Introduction to Analog Interfacing

- Most embedded systems include components that measure and/or control real-world parameters.
- These include position, speed, temperature, etc.
- Usually exist in a continuous, or analog, form.
- We often need to amplify, filter, and convert these signals to a digital form.
- This chapter develops analog circuit building blocks for data acquisition and control systems.

Ideal Op Amps

\[ V_{\text{out}} = K(V_y - V_x) \]

- Voltage ranges are bounded by the supply voltages, \( \pm V_s \).
- Input currents, \( I_x \) and \( I_y \), are zero.
- Negative feedback drives \( V_x \) to equal \( V_y \).
- Positive or no feedback drives \( V_{\text{out}} \) to equal \(-V_s\) or \(+V_s\).

Various Op Amps

<table>
<thead>
<tr>
<th>Op amp</th>
<th>Description</th>
<th>Open loop gain</th>
<th>( \pm V_s )</th>
<th>( \pm I_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPA4227</td>
<td>High Precision</td>
<td>160 dB</td>
<td>( \pm 5 ) to ( \pm 15 ) V</td>
<td>( 3.8 ) mA</td>
</tr>
<tr>
<td>OPA4132</td>
<td>High-Speed FET</td>
<td>130 dB</td>
<td>( \pm 2.5 ) to ( \pm 18 ) V</td>
<td>( 4.8 ) mA</td>
</tr>
<tr>
<td>TLC2274</td>
<td>Rail-to-Rail</td>
<td>104 dB</td>
<td>0 to 5 or ( \pm 5 ) V</td>
<td>3 mA</td>
</tr>
</tbody>
</table>

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**Input Impedance**

\[ R_{cm} = \frac{V_{cm}}{I_{cm}} \]

\[ R_{diff} = \frac{V_{diff}}{I_{diff}} \]

<table>
<thead>
<tr>
<th>Op amp</th>
<th>( R_{cm} )</th>
<th>( R_{diff} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPA4227</td>
<td>1 GΩ</td>
<td>10 MΩ</td>
</tr>
<tr>
<td>OPA4132</td>
<td>( 10^{13} ) Ω</td>
<td>( 10^{13} ) Ω</td>
</tr>
<tr>
<td>TLC2274</td>
<td>( 10^{12} ) Ω</td>
<td>( 10^{12} ) Ω</td>
</tr>
</tbody>
</table>

**Output Impedance**

\[ R_{out} = \frac{V_{open}}{I_{short}} \]

**Offset Voltage, Offset Current, and Bias Current**

<table>
<thead>
<tr>
<th>Op amp</th>
<th>( V_{os} )</th>
<th>( I_{os} )</th>
<th>( I_{b} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPA4227</td>
<td>0.075 mV</td>
<td>10 nA</td>
<td>10 nA</td>
</tr>
<tr>
<td>OPA4132</td>
<td>0.5 mV</td>
<td>50 pA</td>
<td>50 pA</td>
</tr>
<tr>
<td>TLC2274</td>
<td>3 mV</td>
<td>100 pA</td>
<td>100 pA</td>
</tr>
</tbody>
</table>

**Noise Density**

<table>
<thead>
<tr>
<th>Op amp</th>
<th>( e_n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPA4227</td>
<td>3 nV/√Hz</td>
</tr>
<tr>
<td>OPA4132</td>
<td>23 nV/√Hz</td>
</tr>
<tr>
<td>TLC2274</td>
<td>50 nV/√Hz</td>
</tr>
</tbody>
</table>
### Transient Response

![Graph showing transient response with voltage and time axes]

- **Op amp** \( dV/dt, \text{ Slew rate} \)
  - OPA4227 2.3 V/\(\mu s\)
  - OPA4132 20 V/\(\mu s\)
  - TLC2274 3.6 V/\(\mu s\)

### Frequency Response

![Graph showing frequency response]

- **Op amp** \( f_1 \)
  - OPA4227 8 MHz
  - OPA4132 8 kHz
  - TLC2274 2.18 MHz

### Power Gain \( (A_{db}) \)

- Combines voltage gain, input impedance, and output impedance.

\[
P_{\text{in}} = \frac{V^2_{\text{in}}}{R_{\text{in}}} \\
P_{\text{out}} = \frac{V^2_{\text{out}}}{R_{\text{out}}} \\
A_{\text{db}} = 10\log_{10} \frac{P_{\text{out}}}{P_{\text{in}}} = 20\log_{10} \frac{V_{\text{out}}}{V_{\text{in}}} + 10\log_{10} \frac{R_{\text{in}}}{R_{\text{out}}}
\]

### Threshold Detector

- Circuit diagram showing a threshold detector with inputs, output, and components such as 3k\(\Omega\) resistor, 5k\(\Omega\) resistor, 0.1\(\mu F\) capacitor, and +5V and -V\(_S\) voltage sources.

- Digital Output with 0.1\(\mu F\) capacitor and 2.2k\(\Omega\) resistor connected to 5V and ground.
Simple Rules for Linear Op Amp Circuits

- Choose quality components.
- Negative feedback required to create linear mode circuit.
- Assume no current flows into the op amp inputs.
- Assume negative feedback equalizes input voltages.
- Choose resistor values in the 1kΩ to 1MΩ range.
- BW depends on the gain and the op amp performance.

Simple Rules for Linear Op Amp Circuits (cont)

- Equalize the effective resistance to ground at the two op amp input terminals.
- Input impedance is input voltage / input current.

Inverting Amplifier
Inverting Amplifier with -2.5V to 2.5V Range

Noninverting Amplifier

Model for Linear Circuit Design

Linear Circuit Design

\[ V_{out} = 5V_1 - 3V_2 + 2V_3 - 10 \]

- Choose a reference voltage from available reference voltage chips.
  \[ V_{ref} = 5V \]

- Rewrite the design equation in terms of the reference voltage, \( V_{ref} \).
  \[ V_{out} = 5V_1 - 3V_2 + 2V_3 - 2V_{ref} \]

- Add a ground input to the equation such that the sum of the gains is 1.
  \[ V_{out} = 5V_1 - 3V_2 + 2V_3 - 2V_{ref} - V_g \]

- Choose a feedback resistor, \( R_f \), in range of 10 k\( \Omega \) to 1 M\( \Omega \).
  \[ R_f = 150k\Omega \quad R_1 = 30k\Omega \quad R_2 = 50k\Omega \]
  \[ R_3 = 75k\Omega \quad R_{ref} = 75k\Omega \quad R_g = 150k\Omega \]

- Build the circuit: connect positive gain inputs to positive terminal and negative gain inputs to the negative terminal.
Linear Op Amp Circuit

Instrumentation Amplifier

Current-to-Voltage Circuit

Voltage-to-Current Circuit
Integrator Circuit

$$I = V_{in}/R$$

$V_{out}(t) = V_{out}(0) - \frac{1}{RC} \int_{0}^{t} V_{in}(s) \, ds$

Derivative Circuit

$$I = \frac{V_{out}}{R}$$

$$V_{out}(t) = -\frac{1}{RC} \frac{dV_{in}}{dt}$$

Hysteresis

Positive logic

Negative logic

Voltage Comparators with Hysteresis

Hysteresis $\Delta V = \frac{10k\Omega}{500k\Omega} = 0.1$V

Hysteresis $\Delta V = \frac{R_1}{R_2} = 0.1$V