General Purpose Operational Amplifiers

OUTLINE

- Op-Amp from 2-Port Blocks
- Op-Amp Model and its Idealization
- Negative Feedback for Stability
- Components around Op-Amp define the Circuit Function

Reading
Hambley 14.1-14.2, pp. 644

General Purpose Amplifier

- General purpose amplifiers called Operational Amplifiers (Op-Amps) were developed before general purpose computers (Microprocessors).
- These Op-Amps can be viewed as being built from two-port circuits.

Stages => Differential High Gain Low R
EE 105 Assemble as amplifier in EE 140
High Quality Dependent Source In an Amplifier

\[ V_0 = AV_+(V_+ - V_-) \]

See the utility of this: this Model when used correctly mimics the behavior of an amplifier but omits the complication of the many many transistors and other components.

Op Amp Terminals

- 3 signal terminals: 2 inputs and 1 output
- IC op amps have 2 additional terminals for DC power supplies
- Common-mode signal = \((v_1 + v_2)/2\)
- Differential signal = \(v_1 - v_2\)
Op Amp Terminal Voltages and Currents

- All voltages are referenced to a common node.
- Current reference directions are into the op amp.

Model for Internal Operation

- A is differential gain or open loop gain
- Ideal op amp
  \[ A \to \infty \]
  \[ R_i \to \infty \]
  \[ R_o = 0 \]
  - Common mode gain = 0
  \[ v_{cm} = \frac{v_1 + v_2}{2} \]
  \[ v_o = A_{cm} v_{cm} + A_d v_d \]
  
  Since \( v_o = A(v_1 - v_2) \), \( A_{cm} = 0 \)
Model and Feedback

- Negative feedback
  - connecting the output port to the negative input (port 2)
- Positive feedback
  - connecting the output port to the positive input (port 1)

Circuit Model

Op-Amp and Use of Feedback

A very high-gain differential amplifier can function in an extremely linear fashion as an operational amplifier by using negative feedback.

We can show that for $A \to \infty$ and $R_i \to \infty$,

$$V_0 \approx V_{IN} \cdot \frac{R_1 + R_2}{R_1}$$

Stable, finite, and independent of the properties of the OP AMP!
**Negative Feedback**

Familiar examples of negative feedback:
- Thermostat controlling room temperature
- Driver controlling direction of automobile
- Photochromic lenses in eyeglasses

Fundamentally pushes toward stability

Familiar examples of positive feedback:
- Microphone “squawk” in room sound system
- Mechanical bi-stability in light switches
- Thermonuclear reaction in H-bomb

Fundamentally pushes toward instability or bi-stability

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**Summing-Point Constraint**

- Check if under negative feedback
  - Small $v_i$ result in large $v_o$
  - Output $v_o$ is connected to the inverting input to reduce $v_i$
  - Resulting in $v_i=0$
- Summing-point constraint
  - $v_1 = v_2$
  - $i_1 = i_2 = 0$
- Virtual short circuit
  - Not only voltage drop is 0 (which is short circuit), input current is 0
  - This is different from short circuit, hence called “virtual” short circuit.
Ideal Op-Amp Analysis Technique

Applies only when Negative Feedback is present in circuit!

Assumption 1: The potential between the op-amp input terminals, \( v_+ - v_- \), equals zero.

Assumption 2: The currents flowing into the op-amp’s two input terminals both equal zero.

EXAMPLE

Non-Inverting Amplifier

Yes Negative Feedback is present in this circuit!

Assumption 1: The potential between the op-amp input terminals, \( v_+ - v_- \), equals zero.

Assumption 2: The currents flowing into the op-amp’s two input terminals both equal zero.

KCL with currents in only two branches

\[
\begin{align*}
\frac{v_{in}}{R_1} + \frac{v_{in} - v_{out}}{R_2} &= 0 \\
\frac{v_{out}}{R_1} &= \frac{R_1 + R_2}{R_1} v_{in}
\end{align*}
\]

Non-inverting Amplifier
**Ideal Op-Amp Analysis: Inverting Amplifier**

Yes Negative Feedback is present in circuit!

\[
\frac{V_R - V_{IN}}{R_1} + \frac{V_R - V_{OUT}}{R_2} = 0
\]

\[V_{OUT} = V_R - \frac{R_2}{R_1} (V_{in} - V_R)\]

Inverting Amplifier with reference voltage

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**The Operational Amplifier**

- The *operational amplifier* ("op amp") is a basic building block used in analog circuits.
  - Its behavior is modeled using a dependent source.
  - When combined with resistors, capacitors, and inductors, it can perform various useful functions:
    - amplification/scaling of an input signal
    - sign changing (inversion) of an input signal
    - addition of multiple input signals
    - subtraction of one input signal from another
    - integration (over time) of an input signal
    - differentiation (with respect to time) of an input signal
    - analog filtering
    - nonlinear functions like exponential, log, sqrt, etc