BIOSIGNAL PROCESSING

Research problem 1: ECG Artifact Removal

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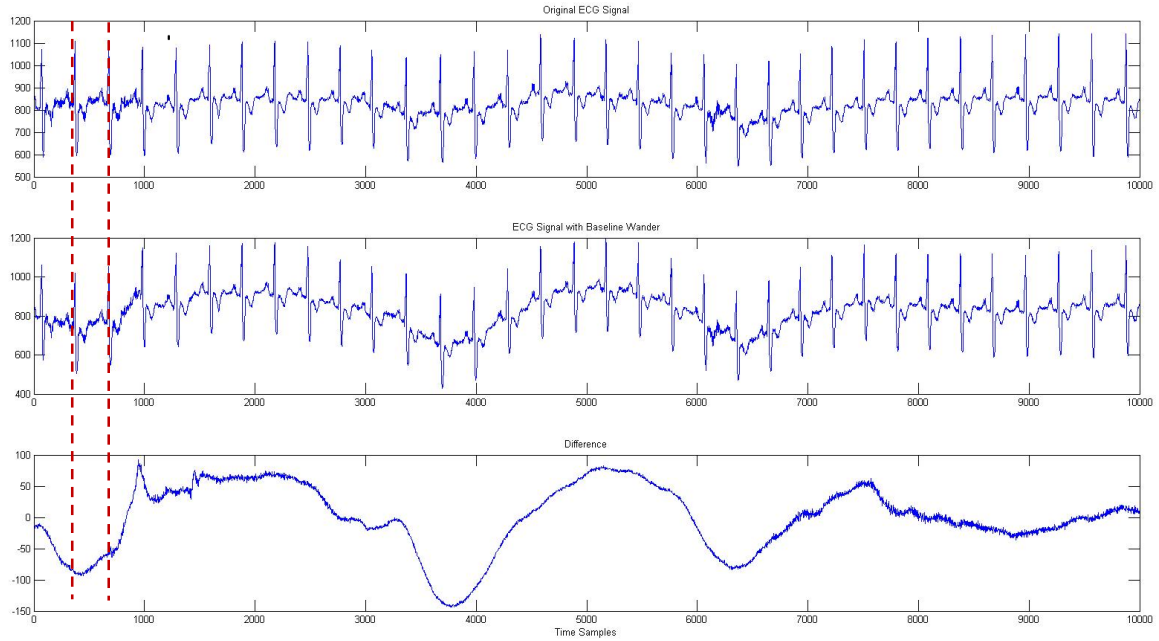
Identifying Signal Artifact

- Qualitative Method: Check whether the artifact signal has lower or higher frequency than original signal
  - Check one period of original signal and corresponding period from artifact signal and compare their frequencies
  - Works for low-frequency (e.g., baseline wander) or high-frequency (e.g., EMG superimposed on ECG) artifacts

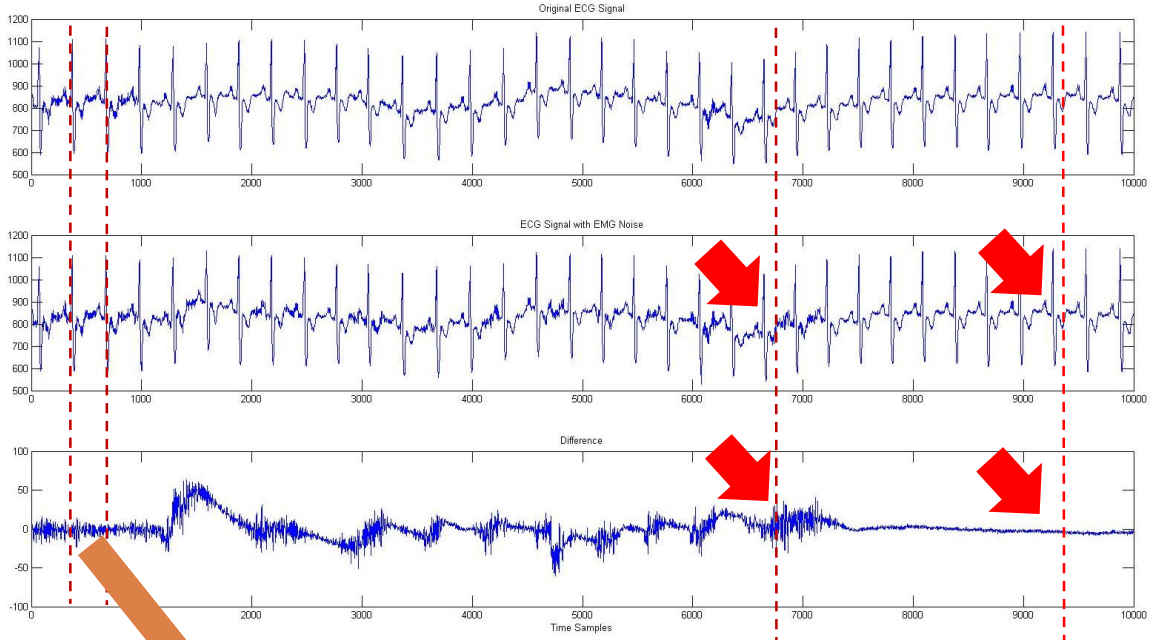
Fast: High-Frequency

Slow: Low-Frequency

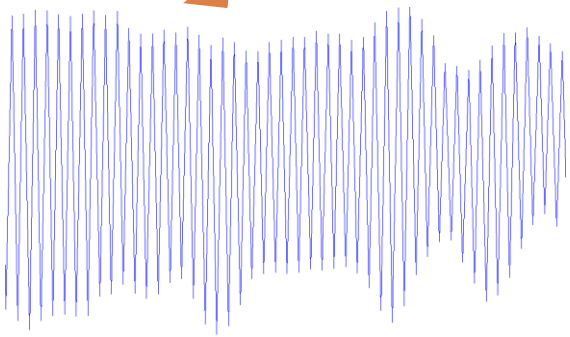


Identifying Signal Artifact

Slow:
Low-Frequency



Fast:
High-Frequency



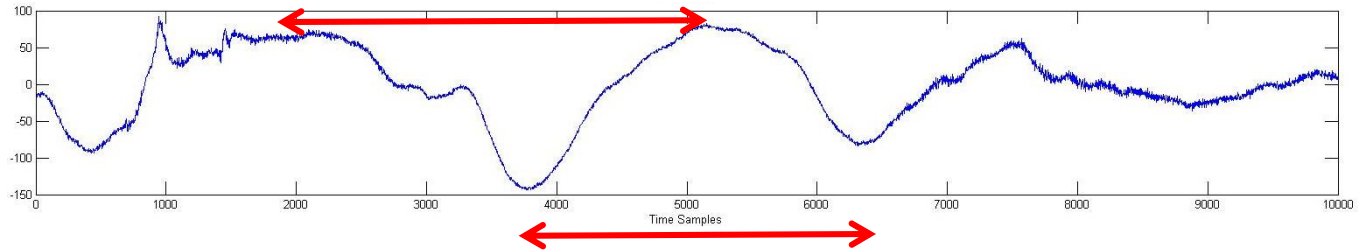
More Noise

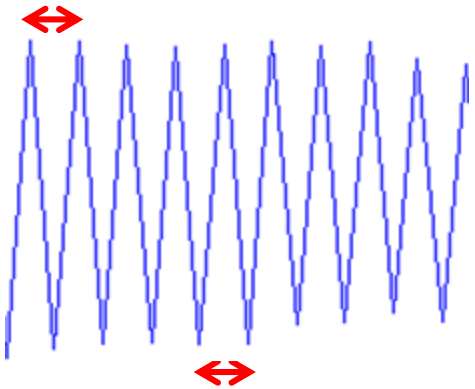
Less Noise

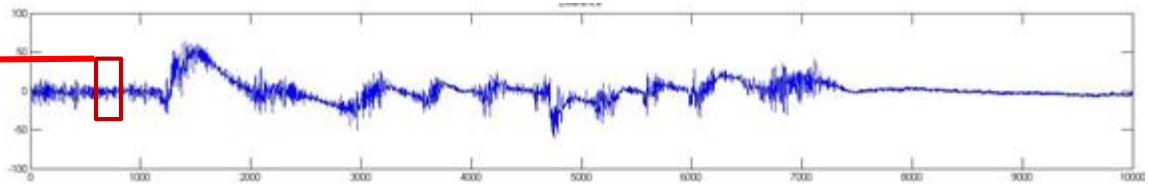
Signals that Appear Thick have high-frequency content

Identifying Signal Artifact

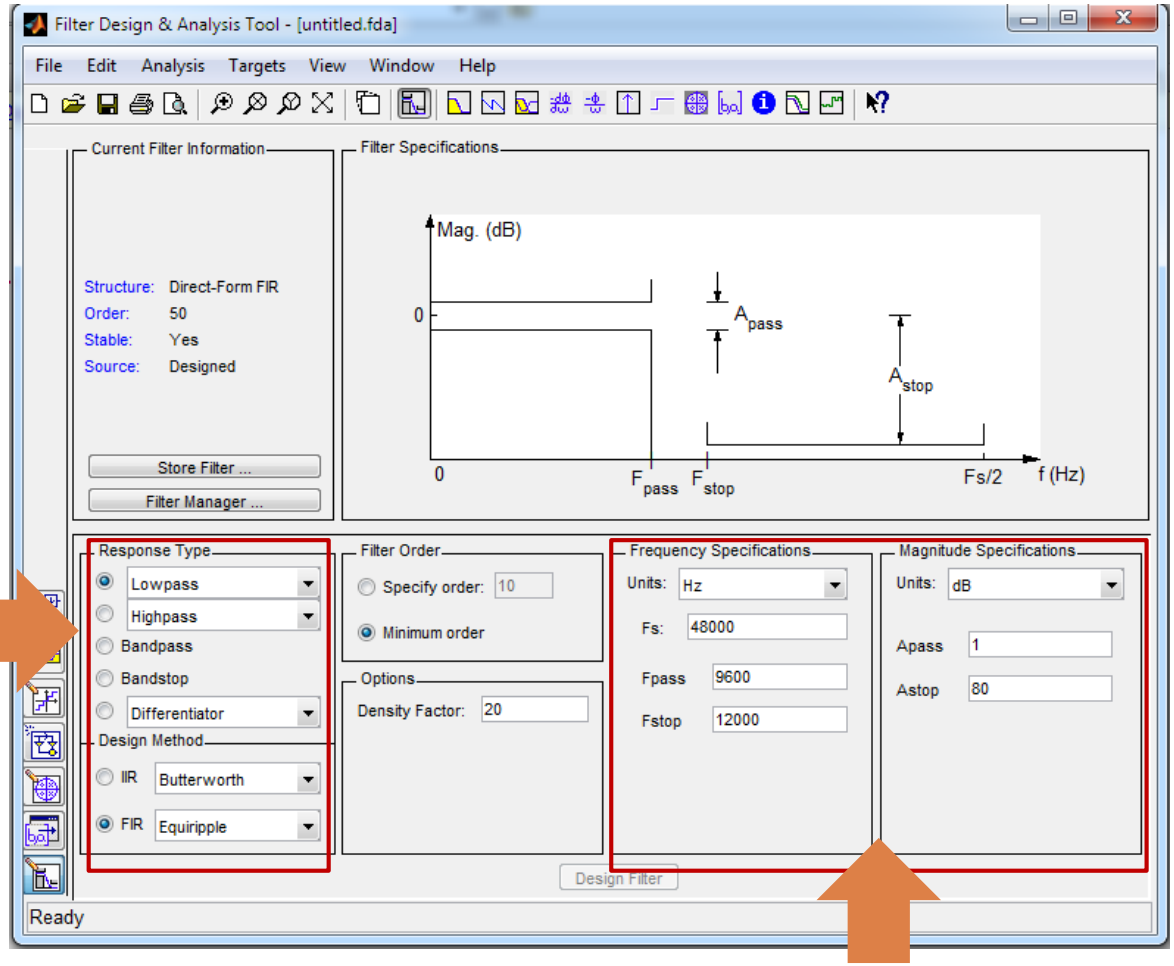
- Obtain "engineering" initial estimate of artifact frequency
  - Estimate time period T between artifact signal peaks (or valleys)
  - Compute artifact frequency initial estimate = 1/T
- More accurate method: using Fourier transform (later)







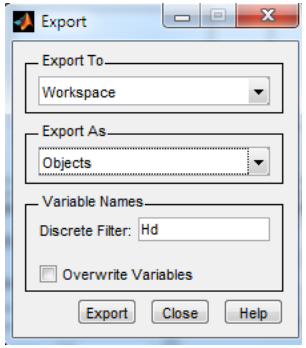
Digital Filter Design Using Matlab



Choose Filter Type

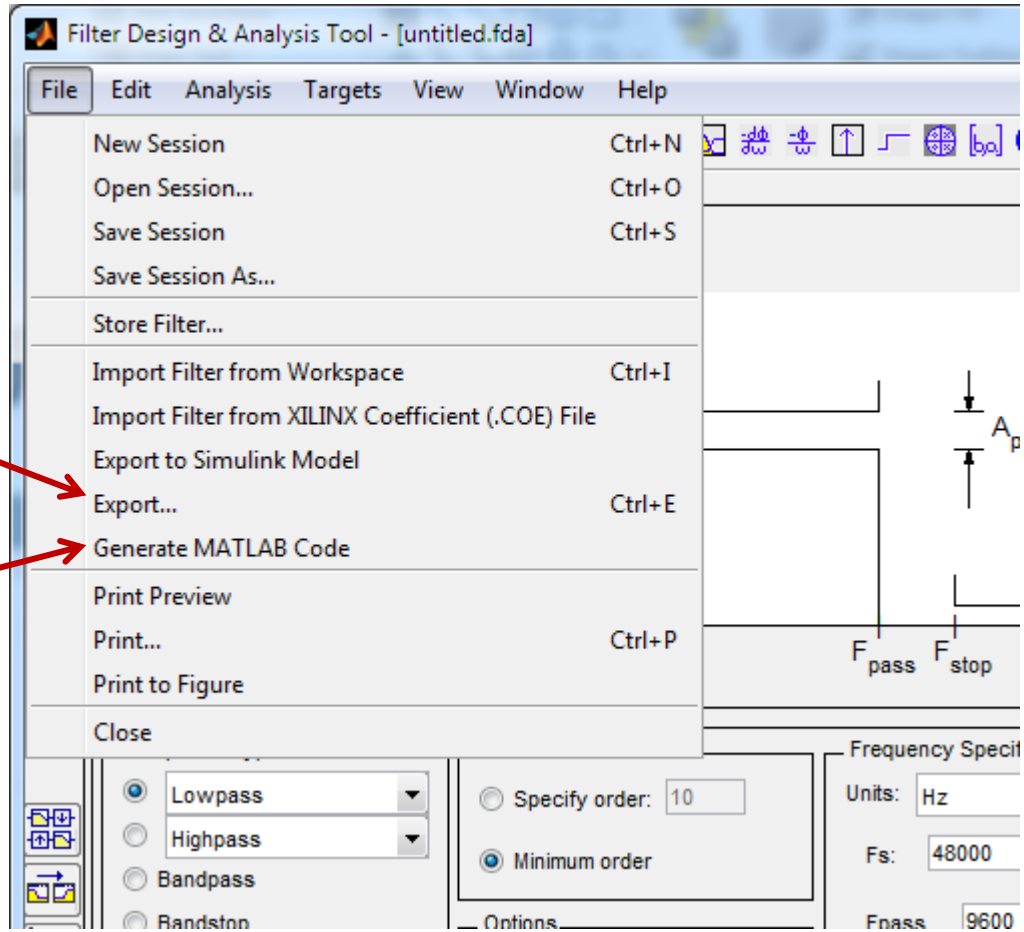
Choose Filter Specs

Use Digital Filter Design on Signal



Export Filter to Workspace

Generate Code for Filter (Preferred)

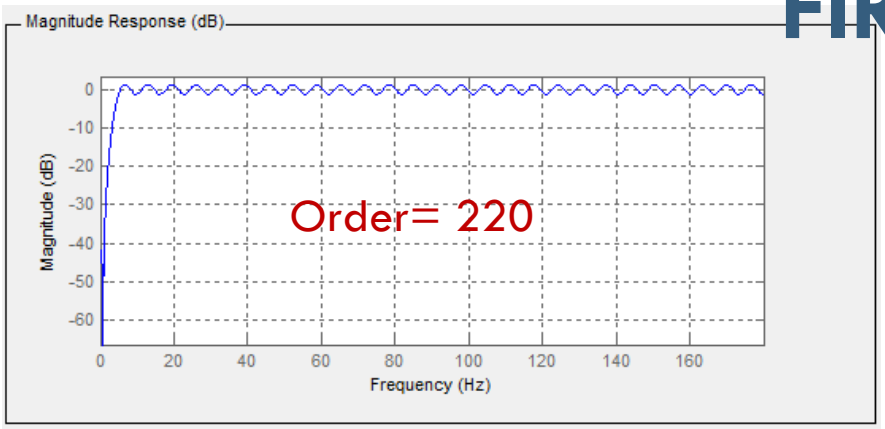


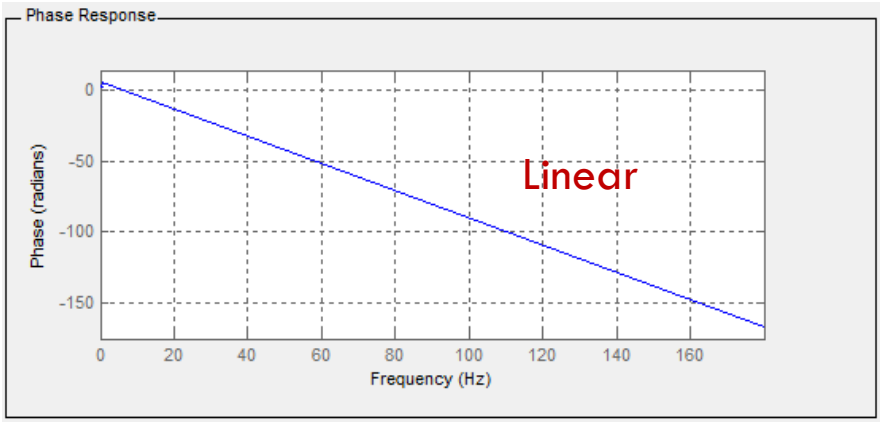

```
function Hd = bw1
%BW1 Returns a discrete-time filter object.

%
% MATLAB Code
% Generated by MATLAB(R) 7.13 and the Signal Processing Toolbox 6.16.
%
% Generated on: 12-Sep-2015 08:24:59
%

% Equiripple Highpass filter designed using the FIRPM function.

% All frequency values are in Hz.
Fs = 360;  % Sampling Frequency

Fstop = 0.1;            % Stopband Frequency
Fpass = 1;              % Passband Frequency
Dstop = 0.01;           % Stopband Attenuation
Dpass = 0.01;  % Passband Ripple
dens  = 20;             % Density Factor

% Calculate the order from the parameters using FIRPMORD.
[N, Fo, Ao, W] = firpmord([Fstop, Fpass]/(Fs/2), [0 1], [Dstop, Dpass]);

% Calculate the coefficients using the FIRPM function.
b  = firpm(N, Fo, Ao, W, {dens});
Hd = dfilt.dffir(b);

% [EOF]
```

```
sigout= filter(Hd,sigin);
```

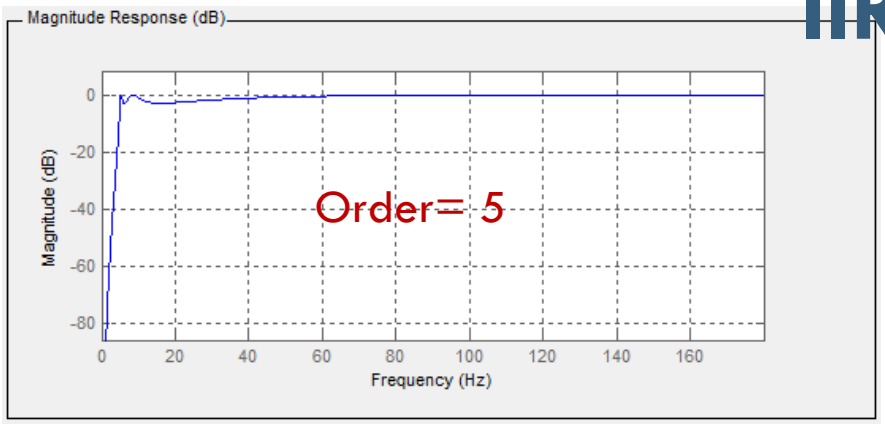
FIR vs. IIR Response

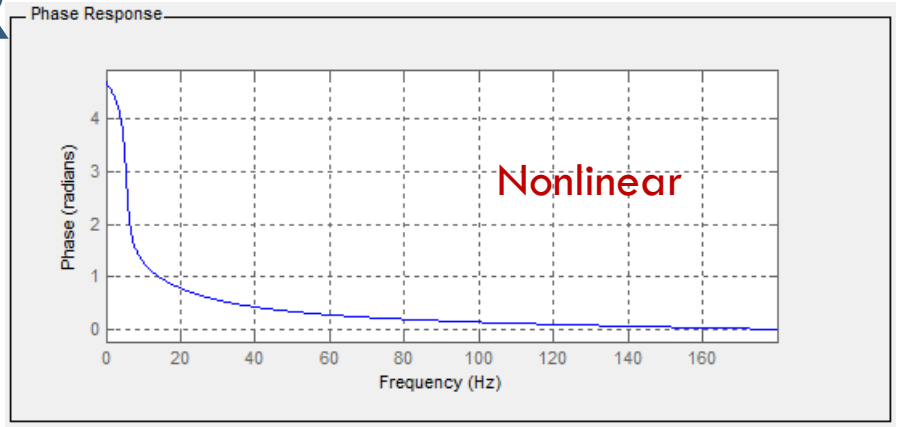
FIR





IIR





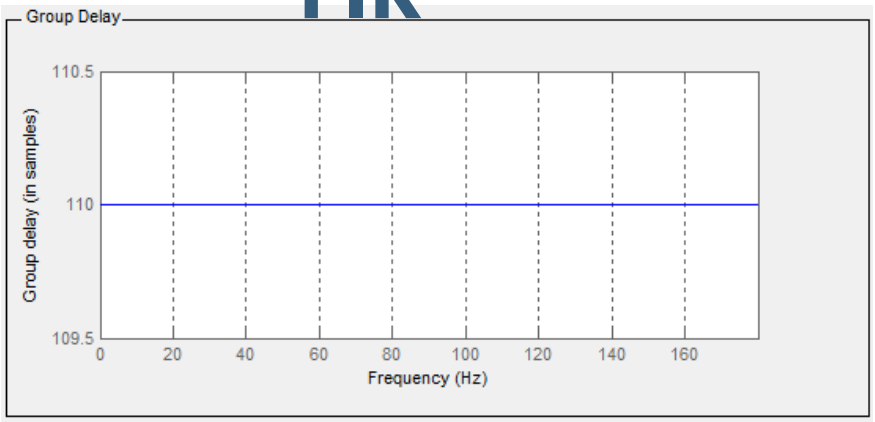
Group Delay

- Since a delay in the time domain results in a linear phase in the frequency domain, the group delay of a filter response is defined as,

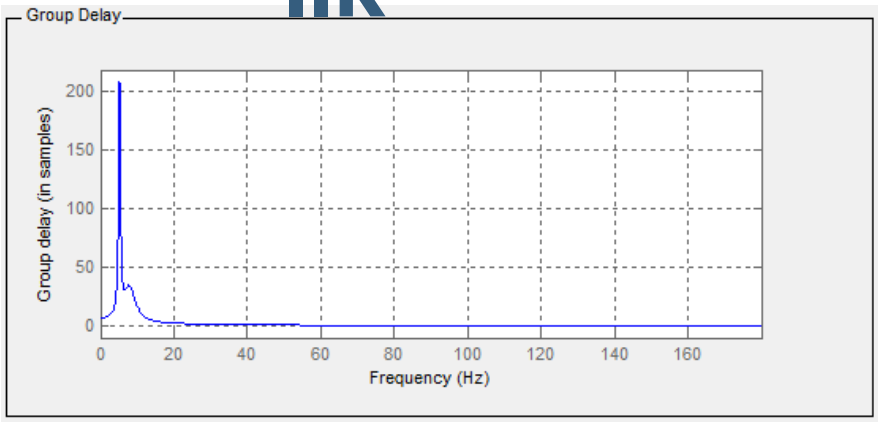
$$\text{Group Delay} = -\frac{d\phi}{d\omega}$$

  - Note: Group delay is constant in FIR filters and nonlinear in IIR filters

FIR



IIR



Quantitative Comparison of Signals

- You have two signals: True X and Estimated Xest
- Required: a quantitative measure of how close they are
- Possible Solution: Root Mean Squared Error (RMSE)
- Matlab: using vector notation

```
RMSE = sqrt (mean((Xest - X).^2));
```

- Requirement: Signals must be aligned to be able to do that
  - Note that shift in filter output does not allow direct subtraction

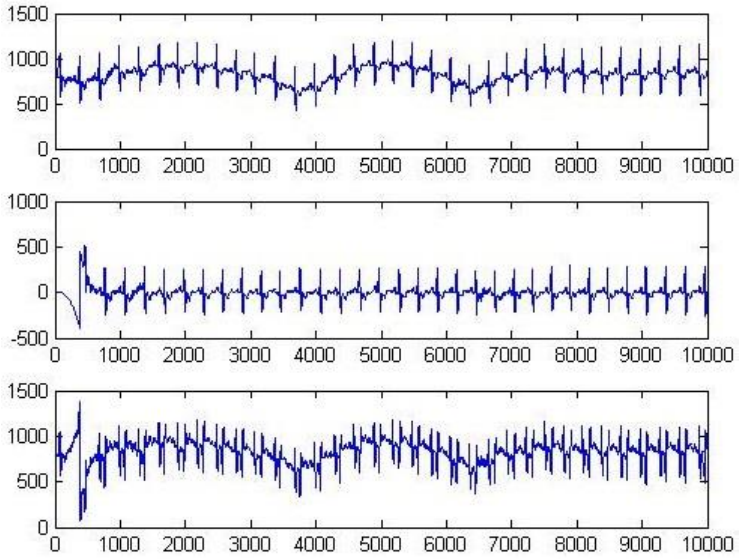
Group Delay Correction

- Shift in filter output is due to Group Delay of filter
  - Use average of group delay for designed filter
  - Shift output signal to correct for it to align input and output signals

```
N2 = mean(grpdelay(Hd)) % filter delay (samples)
sigin= s118bw12(1,:);
sigout= filter(Hd,sigin);
sigout_shifted= sigout(N2+1:end);
```

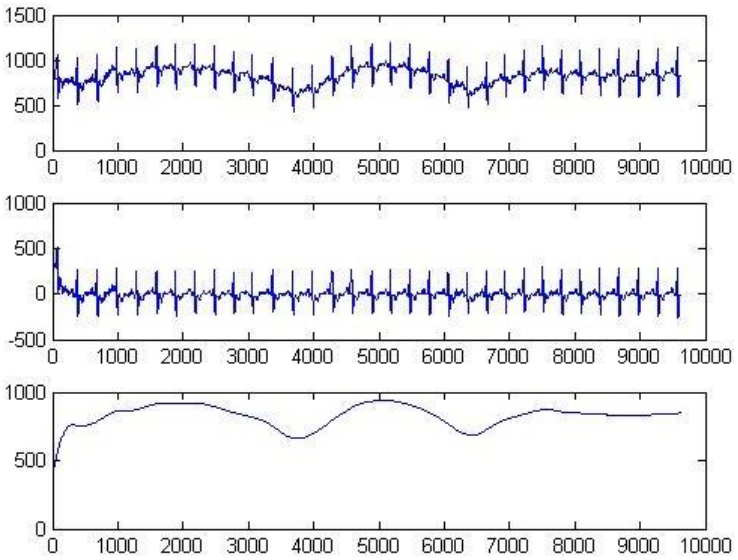
Delayed Output

Error Signal



Shifted Output

Error Signal

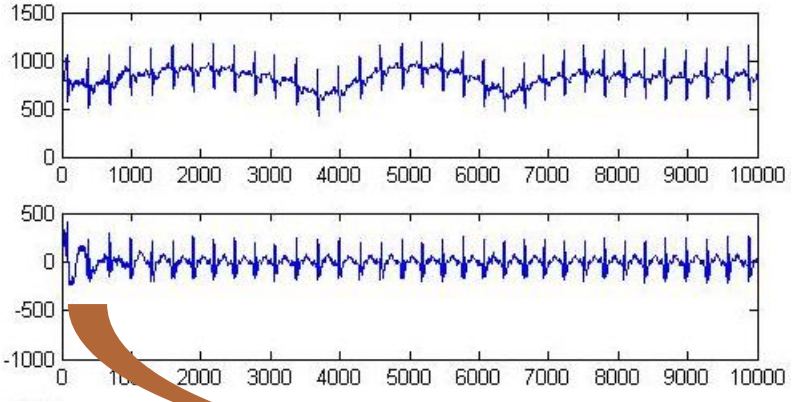


http://www.mathworks.com/help/signal/examples/practical-introduction-to-digital-filtering.html

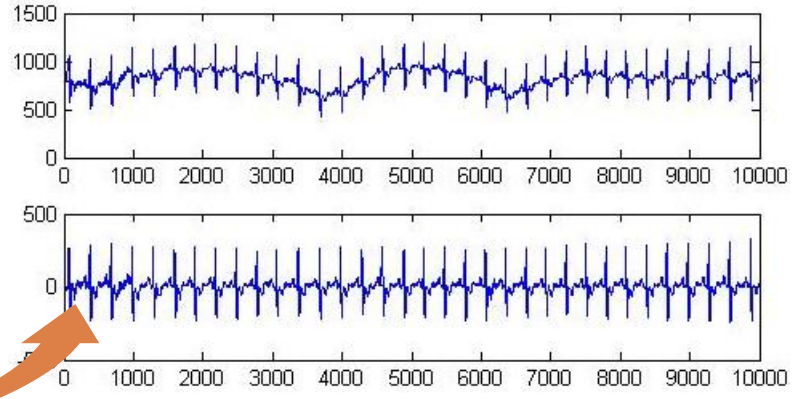
Zero-Phase Filtering

- Zero-phase digital filtering is done by processing the input data in both the forward and reverse directions (Matlab: `filtfilt`)
  - Zero-phase distortion – minimizes start-up and ending transients
  - Filter transfer function = squared magnitude of original filter
  - Filter order = double order of original filter

`filter`: Not Zero Phase



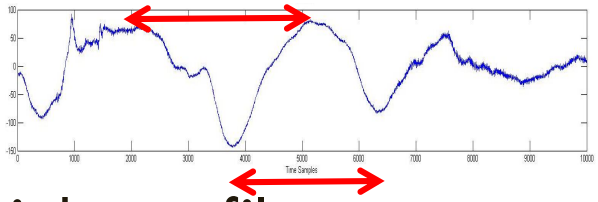
`filtfilt`: Zero Phase

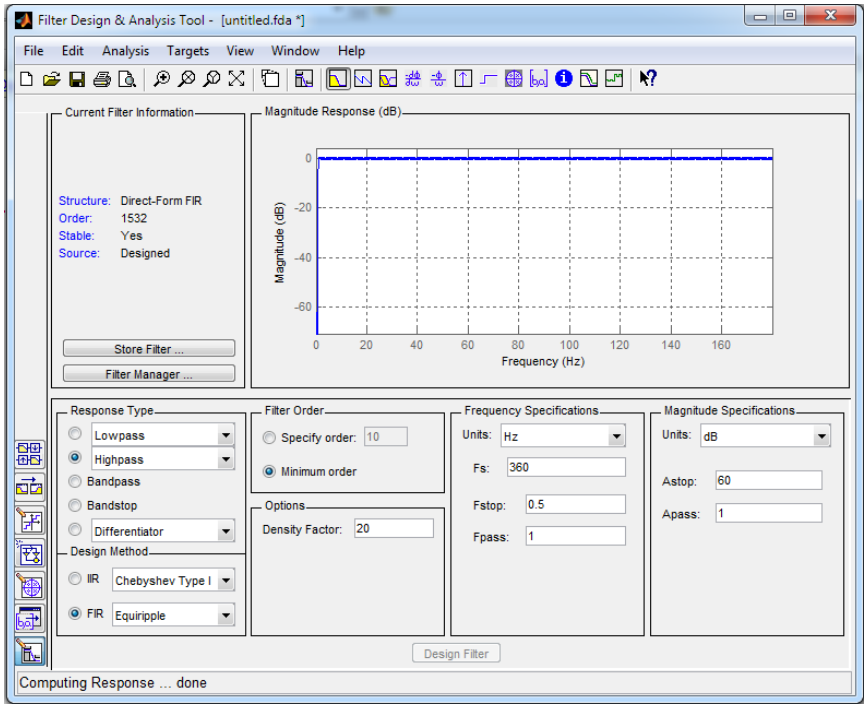


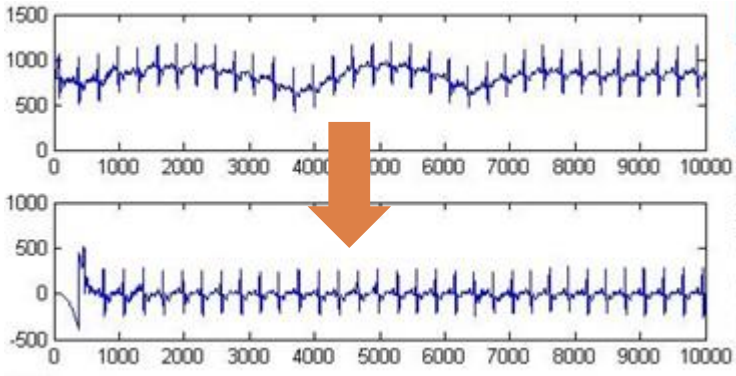
http://www.mathworks.com/help/signal/ref/filtfilt.html

Example: Baseline Wander

- Estimated artifact frequency ≈ 0.1 Hz
  - T ≈ 3000 Sa * 1/(360 Sa/s) ≈ 9 s
- Clearly a low-pass artifact: remove using highpass filter

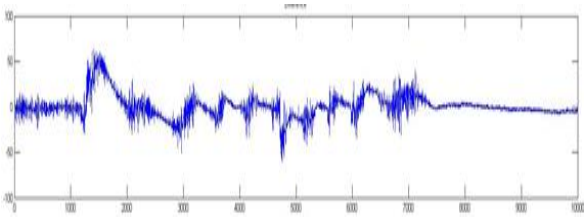


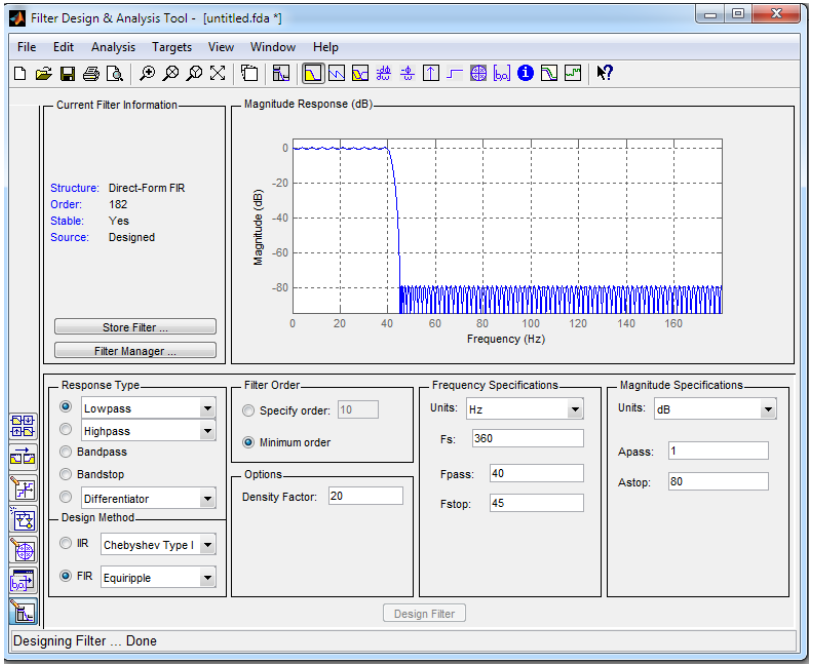


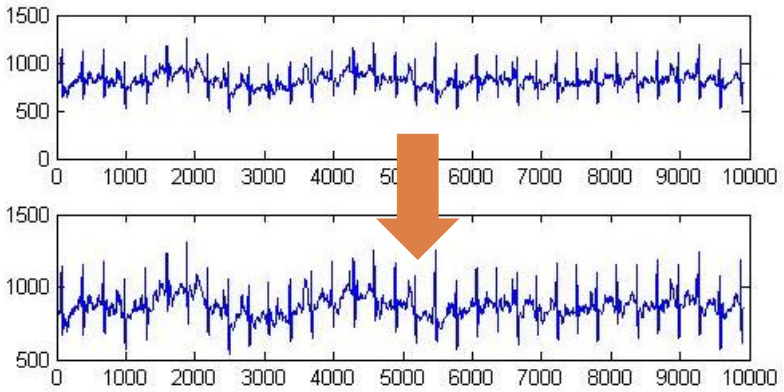


Example: EMG Artifact

- Clearly a high-frequency artifact
  - Need a lowpass filter
- Strategy: use cutoff as low as possible
  - Try to retain as much of ECG signal content (reasonable value = 40 Hz)

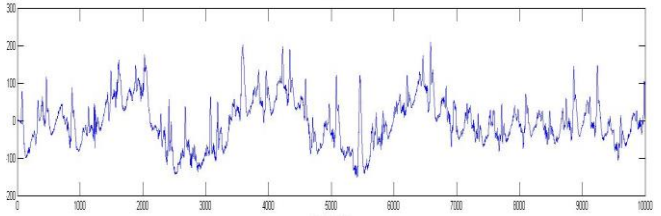


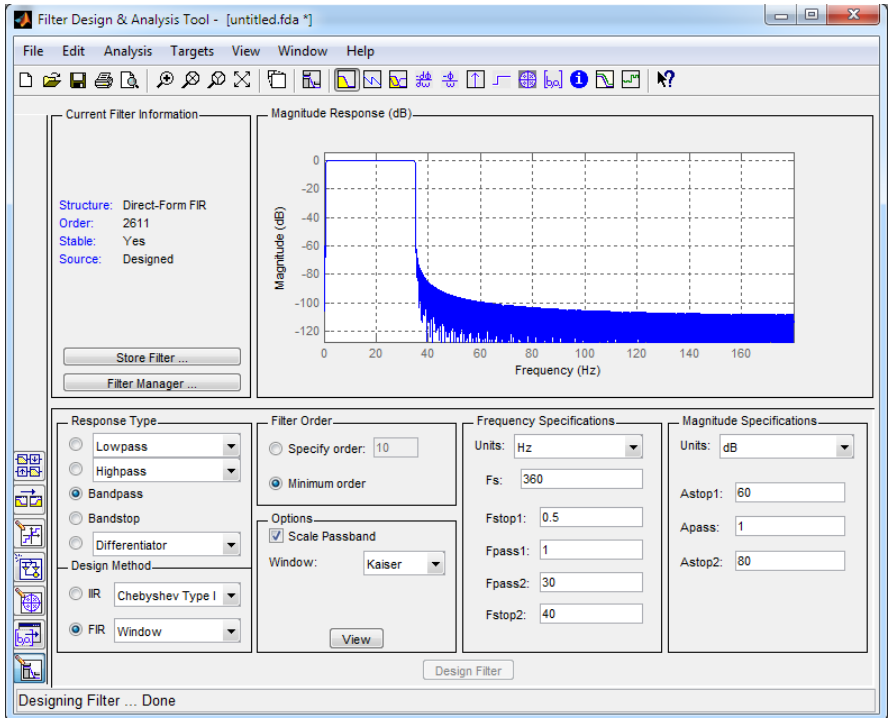


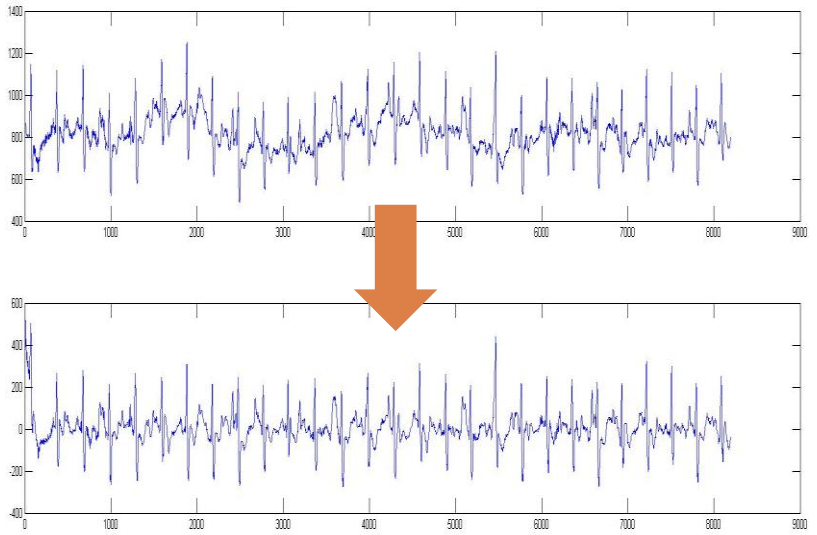


Example: Electrode Motion Artifact

- Complex artifact
  - High frequency + low frequency components
  - Needs a bandpass filter







Research Information Sources

Source	Advantages	Information	Disadvantages
Books	• Comprehensive information • Background and historical information • Bibliography of sources	• Historical context • Broad overviews • broader audience	• Dated information • Content level • Bias or slant (author)
Popular/Special Interest Magazine	• Current information • Shorter, easy to understand • Photos and illustrations	• Long-form stories. • Discuss impact on society • Offers perspectives • General audience	• Authors not experts • May lack depth • Sources not always cited • Editorial bias
Professional/Trade Magazines	• Specialized information • Current information • Some bibliographies	• Long articles or reports • Context and analysis • Professional audience	• Vary between short, easy to lengthy and specialized • Sources not always cited
Scholarly/Academic Journals	• Depth • Written by experts • Charts and graphs • Recent research • Bibliographies of sources	• Often theoretical • Peer-reviewed • Often narrow focus • Scholars, researchers, professionals and students	• Specialized Terminology and depth • Dated information
Newspapers	• Daily local information	• General audience	• Authors usually not experts
Web Sites	• Various points of view • Statistics • Industry information	• Explains the who, what, when and where of an event • Is intended for a general audience	• Credibility and accuracy cannot be assured • Information may be biased • Sources not always cited

Lab Notebook Documentation

- Please take the habit of documenting all your experiments in a Lab notebook (paper or electronic)