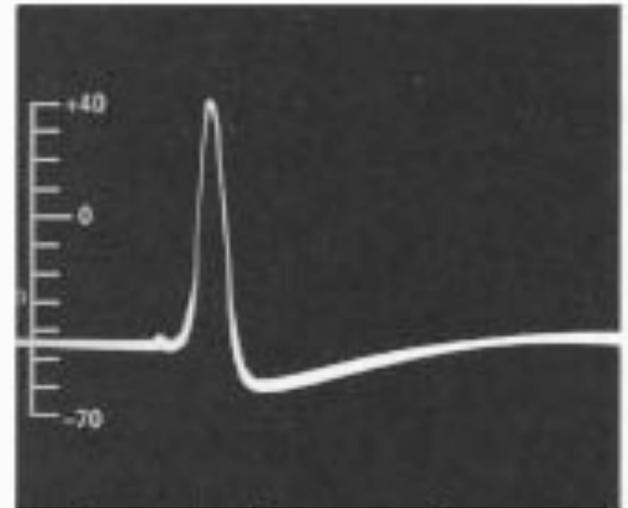


Neurophysiology

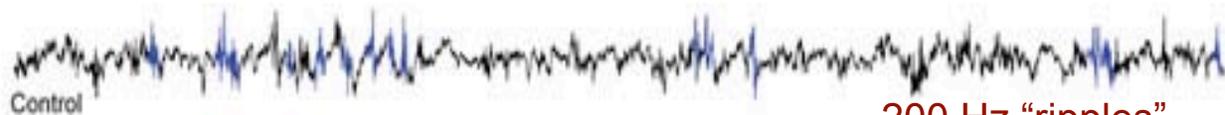
Why should we care?

- AP is the elemental unit of nervous system communication
- Time course, propagation velocity, and patterns all constrain hypotheses on how the brain works
- Understand what biophysical mechanisms we are measuring in the brain
- Teach us how we might interact with the nervous system

The action potential



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200 Hz "ripples"
localized to pyramidal
cell layer of CA1

What "signals" can we measure?

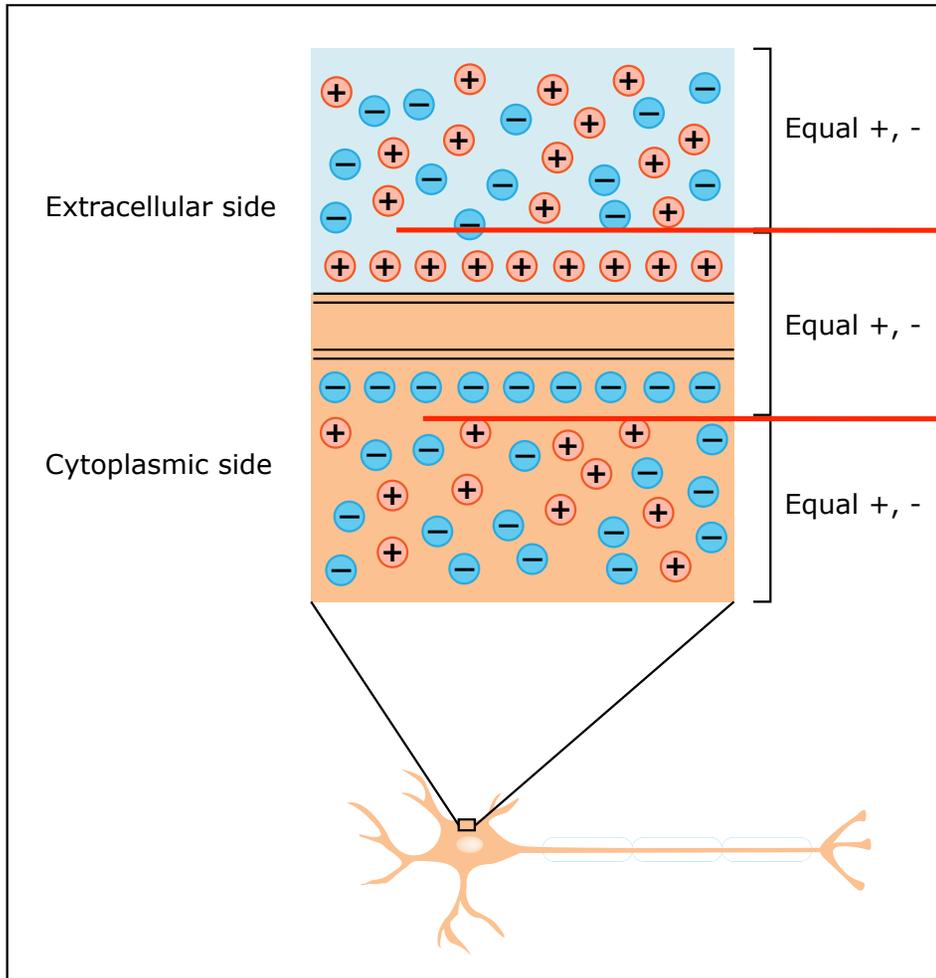


Image by MIT OpenCourseWare.

Membrane potential (V_m)

Potential (mV) ->



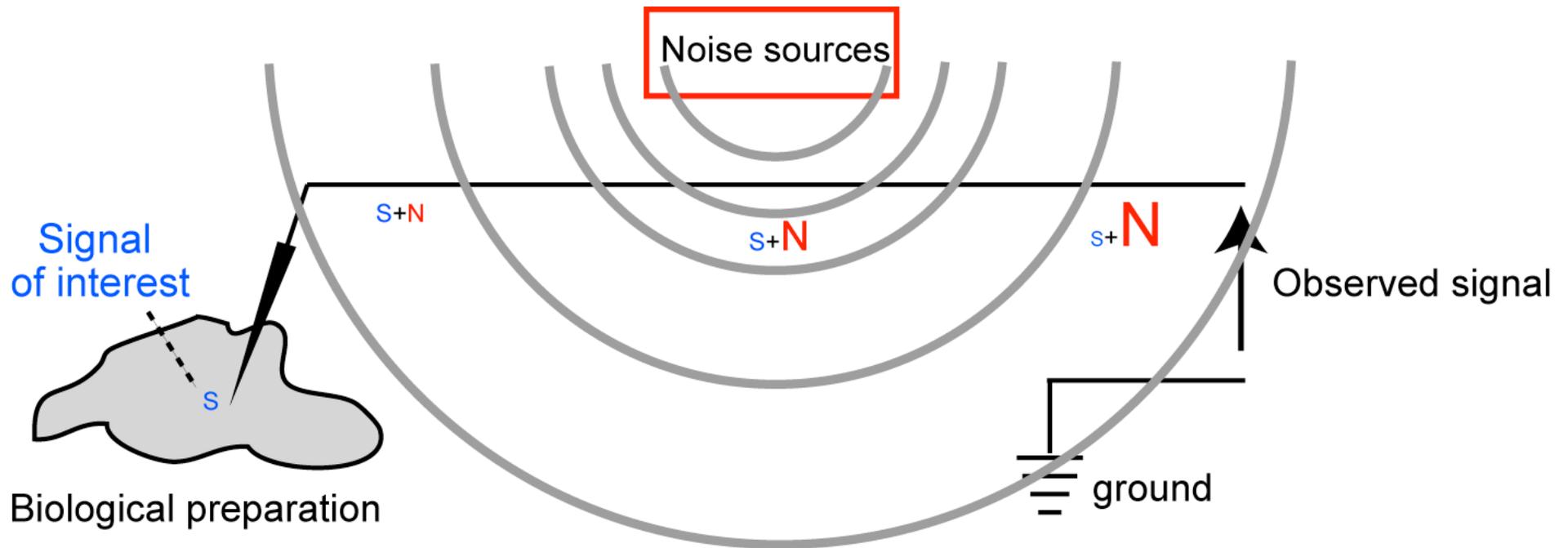
Time ->

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These signals are small
(microvolts outside the cell)

Goal: Measure a very small signal (voltage) as a function of time.

Problem: How do we “see” such a small signal in the presence of inevitable noise ?



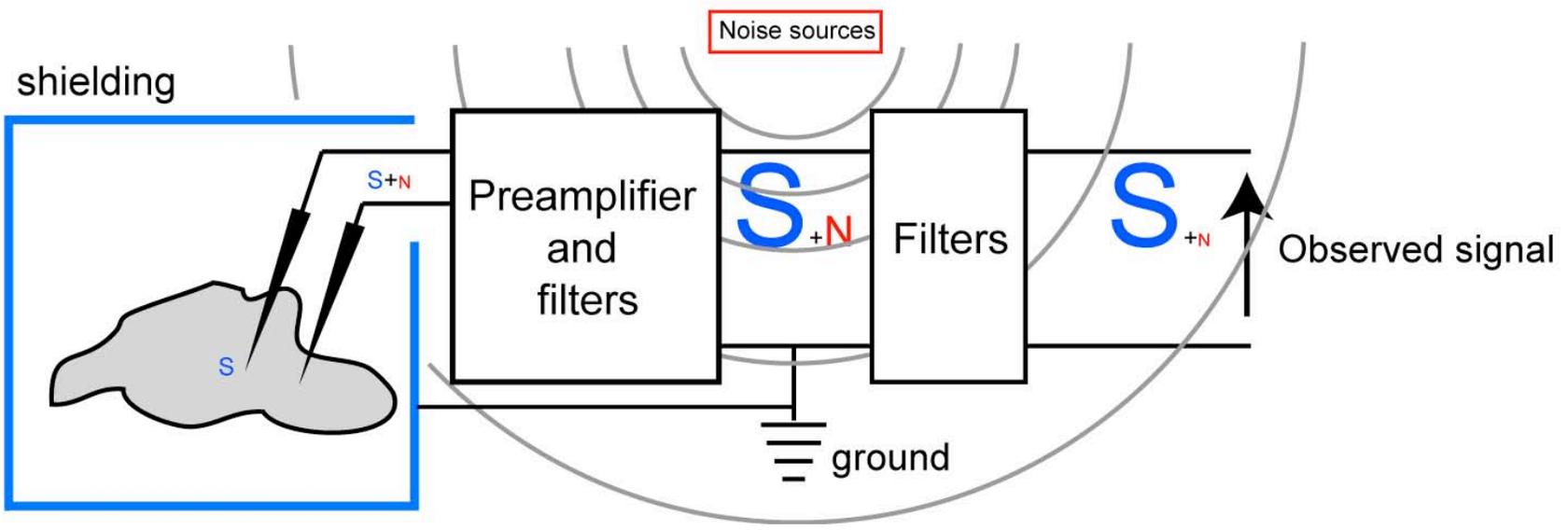
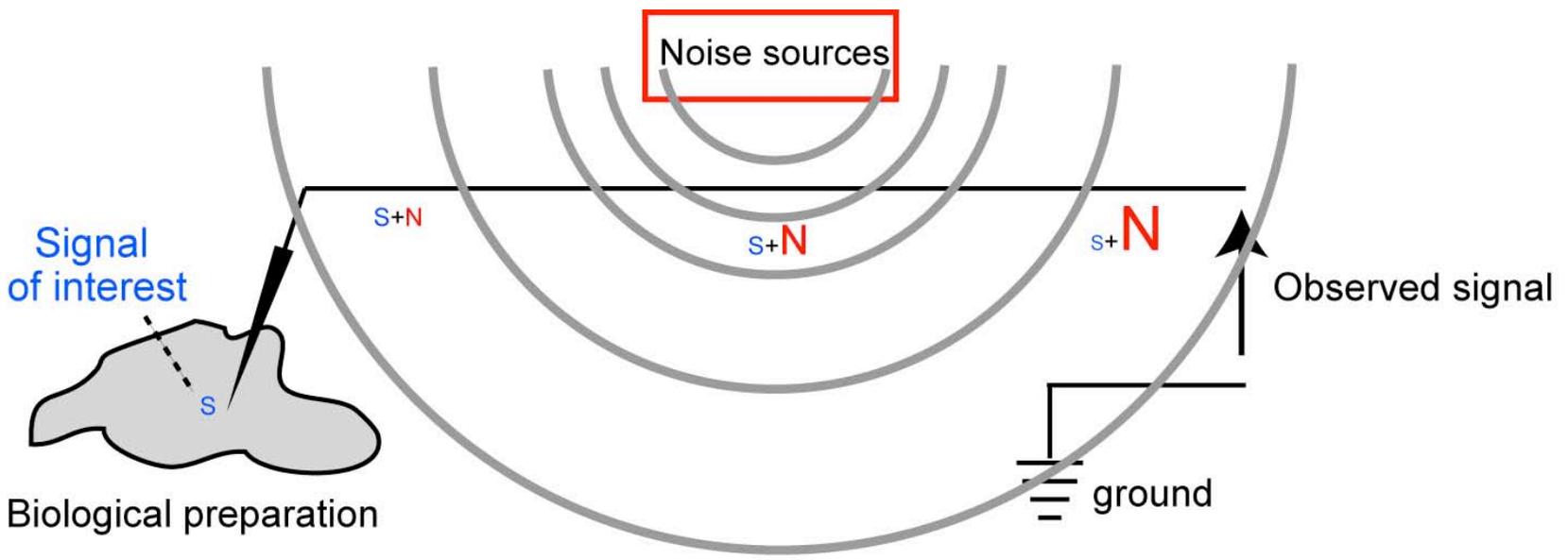
Amplifier and filters

**Simple concept: increase the size of the signal
(relative to the size of the noise).**

1. Minimize noise entering the electrode and electrode leads (wires):
 - Remove noise sources in the area
 - Use short leads from prep to amp (reduce entry of noise)
 - Shielding (reduce entry of noise)
2. Increase the amplitude (gain) of the small potentials on the recording leads with minimal distortion: Amplifier with high input impedance
3. Eliminate noise that found its way into the electrode:
 - Differential amplification (ignore signals are common to both the electrode and the reference electrode)
 - **Filtering (attenuate frequencies likely to be “noise”, preserve frequencies that are likely to be “signal”)**

Helpful concept: frequency representation of a voltage signal

Amplifier and filters



Filters and Amplifiers

Filters are often built in to the amplifier

Filtering generally comes first (remove signal components that might cause amplifier to saturate)

9.02 amplifier/filters

Input 1 (active/recording)

Input 2 (reference/indifferent)

Ground (common)

filter settings

amplification



output
(center
wire vs.
shield)

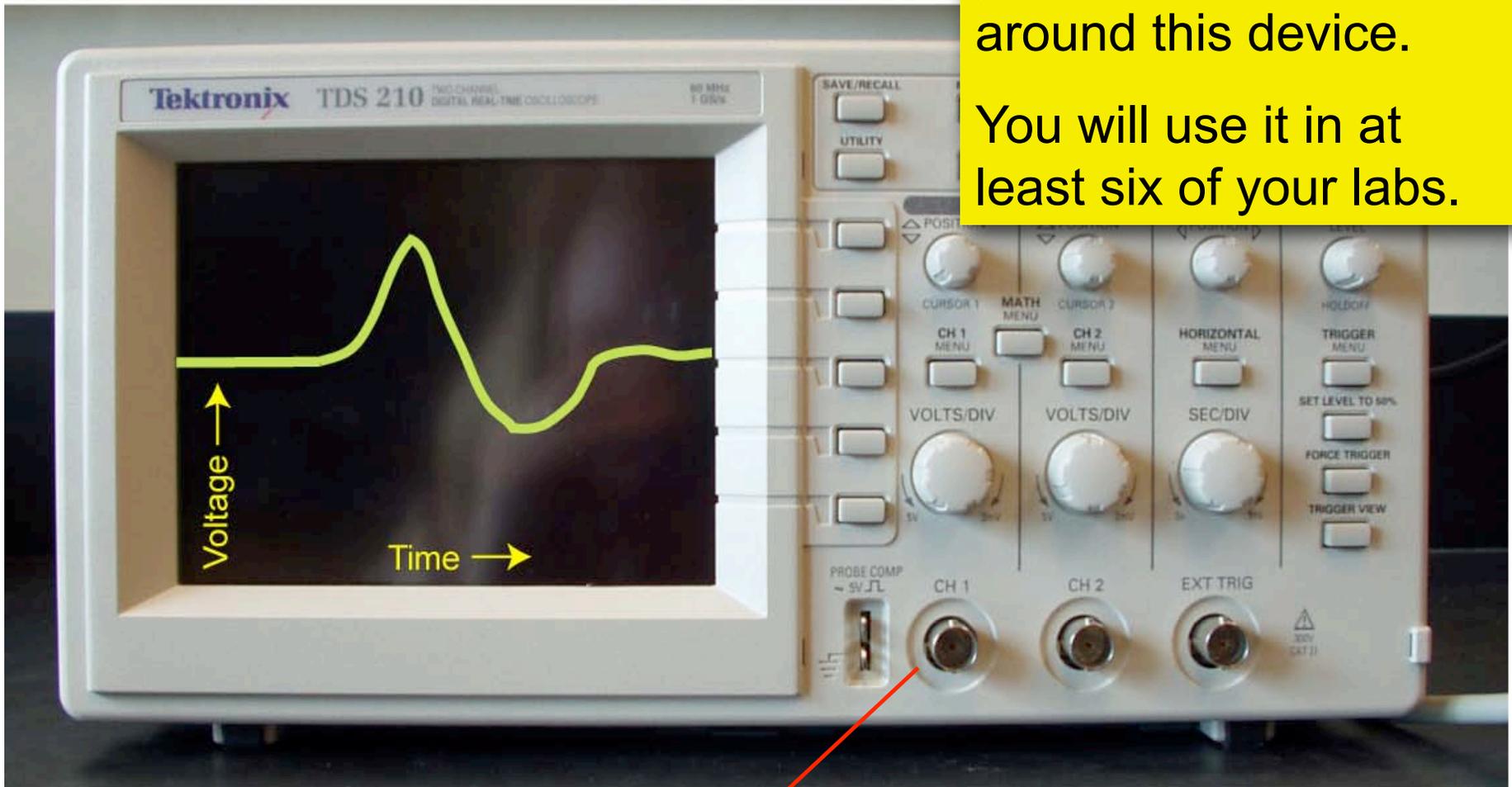
OK -- we have large voltage signal (relative to noise).

But how do we “see” it??

Digital oscilloscope

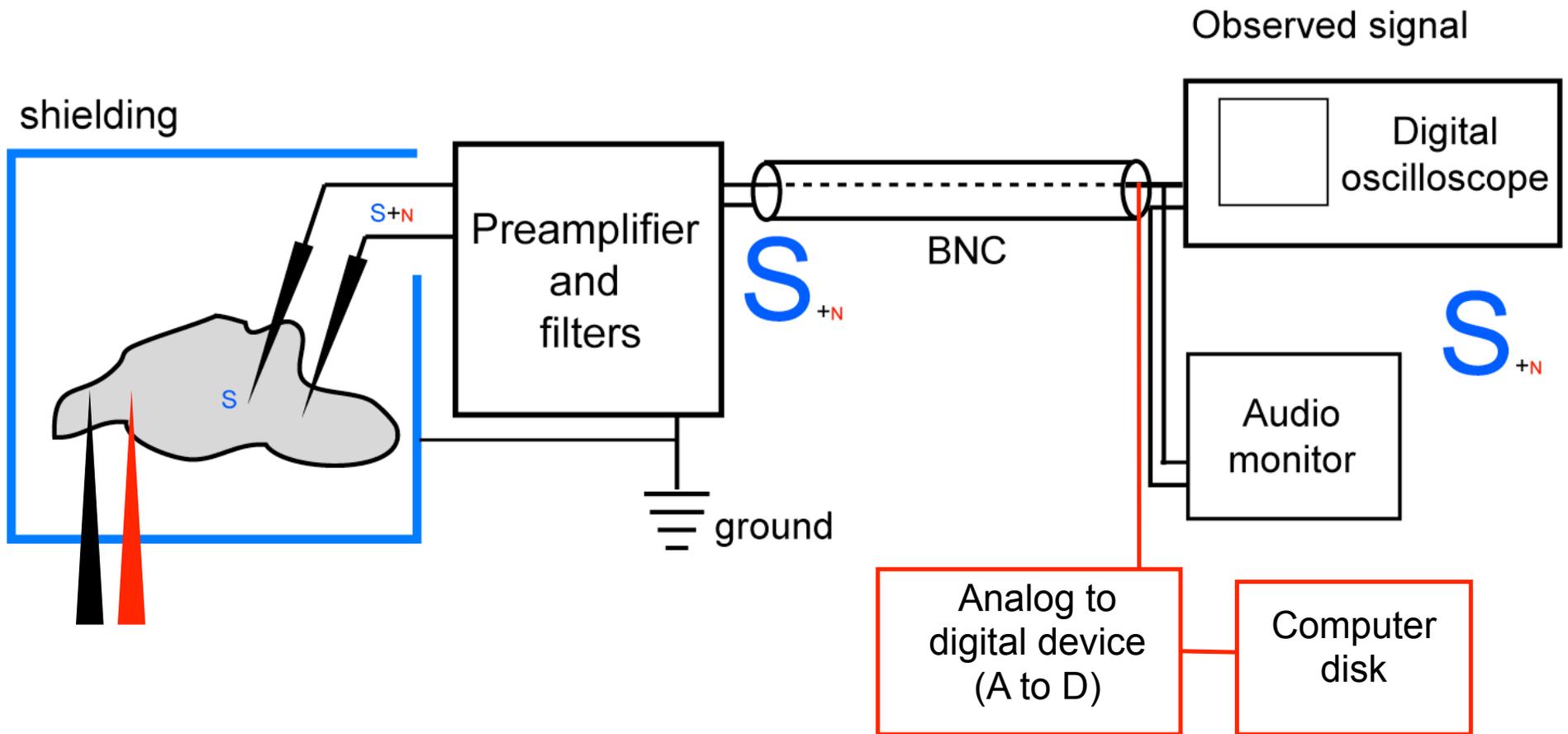
By the end of the lab, you will know your way around this device.

You will use it in at least six of your labs.



Input line

Basic electrophysiological setup



Filters and Amplifiers

Filters are often built in to the amplifier

Filtering generally comes first (remove signal components that might cause amplifier to saturate)

9.02 amplifier/filters

Input 1 (active/recording)

Input 2 (reference/indifferent)

Ground (common)

filter settings

amplification



output
(center
wire vs.
shield)

Filtering

What is filtering? What is it good for?

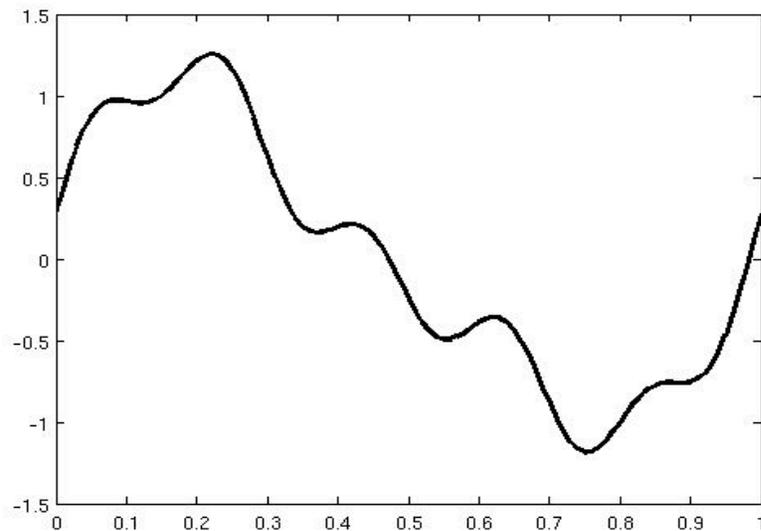
Filtering is a *frequency-domain* operation. It removes part of the signal, corresponding to certain frequencies, and lets other parts of the signal through.

It is useful because we often care about only certain parts of the signal, and consider other parts to be “noise”.

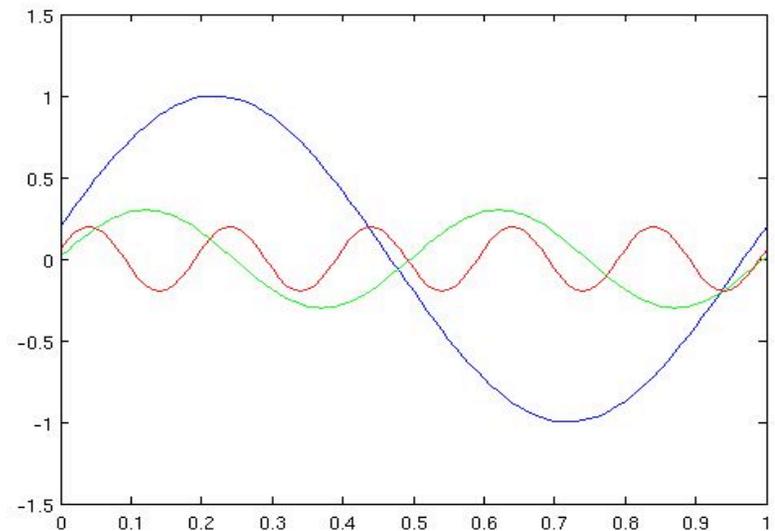
Often, the part of the signal that we care about and the noise occur at different frequencies.

Thinking about signals $V(t)$ as combinations of sine waves

Every signal can be represented as the weighted sum of sinusoids.



time



time

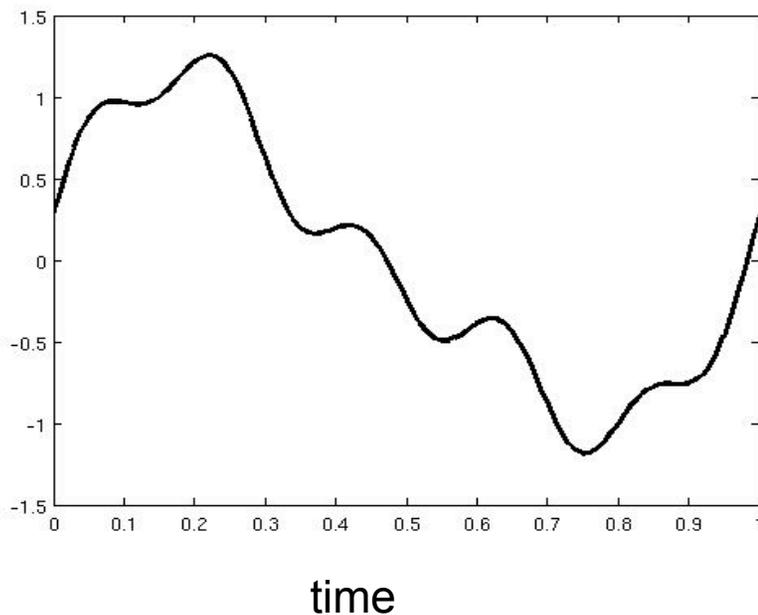
$$\begin{aligned} &1.0 \sin(2\pi t + 0.2) \\ &0.3 \sin(4\pi t + 0.05) \\ &0.2 \sin(10\pi t + 0.1) \end{aligned}$$

Fourier transform

A formula exists that tells us the required amplitudes and phases of the sinusoids that constitute any given signal $V(t)$.

This formula is called the **Fourier transform**.

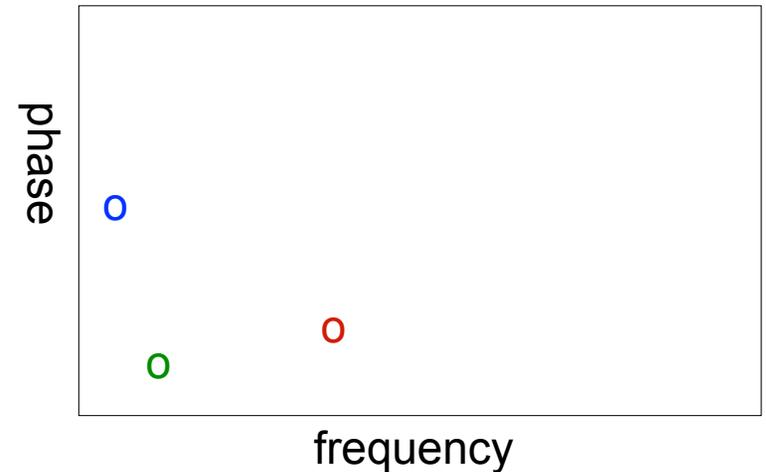
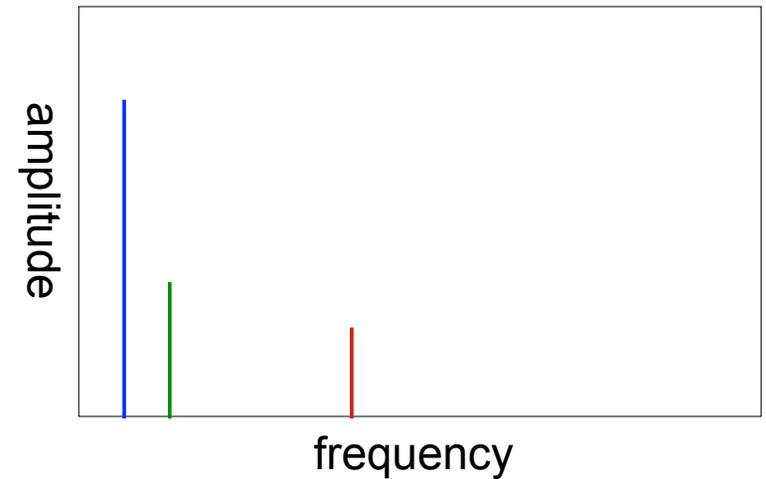
A formula also exists for the inverse operation: the inverse Fourier transform.



Fourier transform



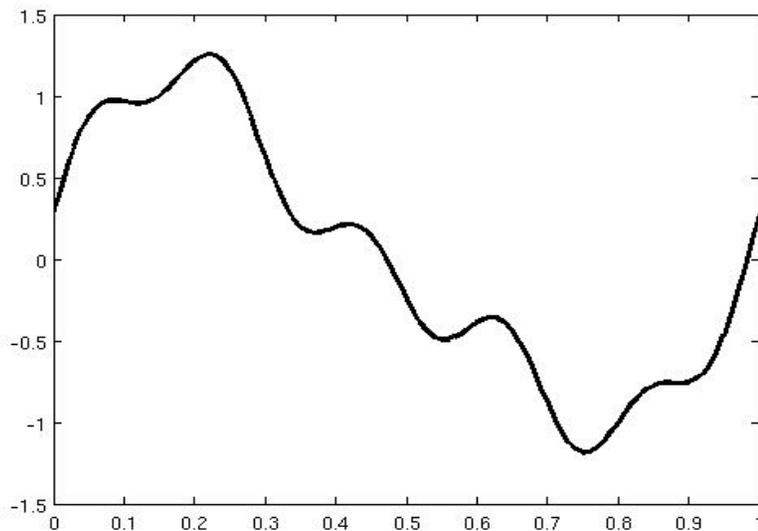
inverse Fourier transform



Fourier transform

We call these two representations “time domain” and “frequency domain”.
They contain exactly the same information!

time domain representation

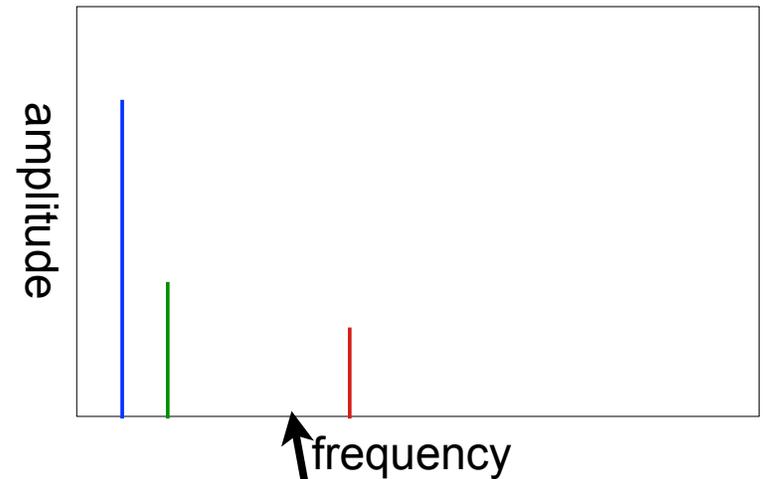


Fourier transform
→

←
inverse Fourier transform

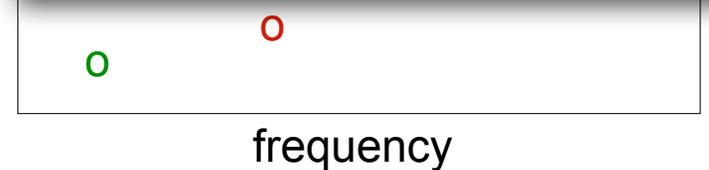
time (s)

frequency domain representation



phase

The square of this is called the “power spectrum.”
It is very helpful for understanding how filters work.



Fourier transform

$$G(f) = \int_{-\infty}^{\infty} g(t) e^{-i2\pi ft} dt$$

(you do not need
to know this formula)

The Fourier transform returns complex values for each frequency.

The absolute value is the amplitude at that frequency, and collectively they form the amplitude spectrum. More commonly, the square of the amplitude is reported as the power spectrum.

Fourier transform

$$G(f) = \int_{-\infty}^{\infty} g(t) e^{-i2\pi ft} dt$$

(you do not need
to know this formula)

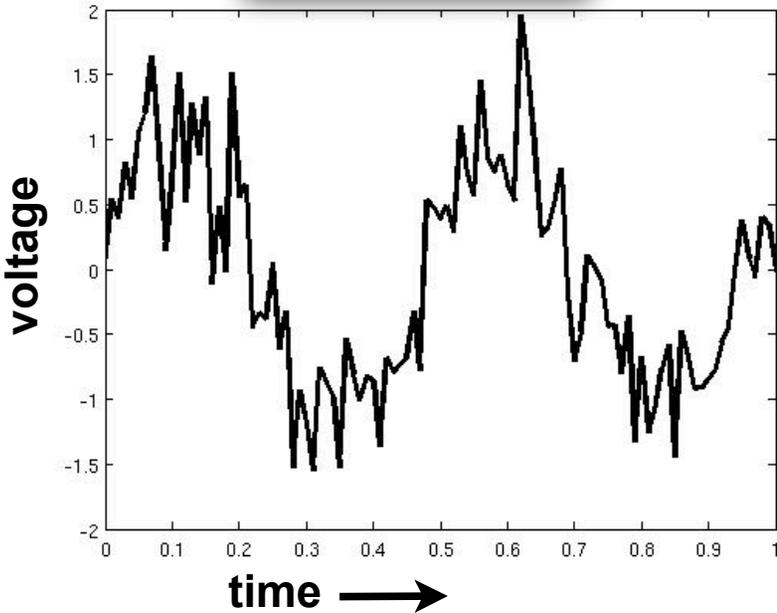
A **discrete Fourier transform** (DFT) is simply a Fourier transform applied to discretely sampled data (the voltage is only known at specific timepoints). Used for digitized data.

A **fast Fourier transform** (FFT) is a particular algorithm for implementing the Fourier transform that runs quickly on computers.

Back to Filtering ...

Low-pass filter: Remove high frequency components.

Original signal

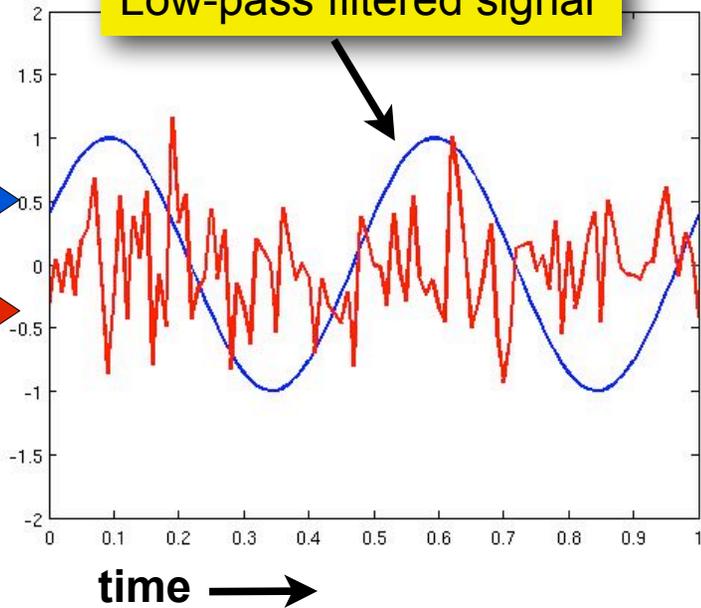


Apply low-pass filter



Apply high-pass filter

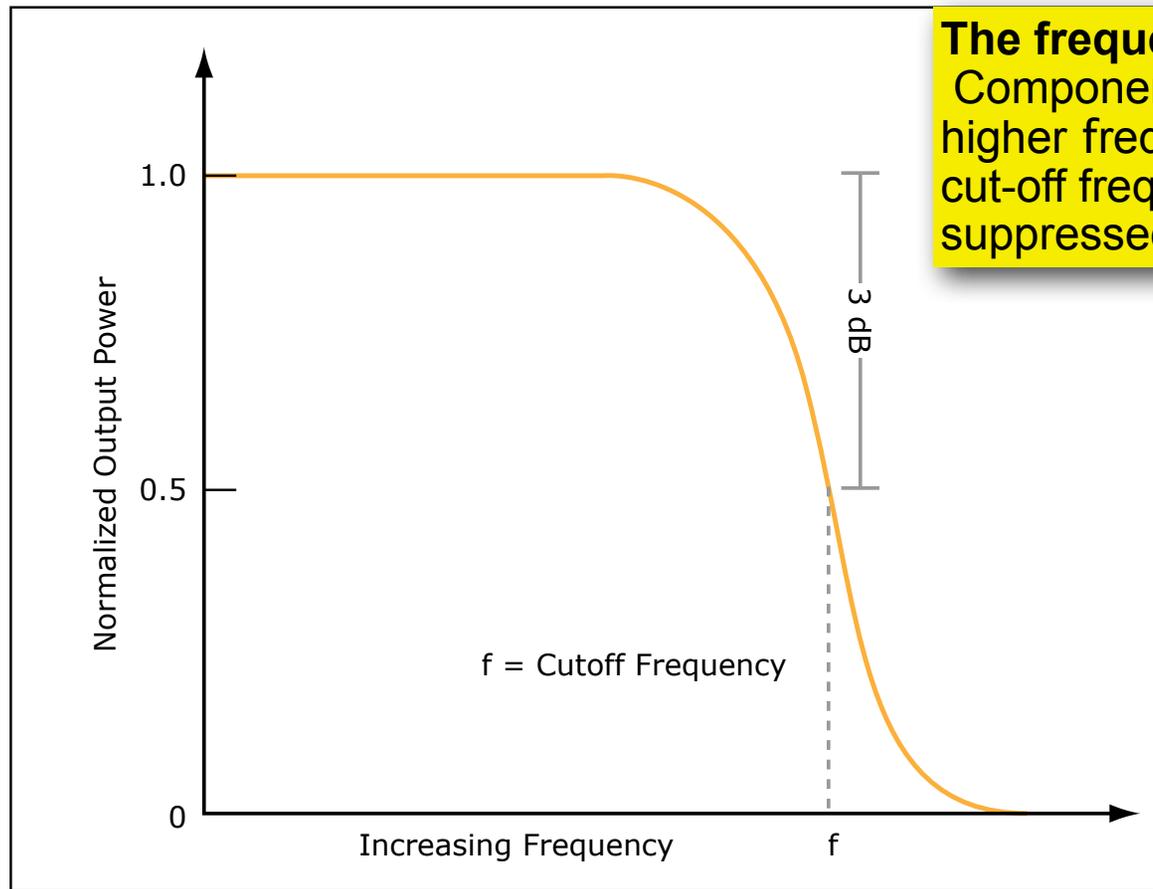
Low-pass filtered signal



Back to Filtering ...

Low-pass filter: Remove high frequency components.

An example low-pass filter



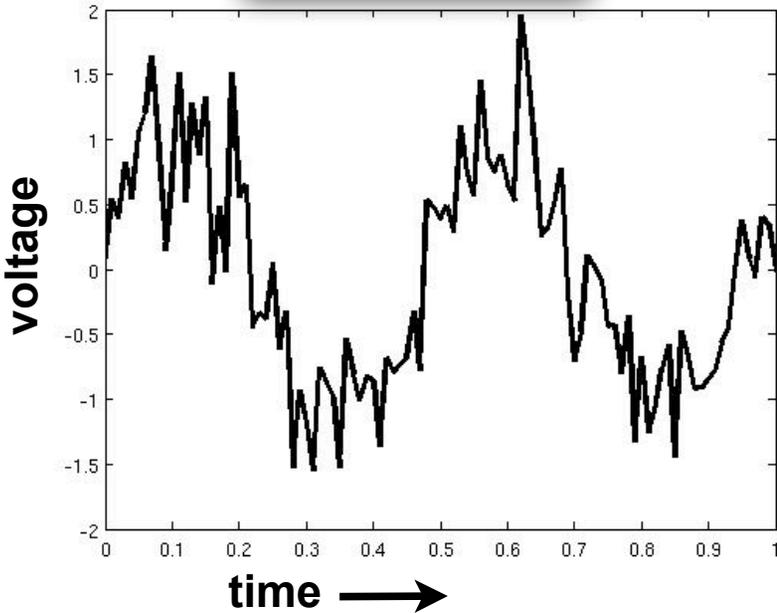
The frequency-domain view:
Components of the signal at higher frequencies than the cut-off frequency are suppressed

Image by MIT OpenCourseWare.

Back to Filtering ...

Low-pass filter: Remove high frequency components.

Original signal

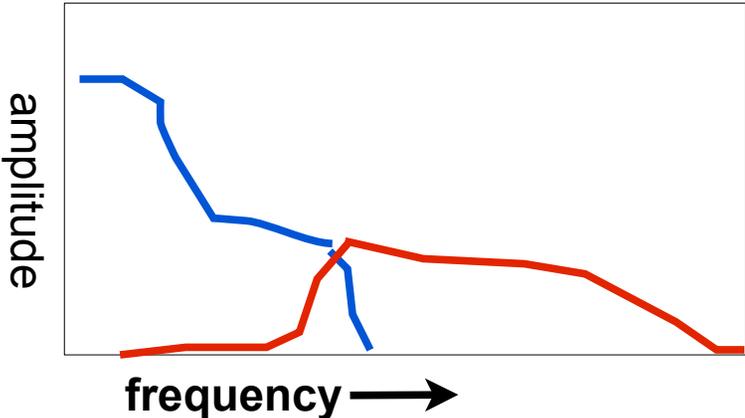
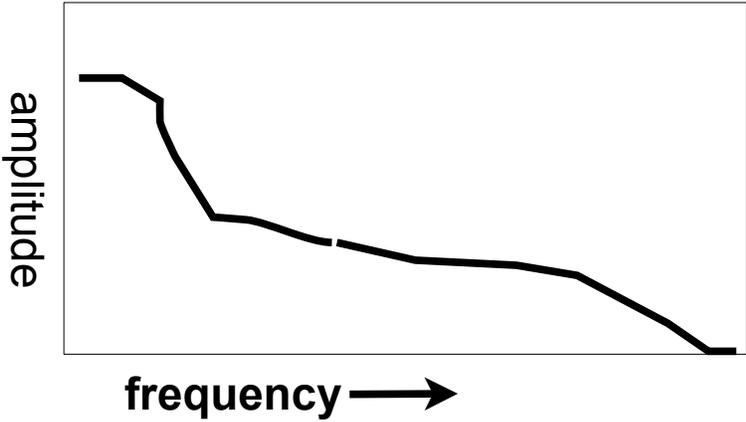
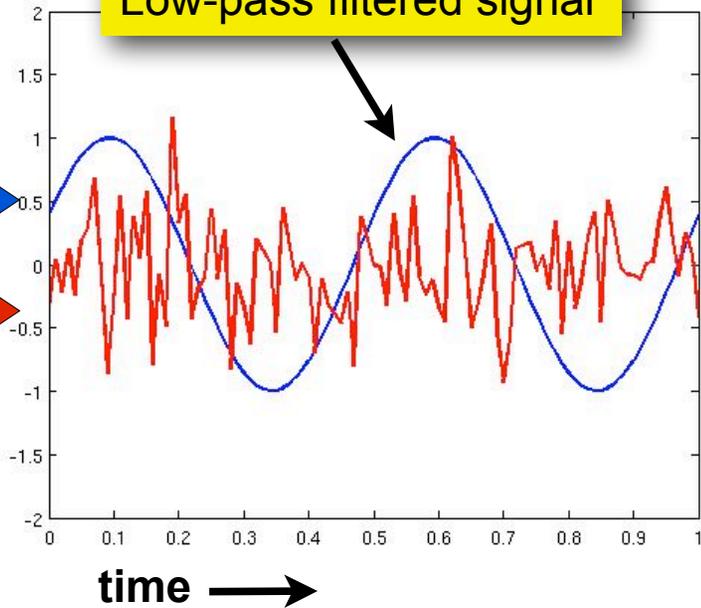


Apply low-pass filter



Apply high-pass filter

Low-pass filtered signal



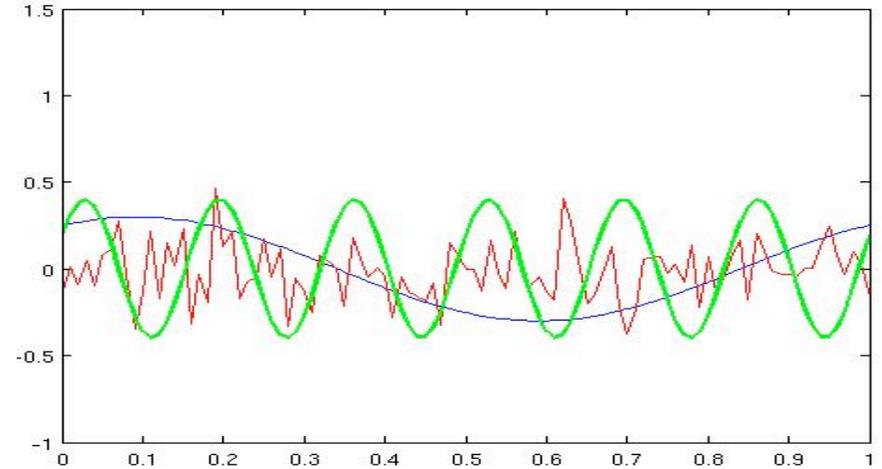
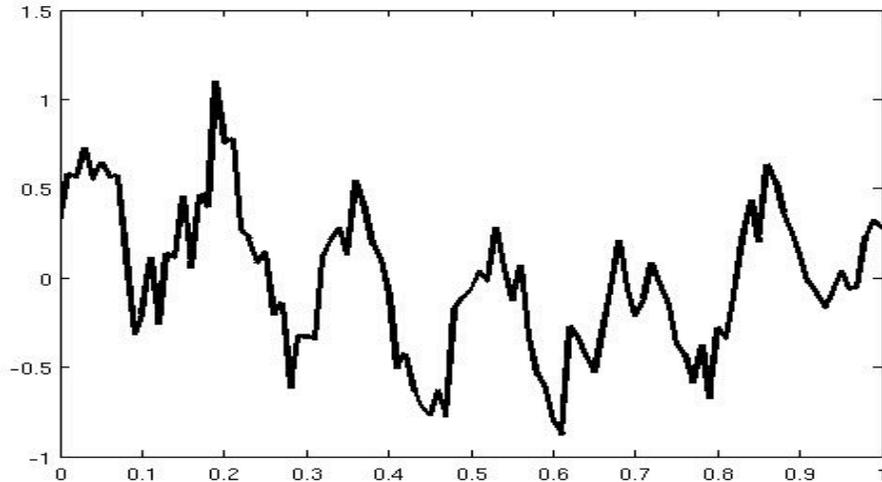
Back to Filtering ...

High-pass filter: Remove low frequency components.

Low-pass filter: Remove high frequency components.

Band-pass filter: Remove both low- and high-frequency components, allow frequencies in between.

9.02



Back to Filtering ...

High-pass filter: Remove low frequency components.

Low-pass filter: Remove high frequency components.

Band-pass filter: Remove both low- and high-frequency components, allow frequencies in between.

band-pass filter

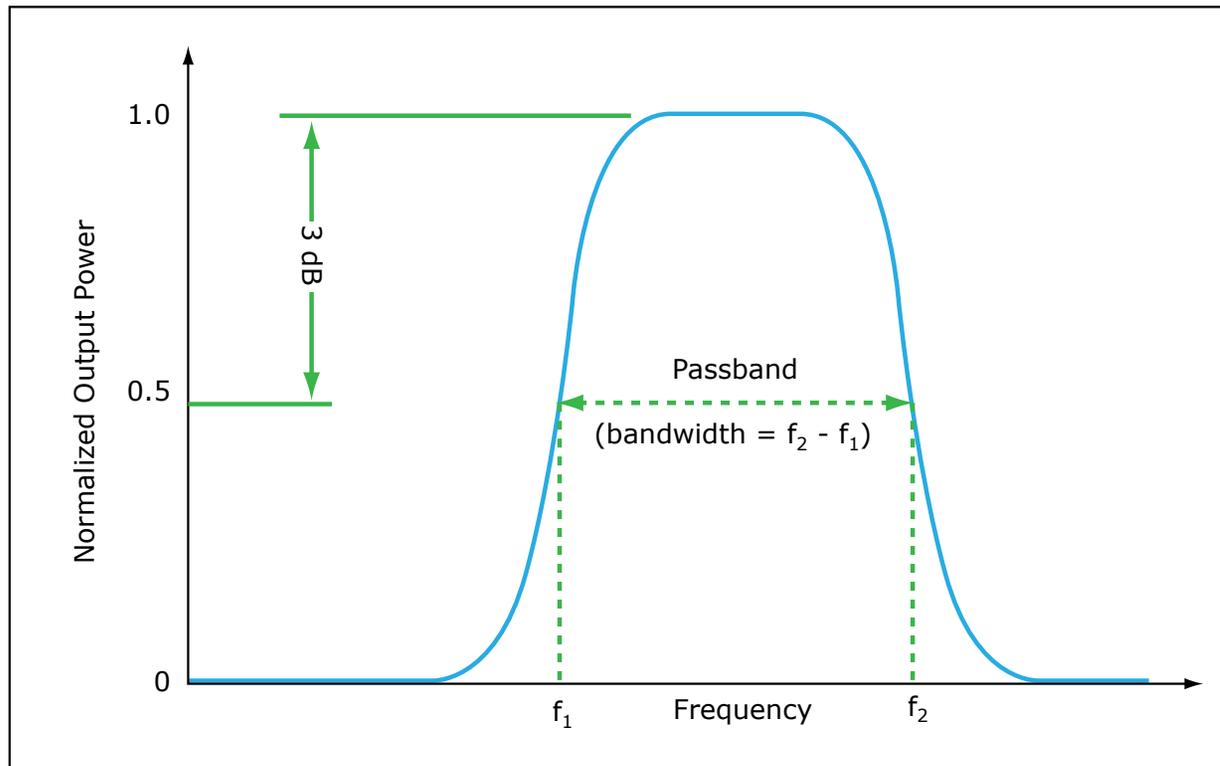


Image by MIT OpenCourseWare.

Back to Filtering ...

High-pass filter: Remove low frequency components.

Low-pass filter: Remove high frequency components.

Band-pass filter: Remove both low- and high-frequency components, allow frequencies in between.

Band-reject filter or notch filter: Remove only a band of frequencies, allow both higher and lower frequency components to pass. Typically used to remove “line noise” at 60 Hz.



our amplifiers have a “line filter”

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Typical frequencies of interest

0.1 – 200 Hz field potentials (synaptic)

← EEG

There are many “bands” corresponding to natural brain oscillations
e.g. hippocampal theta in rodents is ~7 – 9 Hz.

300 – 3000 Hz action potentials (“single units” “multi-units”)

← roach, rat, fly

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9.17 Systems Neuroscience Lab
Spring 2013

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