EE 171

Op Amp Imperfections and Circuits
(Chapter 2)

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Clipping

- Occurs for large input swing
- Output voltage of an op amp cannot exceed certain level
- Loading can cause clipping too, since there is a limit on the output current

For a real op amp, clipping occurs if the output voltage reaches certain limits.
The rate of change of the output voltage in an ideal op amp is also limited. (Slew rate limitation)
DC Imperfections

- Bias current
- Offset current
- Offset voltage

Current sources and a voltage source model the dc imperfections of an op amp.

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Let's see the effect of each imperfection in the circuit given below.

(a) Original circuit

Circuit of Example 2.10.

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Effect of offset voltage:

- Assume $V_{\text{off}}$ varies from $-2 \text{ mV}$ to $2 \text{ mV}$
Effect of bias current:

- Assume $I_B$ varies from 0 nA to 100 nA

Circuit of Example 2.10.

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Effect of offset current:

- Assume $I_{\text{off}}$ varies from $-40$ nA to $40$ nA
Adding the resistor $R$ to the inverting amplifier circuit causes the effects of bias currents to cancel.
Amplifier Circuits

Inverting Amplifier:

\[ v_o = -\frac{R_2}{R_1} v_{in} \]

\[ R_{bias} = \frac{R_1 R_2}{R_1 + R_2} \]
AC-coupled inverting amplifier:

- Note that $R_{bias}$ is different (vs. DC version)
- Gain at LF = 0
- Gain at HF = $-\frac{R_2}{R_1}$
Summing amplifier:

\[ v_o = -\left( \frac{R_f}{R_A} v_A + \frac{R_f}{R_B} v_B \right) \]

\[ \frac{1}{R_{\text{bias}}} = \frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_f} \]
Non-inverting amplifier:

\[ v_o = \left(1 + \frac{R_2}{R_1}\right) v_{in} \]

Noninverting amplifier. This circuit approximates an ideal voltage amplifier.
AC-coupled non-inverting amplifier

- Disadvantage: it has a low input impedance ($R_{bias}$) at high frequency
  - Needed to prevent charge up of capacitor due to bias current

$$R_{bias} = \frac{R_1 R_2}{R_1 + R_2}$$

Ac-coupled noninverting amplifier.

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Bootstrap AC-coupled voltage follower

- Much higher input impedance
  - At high frequency, capacitors are short circuits
  - $V$ across $R_1 = 0$ ($V_{\text{out}} = V_{\text{in}}$)
  - Input impedance infinitely large
Differential amplifier:

\[ v_o = \frac{R_2}{R_1} (v_1 - v_2) \]

**Note:** \( \frac{R_4}{R_3} = \frac{R_2}{R_1} \)

Differential amplifier.

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Instrumentation-quality differential amplifier

- Input impedance infinitely large
- Node A is not grounded so that the gain for $V_1 = V_2$ (common mode) is much lower than the gain when $V_1 = -V_2$ (differential mode)
- Desirable feature in differential amplifiers (see Section 1.11)

$$v_o = \left(1 + \frac{R_2}{R_1}\right) (v_1 - v_2)$$
Voltage to current converter:
  - disadvantage: the load can not be grounded.

Voltage-to-current converter (transconductance amplifier).

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Howland circuit:

\[
\frac{R_3}{R_2} = \frac{R_4}{R_1}
\]

Voltage-to-current converter with grounded load (Howland circuit).

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Current to voltage conversion:

\[ v_o = -R_f i_{in} \]
Current amplifier:
Integrator:

\[ v_o = -\frac{1}{RC} \int_{0}^{t} v_{in} \, dt \]
Differentiator:

\[ v_o = -RC \frac{dv_{in}}{dt} \]
Frequency response of an integrator:

\[ 20 \log \left| \frac{V_o}{V_{in}} \right| \text{(dB)} \]

\[ -20 \text{ dB/decade} \]

\[ \frac{1}{2\pi RC} \]

(a) Integrator

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Frequency response of a differentiator:

- Opposite to op amp frequency response
  - Poor actual circuit performance
  - Noise sensitive
Open loop gain of an op amp with frequency: