Analog Processing of Signals

Suresh Devasahayam
Department of Bioengineering
Christian Medical College, Vellore

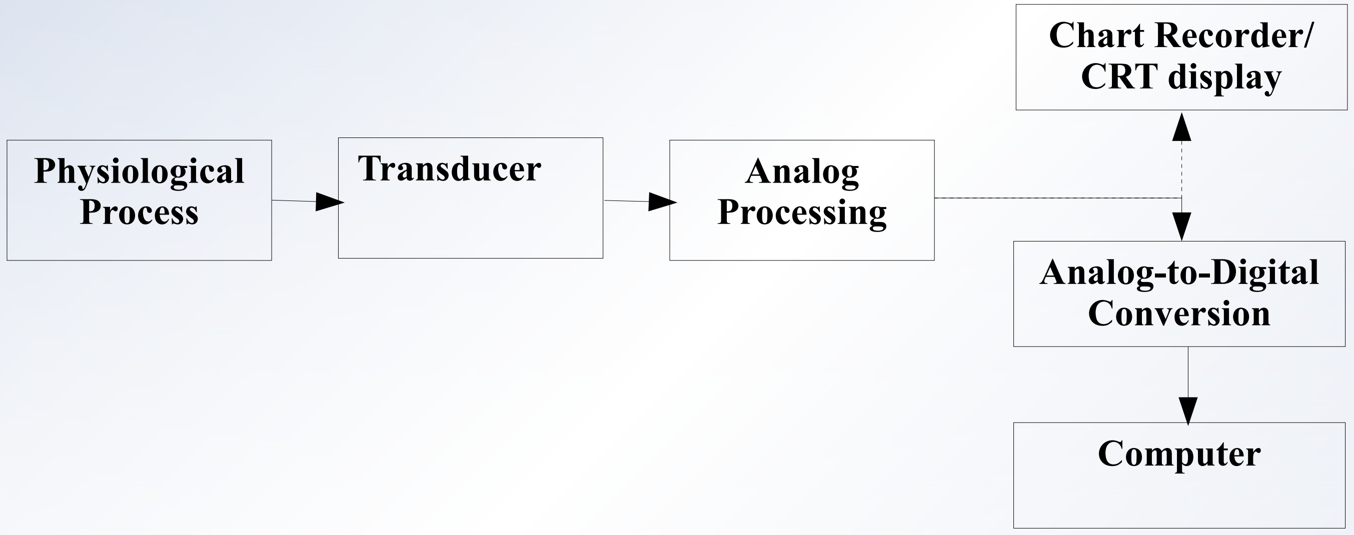
Outline

- Sensors for physiological data
- Amplification, linearity, offset
- Concepts of Filtering
- Frequency filtering
- Frequency content of signals
- Conclusions

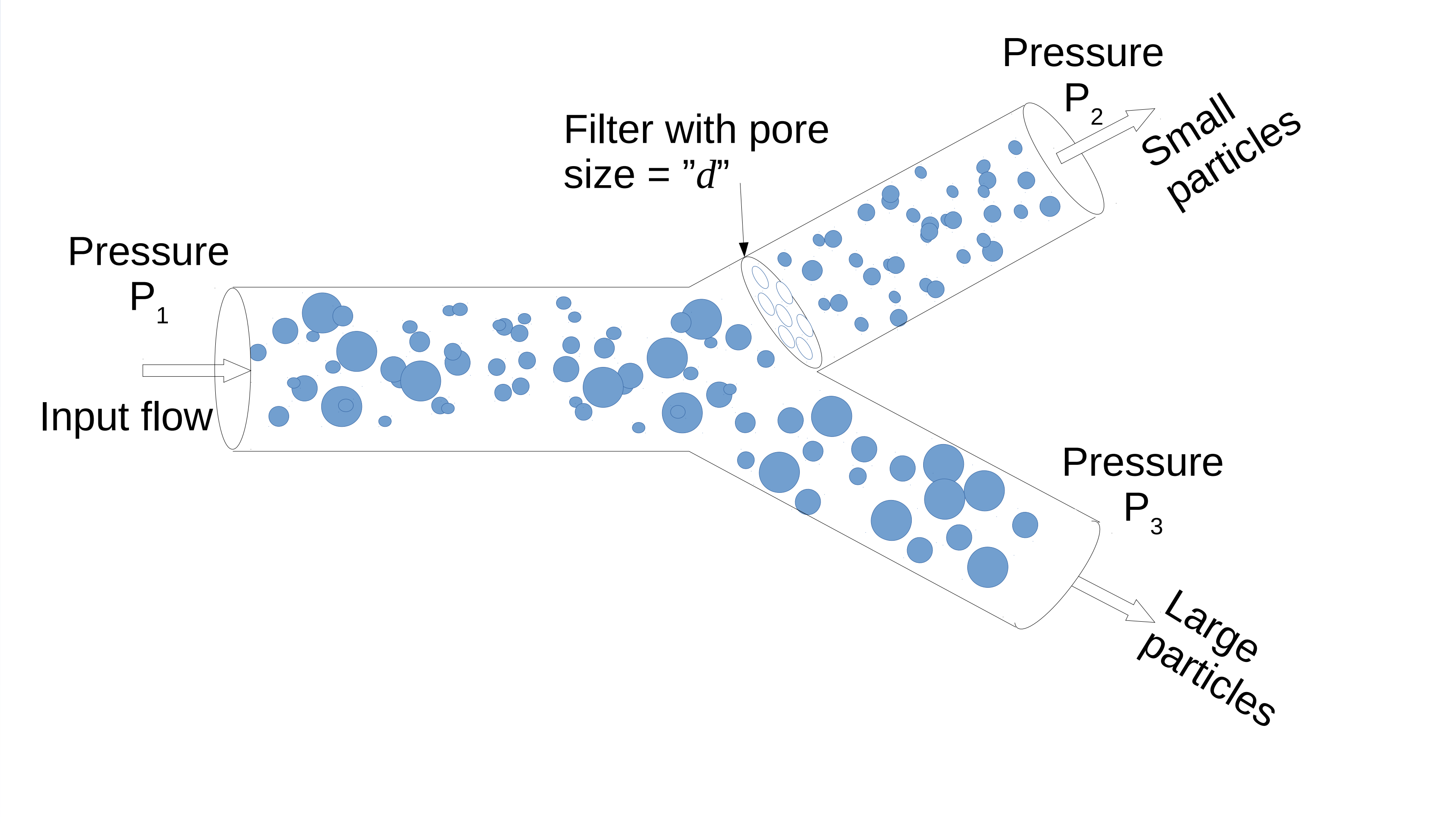
Transducers for Physiological Signals

- Mechanical measurement
  - Strain gauges and bridge measurement
  - Piezoelectric sensors
  - Electromagnetic sensors
- Electrophysiological measurement
  - Biopotential electrodes
- Displacement or length measurement
  - Camera based measurement
  - Resistive, capacitive, inductive sensors
- Optical measurement
  - Spectral measurement - spectrophotometry
- Actuators
  - Electromagnetic actuators
  - Piezoelectric actuators

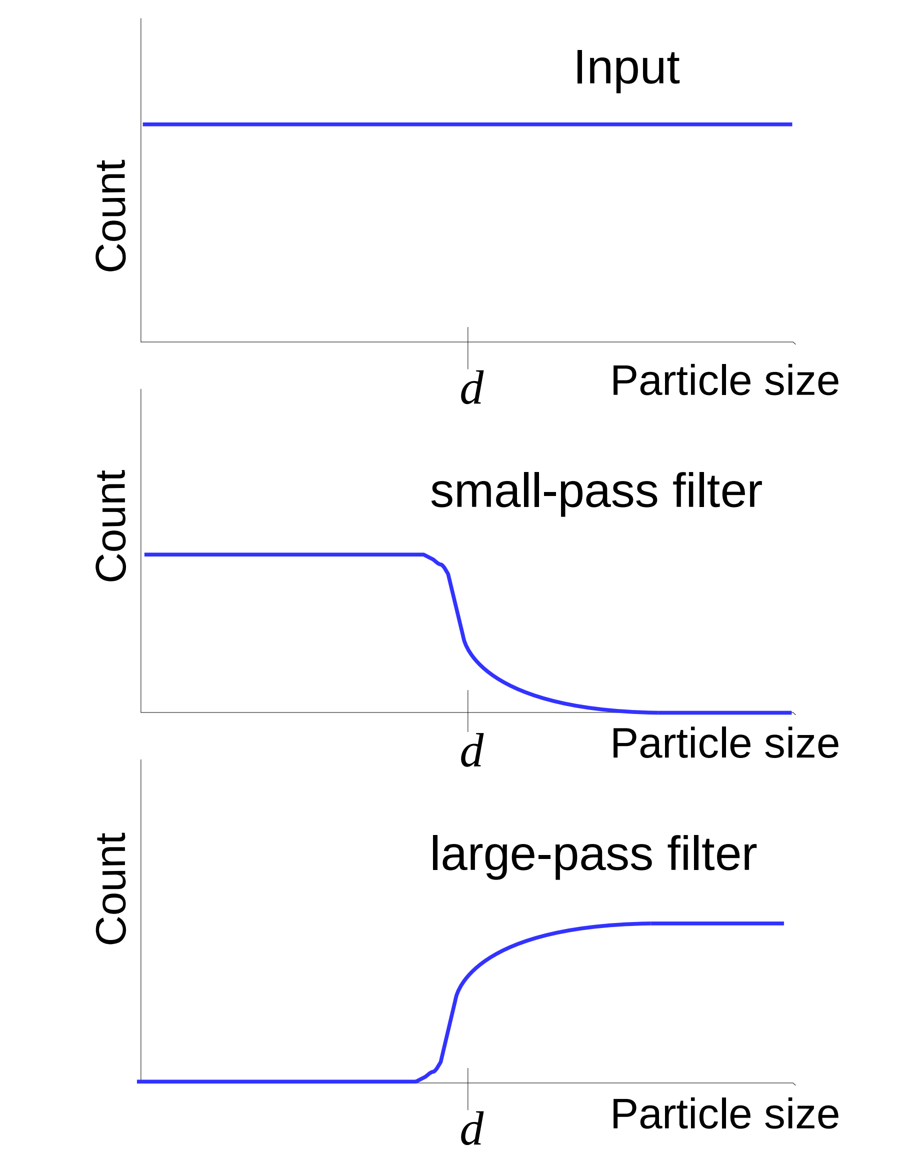
Measurement System - I



Particle Filtering by Size

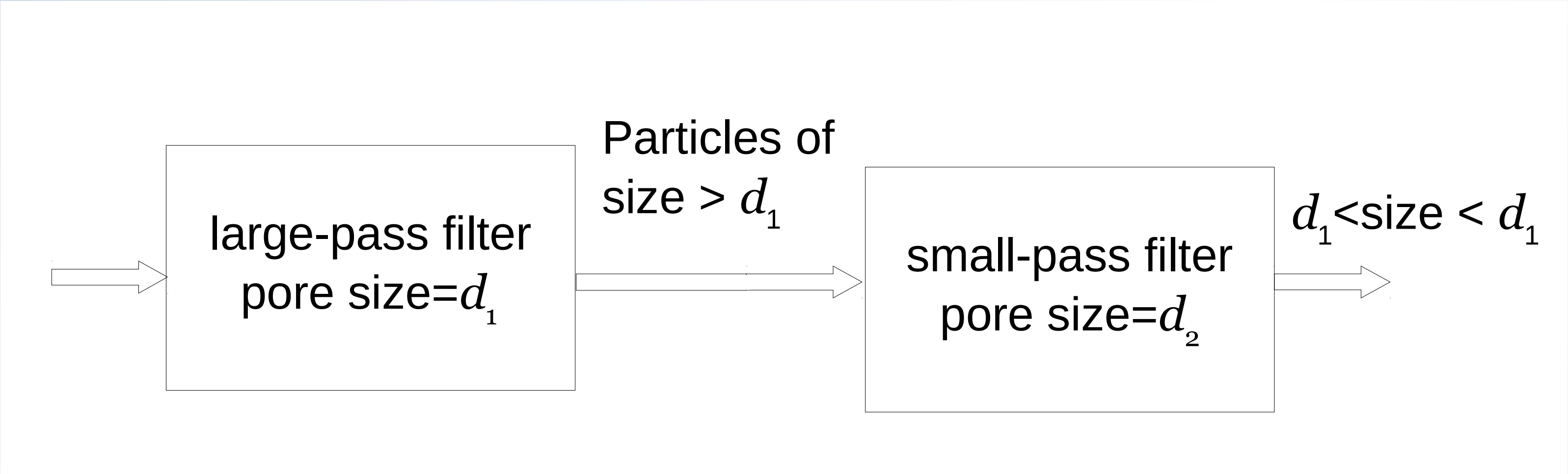


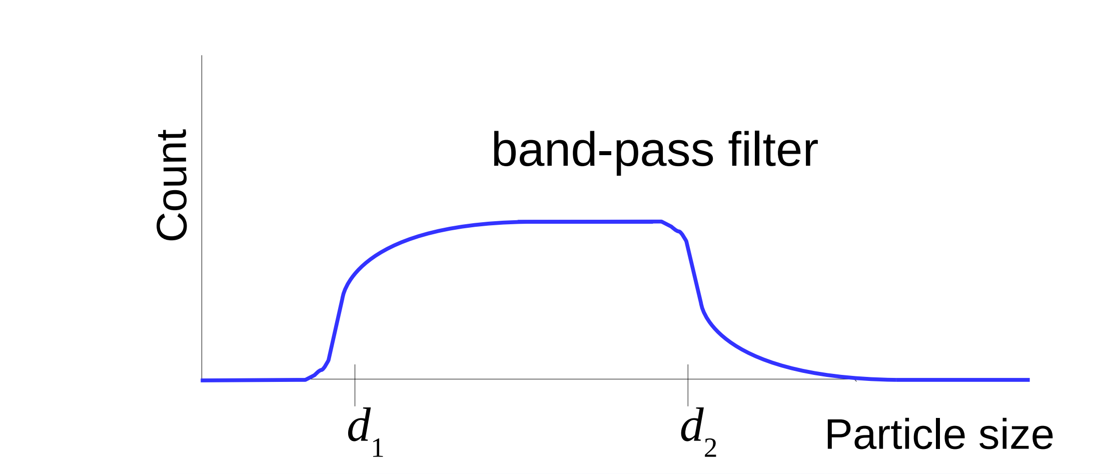
Filtered Particle Size Distribution



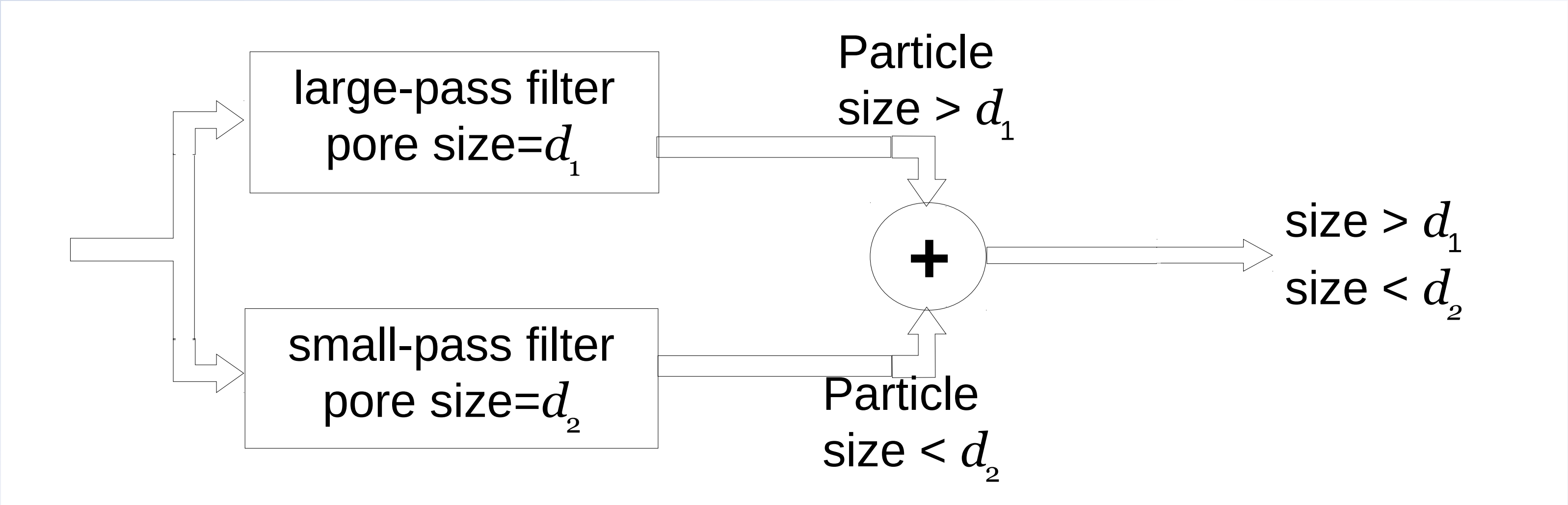
- Driving forces:
  P_1-P_2, and P_1-P_3
- Separation is not perfect, some small particles miss the filter
- Quality of filtering depends on filter pore size accuracy and driving forces
- Filter is described by:
  - Pore size (size threshold)
  - Small-pass or Large-pass

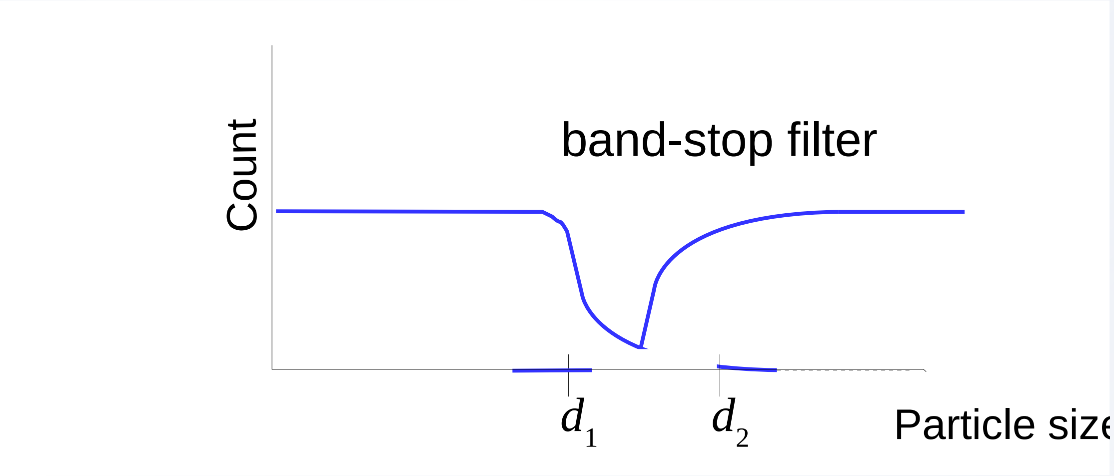
Combination of filters I – cascading filters





Combination of filters II – adding filters





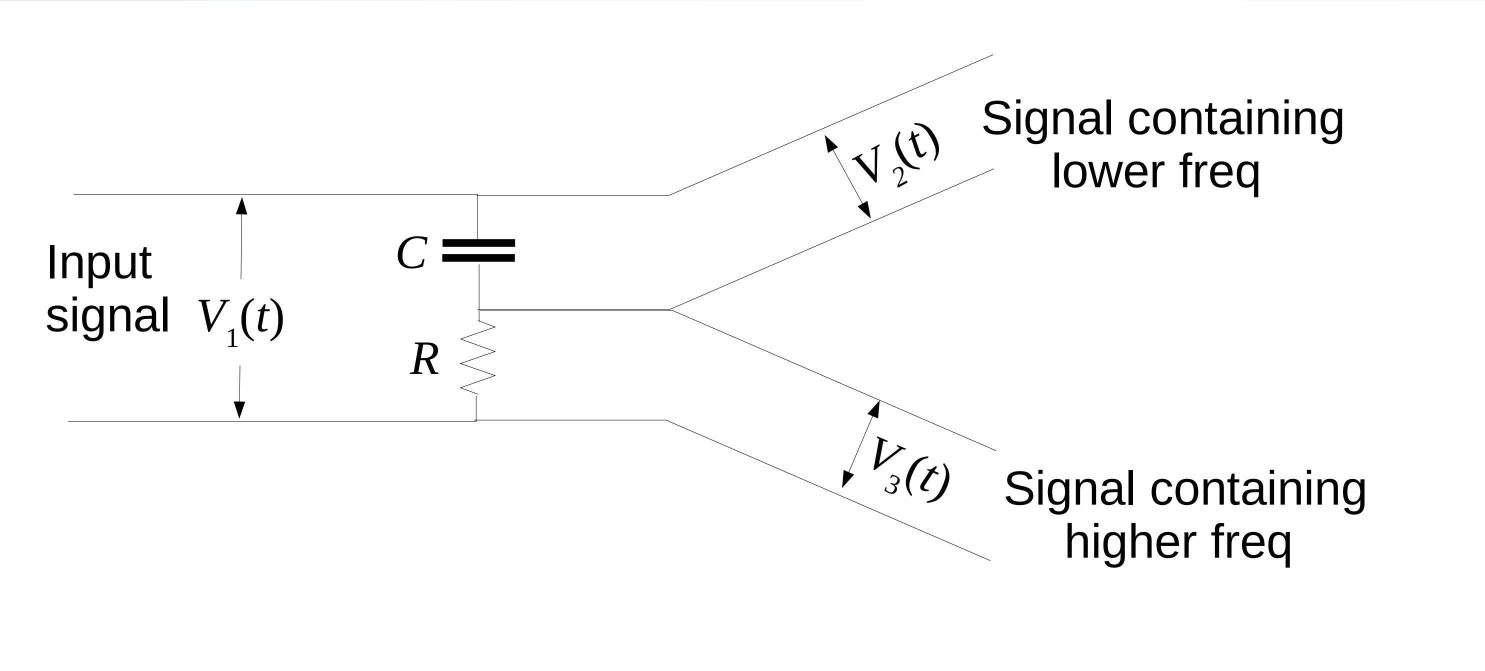
Summary of Particle-Size Filter

- Size filtering is imperfect, but can be improved by using multiple screens one after the other (cascade)
- Combinations of filters can be used to produce complex size filtering. The basic combinations are:
  - Cascading: this is equivalent to multiplying size distribution function
  - Adding: this is equivalent to adding size distribution function
- Filtering quality depends on accuracy of pore-size and pressure differences
  - Pressure differences can be controlled using fluid pumps

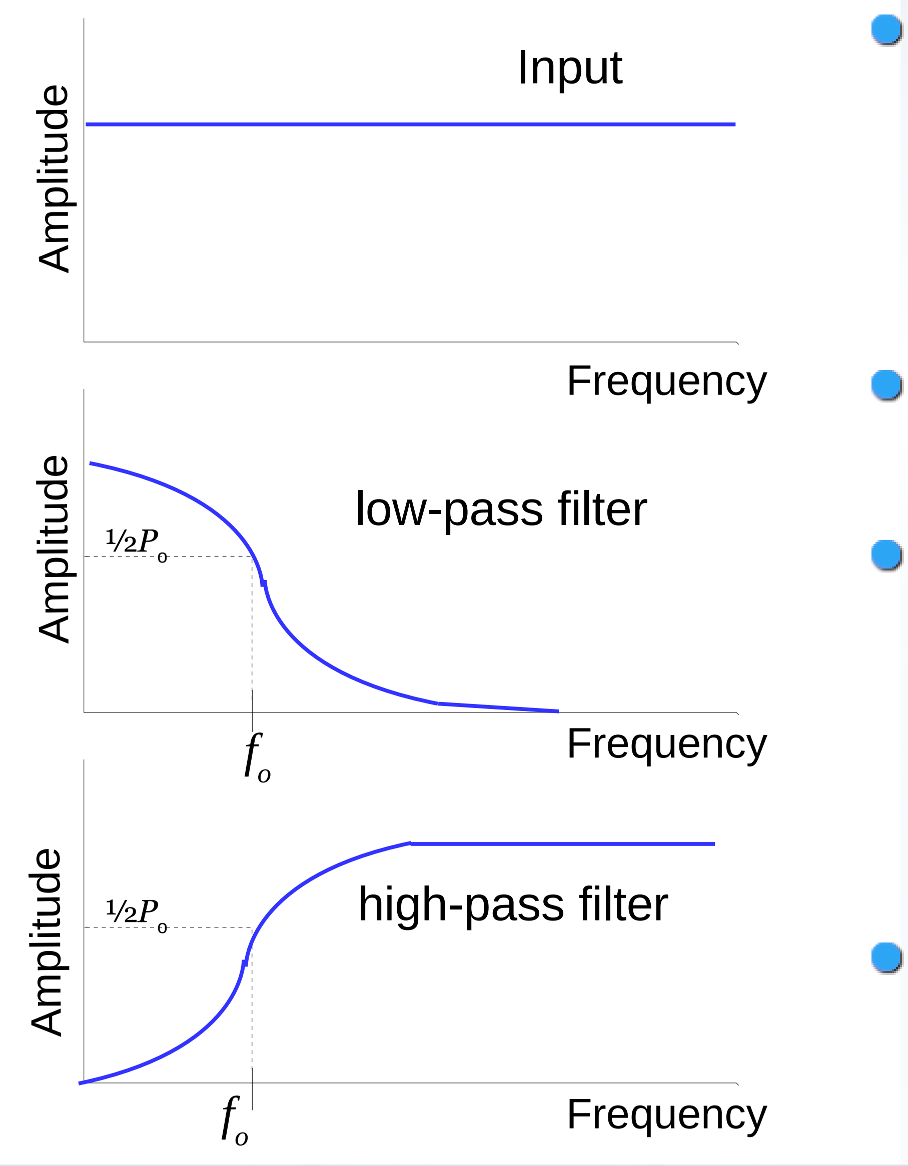
The use of analogies

- Analogies are useful to extend intuition to an unusual or unaccustomed situation
- Analogies are imperfect
- The particle filter analogy has some important limitations
  - The temporal and spatial relation between particles is not preserved during flow
  - In the case of most time signals in physiology, the temporal relation between components of the signal is very important

Electrical Filters – the basic RC filter



Filtered Signal Frequency Distribution



- Cutoff frequency: $f_o = \frac{1}{2\pi RC}$

  Cutoff freq is half-power freq, or -3dB freq
- Separation is not perfect, there is a transition region
- Quality of filtering depends on source current, load currents. These depend on source impedance and load impedances
- Quality of filtering can be improved using active components

Summary of Frequency Filtering

- Frequency filtering is imperfect, but can be improved by using multiple filters one after the other (cascade)
- Combinations of filters can be used to produce complex frequency filtering. Basic combinations are:
  - Cascading: this is equivalent to multiplying frequency distrbution functions
  - Adding: this is equivalent to adding frequency distrbution functions
- Filtering quality depends on accuracy of resistor & capacitor values and source and load impedances
- Using active components (transistors, integrated circuits), the effect of source and load impedances can be greatly reduced

Frequency content of a time-varying signal

- Preface: Any composite fluid (like blood) can be regarded as a mixture of particles of different sizes
- Any composite signal (any general time varying signal) can be regarded as a mixture of pure frequencies

  [Note: Here, “pure frequency” means a signal whose shape doesn't change with differentiation or integration. Sines and cosines (sinusoids) are such functions]
- Fourier decomposition is a mathematical process of identifying the component frequencies in a signal

Basic Filter Characteristics

- The basic RC filter is a first order filter (described by a first order differential equation)
- Cascading two filters will result in multiplication of the frequency selectivity. This makes a second order filter.
- Adding two filters in parallel will add the frequency selectivity. This usually results in a 2nd order system.
- The basic filter types are:
    - Low-pass filter
    - High-pass filter
    - Bandpass filter
        - cascade HPF (f_H) and LPF (f_L), with $f_H < f_L$
    - Bandstop filter
        - add LPF (f_L) and HPF (f_H), with $f_L < f_H$

What is frequency analysis of signals and systems

- Fourier series: Any periodic signal can be described by a set of sine waves
- Fourier transform: Any arbitrary signal can be described by a continuum of sine waves
- Illustration: simulation from Signals & Systems book

- Freq spectrum=Freq distribution of signal power
- Freq response=Freq distribution of system response

Frequency distribution graphs

- Linear plots – linear frequency and linear amplitude
  - Graphs are complex curves
  - Combining graphs is tedious

- Log-Log plots – logarithm of frequency and logarithm
  - Graphs can be approximated by a few straight lines
  - Combining graphs is easy – can usually be added

  - Log of frequency – shows small frequencies with high resolution and high frequencies with large range

More complex filters

- Filters can be combined by cascading or addition to make more complex filters
- Higher order filters
  - Better stopping of unwanted frequencies
  - Transition region between passband and stopband can be designed
    - Butterworth, Bessel, Chebyshev, Elliptic, etc.
- Higher order filters can be unstable – producing artificial oscillations

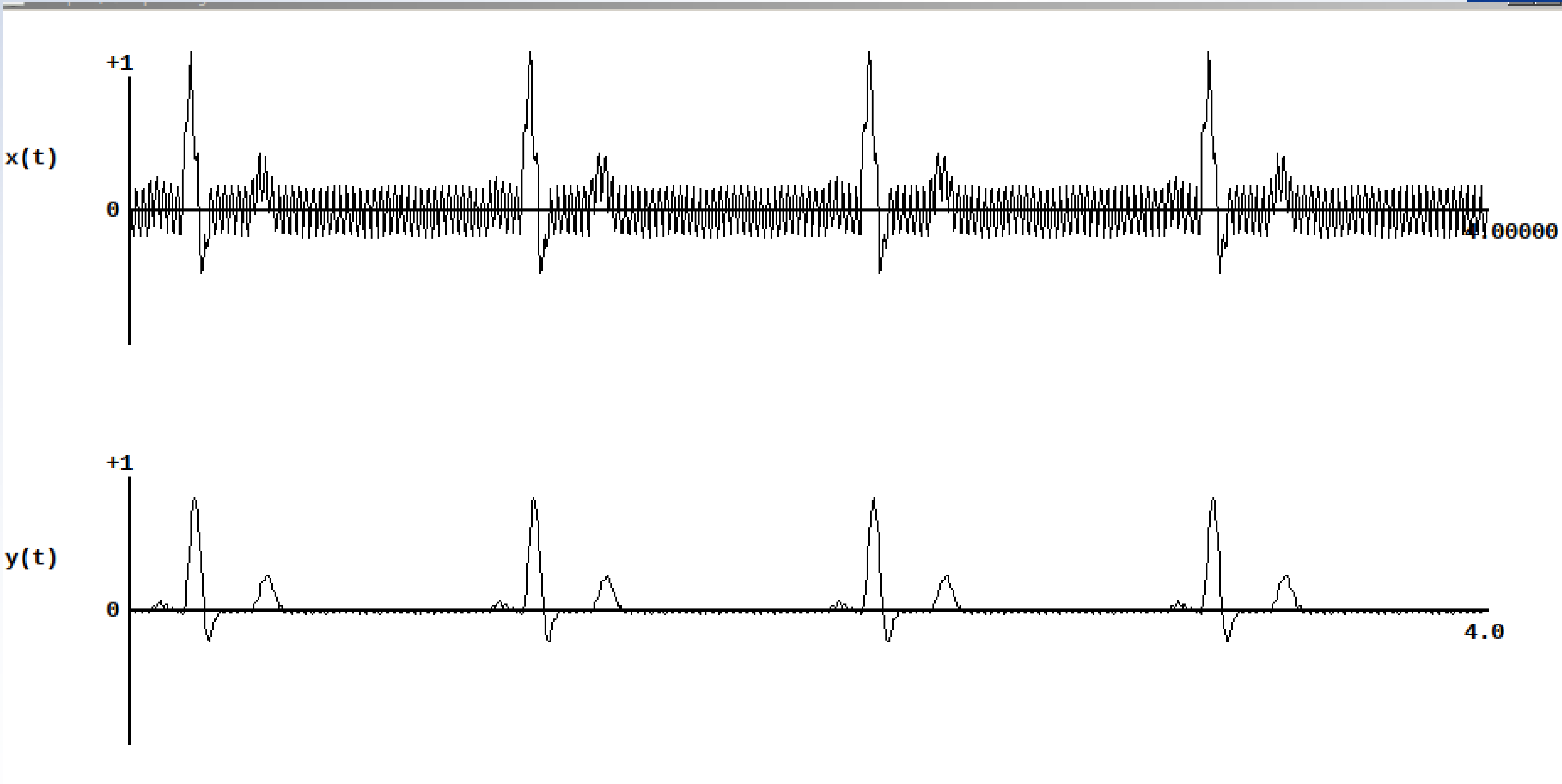
Part II ...

Noise Removal

What is “noise”?

- Contamination by unwanted signals
  - Usually of external origin
  - Could also be of biological origin
- Noise can be periodic or it can be random
  - Electrical mains – caveat: SMPS
  - Radio waves, thermal noise

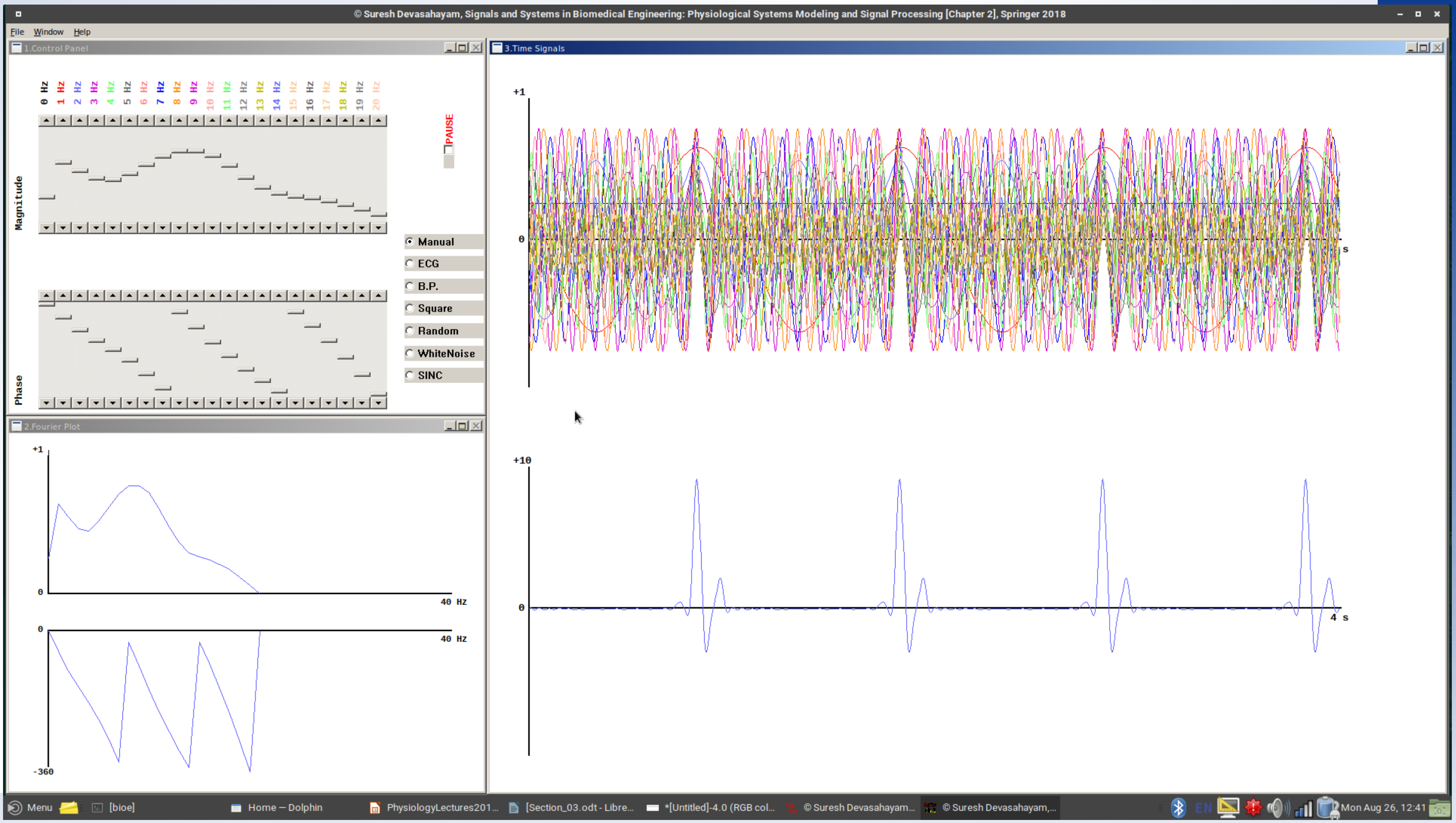
Filtering Noise



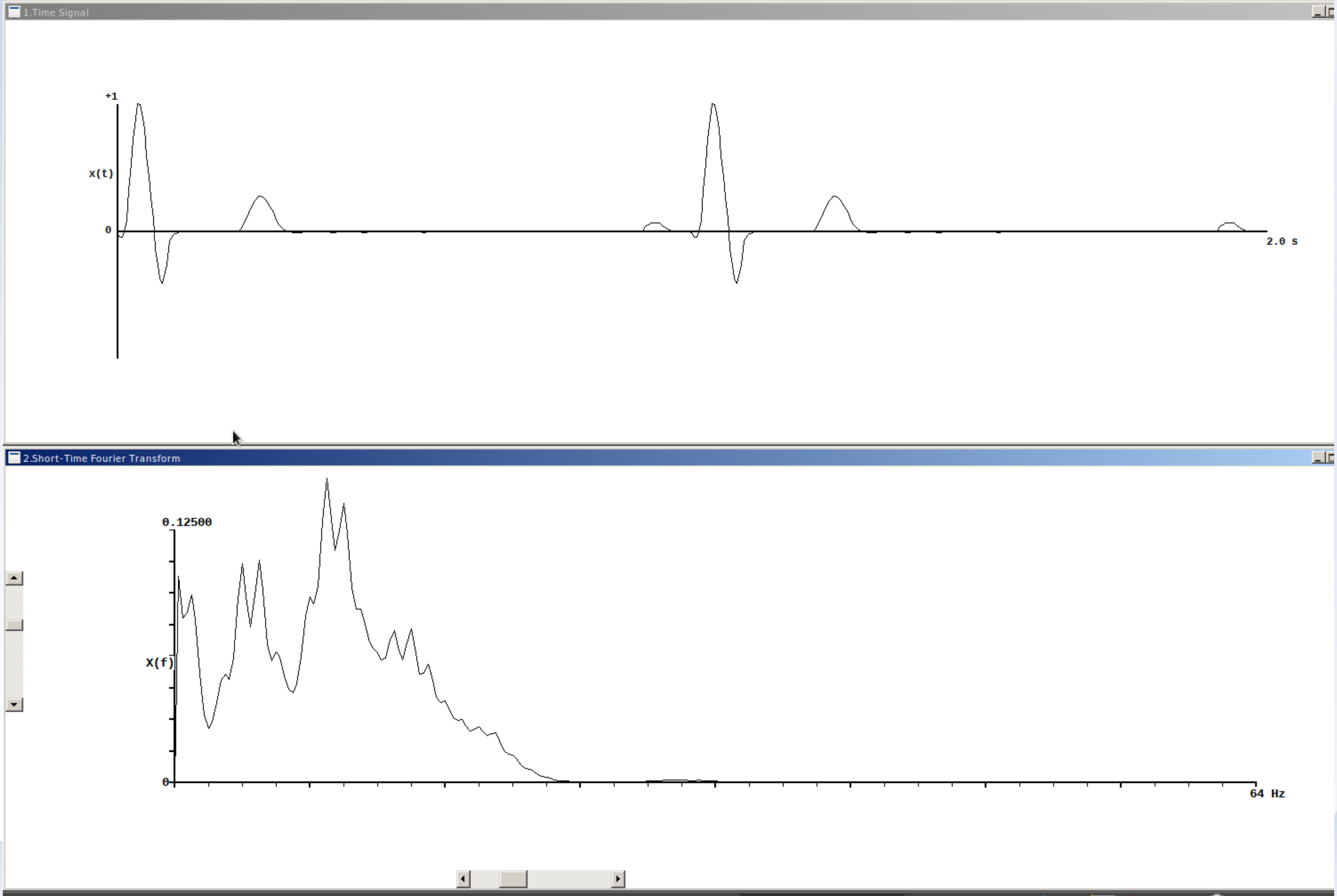
Frequency composition of Signal

- Every signal can be described in terms of a set of sinusoids
- Conversely, any signal can be constructed from a suitable set of sinusoids
- This is the Fourier Transform

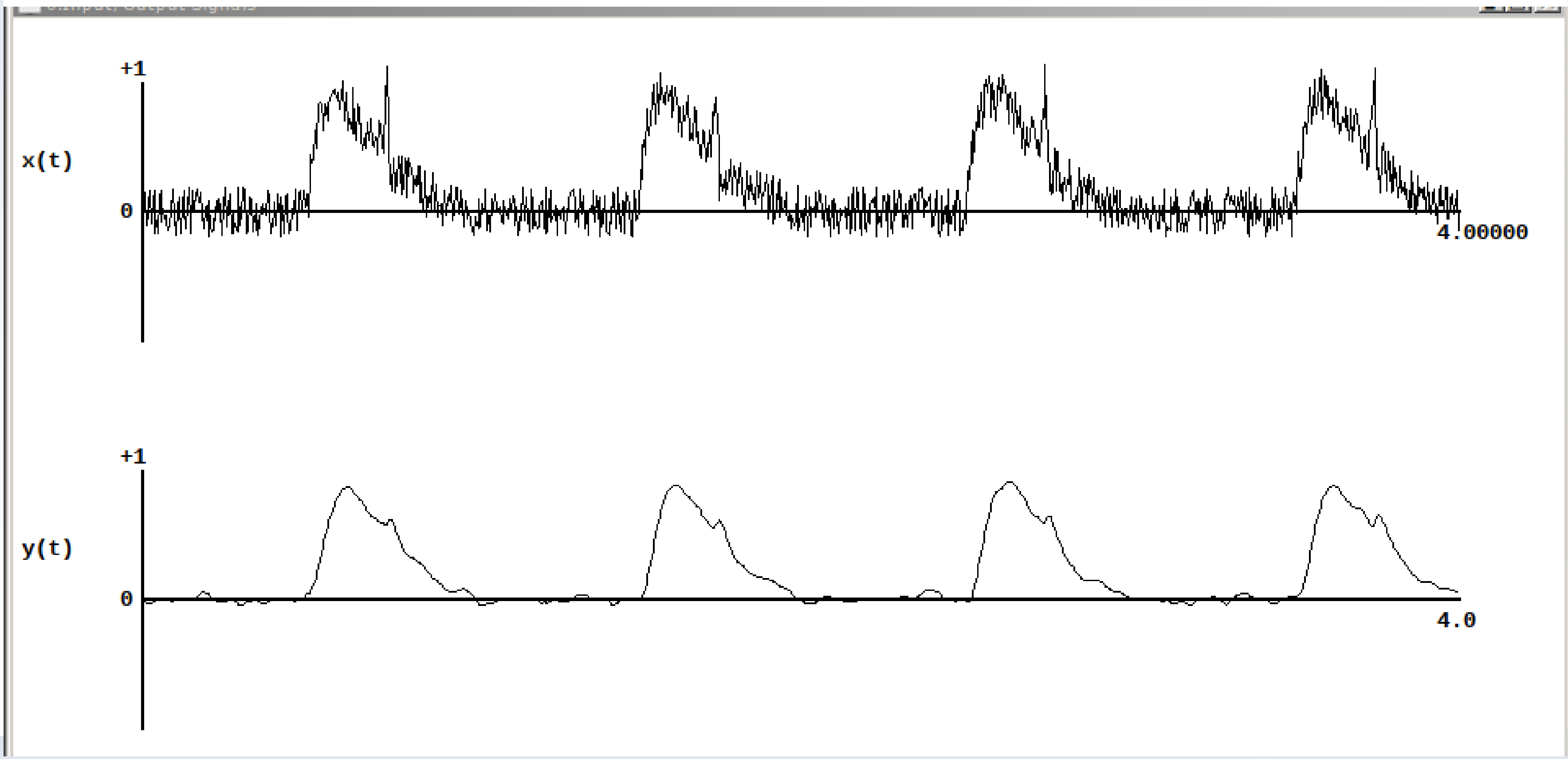
Fourier Decomposition



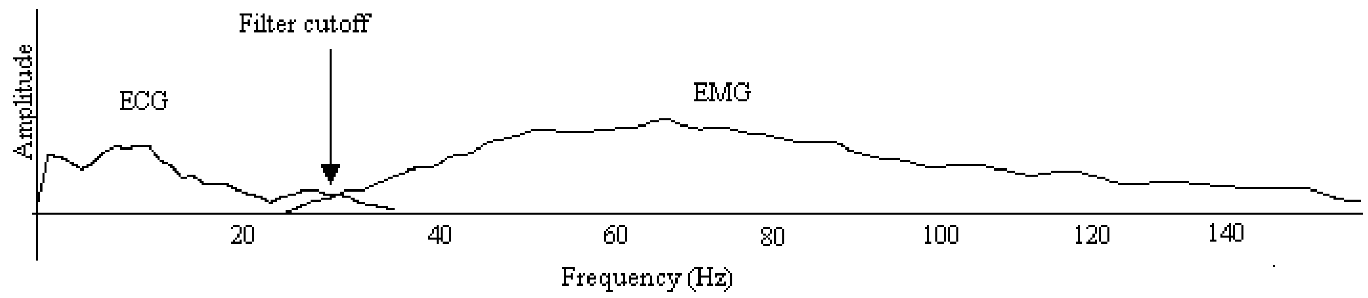
Spectrum Analysis



Filtering: 1st and 2nd Order filters



How to select the cutoff freq: The Optimal Filter



The Optimal Filter

- Keep as much of the signal as possible
- Remove as much of the signal as possible
- Decide on a compromise between these two

Other Techniques

- Noise removal:
  - Ensemble Averaging
  - Adaptive filtering
- Signal Decomposition
  - Wavelet transforms