Amplifiers in General (pp 72-78)

- The amplifier, another electronic component in a measurement system, scales the magnitude of a signal from its input value, $E_i$, to its output value, $E_o$.
- Functionally, this is expressed as $E_o = f(E_i)$, where $f$ is an amplification operator.
- For a linear amplifier, $E_o = G \cdot E_i$, where $G$ is the gain of the linear amplifier.
- For a logarithmic amplifier, $E_o = G \cdot \log(E_i)$. (Which of our sensors would be good to use with a logarithmic amplifier?)
- The symbol for an amplifier contains negative ($E_{i1}$) and positive ($E_{i2}$) inputs and an output ($E_o$).

Figure 1: An amplifier with its inputs and output.
EXAMPLE PROBLEM: Determine the gain, $G$, of a linear amplifier that is placed between a resistive sensor with a voltage divider and a data acquisition system that accepts DC signals up to 5 V. Over the experimental operating range, the sensor’s resistance varies from 1000 Ω to 6000 Ω. The voltage divider’s fixed resistance equals 100 Ω and its supply voltage equals 5 V.
**Operational Amplifiers**

- An operational amplifier (op amp) actually is an integrated circuit that is comprised of many transistors, resistors, capacitors, and diodes.
- This complex circuit can be modelled as a ‘black box’ having two inputs (+ and −) and one output.
- Input/Output equations can be developed for various op amp configurations using Kirchhoff’s current and voltage laws and noting three main attributes.
- The three main attributes of an op amp are:
  1. very high input impedance ($> 10^7 \ \Omega$),
  2. very low output impedance ($< 100 \ \Omega$), and
  3. high internal open-loop gain ($\sim 10^5$ to $10^6$).
- Attribute (1) implies negligible current flows into the inputs and between them.
- Attribute (2) assures that the output voltage is independent of the output current.
- Attribute (3) yields that the voltage difference between the inputs is zero.
- Attributes (1) and (3) are used frequently in circuit analysis.
• When used in the closed-loop configuration, the output is connected externally to the input through a feedback loop.

**EXAMPLE PROBLEM:** Using Kirchoff’s laws (see p.26) and the attributes of an operational amplifier, determine $E_o = f(E_i$ and $R$) for the closed-loop circuit shown in Figure 2.
• The exact relation between the input voltages, $E_{i1}(t)$ and $E_{i2}(t)$, and the output voltage, $E_o(t)$, depends upon the specific feedback configuration.

• The six most common op amp configurations are
  
  (1) noninverting,
  (2) inverting,
  (3) differential,
  (4) integrating,
  (5) voltage following, and
  (6) differentiating.
Figure 3: Six common operational amplifier configurations.

NOTE: In the following circuit analyses, node A denotes that at the + input and node B that at the − input.
The voltage follower configuration uses no resistors or capacitors. Attribute (3) immediately implies that

\[ E_o = E_i. \]
The Inverting Op Amp

- As a consequence of attribute (3),

\[ E_B = E_A = 0. \]

- Noting attribute (1), the current that flows the input resistor, \( R_1 \), to node B is the same as the current that flows through the feedback resistor, \( R_2 \), from node B. Thus,

\[ \frac{E_1 - 0}{R_1} = \frac{0 - E_o}{R_2}. \]

- A simple rearrangement gives

\[ E_o = -E_1 \frac{R_2}{R_1}. \]
The Noninverting Op Amp

- As a consequence of attribute (3),

\[ E_B = E_i. \]

- Noting attribute (1), the current that flows the input resistor, \( R_1 \), to node B is the same as the current that flows through the feedback resistor, \( R_2 \), from node B. Thus,

\[ \frac{0 - E_B}{R_1} = \frac{E_B - E_o}{R_2}. \]

- This implies that

\[ E_o = \frac{R_2 E_B}{R_1} + E_B = \frac{R_1 + R_2}{R_1} E_i, \]

using the first equation.
The Differential Op Amp

From attribute (1), it follows that

$$\frac{E_{i2} - E_A}{R_1} = \frac{E_A - 0}{R_2}.$$  

This implies

$$E_A = \left[ \frac{R_2}{R_1 + R_2} \right] E_{i2}. $$

Similarly, at node B

$$\frac{E_{i1} - E_B}{R_1} = \frac{E_B - E_o}{R_2}.$$  

This gives

$$E_B = \left[ \frac{R_1 R_2}{R_1 + R_2} \right] \left[ \frac{E_{i1}}{R_1} + \frac{E_o}{R_2} \right].$$

Because of attribute (3), $E_A = E_B$. Equating the expressions for $E_A$ and $E_B$ in the above yields

$$E_o = (E_{i2} - E_{i1})(R_2/R_1).$$
The Integrating Op Amp

Noting attribute (1), the current that flows through the input resistor, $R$, into node B is the same as the current that flows into the feedback capacitor, $C$, from node B. Thus,

$$\frac{E_i - 0}{R} = C \frac{dV}{dt} = C \frac{d(0 - E_o)}{dt}.$$  

Here, because of attribute (3), $E_A = E_B = 0$.

This can be rearranged to give

$$-\frac{dE_o}{dt} = \frac{E_i}{RC}.$$  

This equation can be integrated to yield

$$E_o = -\frac{1}{RC} \int E_i dt + \text{constant}.$$
The Differentiating Op Amp

- As a consequence of attribute (3),

\[ E_B = E_A = 0. \]

- Thus, also noting attribute (1), the current that flows through the input capacitor, \( C \), into node B is the same as the current that flows into the feedback resistor, \( R \), from node B. This gives

\[ C \frac{d(E_i - 0)}{dt} = \frac{0 - E_o}{R}. \]

- Rearranging yields

\[ E_o = -RC \frac{dE_i}{dt}. \]