Tutorial 4 EE4C5

Q1

As an intern in a bioacoustics lab, you are tasked with designing a discrete-time bandpass filter for processing audio recordings of bat echolocation signals. The filter should attenuate frequencies below 20 kHz to suppress low-frequency ambient noise, while preserving the critical frequency range of 20 kHz to 200 kHz, where bat calls are prominent. The sampling rate used is 500 kHz.

Determine a suitable set of specifications for this filter. Justify your choice of filter parameters.

Sketch the target magnitude response in radians or normalised frequency, labelling all important features.

Q2

Users of your music streaming service have reported issues with distortion in the bass frequencies of certain tracks, especially during playback on smaller speakers. Propose a specification of a digital filter to address this problem by attenuating frequencies below 80 Hz while minimizing the impact on the rest of the audio spectrum. Assume the music sampling frequency is 44.1 kHz

Determine a suitable set of specifications for this filter. Justify your choice of filter parameters.

Sketch the target magnitude response in radians or normalised frequency, labelling all important features.

Use the Filter Designer toolbox in MATLAB to explore the tradeoffs encountered in designing this filter to have a narrow transition region. What order filter is required if using an FIR filter designed using the windowing method with a Kaiser window? If you reduce the order to 16, can you get close to your requirements?

Q3

The table below (from Section 5.1 in the O&S textbook) shows the properties of various windows we have considered in lectures for the windowing method in FIR filter design.

TABLE 2 COMPARISON OF COMMONLY USED WINDOWS

Type of Window	Peak Side-Lobe Amplitude (Relative)	Approximate Width of Main Lobe	Peak Approximation Error, $20\log_{10}\delta$ (dB)	Equivalent Kaiser Window, β	Transition Width of Equivalent Kaiser Window
Rectangular	-13	$4\pi/(M+1)$	-21	0	$1.81\pi/M$
Bartlett	-25	$8\pi/M$	-25	1.33	$2.37\pi/M$
Hann	-31	$8\pi/M$	-44	3.86	$5.01\pi/M$
Hamming	-41	$8\pi/M$	-53	4.86	$6.27\pi/M$
Blackman	-57	$12\pi/M$	-74	7.04	$9.19\pi/M$

We wish to design an FIR lowpass filter satisfying the specifications

$$0.95 < H(e^{j\omega}) < 1.05, \qquad 0 \le |\omega| \le 0.25\pi,$$
$$-0.1 < H(e^{j\omega}) < 0.1, \qquad 0.35\pi \le |\omega| \le \pi,$$

by applying a window $w[n]$ to the impulse response $h_d[n]$ for the ideal discrete-time lowpass filter with cutoff $\omega_c = 0.3\pi$. Which of the windows listed in Section 5.1 can be used to meet this specification? For each window that you claim will satisfy this specification, give the minimum length $M + 1$ required for the filter.

[Hint: consider how these specs give you a value for δ . For the length, consider the mainlobe width and how that is related to cut-off. Figure 31 in Chapter 7 (also given in Lecture 10) may help you visualise this.]

Extra exploration – verify your answer in the Filter Designer in Matlab

Q4

Use the window design method to design a linear phase FIR filter of order $N = 24$ to approximate the following ideal frequency response magnitude:

$$|H_d(e^{j\omega})| = \begin{cases} 1 & |\omega| \le 0.2\pi \\ 0 & 0.2\pi < |\omega| \le \pi \end{cases}$$

[Hint – consider that $H_d(e^{j\omega}) = \sum_{n=-\infty}^{\infty} h_d[n]e^{-j\omega n}$ and the form of $h_d[n]$. You have a design method in lecture 10. You have to choose a window type and see if it will work to your specs.]

Q5.

(a) An ideal discrete-time highpass filter has a frequency response, $H_{id}(e^{j\omega})$, given by

$$H_{id}\left(e^{j\omega}\right) = \begin{cases} 0, \ |\omega| < \dfrac{\pi}{2}, \\ 1, \ \dfrac{\pi}{2} < |\omega| < \pi. \end{cases}$$

Obtain an expression for the unit-sample response of this filter.

(b) An 11-point Hamming window, $w_H[n]$, is given by

$$w_H[n] = \begin{cases} 0.54 + 0.46\cos\left(\dfrac{\pi n}{5}\right), & -5 \le n \le 5, \\ 0, & \text{otherwise.} \end{cases}$$

Using the Hamming window, design an 11-point finite impulse response filter that approximates the magnitude response of the ideal highpass filter in part (b).

[Hint – you will have to derive an expression for your ideal impulse response here]