Amplifiers

- another basic building block (analog)
- inside quite complex (many transistors, etc.) but operationally simple; use like another element similar to $R, L, C$, etc.

- many applications
  - boost power in a signal
  - active filters with complex freq. response

Symbol

\[ \text{Input} \rightarrow \text{Amplifier} \rightarrow \text{Output} \]

Characteristics

1. Gain

\[ G = \frac{\text{Output}}{\text{Input}} \]

Voltage gain; other gain types e.g. current may be equally important.

\[ G_{\text{dB}} = 10 \log_{10} \frac{P_{\text{out}}}{P_{\text{in}}} \]
\[ \text{Since } P \propto V^2 \Rightarrow dB = 20 \log_{10} \frac{V_{out}}{V_m} \]

\[ G_{dB} = 20 \log_{10} \left( \frac{V_{out}}{V_m} \right) = 20 \log_{10} G \]

Q: why dB?   A: add gain in dB for successive stages

<table>
<thead>
<tr>
<th>( G = \frac{V_{out}}{V_m} )</th>
<th>( G_{dB} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 dB</td>
</tr>
<tr>
<td>( \sqrt{2} )</td>
<td>+3 dB</td>
</tr>
<tr>
<td>2</td>
<td>+6 dB</td>
</tr>
<tr>
<td>10</td>
<td>+20 dB</td>
</tr>
<tr>
<td>( \frac{1}{10} )</td>
<td>-20 dB</td>
</tr>
</tbody>
</table>

(2) Input resistance (impedance)

\[ R_{in} = \frac{\delta m}{i_{in}} (= \text{const}) \]

Q: what input impedance is ideal?   A: depends.

If maximizing power transfer:

\[ P_{in} = \delta_m \cdot i_{in} \]

\[ i_{in} = \frac{\delta_s}{R_s + R_m} ; \quad \delta_m = R_{in} \cdot i_{in} \Rightarrow P_m = \delta_s^2 \frac{R_m}{(R_s + R_m)^2} \]

\[ P_{in} (R_{in} = 0) \rightarrow 0 \]

\[ P_{in} (R_{in} \rightarrow \infty) \rightarrow 0 \]

\[ P_{in} \text{ is max when } R_{in} = R_s \]
If maximizing input **current** \( R_{in} = 0 \) \( (P_s \text{ is max}) \)
If maximizing input **voltage** \( R_{in} \to \infty \) \( (P_s \approx 0) \)
**\( R_{in} \) large** is most common for amplifiers of small signals

(3) **Output impedance** (resistance)

\[ V_L = V_{out} \frac{R_L}{R_L + R_{out}} \]

if \( R_{out} \ll R_L \), \( \Rightarrow V_L \approx V_{out} \)

Need \( R_{out} \) small when driving large power loads

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**Input types**

a) single input

\[ V_{in} \quad \overset{0}{\Rightarrow} \quad V_{out} \quad \overset{0}{\Rightarrow} \]

\[ V_{out} = G \cdot V_{in} \]

b) differential

\[ V_+ \quad \overset{+}{\Rightarrow} \quad V_- \quad \overset{-}{\Rightarrow} \]

\[ V_{out} = G (V_+ - V_-) + G_{cm} \frac{V_+ + V_-}{2} \]

**\( G \) = differential gain**

**Common mode gain** : for \( V_+ = V_- = V_{cm} \), \( G_{cm} = \frac{V_{out}}{V_{cm}} \)

**CMRR** = \( \frac{G}{G_{cm}} \) \( \gg 1 \) for a good diff. amp.

(usually \( \text{in dB} \))
Operational amplifier (op-amp)

- standard IC diff. amplifier, widely used in analog
- "operational" b/c it was used in analog computers (i.e. volt. is a math variable, can perform operations such as integration, different., sum, log, exp, etc.)

741 and 3140 op-amps used in the lab

legacy, can use NTE 7144 instead

Manufacturer spec sheets
- everything you need to know about an IC
- see PDFs on the course web-site / books in the lab

Powering op-amp

- need 2 power supplies
- 2 bypass caps (0.01-0.1μF)
- long wires can act as antennas, bypass caps block hi-freq. noise
- usually don't draw all that