Lecture 5

Today

OP-AMPS

Positive "Vcc"

Negative Supply "Vee"

Omit Power Terminals

Real op-amp

- non-linear, high hysteresis
- temperature dependent
- variable acrospects

A is BIG (Ideally A = \infty)

But, A is BIG

Use negative feedback

Feed back fraction of Vout

back to neg input
Lecture 5

\[ V_{\text{out}} = A \left( V_{\text{IN}} - \frac{R_2}{V_{\text{out}} + R_2} \right) \]

\[ V_+ = V_{\text{IN}} \]

\[ V_- = \frac{R_2}{R_1 + R_2} V_{\text{out}} \]

\[ V_{\text{out}} = \frac{A R_2}{1 + R_1 + R_2} = A V_{\text{IN}} \]

\[ \frac{V_{\text{out}}}{V_{\text{IN}}} = \frac{A}{1 + \frac{A R_2}{R_1 + R_2}} = \frac{1}{A + \frac{R_2}{R_1 + R_2}} \]

If \( A \gg R_2 \):

\[ \frac{V_{\text{out}}}{V_{\text{IN}}} = \frac{R_1}{1 + R_2} \]

\[ \text{NON-INVERTING OP-AMP} \]

\[ \text{DOES NOT DEPEND ON } A \]

\[ V_{\text{out}} \text{ is now:} \]

- linear
- temp independent
- \( 0 \) gain

\[ \Rightarrow V_+ - V_- = 0 \]

Ex: \( A = 200,000 \) and \( V_{\text{out}} = 10 \text{V} \)

\[ \Rightarrow V_+ - V_- = 50 \mu \text{V} \]

Ideal op-amp assumptions:

- \( V_+ = V_- \)
- \( i_+ = i_- = 0 \)
- \( \text{op-amp in negative feedback} \)
- \( V_{\text{EE}} \leq V_{\text{out}} \leq V_{\text{EE}} \)

If \( \frac{R_2}{R_1} \to \infty \)

\[ V_{\text{out}} \approx \frac{R_2}{R_1} V_{\text{IN}} \]

\[ V_{\text{out}} \approx V_{\text{IN}} \]

\[ \text{Buffer} \]

\[ \text{commonly used to isolate stages} \]
Sensor

\[ V_L = V_S \]

Buffer isolates sensor and load

\[ V_L = \frac{R_L}{R_L + R_S} V_S \]
Recap: Dependent sources

**Two-port devices**
- Control port: sets the value of the source
- Output port: source terminals

4 types of dependent sources

- **Voltage-controlled current source (VCCS)**
- **Current-controlled current source (CCCS)**
- **Voltage-controlled voltage source (VCVS)**
- **Current-controlled voltage source (CCVS)**

**Linear dependent source**
\[ f(x) = kx \]

1. Nodal analysis
   - Pretty much the same. May need one more step to substitute a dependent voltage or current in terms of node voltages.

2. Superposition
   - Only for linear dependent sources, aka \[ f(x) = kx \].
   - Same procedure, but only turn off independent sources. Leave dependent sources ON.

3. Thevenin and Norton
   - Only for linear dependent sources, aka \[ f(x) = kx \].
   - Both ports must be inside subcircuit being analyzed.
   - Find \( V_{TH} \) and \( I_N \) as before (\( V_{TH} = V_{oc}, I_N = I_{sc} \)).
   - To find \( R_{TH} \), only turn off independent sources. Leave dependent sources on. It is sometimes hard to figure out \( R_{TH} \) when there are dependent sources, so use \( i_{test} \) and \( v_{test} \) approach instead.
Recap

1. Amplifiers
   - 3-port element
   - We often want to increase the voltage, current, or power of a signal
   - We use transistor-based electronics to do this

Op amps (op-amps, opamps, etc.)

- Operational Amplifier
  - Historical name
- Extremely common building block for analog circuits
Op-amp wishlist

- High gain
- Linear operation
- Rail-to-rail operation
- Single- or dual-supply operation
- Wide bandwidth \(\leftrightarrow\) fast operation
- Low noise
- High power-handling capability
- Wide temperature operating range
- Differential input
- Small package
- Infinite input resistance
- Zero output resistance
- No manufacturing variation
- Low cost

- Op-amps provide many of these features
- No op-amp provides all of these features
- Desired features dictates choice of op-amp

- LM741/UA741 is the canonical op-amp
- We’ll use TLE2141, TLV2371, and maybe a 1-2 others in class
• TLE2141 typical gain

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>T&lt;sub&gt;a&lt;/sub&gt;</th>
<th>TLE2141C</th>
<th>TLE2141AC</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVD</td>
<td>Large-signal differential voltage amplification</td>
<td>25°C</td>
<td>50</td>
<td>50</td>
<td>V/mV</td>
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<td></td>
<td>V&lt;sub&gt;CC&lt;/sub&gt; = ±2.5 V, R&lt;sub&gt;L&lt;/sub&gt; = 2 kΩ, V&lt;sub&gt;o&lt;/sub&gt; = 1 V to −1.5 V</td>
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<td>220</td>
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<tr>
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<td>Full range</td>
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220,000

Non-idealities

• Gain is finite, non-linear and non-differential
• Finite bandwidth
• Temperature dependence
• Non-zero output resistance
• Finite input resistance
• Input offsets and noise
- Non-idealities are the reason that datasheets exist and are so long
- TLE2141 data sheet is 83 pages long