Lecture 3
Basics of Sensing:
Interface Electronics
Interface Electronics
OR
Signal Conditioning Circuit

- purpose
- amplifier
  - op amp basics
  - op amp circuits
- Wheatstone bridge circuit
- Useful tips
Why is there a need for interface electronics?

- **Q**: Can you connect a sensor directly to the data acquisition (DAQ) system?
  
  **A**: No!

- We would need to convert the output signal from the sensor to the format compatible by the data acquisition (DAQ) system

- Interface circuit should 'gel' together with sensor and the load/DAQ

- Interface circuit should
  
  1) amplify the weak signal produced by the sensor
  2) filter out the noise in the signal produced by the sensor
  3) convert the output format as necessary (current or charge to voltage or voltage to current)

- Interface circuit conditions the sensor output before passing it to the processing device hence it is also called signal conditioning circuit
Fig. 5.2 Complex input impedance of an interface circuit (a), and equivalent circuit of a voltage generating sensor (b)
Most sensors produce weak output signals in the order of $\mu$V or pA/nA.

Whereas, A/D converter and data recorders require the signals in the order of V and mA.

Amplifiers can also be used for impedance matching, filtering, and increasing SNR by rejecting noise.

Use one or two stage BJT or MOSFET amplifiers or use commercial op-amps.
Interface Electronics: Important Circuits

- Differential Amplifier
- Instrumentation Amplifier
- Active Low Pass Filter
- Active High Pass Filter
- Voltage Follower or Buffer
- Charge-to-Voltage Converter
- Current-to-Voltage Converter
- Wheatstone (Resistance) Bridge
- Wheatstone Bridge + Instrumentation Amplifier
An ideal opamp has no current going into the input pins
An ideal opamp exhibits equal voltage on its input pins
Closed loop gain drops by feedback amount, bandwidth increases by feedback amount

**Desirable Properties**
- High input resistance, low output resistance
- Very high ($10^4$-$10^6$) open loop gain
- Broad frequency range, large gain-bandwidth (GBW) product
- Low input offset voltage
Interface Electronics: Op Amp Model

Inverting input

Noninverting input

Output

\[ A(v_2 - v_1) \]

(Power-supply common terminal)

\[ i_1 = 0 \]

\[ i_2 = 0 \]
Interface Electronics: Op Amp Circuits

Inverting Opamp

Non-inverting Opamp

Q: Why use the inverting configuration?
A: 1) gain 2) matching

Q: Why use the non-inverting configuration?
A: 1) slew rate 2) CMRR 3) GBW product
Interface Electronics: Op Amp Circuits

**Summing Amplifier**

\[ v_O = -\left( \frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2 + \cdots + \frac{R_f}{R_n} v_n \right) \]

**Difference (Differential) Amplifier**

\[ V_0 = (V_{I2} - V_{I1}) \frac{R_2}{R_1} \]
Interface Electronics: Op Amp Circuits

Differential Amplifier
- unbalanced
- high z sensor will produce common-mode gain
- differential sensor will have more noise

Instrumentation Amplifier
- balanced
- high input impedance at both inputs and low output impedance
- variable gain by changing
Interface Electronics: Op Amp Circuits

Low Pass Filter with Amplification
- Also known as the Integrator
- Transfer Function
- Cut-off frequency
- DC
- AC
Integrator
- Transfer Function
\[ V_{out} = -\frac{1}{R_{in}C} \int_{0}^{t} V_{in} \, dt \]

Improved Integrator
Interface Electronics: Op Amp Circuits

High Pass Filter with Amplification
  - Also known as the Differentiator
    - Transfer Function
    - Cut-off frequency
    - DC
    - AC
Differentiator
- Transfer Function

\[ V_{out} = -R_f C \frac{dV_{in}}{dt} \]

Improved Differentiator

\[ A (\text{dB}) = \frac{-R_f}{R_{in}} \]

\[ -20 \text{ dB/decade} \]
Interface Electronics: Op Amp Circuits

Voltage Follower (Buffer)

\[ v_o = v_i \]

Voltage Comparator

\[ V_{\text{out}} = V_{\text{cc}} \left( \frac{R_2}{R_1 + R_2} \right) \]

Vout when Vin > Vref
Fig. 5.9 Charge-to-voltage (a) and current-to-voltage (b) converters
Interface Electronics: Op Amp Circuits

Example of Charge to Voltage Converter

\[ V_o = -\frac{qp}{C_f} + \frac{V_{cc}}{2} \]
Example of Current to Voltage Converter (Transimpedance Amplifier)
Interface Electronics: Wheatstone Bridge

Wheatstone Bridge

- Examples: measure resistive sensors such as RTD and strain gages
- Under balanced operation ($I_g=0$), $R_x=R_3$ if $R_2=R_1$

\[
\frac{R_x}{R_3} = \frac{R_2}{R_1} \quad \text{or} \quad \frac{R_x}{R_3} = \frac{R_1}{R_1}
\]
Quarter Bridge Circuit

unknown Resistor

where, \( V_{out} = V_{+OUT} - V_{-OUT} \)
\( V_{in} = V_{+IN} - V_{-IN} \)

\[ V_{out} = \left( \frac{R_2}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \right) V_{in} \]

\( V_{out} = 0 \Rightarrow \left( \frac{R_2}{R_1 + R_2} \right) V_{in} = \left( \frac{R_4}{R_3 + R_4} \right) V_{in} \)

\( \Rightarrow \frac{R_1}{R_2} = \frac{R_3}{R_4} \)

\[ R_4 = \frac{R_3}{R_1} R_2 \]

Make \( R_3 = R_1 \)
Tune \( R_2 \) till \( V_{out} = 0 \) (\( I_{out} = 0 \))
Then \( R_4 = R_2 \)
Linearized WheatStone Bridge

Wheatstone Bridge with Instrumentation Amplifier

- **Advantages:**
  - Excellent common mode noise rejection,
  - Detection of open sensor (failure)
Resistance Multiplier

- Piezoelectric and Pyroelectric sensors may require very high output resistance to minimize current errors.
- Instead of using a physical resistor in parallel with the sensor, we can use resistance multiplier (< 10 times is good for low noise).

\[ V_+ = i_b R_b \left( 1 + \frac{R_2}{R_1} \right) \]

Current generating sensor
Interface Electronics: Useful Tips

Opamp
- Use perfboard and PCB whenever possible
- Use shortest wires whenever possible
- Use decoupling capacitors for power supplies
- Terminate traces to ground with vias instead of drawing traces
- Use Teflon pins for input and output to avoid current leakage through the leads
- Use guard trace

[Diagram showing correct and incorrect decoupling and tracing techniques]
Opamp

- Use guard trace
- Use Teflon standoff for input pin