% Tune-Up Tuesday #8 for October 30, 2018

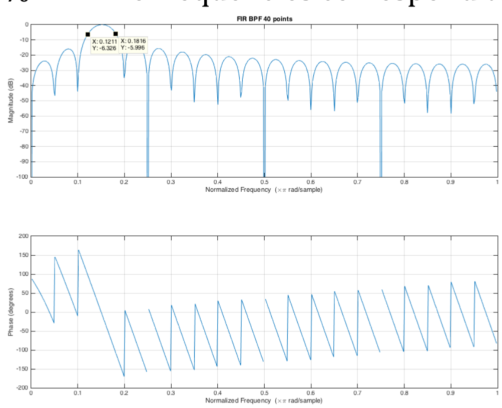
% (a) Define impulse response $h_{40}[n]$ of a bandpass filter (BPF).
% It is a finite impulse response with 40 coefficients with
% center frequency of 600 Hz. Sampling rate is 8000 Hz.

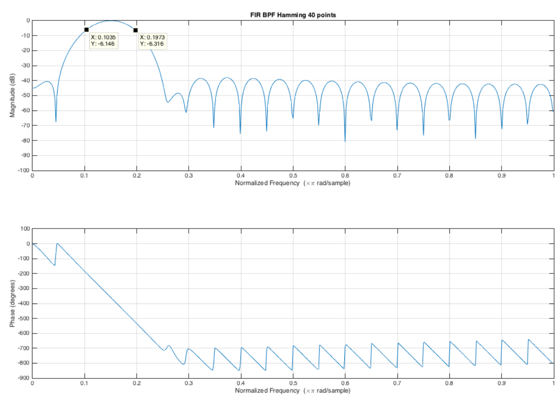
```
fs = 8000;
fA = 600;
wA = 2*pi*fA/fs;  % discrete-time frequency for 600 Hz
L = 40;
n = 0 : L-1;      % vector of n values to consider
h40 = (2/L)*cos(wA*n);
```

% (b) Plot the magnitude response. What is the bandwidth?

```
freqz(h40); title('FIR BPF 40 points'); ylim( [-100 0] );
```

% **Answer**: The freqz command plots the magnitude in dB using $A_{\mathrm{dB}} = 20 \log_{10} |A|$:
% |A| A_{dB} |A| A_{dB} |A| A_{dB}
% 1.0 0dB 0.5 -6dB 0.0 -infinity
% Bandwidth is the extent in positive frequencies.
% For a bandpass filter, one way to measure bandwidth is to find the two frequencies
% with magnitude values that are 6 dB down from the maximum magnitude, or
% equivalently, 0.5 times full amplitude in linear units.
% By using the data cursor tool, discrete-time frequency values are 0.12*pi and
% 0.18*pi in rad/sample. Bandwidth = 0.06*pi rad/sample. See left plot below.
% The frequencies correspond to 480 Hz and 720 Hz. Bandwidth = 240 Hz.





% (c) Plot the magnitude/phase response for the 40-point BPF
% based on the Hamming window. What is the bandwidth?
% How does it compare to part (b)?

```
hammingL = hamming(L)';    %% hamming(L) is Lx1
C = 3.78177 / L;           %% normalize max mag to 1
h40hamming = C*hammingL.*cos(wA*n);
figure; freqz(h40hamming);
title('FIR BPF Hamming 40 points'); ylim( [-100 0] );
```

% **Answer:** By using the method to compute the bandwidth in (b), the -6 dB down
% discrete-time frequencies are 0.103*pi and 0.197*pi in rad/sample.
% Bandwidth = 0.094*pi rad/sample. See right plot on previous page
% The frequencies correspond to 412 Hz and 788 Hz. Bandwidth = 376 Hz.

% (d) Below $x[n]$ contains a C major scale over two octaves.
%   It might sound louder as the principal frequency increases.

```
C4 =  261.63;
D4 =  293.67;
E4 =  329.63;
F4 =  349.23;
G4 =  392.00;
A4 =  440.00;
B4 =  493.88;
C5 =  523.25;
D5 =  587.33;
E5 =  659.26;
F5 =  698.26;
G5 =  783.99;
A5 =  880.00;
B5 =  987.77;
C6 = 1046.50;
f = [C4,D4,E4,F4,G4,A4,B4,C5,D5,E5,F5,G5,A5,B5,C6];
bpm = 60;
beattime = 60/bpm;
fs = 8000;
Ts = 1/fs;
N = beattime/Ts;
t = 0 : Ts : (N-1)*Ts;
Tmax = beattime*length(f);
x = zeros(1, length(f)*N);
for i = 1:length(f)
    note = exp(-t/0.5).*cos(2*pi*f(i)*t);
    x((i-1)*N+1 : i*N) = note;
end
sound(x, fs); pause(Tmax+1);
```

% (e) Filter $x[n]$ with the 40-point Hamming BPF.
%   How does the filter output sound compared to (d).

```
% Superimpose note frequencies on BPF magnitude response
[H, W] = freqz(h40hamming);
figure; hold on;
plot(W, abs(H));
H2 = freqz(h40hamming, 1, 2*pi*f/fs);
stem(2*pi*f/fs, abs(H2), 'r.');
xlabel('Normalized frequency (x \pi rad/sample)');
xlim( [0 1] ); hold off;

display 'hit any key for playback of filter output'
pause
y = filter(h40hamming, 1, x);
sound(y, fs);
```

% **Answer:** The amplitude of each note has been scaled by the magnitude response of
% the filter. The notes increase in amplitude, and then decrease in amplitude.