Op-amps, positive & negative feedback, the `Golden Rules' and a few devices

READING: Art of Electronics, 4.01-4.09

& Harold S. Black, IEEE Spectrum 1977 (on wiki)

Why not turn it up to 11?

At the end of last week's lab, we used feedback to make an 11 x amplifier.
The 11 x gain with the feedback significantly reduced the gain of the amplifier *without* feedback – the so-called `open-loop' gain.

Why would one wish to do this? Doesn't this *throw away* gain that we worked very hard to incorporate into our amplifier?

The short answer is – yes, it does `throw away' gain. But not without redeeming merit – keep in mind, we now have *feedback* in our circuit. This is the key advantage. When the open-loop gain vastly exceeds the gain attained via feedback, we refer to this as *negative feedback* – not like a news-cycle, where bad news begets bad news (this is *positive* feedback by our definition. If you're not confused, just wait a moment…)

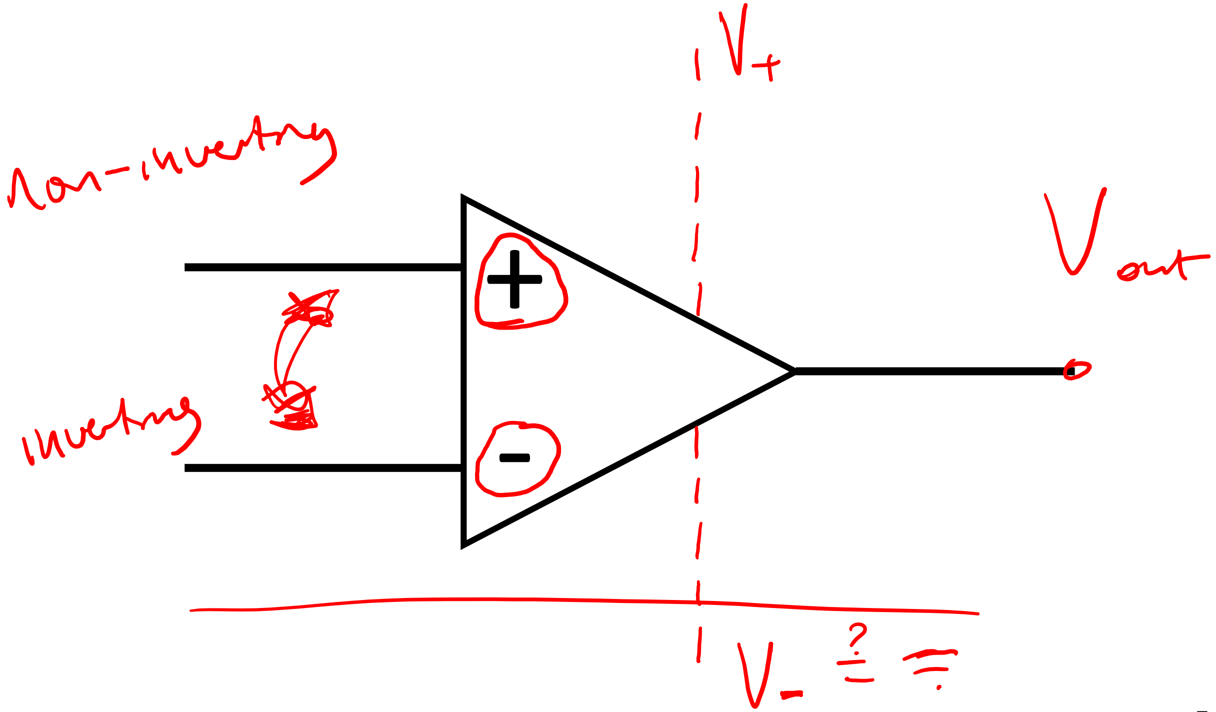
Negative feedback essentially consists of throwing away the `bad' while keeping the `good.' The output of the amplifier is attenuated, and compared with another input to the amplifier, and the *deviation from the input* then `directs' the amplifier to move in the correct direction – thus suppressing noise, for example.

Next week, we'll learn what happens when you use these devices with their incredible gain to make circuits with positive feedback; this week, we'll only focus on negative feedback and the amazing properties it has.

Point for discussion on Piazza: 1. What problem did Harold S. Black solve by inventing negative feedback amplifiers?
2. Harold Black wrote his idea for the negative feedback amplifier on the newspaper – why might he have done this?

Now, on to the op-amp:

An op-amp is a very high-gain* dc-coupled differential amplifier with a single-ended output.

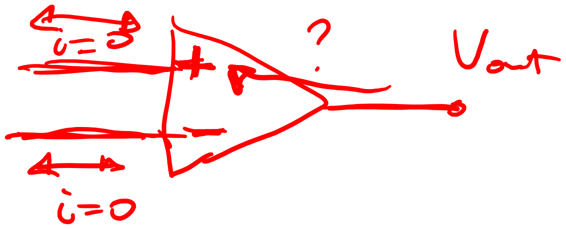


* The typical op-amp (e.g. the LF411) has an open-loop gain of 10^5 - 10^6

Why would we call the non-inverting input *the non-inverting input?* Isn't it much easier just to call it the `positive input?'
How many leads would be necessary for such an amplifier? How many wires?

The `golden rules' for op-amp behavior ***assuming it is operating with feedback***

I. The output attempts to do whatever is necessary to make the voltage difference between the inputs 0.

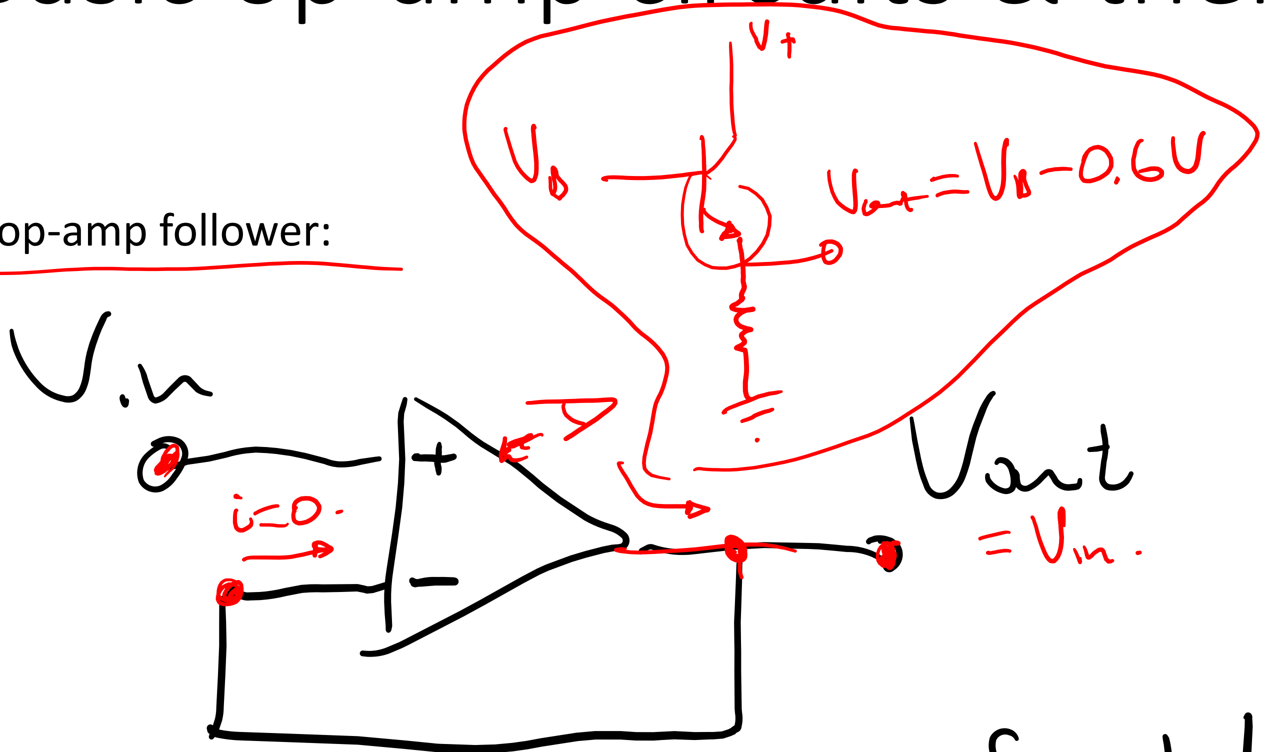


II. The inputs draw no current.

Can the op-amp dictate the voltage at the inputs? Why or why not?

Basic op-amp circuits & their analysis

An op-amp follower:



1. V_{in} increases.
2. $\Delta V_{\pm}$ increases.
3. Amp drives output up until $V_{out} = V_{in}$.

Simple! At step 3, both Golden Rules apply – first, GR I: the output responds to $\Delta V_{\pm}$; Second, GR II: $V_- = V_{out}$.

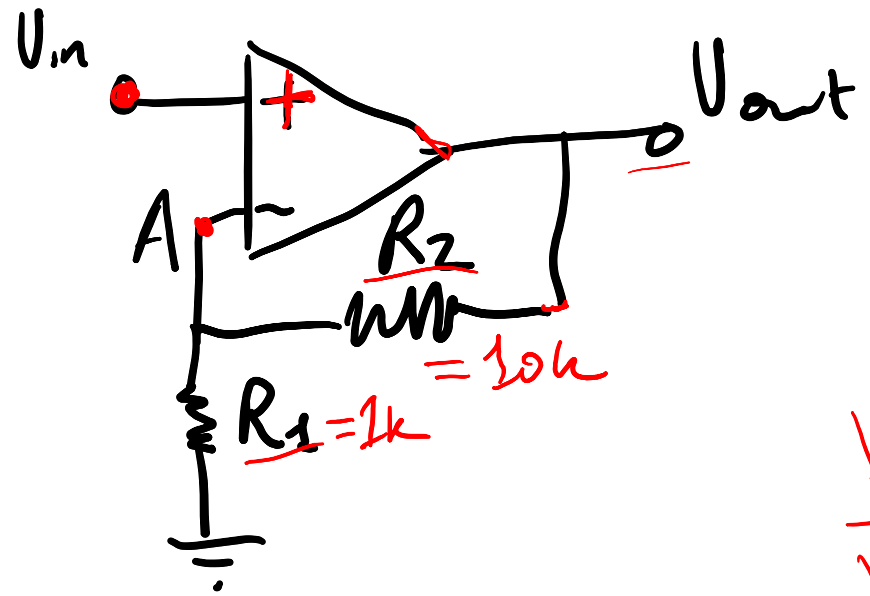
Also called a buffer.

On Piazza

What is the benefit of this circuit – e.g. why would one want to use it?

Basic op-amp circuits & their analysis

non-inverting amplifier: (might look familiar from last week's lab):



- From GR I, $V_A = V_{in}$
- But, V_A comes from a V-divider:

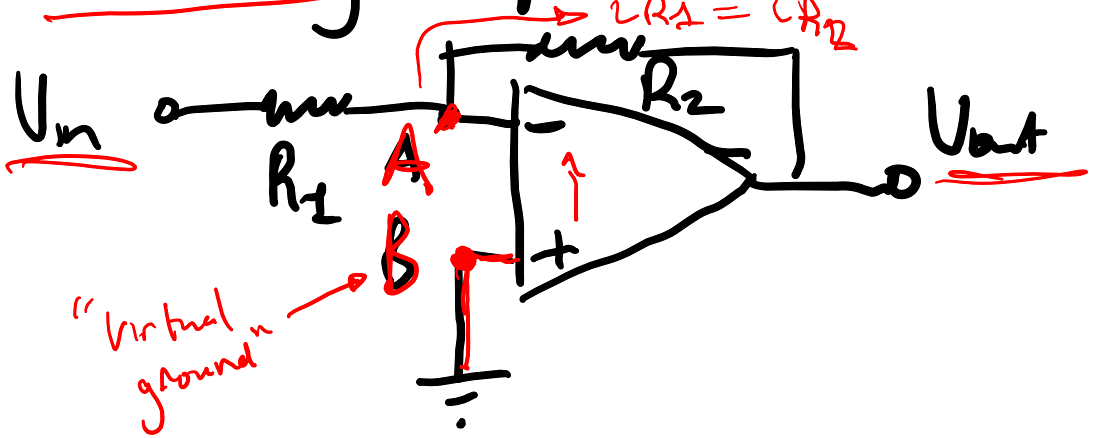
$$V_A = \frac{V_{out}\, R_1}{R_1 + R_2}$$ } this is our gain!

$$\frac{V_{out}}{V_{in}} = G = \frac{R_1 + R_2}{R_1} = \boxed{1 + \frac{R_2}{R_1}}$$

$$G = 1 + \frac{10k}{1k} = 11.$$

Basic op-amp circuits & their analysis

Inverting amplifier:



→ • Point B is a "virtual ground".

GR I: Point A is also at $V=0$.

• $\Delta V_{in-A} = I_{R1} \cdot R_1 = V_{in}$

• GR II: $I_{R1} = I_{R2} = I$

$\Rightarrow \Delta V_{o-A} = I \cdot R_2 = V_{out}$

Thus, $$\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1} = G.$$

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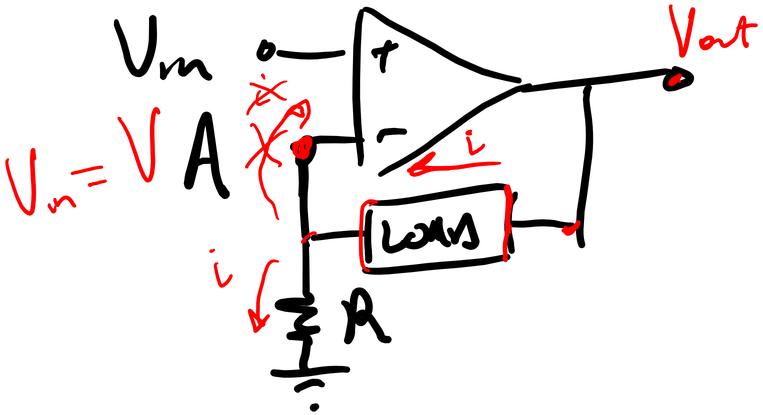
What is the input impedance of this amplifier? (hint: it is not the input impedance of the op-amp!)

Basic op-amp circuits & their analysis

Current sources:

A basic design, with a glaring problem:



GRI: $V_A = V_{IN}$; Thus, by GRII, $I = \frac{V_{in}}{R}$

• I passes through the load.

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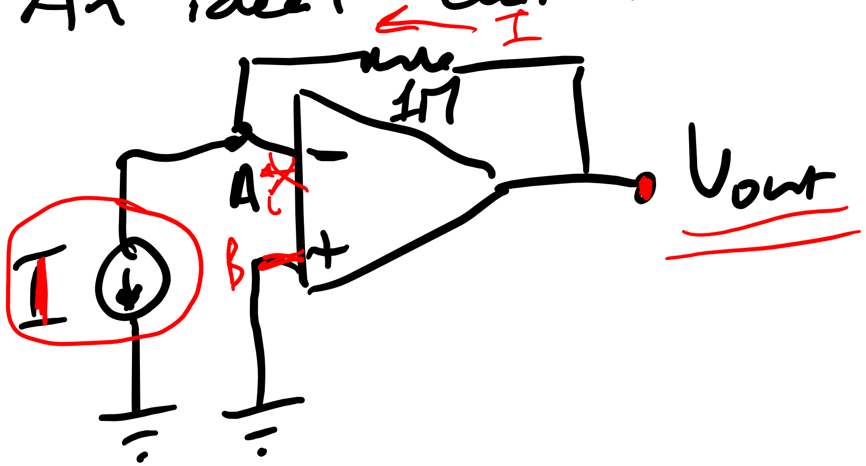
What is the `glaring problem' with this design? E.g. Why might it not be ideal for use in pushing a current through a resistive load?

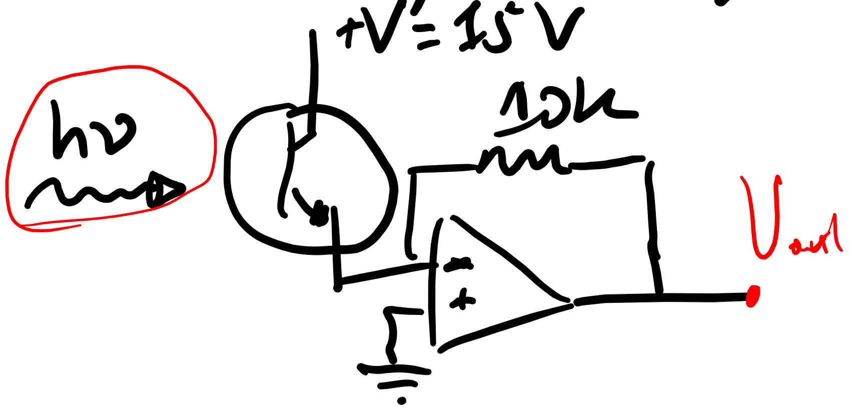
Basic op-amp circuits & their analysis

An ideal current-to-voltage converter (a "trans-impedance" amp)



This circuit produces an output of $1V/\mu A$ of current: useful for e.g. a photodiode, which makes current when exposed to light.

Alternatively, suppose your current source requires power:



For e.g. a PMT

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The devices we've review thus far do not constitute a comprehensive list of useful op-amp circuits. Find another circuit that uses negative feedback to do something useful!

Cautionary notes for application of the GRs

- Golden rules only apply if the op-amp is in the `active region' (i.e. not saturated at V_+ or V_- of the supply)

  ← see e.g. lab.

- Feedback *must be negative* – be careful not to mix up the inverting and non-inverting inputs

  , you'll +'ve feedback

- There must always be feedback at DC – otherwise, you're guaranteed to saturate. Alternatively, apply a high-pass filter to the input to eliminate concerns about DC offset driving the amp into saturation.

  See e.g. exercises this week.

- Beware the maximum differential input voltage – if overdriven, the amp can fail catastrophically.

  LF411 has > 20 transistors. Some will burn if overdriven.