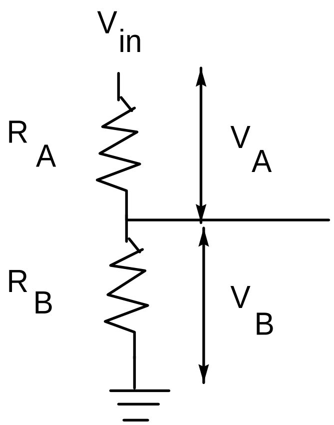
Voltage Dividers

Analog-to-Digital converters (ADC) and Digital-to-Analog Converters (DAC) generate voltage using n-bit digital data

A. Voltage Dividers



Ohm's Law, can prove that:

$$V_A = \frac{R_A}{R_A + R_B} V_{in} \quad \text{and} \quad V_B = \frac{R_B}{R_A + R_B} V_{in}$$

NB: $V_A + V_B = V_{in}$

B. An N-bit ADC has N voltage dividers

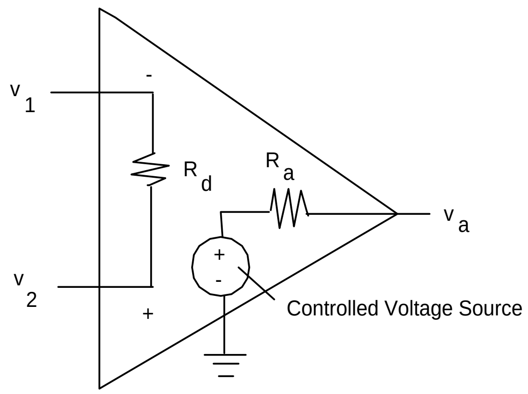
Example: Lab 10-bit circuit: $V_{out} = \frac{raw}{1023} \cdot V_{ref}$ Where $V_{ref} = 5.0$ V

raw = 1023	5.000 V
WORD = 1022	4.995 V
WORD = 512	2.502 V
WORD = 0	0.000 V

} Resolution = 5 mV

Op-Amps

Ideal Op-Amps: 2 rules and 5 properties

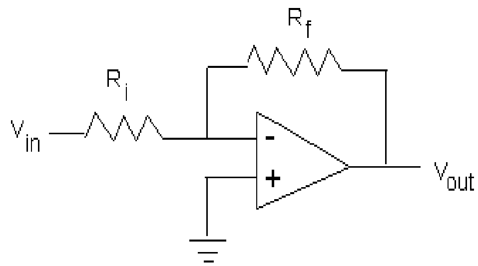


Rule 1: Voltage at "+" and "-" terminals are equal

Rule 2: No current at "+" and "-" terminals

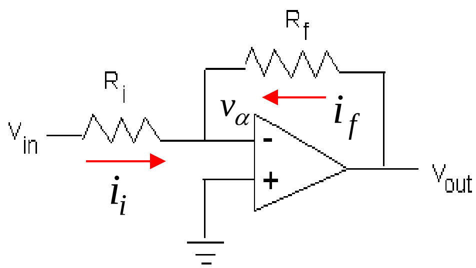
- Input impedance $R_d \approx \infty$
- Output impedance $R_a \approx 0$
- Open-loop gain is ∞
- Bandwidth is ∞
- $v_a = 0$ when $v_1 = v_2$

Example: Derive the op-amp's input-output relationship

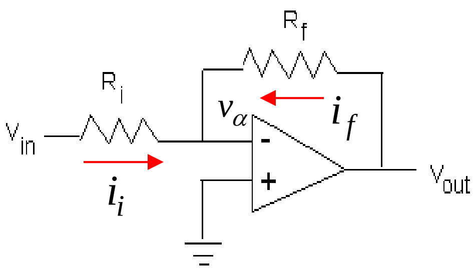


Solution:

Step 1: Label currents and voltage points



Step 2: Apply Rules 1 and 2



With Rule 2, observe that $i_i + i_f = 0$

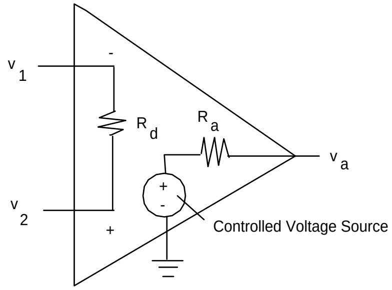
Or, $\dfrac{v_i - v_\alpha}{R_i} + \dfrac{v_o - v_\alpha}{R_f} = 0$

With Rule 1, observe that $v_\alpha = 0$

Hence $\dfrac{v_i}{R_i} = -\dfrac{v_o}{R_f}$ or $v_o = -\dfrac{R_f}{R_i} v_i$

The gain is $-\dfrac{R_f}{R_i}$ and hence is called an inverting op-amp. In practice, one cannot have infinite gain.

In fact, even if the input and feedback resistors are small and large respectively, the gain will be clamped. Op-amps have rail voltages, often denoted as +V and –V. Instead of swinging to infinity, we have



If $v_1 > v_2$ then $v_a = +V$

If $v_1 < v_2$ then $v_a = -V$

Impedance – what's the big deal?

Illustrative Problem: Design an inverting op-amp that has a gain of -10

Solution (non-unique):

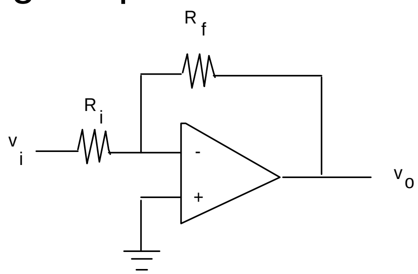
Recall, we solved that: $v_o = -\frac{R_f}{R_i} v_i$ Choose $\underbrace{R_f = 1000\Omega \text{ and } R_i = 100\Omega}$

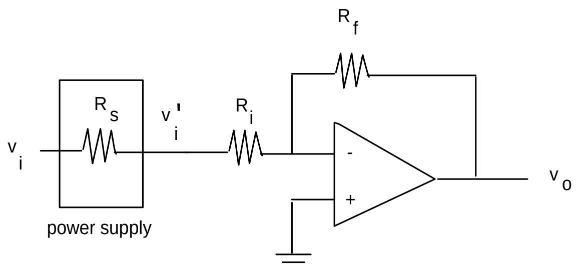
Naïve solution! Gain is -10 if no impedance!

Impedance and Resistance obstruct alternating (AC) and direct current (DC) respectively

Impedance is zero only at absolute zero temperature (molecule don't move). Otherwise, everything in nature has impedance, including power supplies.

Re-examining the problem realistically:

This 

is really 

Thus have by voltage divider equation $v_i' = \frac{R_i v_i}{R_i + R_s}$ where $R_s \approx 25\Omega$ typically

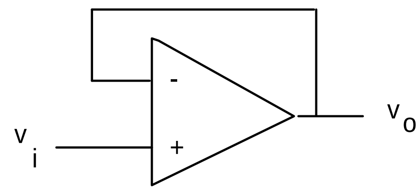
Hence using a naive selection of resistors $v_i' = \frac{100}{100+25} v_i = 0.8 v_i$

You're only getting 80% of the input voltage you think you're putting in

Rule of thumb: $\begin{cases} R_i > 10 \cdot R_s \text{ is a sloppy circuit} \\ R_i > 100 \cdot R_s \text{ is reasonable} \end{cases}$

Voltage Follower – what's the big deal?

Illustrative Problem: Derive the input-output relationship for the following



Solution: Rule 1 says that the "+" and "-" voltages are equal.

$$\text{Thus have } v_o = v_i$$

Question: Why would anyone want a unity gain amplifier?

Answer: Because op-amps have near zero output impedance.

Thus even though the power supply generating v_i has impedance R_s

v_o will give $v_i^{'}$ with little output impedance

As such, voltage followers are great and often used in instrumentation amplifiers