Electronics & Signal Processing for Experimental Rigs

Day 2: Noise and OpAmp Circuits

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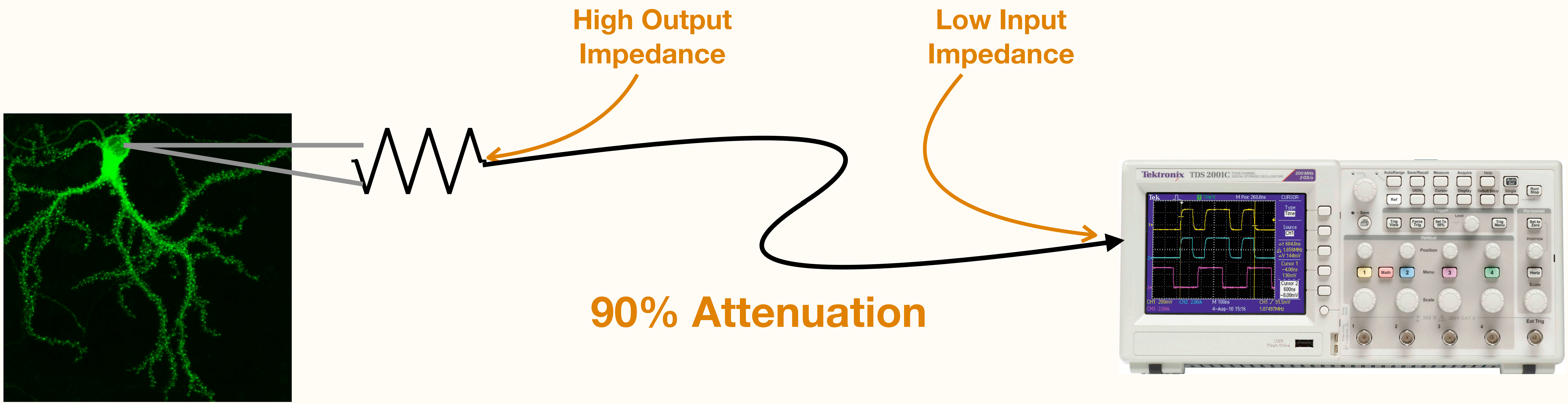
Lecture 2 Outline

- Questions from Lecture 1 / Assignment 1
  - *Capacitive coupling: will be addressed in this lecture*
- Noise: Sources & Solutions
  - Mechanisms behind common sources of rig noise
  - Methods for reducing each kind of noise
- Amplifiers
  - OpAmps
  - Voltage follower (buffer)
  - Gain amplifiers

Maximizing Signal Quality

Last lecture:

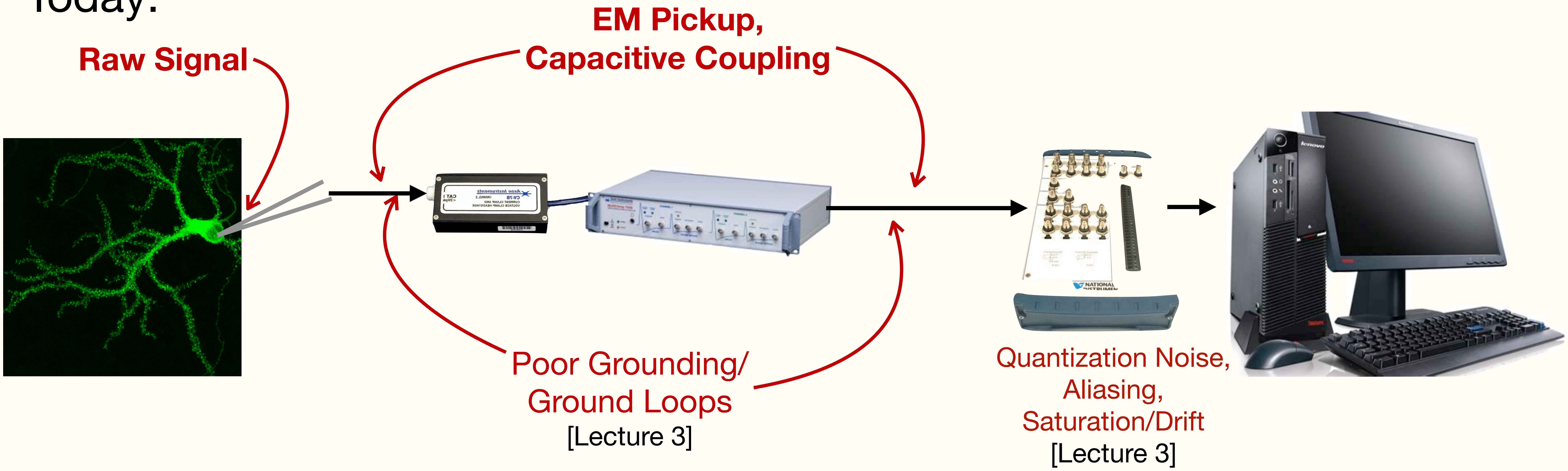


$R_{electrode} \approx 10\text{M}\Omega$

$R_{in} = 1\text{M}\Omega$

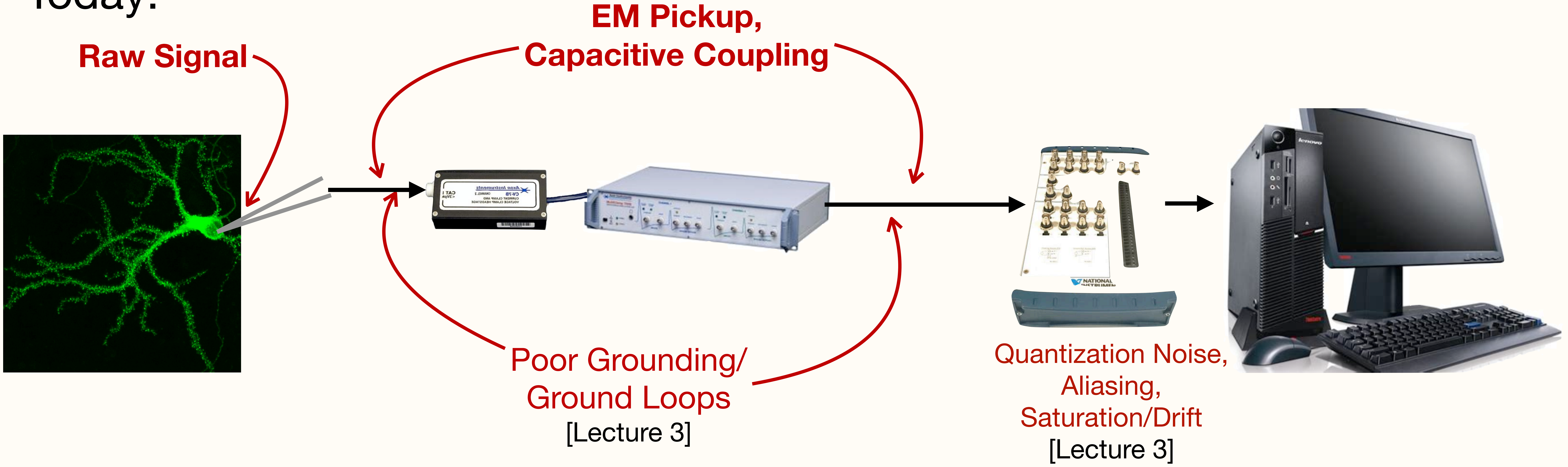
Maximizing Signal Quality

Today:



Maximizing Signal Quality

Today:



Signal to noise ratio:

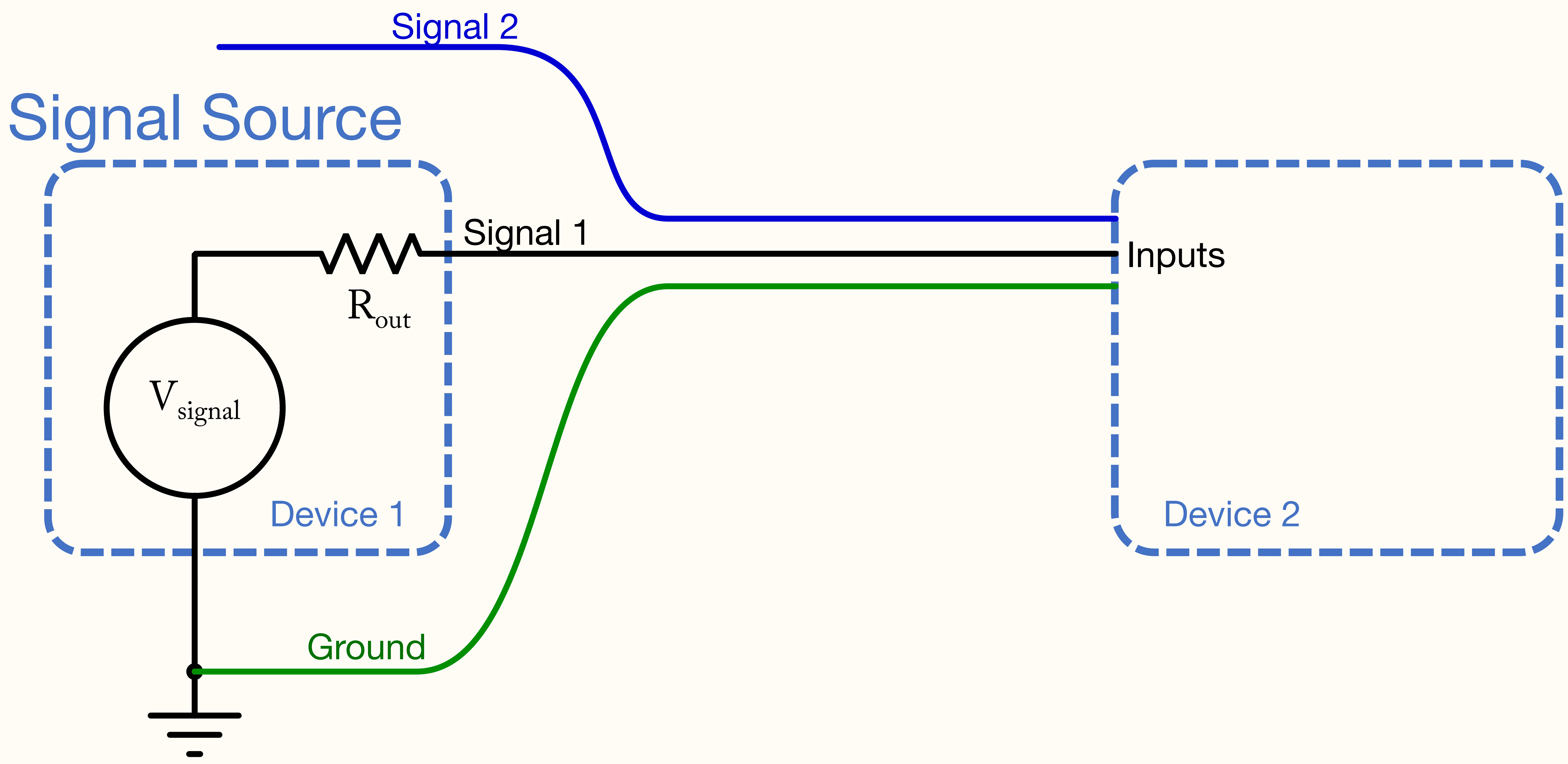
$$\mathrm{SNR} = \frac{Power(\mathrm{Signal})}{Power(\mathrm{Noise})} = \frac{Amplitude(\mathrm{Signal})^2}{Amplitude(\mathrm{Noise})^2}$$

Raw Signal Quality

It's always best to start with a clean raw signal (with large SNR) than to try to "fix" it with hardware or software

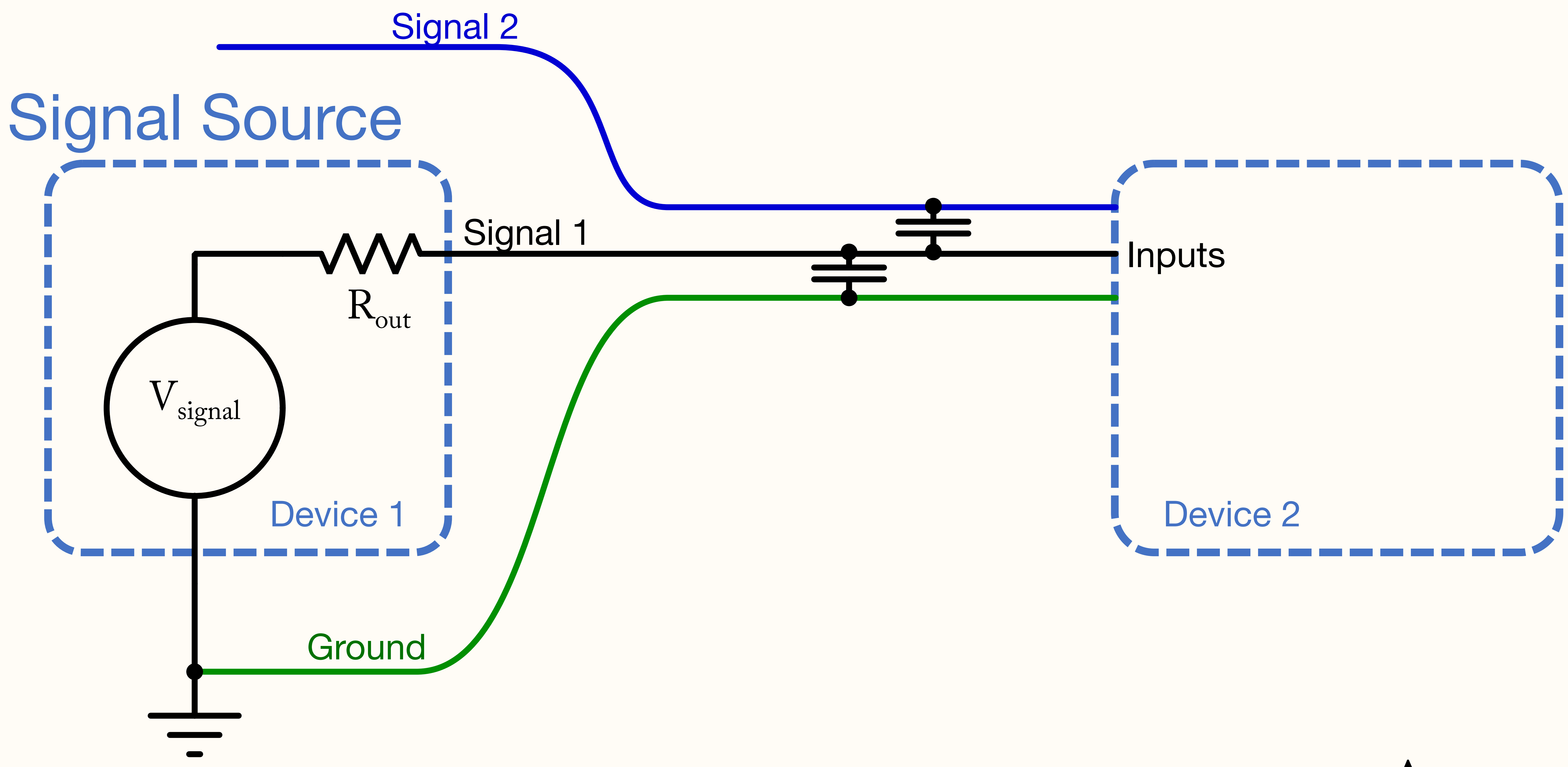
- Minimize environmental noise
  - Eliminate stray light, vibrations, electrical noise sources
- Maximize signal:
  - Healthy preparation/sample
  - Imaging: clean optics, good lighting, high contrast
  - Electrophysiology: good cell, high-quality electrode, good seal, etc

Stray Capacitance



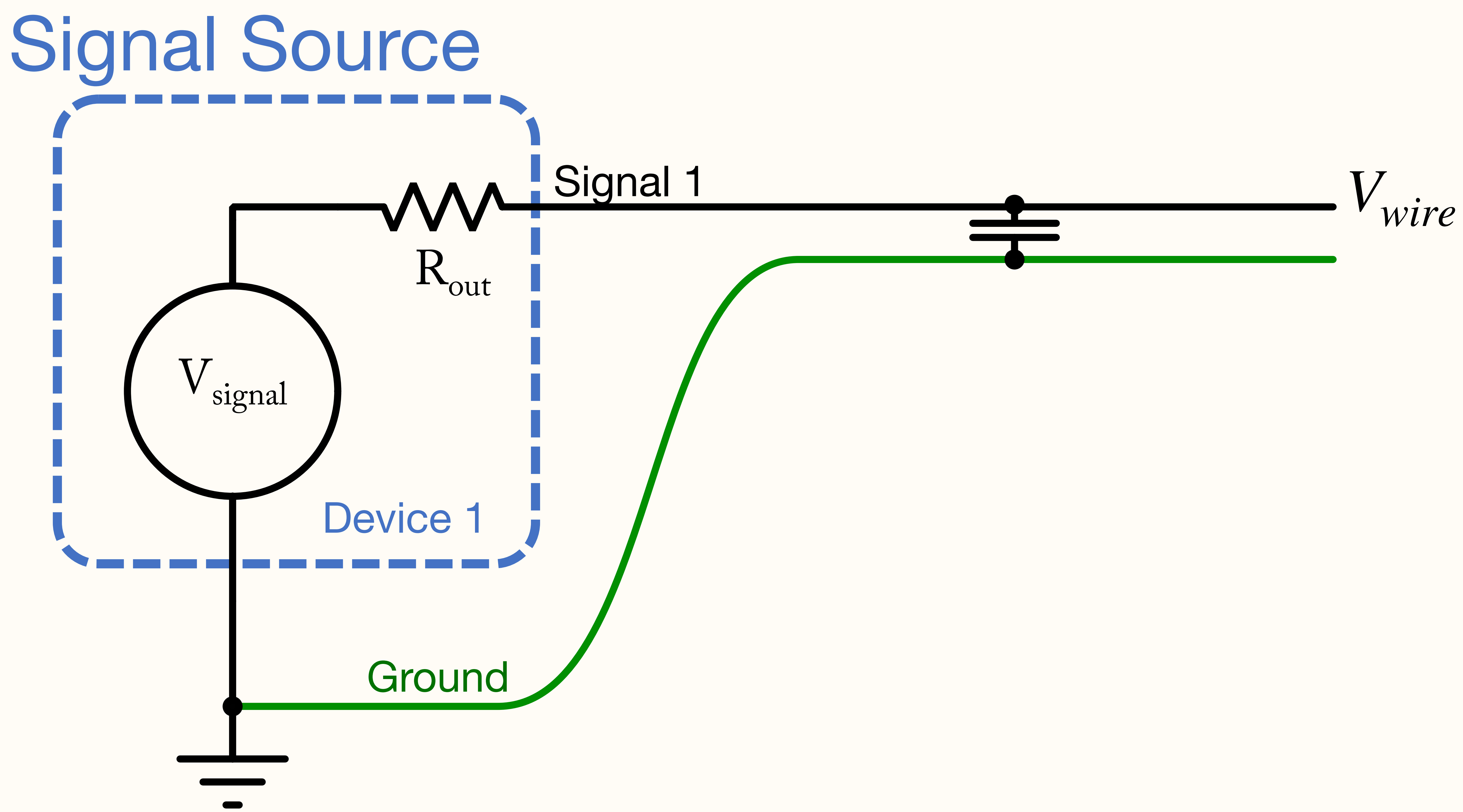
Unintended capacitance is present when two signal line run side-by-side
Or when a signal runs alongside ground

Stray Capacitance



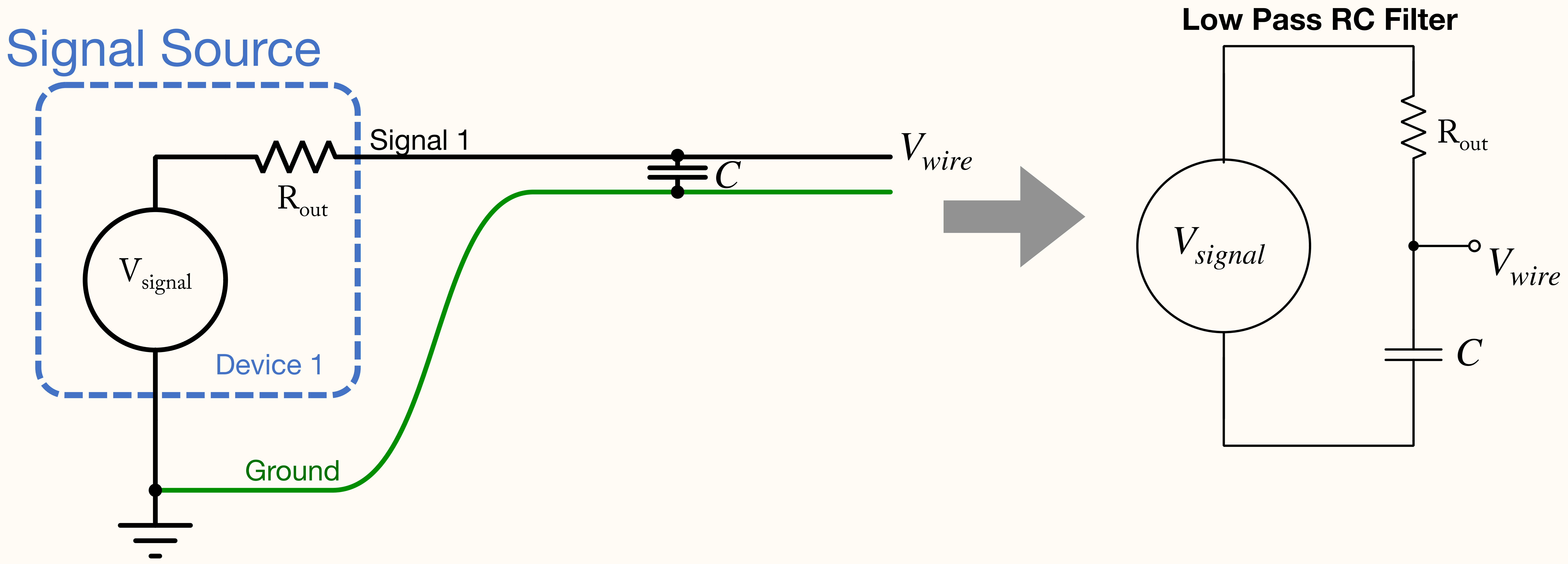
Unintended (stray) capacitance can arise: $C \propto \frac{\text{Area of overlap}}{\text{Distance between conductors}}$

Stray Capacitance



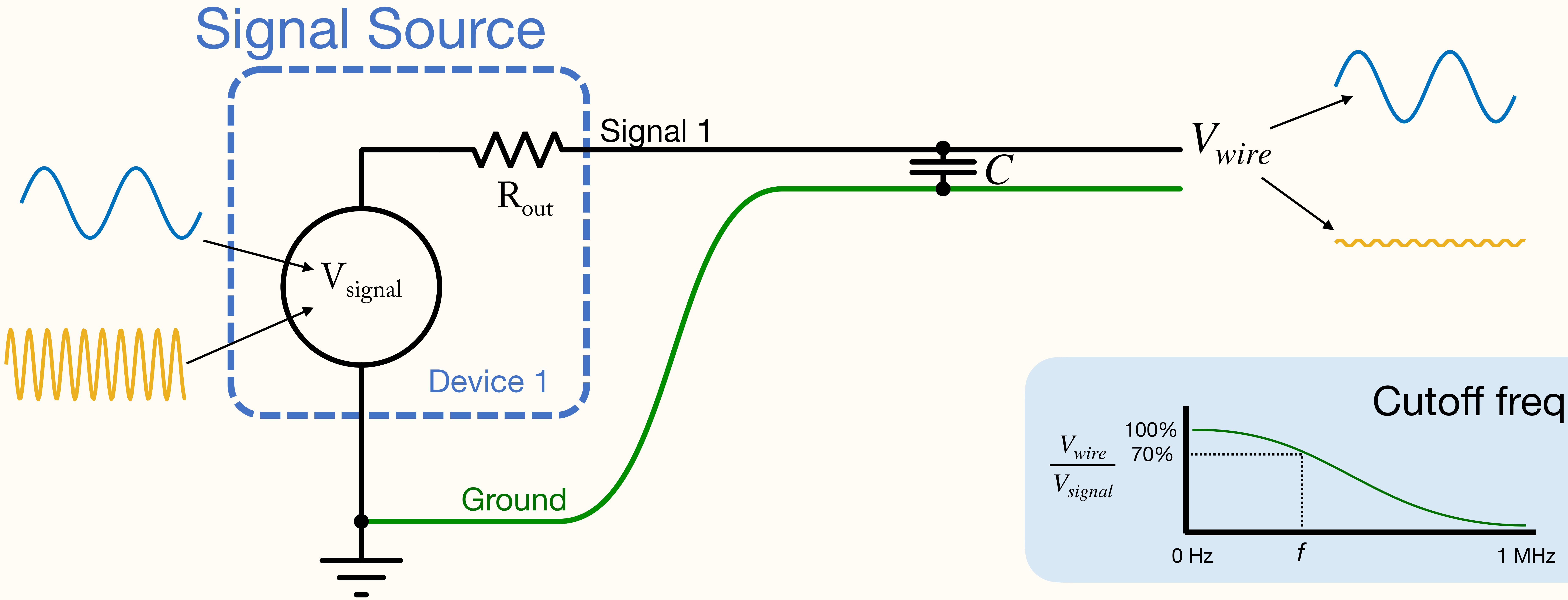
Stray capacitance to ground: Recognize the circuit motif?

Stray Capacitance



Stray capacitance to ground: Low-pass RC filter

Stray Capacitance



Cutoff frequency, $f = 1/(2\pi RC)$

f: frequency in Hz
R: resistance in Ω
C: capacitance in F

Stray capacitance to ground: Low-pass RC filter

- Effect is stronger for larger values of **R** and **C**

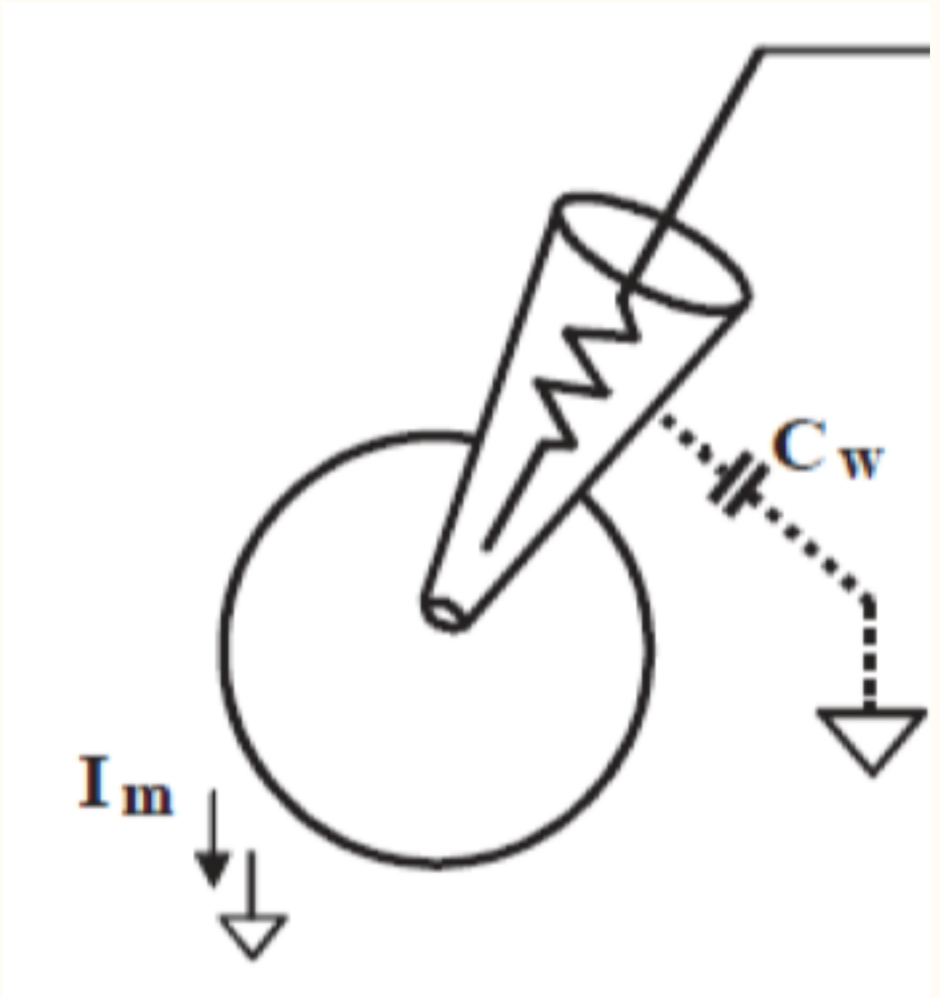
Stray Capacitance: Example & Solutions

Stray capacitance to ground: Low-pass RC filter

- Effect is stronger for larger values of **R** and **C**

Examples

- High impedance signals are particularly sensitive
- Capacitance between pipette and bath

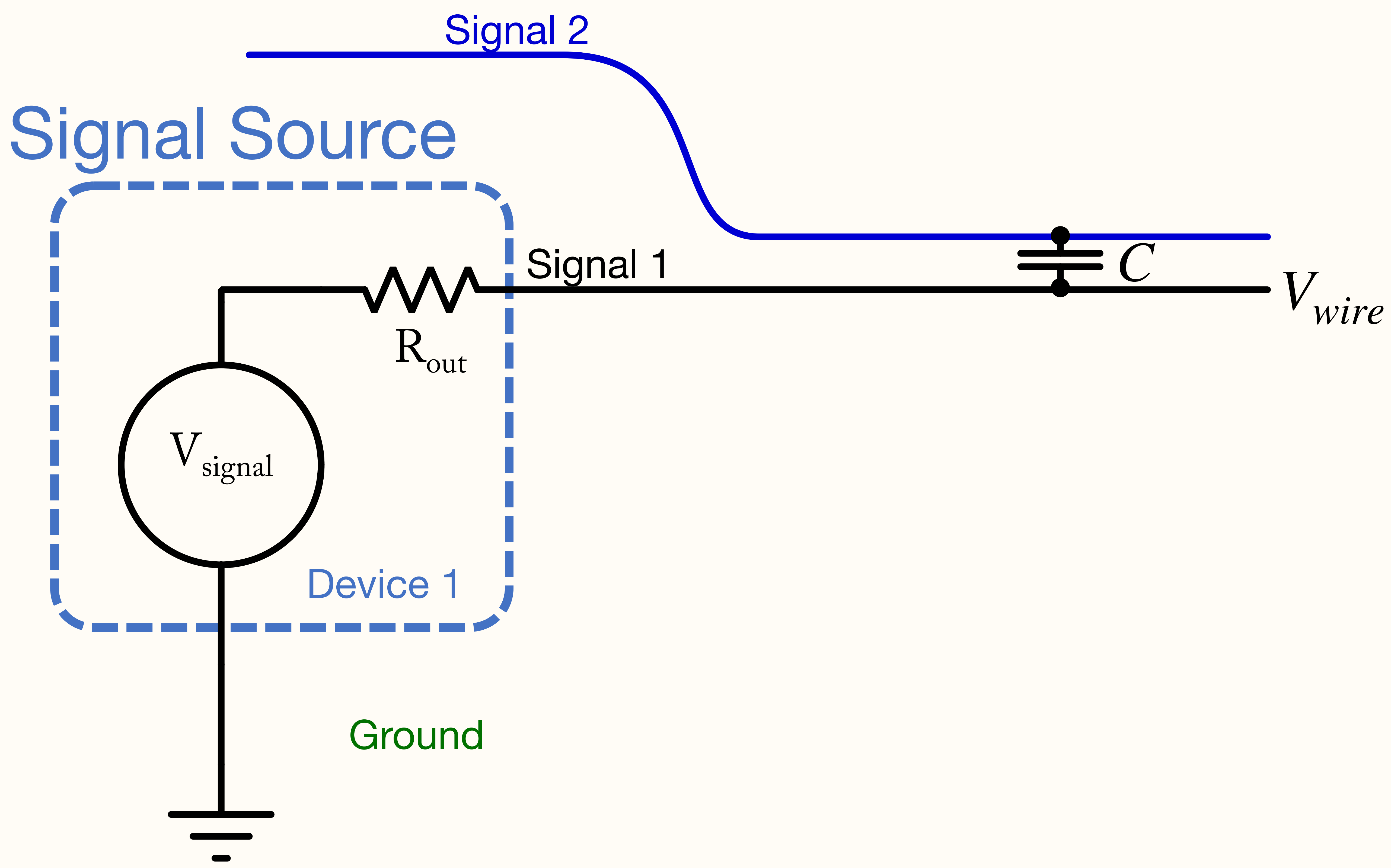


(From: The Axon Guide, Third Edition, Molecular Devices, LLC, 2012)

Mitigation Strategies

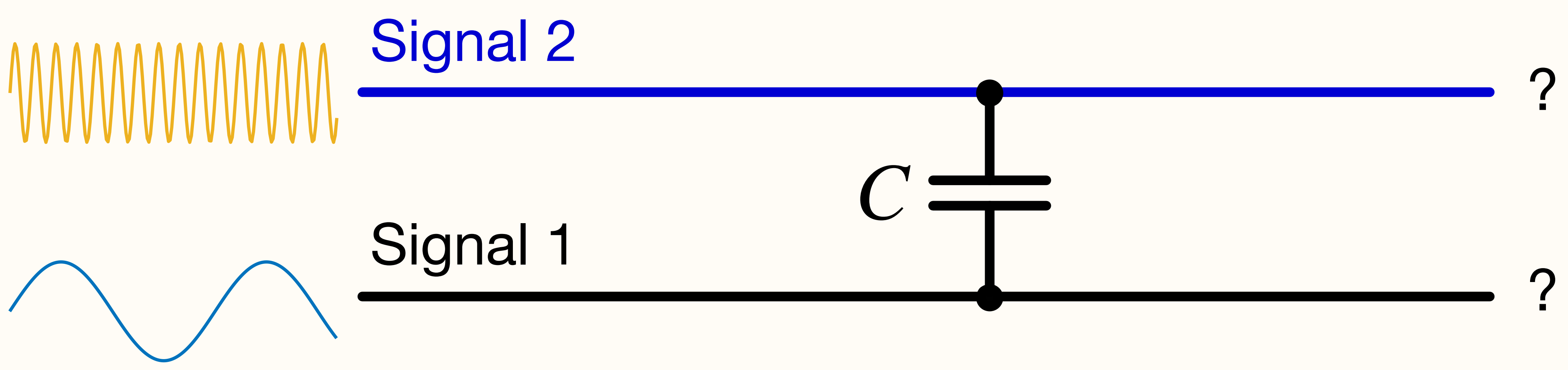
- For glass electrodes
  - Reduce overlap area (lower bath level)
  - Increase distance (coat with Sylgard)
- Keep high-impedance signal lines short

Capacitive Coupling



Stray capacitance between signal lines:

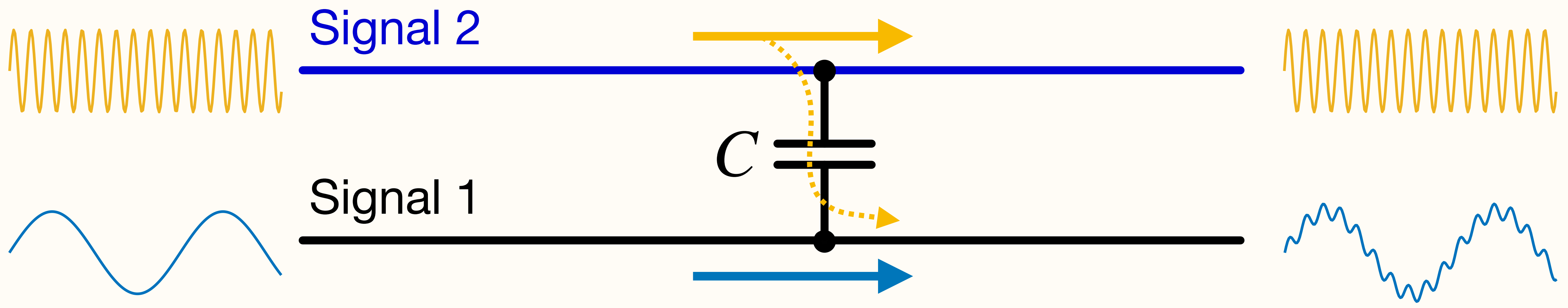
Capacitive Coupling



Stray capacitance between signal lines

(Capacitor acts as a selective conductor for high frequencies)

Capacitive Coupling

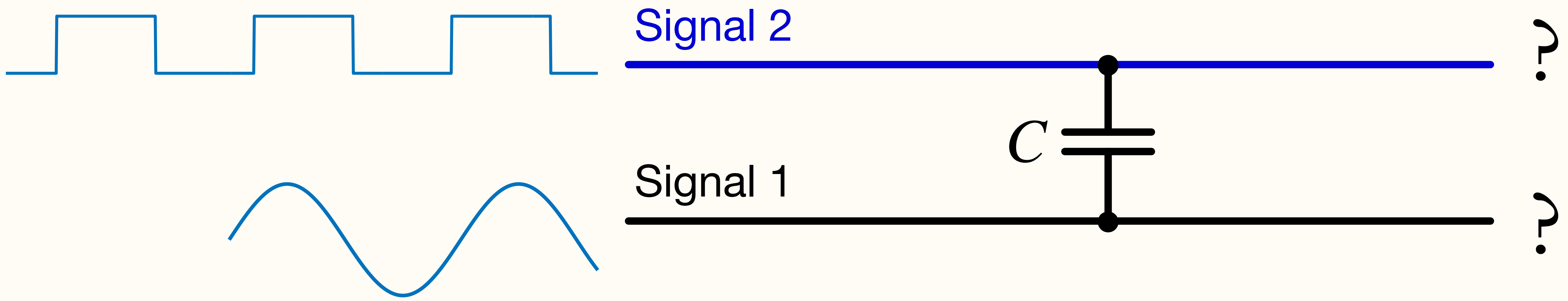


Stray capacitance between signal lines:

- Signal coupling (cross-talk) at high frequencies

  (Capacitor acts as a conductor for high frequencies)

Capacitive Coupling

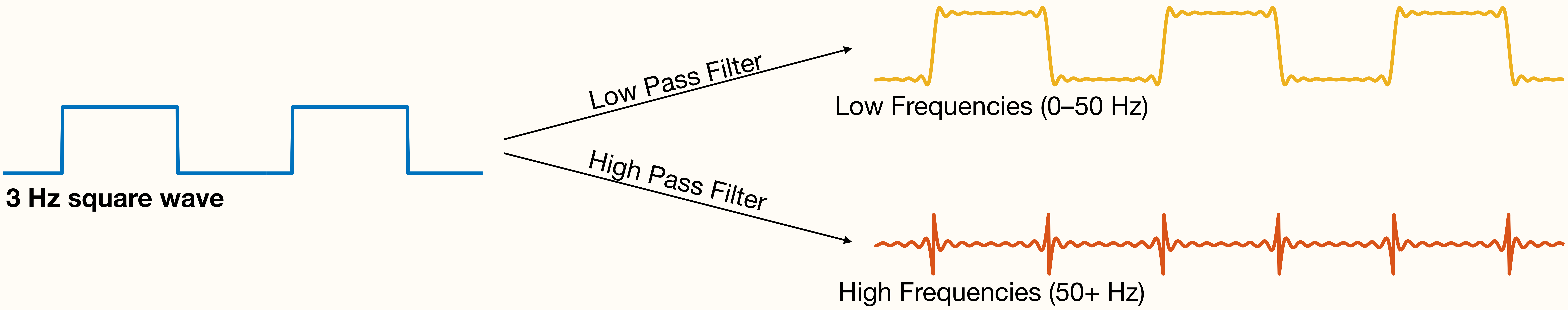


Stray capacitance between signal lines:

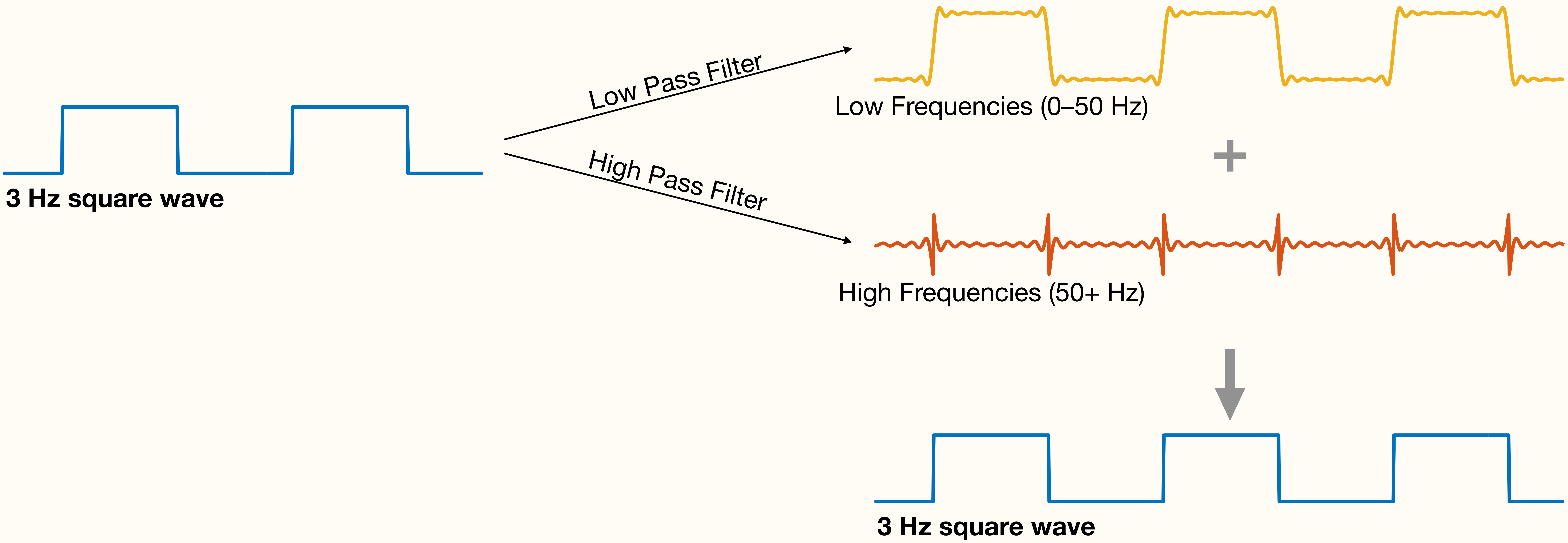
- Signal coupling (cross-talk) at high frequencies

  (Capacitor acts as a conductor for high frequencies)

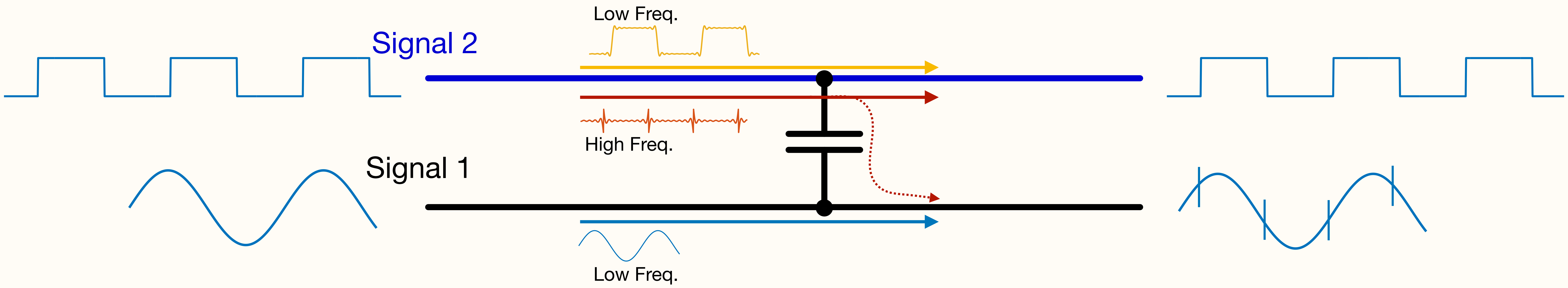
Complex Signals Are Composed of Multiple Frequencies



Complex Signals Are Composed of Multiple Frequencies



Capacitive Coupling



Stray capacitance between signal lines:

- Signal coupling (cross-talk) at high frequencies

  (Capacitor acts as a conductor for high frequencies)

Capacitive Coupling: Example & Solutions

Examples

- High impedance signals are particularly sensitive
- Digital signals have high frequency components
  (Fast transitions between 0 and 1)
- High frequency switching in some power supplies

Mitigation Strategies

- Keep sensitive analog signals away from digital lines
- If you suspect capacitive coupling:
  - Reduce path lengths
  - Increase inter-wire spacing

Antennas & EM Pickup

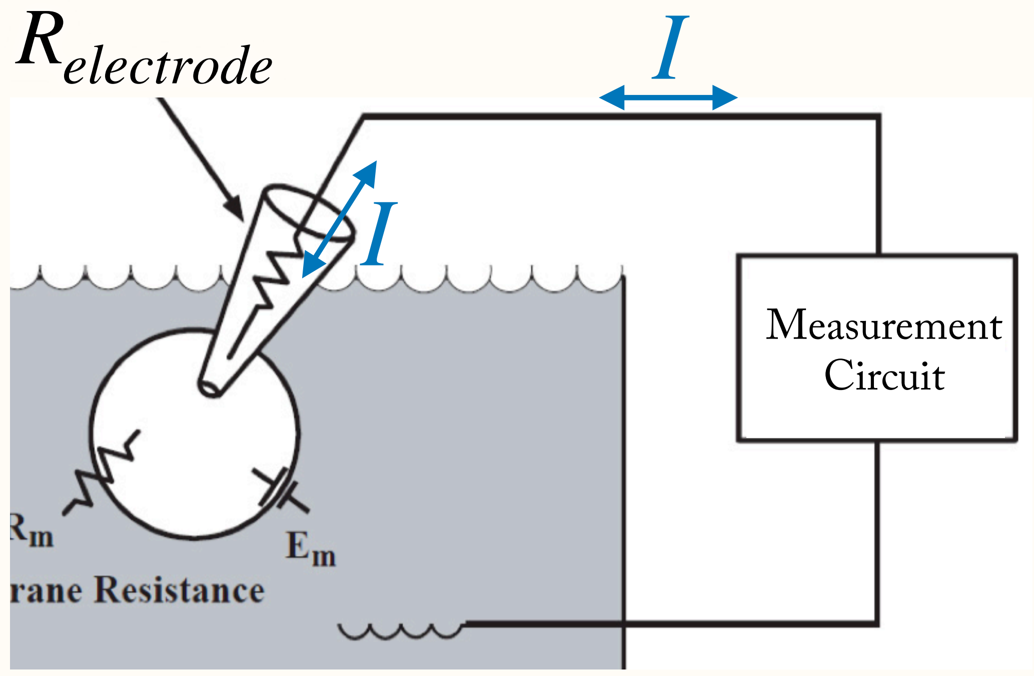
Electromagnetic (EM) radiation

- EM waves are emitted by time-varying currents (in nearby equipment)
- Steady (DC) voltages and current are not culprits for EM noise
- Dynamic signals (digital lines, many power supplies), especially with large currents (motors) are common sources of unwanted radiation

Motor
(Large oscillating currents)

Wires act as antennas

- Wires pick up EM radiation and convert it into time-varying currents
- These currents will generate voltages as they flow through resistance in the circuit ($V = IR$)
- High-impedance signal sources will exhibit larger amplitude noise



Antennas & EM Pickup

Solutions

- Separate EM radiation sources from sensitive electronics
  - E.g., power supplies, motors, AC power cables, digital circuits
  - Hint: 60 Hz noise is often a sign of EM pickup
- Shielding: Faraday cage, coaxial cables (e.g., BNC), aluminum foil
  - Avoid AC power cords inside Faraday cage
  - Avoid antennas that exit the Faraday cage (e.g. perfusion lines)
  - Grounded shields are typically better
- Pay attention to high output impedance signals
  - Minimize length of output high impedance lines
  - Keep them shielded
  - **Amplifiers** can “convert” from high to low impedance signal
- Increase signal amplitude (to increase SNR)
  - A 50 mV signal is swamped by 10 mV noise; a 5 V signal might be OK
  - **Amplifiers** can increase the voltage gain