University of Illinois at Urbana-Champaign

ECE 311: Digital Signal Processing Lab

LAB 6: SOLUTIONS

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Problem 1

The MATLAB code for this problem is on the course website.

(a) For a rectangular window with $N = 21$ we have,

$$h[n] = \frac{sin\left(\frac{\pi}{4}\right)(n-10)}{\pi(n-10)}, \quad n = 0, 1, \ldots, 20$$

The plot of $h[n]$ and $H_d(\omega), \angle H_d(\omega)$, is shown in the Figs. 1 and 2 respectively,

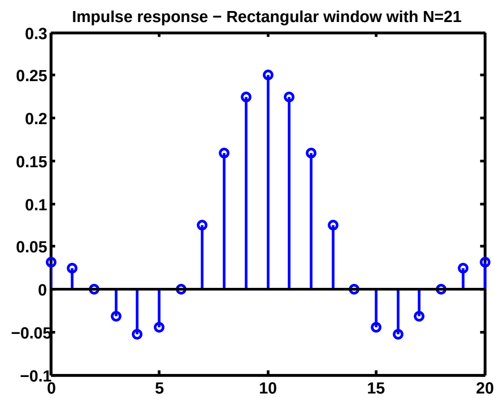

Figure 1: Impulse Response for Problem 1(a)

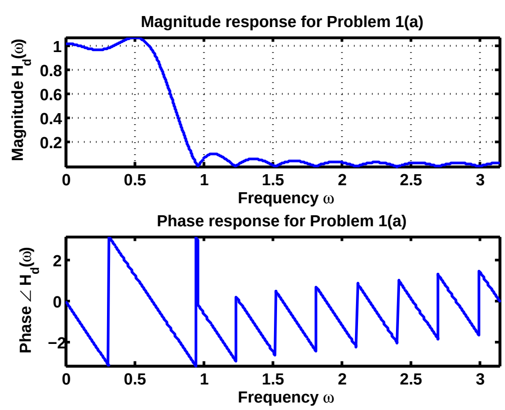

Figure 2: Frequency response of $h[n]$ in Problem 1(a)

(b) The plot of h[n] and $H_d(\omega)$ and $\angle H_d(\omega)$ are shown in Fig. 3 and 4 respectively. We can see from the figures that the sidelobe of the frequency response is reduced by the hamming window while the transition band width is increased.

(c) The plot of h[n] and $H_d(\omega)$ and $\angle H_d(\omega)$ are shown in Fig. 5 and 6 respectively. The larger window length results in a narrower transition band.

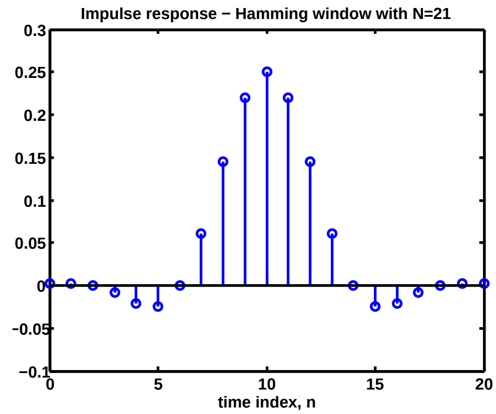

Figure 3: Impulse Response for Problem 1(b)

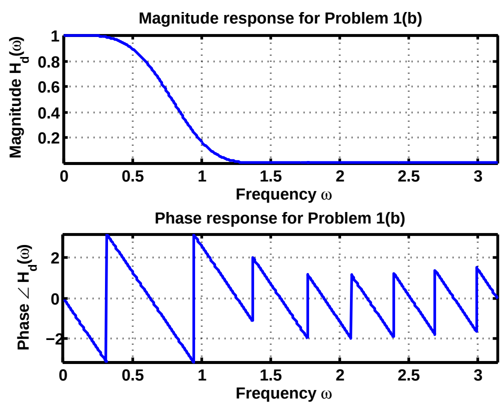

Figure 4: Frequency response of $h[n]$ in Problem 1(b)

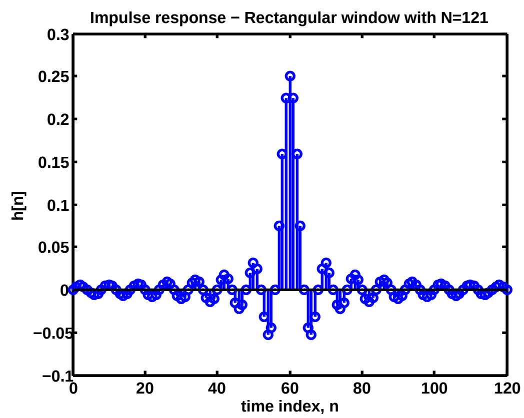

Figure 5: Impulse Response for Problem 1(c)

Problem 2
The MATLAB code for this problem is on the course website.

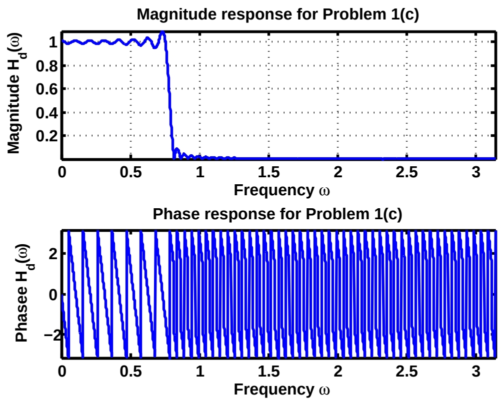

Figure 6: Frequency response of $h[n]$ in Problem 1(c)

(a) The sampled frequency response is given by,

$$H_d(\omega)|_{\omega=\frac{2\pi k}{121}} = \begin{cases} e^{-j\frac{60(2\pi k)}{121}}, & 0 \leq k \leq 15 \\ 0 & 16 \leq 15 \leq 105 \\ e^{-j\frac{60(2\pi k)}{121}} & 106 \leq k \leq 120 \end{cases}$$

Complex exponential terms are introduced in the sampled frequency response to ensure a generalized linear phase. Also, there is no minus sign in the complex frequency response for $0 \leq k \leq 120$ since $e^{-j60(\omega-2\pi)} = e^{-j60\omega}$. For $N = 120$ there would have been a minus sign since $e^{-j\frac{119}{2}(2\pi k)} = -e^{-j\frac{119}{2}\omega}$.

(b) The plots for $h[n]$, $|H_d(\omega)|$ and $\angle H_d(\omega)$ are shown in Figs. 7 and 8 respectively.

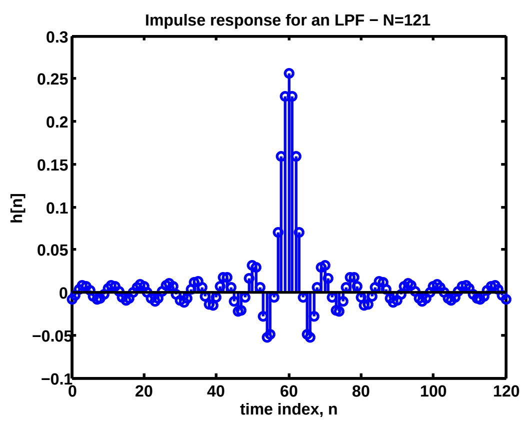

Figure 7: Impulse Response for Problem 2(b)

(c) The plots for the HPF are shown in Figs. 11 and 10 respectively.

Problem 3

(a) The length of the filter is $n = 31$. The cut-off frequency is $\omega = \pi/4 radians$. The filter can be designed using the `fir1` command. The parameter `Wn` which denotes the cut-off frequency must be between (0,1), hence for this case we have $Wn = \frac{1}{\pi} * \frac{\pi}{4} = \frac{1}{4}$. The followind code can be used to design the FIR filter.

```
[h] = fir1(31,0.25);
```

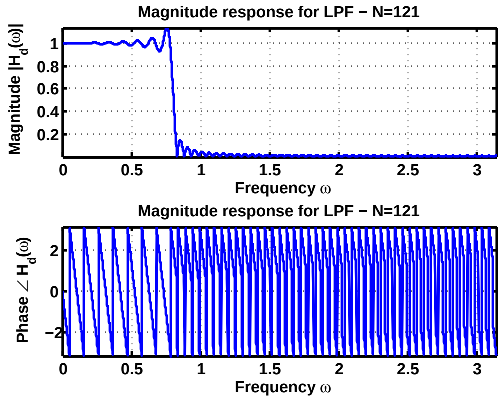

Figure 8: Frequency response of $h[n]$ in Problem 2(b)

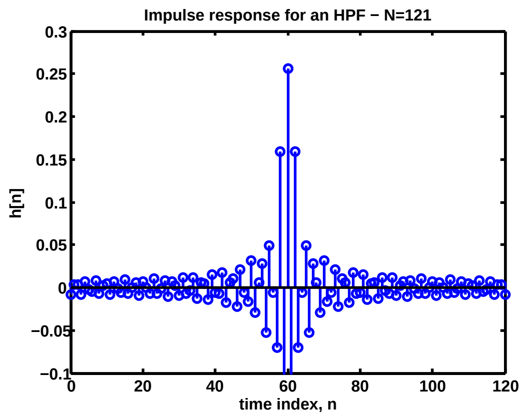

Figure 9: Impulse Response for Problem 2(c)

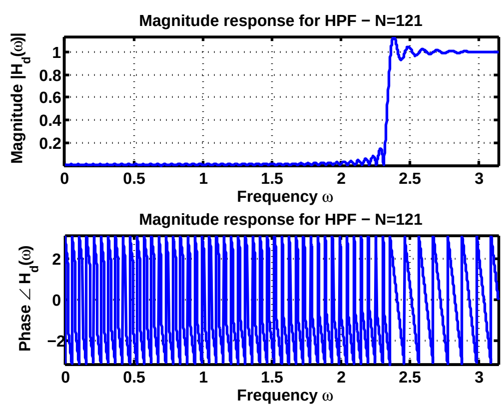

Figure 10: Frequency response of $h[n]$ in Problem 2(c)

(b) The plot of the magnitude and phase response can be obtained using the `freqz` command. The frequency response is shown in Fig. **??**. The passband nearly flat. The stopband attenuation is $\approx 50dB$ and the transition bandwidth is 0.13π.

(c) The sinusoid of frequency $\omega = \pi/6$ falls within the passband of the filter and should appear at the output. The frequency component $\omega = \pi/3$ should be filtered out. The code is shown below,

```
>> n = 0 :500;
```

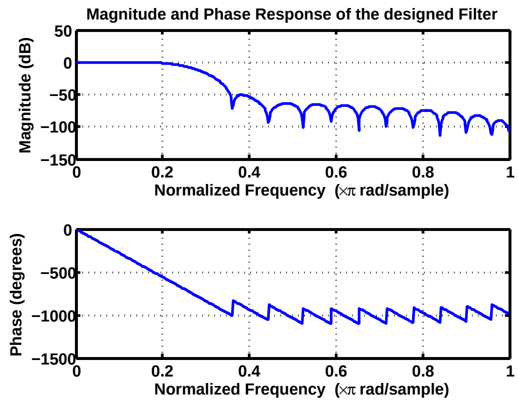

Figure 11: Frequency Response of the LPF designed in Problem 3(a)

```
>> x = cos((pi/6)*n)+cos((pi/3)*n);
>> y = conv(x,y);
```

The spectrum of the input signal is shown in Fig. 12 and the spectrum of the output signal is shown in Fig. 13.

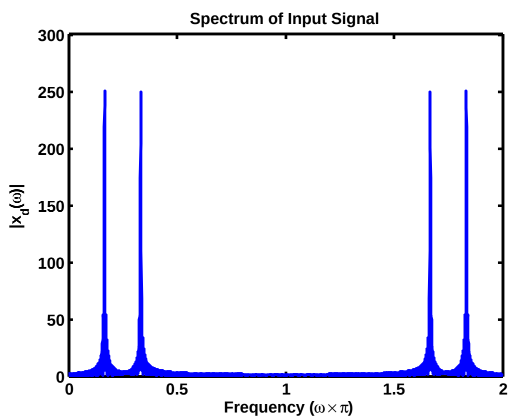

Figure 12: Impulse Response for Problem 2(c)

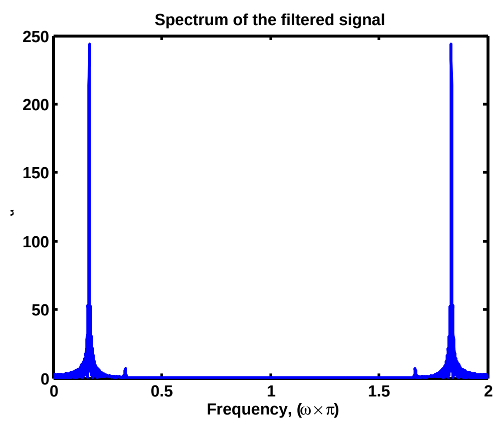

Figure 13: Frequency response of $h[n]$ in Problem 2(c)

Problem 4

(a) The magnitude response of the filters is shown in Figs. 14, 15, and 16. Based in the magnitude response Filters 1 and 2 must have the most similar outputs. The code for generating the plot for one filter is below. The code for other two filters will be similar.

```
>> [H,w] = freqz(b1,a1,4096);
>> plot(w/pi,abs(H))
>> xlabel('Frequency (\omega \times \pi)'),ylabel('|H_d^1(\omega)|'),title('Magnitude Response of First Filt
```

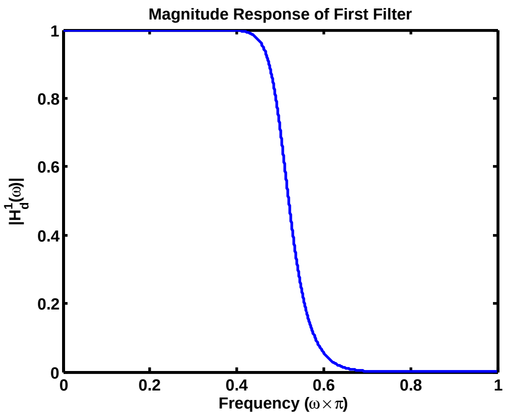

Figure 14: Magnitude Response of Filter 1

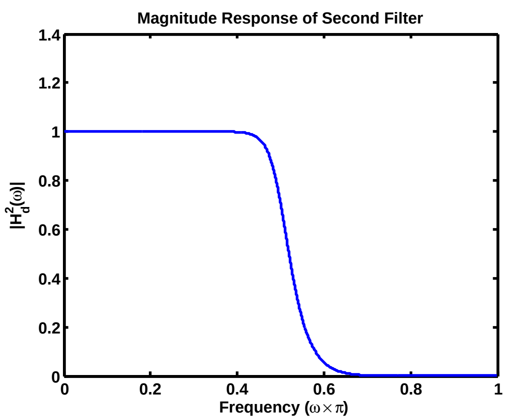

Figure 15: Magnitude Response of Filter 2

(b) The phase response is shown in Figs. 17, 18, and 19. Based on the phase response plots, Filter 1 and Filter 3 seem to have the most linear phase and hence should give the closest outputs

(c) The filtered output of the second filter has very minor distortion if one hears very carefully. One notice some difference if `sound` command is used. Though overall the outputs sound similar. In general for applications like speech, image etc the phase is very important though this particular example does not illustrate this very well.

(e) The spectrum of the clean and noisy speech is shown in Figs. 20 and 21 respectively. The noise can be clearly seen in Fig. 21.

(f) All three filters eliminate noise. The results of filter 1 seems to work the best.

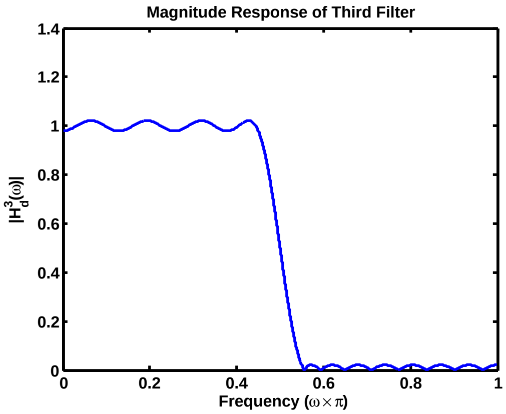

Figure 16: Magnitude Response of Filter 3

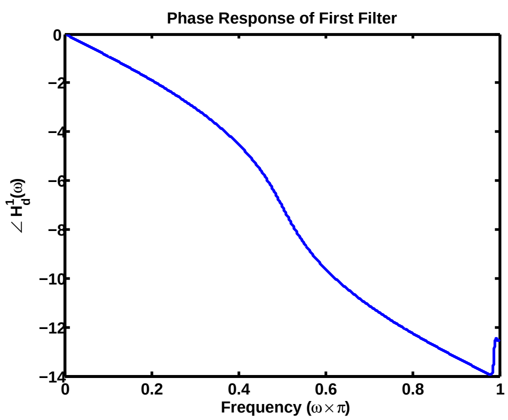

Figure 17: Phase Response of Filter 1

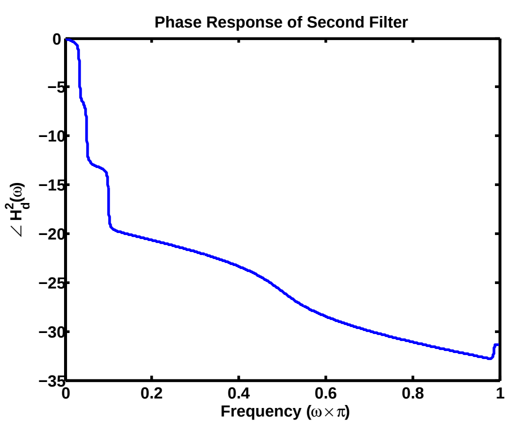

Figure 18: Phase Response of Filter 2

(g) The plots of the spectrum of the filtered signal using each is shown in Figs. 22, 23, and 24 respectively. For practical purposes the spectrum of the filtered signals are similar. One can zoom into the plots and notice some differences in the part which had noise.

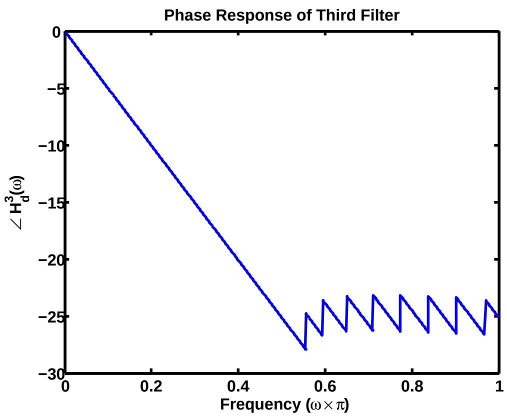

Figure 19: Phase Response of Filter 3

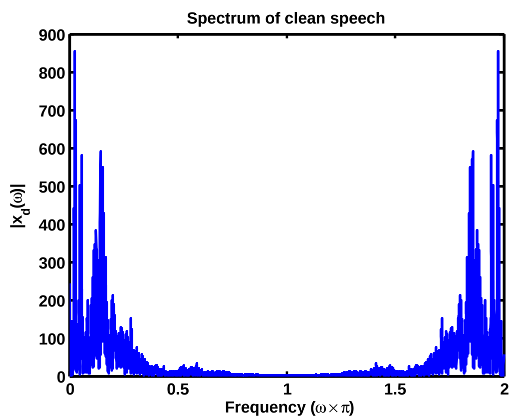

Figure 20: Spectrum of clean speech.

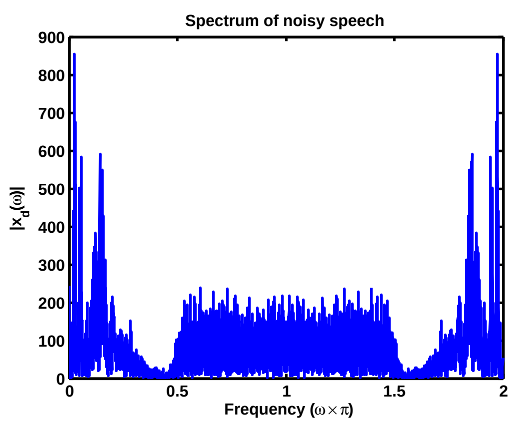

Figure 21: Spectrum of noisy speech.

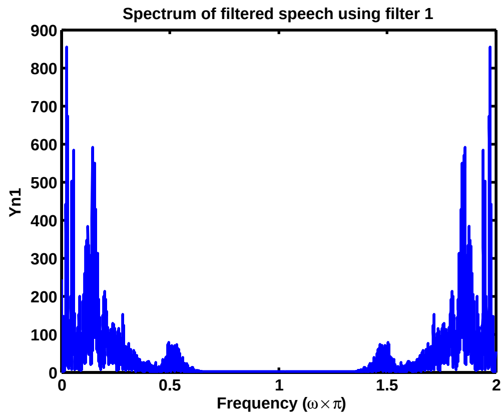

Figure 22: Spectrum of clean speech.

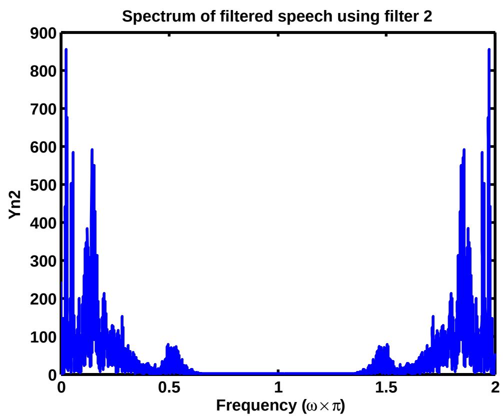

Figure 23: Spectrum of Yn2.

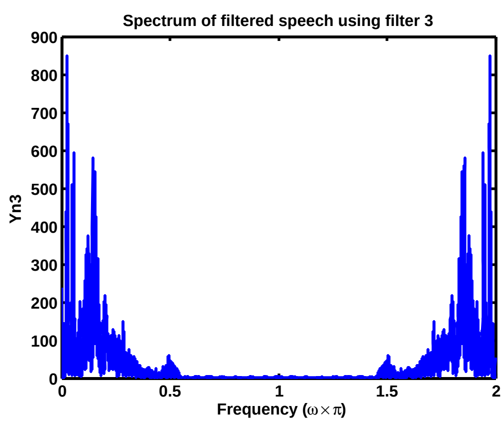

Figure 24: Spectrum of Yn3.