Lecture 9
Op Amps 1

Heathkit Analog Computer H-1
Feedback

- Feedback means coupling some of the output of an amplifier (or other system) back into the input.
- **Negative Feedback** partially cancels input to improve amplifier performance.
- **Positive feedback** boosts gain, but leads to instability and/or oscillation.
Figure 11.2 Input waveform and corresponding output waveforms.
Negative Feedback
Operational Amp LM 741

An op amp is a
• very high gain (~ $10^6$)
• dc-coupled
• differential amplifier with single-ended output.
Pinout & Circuit Diagram: 741 etc.

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(a) Pinout diagram:
- Balance: 1, 8 (No connection)
- Inverting input: 2, 7 (V+)  
- Noninverting input: 3, 6 (Output)
- V−: 4, 5 (Balance)

(b) Circuit diagram:
- Inverting input: 2
- Noninverting input: 3
- Output: 6
- V+: 7
- Offset Null: V−

Diagram details include:
- Pin 1: Balance
- Pin 2: Inverting input
- Pin 3: Noninverting input
- Pin 4: V−
- Pin 5: Balance
- Pin 6: Output
- Pin 7: V+
- Pin 8: No connection

Offset Null is marked at V−.
Golden Rules of Op Amps
(good enough for almost everything you do)

• The output attempts to do whatever it can to make the voltage difference between the inputs = 0.

  Interpretation: The op amp looks at its input terminals and swings the output to make the input voltage difference go to 0. To do this the output and input have to have a connection (i.e. there must be feedback)

• The op amp input draws no current (typically less than a nA).
Putting the Golden Rules to Work (Ideal Op Amp)

\[ i_1 = i_2 \text{ (current in = current out at node 1)} \]

\[ \Rightarrow v_i - v_1 \frac{1}{R_1} = v_1 - v_o \frac{1}{R_f} \]

\[ \Rightarrow \frac{v_1}{R_1} = -\frac{v_o}{R_f} \Rightarrow A_v = -\frac{R_f}{R_i} \]

*Note: gain is negative, i.e. it is an inverting amplifier*

\[ A_v = -\frac{R_f}{R_1} \]
Inverting Op Amp Example
Difference $v_d$ between and $v_1$ and ground is only 20 mV and the current into the op amp is only 10 pA.
Typical ranges for Op Amp Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Typical range</th>
<th>Ideal values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-loop gain, $A$</td>
<td>$10^5$ to $10^8$ Ω</td>
<td>$\infty$</td>
</tr>
<tr>
<td>Input resistance, $R_i$</td>
<td>$10^5$ to $10^{13}$ Ω</td>
<td>$\infty$ Ω</td>
</tr>
<tr>
<td>Output resistance, $R_o$</td>
<td>10 to 100 Ω</td>
<td>0 Ω</td>
</tr>
<tr>
<td>Supply voltage, $V_{CC}$</td>
<td>5 to 24 V</td>
<td></td>
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</tbody>
</table>
Railing the Op Amp

Railing means that input is too big, either ±.

Solution is to reduce gain or get op amp with bigger rail voltages.
Non-Inverting Op Amp

At node A

\[ i_1 = i_2 \]

\[ \frac{v_i - v_1}{R_1} = \frac{v_1 - v_o}{R_f} \]

\[ v_o = \left(1 + \frac{R_f}{R_1}\right) v_i \]
Voltage Follower

\[ v_o = v_i \]
Summing Amplifier

\[ v_o = -\left(\frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2 + \frac{R_f}{R_3} v_3\right) \]

Think superposition
Simple Audio Mixer

Compensation resistor to make path to ground about the same resistance for both inputs (- and +). It helps improve op amp performance (biasing of transistors in op amp IC).
Stereo Mixer