भारतीय प्रौद्योगिकी संस्थान तिरुपति

TIRUPATI

ADVANCED SIGNAL ANALYSIS AND PROCESSING LAB

Lab sheet. No: 08

NAME: Pedasingu Rajesh **Roll. No:** EE21M019

Q1. Design a low-pass FIR filter whose cut-off frequency is 1,000 Hz using the Hamming window function for the following specified filter lengths. Assume that the sampling frequency is 8,000 Hz.

(a) 21 filter coefficients

(b) 31 filter coefficients

(c) 41 filter coefficients.

List FIR filter coefficients for each design and compare the magnitude frequency responses.

AIM: To design the low-pass FIR filter using hamming window for different length of filter coefficients. And plot the frequency response.

Short Theory:

In signal processing, a finite impulse response (FIR) filter is a filter whose impulse response (or response to any finite length input) is of finite duration, because it settles to zero in finite time. This is in contrast to infinite impulse response (IIR) filters, which may have internal feedback and may continue to respond indefinitely (usually decaying).

A window function is a symmetrical function which can gradually weight the designed FIR coefficients down to zeros at both ends of for the range $-M \leq n \leq M$. Applying the window sequence to the filter coefficients gives

$$h_w(n) = h(n) \cdot w(n)$$

where, $w(n)$ designates the window function. Commonly used window functions in FIR filters are:

1. Rectangular Window: $$w_{rec}(n) = 1, \qquad -M \le n \le M$$
2. Triangular (Bartlett) Window: $$w_{tri}(n) = 1 - \frac{\lvert n \rvert}{M}, \qquad -M \le n \le M$$
3. Hanning Window: $$w_{han}(n) = 0.5 + 0.5\cos\left(\frac{n\pi}{M}\right), \qquad -M \le n \le M$$
Hamming Window: $$w_{ham}(n) = 0.54 + 0.46\cos\left(\frac{n\pi}{M}\right), \qquad -M \le n \le M$$
5. Blackman Window: $$w_{black}(n) = 0.42 + 0.5\cos\left(\frac{n\pi}{M}\right) + 0.08\cos\left(\frac{2n\pi}{M}\right), \qquad -M \le n \le M$$

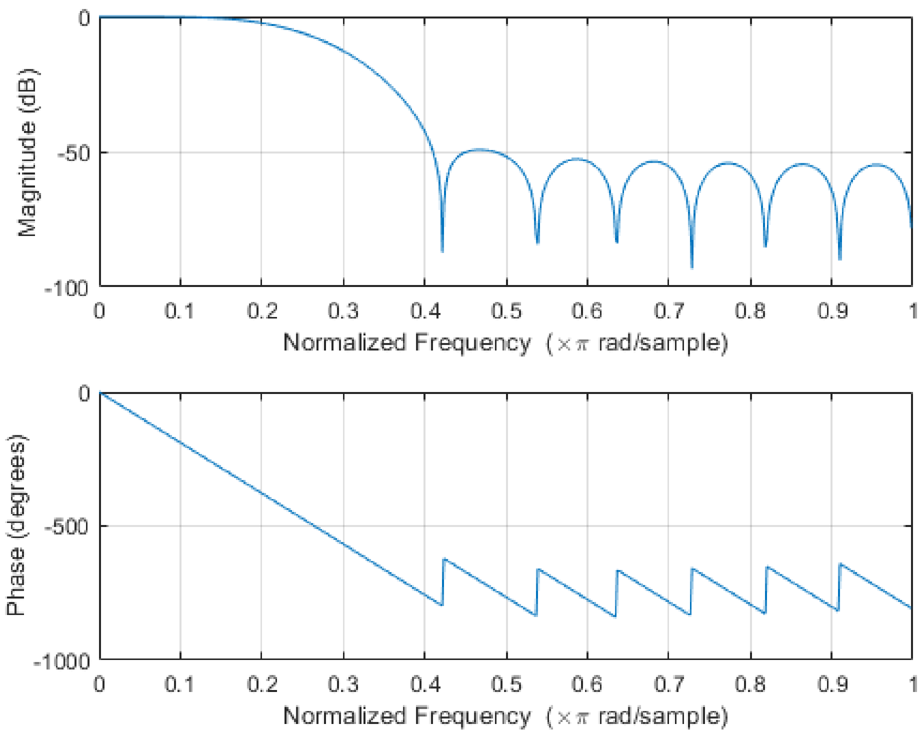
Key Commands:

Fir1 % fir1(n,Wn) uses a Hamming window to design an nth-order lowpass, bandpass, or multiband FIR filter with linear phase. The filter type depends on the number of elements of Wn.

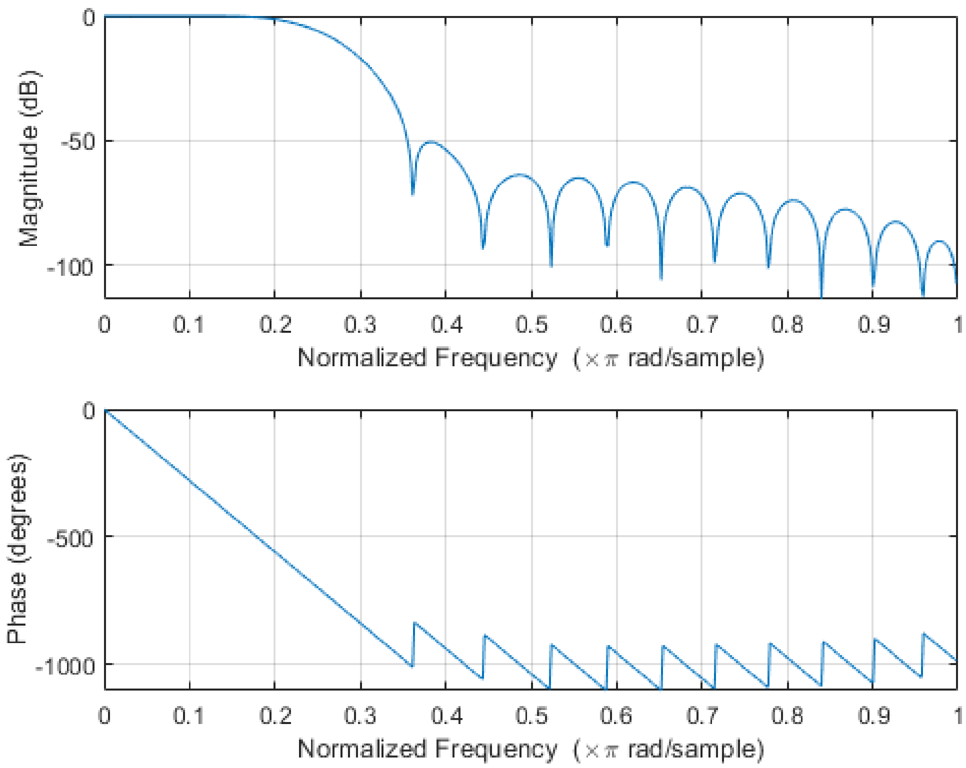
Freqz % freqz(b,a,n) returns the n-point frequency response vector h and the corresponding angular frequency vector w for the digital filter with transfer function coefficients stored in b and a.

Plots:

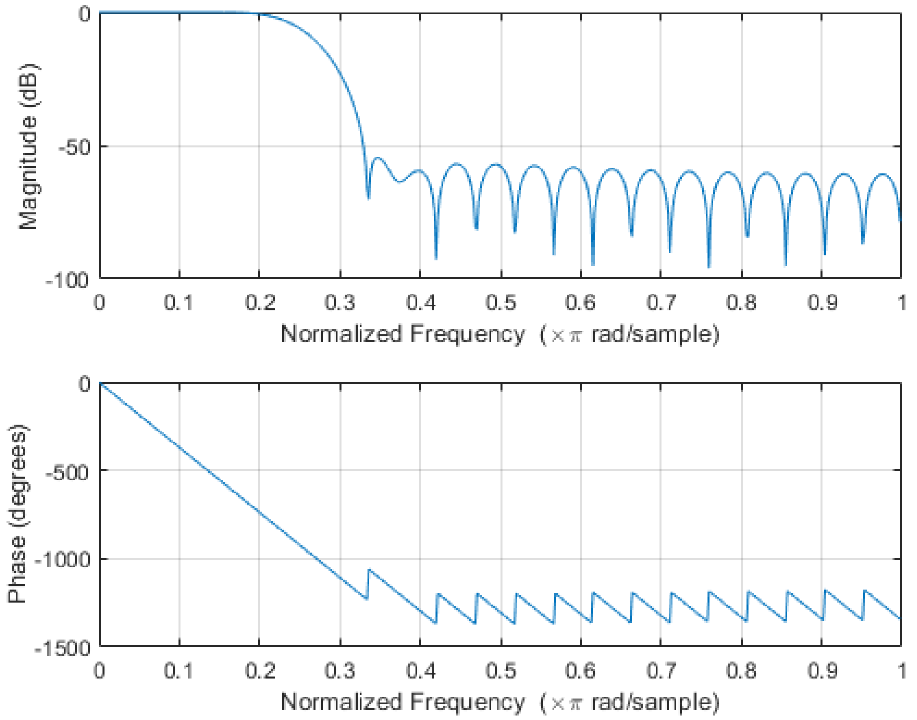
a) Low pass hamming window with a length 21.



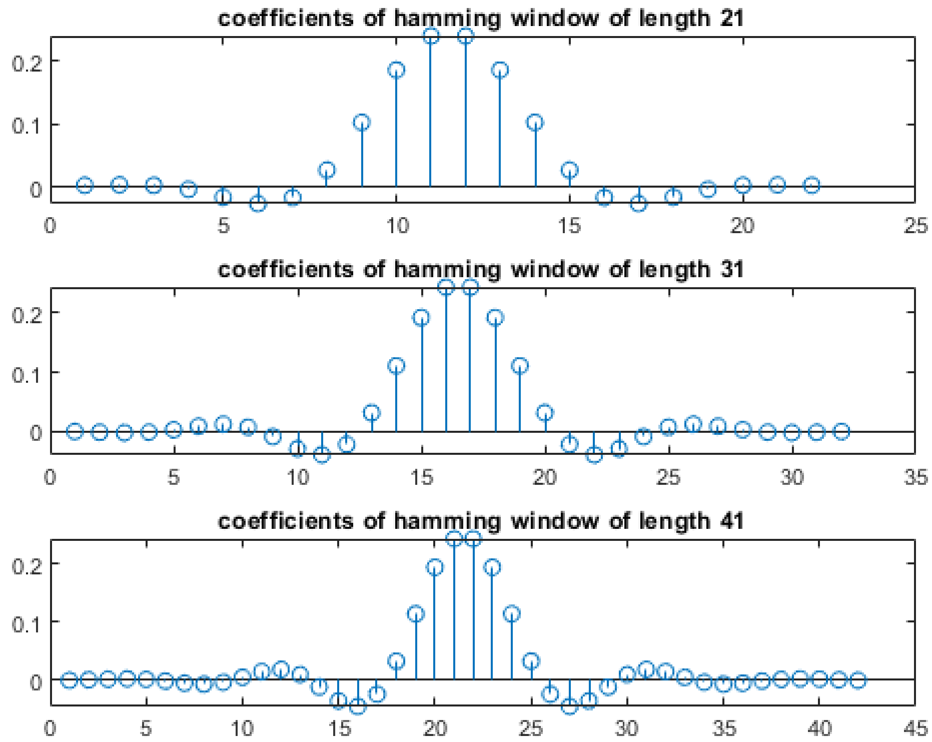
b) Low pass hamming window with a length 31.



c) Low pass hamming window with a length 41.



d) The impulse response of the above 3 window functions..



Inferences/comments:

1) Hamming window function coefficient's with a length 21, 31, 41 are b1, b2, b3 respectively.

b1	**[0.0022 0.0031 0.0023 -0.0041 -0.0168 -0.0269 -0.0173 0.0267 0.1028 0.1865 0.2415 0.2415 0.1865 0.1028 0.0267 -0.0173 -0.0269 -0.0168 -0.0041 0.0023 0.0031 0.0022]**
b2	**[-0.0006 -0.0018 -0.0026 -0.0016 0.0024 0.0083 0.0118 0.0068 -0.0092 -0.0297 -0.0398 -0.0223 0.0310 0.1111 0.1925 0.2437 0.2437 0.1925 0.1111 0.0310 -0.0223 -0.0398 -0.0297 -0.0092 0.0068 0.0118 0.0083 0.0024 -0.0016 -0.0026 -0.0018 -0.0006]**
b3	**[-0.0005 0.0005 0.0016 0.0021 0.0012 -0.0016 -0.0053 -0.0070 -0.0037 0.0048 0.0146 0.0183 0.0095 -0.0118 -0.0357 -0.0452 -0.0242 0.0325 0.1135 0.1934 0.2429 0.2429 0.1934 0.1135 0.0325 -0.0242 -0.0452 -0.0357 -0.0118 0.0095 0.0183 0.0146 0.0048 -0.0037 -0.0070 -0.0053 -0.0016 0.0012 0.0021 0.0016 0.0005 -0.0005]**

2) Length of the filter coefficient increases then the width of the main lobe is decreases.

3) Length of the filter coefficient increases then the number of side lobes also increases.

Q2. Design a 31-tap high-pass FIR filter whose cut-off frequency is 2,500 Hz using the following window functions. Assume that the sampling frequency is 8,000 Hz.

(a) Hanning window function

(b) Hamming window function

(c) Blackman window function.

List the FIR filter coefficients and plot the frequency responses for each design.

AIM: To design 31-tap high-pass FIR filter using hamming window , hanning window, blackman window. And plot the frequency response.

Short Theory:

In signal processing, a finite impulse response (FIR) filter is a filter whose impulse response (or response to any finite length input) is of finite duration, because it settles to zero in finite time. This is in contrast to infinite impulse response (IIR) filters, which may have internal feedback and may continue to respond indefinitely (usually decaying).

A window function is a symmetrical function which can gradually weight the designed FIR coefficients down to zeros at both ends of for the range $-\boldsymbol{M} \leq \boldsymbol{n} \leq \boldsymbol{M}$. Applying the window sequence to the filter coefficients gives

$$\boldsymbol{h_w(n) = h(n) \cdot w(n)}$$

where, $\boldsymbol{w(n)}$ designates the window function. Commonly used window functions in FIR filters are:

1. Rectangular Window: $$w_{rec}(n) = 1, \qquad -M \le n \le M$$
2. Triangular (Bartlett) Window: $$w_{tri}(n) = 1 - \frac{\lvert n \rvert}{M}, \qquad -M \le n \le M$$
3. Hanning Window: $$w_{han}(n) = 0.5 + 0.5\cos\left(\frac{n\pi}{M}\right), \qquad -M \le n \le M$$
Hamming Window: $$w_{ham}(n) = 0.54 + 0.46\cos\left(\frac{n\pi}{M}\right), \qquad -M \le n \le M$$
5. Blackman Window: $$w_{black}(n) = 0.42 + 0.5\cos\left(\frac{n\pi}{M}\right) + 0.08\cos\left(\frac{2n\pi}{M}\right), \qquad -M \le n \le M$$

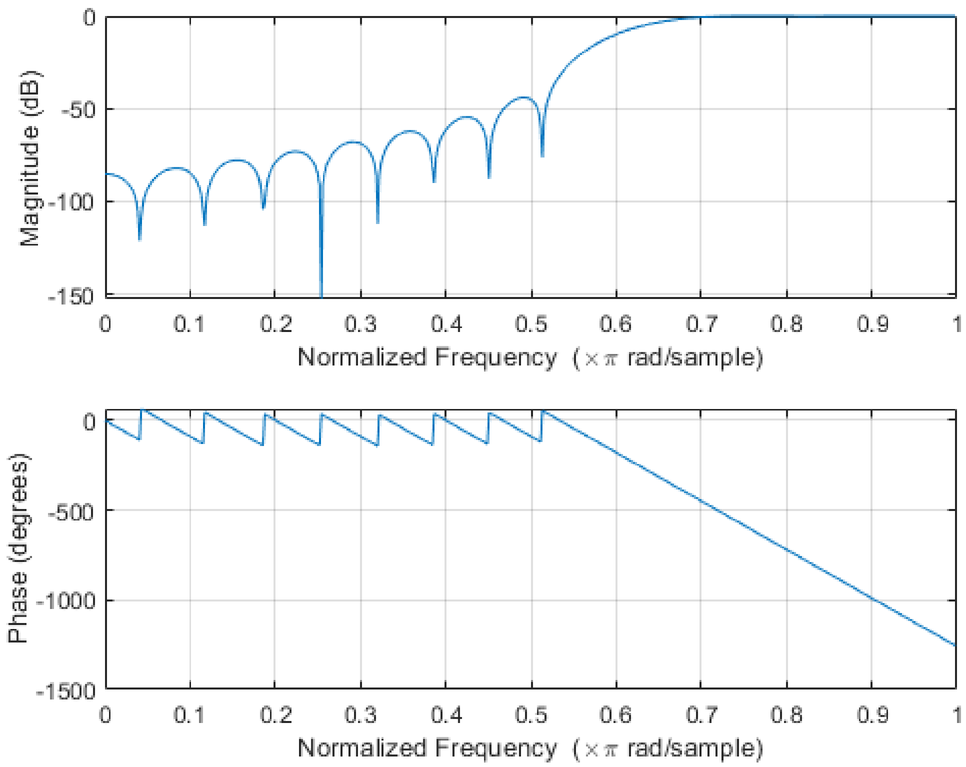
Key Commands:

Fir1 % fir1(n,Wn) uses a Hamming window to design an nth-order lowpass, bandpass, or multiband FIR filter with linear phase. The filter type depends on the number of elements of Wn.

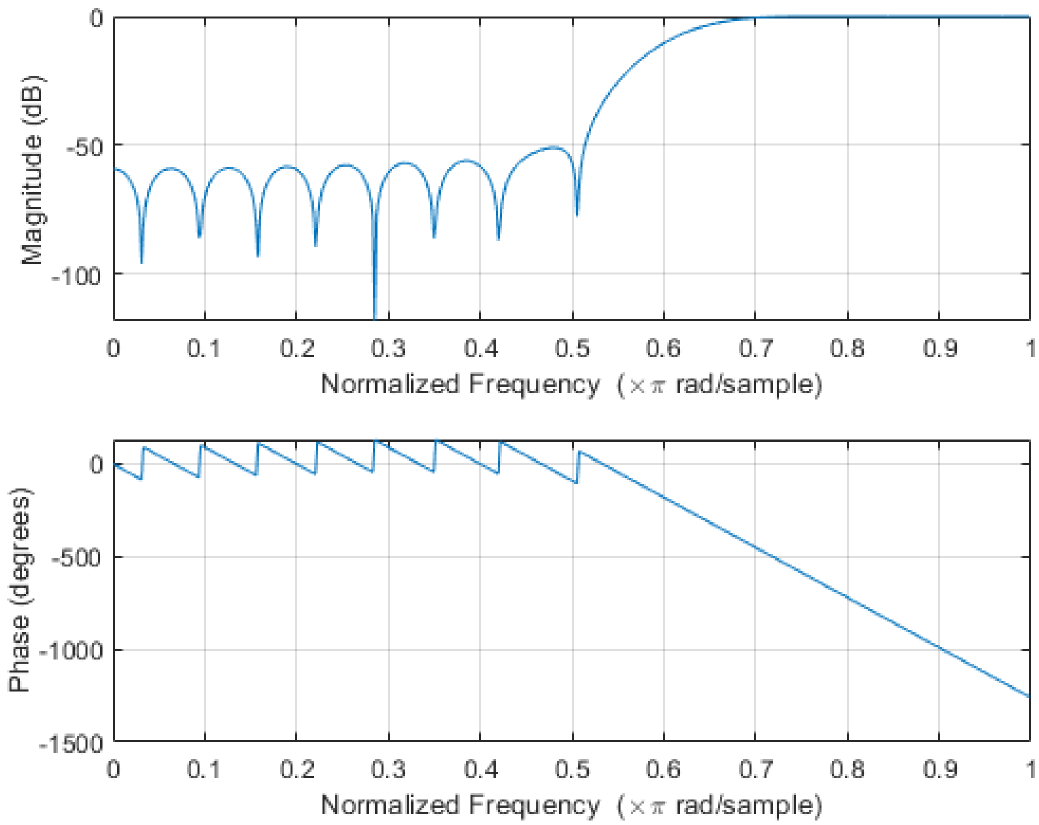
Freqz % freqz(b,a,n) returns the n-point frequency response vector h and the corresponding angular frequency vector w for the digital filter with transfer function coefficients stored in b and a.

Plots:

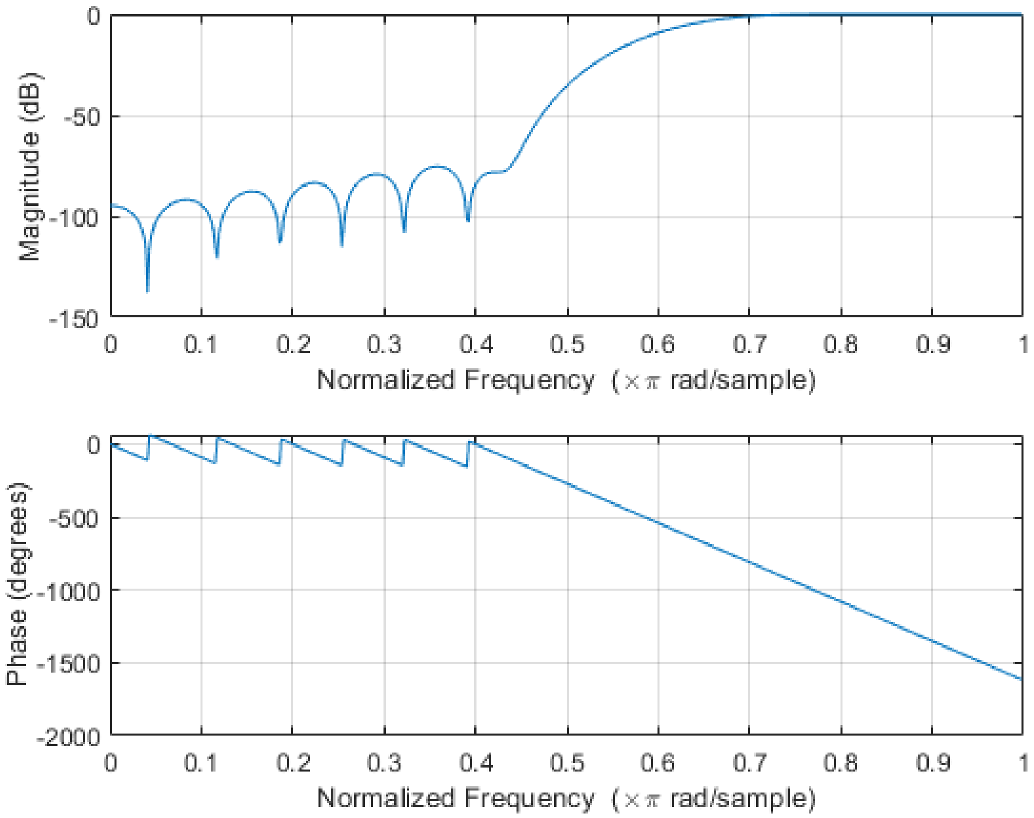
a) high pass hanning window with a length 31.



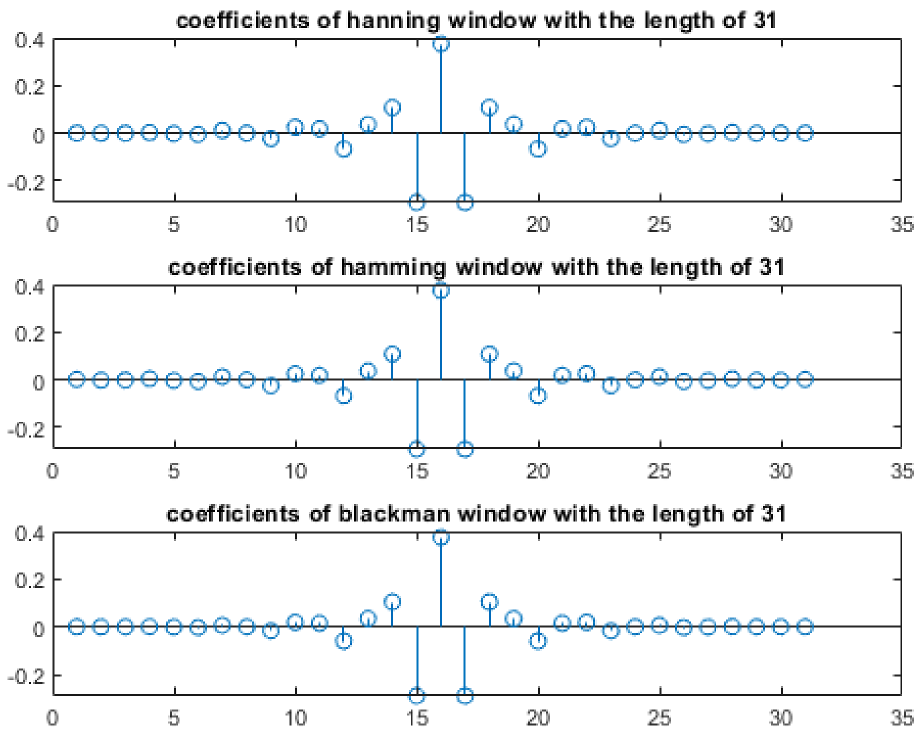
b) high pass hamming window with a length 31.



c) high pass blackman window with a length 31.



d) The impulse response of the above 3 window functions..



Inferences/comments:

1) b1,b2,b3 are the coefficients of high pass FIR filter with hanning , hamming , blackman window with a length of 31 respectively .

b1	**[0 -0.0002 -0.0004 0.0025 -0.0018 -0.0056 0.0113 -0.0000 -0.0232 0.0245 0.0183 -0.0664 0.0367 0.1077 -0.2908 0.3750 -0.2908 0.1077 0.0367 -0.0664 0.0183 0.0245 -0.0232 -0.0000 0.0113 -0.0056 -0.0018 0.0025 -0.0004 -0.0002 0]**
b2	**[0.0016 -0.0015 -0.0011 0.0045 -0.0026 -0.0070 0.0130 -0.0000 -0.0248 0.0256 0.0188 -0.0676 0.0371 0.1083 -0.2918 0.3758 -0.2918 0.1083 0.0371 -0.0676 0.0188 0.0256 -0.0248 -0.0000 0.0130 -0.0070 -0.0026 0.0045 -0.0011 -0.0015 0.0016]**
b3	**[0 -0.0001 -0.0002 0.0011 -0.0009 -0.0029 0.0066 -0.0000 -0.0166 0.0191 0.0153 -0.0594 0.0345 0.1047 -0.2888 0.3750 -0.2888 0.1047 0.0345 -0.0594 0.0153 0.0191 -0.0166 -0.0000 0.0066 -0.0029 -0.0009 0.0011 -0.0002 -0.0001 0]**

2) for the same length of window , blackman window has the highest relative peak side load, when compared with hamming and hanning window techniques.

Q3. Design a 41-tap bandpass FIR filter with the lower and upper cut-off frequencies being 2,500 Hz and 3,000 Hz, respectively, using the following window functions. Assume a sampling frequency of 8,000 Hz.

(a) Hanning window function

(b) Blackman window function.

List the FIR filter coefficients and plot the frequency responses for each design.

AIM: To Design a 41-tap bandpass FIR filter for a given lower and upper cut-off frequencies using Hanning window function, Blackman window function. And plot the frequency response.

Short Theory:

In signal processing, a finite impulse response (FIR) filter is a filter whose impulse response (or response to any finite length input) is of finite duration, because it settles to zero in finite time. This is in contrast to infinite impulse response (IIR) filters, which may have internal feedback and may continue to respond indefinitely (usually decaying).

A window function is a symmetrical function which can gradually weight the designed FIR coefficients down to zeros at both ends of for the range $-\boldsymbol{M} \leq \boldsymbol{n} \leq \boldsymbol{M}$. Applying the window sequence to the filter coefficients gives

$$\boldsymbol{h_w(n) = h(n) \cdot w(n)}$$

where, $\boldsymbol{w(n)}$ designates the window function. Commonly used window functions in FIR filters are:

1. Rectangular Window: $$w_{rec}(n) = 1, \qquad -M \le n \le M$$
2. Triangular (Bartlett) Window: $$w_{tri}(n) = 1 - \frac{\lvert n \rvert}{M}, \qquad -M \le n \le M$$
3. Hanning Window: $$w_{han}(n) = 0.5 + 0.5\cos\left(\frac{n\pi}{M}\right), \qquad -M \le n \le M$$
Hamming Window: $$w_{ham}(n) = 0.54 + 0.46\cos\left(\frac{n\pi}{M}\right), \qquad -M \le n \le M$$
5. Blackman Window: $$w_{black}(n) = 0.42 + 0.5\cos\left(\frac{n\pi}{M}\right) + 0.08\cos\left(\frac{2n\pi}{M}\right), \qquad -M \le n \le M$$

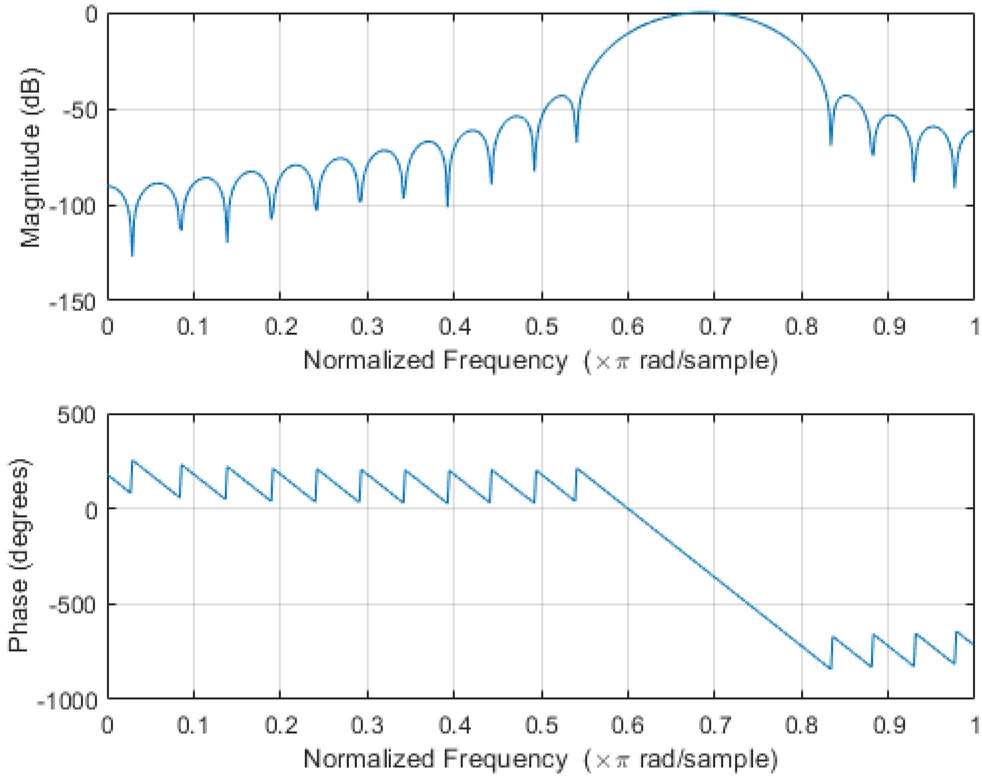
Key Commands:

Fir1 % fir1(n,Wn) uses a Hamming window to design an nth-order lowpass, bandpass, or multiband FIR filter with linear phase. The filter type depends on the number of elements of Wn.

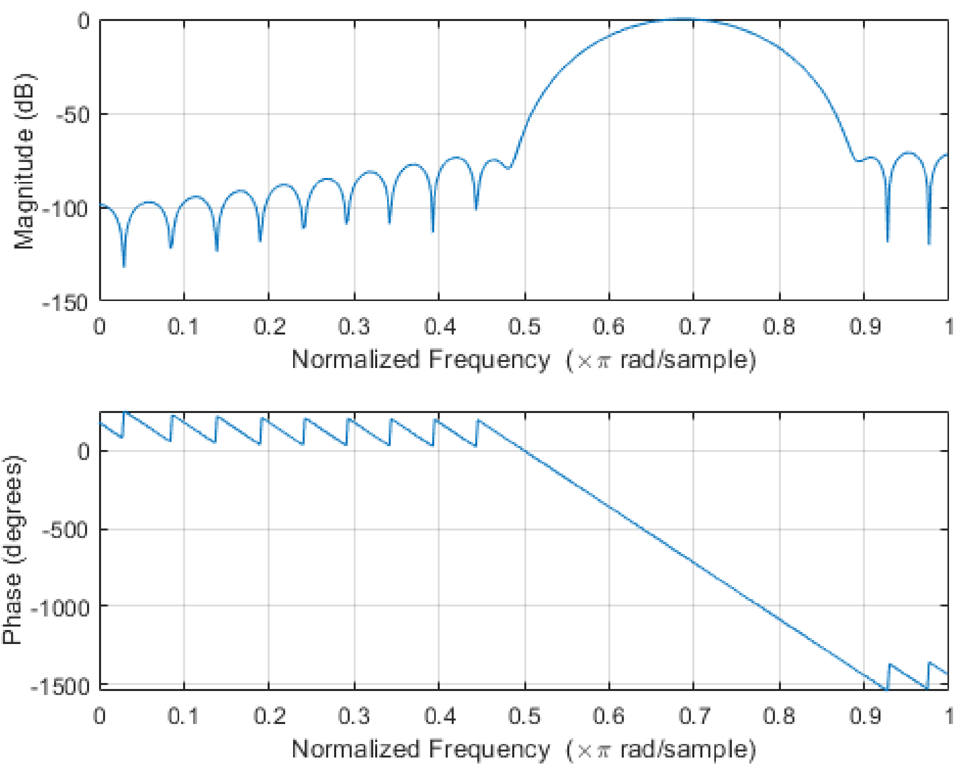
Freqz % freqz(b,a,n) returns the n-point frequency response vector h and the corresponding angular frequency vector w for the digital filter with transfer function coefficients stored in b and a.

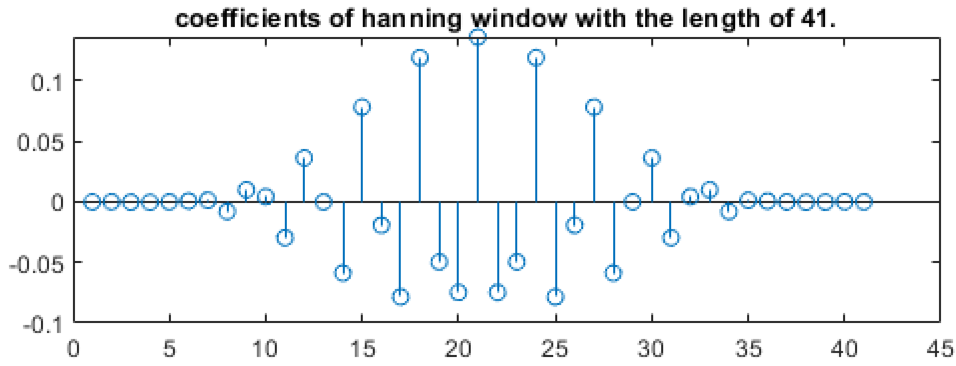
Plots:

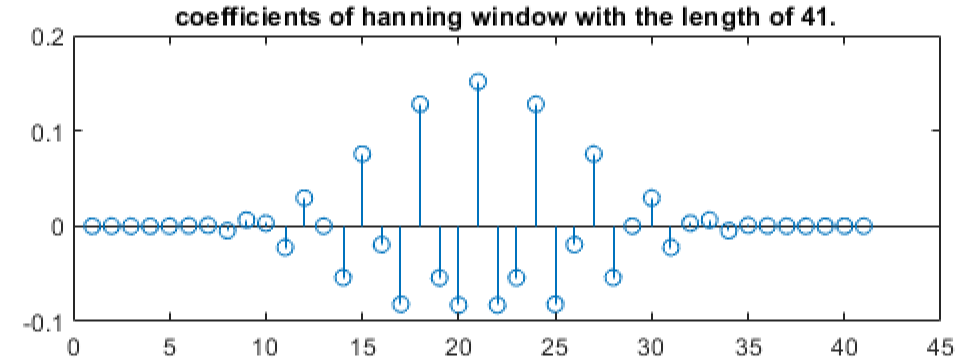
a) band pass hanning window with a length 41.



b) band pass blackman window with a length 41.







Inferences/comments:

1) b1,b2 are the coefficients of band pass FIR filter with hanning, blackman window with a length of 41 respectively .

b1	**[0 0.0001 -0.0001 -0.0002 -0.0000 0.0007 0.0015 -0.0079 0.0100 0.0043 -0.0296 0.0364 -0.0000 -0.0588 0.0784 -0.0192 -0.0785 0.1192 -0.0496 -0.0748 0.1363 -0.0748 -0.0496 0.1192 -0.0785 -0.0192 0.0784 -0.0588 -0.0000 0.0364 -0.0296 0.0043 0.0100 -0.0079 0.0015 0.0007 -0.0000 -0.0002 -0.0001 0.0001 0]**
b2	**[0 0.0000 -0.0001 -0.0001 -0.0000 0.0004 0.0008 -0.0047 0.0065 0.0030 -0.0224 0.0295 -0.0000 -0.0540 0.0757 -0.0194 -0.0819 0.1279 -0.0543 -0.0828 0.1516 -0.0828 -0.0543 0.1279 -0.0819 -0.0194 0.0757 -0.0540 -0.0000 0.0295 -0.0224 0.0030 0.0065 -0.0047 0.0008 0.0004 -0.0000 -0.0001 -0.0001 0.0000 0]**

2) for the same length of window , blackman window has the highest relative peak side load, when compared with hanning window techniques.

Q4. In a speech recording system with a sampling rate of 10,000 Hz, the speech is corrupted by broadband random noise. To remove the random noise while preserving

speech information, the following specifications are given:
Speech frequency range = 0 - 3000 Hz
Stop-band range = 4000 - 5000 Hz
Passband ripple = 0.1 dB
Stop-band attenuation = 45 dB

Determine the FIR filter length (number of taps) and the cut-off frequency; use MATLAB to design the filter; and plot the frequency response.

AIM: To Design a lowpass FIR filter for a given specifications and determine the filter length and the cut-off frequency by using the given filter specifications. And plot the frequency response.

Short Theory:

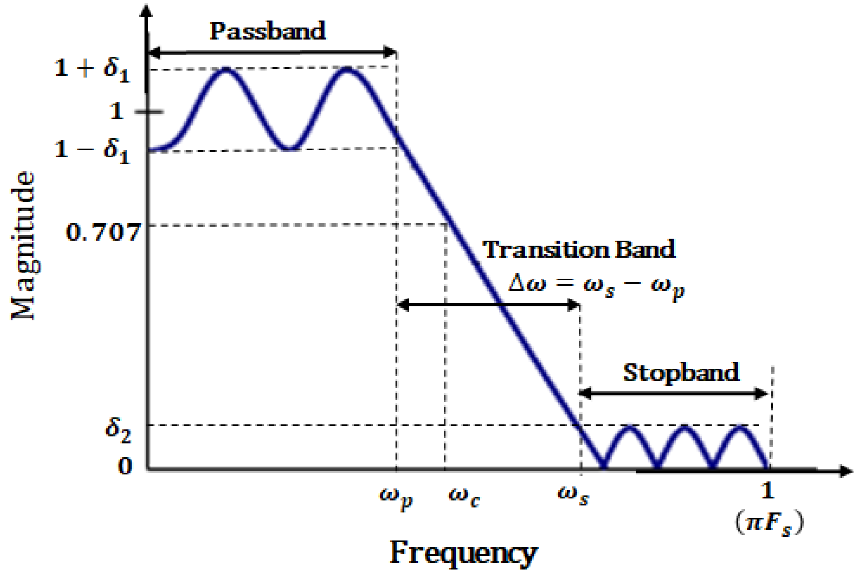
the required passband ripples specification and stopband attenuation, the appropriate window length can be estimated based on the performances of the window functions. For illustrative purpose, we use the lowpass filter frequency domain specification (the same can be extended to other types of filter specifications).

The normalized transition band frequency is defined as

$$\Delta f = \left|f_{stop} - f_{pass}\right|/f_s$$

Based on this, the FIR filter lengths for various window functions are given in Table 7.7 below. It can be noted that the cutoff frequency is determined by

$$f_c = \left(f_{stop} - f_{pass}\right)/2$$



The passband ripple is defined as

$$\delta_p\ dB = 20 \cdot \log_{10}(1+\delta_p)$$

while the stopband attenuation is defined as

$$\delta_s\ dB = -20 \cdot \log_{10}(\delta_s)$$

Filter length estimation using window ($\Delta f = |f_{stop} - f_{pass}|/f_s$)

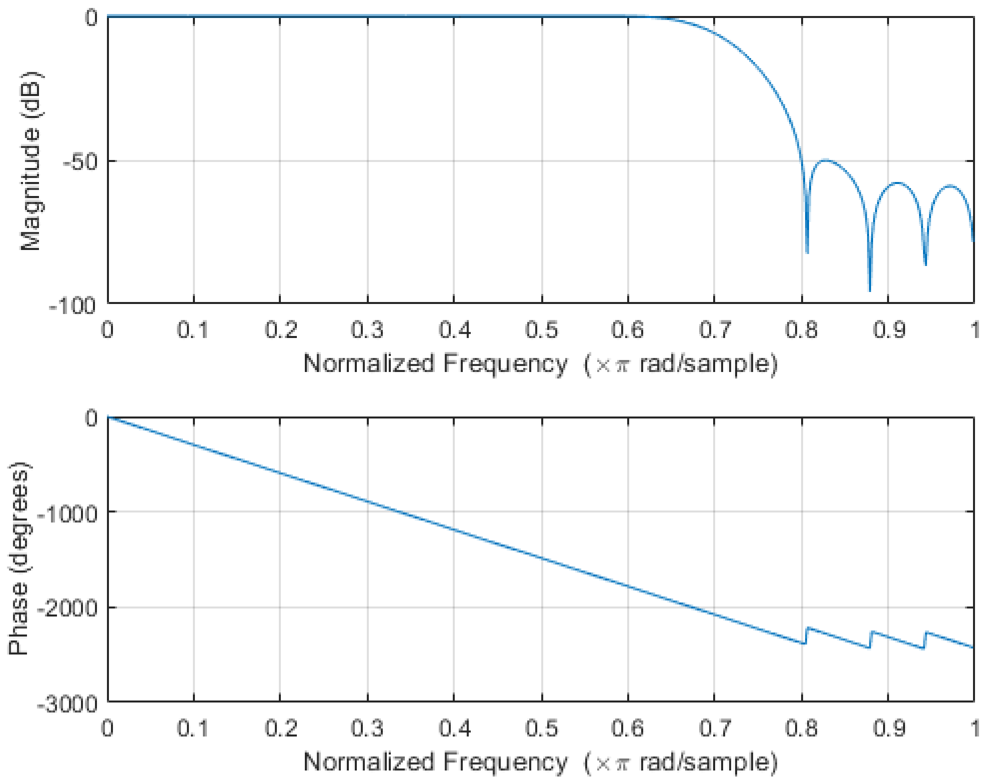
Window Type	Window Function $w(n)$, $-M \le n \le M$	Window Length	Passband Ripple (dB)	Stopband Attenuation (dB)
Rectangular	1	$N = 0.9/\Delta f$	0.7416	21
Hanning	$0.5 + 0.5\cos\left(\frac{n\pi}{M}\right)$	$N = 3.1/\Delta f$	0.0546	44
Hamming	$0.54 + 0.46\cos\left(\frac{n\pi}{M}\right)$	$N = 3.3/\Delta f$	0.0194	53
Blackman	$0.42 + 0.5\cos\left(\frac{n\pi}{M}\right) + 0.08\cos\left(\frac{2n\pi}{M}\right)$	$N = 5.5/\Delta f$	0.0017	74

Key Commands:

Fir1 % fir1(n,Wn) uses a Hamming window to design an nth-order lowpass, bandpass, or multiband FIR filter with linear phase. The filter type depends on the number of elements of Wn.

Freqz % freqz(b,a,n) returns the n-point frequency response vector h and the corresponding angular frequency vector w for the digital filter with transfer function coefficients stored in b and a.

Plots:



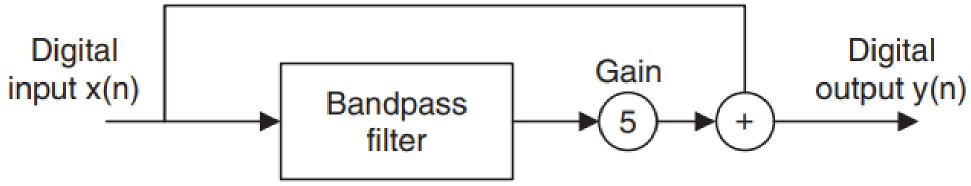
Inferences/comments:

1) first we decide the appropriate window technique from the passband ripple to stopband attenuation . for a given question we use a hamming window technique.

2) length filter window can be determined by using passband and stop band cut of frequencies. I,e ($\Delta \boldsymbol{f} = |\boldsymbol{f}_{stop} - \boldsymbol{f}_{pass}|/\boldsymbol{f}_s$) and ($\boldsymbol{N} = \mathbf{3.3}/\Delta \boldsymbol{f}$).

3) for a given specifications , the length of the filter = 33 . and cut-off frequency = 0.7π *rad/samples.*

Q5. Given a speech equalizer shown in Figure 1 to compensate midrange frequency loss of hearing:



Sampling rate = 8,000 Hz
Bandpass FIR filter with Hamming window
Frequency range to be emphasized = 1,500-2,000 Hz
Lower stop-band = 0-1,000 Hz
Upper stop-band = 2,500-4,000 Hz
Passband ripple = 0.1 dB
Stop-band attenuation = 45 dB,

Determine the filter length and the lower and upper cut-off frequencies

AIM: To Design a lowpass FIR filter for a given specifications and determine the filter length and the cut-off frequency by using the given filter specifications. And plot the frequency response.

Short Theory:

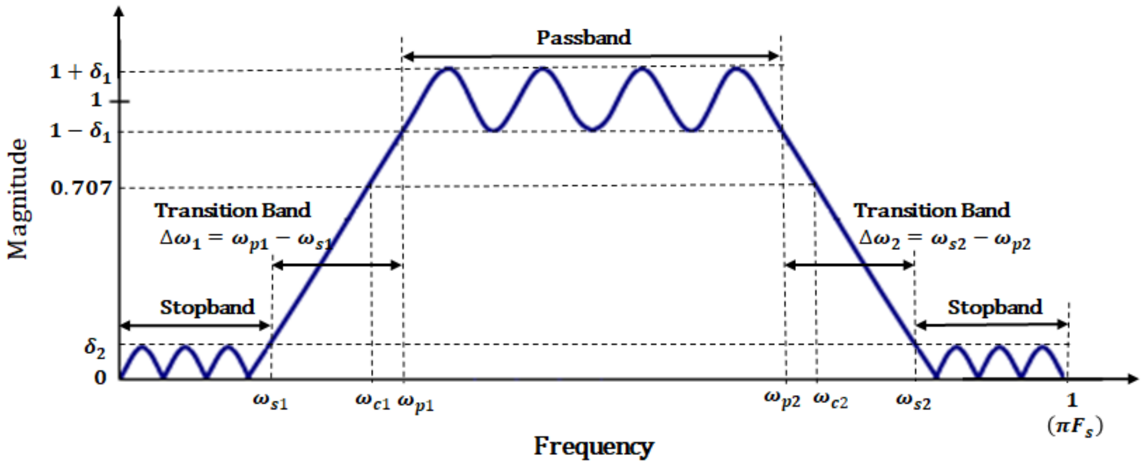
the required passband ripples specification and stopband attenuation, the appropriate window length can be estimated based on the performances of the window functions. For illustrative purpose, we use the lowpass filter frequency domain specification (the same can be extended to other types of filter specifications).

The normalized transition band frequency is defined as

$$\Delta f = |f_{stop} - f_{pass}|/f_s$$

Based on this, the FIR filter lengths for various window functions are given in Table 7.7 below. It can be noted that the cutoff frequency is determined by

$$f_c = (f_{stop} - f_{pass})/2$$



The passband ripple is defined as

$$\delta_p\, dB = 20 \cdot \log_{10}(1+\delta_p)$$

while the stopband attenuation is defined as

$$\delta_s\, dB = -20 \cdot \log_{10}(\delta_s)$$

Filter length estimation using window ($\Delta f = |f_{stop} - f_{pass}|/f_s$)

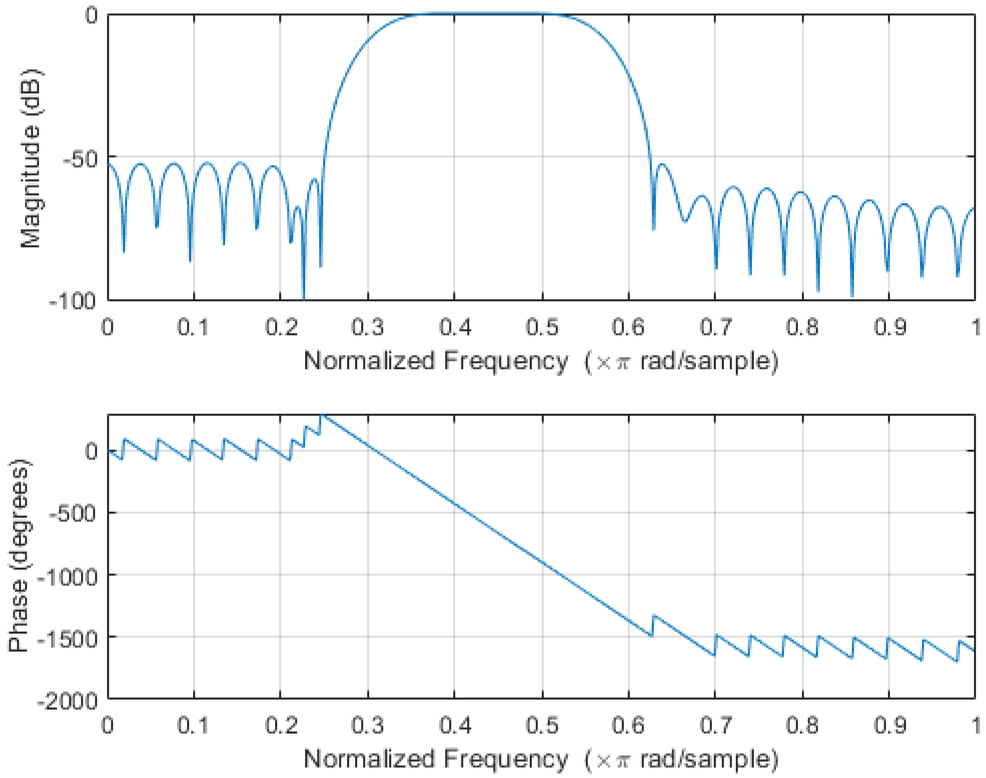
Window Type	Window Function $w(n)$, $-M \le n \le M$	Window Length	Passband Ripple (dB)	Stopband Attenuation (dB)
Rectangular	1	$N = 0.9/\Delta f$	0.7416	21
Hanning	$0.5 + 0.5\cos\left(\frac{n\pi}{M}\right)$	$N = 3.1/\Delta f$	0.0546	44
Hamming	$0.54 + 0.46\cos\left(\frac{n\pi}{M}\right)$	$N = 3.3/\Delta f$	0.0194	53
Blackman	$0.42 + 0.5\cos\left(\frac{n\pi}{M}\right) + 0.08\cos\left(\frac{2n\pi}{M}\right)$	$N = 5.5/\Delta f$	0.0017	74

Key Commands:

Fir1 % fir1(n,Wn) uses a Hamming window to design an nth-order lowpass, bandpass, or multiband FIR filter with linear phase. The filter type depends on the number of elements of Wn.

Freqz % freqz(b,a,n) returns the n-point frequency response vector h and the corresponding angular frequency vector w for the digital filter with transfer function coefficients stored in b and a.

Plots:



Inferences/comments:

1) first we decide the appropriate window technique from the passband ripple to stopband attenuation . for this question we use a hamming window technique.

2) length filter window can be determined by using passband and stop band cut of frequencies. I,e ($\Delta \boldsymbol{f} = |\boldsymbol{f}_{stop} - \boldsymbol{f}_{pass}|/\boldsymbol{f}_s$) and ($\boldsymbol{N} = \mathbf{3.3}/\Delta \boldsymbol{f}$).

3) For a given specifications, the length of the filter = 53 . and lower cut-off frequency = 0.3125 π *rad/samples* and upper cut-off frequency = 0.5625 π *rad/samples*