Op-amp based algebra.

**Multiplication**: non-inverting amp.

**Addition**: summing amp + inverting amp.

**Subtraction**: inverting amp (for one input) + summing amp.

Can implement analog computing.

**Special amplifier circuits (7.18)**

Instrumentation amplifier core of:

* accurate amplification of small-voltage diffs.
* in presence of huge CM signal

* avoid loading the transducer by keeping current thru it small as possible

Stage 1: increase transducer

\[ R_2 = R_3 \]
\[ R_4 = R_5 \]
\[ R_6 = R_7 \]

\[ e_{o} \]

Input stage (voltage followers \( \omega/k_1 \rightarrow \infty \))

\[ G = \left( 1 + \frac{2R_2}{R_1} \right) \frac{R_6}{R_4} \]

\[ e_o = G \left( e_{i1} - e_{i2} \right) \]
Additional uses of op amps (7.22, 7.23)

Filtering (7.22)

Passive filter network:
- built from resistors and capacitors
- do not have explicit inductive characteristics (unlike LC filters)

Examples of active filters

Low-pass filter: suppresses high-frequency components
\[ \frac{V_o}{V_i} [\text{dB}] \]

\[ f_c - \text{cutoff frequency} \]

RC low-pass filter:
\[ f_c = \frac{1}{2\pi RC} \]

High-pass filter: suppresses low frequency
\[ \frac{V_o}{V_i} = \frac{1}{1 + \left(\frac{f}{f_c}\right)^2} \]
Corresponding RC filter would be... 
\[ v_e = i_e R C_e = 0 \]

Band-pass filter (chops out low and high freq.)

\[ \frac{V_o}{V_i} \quad [\text{dB}] \]

RC analog
\[ + \cos \left( \frac{t}{T} \right) \]

What's good about active filters compared w/RC or LC?

Roll-off: \( \frac{\Delta f}{\Delta f} \) in terms of \( \frac{dB}{\text{octave}} \) or \( \frac{dB}{\text{decade}} \)

Decade = frequency change by a factor of 10
Octave = \( \frac{1}{\text{decade}} = \frac{1}{2} \)

Roll-off for RC filters: \( \approx 6 \frac{dB}{\text{octave}} \)
active filters: \( \approx 80 \frac{dB}{\text{octave}} \)

Differentiators & Integrators (7.23)
Addition to "op amp algebra."

- Responds to rate of change of input
- Time history of input
Op. amp. differentiator

Currents through \( R \) and \( C \) are equal (impedance of op amp is huge):
\[ e_- = e_+ = 0. \]

\[ C \frac{\text{d}}{\text{d}t} (e_i - 0) = \frac{\text{R} \cdot e_0}{\text{R}}. \]

\[ \downarrow \]

\[ e_o = -RC \frac{\text{d}}{\text{d}t} e_i. \]

Output = time derivative of input \( \times \text{const} \)

Op. amp. integrator

From resistor and capacitor current equality (again),
\[ \frac{e_i}{\text{R}} = -C \frac{\text{d}}{\text{d}t} e_0. \]

Integrate:
\[ e_0 = -\frac{1}{\text{RC}} \int e_i \, \text{d}t + \text{const}. \]

\( \text{Re} \) - may be placed in parallel \( \text{w}/C \).

\( \text{huge resistor} \).

\( \times \text{Prevents drift in capacitor charge over long-time intervals} \).

\( \times \text{Restricts signal frequencies to } f \gg 20\text{kHz} \).