Assignment #6  Due Tue March 3 11:59 PM

Midterm 2  - Scores posted on Canvas
1st: 100/100  Lo: 16/100
Avg: 70.9/100  Median: 73/100

Please collect exams: Today 11 AM-Noon (KEC 4095)
3-5 PM (KEC 3114)

Operational Amplifier (opamp)

An active circuit element that performs mathematical operations (+, -, *, differentiation, ...) and also provides gain.

A versatile circuit building block and used in instrument-ation applications.

Terminals & Characteristics

![Operational Amplifier Diagram]

\[ V^+ = \text{positive power supply (+15V)} \]
\[ V^- = \text{negative "-" (-15V)} \]

Three distinct regions:

1) Linear region

\[ V^- \leq V_o \leq V^+ \]

\[ V_o = A \cdot (V_p - V_n) \]

\( A \) is the open-loop gain

2) Positive saturation \( V_o = V^+ \)

3) Negative \( V_o = V^- \)

Common symbol
(powers supplies not shown)
2 input terminals
1 output terminal

V0

V+ on

V-

A(Vp-Vn)

differential voltage
The opamp provides gain in the linear region only and the output cannot exceed $V^+$ or decrease below $V^-$.

**Equivalent Circuit**

$R_i$ = input resistance
$R_o$ = output resistance
$A$ = open loop voltage gain

unilateral device: input affects the output but not vice versa

**Typical Parameter Values**

<table>
<thead>
<tr>
<th></th>
<th>Typical</th>
<th>Ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A$</td>
<td>$10^5 - 10^8$</td>
<td>$\infty$</td>
</tr>
<tr>
<td>$R_i$</td>
<td>$10^6 - 10^{12}$</td>
<td>$\infty$</td>
</tr>
<tr>
<td>$R_o$</td>
<td>$10 - 100 , \Omega$</td>
<td>$0$</td>
</tr>
</tbody>
</table>

If $V^+ = 10 \, V$ and $A = 10^6$, $\frac{-10}{10^6} \, \mu V < v_p - v_n < \frac{10}{10^6} \, \mu V$

$V^- = -10 \, V$

Feedback configuration (negative feedback)

Assume ideal opamp in a negative feedback configuration, $A = \infty$, $R_i = \infty$, $R_o = 0$

For a finite $v_o$

$v_o = A (v_p - v_n)$

$\lim_{v \to \infty} \frac{v_p - v_n}{A} = 0$

$v_p = v_n$
Analysis of an opamp circuit

\[ v_p = v_n \]
\[ v_p = v_s ; \quad v_s = v_n \]

To solve opamp circuits write KCL only at the input nodes.

\[ v_n + \frac{v_n - v_o}{R_1} + \frac{v_n}{R_2} = 0 \]

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

\[ \frac{v_o}{v_n} = \frac{R_1 + R_2}{R_2} = 1 + \frac{R_1}{R_2} \]

\[ G = \frac{v_o}{v_s} = 1 + \frac{R_1}{R_2} \quad \text{closed-loop gain} \]

\[ \text{Ex.} \quad G = 1 + \frac{R_1}{R_2} \]

\[ = 1 + \frac{10}{2} = 1 + 5 = 6 \]

For \( v_s = 1 \text{ V} \); \( v_o = G v_s \)

\[ = 6 \times 1 = 6 \text{ V} \]

Special case

\[ v_o = v_n \]
\[ v_s = v_p = v_n \]
\[ v_o = v_s \]
\[ G = \frac{v_o}{v_s} = 1 \]

This is a unity gain amplifier that is used as a buffer amplifier.