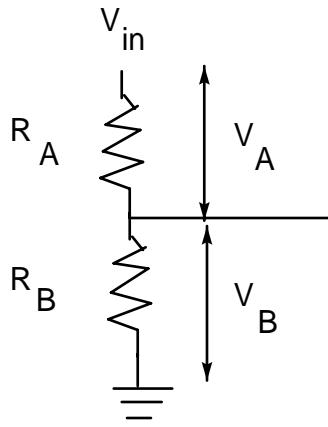


# Voltage Dividers

MEM 639 Real-Time Microcomputer Control 1

# 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 DAC has N voltage dividers

Example: Class circuit:  $V_{out} = \frac{WORD - 128}{128} V_{ref}$       Where  $V_{ref} = 5.0 \text{ V}$

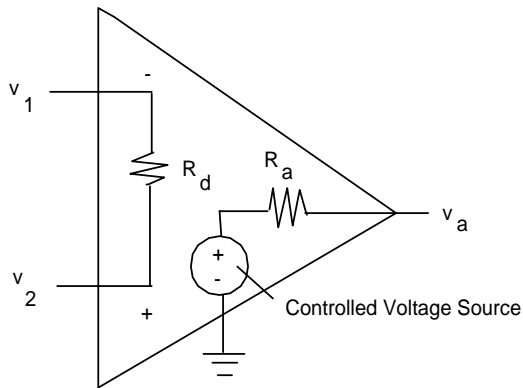
WORD = 255	4.961 V
WORD = 128	0.00 V
WORD = 129	0.039 V
WORD = 0	-5.00 V

} Resolution = 40 mV

# Op-Amps

MEM 639 Real-Time Microcomputer Control 1

## Ideal Op-Amps: 2 rules and 5 properties



**Rule 1:** Voltage at “+” and “-” terminals are **equal**

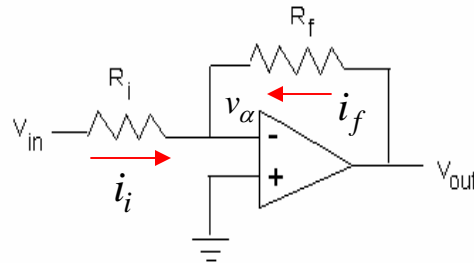
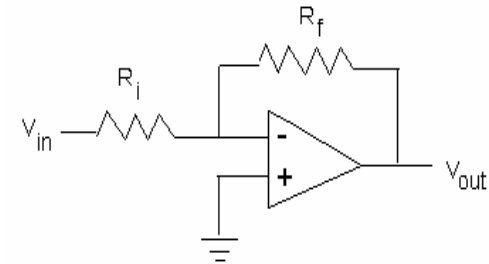
**Rule 2:** **No** current at “+” and “-” terminals

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

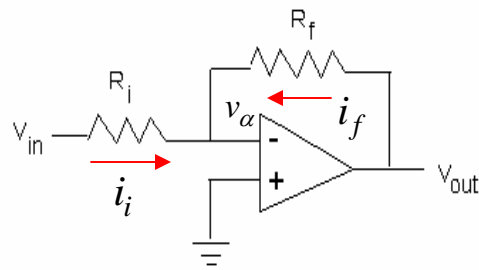
**Example:** Derive the op-amp's input-output relationship

**Solution:**

Step 1: Label currents and voltage points



Step 2: Apply Rules 1 and 2



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

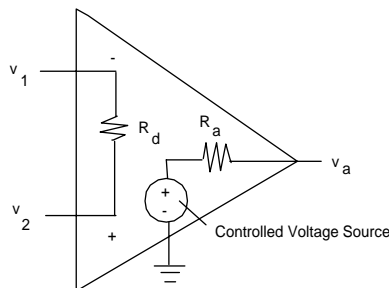
$$\text{Or, } \frac{v_i - v_\alpha}{R_i} + \frac{v_o - v_\alpha}{R_f} = 0$$

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

$$\text{Hence } \frac{v_i}{R_i} = -\frac{v_o}{R_f} \quad \text{or} \quad v_o = -\frac{R_f}{R_i} v_i$$

The gain is  $-\frac{R_f}{R_i}$  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?

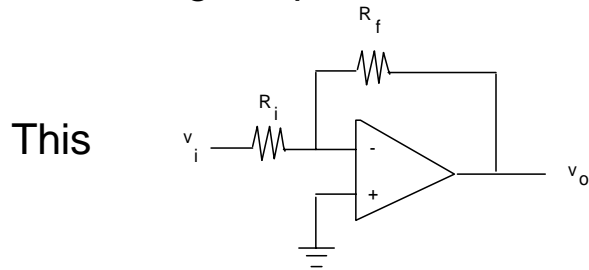
**Illustrative Problem:** Design an inverting op-amp that has a gain of -10

**Solution (non-unique):**

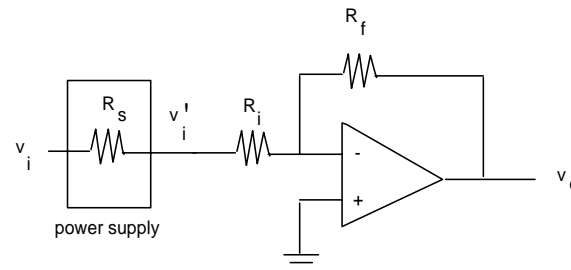
Recall, we solved that:  $v_o = -\frac{R_f}{R_i} v_i$  Choose  $R_f = 1000\Omega$  and  $R_i = 100\Omega$   
 Naïve solution! Gain is -10 if no impedance!

**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:



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

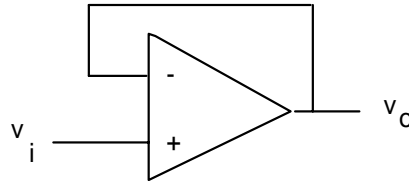
Hence using a naive selection of resistors  $v'_i = \frac{100}{100 + 25} v_i = 0.8 v_i$

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