Lecture 4

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- Ideal Op-Amp Summing Constraint
  - Only applies when the op-amp is used in negative feedback, which is often the case
- Ideal Op-Amp Circuit Analysis Procedure
  - Check that the op-amp is connected with negative feedback
  - Assume $V_+ - V_- = 0$ based on the summing node constraint
  - Apply standard circuit analysis techniques (KVL, KCL, Ohm's Law)
  - For an inverting amplifier:

$$i_i = V_i/R_1, \text{ and from KCL we obtain } i_2 = i_1$$
$$\text{From KVL: } V_o = -i_2 R_2$$

  - For non-inverting amplifiers:

$$A_v = \frac{V_o}{V_i} = 1 + \frac{R_2}{R_1}$$
$$R_i = \frac{V_i}{i_i} = \infty \text{ (with ideal op-amp model)}$$
$$R_o = 0 \text{ (with ideal op-amp model)}$$

- Differential Amplifier
  - A few observations

$$i_2 = -i_1 \text{ (per summing-point constraint)}$$

- The voltage division principles give the following equation:

$$V_+ = V_2 \left(\frac{R_2}{R_1 + R_2} \right) \text{ and } V_+ = V_-$$

- Employing KCL, we can calculate:

$$\frac{R_2}{R_1} V_1 - V_o = \frac{R_1 + R_2}{R_1} V_+$$
$$V_o = \frac{R_2}{R_1}(V_2 - V_1)$$

- The differential gain becomes:

$$A_{vd} = \frac{V_o}{(V_2 - V_1)} = \frac{R_2}{R_1}$$

- The common-mode gain is evaluated with $V_1 = V_2 = V_{icm}$:

$$V_{ocm} = (R_2/R_1)(V_2 - V_1) \to A_{cm} = \frac{V_{ocm}}{V_{icm}} = 0$$

- The CMRR becomes ∞

- Voltage Follower
  - $V_o = V_i$ per summing point constraint

$$A_v = (V_o/V_i) = 1$$

  - Also called "unity gain buffer"

$$R_i = \infty$$
$$R_o = 0$$

  - A good circuit to couple amplifier stages together with reduced loading effects:
    * High R_i regardless of R_1

- Finite Open-Loop Gain
  - In practice, the open-loop gain (A_{OL}) is 60-120dB
  - Degraded summing point quality: $V_x = V_+ - V_- \neq 0 \to V_z = \frac{V_o}{A_{OL}}$
  - Feedback factor for this circuit: $\beta = R_1/(R_1 + R_2)$ occurs due to voltage division
    * β is the fraction of the output that is fed back to the V_- terminal

$$V_o = (V_+ - V_-)A_{OL} = -V_- A_{OL} \to V_- = \frac{-V_o}{A_{OL}}$$

- Error Due to Finite Gain
  - When $\beta A_{OL} >> 1$ by design, the gain depends on the feedback network components (resistors in the above examples)
  - With real components
    * A_{OL} varies significantly from part to part
    * Matching of passive components (resistors, capacitors, inductors) is more accurate and reliable
  - The use of feedback (closed-loop) reduces gain variations