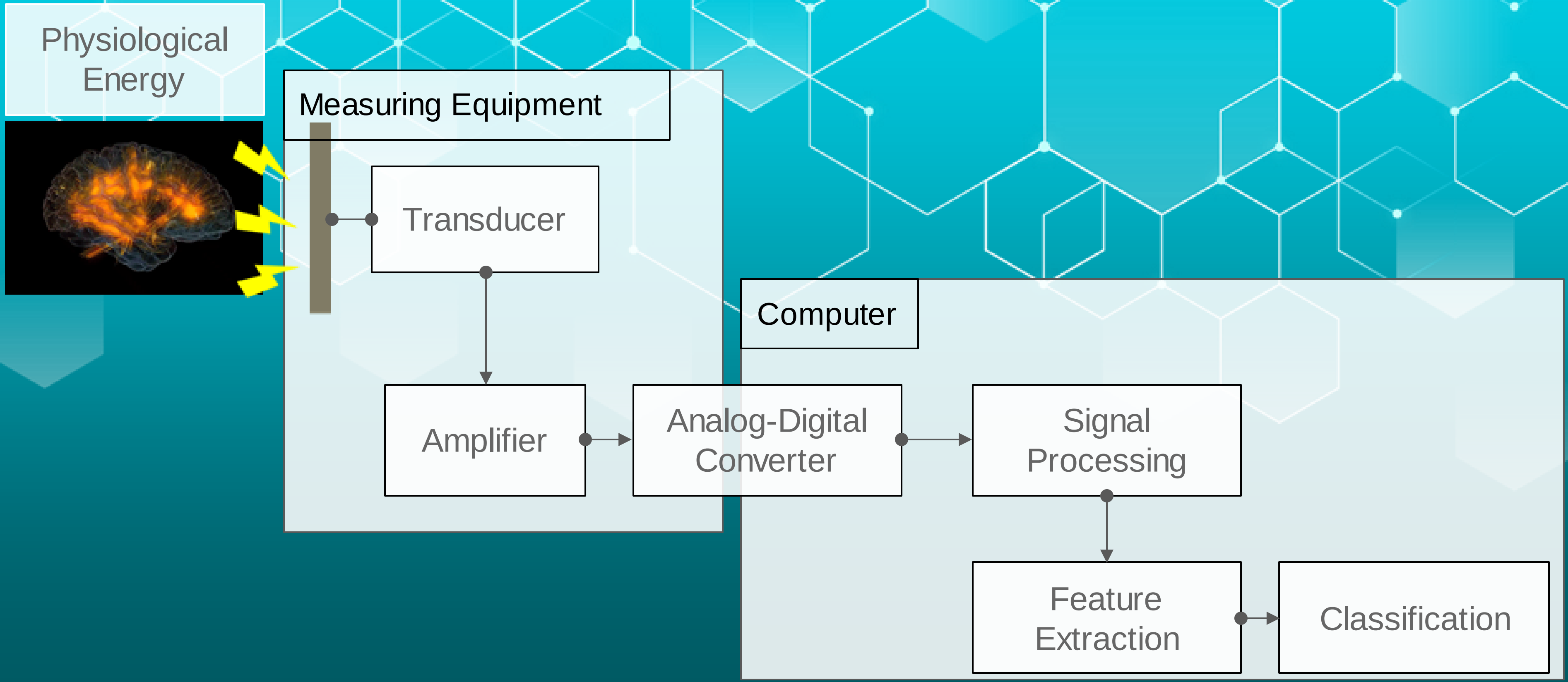
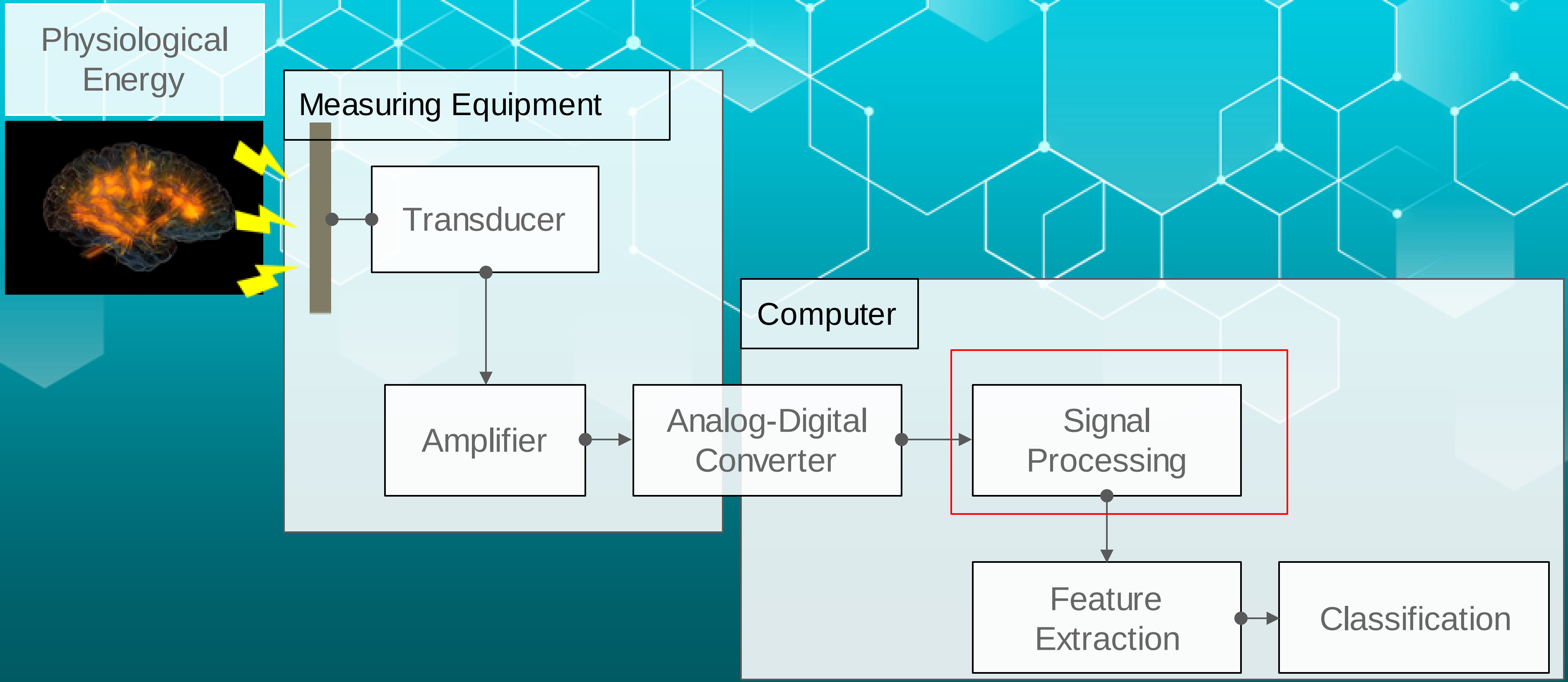
Biosignal Processing

July 28, 2022

Accurate Biosignal Representation Starts with Processing



Accurate Biosignal Representation Starts with Processing



Workshop Objectives

01
Signal Sampling

02
Time and Frequency Domains

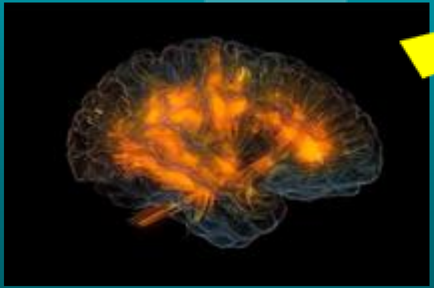
03
Noise

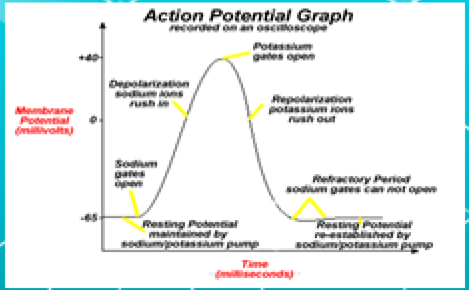
04
Filtering

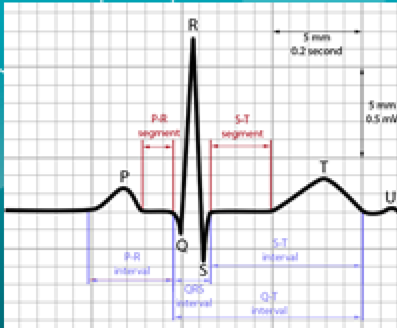
Part 1:
Signal Sampling

Continuous System

Discrete Representation

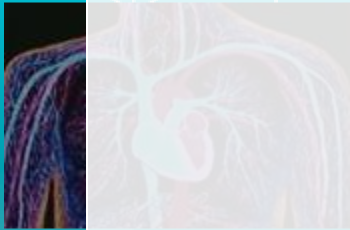


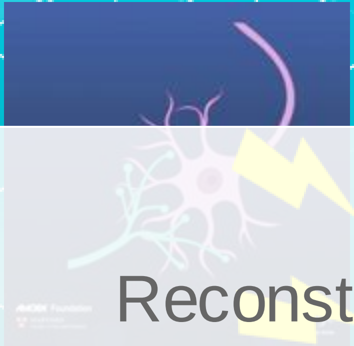


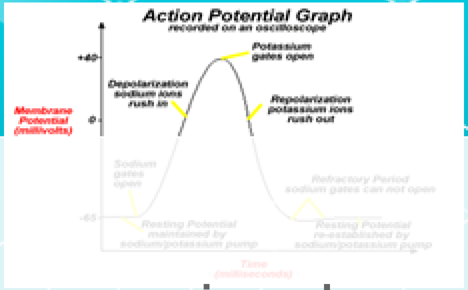


Continuous System

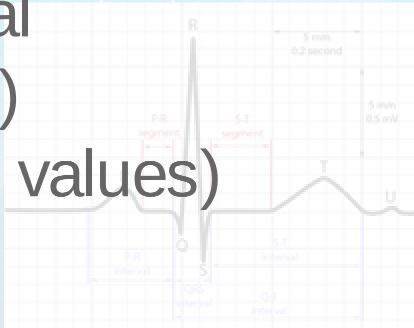
Discrete Representation

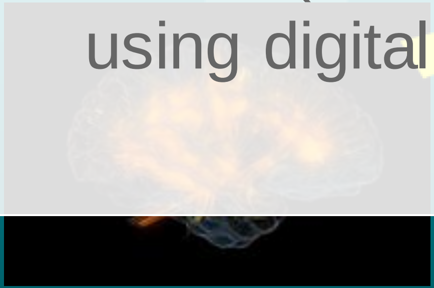




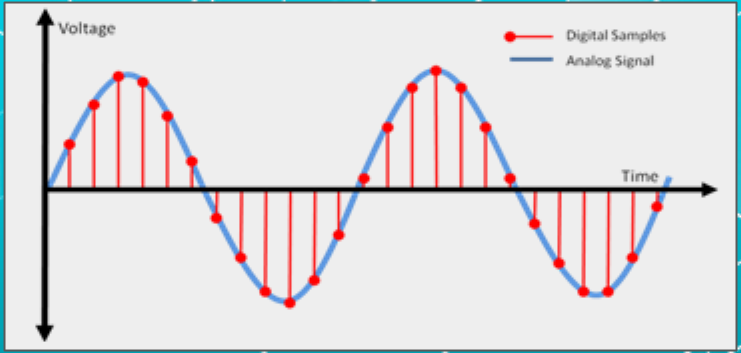


Reconstruct the continuous signal
(with infinite # of possible values)
using digital signals (finite # of possible values)



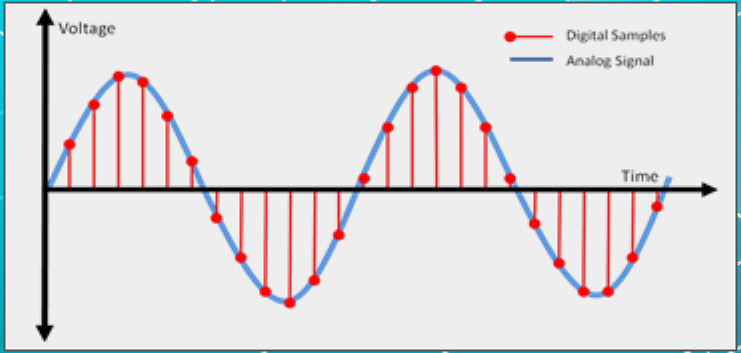


Sampling Rate



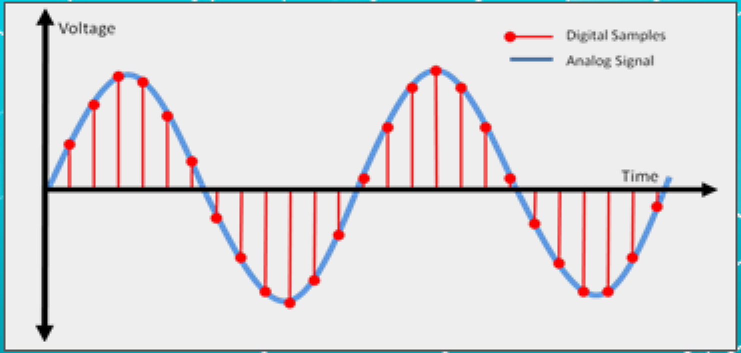
- Sample the continuous signal at discrete time points at a constant rate (sampling frequency)
- Connect the discrete voltage values at the sampled times to reconstruct/represent continuous signal

Sampling Rate



How do we know if our sampling rate accurately represents our measured signal?

Sampling Rate



How do we know if our sampling rate accurately represents our measured signal?

The Nyquist Theorem!

Nyquist Theorem

We must sample a signal at a rate that is at least 2x higher than the highest frequency in the signal

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Let’s practice choosing our sampling frequency!

Nyquist Theorem

We must sample a signal at a rate that is at least 2x higher than the highest frequency in the signal

Example 1: We want to measure a Human ECG signal (heart activity). The clinically defined signal bandwidth is 0.05-100 Hz. What should our sampling frequency be?

Nyquist Theorem

We must sample a signal at a rate that is at least 2x higher than the highest frequency in the signal

Example 2: We want to measure the alpha wave activity in an EEG signal. What is the signal bandwidth? What is the minimum sampling frequency to accurately represent the signal?

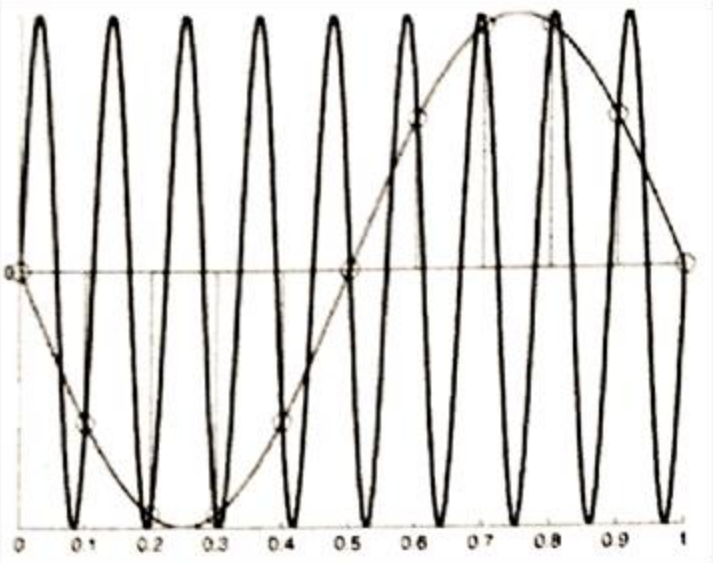
Nyquist Theorem

We must sample a signal at a rate that is at least 2x higher than the highest frequency in the signal

What happens if we sample below the Nyquist frequency?

Aliasing and the Nyquist Theorem

Aliasing!



Practical biomedical signal analysis using Matlab, KJ Blinowska and J Zygierewicz, Boca Raton: CRC Press, 2012

- 9 Hz sinusoid (black) sampled every 0.1 s (10 Hz)
- Sampled signal appears as 1 Hz sinusoid ($Fs – f_0$)

Aliasing and the Nyquist Theorem

Aliasing!

https://www.youtube.com/watch?v=yr3ngmRuGUc

Activity 1: ECG signal and Aliasing

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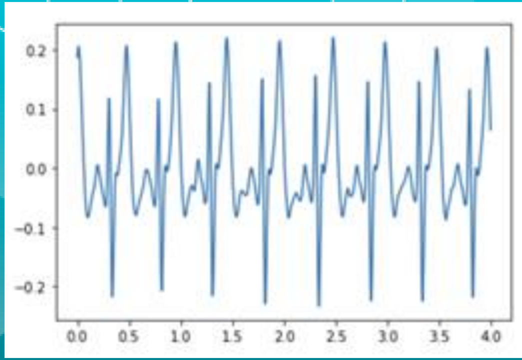
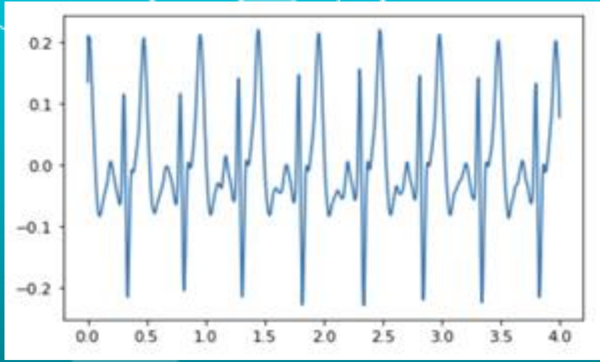
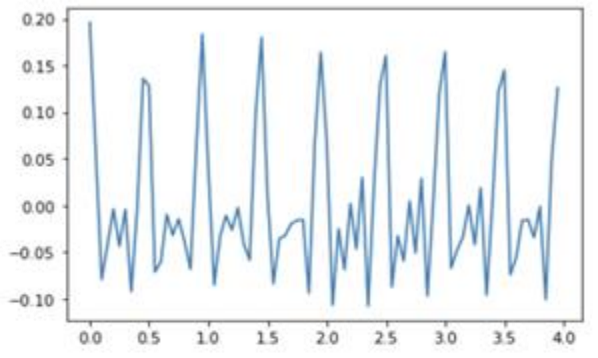
2000 Hz



200 Hz



200 Hz

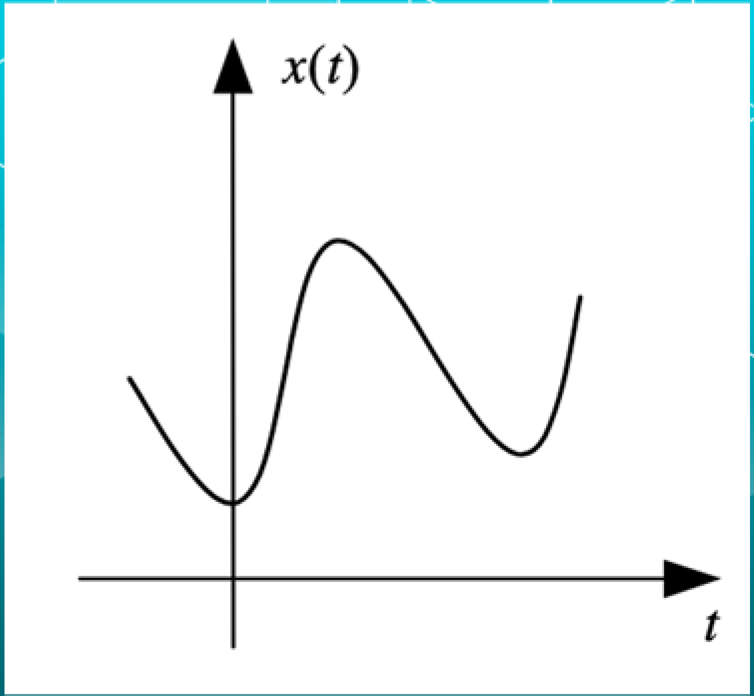


Why not always have a high sampling frequency?

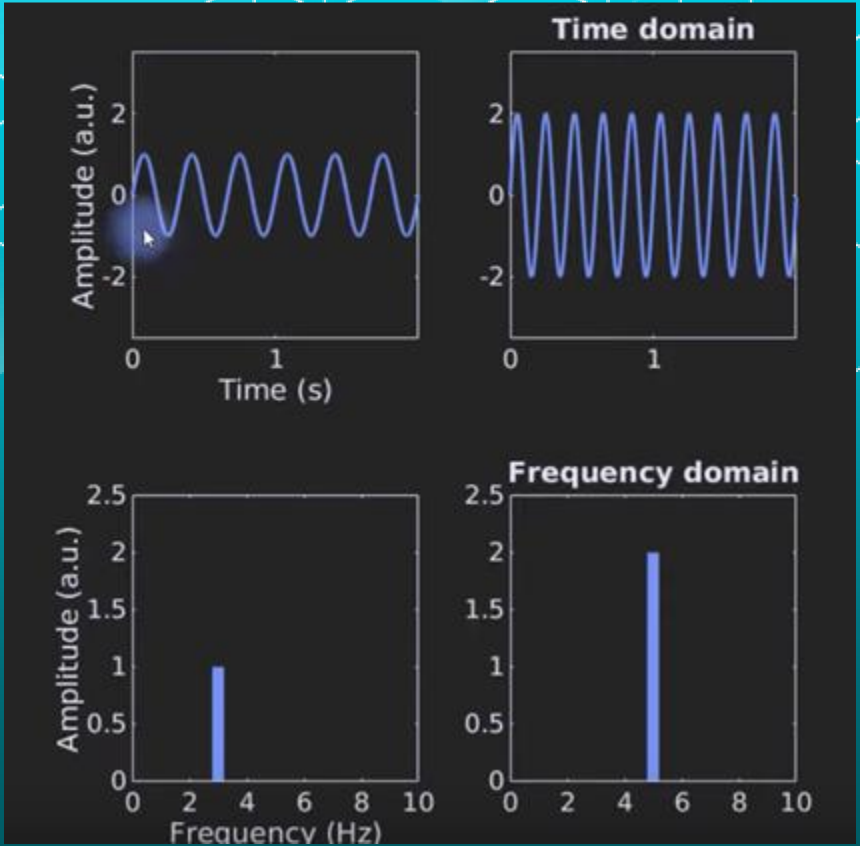
- ✓ Can reconstruct the original signal accurately
- ✗ Have to store a lot of data (Need more storage space)
- ✗ Have to collect & save the data quickly
  (Need high processing power)

Part 2:
Time and Frequency Domain

Time and Frequency Domains



Time and Frequency Domains

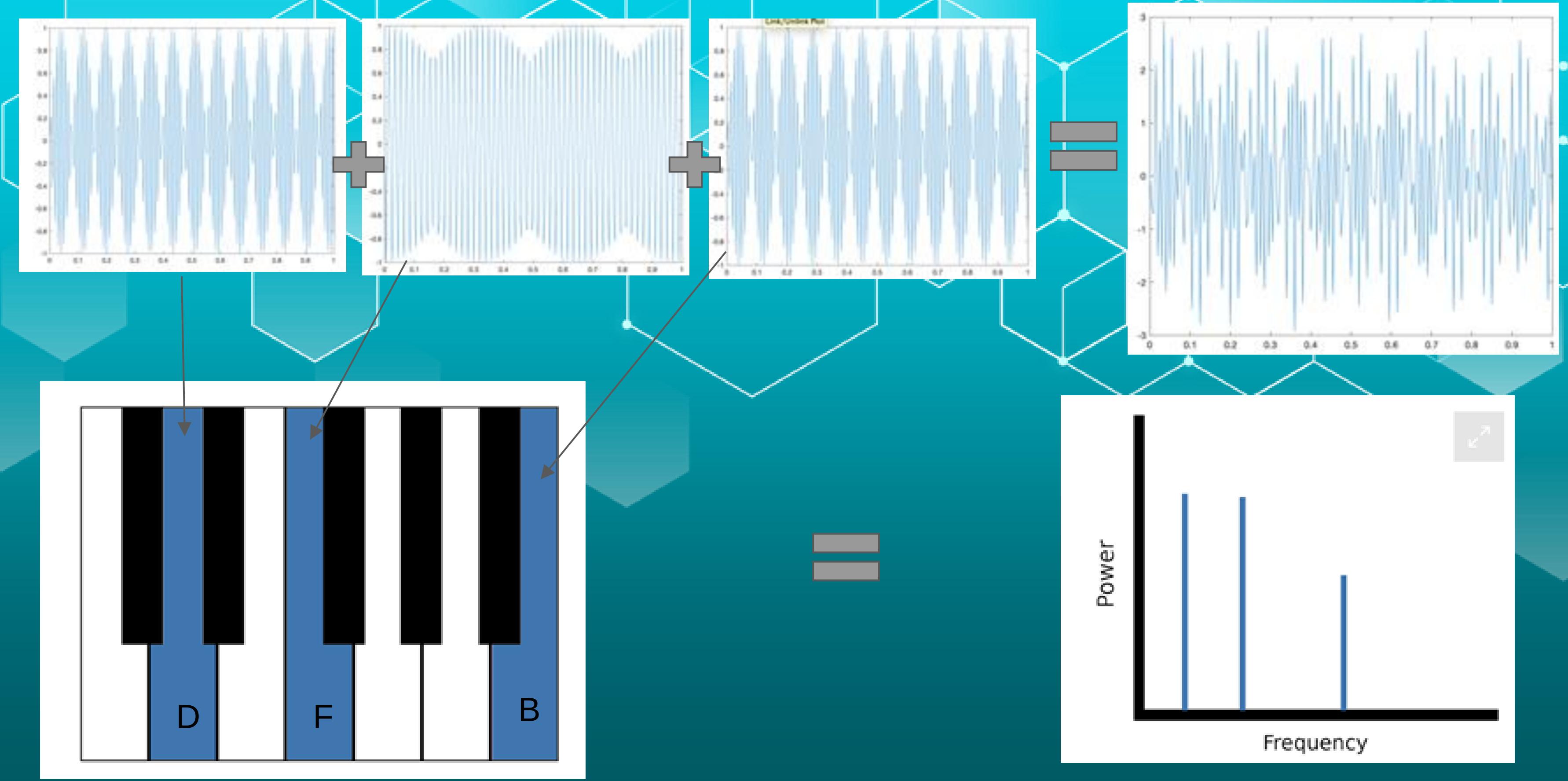


https://www.youtube.com/watch?v=fYtVHhk3xJ0

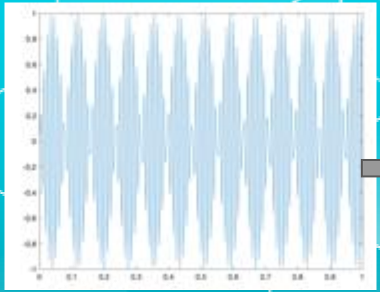
Time and Frequency Domains

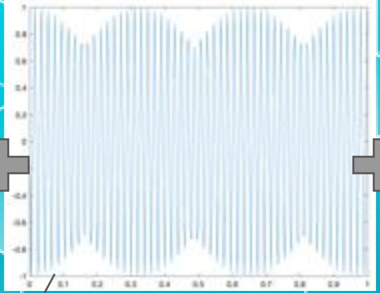
How do we interpret complex signals in the frequency domain?

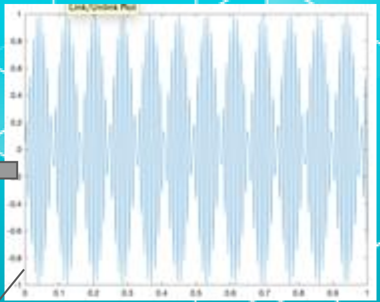
Time vs. Frequency Domain

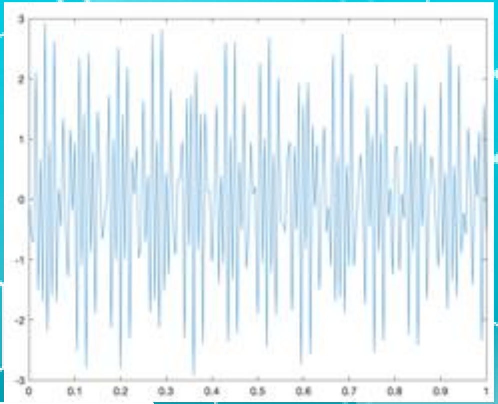


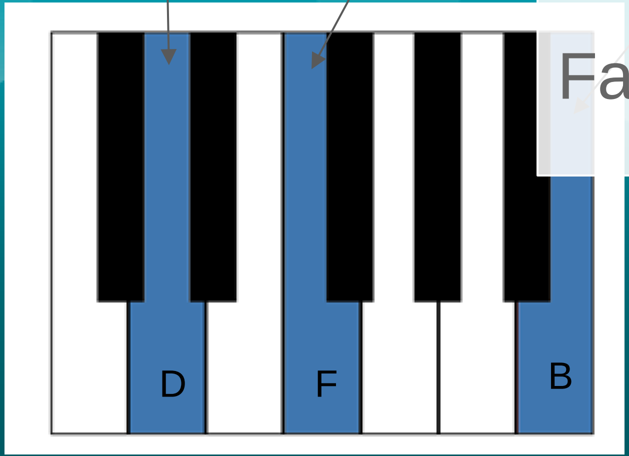
Time vs. Frequency Domain



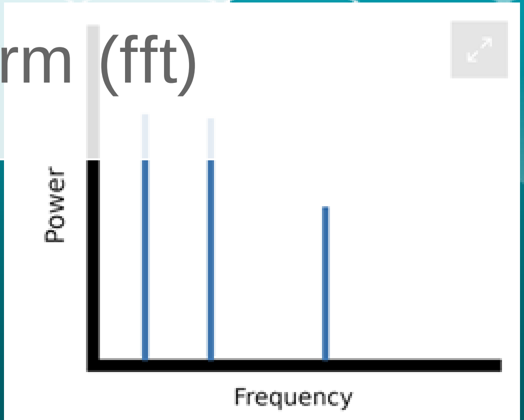








Fast Fourier Transform (fft)



Activity 2: Identify Frequency Components using fft()

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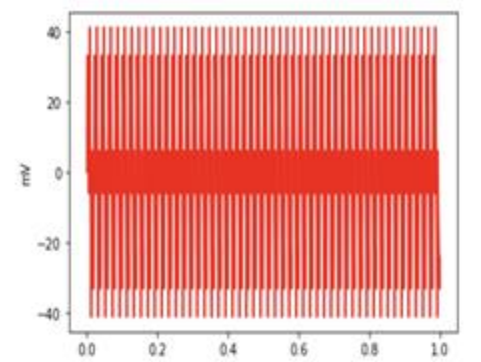
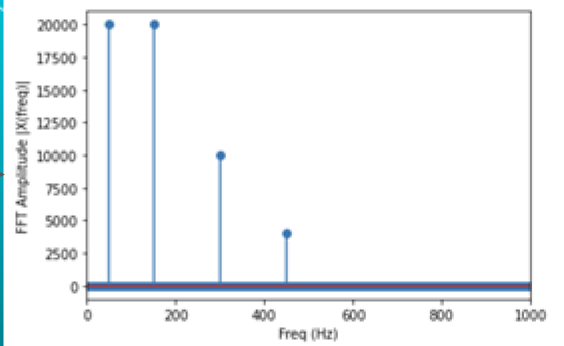
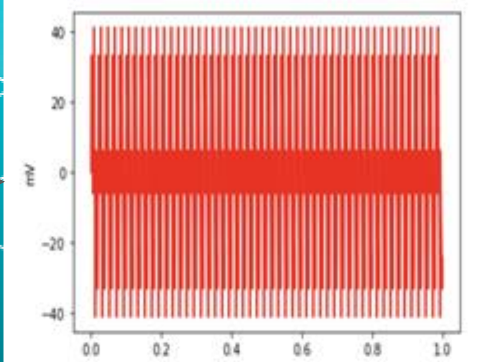
Time Domain



Frequency Domain



Time Domain



Aliasing in the Frequency Domain?

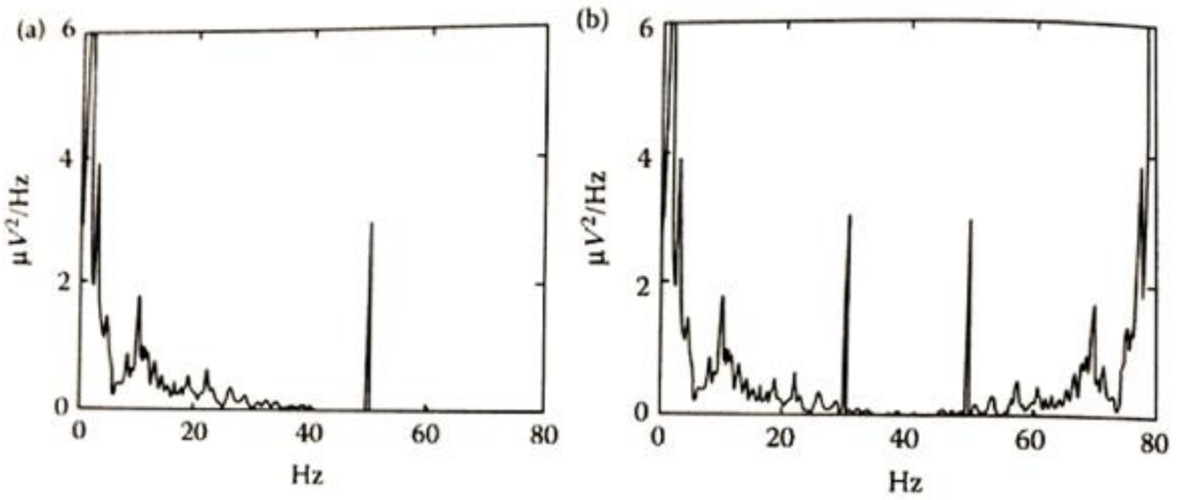
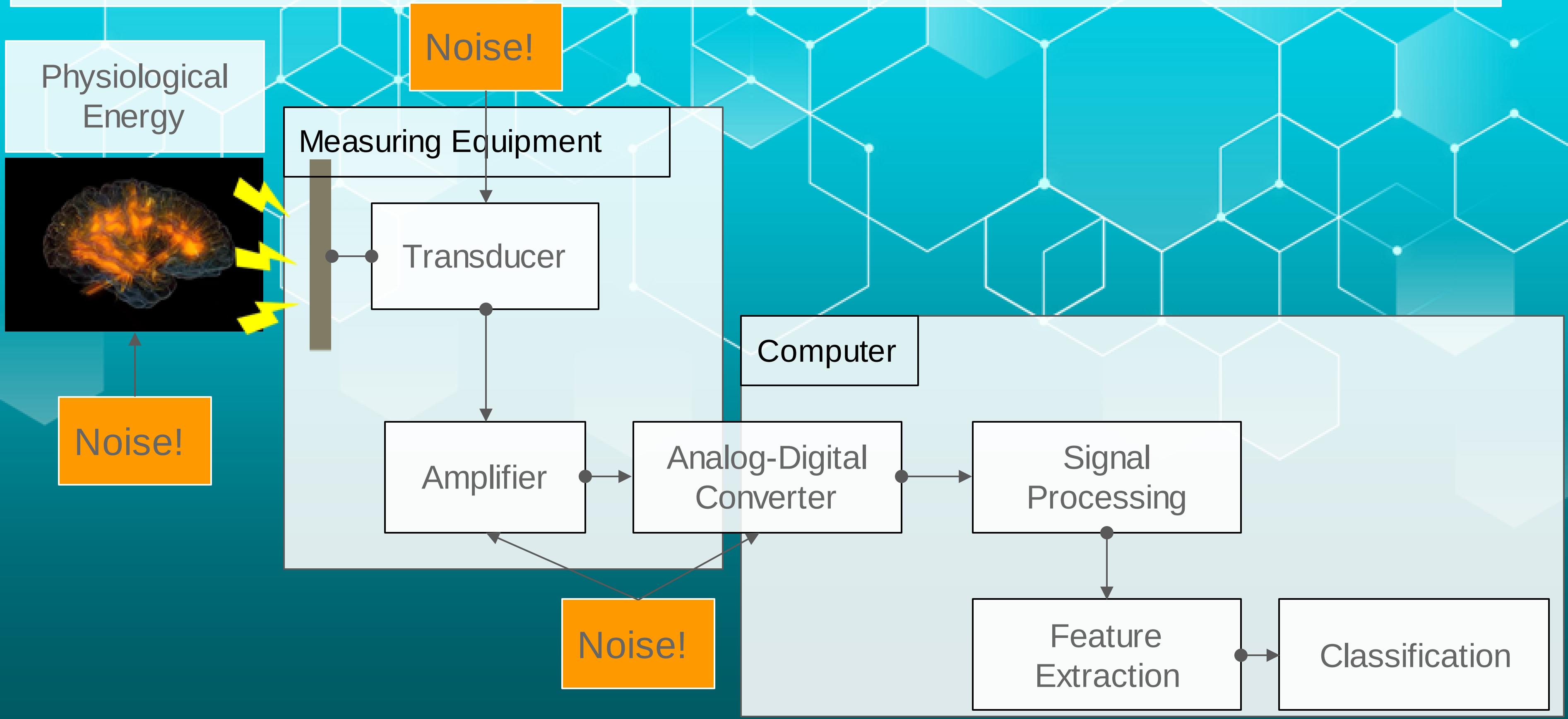


FIGURE 1.3 Power spectrum of an EEG signal (originally bandlimited up to 40 Hz). The presence of 50 Hz mains noise (a) causes aliasing error in the 30 Hz component (i.e., in the b diagnostic band) in the sampled signal (b) if $f_s = 80$ Hz.

Biosignal processing : principles and practices Eds. H. Liang, J.D. Bronzino, D.R. Peterson. Boca Raton : CRC Press, 2013

Part 3:
Noise

Noise affects all parts of acquisition



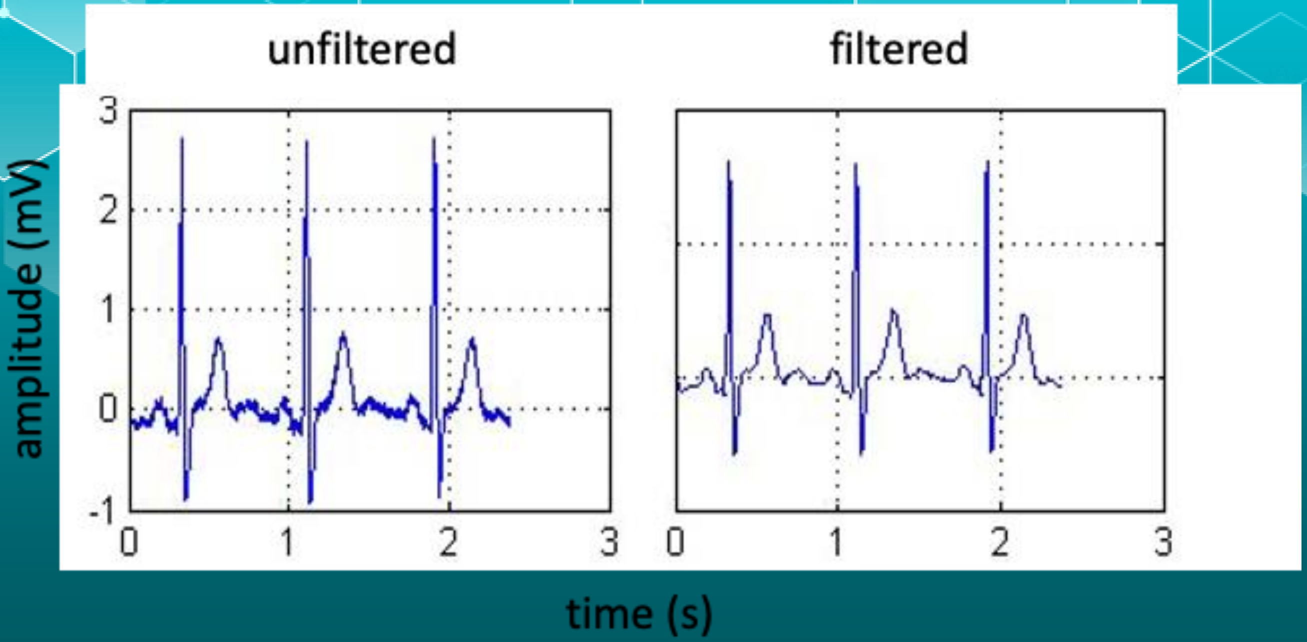
Sources of Noise

Measurement noise from:

- Electrodes
  - Movement, coupling to skin changes
  - Thermal noise àcaused by thermal agitation of electrons in a conductor
- Electronic components in the measurement circuit
  - Amplifiers, resistors, *etc* each contribute some noise to the signal
- Electrical sources in the surrounding environment
  - *e.g.* 60 Hz AC noise from power lines, fluorescent lights

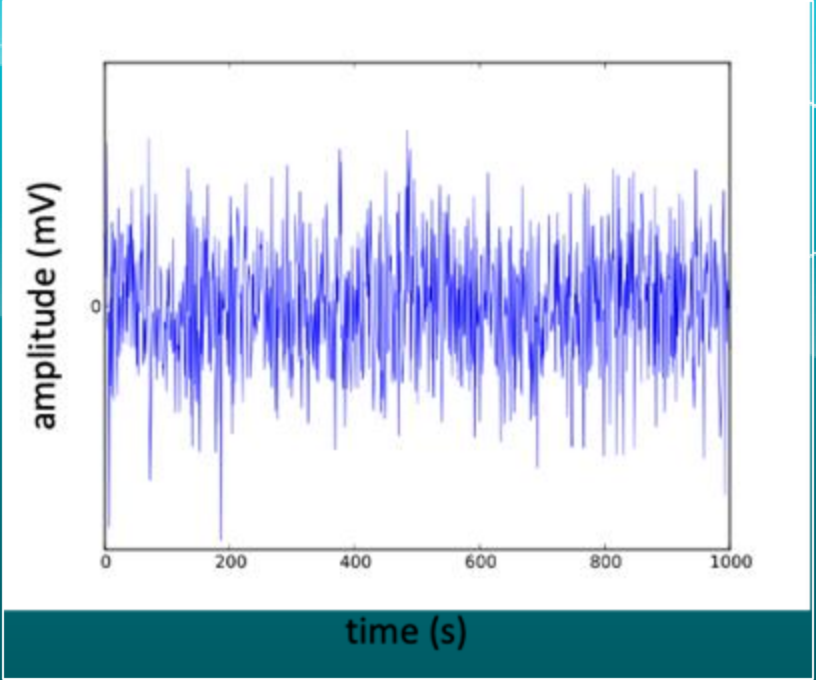
Sources of Noise

60Hz noise (Mains Hum)



Sources of Noise

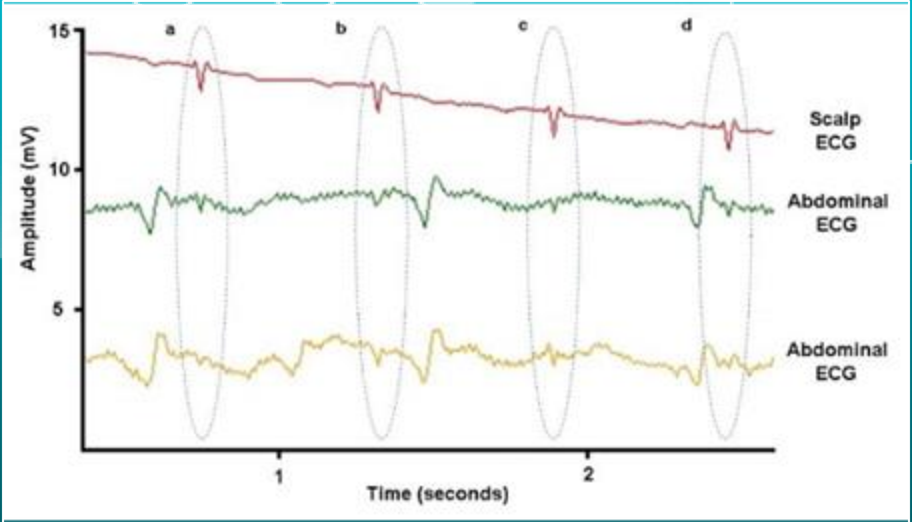
White noise



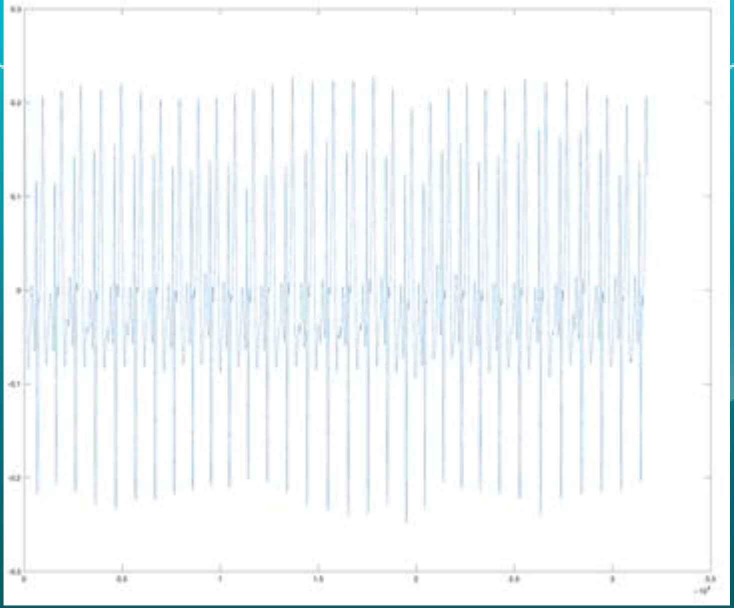
Sources of Noise

Physiological Noise

e.g. heart rate or respiration in MRI

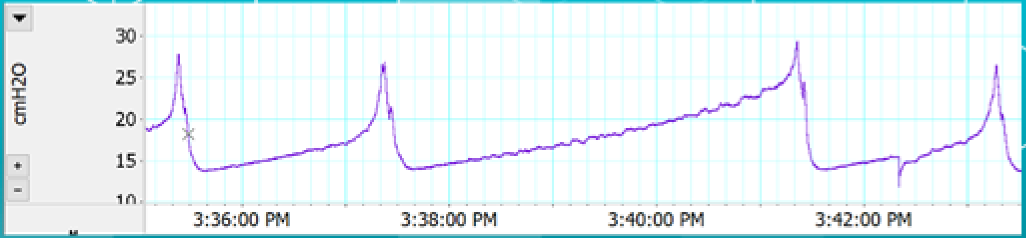


Sameni, et al. A Review of Fetal ECG Signal Processing; Issues and Promising Directions, 2010

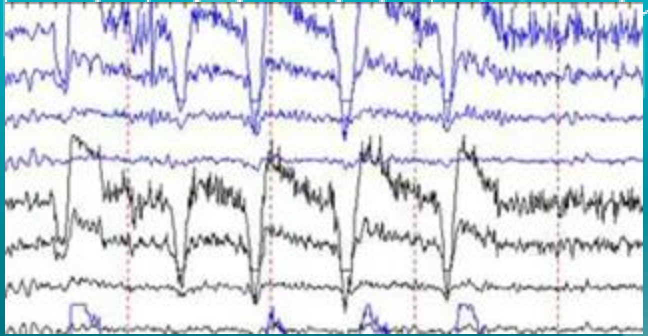


Sources of Noise

Motion Artifact



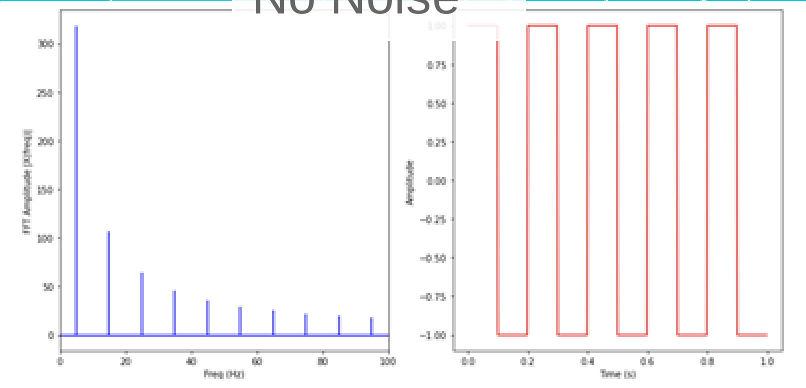
Franz, Karly S., CMG Data in Rat



Activity 3: How does noise affect our signal in time and frequency domains?

“Respiration” (Physiological) noise

No Noise



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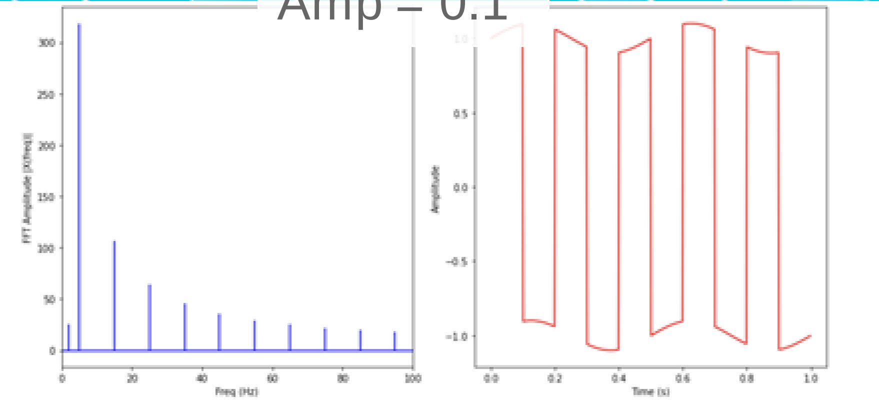

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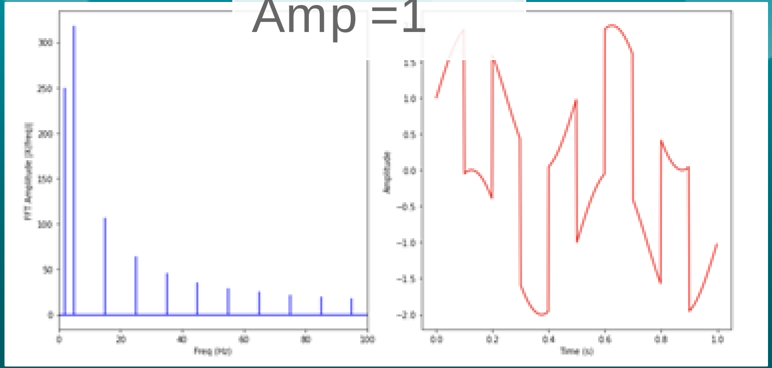

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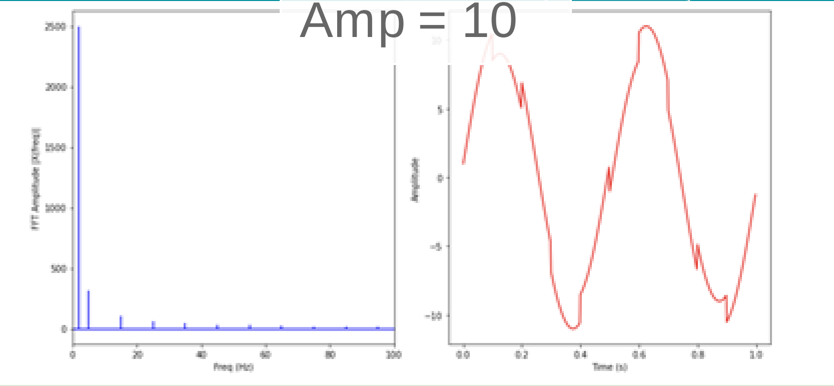
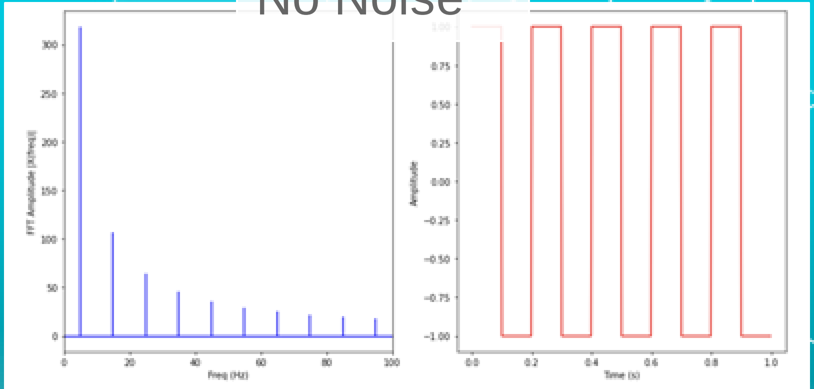


Mains Hum

No Noise



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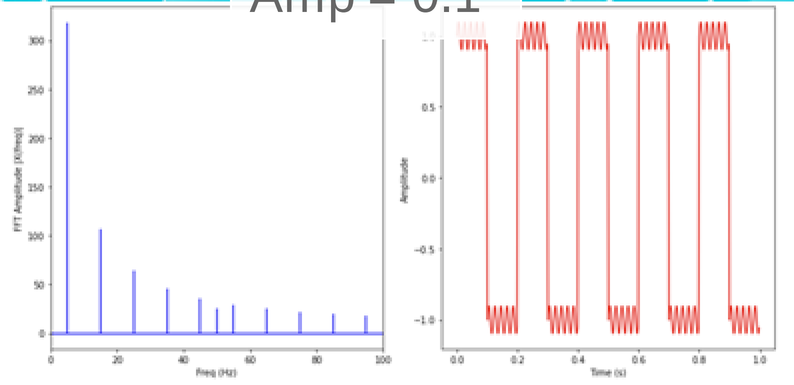

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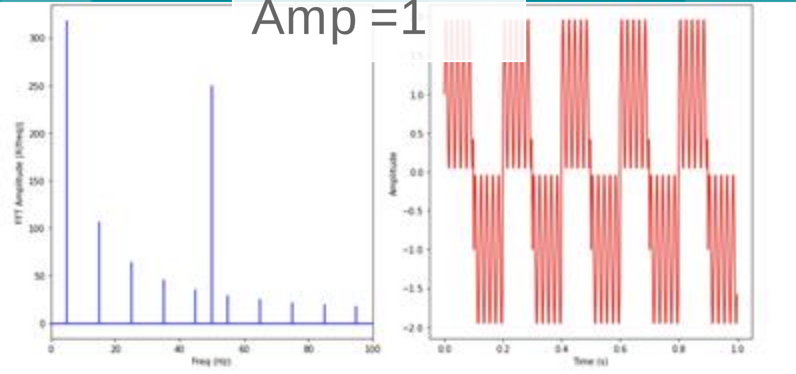

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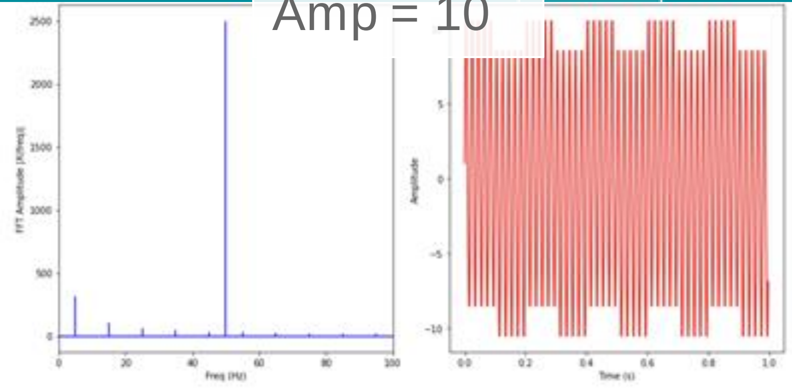
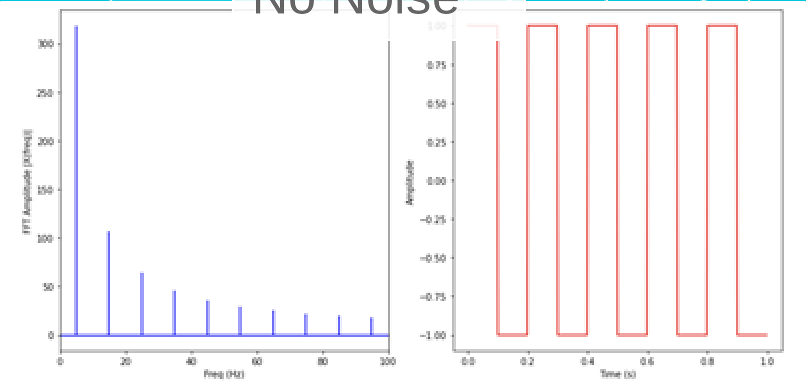


White Noise

No Noise



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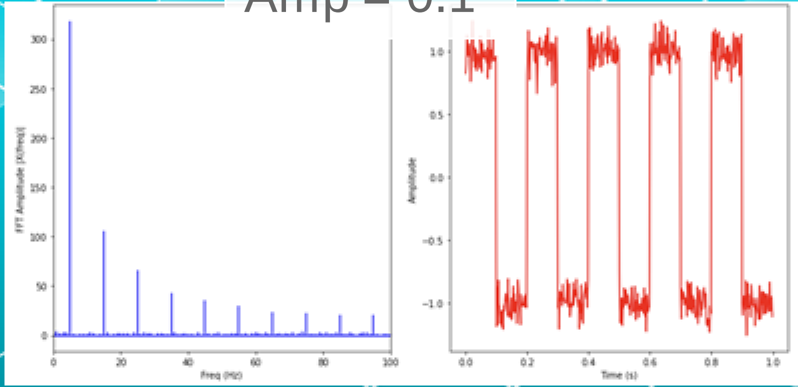

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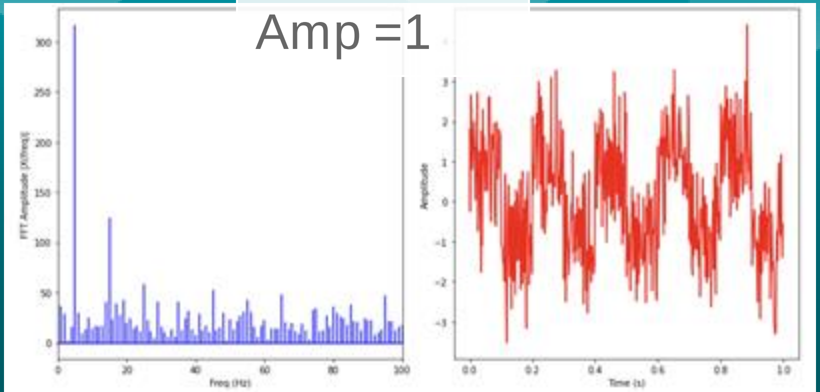

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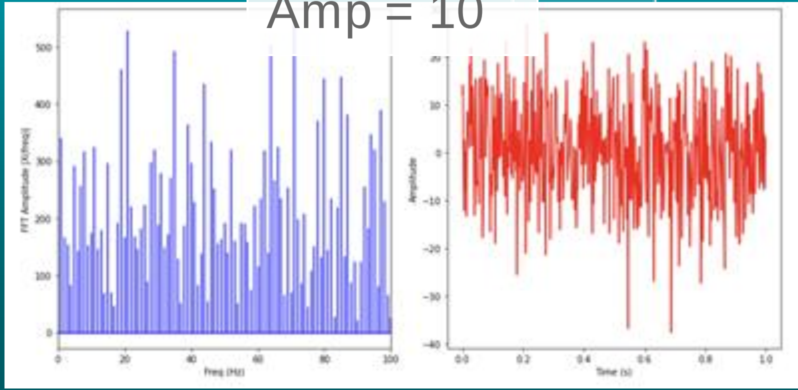
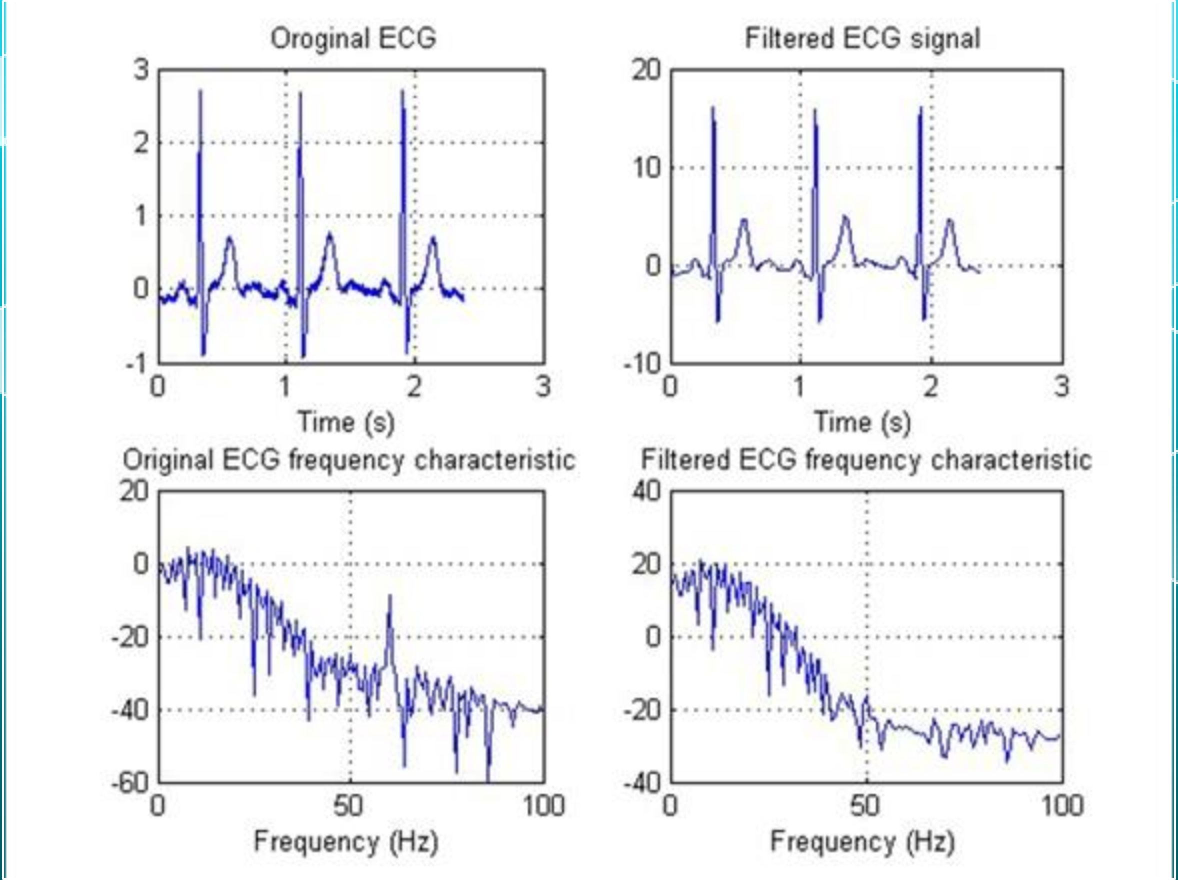


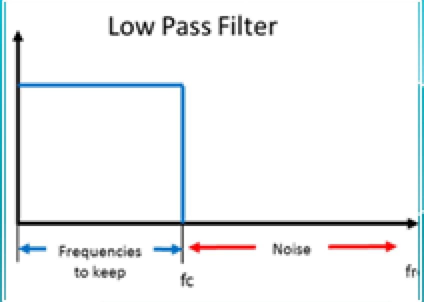
Part 4: Filtering

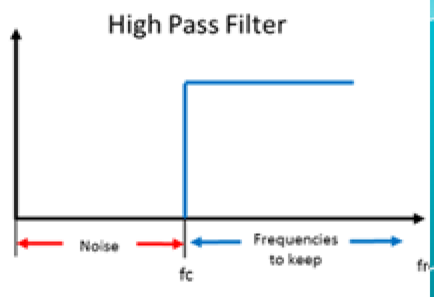
Noise can easily be identified in the frequency domain

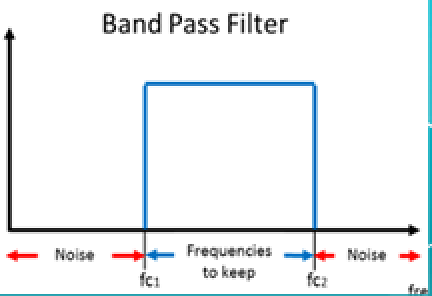


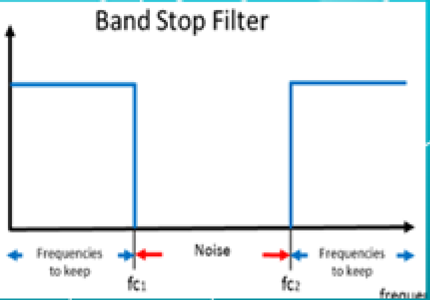
How can we remove noise?

Digital Filters can be used to eliminate noise

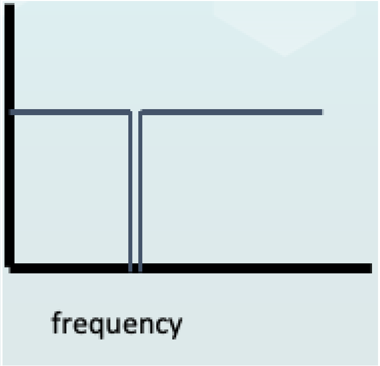






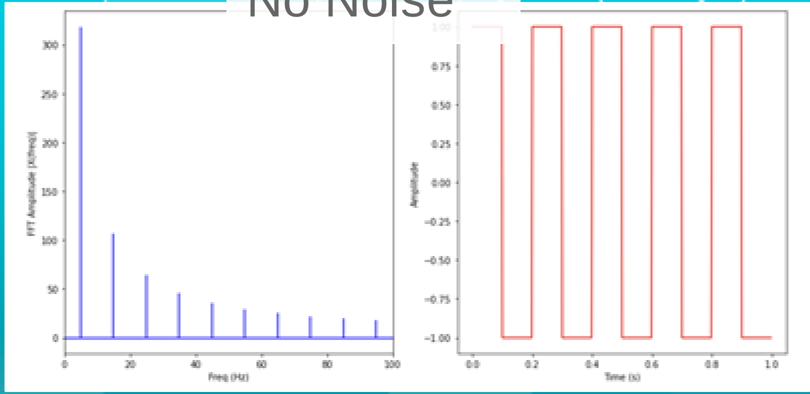


Notch filter….



Example: “Respiration” (Physiological) noise

No Noise



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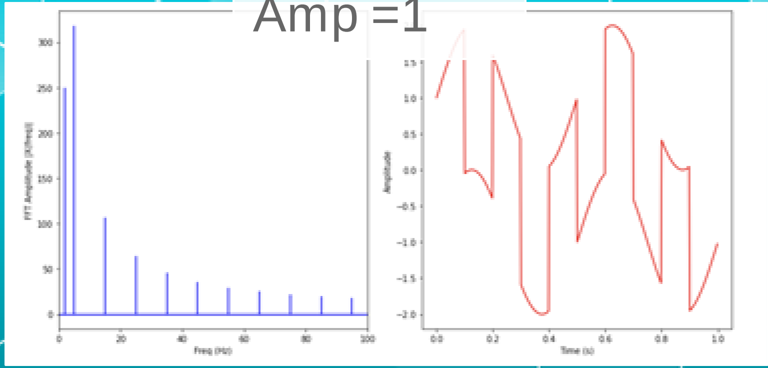
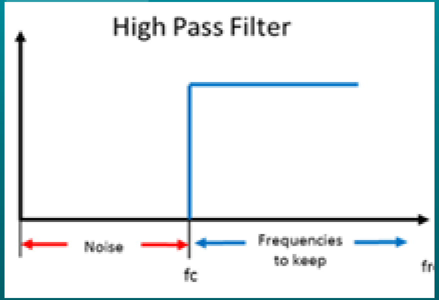
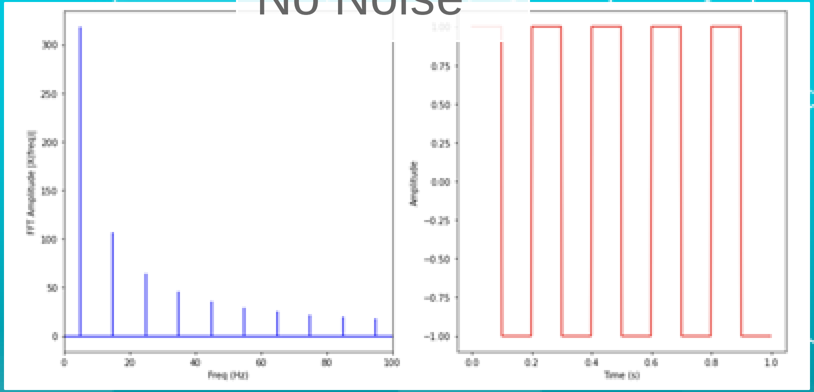




Example: Mains Hum

No Noise



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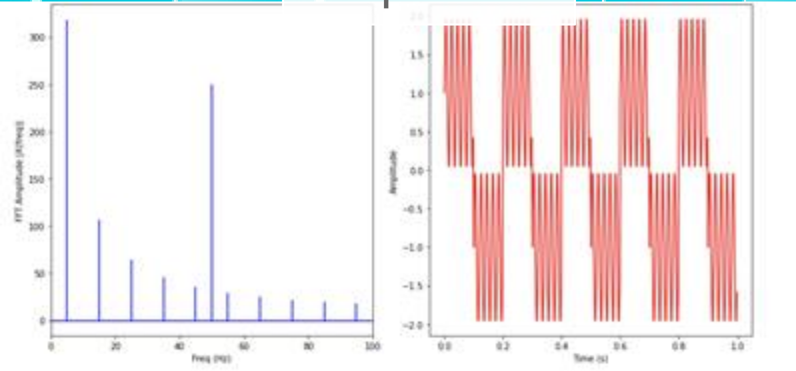
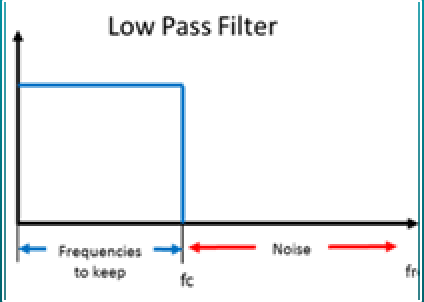
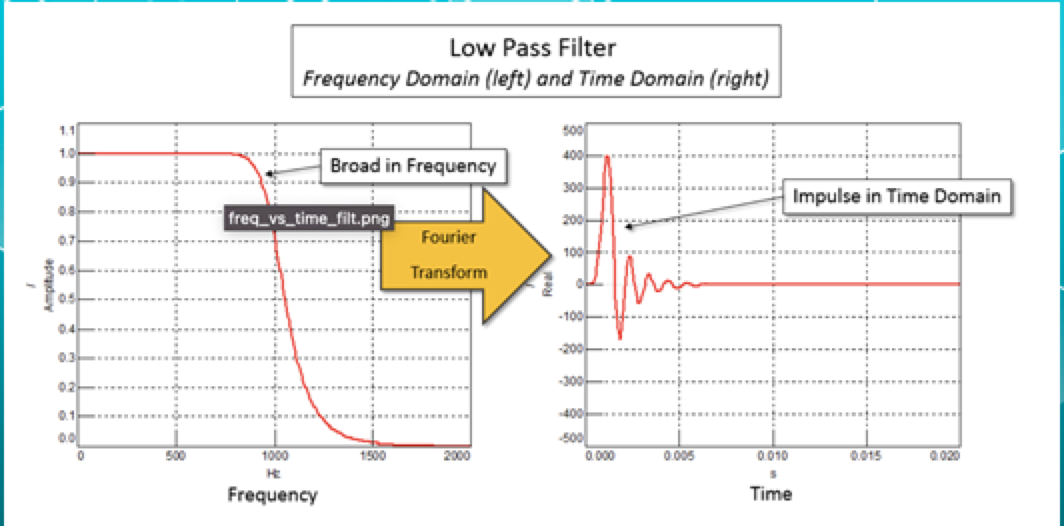




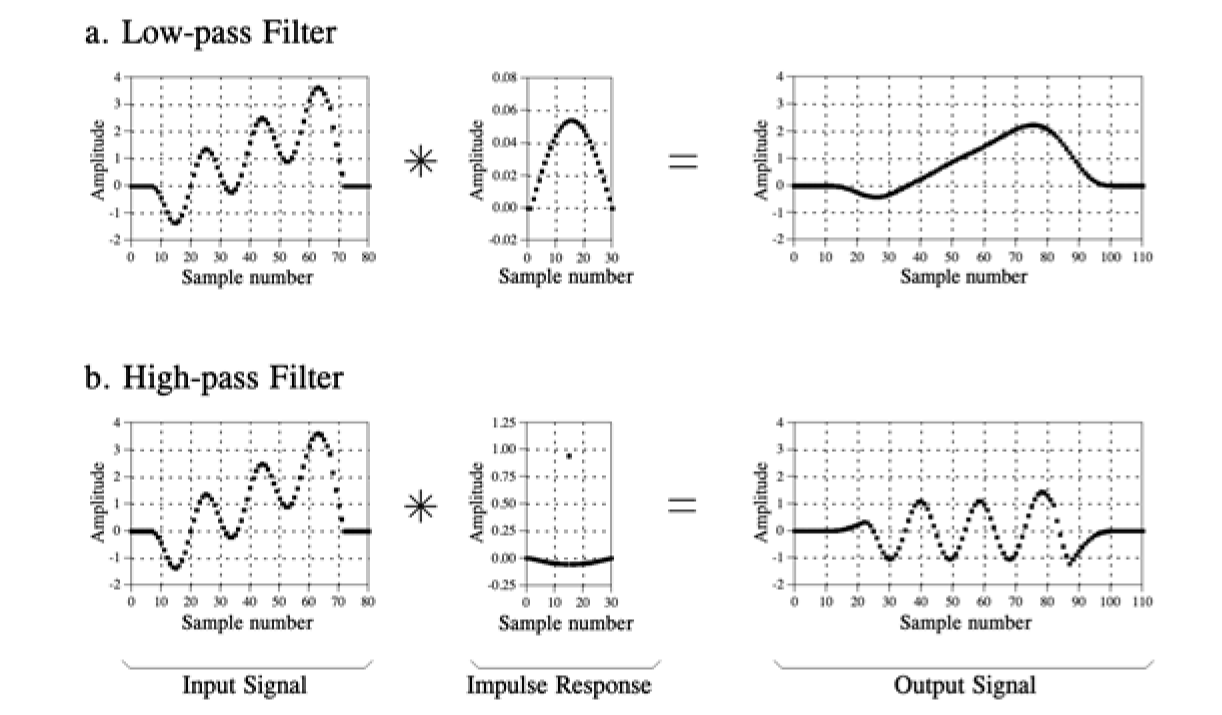
How do Filters work?

Impulse response is the filter response in the time domain



How do Filters work?

Convolution



How do Filters work?

FIR and IIR filters

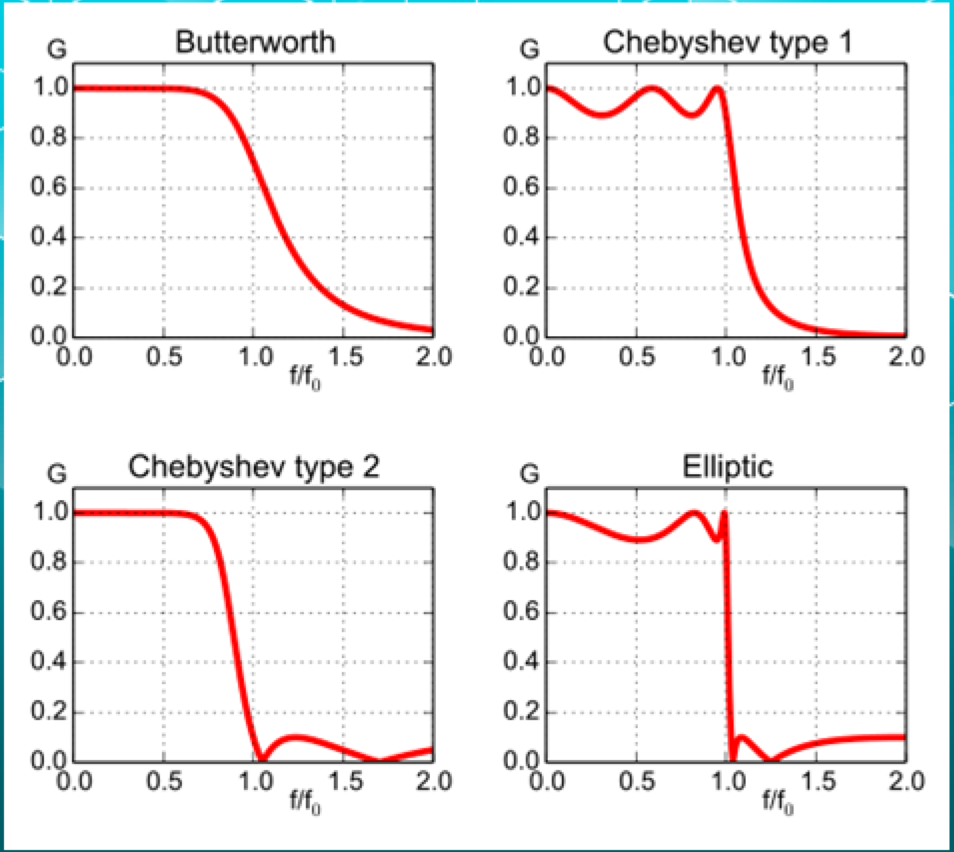
FIR Filter Equation: $y(n) = \sum_{k=0}^{N} a(k)x(n-k)$

IIR Filter Equation: $y(n) = \sum_{k=0}^{N} a(k)x(n-k) + \sum_{j=0}^{P} b(j)\underbrace{y(n-j)}_{\text{Output used recursively}}$

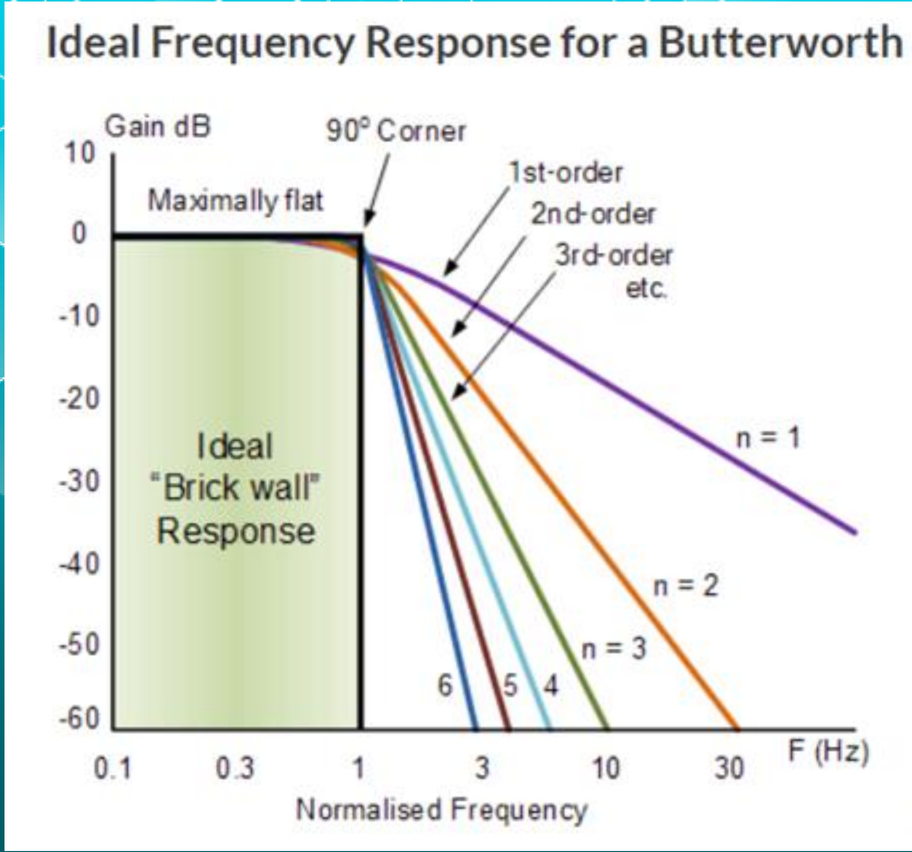
	IIR	FIR
Computational Speed	Fast – Low Order	Slow – High Order
Phase / Delay	Not constant	Constant
Stability	Sometimes	Always

https://community.sw.siemens.com/s/article/introduction-to-filters-fir-versus-iir

Filter Design Considerations: Filter Types



Filter Design Considerations: Filter Order



Activity 4: Let’s build filters and apply them!

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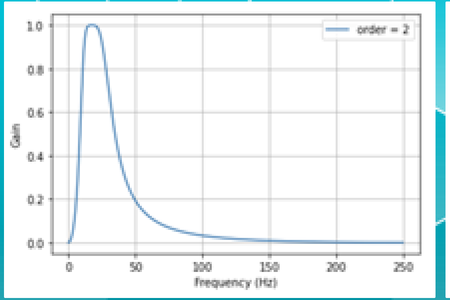
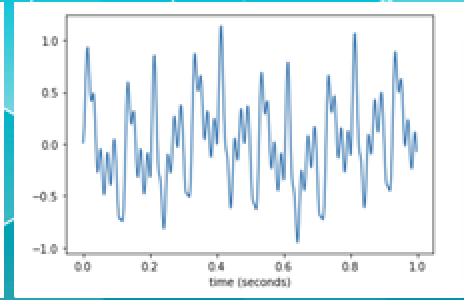
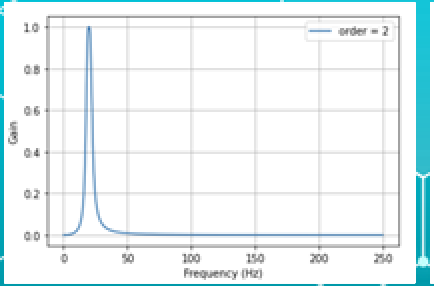
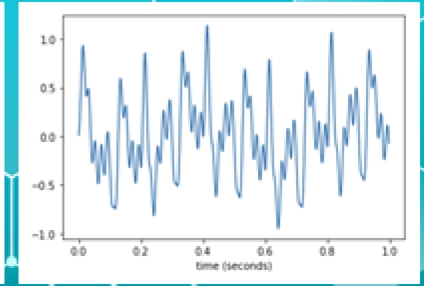
Fc1 = 10 Hz; fc2 = 30 Hz; order = 2





Fc1 = 18 Hz; fc2 = 22 Hz; order = 2





Fc1 = 18 Hz; fc2 = 22 Hz; order = 6