2.3 The Non-Inverting Configuration

Reading **Assignment**: *pp.*

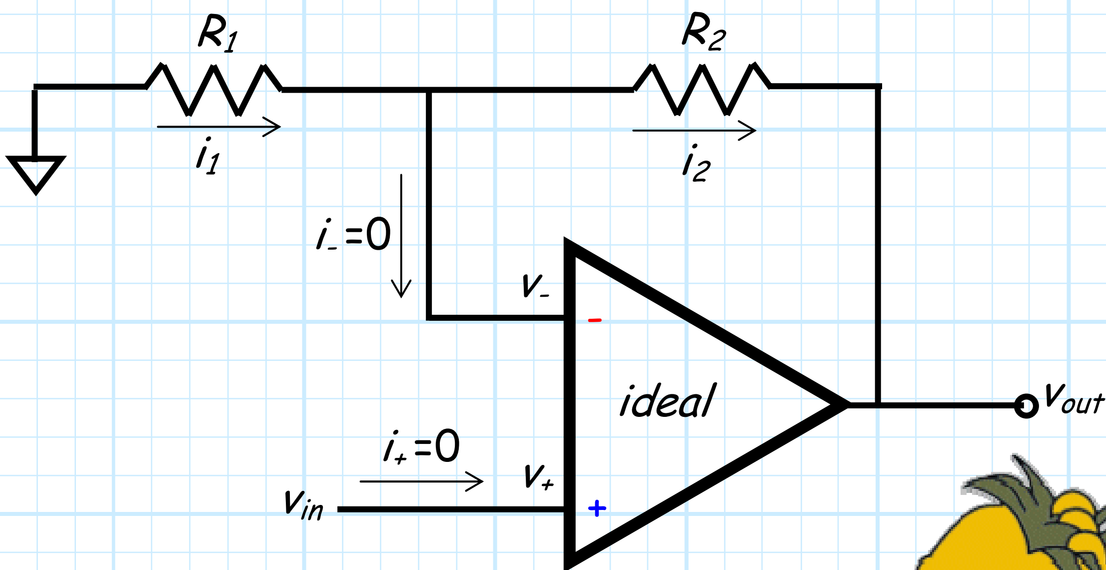
Another standard op-amp circuit configuration is the non-inverting configuration.

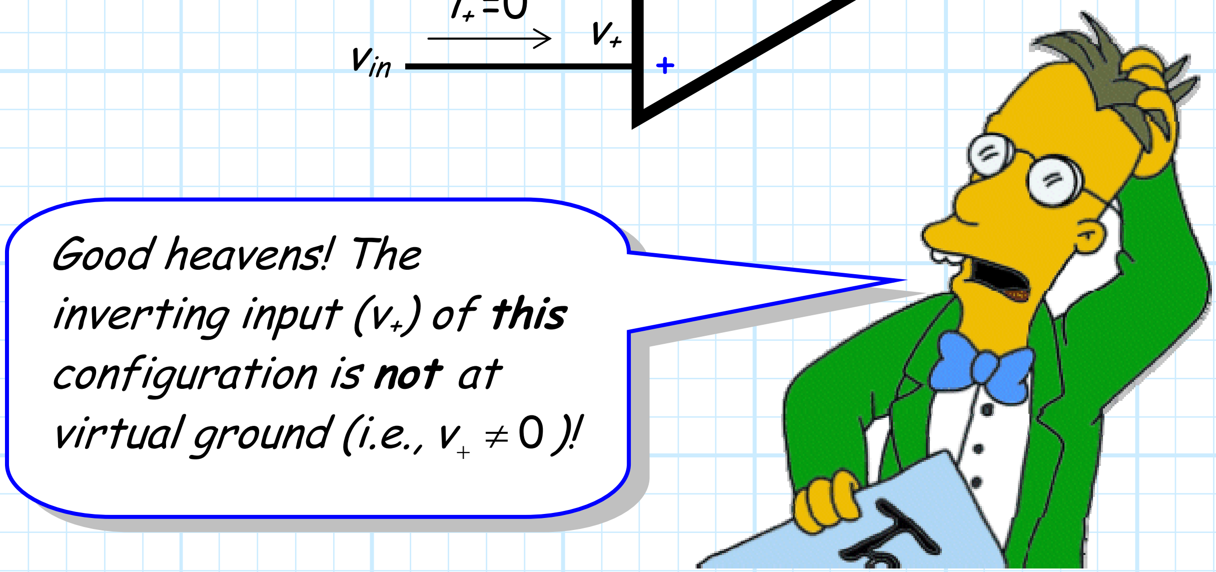
HO: THE NON-INVERTING CONFIGURATION

An important non-inverting circuit is the voltage vollower.

HO: THE VOLTAGE FOLLOWER

The Non-Inverting Configuration





Recall that $v_- = v_+$ (the virtual **short**) ALWAYS for feedback amplifiers.

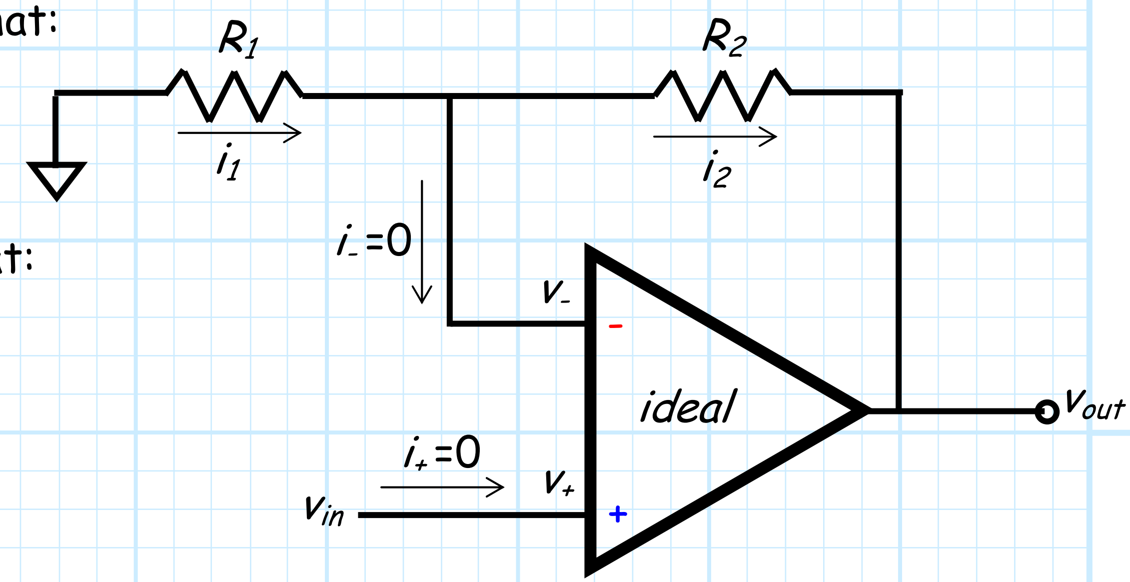
No virtual ground here!

Notice also that for the circuit above, the voltage at the **non-inverting** terminal is the **input** voltage v_{in}:

$$\therefore \quad v_- = v_{in} \neq 0$$

We use this fact to **analyze** this non-inverting configuration.

First, we use **KCL** to determine that:



$$i_1 = i_- + i_2$$

and since $i_- = 0$, we again find that:

$$i_1 = i_2$$

and from **Ohm's Law**:

$$i_1 = \frac{0 - v_-}{R_1} = \frac{-v_-}{R_1} \qquad i_2 = \frac{v_- - v_{out}}{R_1}$$

i_- = 0 is the key

These results are of course **very similar** to the expressions we derived when analyzing the **inverting** configuration.

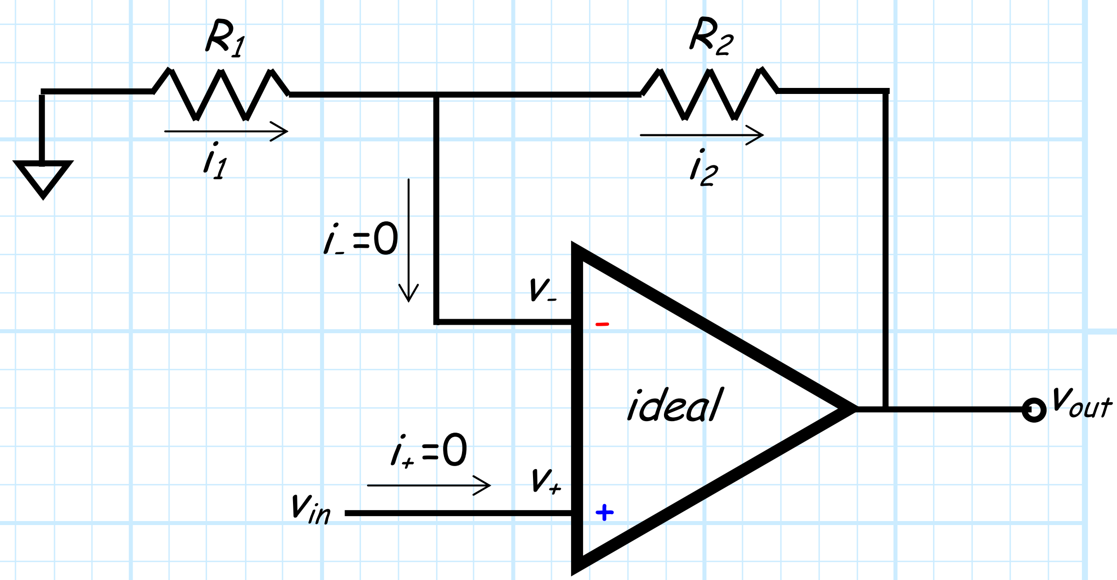
The main difference is of course that v_- is **not** equal to zero.

Instead, we know that $v_- = v_{in}$. Thus:

$$i_1 = \frac{-v_{in}}{R_1} \qquad\qquad i_2 = \frac{v_{in} - v_{out}}{R_1}$$

and since $i_1 = i_2$, we determine a relationship involving v_{in} and v_{out} **only**:

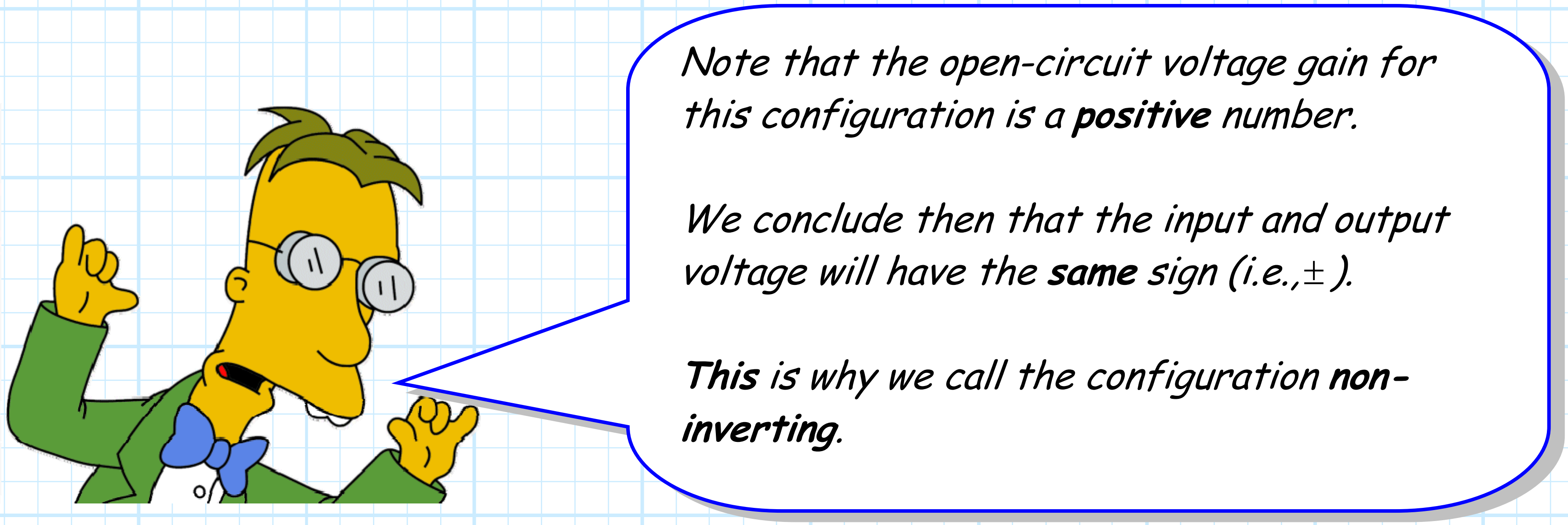
$$\frac{-v_{in}}{R_1} = \frac{v_{in} - v_{out}}{R_2}$$



Note the gain is a positive number

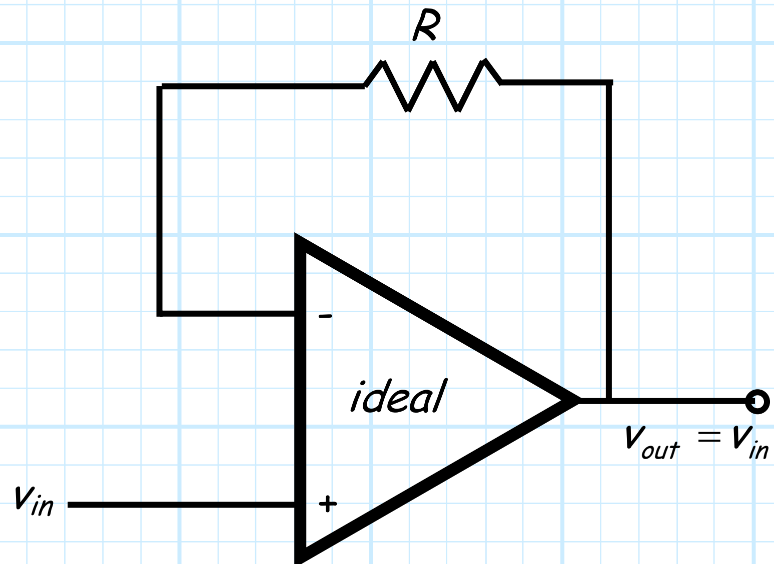
Performing some simple algebra, we rearrange this expression and find the **open-circuit voltage gain** of the **non**-inverting configuration:

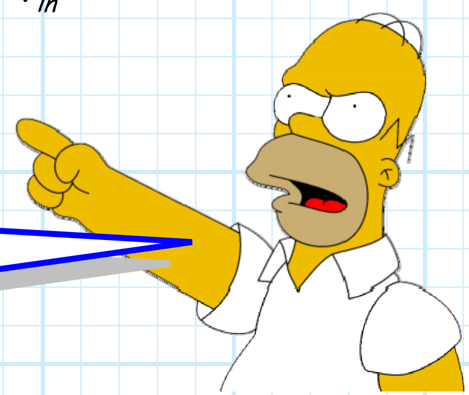
$$A_{vo} = \frac{v_{out}^{oc}}{v_{in}} = 1 + \frac{R_2}{R_1}$$



The Voltage Follower

The **voltage follower** has a open-circuit voltage gain $A_{vo} = 1$—with the result that $v_{out} = v_{in}$!





Q: *Pfft! The output voltage is **equal** to the input voltage?!*

***Why** even bother?*

A: To see **why** the voltage follower is **important**, consider the following example.

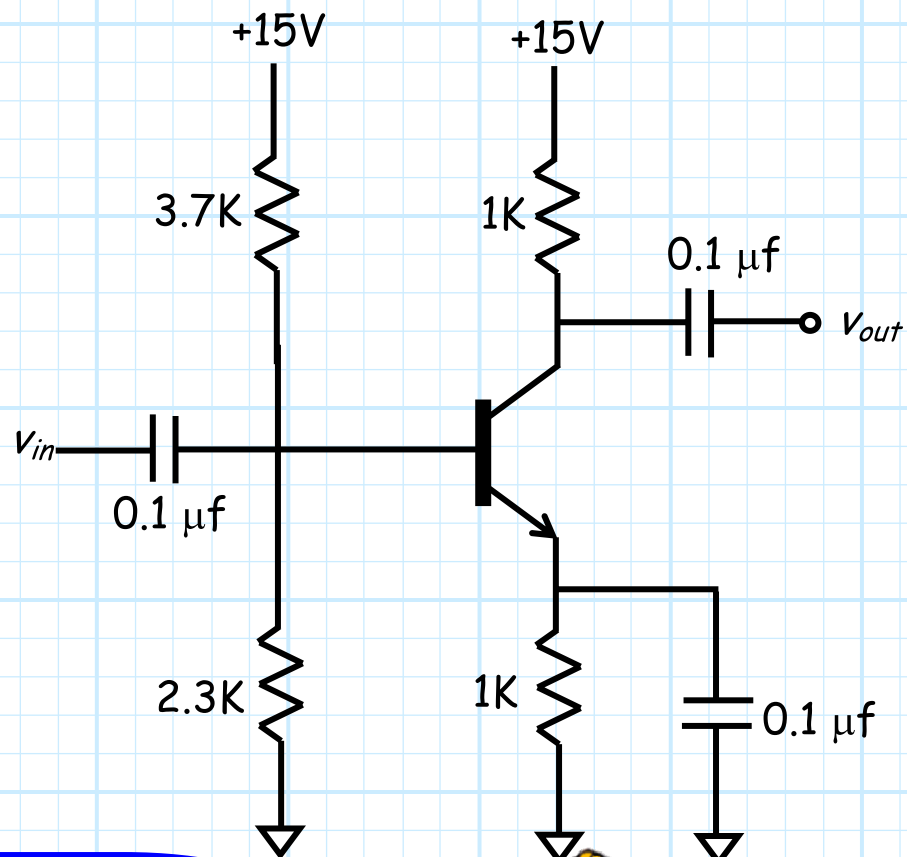
What a great amp…

Say **you** have toiled for hours to design and build the following **audio amplifier**:

A_{vo} = -200 (midband)

R_{out} = 1 K

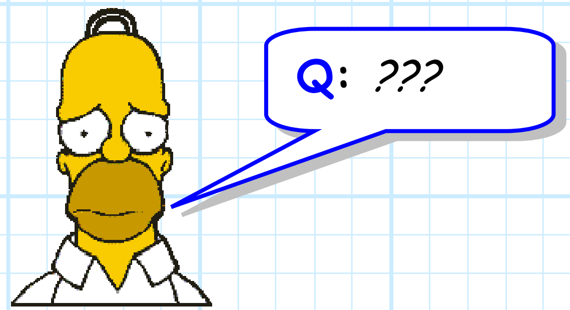
R_i = 370 Ω



Q: $A_{vo} = -200$! *With this much gain we'll be shakin the windows—right?*

...or, maybe not

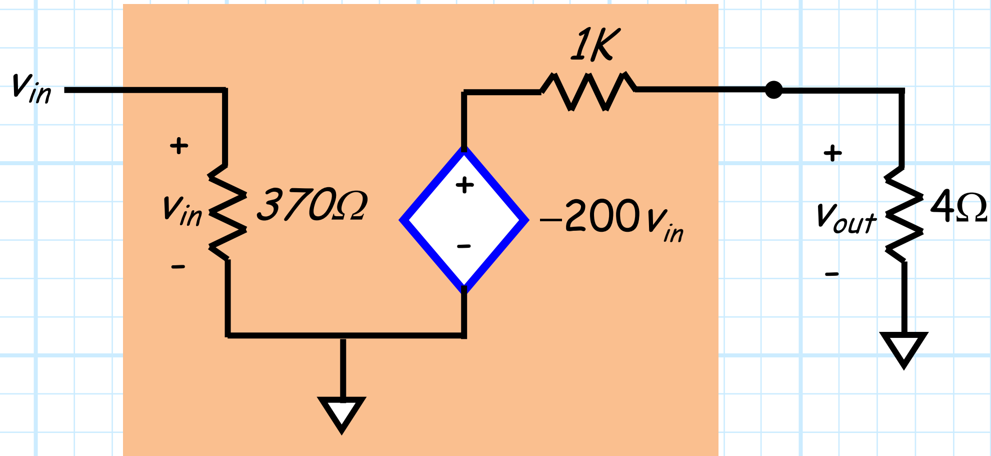
A: Actually, if we connected this amplifier **directly** to a speaker, **nothing** would happen—**silence**!



A: The reason for this is that the **resistance** of most **speakers** is **very small** (4 Ω-8 Ω).

What's the problem then?

We can use the linear equivalent **circuit model** of the audio amplifier to **analyze** the result:



$$v_{out} = -200\,v_{in}\left(\frac{4}{4+1000}\right) = -0.8\,v_{in}$$

The **output** of this amplifier is even **smaller** than its **input**!

The **problem**, of course, is **not** that the open-circuit voltage **gain** is too small—after all, it's -200!

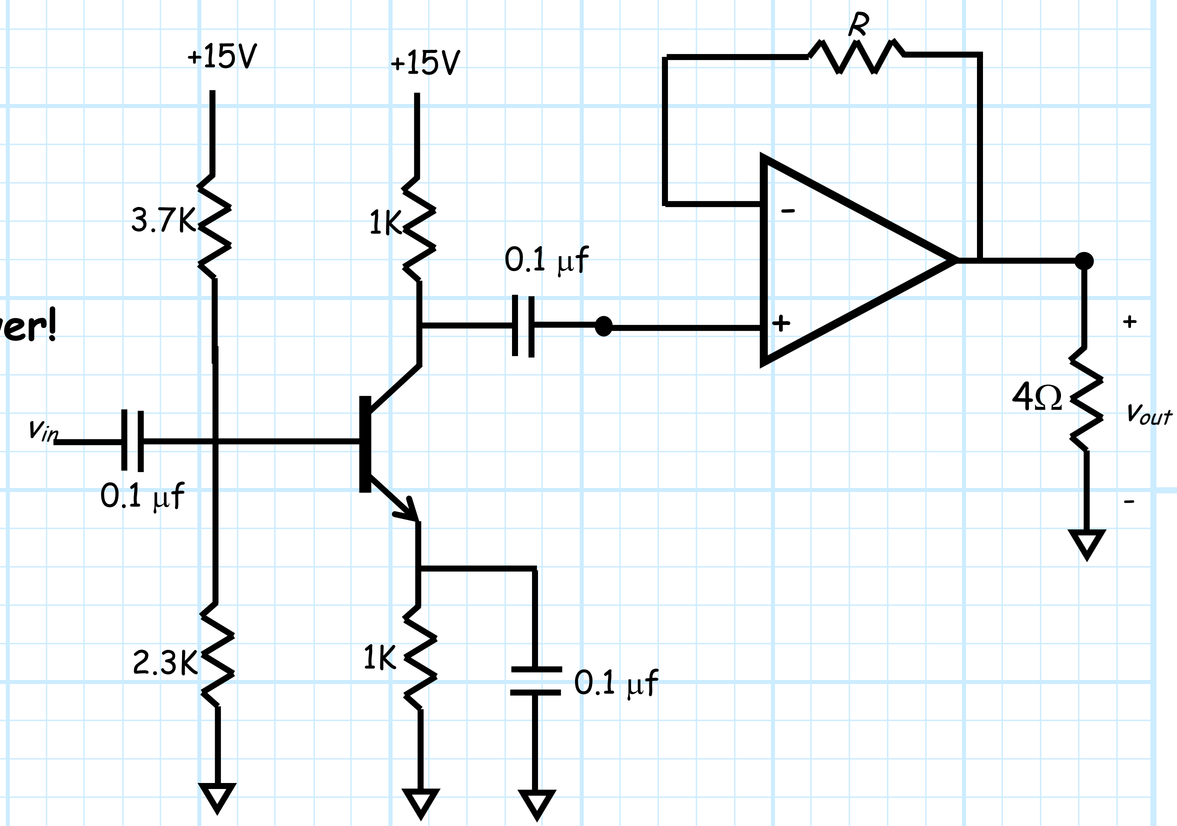
The output resistance is just too large!

The **problem** is that the amplifier **output resistance** (R_{out} = 377Ω) is much **larger** than the **load** resistance R_L= 4 Ω.

Therefore, we have **tremendous loss** due to the resulting **voltage divider**:

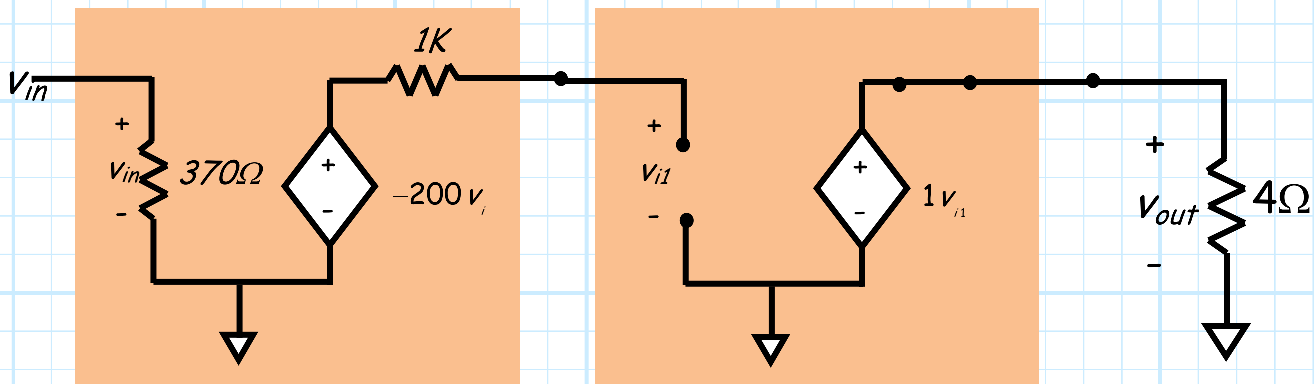
$$\frac{4}{4+1000} \approx 0.004$$

There is a solution to this problem—use a voltage follower!



The voltage follower to the rescue!

Let's again use the **linear equivalent model** to analyze this circuit and find the output voltage v_{out}.



$$v_{out} = -200\, v_{in} \left(\frac{\infty}{1000+\infty} \right) 1 \left(\frac{4}{0+4} \right) = -200\, v_{in}$$

We've got back our **gain**!

The voltage follower: a useful buffer

Note:

1. **Instead** of 4Ω, the audio amp "sees" a load of ∞, the **input resistance** of the voltage follower—this is **ideal**!

2. **Instead** of 377Ω, the speaker "sees" a source resistance of 0, the **output resistance** of the voltage follower—this too is **ideal**!

Remember, there are **three** characterizing parameters of an amplifier—open circuit voltage gain is just **one** of those three!

The input and output impedance of the voltage follower make it an excellent **"buffer"** between two circuits!