Lecture #4
Special-purpose Op-amp Circuits

Instructor:
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Agenda

- Instrumentation Amplifiers
- Isolation Amplifiers
- Operational Transconductance Amplifiers (OTAs)
- Log and Antilog Amplifiers
- Converters and Other Op-Amp Circuits
A general-purpose op-amp, such as the 741, is a versatile and widely used device.

However, some specialized IC amplifiers are available that have certain features or characteristics oriented to special applications.

These special circuits include:

- The instrumentation amplifier that is used in high-noise environments.
- The isolation amplifier that is used in high-voltage and medical applications.
- The operational transconductance amplifier (OTA) that is used as a voltage-to-current amplifier.
- The logarithmic amplifiers that are used for linearizing certain types of inputs and for mathematical operations and in communication systems, including fiber optics.
INSTRUMENTATION AMPLIFIERS
Basic Instrumentation Amplifier

• An **instrumentation amplifier** is a **differential voltage-gain device** that amplifies the difference between the voltages existing at its two input terminals.
• The main **purpose** of an instrumentation amplifier is to **amplify small signals** that may be riding on large **common-mode voltages**.
• The key **characteristics** are high input impedance, high common-mode rejection, low output offset, and low output impedance.
Applications
A Specific Instrumentation Amplifier (AD622)

\[ R_G = \frac{50.5 \, k\Omega}{A_v - 1} \]

<table>
<thead>
<tr>
<th>Features</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage gain</td>
<td>2:1000</td>
</tr>
<tr>
<td>Input Impedance</td>
<td>10 GΩ</td>
</tr>
<tr>
<td>CMRR</td>
<td>66 dB</td>
</tr>
<tr>
<td>B.W.</td>
<td>800 kHz</td>
</tr>
<tr>
<td>Slew Rate</td>
<td>1.2 V/us</td>
</tr>
</tbody>
</table>
Noise Effects in Instrumentation Amplifier Applications

- Degradation of common-mode rejection in a shielded cable connection due to unwanted phase shifts.
Noise Effects in Instrumentation Amplifier Applications

- Shield Guard: Guarding is a technique to reduce the effects of noise on the common-mode operation of an instrumentation amplifier operating in critical environments by connecting the common-mode voltage to the shield of a coaxial cable.

- Instrumentation amplifier with shield guard to prevent degradation of the CMR.
A Specific Instrumentation Amplifier with a Guard Output (AD522)
ISOLATION AMPLIFIERS
A Basic Capacitor-Coupled Isolation Amplifier

• An isolation amplifier is a device that consists of two electrically isolated stages. The input stage and the output stage are separated from each other by an isolation barrier so that a signal must be processed in order to be coupled across the isolation barrier.
• Isolation by:
  • optical coupling
  • transformer coupling
  • capacitive coupling
• Each stage has separate supply voltages and grounds so that there are no common electrical paths between them.
Modulation

**Modulation** is the process of allowing a signal containing **information** to **modify** a characteristic of **another signal**, such as amplitude, frequency, or pulse width, so that the information in the first signal is also contained in the second.
The 3656KG Transformer Coupled Isolation Amplifier

\[ A_v1 = \frac{R_{f1}}{R_{i1}} + 1 \]

\[ A_v2 = \frac{R_{f2}}{R_{i2}} + 1 \]

\[ A_{v(tot)} = A_v1A_v2 \]
Application: Fetal heartbeat monitoring using an isolation amplifier

Heart signals, which are very small, are combined with much larger common-mode signals caused by muscle noise, electrochemical noise, residual electrode voltage, and 60 Hz power-line pickup from the skin.
OPERATIONAL TRANSCONDUCTANCE AMPLIFIERS (OTAS)
OTA

- The operational transconductance amplifier (OTA) is primarily a voltage-to-current amplifier in which the output current equals the gain times the input voltage.

<table>
<thead>
<tr>
<th>OTA</th>
<th>Conventional Op-Amp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two Differential Input</td>
<td>✓</td>
</tr>
<tr>
<td>high input impedance</td>
<td>✓</td>
</tr>
<tr>
<td>high CMRR</td>
<td>✓</td>
</tr>
<tr>
<td>bias-current input terminal</td>
<td>x</td>
</tr>
<tr>
<td>high output impedance</td>
<td>x</td>
</tr>
<tr>
<td>no fixed open-loop voltage gain</td>
<td>x</td>
</tr>
</tbody>
</table>

- The transconductance of an electronic device is the ratio of the output current to the input voltage.

\[
g_m = \frac{I_{out}}{V} \\
g_m = KI_{BIAS} \\
I_{out} = g_mV_{in} = KI_{BIAS}V_{in}
\]
Basic OTA Circuits

\[ V_{\text{out}} = I_{\text{out}}R_L \]

\[ \frac{V_{\text{out}}}{V_{\text{in}}} = \left( \frac{I_{\text{out}}}{V_{\text{in}}} \right)R_L \]

\[ A_v = g_m R_L \]

Voltage gain is controlled by this variable resistor.

Voltage gain is controlled by this variable voltage. 

\[ +V_{\text{BIAS}} \]

(a) Amplifier with resistance-controlled gain

(b) Amplifier with voltage-controlled gain
A Specific OTA (LM13700)

The LM13700 is a **dual-device package** containing two OTAs and buffer circuits.

\[ I_{\text{BIAS}} = \frac{+V_{\text{BIAS}} - (-V) - 1.4 \text{ V}}{R_{\text{BIAS}}} \]

- The input and output resistances varies also with the bias current.
OTA Applications

• Amplitude Modulation

• Schmitt Trigger
LOG AND ANTILOG AMPLIFIERS
Basic Logarithmic Amplifier

- **Log and antilog amplifiers** are used in applications that require **compression** of analog input data, **linearization** of transducers that have **exponential outputs**, and analog **multiplication and division**.
- They are often used in **high-frequency communication systems**, including fiber optics, for processing wide dynamic range signals.
- The **key element** in a log amplifier is a device that exhibits a **logarithmic characteristic** that, when placed in the feedback loop of an op-amp, produces a logarithmic response.

\[ V_{out} = -K \ln(V_{in}) \]

\[ I_F \approx I_R e^{q V_F / kT} \]

\[ \ln I_F = \ln I_R e^{q V_F / kT} \]

\[ \ln I_F = \ln I_R + \ln e^{q V_F / kT} = \ln I_R + \frac{q V_F}{kT} \]

\[ \ln I_F - \ln I_R = \frac{q V_F}{kT} \]

\[ \ln \left( \frac{I_F}{I_R} \right) = \frac{q V_F}{kT} \]

\[ V_F = \left( \frac{kT}{q} \right) \ln \left( \frac{I_F}{I_R} \right) \]
Log Amplifier with a Diode/BJT

\[ V_{out} = -V_F \]
\[ I_F = I_{in} = \frac{V_{in}}{R_1} \]
\[ V_{out} = -\left(\frac{kT}{q}\right) \ln\left(\frac{V_{in}}{I_R R_1}\right) \]
\[ V_{out} \approx -(0.025 \, \text{V}) \ln\left(\frac{V_{in}}{I_R R_1}\right) \]

\[ I_C = I_{EBO} e^{q V_{BE}/kT} \]
\[ V_{out} = -(0.025 \, \text{V}) \ln\left(\frac{V_{in}}{I_{EBO} R_1}\right) \]
Basic Antilog Amplifier

\[ V_{out} = -R_f I_C \]

\[ I_C = I_{EBO} e^{qV_{BE}/kT} \]

\[ V_{out} = -R_f I_{EBO} e^{qV_{BE}/kT} \]

\[ V_{out} = -R_f I_{EBO} e^{qV_{in}/kT} \]

\[ V_{out} = -R_f I_{EBO} \text{antilog} \left( \frac{V_{in} q}{kT} \right) \]

\[ V_{out} = -R_f I_{EBO} \text{antilog} \left( \frac{V_{in}}{25 \text{ mV}} \right) \]
Signal Compression with Logarithmic Amplifiers

This portion of the signal may be lost when compressed to a very small amplitude.

Large voltages are reduced more than small voltages.
CONVERTERS AND OTHER OP-AMP CIRCUITS
Constant-Current Source

\[ I_i = \frac{V_{IN}}{R_i} \]

\[ I_L = \frac{V_{IN}}{R_i} \]

Current-to-Voltage Converter

\[ V_{out} = I_i R_f \]

(a) Basic circuit

(b) Circuit for sensing light level and converting it to a proportional output voltage
Voltage-to-Current Converter

\[ I_L = \frac{V_{in}}{R_1} \]

Peak Detector

This circuit is used to detect the peak of the input voltage and store that peak voltage on a capacitor.
• For more details, refer to:
• The lecture is available online at:
  • [http://bu.edu.eg/staff/ahmad.elbanna-courses/12135](http://bu.edu.eg/staff/ahmad.elbanna-courses/12135)
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  • ahmad.elbanna@feng.bu.edu.eg