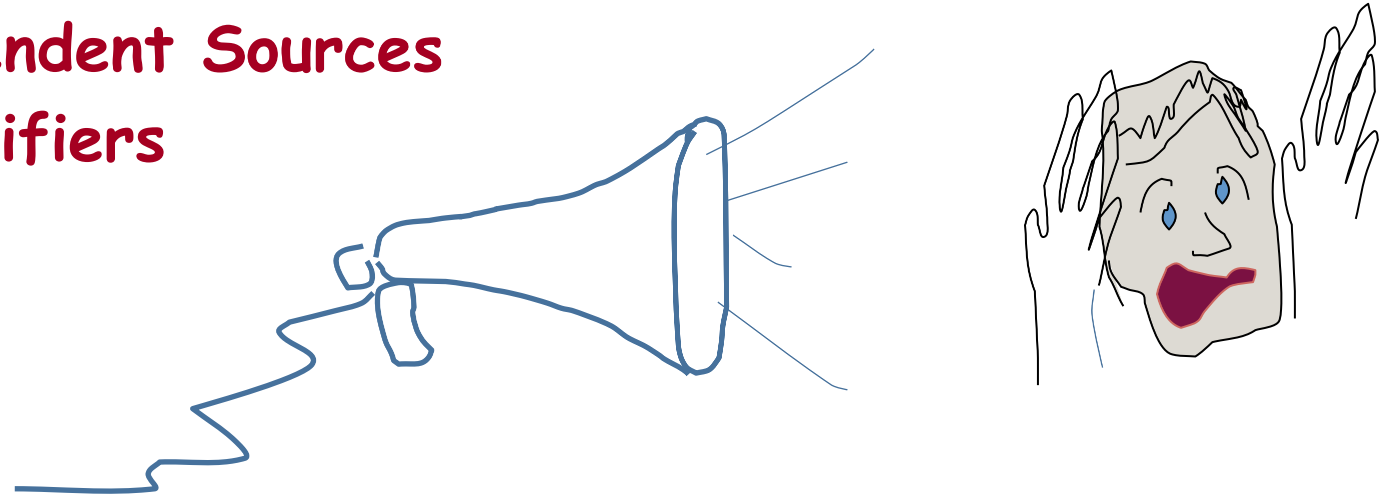
6.002x

CIRCUITS AND ELECTRONICS

Dependent Sources
Amplifiers



Review

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

Today

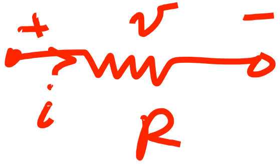
- Dependent sources
- Amplifiers

Reading: Chapter 7.1, 7.2

Dependent Sources

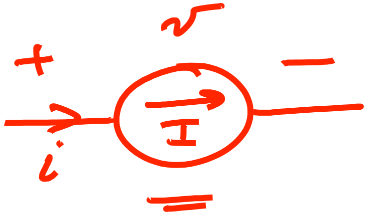
Elements we have seen previously

Resistor



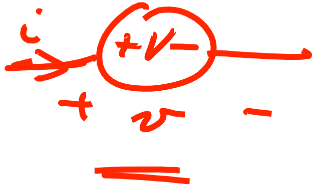
$$i = \frac{v}{R}$$

Independent
Current source



$$i = I$$

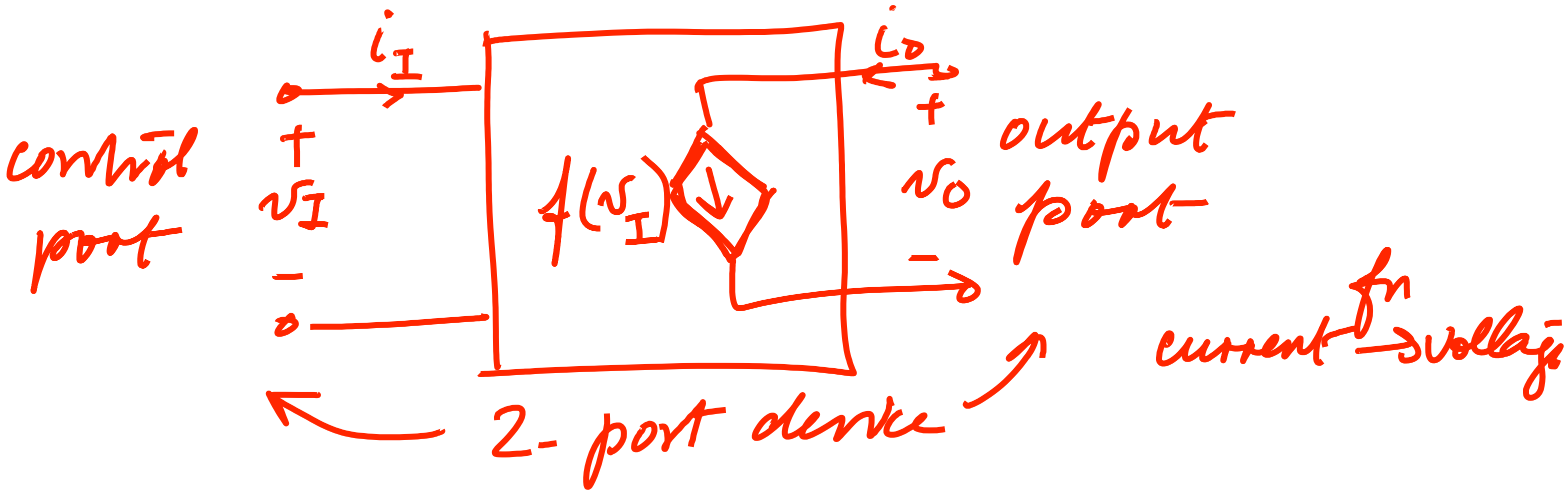
Independent voltage source



2-terminal 1-port devices

Dependent sources

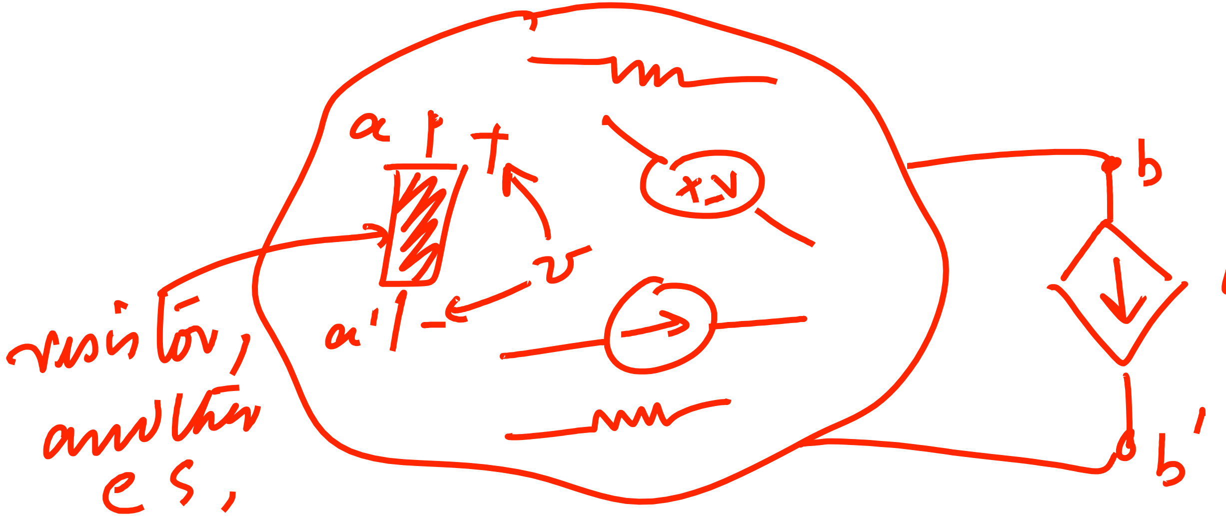
A new element for our toolchest; can be linear or nonlinear



E.g., Voltage Controlled Current Source VCCS

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

Dependent source in a circuit

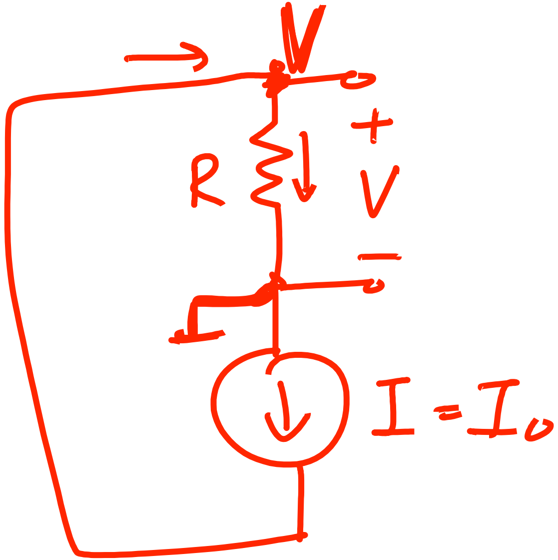


$i = f(v)$ VCCS

First, an Example with an independent source

Example 1: Find V

independent current source



Node method:

$$\frac{V}{R} - I_0 = 0$$

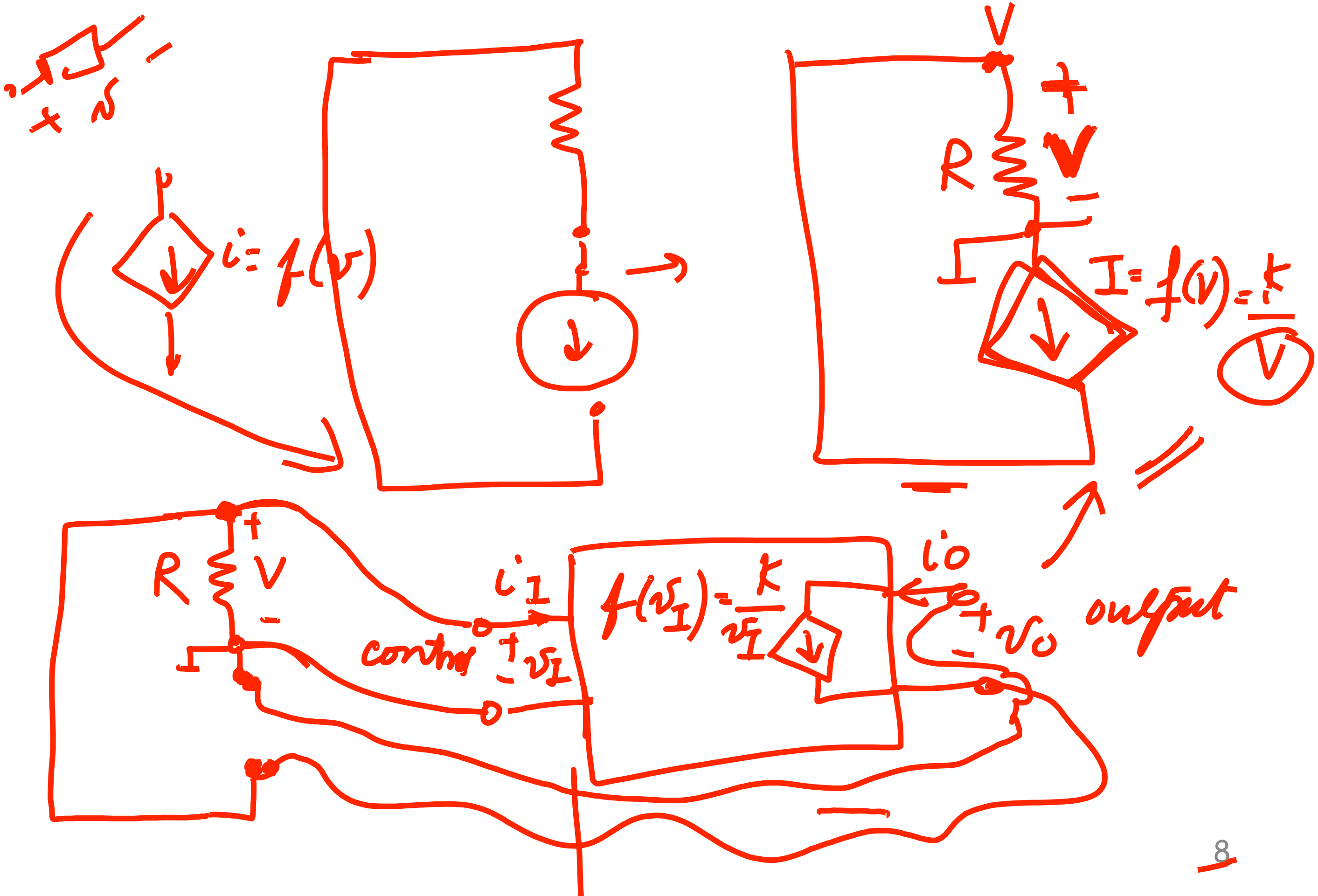
$$\boxed{V = I_0 R}$$

Dependent Sources: Example

Example 2: Find V

voltage
controled
current
source

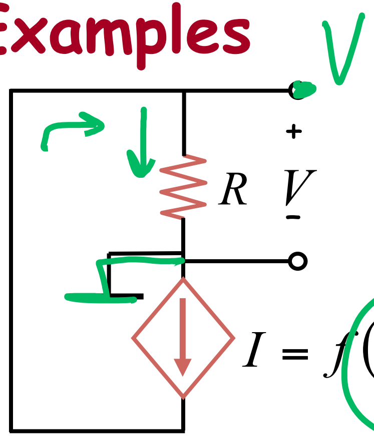
Note that above is abstracted view of:



Dependent Sources: Examples

Example 2: Find V

voltage
controled
current
source



$$I = f(V) = \frac{K}{V}$$

e.g.
$K = 10^{-3}$ Amp·Volt,
$R = 1k\Omega$

Node method: $\frac{V}{R} - I = 0$

$V = IR$

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

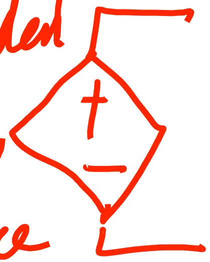
$V^2 = KR$

$V = \sqrt{KR}$

$= \sqrt{10^{-3} \cdot 10^{3}} = 1$ Volt

Other Types of Dependent Sources

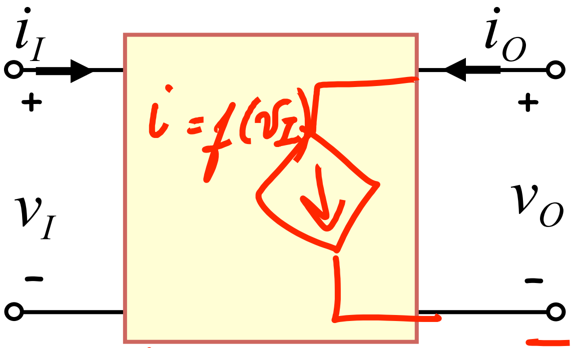
dependent voltage source



VCVS, CCVS

VCCS

control port

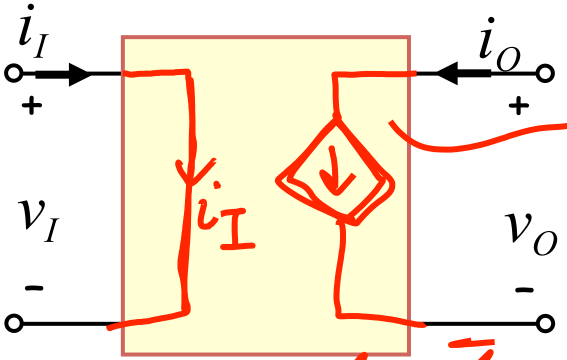


output port

Voltage Controlled Current Source

Similarly, CCVS, VCVS

control port



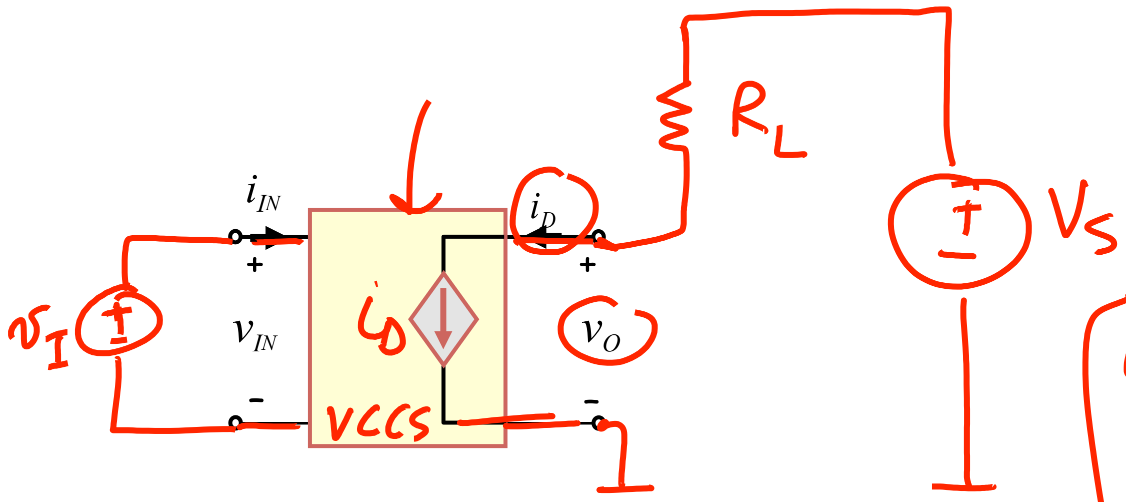
$i = f(i_I)$

output port

CCCS

Current Controlled current source

Another dependent source example

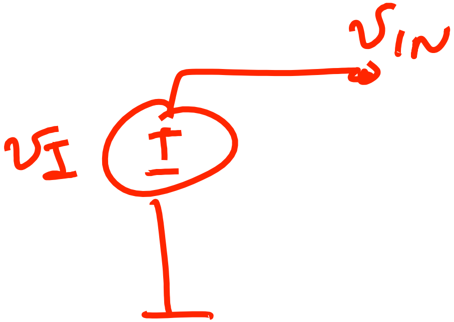


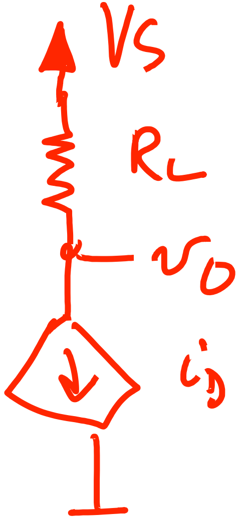
$$i_D = f(v_{IN})$$

$$i_D = \begin{cases} \dfrac{K}{2}(v_{IN}-1)^2 & \text{for } v_{IN} \geq 1V \\ = 0 & \text{otherwise} \end{cases}$$

Find v_O as a function of v_{IN}

Simplify our Drawing





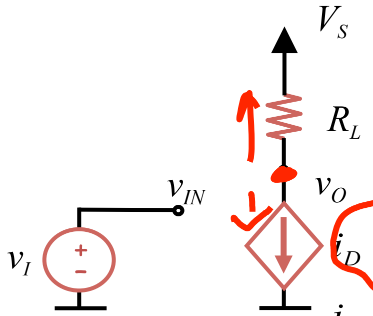
$$i_D = \frac{k}{2}(v_{IN} - 1)^2 \text{ for } v_{IN} \geq 1$$
$$= 0 \text{ otherwise}$$

Solve

v_O vs v_I

Node method

$$\frac{v_O - V_S}{R_L} + i_D = 0$$



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

$i_D = 0$ otherwise

$$v_O = V_S - i_D R_L$$

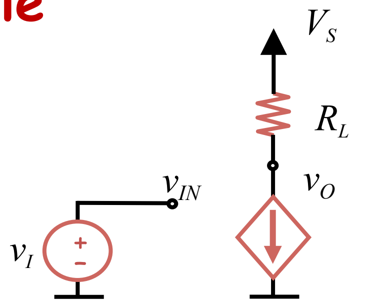
$$v_O = V_S - \frac{K}{2}(v_{IN} - 1)^2 R_L \quad \text{for } v_{IN} \geq 1V$$

$$v_O = V_S \quad \text{for } v_{IN} < 1V$$

Hold that thought

Plot v_O versus v_I curve for our dependent source example

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



1 — $v_O = V_S - \frac{K}{2}(v_I - 1)^2 R_L$ for $v_I \geq 1V$

2 — $v_O = V_S$ for $v_I < 1V$

For $v_I \geq 1V$

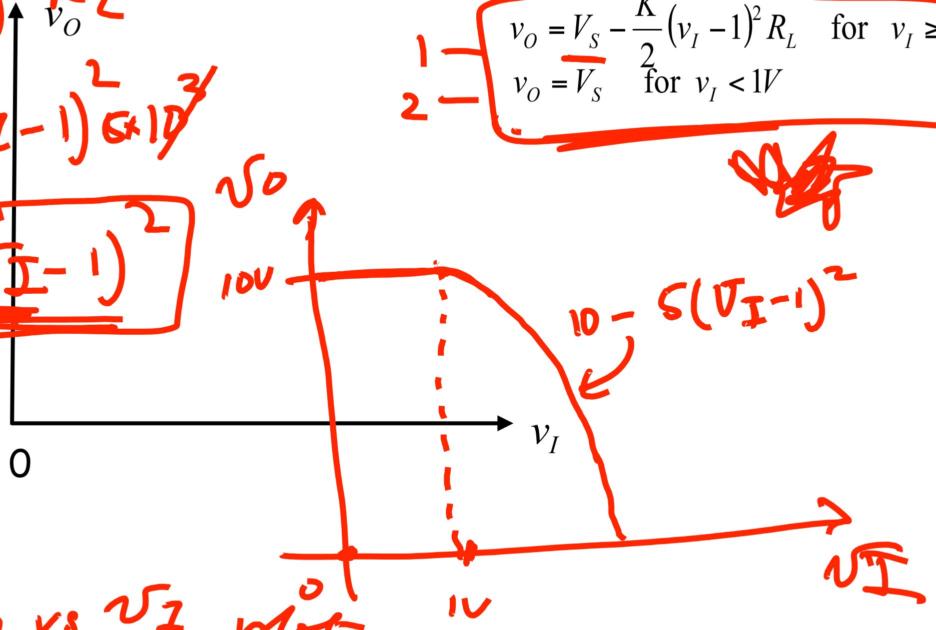
$$v_O = V_S - \frac{K}{2}(v_I - 1)^2 R_L$$

$$= 10 - \frac{\cancel{2}\times 10^{-3}}{\cancel{2}}(v_I - 1)^2\, 5\times 10^{3}$$

$$v_O = 10 - \boxed{5(v_I - 1)^2}$$

For $v_I < 1V$

$$v_O = V_S = 10V$$



v_O vs v_I plot

Superposition with Dependent Sources

linear

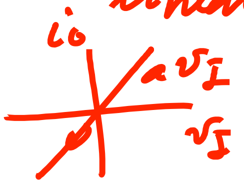
One way

- leave all dependent sources in (note, dependent sources must be linear!)
- solve for one independent source at a time
- [section 3.5.1 of the text]

VCCS

$i_o = f(v_I)$

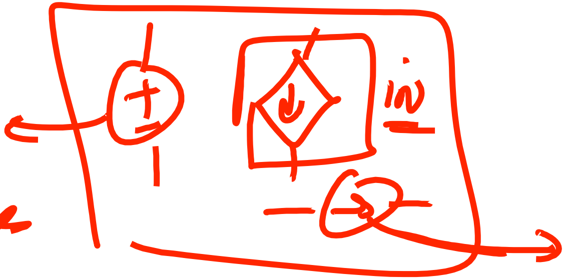
$i_o = a \cdot v_I$ linear



$i_o = b \cdot v_I^2$ nonlinear

"linear circuit"

resistive nets + indep. sources



Tutorial end of W2

Next, Amplifiers

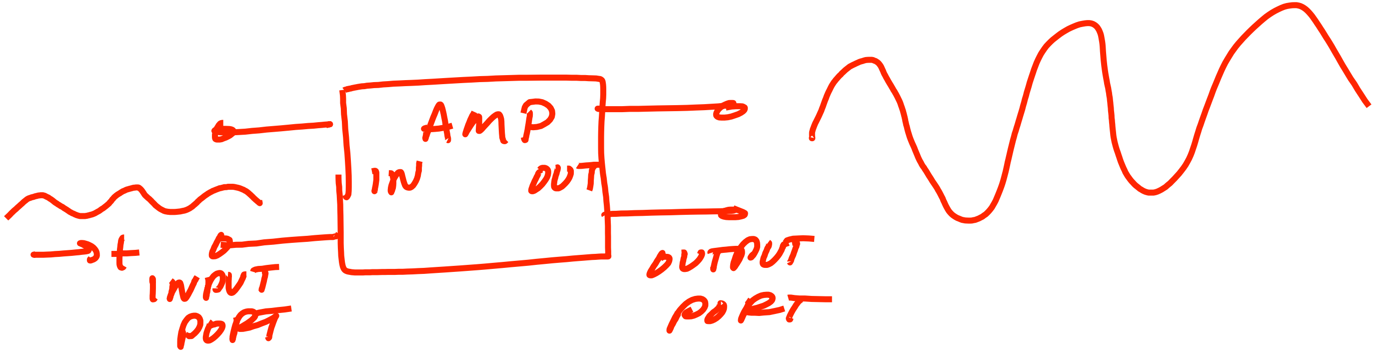
big abstraction

- gate
-

Why amplify?

Signal amplification key to both analog and digital processing.

Analog:

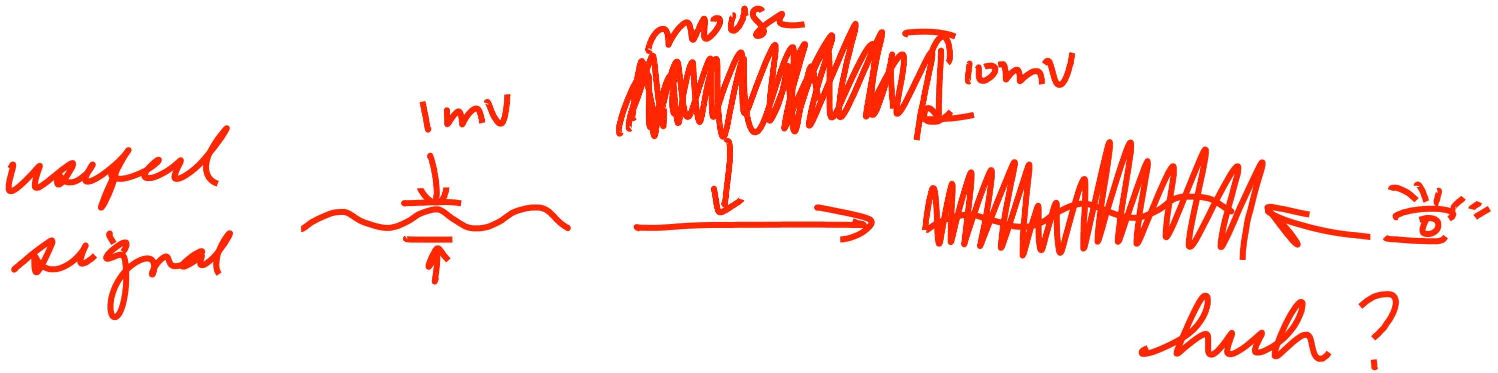


Besides the obvious advantages of being heard farther away, amplification is key to noise tolerance during communication

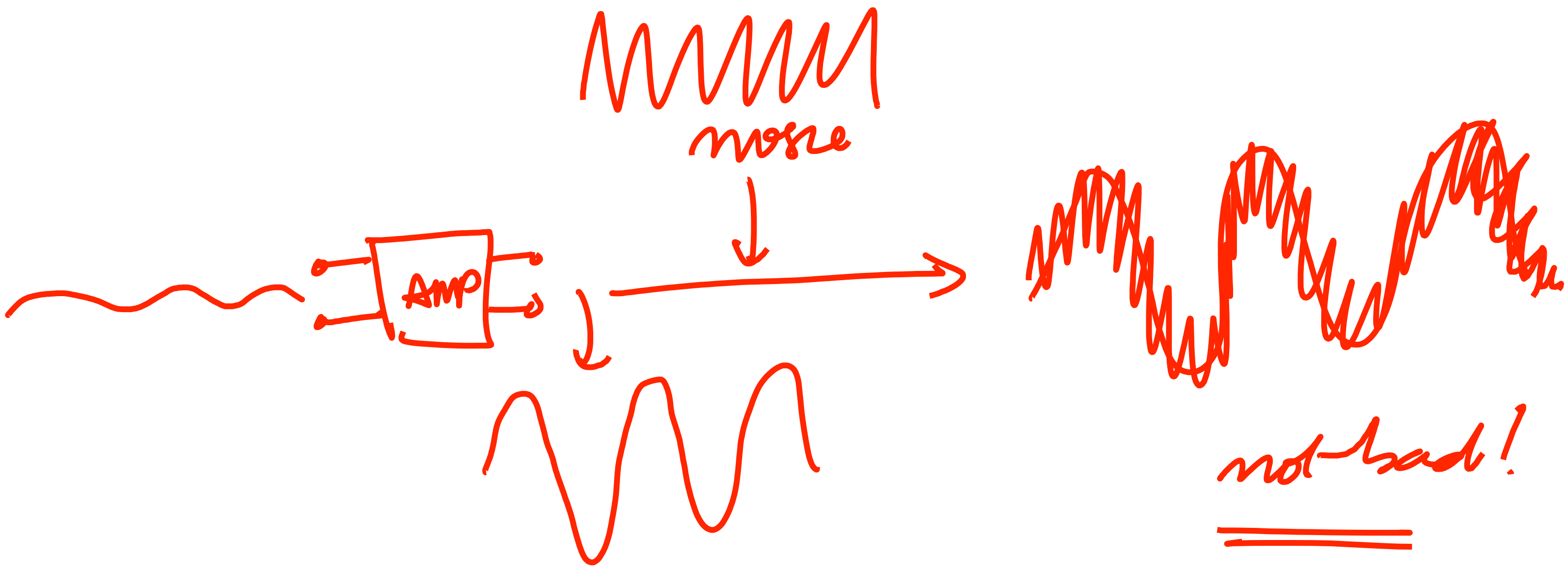
Why amplify?

Amplification is key to noise tolerance during communication

No amplification

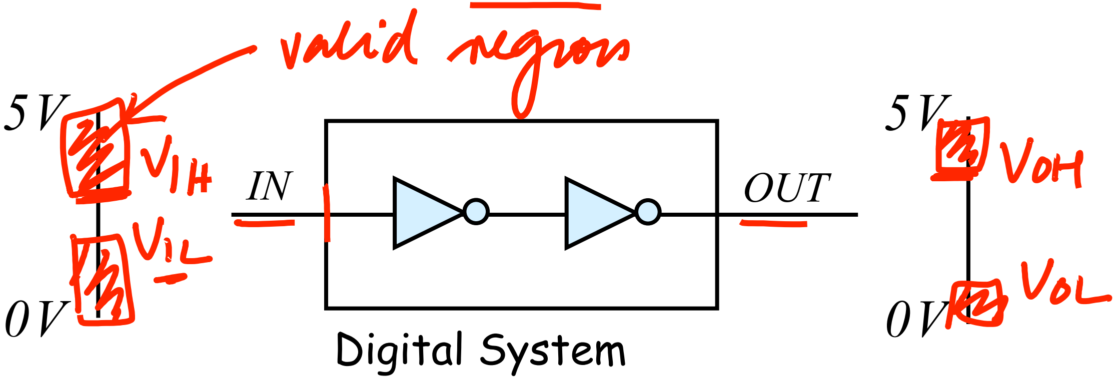


Try amplification

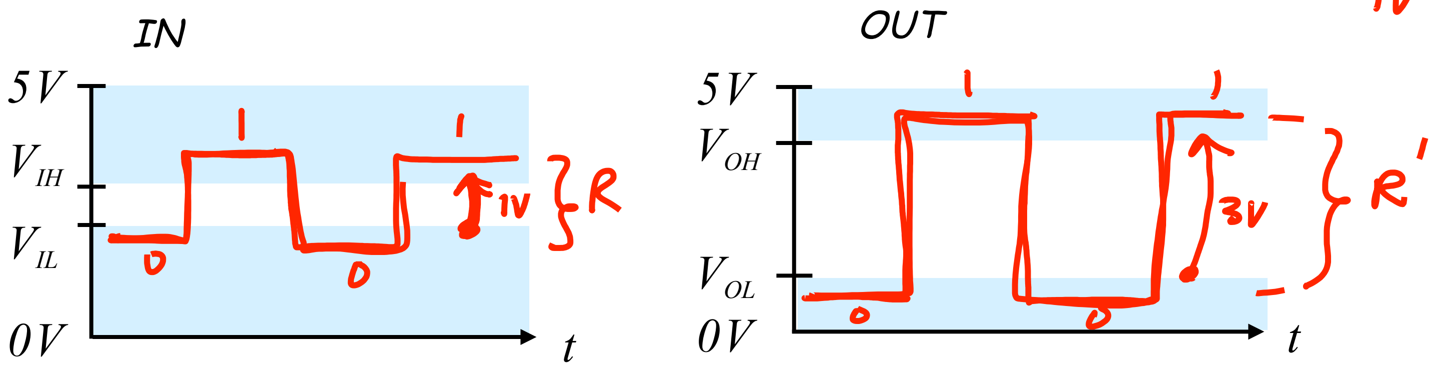


Why amplify?

Amplification if fundamental to the digital domain as well



$\frac{3V}{1V} = 3$

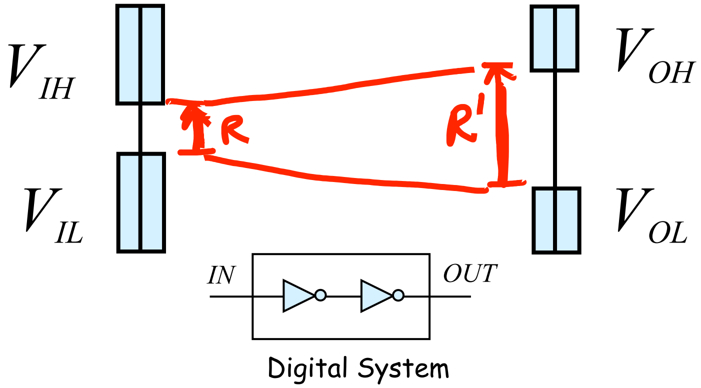


Why amplify?

Digital domain:

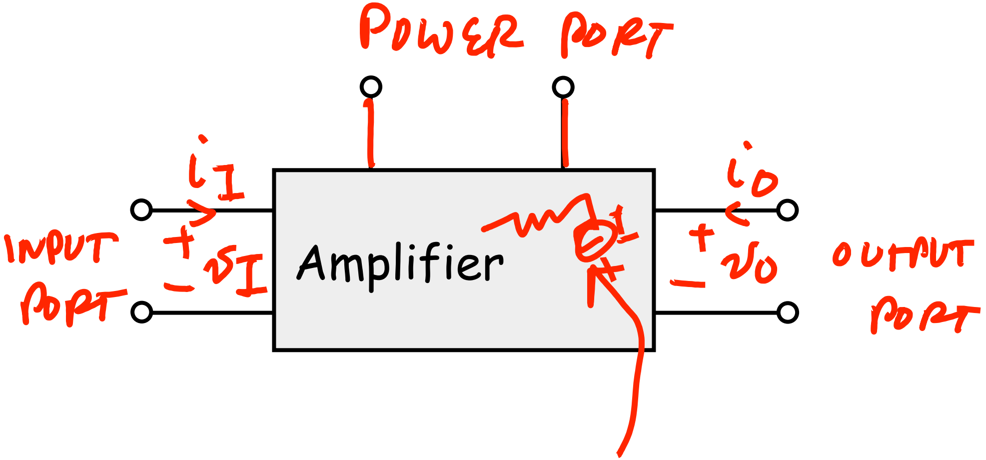
Static discipline requires amplification!

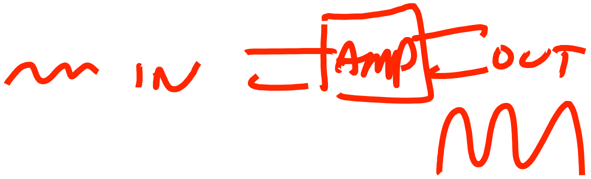
Minimum amplification needed:

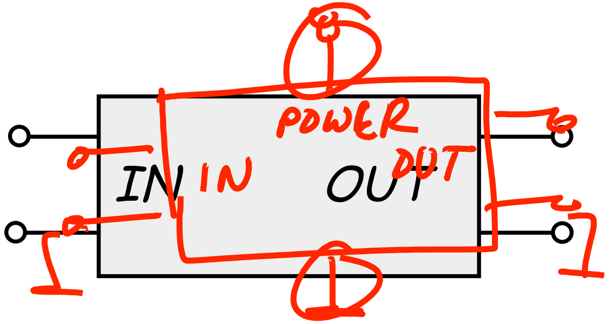


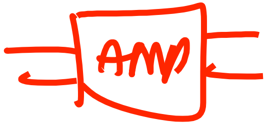
$$\frac{R'}{R} = \frac{V_{OH} - V_{OL}}{V_{IH} - V_{IL}}$$

An amplifier is a 3-ported device, actually







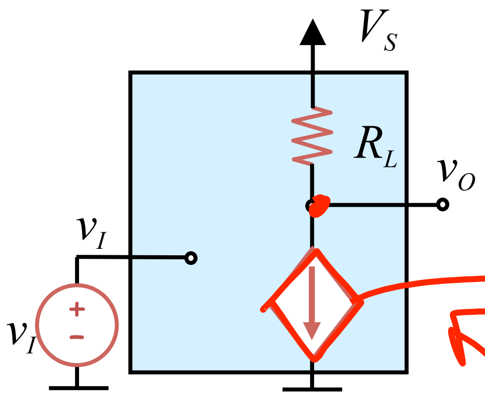


We often don't show the power port.

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?

You already have! Remember...



Node method:

$$\frac{v_O - V_S}{R_L} + i_D = 0$$

$$v_O = V_S - i_D R_L$$

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

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

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

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

?

Claim: This is an amplifier

So, where's the amplification?

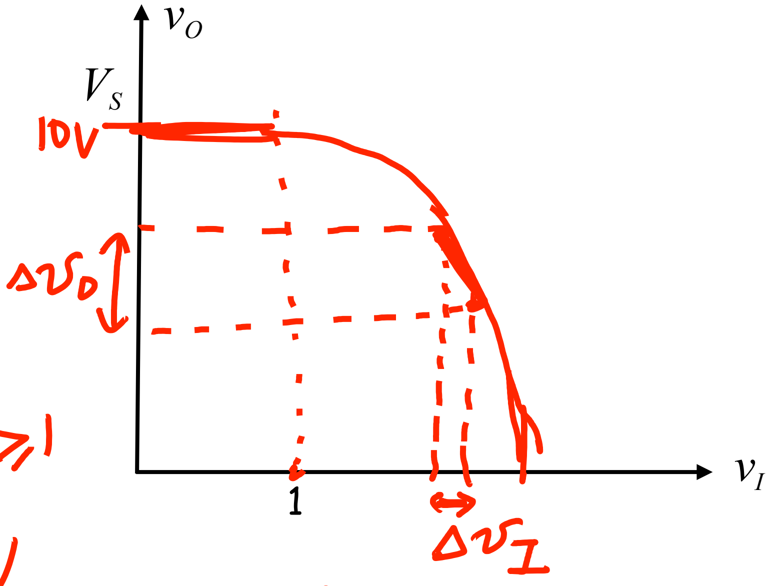
v_O versus v_I curve

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

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

$$v_O = 10 - 5(v_I - 1)^2 \quad \text{for } v_I \geq 1$$

$= V_S$ (10V) for $v_I < 1V$



$$\frac{\Delta v_O}{\Delta v_I} > 1 \Rightarrow \text{amplification}$$

Plot v_O versus v_I

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

$v_O = V_S$ $v_I < 1V$

Demo

v_I	v_O
0	10V
1	10V
1.5	8.75V
2V	5V
2.1	4V
2.2	2.8V
2.3	1.5V
2.4	~0V

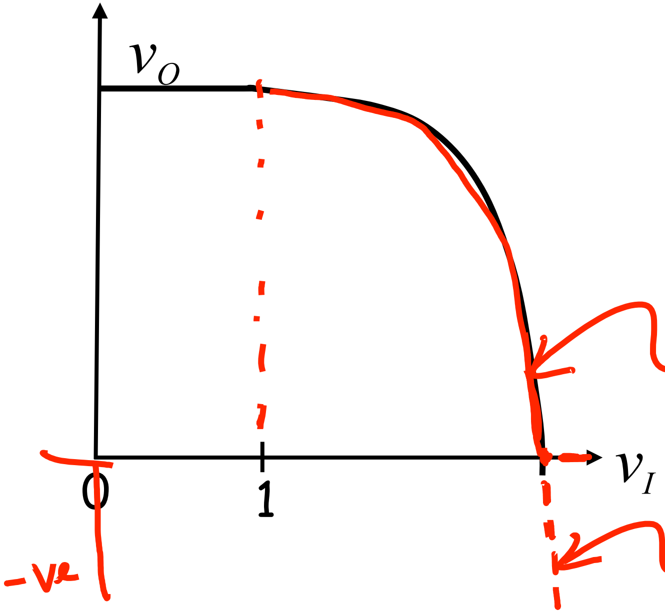
0.1V change in v_I

1V change in v_O

Gain!

Measure v_O.

One nit …



Mathematically,

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

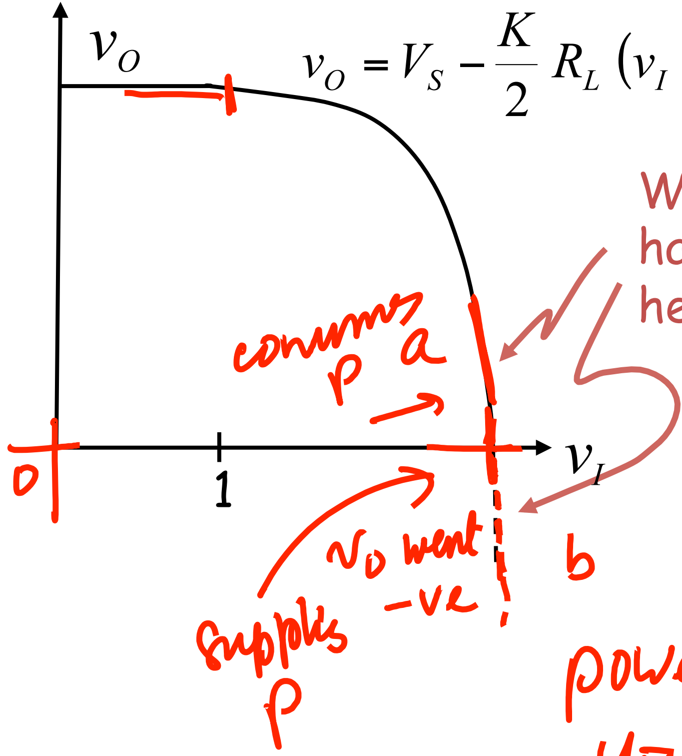
for $v_I \geq 1V$

But, what happens Here with a practical device?

So this is mathematically predicted behavior in our amplifier built with an abstract dependent source

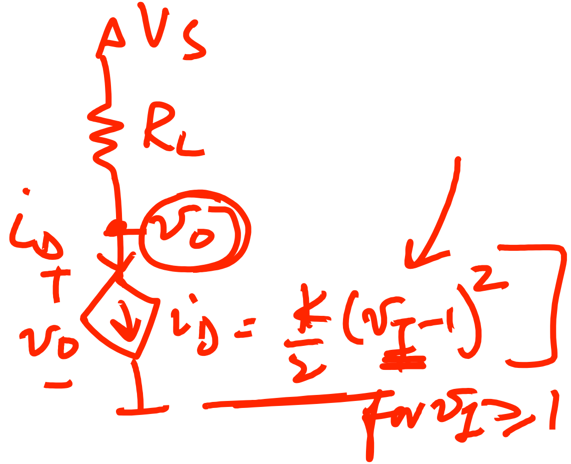
One nit ...

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



What happens here?

However, looking at the circuit



power consumed by device

$v_O i_D$

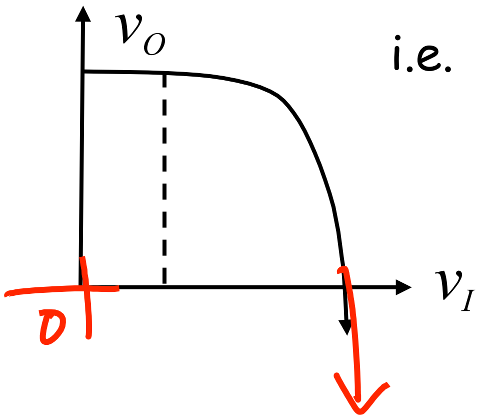
power consumed by the device

a: $v_O > 0$, VCCS consumes power

b: $v_O < 0$, VCCS supplies power

If our VCCS is a device that can source (or supply) power

then the mathematically predicted behavior will be observed



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

where v_O goes *-ve*

However, if our VCCS is a passive device

i.e., it does not provide power gain

Then it cannot source power,
so v_O cannot go -ve.

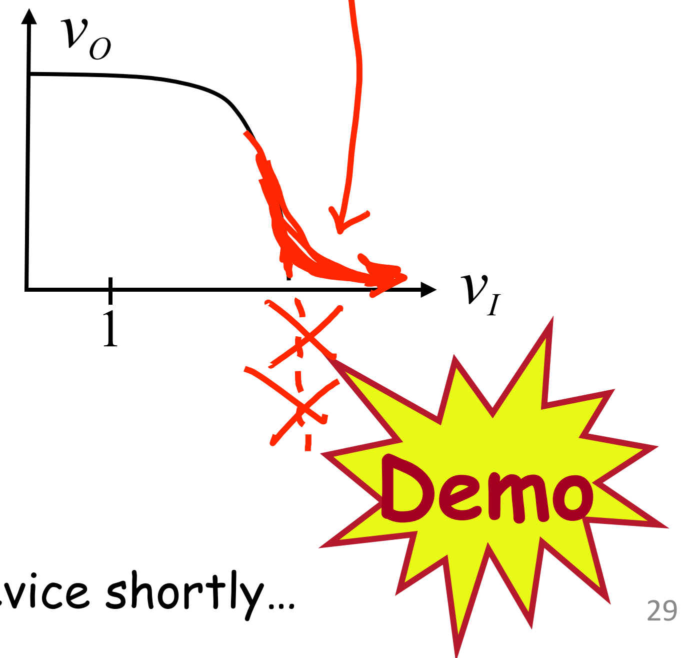
e.g. i_D saturates (stops increasing)
and we observe:

So, something must give!

Turns out, our model breaks down.

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

will no longer be valid when $v_O \leq 0$.



We will look at a practical device shortly...