

## Steven Bolt - Homework 8

```
answersOn = true;

% Units
ONE.kOhm = 1e3;
ONE.pF = 1e-12;
ONE.kHz = 1e3;
ONE.MHz = 1e6;
ONE.GHz = 1e9;
ONE.nH = 1e-9;
ONE.uH = 1e-6;
ONE.uF = 1e-6;
ONE.uSec = 1e-6;
ONE.mSec = 1e-3;
ONE.uV = 1e-6;
ONE.mV = 1e-3;
ONE.mW = 1e-3;

clearvars -except answersOn ONE
```

## Digital Signal Processing Homework 08 -- Butterworth and Chebyshev Filters using MATLAB

Reading -- Review Chapter 19 and 20 on Recursive Filters and Chebyshev Filters

### Problem 1

Design a 5 pole IIR Chebyshev lowpass filter with 1 dB of ripple that has a corner frequency of 12 BPM using a sample rate of 600 BPM. Compute the filter coefficients using the MATLAB low pass filter design tool.

You can get the coefficients of the filter after running the script by looking at the values of a and b displayed for the Direct Form of the IIR for easy copy to MATLAB. Copy the values for variables a and b (see example output from MATLAB function below)

Direct IIR Filter Coefficients for easy copy to MATLAB

```
b = [0.0008160, 0.0040802, 0.0081603, 0.0081603, 0.0040802, 0.0008160];
a = [1.0000000, -3.5596819, 5.5972100, -4.7578789, 2.1711919, -0.4247281];
```

The numerator coefficients are saved in the b variable and the denominator coefficients in the a variable. This is opposite of how the text labels the numerator and denominator coefficients.

## Part A

Copy the values from the command window into this Live script and then use the `impz` and `freqz` functions to compute the impulse and frequency responses respectively. Compute 512 points for each response.

```
clearvars -except answersOn ONE

num = [0.0000001, 0.0000006, 0.0000011, 0.0000011, 0.0000006, 0.0000001];
den = [1.0000000, -4.8628843, 9.4795648, -9.2592853, 4.5315589, -0.8889505];

% Find the impulse response using the impz function
impResp = impz(num, den, 512);

% Find the frequency response. Results in two return variables. The
% first is the frequency response (complex) and the second is a vector of
% frequencies from 0 to pi. Pi is 1/2 of the sample rate
freqResp = freqz(num, den, 512);
```

## Part B

Using MATLAB create a normally distributed random noise sequence of length 32768. Use the `randn( 32768, 1)` function to create a column vector of length 32768 of random numbers. In the sample domain, convolve the random noise sequence with the impulse response of the filter. What will be the length of the convolution output?

**The convolution output length is the length of the input sequence plus the length of the impulse response minus one, which in this case is  $32768 + 512 - 1 = 33279$ .**

The result of the convolution will have end effects at the beginning and at the end. Which samples of the output of the convolution are valid, that is which samples have no end effects? Think about the length of the impulse response and how many samples would have to enter the system so that the impulse response would be multiplied by valid input values.

**The amount of end effects on each side is the length of the impulse response minus one, which in this case is  $512 - 1 = 511$ .**

Plot the input noise and the output of the convolution, the filtered noise.

Plot the frequency spectrum of the noise using the FFT.

What do you notice about the frequency spectrum of the noise?

```
% The length of the convolution is M+N-1 where M is the length of the
% input sequence (32768), N is the length of the impulse response (512).
```

```

% Then the length of the convolution is  $M+N-1 = 32768 + 512-1 = 33279$ 
%

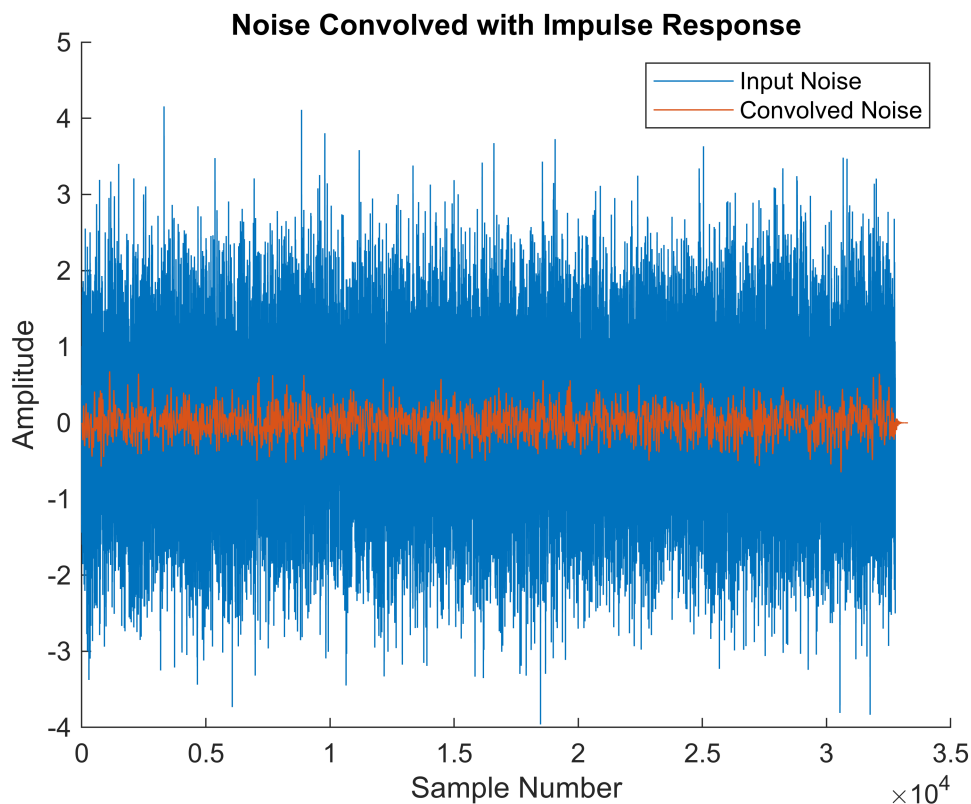
% The convolution will have N-1 values that are part of the end effects of
% the convolution. Therefore valid samples are from sample 512 to 32768

% Create a noise vector of length 32768
noise = randn(32768, 1);

% Convolve the noise sequence with the impulse response
convolve = conv(noise, impResp);

% Put your solution here
x = 0:1:33278;
figure
hold 'on'
plot(noise)
plot(convolve)
hold 'off'
legend("Input Noise", "Convolved Noise")
xlabel("Sample Number")
ylabel("Amplitude")
title("Noise Convolved with Impulse Response")

```



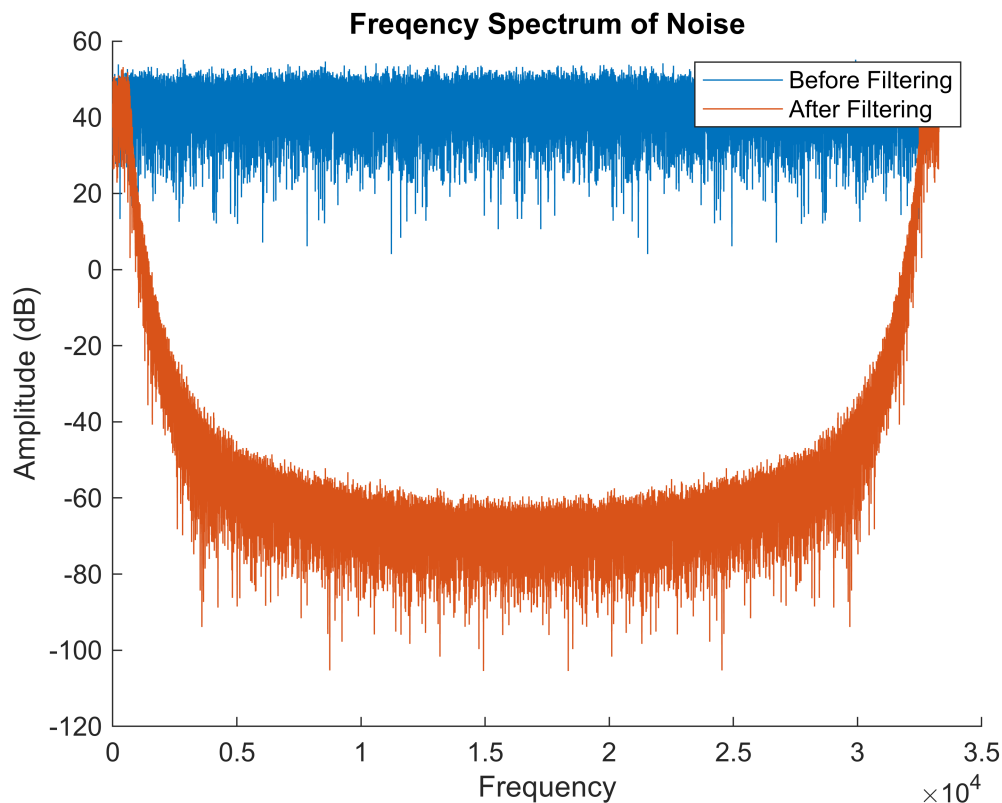
```

% Find the FFT of the noise
noiseFreq = 20*log10(abs(fft(noise)));

```

```
convFreq = 20*log10(abs(fft(convolve)));

% Plot FFT of the noise
figure
hold 'on'
plot(noiseFreq)
plot(convFreq)
hold 'off'
legend("Before Filtering", "After Filtering")
xlabel("Frequency")
ylabel("Amplitude (dB)")
title("Frequency Spectrum of Noise")
```



## Problem 2

A filter has the following impulse response of length 11.

$h = 0.0000000, 0.0398999, 0.0860792, 0.1291187, 0.1595995, 0.1706054, 0.1595995, 0.1291187, 0.0860792, 0.0398999, 0.0000000$

Plot the frequency response of the filter with this impulse response assuming a sampling frequency of 8 kHz.

Generate a signal that consists of two sinusoids. One is 300 Hz with and the other 3kHz. Each has a length of 1014 samples. A sinusoid with frequency "freq" can be created in MATLAB using where "freq" is the sinusoid frequency and "sampleFreq" is the sampling frequency

```
signal = sin(2*pi * freq/sampleFreq * [0:1013] );
```

Then add the two signals together.

Convolve the combined signal with the impulse response of the filter using Frequency Domain convolution. Remember to pad each sequence to the length of the output convolution.

Plot the resulting time domain signal. Plot the frequency spectrum of the signal before filtering and after filtering

```
clearvars -except answersOn ONE

% Impulse response of the filter

impResp = [ 0.0000000 ,0.0398999 ,0.0860792 ,0.1291187 ,0.1595995 ,0.1706054
,0.1595995 ,0.1291187 ,0.0860792 ,0.0398999 ,0.0000000];

% Put your solution here
sampleFreq = 8 * 10^3;
freq1 = 300;
freq2 = 3 * 10^3;

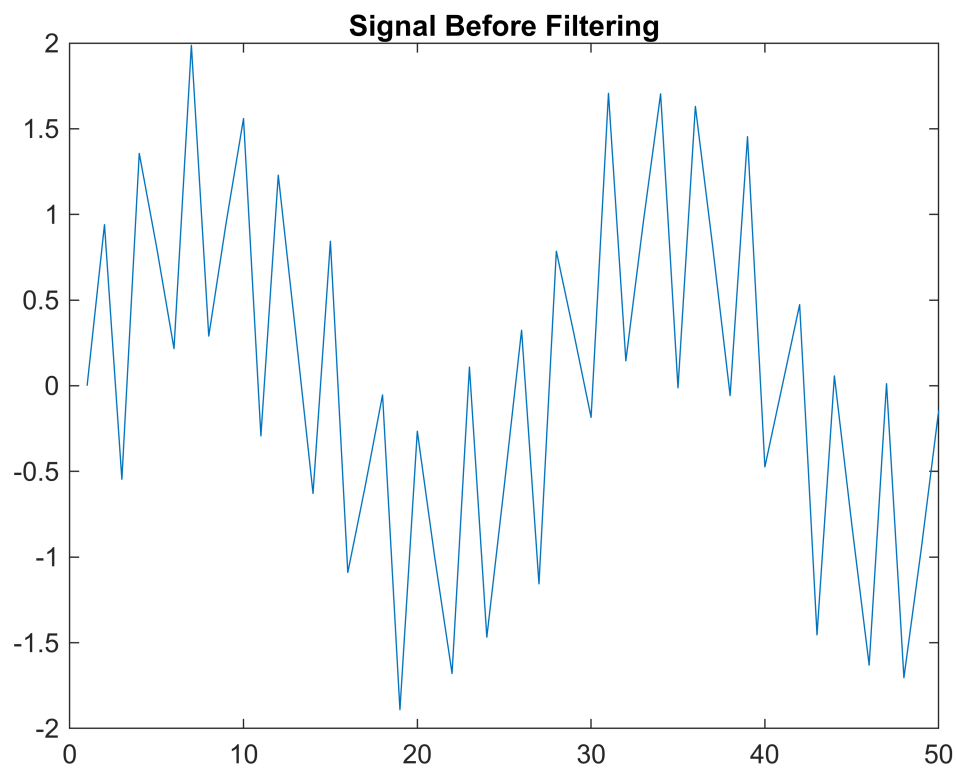
signal = sin(2*pi * freq1/sampleFreq * [0:1013]) + sin(2*pi * freq2/sampleFreq *
[0:1013]);

% convolution output length will be 1014 + 11 - 1 = 1024
% have to pad each sequence to 1024 samples
convLength = length(signal) + length(impResp) - 1;

inputPad = fft(signal.', convLength);
impulsePad = fft(impResp.', convLength);

% perform frequency domain convolution
convFreq = inputPad .* impulsePad;

% plot time domain signal
figure
plot(signal)
title("Signal Before Filtering")
xlim([0 50])
```



```
figure
plot(iffreq(convFreq))
title("Signal After Filtering")
xlim([0 50])
```

