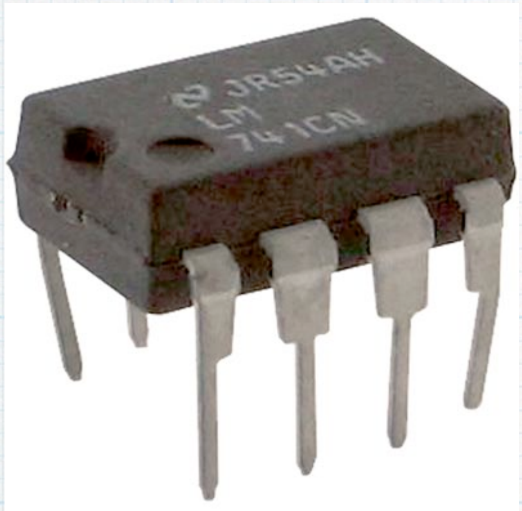
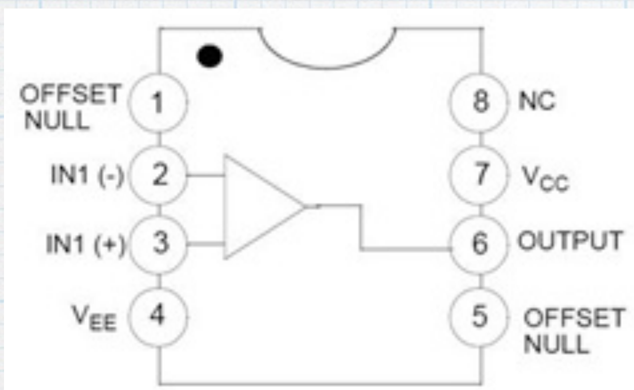
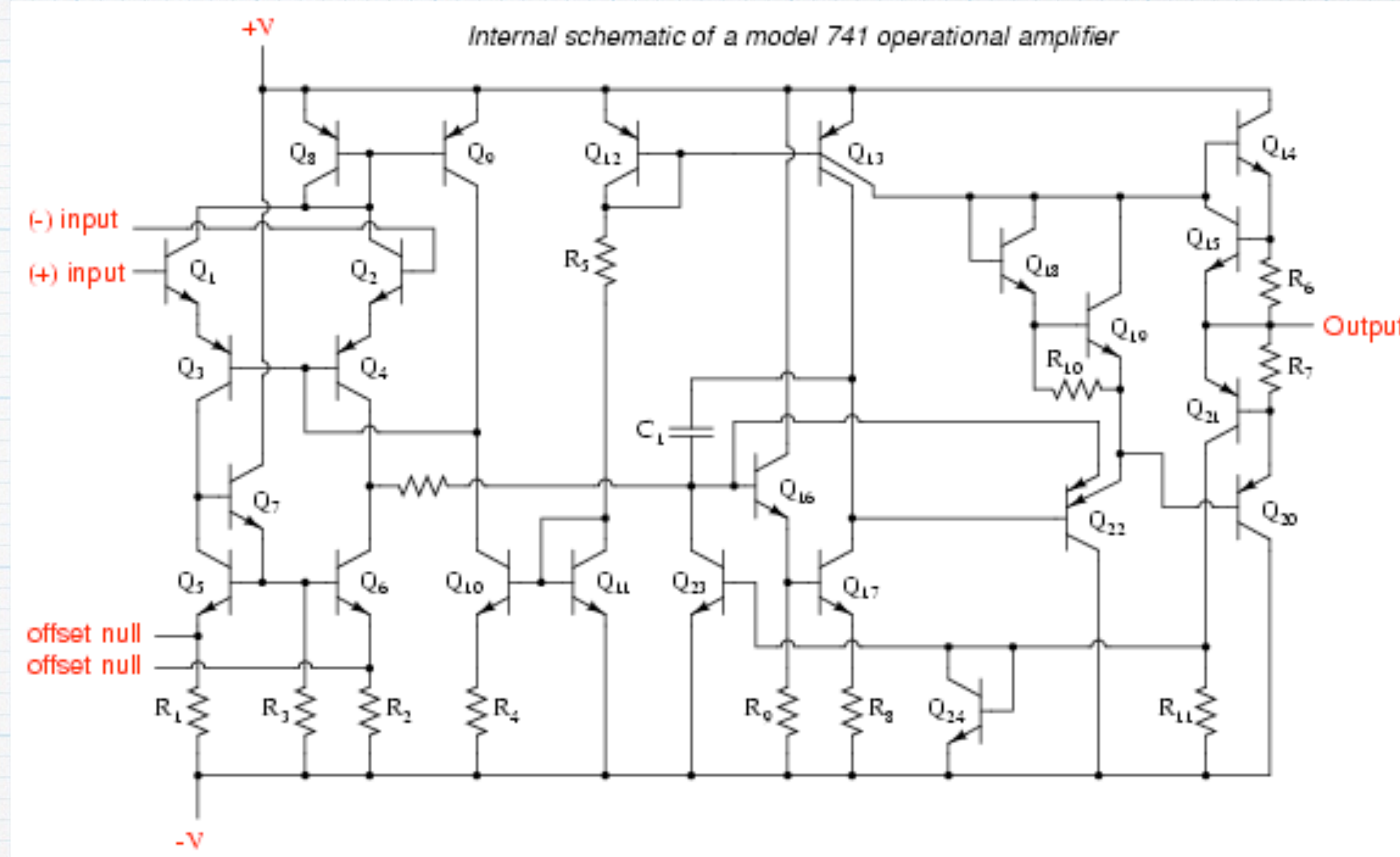
# Amplifiers



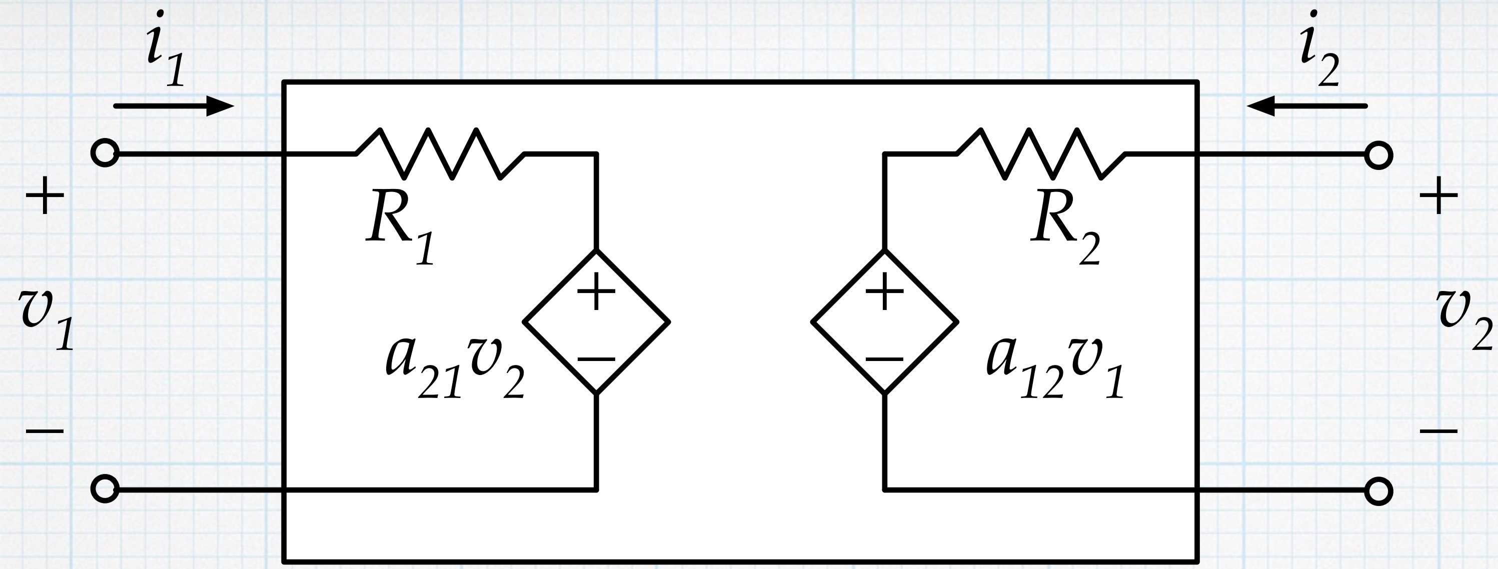




Internal circuitry of a 741 operational amplifier.

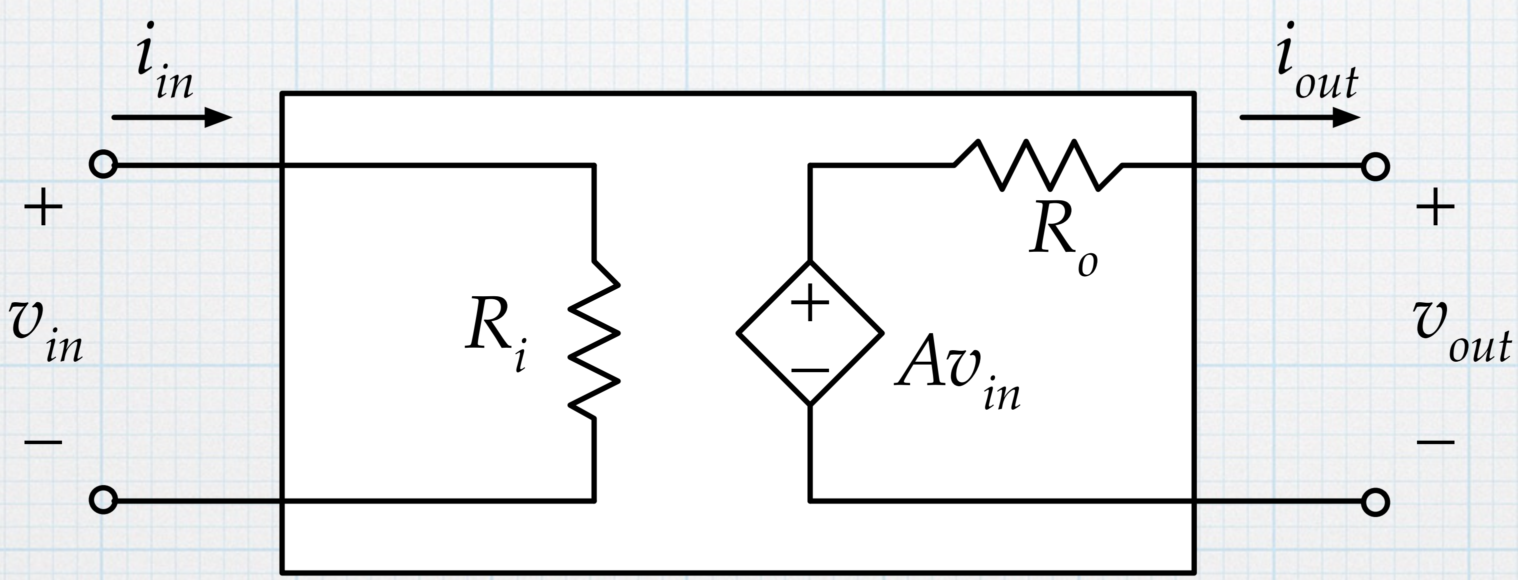
We will need a simpler circuit model.

We apply a *signal* at the input. The signal is usually a voltage of some sort, but it could be a current. The amplifier magnifies the signal and provides a bigger version of it at the output. We often use a sine wave as a simple representative signal.

$$v_{out} = A_T v_S \qquad A_T = \frac{v_{out}}{v_S}$$

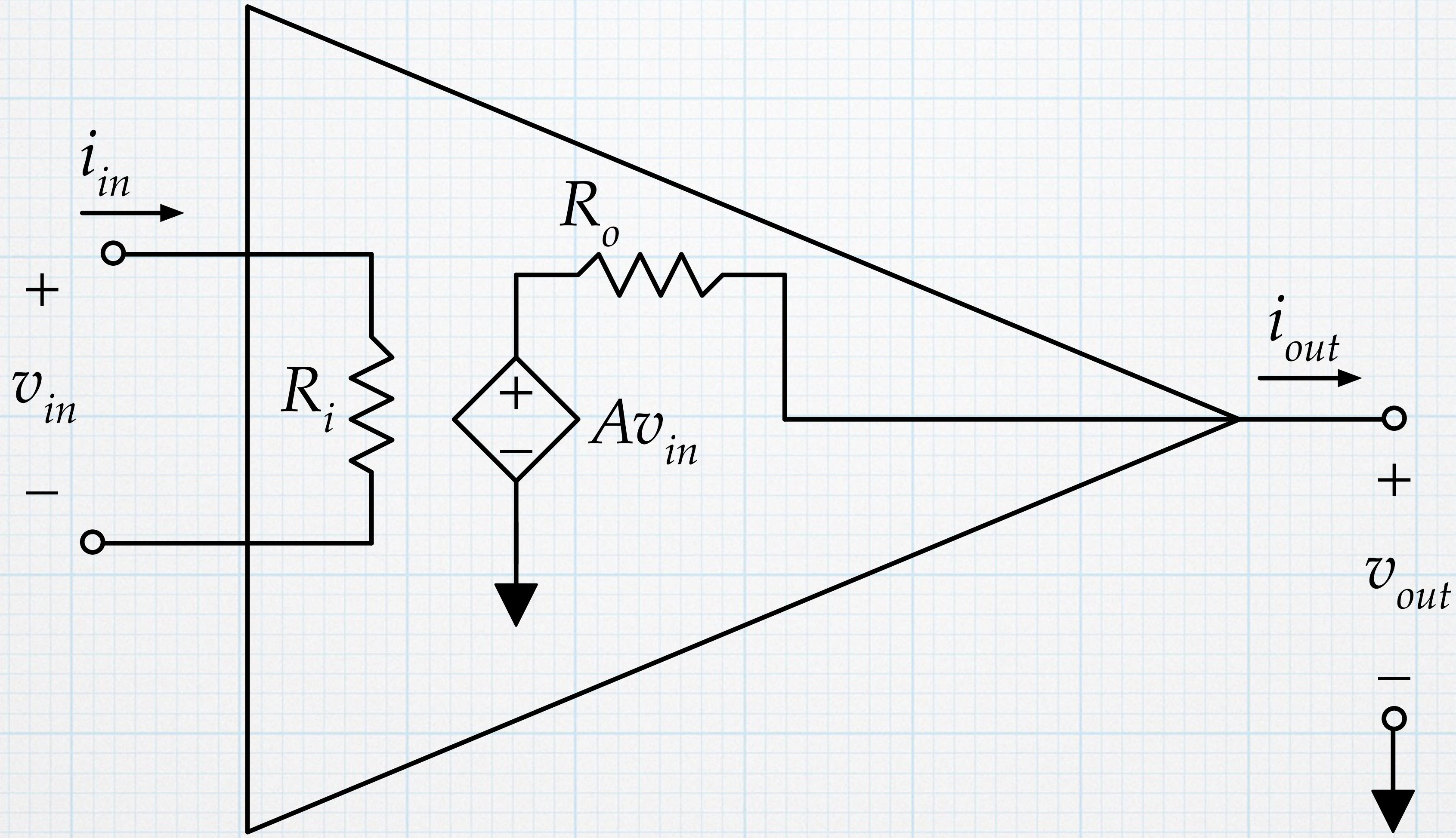



Take the basic two-port. Specialize it for an amplifier, which is usually designed to work in one direction only.

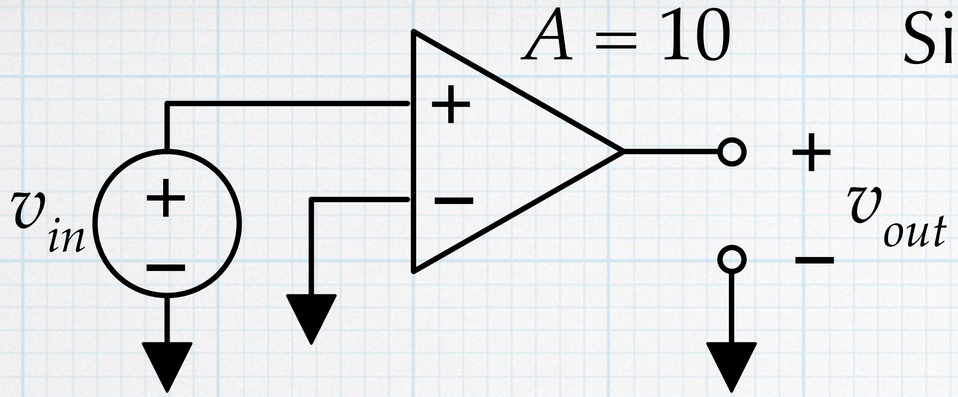



- $a_{12}$ = A – open-loop gain
- $a_{21}$ = 0 – it doesn't work "backwards"
- $R_1 = R_i$ – input resistance
- $R_2 = R_o$ – output resistance

# Alternative representation



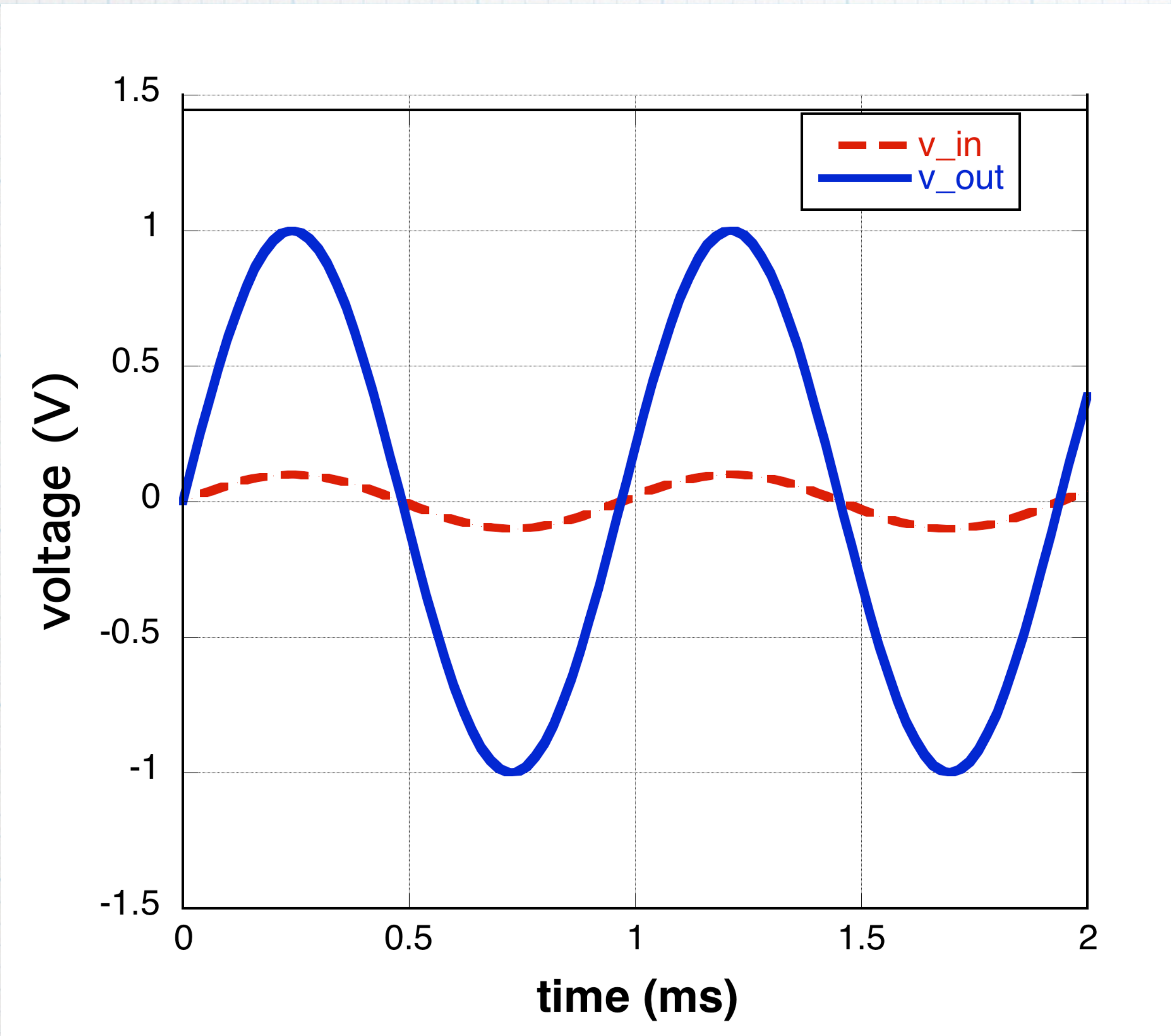

The usual circuit symbol for an amp is a triangle, with the input port at the base and the output port at the point. Many (most) amps use the circuit ground as one of the nodes defining the output port. So there is usually single output connection, and that output is referenced to ground. The ground in the circuit is defined by the DC power supplies that must connected to provide power for the amp to do its thing.

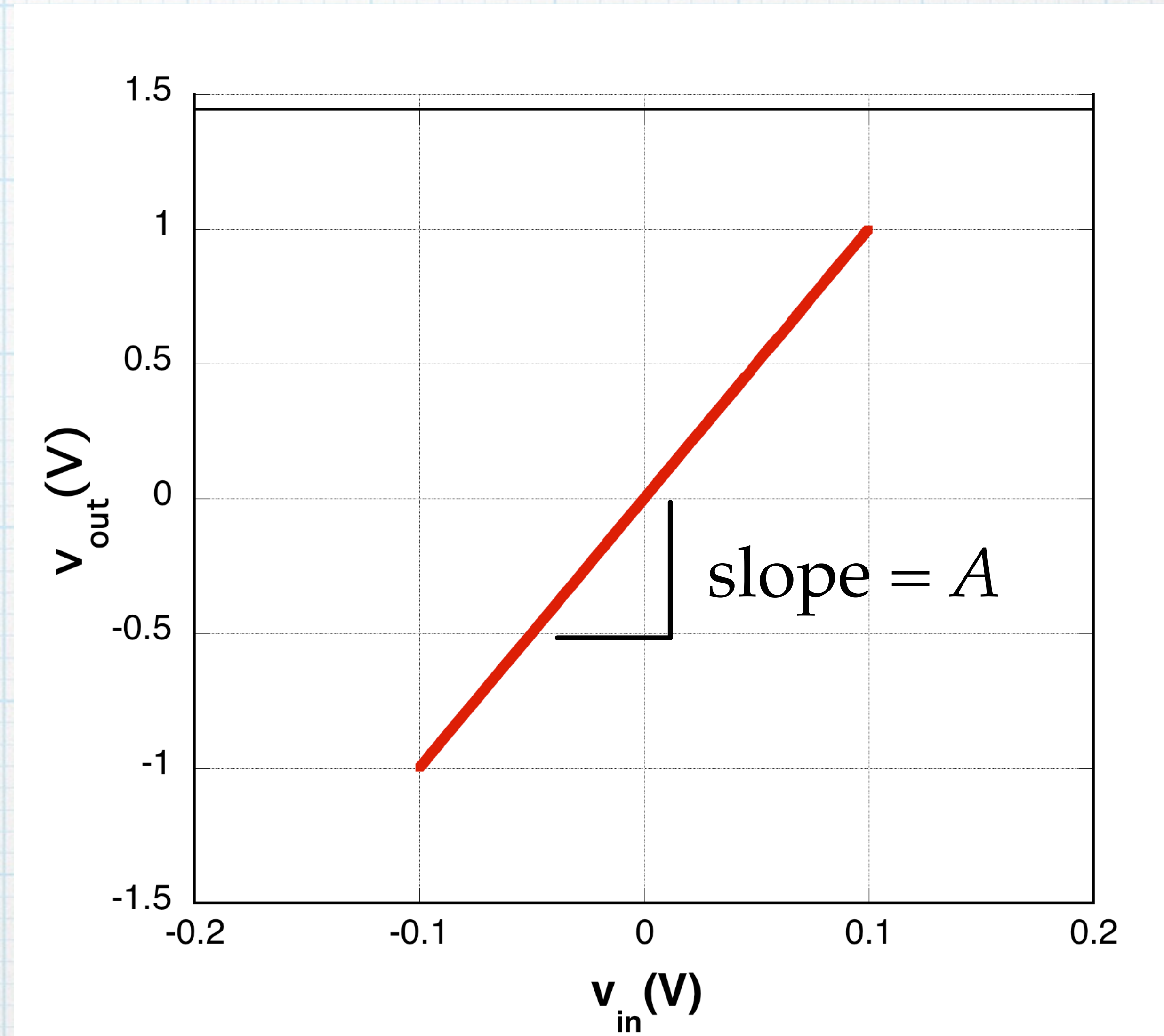



Simplified case with no source or load resistances.

$$v_{in} = (0.1\ \text{V})\cdot\sin(2\pi f\cdot t)$$

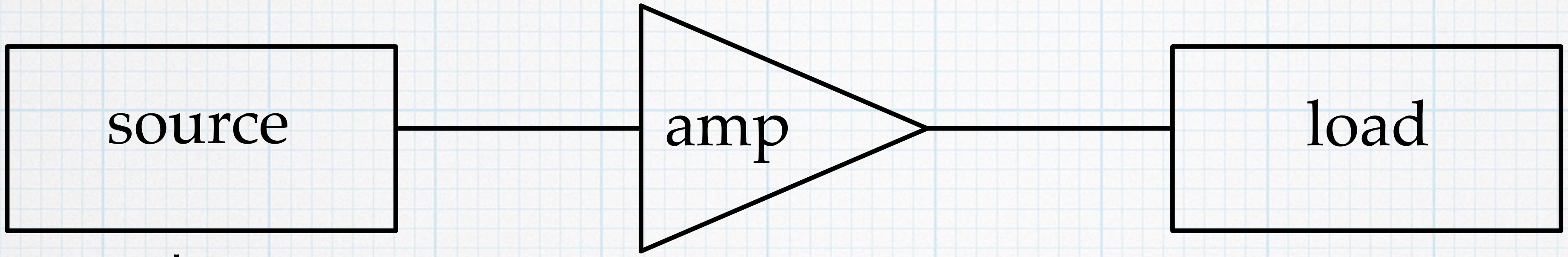
$$v_{out} = A\cdot v_{in} = (1\ \text{V})\cdot\sin(2\pi f\cdot t)$$



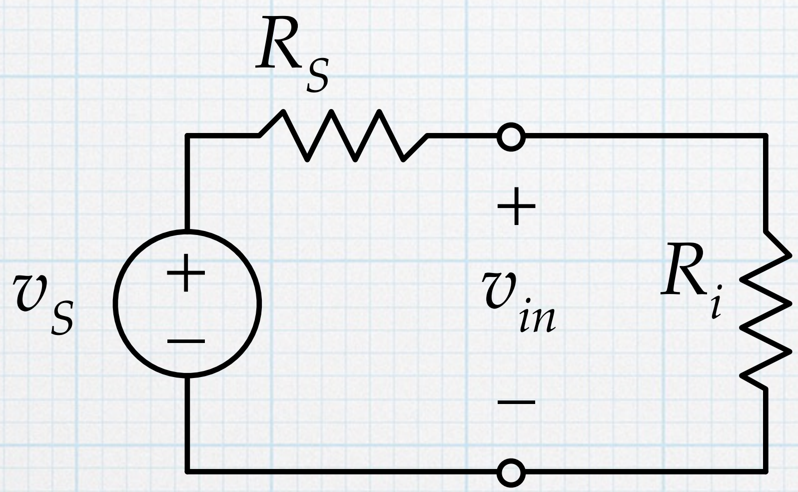

Two ways to represent the behavior of an amplifier. The plot on the left shows both $v_{in}$ and $v_{out}$ as functions of time. The plot on the right shows $v_{out}$ as a function of $v_{in}$, which is known the *transfer characteristic*. Both plots can obtained easily with an oscilloscope.

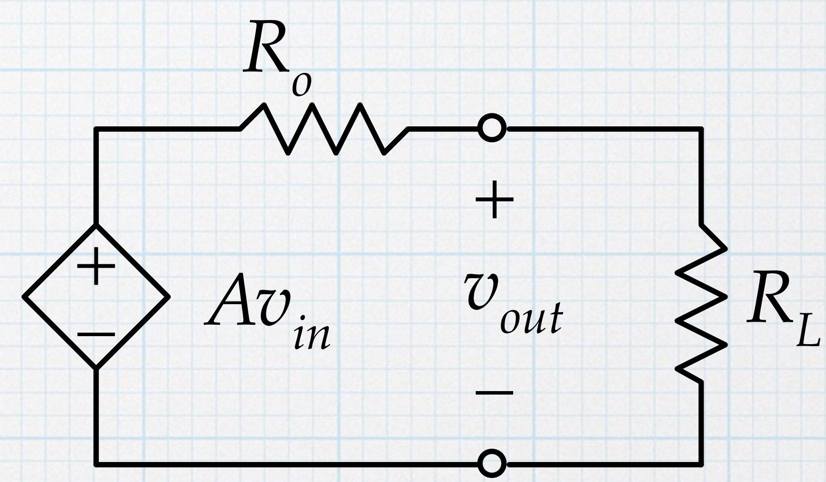
# A simple system to show the effect of the resistances




mp3 player
am/fm radio
cell phone
CD player ?
phonograph ?
sensor
etc.

speaker
switch (relay)




$$v_{in} = \frac{R_i}{R_i + R_S} v_S$$

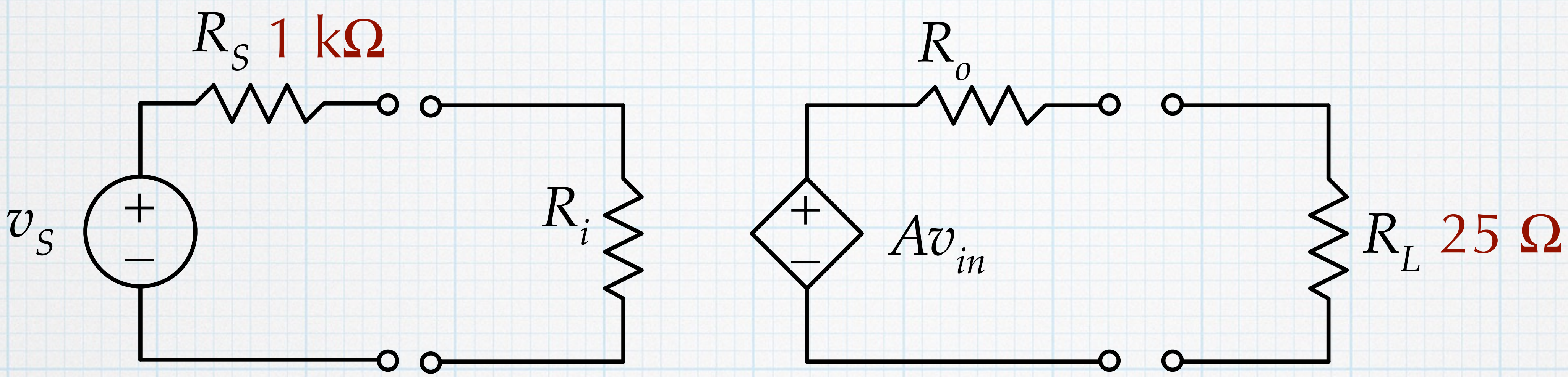
$$v_{out} = \frac{R_L}{R_L + R_o} A v_{in}$$

$$v_{out} = \frac{R_L}{R_L + R_o} A \frac{R_i}{R_i + R_S} v_S$$

$$A_T = \frac{v_{out}}{v_S} = \frac{R_L}{R_L + R_o} A \frac{R_i}{R_i + R_S}$$

So the total gain that depends on the resistances, as well.

# Example




Amp 1: $R_i$ = 500 Ω, $A$ = 60, $R_o$ = 75 Ω

$$A_T = \frac{R_i}{R_i + R_S} A \frac{R_L}{R_L + R_o}$$

$$= \frac{500\Omega}{500\Omega + 1\text{k}\Omega} (60) \frac{25\Omega}{25\Omega + 75\Omega} = 5$$

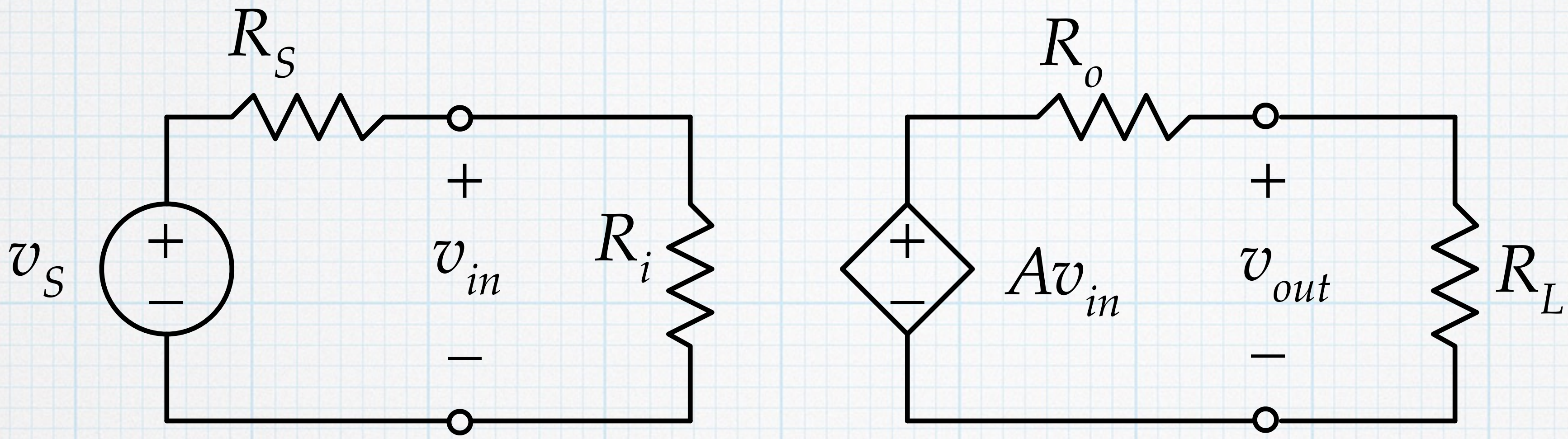
Not that great.

Try again with a different amp: $R_i$ = 4 kΩ, $A$ = 30, $R_o$ = 5 Ω

$$A_T = \frac{4\text{k}\Omega}{4\text{k}\Omega + 1\text{k}\Omega} (30) \frac{25\Omega}{25\Omega + 5\Omega} = 20$$

Clearly, the second choice gives more overall gain, even though it had lower open-loop gain.

# Ideal amplifier




$$A_T = \frac{v_{out}}{v_S} = \frac{R_L}{R_L + R_o} A \frac{R_i}{R_i + R_S}$$

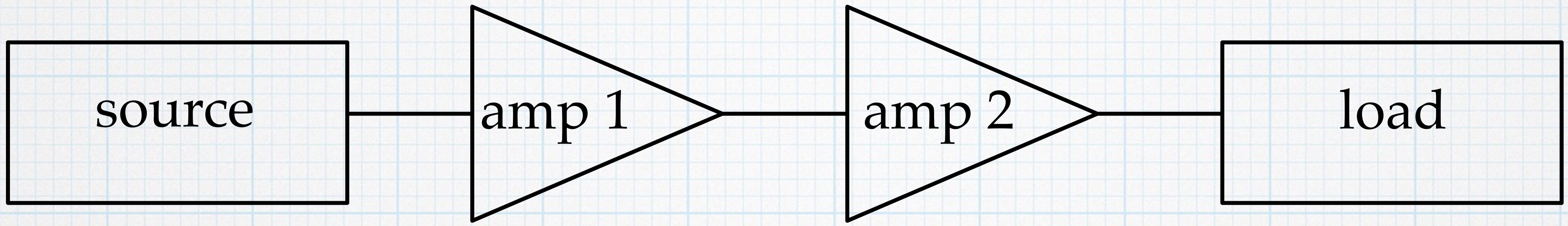
Ideally we would try to minimize the voltage lost across the voltage dividers, meaning that we make the divider ratio → 1. An ideal amplifier would provide the same gain independent of the source and load resistances.

If $R_i \to \infty$ and $R_o \to 0$

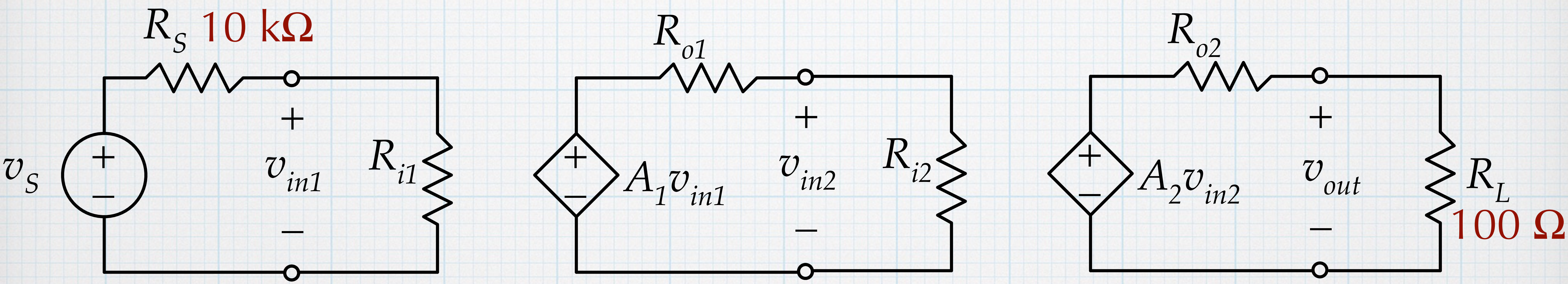
Then $A_T \to A$

We can make amps that approach the ideal input and output resistances, but there is a big trade-off, as we'll see.

# Cascading amps




The two-port model makes it easy to handle this situation.



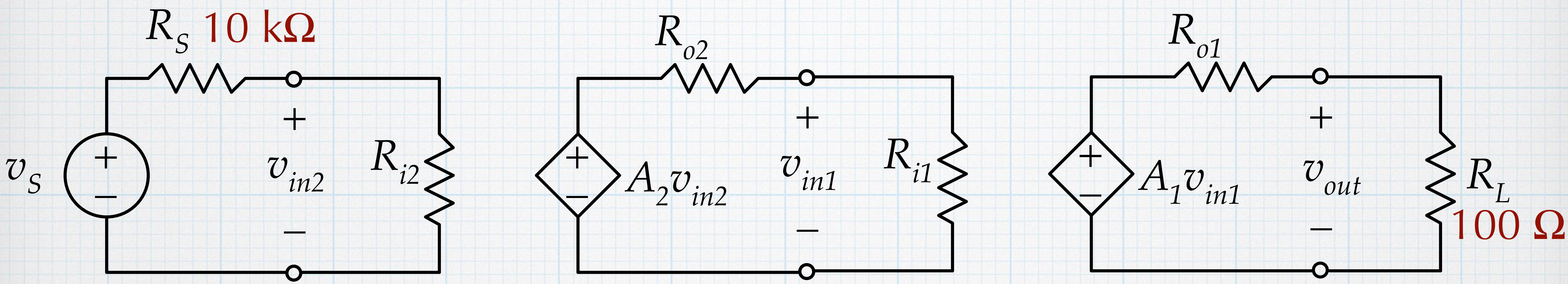

Amp 1: $R_{i1}$ = 1 kΩ,
$A_1$ = 20, $R_{o2}$ = 50 Ω

Amp 2: $R_{i2}$ = 1 MΩ,
$A_2$ = 20, $R_{o2}$ = 1 kΩ

$$v_{out} = \frac{R_{i1}}{R_{i1} + R_S} A_1 \frac{R_{i2}}{R_{i2} + R_{o1}} A_2 \frac{R_L}{R_L + R_{o2}} v_S$$

$$A_T = \frac{1\text{k}\Omega}{1\text{k}\Omega + 10\text{k}\Omega}(20)\frac{1\text{M}\Omega}{1\text{M}\Omega + 50\Omega}(20)\frac{100\Omega}{100\Omega + 1\text{k}\Omega} = 3.31$$

The order of the amps in cascade can make a huge difference. If we swap the two amps:




Amp 2: $R_{i2}$ = 1 MΩ,
$A_2$ = 20, $R_{o2}$ = 1 kΩ

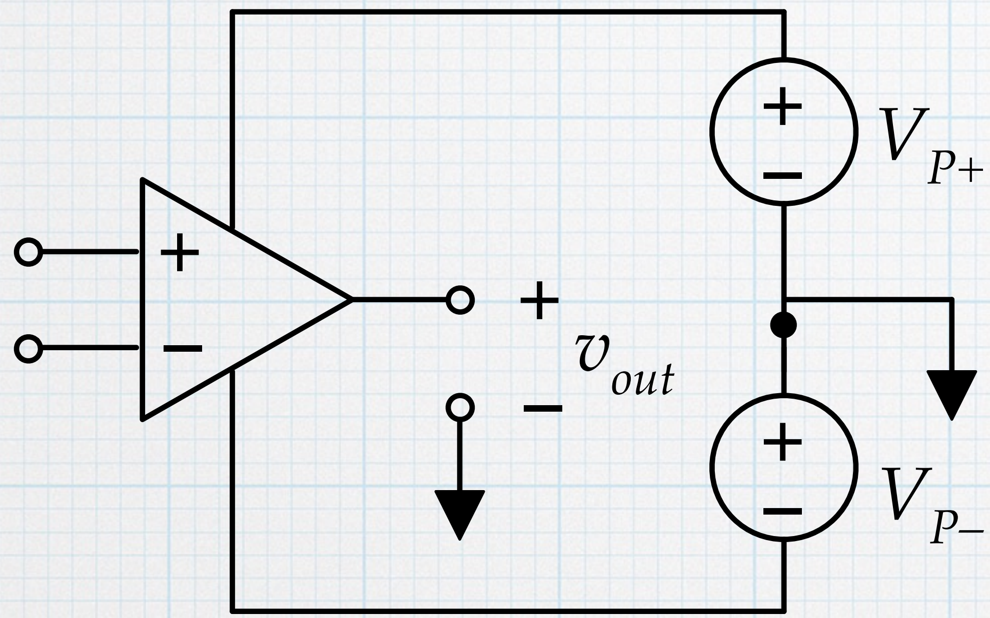
Amp 1: $R_{i1}$ = 1 kΩ,
$A_1$ = 20, $R_{o2}$ = 50 Ω

$$A_T = \frac{1\text{M}\Omega}{1\text{M}\Omega + 10\text{k}\Omega}(20)\,\frac{1\text{k}\Omega}{1\text{k}\Omega + 1\text{k}\Omega}(20)\,\frac{100\Omega}{100\Omega + 50\Omega} = 132$$

Much higher gain! This happens because of the more favorable voltage divider combinations in this arrangement.

# Practical matters

There will always be at least one DC source that supplies power to the amp. Many amps require two DC supplies, one positive and one negative.



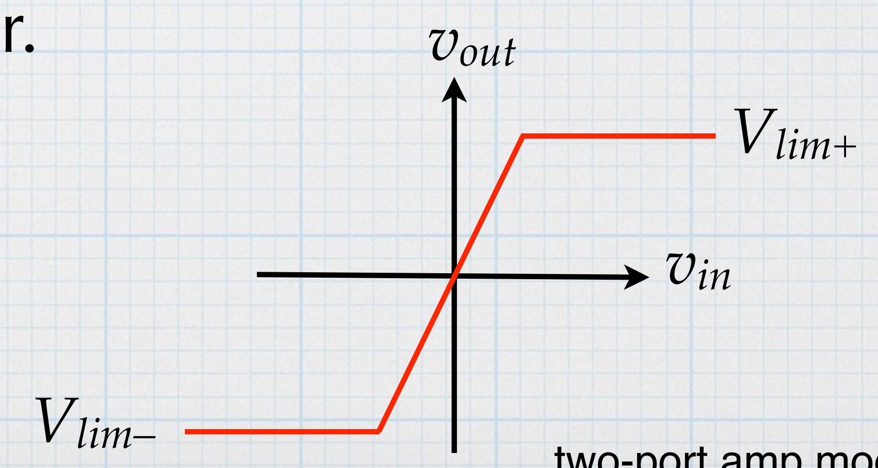

The power supply connections define the ground point in the circuit.

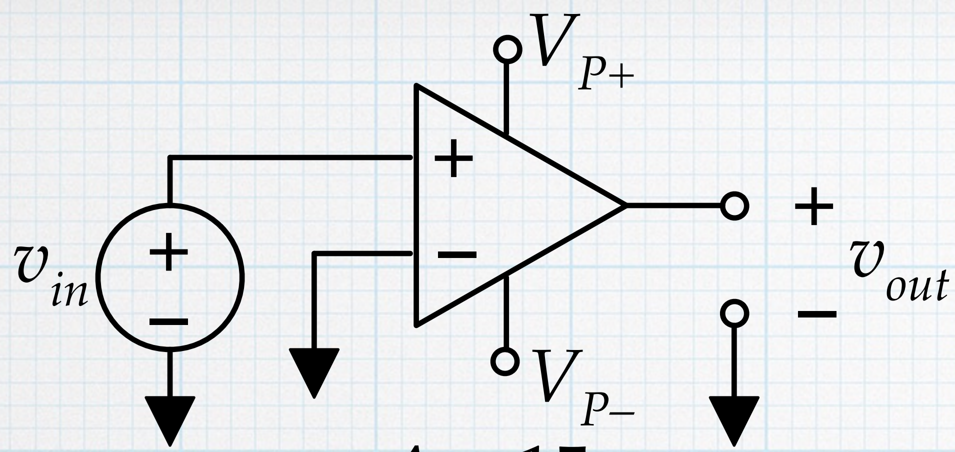
Usually, we don't include the power supplies in the circuit diagrams.

The power supplies also impose limits on the output voltage. You can't get out more voltage than what is available from the supplies. The actual output limit may be somewhat lower than the power supply voltage, depending on the particular amplifier.

$$V_{lim+} \le V_{P+} \text{ and } V_{lim-} \ge V_{P-}$$

$$V_{lim-} < v_o < V_{lim+}$$



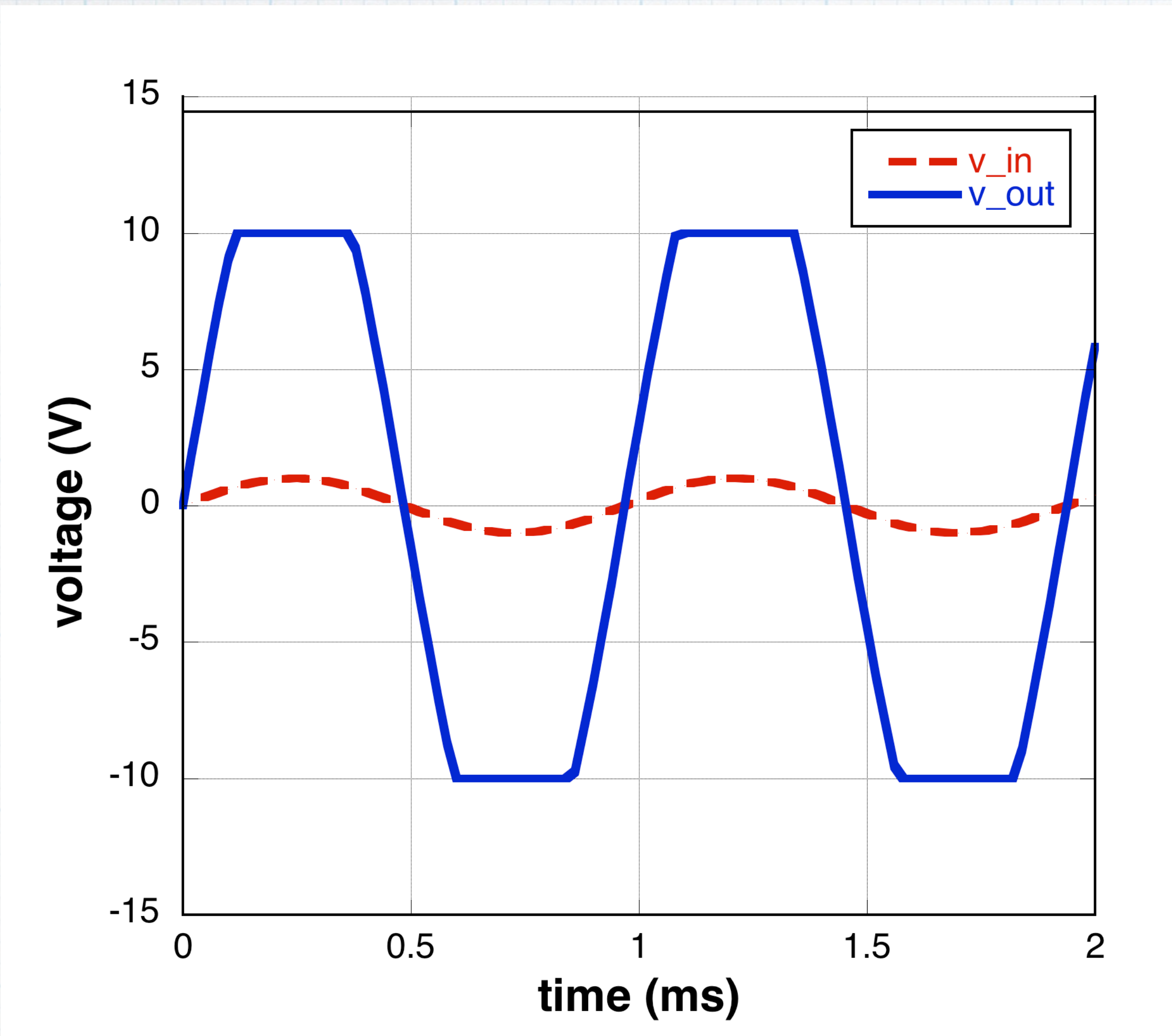


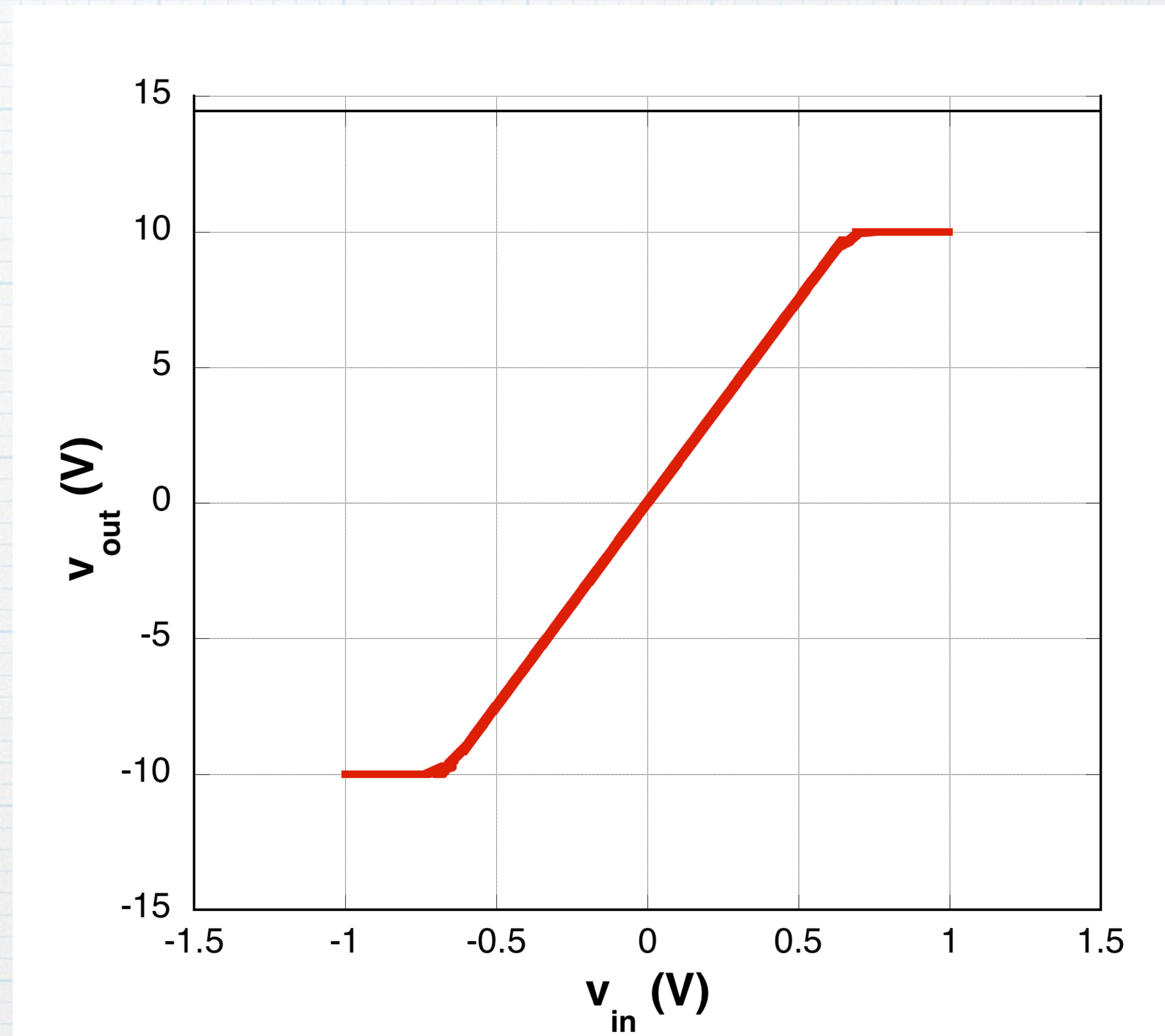

$A = 15$

$v_{in} = (1\text{ V})\cdot\sin(2\pi f\cdot t)$

$v_{out} = A\cdot v_{in} = (15\text{ V})\cdot\sin(2\pi f\cdot t)$ (expected)

But if the power supplies limit at ± 10 V:




If input voltage and/or gain are too the bit, the output will “clip” at the limiting voltages. Since the output no longer has the same shape as the input, we say that it is “distorted”. We will study this more later.