MCT242: Electronic Instrumentation

Lecture 4: Signal Conditioning
Transducer

Bridge Completion

Excitation

Amplification

Low Pass Filter

Signal Conditioner

Recorded, Storage and Display

End To End Data Acquisition

Last Week - Sensors

This Week - Signal Conditioning

Next week from today – D/A and A/D Conversion

Two Weeks From Today - Communication

Sample and Hold

Analog To Digital Converter

Multiplexing and data transmission

Data Acquisition Unit
Overview

- Signal Conditioning – Overview
- Grounding and Input Types
- Isolation
Typical Roles of Signal Conditioning

- Signal Conditioning
  - Provides external excitation and grounding
  - Completes the circuit (bridges)
  - Linearizes
  - Filters (typically low pass filter which only allows low frequency signals through)
  - Amplifies
  - Isolates one part of a system electrically from other parts of the system
  - Typical input is in millivolts, output is in volts
Figure 18-1. Common Types of Transducers/Signals and Signal Conditioning
<table>
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<th>Sensor</th>
<th>Electrical Characteristics</th>
<th>Signal Conditioning Requirement</th>
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<td>Thermocouple</td>
<td>Low-voltage output</td>
<td>Reference temperature sensor (for cold-junction compensation)</td>
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<tr>
<td></td>
<td>Low sensitivity</td>
<td>High amplification</td>
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<tr>
<td></td>
<td>Nonlinear output</td>
<td>Linearization</td>
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<tr>
<td>RTD</td>
<td>Low resistance (100 Ω typical)</td>
<td>Current excitation</td>
</tr>
<tr>
<td></td>
<td>Low sensitivity</td>
<td>Four-wire/three-wire configuration</td>
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<td></td>
<td>Nonlinear output</td>
<td>Linearization</td>
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<td>Strain gauge</td>
<td>Low resistance device</td>
<td>Voltage or current excitation</td>
</tr>
<tr>
<td></td>
<td>Low sensitivity</td>
<td>High amplification</td>
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<td></td>
<td>Nonlinear output</td>
<td>Bridge completion</td>
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<td>Linearization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shunt calibration</td>
</tr>
<tr>
<td>Current output device</td>
<td>Current loop output (4 – 20 mA typical)</td>
<td>Precision resistor</td>
</tr>
<tr>
<td>Thermistor</td>
<td>Resistive device</td>
<td>Current excitation or voltage excitation with reference resistor</td>
</tr>
<tr>
<td></td>
<td>High resistance and sensitivity</td>
<td>Linearization</td>
</tr>
<tr>
<td></td>
<td>Very nonlinear output</td>
<td></td>
</tr>
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<td>Active Accelerometers</td>
<td>High-level voltage or current output</td>
<td>Power source</td>
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<td></td>
<td>Linear output</td>
<td>Moderate amplification</td>
</tr>
<tr>
<td>AC Linear Variable Differential Transformer (LVDT)</td>
<td>AC voltage output</td>
<td>AC excitation</td>
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<tr>
<td></td>
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<td>Demodulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Linearization</td>
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</tbody>
</table>
Figure 18-2. Amplifying Signals near the Source to Increase Signal-to-Noise Ratio
Floating Versus Ground References

- Voltage is a measurement of the difference in electrical potential between two points.
- As such, voltage measurements must always be referenced to a known level.
- Traditionally voltage measurements are made with respect to earth ground.
  - A spike drilled into the ground provides a reference to the lowest potential, literally the “earth ground.”
- In self generating voltage systems, like batteries and thermocouples, the ground reference is usually the negative terminal of the source.
  - If the negative terminal of a self generating system is connected to an earth ground, then it is “grounded.”
  - If the negative terminal of the self generating system is not connected to earth ground, then it is “floating.”
    - “Floating” means that the local ground reference of a system is not tied to earth ground.
    - Accumulation of static charge, electromagnetic coupling and other phenomena can cause the local ground to raise to a energy potential that is above earth grounds.
- Other power systems, such as dc-dc converters and transformer coupling, can generate local grounds that are isolated from earth ground.
Figure 5-2. Grounded Signal Sources

Figure 5-3. Floating Signal Sources
Differential Voltage Measurements

- Ideally every measurement of voltage would be purely differential
  - We would measure the potential difference between two points
  - These points are typically referred to as \( V_+ \) and \( V_- \)
- A differential amplifier is a device that amplifies the difference between two voltages

\[
V_{\text{output}} = \text{Gain} \times (V_+ - V_-)
\]

- This requires two wires from every measurement and someway to connect both wires to a differential amplifier to measure the signal
  - Either a dedicated differential amplifier for each measurement or
  - A switch (multiplexer or “mux”) that switches both wires into a differential amplifier for each measurement
- A reference to instrumentation system ground is established through the amplifier
  - This allows comparison between measurement channels in a system
  - In large instrumentation systems this is a problem as it doubles the system
Differential

From LabVIEW Data Acquisition Basics Manual
Analog Multiplexers

• Normally there is one analog to digital converter that is shared in all the analog channels
• In order to switch the different analog channels into the analog to digital converter at the appropriate times, there is an analog multiplexer
• Definition of multiplexer is a set of electromechanical or semiconductor switches arranged to allow the selection of one of many inputs to a single output
  – Digital multiplexer allow the selection of a digital value or pulse train to an output
  – Analog multiplexers allow the selection of one of several analog line voltages signals to an output
Common Mode Voltage Rejection Ratio (CMRR)

• Any voltage measured with respect to the instrumentation amplifier ground that is present at both of the inputs to a differential amplifier is called Common Mode Voltage
• Common Mode Voltage is rejected by an ideal amplifier, i.e. not measured
• This is an important noise reduction feature as noise due to electromagnetic coupling and other sources is usually present on both inputs
  — A differential amplifier can improve the signal to noise ratio
• Practical devices are imperfect and can be described by parameters such as common mode voltage range and Common Mode Rejection Ratio (CMRR)
• CMRR is frequency dependent
• Most data acquisition devices will specify the CMRR up to 60 hertz, the power line frequency
CMRR Measurement

Test requires Periodic signal Source at frequencies of interest

\[
CMRR\,(db) = 20\log\left(\frac{V_+ + V_-}{V_{out}}\right)
\]

\[
CMRR\,(db) = 20\log\left(\frac{\text{Differential Gain}}{\text{Common Mode Gain}}\right)
\]
• In GRSE, all measurements are made with respect to a single node, AI GND, that is directly connected to measurement system ground.
• This reduces the number of wires and channels of multiplexing required.
• High frequency signals often require the use of coaxial cables
  • A coaxial cable utilizes a solid center conductor surrounded by an insulator which is surrounded by a grounded shield
  • Coaxial cables are needed in high frequency because most of the signal travels along the outside surface of the cable
  • The shield also reduces the amount of noise coupling in high frequency signals
• These are by necessity single ended measurements
In an non-referenced signal ended system, the channel and the sense line (low reference point at the sensor) are not direct connected to a ground but have a finite resistance to ground. This may be large or small. Bias resistors may be installed to control this resistance to a known value to reduce the error in the signal.
Bleed Resistors on thermocouples

Because the – terminal of the Data Acquisition Input is a transistor device it sits naturally above the instrumentation ground. Usually around .7 volts.

If the sensor is floating like a thermocouple, a battery or a piezo-electric device then the voltage being generated may be much less than .7 volts.

In this case current flows from the – terminal through the transducer back into the + junction and is read as noise at the input to the channel.

The way to prevent this is to put a bleed resistor of approximately 1k ohms on the negative input to the instrumentation ground.
A ground loop is when there is difference in potential between two ground points resulting in current flow between the two ground points. This can introduce error into measurements through direct effects (raising the ground) and indirect effects (electromagnetic coupling).
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<td>Floating Signal Source (Not Connected to Building Ground)</td>
<td>Examples</td>
<td>Grounded Signal Source</td>
<td>Examples</td>
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<td></td>
<td></td>
<td>• Thermocouples</td>
<td>• Plug-in Instruments with Nonisolated Inputs</td>
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<td>• Signal Conditioning with Isolated Outputs</td>
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<td>• Battery Devices</td>
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<td>Differential (DIFF)</td>
<td></td>
<td>Two resistors (10 kΩ &lt;= R &lt; 100 kΩ) provide return paths to ground for bias currents</td>
<td></td>
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</tr>
<tr>
<td>Single-Ended - Ground Referenced (GRSE)</td>
<td></td>
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<td>Ground-loop losses, V_gr, are added to measured signal.</td>
<td></td>
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<tr>
<td>Single-Ended - Nonreferenced (NRSE)</td>
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</table>
Wheatstone Bridge

\[ V_o = \left[ \frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2} \right] \times V_{EX} \]
Bridge allows elimination of lead wire resistance effects on accuracy
Wheatstone Bridges – Strain Gages

Quarter Bridge – 1 active arm

\[
\frac{V_O}{V_{EX}} = -\frac{GF \cdot \epsilon}{4} \left( \frac{1}{1 + GF \cdot \frac{\epsilon}{2}} \right)
\]

Half Bridge – 2 active arms

\[
\frac{V_O}{V_{EX}} = -\frac{GF \cdot \epsilon}{2}
\]

Full Bridge – 4 active arms

\[
\frac{V_O}{V_{EX}} = -GF \cdot \epsilon
\]
Figure 7. Process current signals, usually 0 to 20 mA or 4 to 20 mA, are converted to voltage signals using precision resistors.
Isolation

- Isolation protects data acquisition and computer circuitry from potentially harmful voltages in the equipment under measurement or control
- A number of technologies exist to isolate circuits
  - Inductive – use transformers to isolate circuitry
    - Only AC signals can cross the interface of the transformer
    - Shorts are DC. Shorts pulling high current on one side of the transformer cannot effect the other side of the transformer.
  - Optical – signal is converted into light and then the light is detected by an opto-detector. This all occurs within a plastic integrated circuit chip
    - A favorite for digital signals
  - Active electronics
    - Modern amplifiers have technologies which can stand high voltage inputs and do not allow the high voltage to go through the circuitry to downstream stages
    - Their output of the amplifier is limited by the supply voltage to the amplifier
    - So a high voltage transient that is greater than the supply voltage to the amplifier cannot pass downstream of the amplifier
Multiplexing

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• If you are going to filter, the question is to filter before or after the multiplexing?
Differential Voltage Measurement of Multiple Channels Using Analog Multiplexers

From Labview Data Acquisition Basics Manual
Multiplex Then Condition

Unless you dwell on each channel for a significant time, the effectiveness of the low pass filter is decreased.

From: “Improved Signal Quality Through Conditioning” by Lauren Sjoboen available at www.ni.com
Pros and Cons of Multiplex Then Condition

• Pros
  – Lower cost
  – Larger variety of gain and filter settings

• Cons
  – Extended settling times for differing gains when scanning
  – Reduced scan rates due to filter settling times
  – Channel interdependence

From: “Improved Signal Quality Through Conditioning” by Lauren Sjoboen available at www.ni.com
Condition Then Multiplex

From: “Improved Signal Quality Through Conditioning” by Lauren Sjoboen available at www.ni.com
Pros and Cons of Condition Then Multiplex

• Pros
  – No amplifier settling times when scanning
  – Continuous tracking of the filter
  – Fast scan rates possible
  – Independent channel behavior

• Cons
  – Higher cost
  – Trade off of available gain and filter setting choices versus channel count