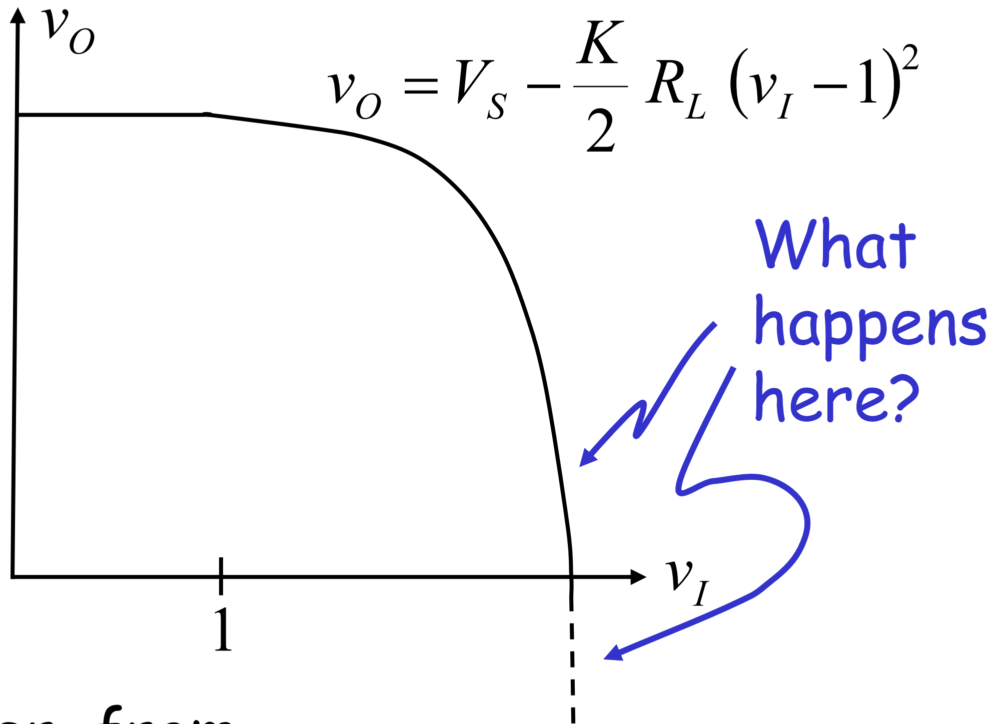


Mathematically,

$$v_O = V_S - \frac{K}{2} R_L \left(v_I - 1\right)^2$$

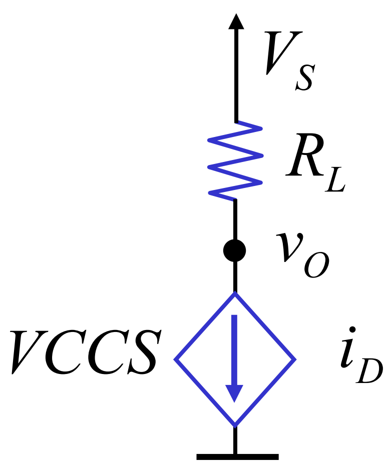
So is mathematically predicted behavior

One nit …



However, from

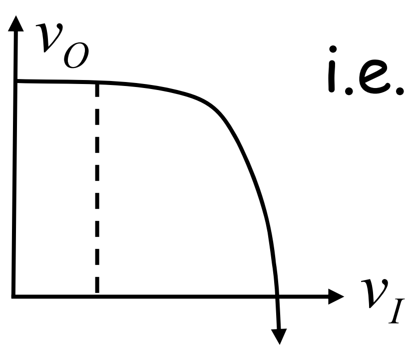
$$i_D = \frac{K}{2} (v_I - 1)^2 \quad \text{for } v_I \geq 1$$



For $v_O > 0$, $VCCS$ consumes power: $v_O i_D$

For $v_O < 0$, $VCCS$ must supply power!

If VCCS is a device that can source power, then the mathematically predicted behavior will be observed —



i.e. $v_O = V_S - \frac{K}{2} R_L \left(v_I - 1\right)^2$

where v_O goes *-ve*

If VCCS is a passive device,
then it cannot source power,
so v_O cannot go *-ve*.
So, something must give!

Turns out, our model breaks down.

Commonly $$i_D = \frac{K}{2}(v_I - 1)^2$$

will no longer be valid when $v_O \leq 0$.
e.g. i_D saturates (stops increasing)
and we observe: