**Op-Amp Applications.**

NB: terminals not used are not shown.
Exclusion: power-supply inputs (always used, never shown)

Negative feedback loop: necessary because of likelihood of saturation. Circuits w/o feedback loop—almost never used.

(Example 1 (7.3) Voltage follower, a.k.a. impedance transformer)

What's the point? 

- \( i_+ \approx 10^{-12} \div 10^{-9} \text{ A} \) (our input impedance is huge)
- Output current \( \approx 25 \text{ mA} \) (greatly amplified)
- Input impedance \( \approx 10^2 \Omega \)
- Output impedance \( < 1 \Omega \)

(Example 2 (7.4) Inverting amplifier)

(Useful not by itself, but as a part of a circuit)

\( R_2 \)-feedback resistor

Resistance between \( 1 \) and \( 2 \)

\( \approx 10^{12} \Omega \) (op.amp. input impedance)

\( i_+ \approx 0 \).
Kirkhoff's rule for \( i_1, i_2, i_3 \): \( i_+ = 0 \Rightarrow i_1 = i_2 \).

\[
\frac{e_i - 0}{R_1} = i_2; \quad \frac{0 - e_0}{R_2} = i_2; \quad \frac{e_i}{R_1} = -\frac{e_0}{R_2}
\]

Phase inverted, \( e_0 = -\frac{R_2}{R_1} e_i \)

\( \therefore g = -\frac{R_2}{R_1} \)

Usually \( R_3 \) is set \( \pi \)

\( R_3 = \frac{R_1 R_2}{R_1 + R_2} \)

to make input impedances \( e_0 \) and \( e_+ \) terminals of op amp equal.

**Example 3 (7.5)**

**Noninverting amplifier**

\( e_+ = e_i; \quad e_- = e_+ \) (negative feedback is present)

\( e_- = \frac{R_2}{R_2 + R_2} e_0 \)

\( \therefore e_0 = \frac{R_1}{R_2 + R_2} e_i \)

\( g = \frac{R_1 + R_2}{R_1} \)

Set \( R_1 = R_2 \)

\( R_3 = R_4 \)

Somewhat similar to inverting amp, but

\( e_+ - e_- \) inst of \( e_+ \).
\[ e_0 = \frac{R_3}{R_1} (e_1 - e_2) \]

Some comments: need accurate resistor matching to get high CMRR

* Can minimize offset and adjustment by making input resistances \( R_1 \) and \( R_2 \) equal.

Voltage comparator

**Example 5 (7.8)**

\( \text{e_ref} \) set to desired reference voltage.

\[ e_0 \]

1) \( e_1 > e_{\text{ref}} \), output positively saturated
2) \( e_1 < e_{\text{ref}} \), output negatively saturated

\[ R_3 \approx \frac{R_2 R_e}{K_2 + R_3} \]

(to equalize \( e_0 \)

\( \Theta \) and \( \Delta \) impedances

**Example 6 (7.9)** Summing amplifier

\[ e_0 = -\left( \frac{1}{R_1} e_1 + \frac{1}{R_2} e_2 + \frac{1}{R_3} e_3 \right) \]

\( R_1 = R_2 = R_3 = R \Rightarrow \)

\[ e_0 = -\frac{R_{\text{in}}}{R} (e_1 + e_2 + e_3) \]

Spin-off of inverting amp.