


# ECE 215/S – Principles of Electronic Cyber Warfare

## Block 2: Signal Processing

## Lesson 21: Signal Conditioning

Department of Electrical and Computer Engineering
United States Air Force Academy

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# Objective 2.6

**I can implement signal conditioning to avoid aliasing and clipping and to ensure maximum compatibility of the dynamic ranges between two devices.**

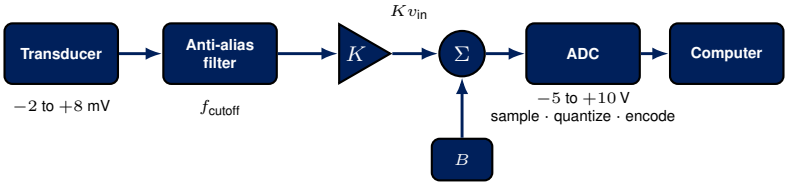
- Lesson 20 assumed the signal already fit the ADC. It almost never does
- Assessed on **Quiz 6** along with Objective 2.5

# Where We Are Going

By the end of this lesson, you will be able to:

- Explain the three pitfalls: **aliasing**, **clipping**, and **wasted dynamic range**
- Specify an **anti-aliasing filter**
- Compute the **gain** $K$ and **bias** $B$ that map a transducer's output onto an ADC's input range
- Verify that your conditioned signal uses the *full* range without clipping

# The Chain, With Conditioning Added




- The triangle **multiplies by** $K$; the $\Sigma$ circle **adds** $B$. Together they are **signal conditioning**, and the values shown are frame 10's worked example
- The filter fixes a *frequency* problem; the gain and bias fix an *amplitude* problem
- The ADC block is Lesson 20's sample–quantize–encode, collapsed into one box
- All of it must happen **before** the ADC. Afterward is too late

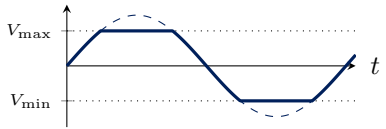
# Pitfall 1: Aliasing

- A transducer picks up more than you want — noise, interference, and content above your band of interest
- Anything above $f_s/2$ will **alias** down into your signal and be indistinguishable from it
- The fix is a **low-pass anti-aliasing filter** ahead of the ADC
  - Set $f_{\text{cutoff}}$ just above the highest frequency you care about
  - Then choose $f_s \geq 2f_{\text{cutoff}}$
- You now know how to build one — it is the R-C circuit from Lesson 17
- **Leave margin.** A real first-order R-C still passes $0.707$ at $f_{\text{cutoff}}$ (Lesson 17), so sampling at exactly $2f_{\text{cutoff}}$ folds that surviving content back in — **oversample**, a few times $2f_{\text{cutoff}}$

**Filter first, then sample.** Once aliased, the signal cannot be repaired.

# Pitfall 2: Clipping

- If the input goes **outside** the ADC's range, the converter saturates — it reports the extreme code and nothing more
- The peaks of the waveform are flattened. That is **clipping**
- Clipping destroys information *and* creates new frequency content that was never in the original signal
- Like aliasing, it is **not recoverable** after the fact




Dashed: what the sensor sent. Solid: what the ADC records.

**Never let the conditioned signal exceed the ADC's range. Not once, not at the peak.**

# Pitfall 3: Wasted Dynamic Range

The opposite failure, and easy to miss because nothing looks broken.

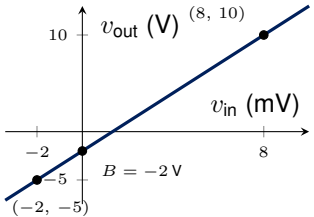
- A device's **dynamic range** is the span between its smallest and largest usable signal — for an ADC, $V_{\max} - V_{\min}$
- A transducer producing $\pm 2$ V into an ADC spanning $\pm 5$ V uses only **40%** of that range: $4$ V of $10$ V
- Every unused level is resolution you paid for and threw away
- An 8-bit ADC across 40% of its range uses $102$ of its $256$ levels — about **6.7 effective bits**. You paid for 8

**The goal is to land the signal's extremes exactly on the ADC's extremes.**

# Gain and Bias

$$v_{\text{out}}(t) = K\, v_{\text{in}}(t) + B$$

- $K$ **— gain.** Stretches or shrinks the signal so its *span* matches the ADC's span
- $B$ **— bias.** Shifts the signal up or down so its *center* matches the ADC's center
- With $B = 0$ this is the gain you already know, $G_{\text{abs}} = |V_{\text{out}}/V_{\text{in}}|$ — but $K$ is **signed**, and unlike a passive filter's gain it may exceed 1
- Two unknowns, so you need **two equations** — the two endpoints




Slope is $K$; the intercept is $B$.

# Method: Matching a Transducer to an ADC

1. Identify the transducer's **min and max** outputs, $V_{\text{sens,min}}$ and $V_{\text{sens,max}}$
2. Identify the ADC's **min and max** inputs, $V_{\text{ADC,min}}$ and $V_{\text{ADC,max}}$
3. Map **min to min** and **max to max**. That gives two equations:
   $V_{\text{ADC,min}} = K\,V_{\text{sens,min}} + B$ and $V_{\text{ADC,max}} = K\,V_{\text{sens,max}} + B$
4. **Subtract** them to eliminate $B$ and solve for $K$
5. Substitute back into either equation to get $B$
6. **Check** both endpoints in $V_{\text{ADC}} = K\,V_{\text{sens}} + B$

**Two cautions:** a span *larger* than the ADC's gives $K < 1$ (attenuation, not a mistake), and an uneven $K$ gets **truncated**.

**Rounding $K$ up pushes the peak past the rail.**
**Truncating only leaves a sliver of range unused.**

# Worked Example

A transducer outputs $-2$ mV to $+8$ mV. The ADC accepts $-5$ V to $+10$ V. Find $K$ and $B$.

**Set up the two equations**

$$-5\,\text{V} = K(-2\,\text{mV}) + B$$

$$10\,\text{V} = K(8\,\text{mV}) + B$$

**Subtract to eliminate $B$**

$$(-5 - 10)\,\text{V} = K(-2 - 8)\,\text{mV}$$

$$-15\,\text{V} = K(-10\,\text{mV})$$

**Solve for $K$**

$$K = \frac{-15\,\text{V}}{-10\,\text{mV}} = 1500$$

**Back-substitute for $B$**

$$-5\,\text{V} = 1500(-2\,\text{mV}) + B$$

$$-5\,\text{V} = -3\,\text{V} + B$$

$$B = -2\,\text{V}$$

**Check:** at $+8$ mV, $v_{\text{out}} = 1500(8\,\text{mV}) - 2\,\text{V} = 12\,\text{V} - 2\,\text{V} = 10\,\text{V}$. ✓

# Your Turn

A pressure sensor outputs $0.5$ V at minimum pressure and $4.5$ V at maximum. It feeds a 10-bit ADC with an input range of $0$ V to $3.3$ V. The signal has content up to $200$ Hz.

1. Specify the anti-aliasing filter and a suitable sampling rate
2. Find the gain $K$ and bias $B$ that use the ADC's full range
3. Verify both endpoints
4. What is the ADC's resolution $\Delta V$, and how many of its levels does the conditioned signal use?
5. What would happen if you skipped conditioning and connected the sensor directly?

$B$ comes out *negative* here because the sensor sits **above** the ADC's range. A sensor sitting **below** it needs a positive $B$.

# Wrap-Up

Key ideas:

- Three pitfalls: **aliasing** (frequency), **clipping** (too big), **wasted range** (too small)
- The **anti-aliasing filter** goes before the ADC, with $f_{\text{cutoff}}$ just above your band
- Conditioning is one linear map: $v_{\text{out}} = Kv_{\text{in}} + B$
- Map **min to min and max to max**, subtract to get $K$, back-substitute for $B$, **check both endpoints**

Due tonight: **Quiz 5** (Objectives 2.3–2.4)

Next lesson:

- **Lesson 22 — ADC / Arduino Lab.** You will point this at a real sensor — and find out what to do when it is not linear
- **Quiz 6** (Objectives 2.5–2.6) is due at **Lesson 24**, and this is the **last new material it covers**