ECE 6255 — Jeet Kiran Pawani, GTid - 903397407

DIGITAL SPEECH PROCESSING

ASSIGNMENT #1 — page ①

① Rabiner 2.6

a) Exponential window

$$w_E[n] = \begin{cases} a^n & 0 \le n \le N-1 \quad |a| \le 1 \\ 0 & \text{else} \end{cases}$$

Z-Transform

$$W_E(z) = \sum_{n=0}^{N-1} w_E[n]\, z^{-n} = \sum_{n=0}^{N-1} a^n z^{-n} = \sum_0^{N-1} (az^{-1})^n$$

$$= \frac{1-(az^{-1})^N}{1-az^{-1}}$$

$$= \frac{(1-a^N z^{-N})}{(1-az^{-1})}$$

Fourier transform

$$W_E(e^{j\omega}) = \sum_{n=0}^{N-1} w_E(n)\, e^{-j\omega n} = \sum_{n=0}^{N-1} a^n e^{-j\omega n}$$

$$= \sum_{n=0}^{N-1} (ae^{-j\omega})^n$$

$$= \frac{(1-a^N e^{-j\omega N})}{(1-ae^{-j\omega})}$$

b) Rectangular window

$$w_R(n) = \begin{cases} 1 & 0 \le n \le N-1 \\ 0 & \text{else} \end{cases}$$

$$W_R(z) = \sum_{n=0}^{N-1} w_r[n]\, z^{-n} = \sum_{n=0}^{N-1} z^{-1} = \frac{(1-z^{-n})}{(1-z)}$$

$$W_R(e^{j\omega}) = \sum_{n=0}^{N-1} w_R(n)\, e^{-j\omega n} = \sum_{n=0}^{N-1} e^{-j\omega n} = \frac{(1-e^{-j\omega n})}{(1-e^{-j\omega})}$$

$$\sin\theta = \frac{e^{i\theta}-e^{-i\theta}}{2i}$$

$$w_R(e^{j\omega}) = \frac{e^{-j\omega N}-1}{e^{-j\omega}-1} = \frac{e^{-j\omega N/2}}{e^{-j\omega/2}}\left(\frac{e^{-j\omega N/2}-e^{j\omega N/2}}{e^{-j\omega/2}-e^{j\omega/2}}\right)$$

multiply and divide by $2j$

$$\Rightarrow w_R(e^{j\omega}) = e^{-j\omega\frac{(N-1)}{2}} \frac{\left(\frac{e^{j\omega N/2}-e^{-j\omega N/2}}{2j}\right)}{\left(\frac{e^{j\omega/2}-e^{-j\omega/2}}{2j}\right)}$$

$$= e^{-j\omega(N-1)/2} \cdot \frac{\sin(N\omega/2)}{\sin(\omega/2)}$$

c) Hamming window

$$w_H[n] = \begin{cases} 0.54 - 0.46\cos[2\pi n/(N-1)] & 0 \leq n \leq N-1 \\ 0 & \text{else.} \end{cases}$$

z-transform

$$W_H(z) = \sum_{n=0}^{N-1}\left[0.54 - 0.46\cos\left(\frac{2\pi n}{N-1}\right)\right] z^{-n}$$

↳ open eulers form.

$$= \sum_{n=0}^{N-1}\left[0.54 - 0.46\left[\frac{e^{j\frac{2\pi n}{N-1}} + e^{-j\frac{2\pi n}{N-1}}}{2}\right]\right] z^{-n}$$

$$= \sum_{n=0}^{N-1}\left(0.54 - 0.23e^{\frac{j2\pi n}{N-1}} - 0.23\, e^{\frac{-j2\pi n}{N-1}}\right) z^{-n}$$

From previous question

$$= 0.54\left(\frac{1-z^{-N}}{1-z^{-1}}\right) - 0.23\left(\frac{1-e^{\frac{j2\pi N}{N-1}} z^{-N}}{1-e^{\frac{j2\pi}{N-1}} z^{-1}}\right)$$

$$- 0.23\left[\frac{1-e^{-\frac{j2\pi N}{N-1}} z^{-N}}{1-e^{-\frac{j2\pi}{N-1}} z^{-1}}\right]$$

Fourier - transform

Seeing part 2 of ques (2)

fourier transform of $\sum 0.54\, e^{-j\omega n} = 0.54\, e^{-j\frac{\omega(N-1)}{2}} \frac{\sin(\omega N/2)}{\sin(\omega/2)}$

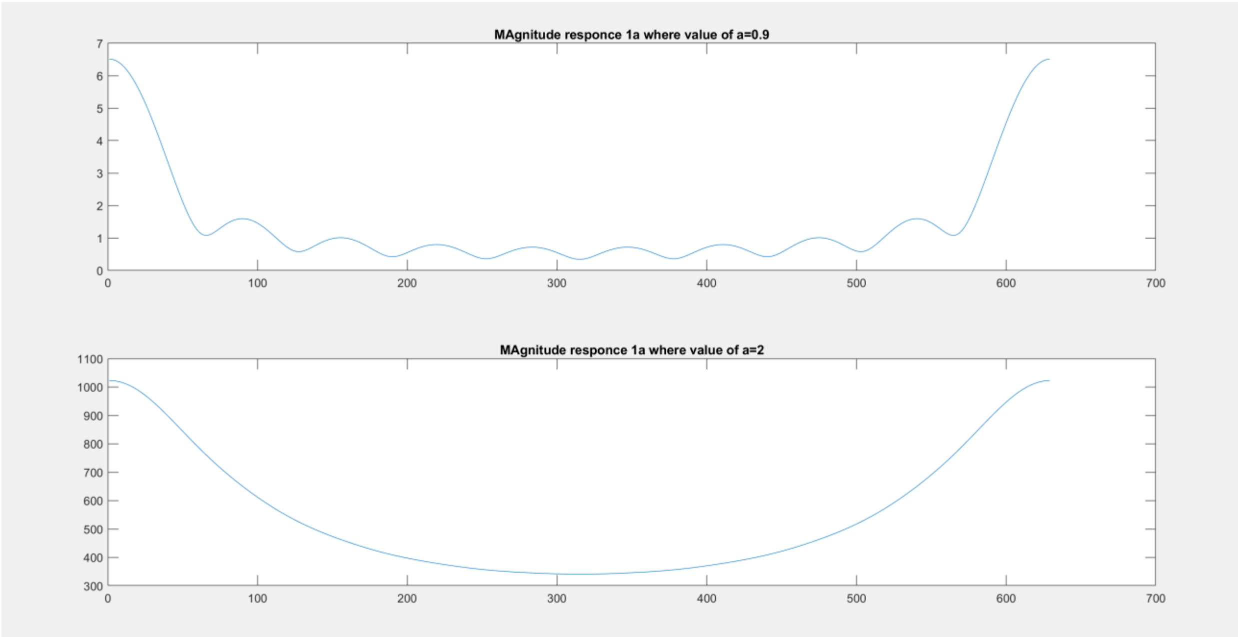
$$-\sum 0.23 e^{\frac{j2\pi n}{N-1}} e^{-j\omega n} = -0.23\, e^{-j\left(\omega - \frac{2\pi}{N-1}\right)\left(\frac{N-1}{2}\right)} \frac{\sin\left(\left(\omega - \frac{2\pi}{N-1}\right)\frac{N}{2}\right)}{\sin\left(\left(\omega - \frac{2\pi}{N-1}\right)\left(\frac{1}{2}\right)\right)}$$

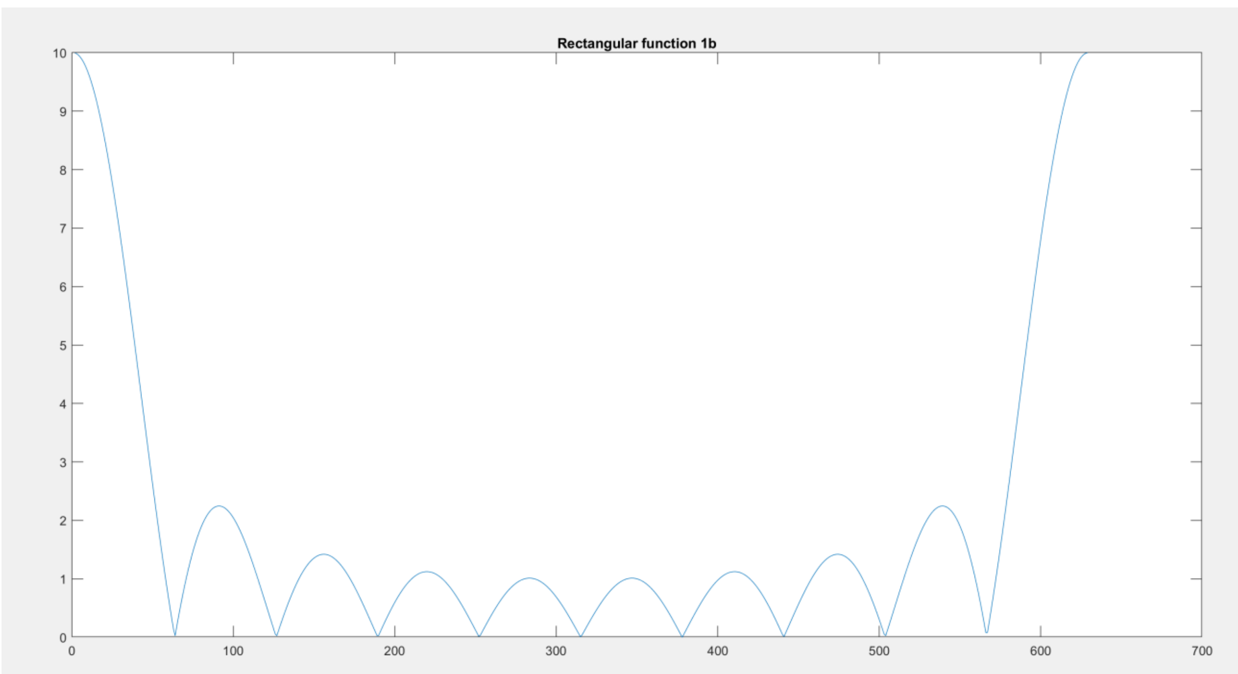
$$-\sum 0.23 e^{-\frac{j2\pi n}{N-1}} e^{-j\omega n} = -0.23\, e^{-j\left(\omega + \frac{2\pi}{N-1}\right)\left(\frac{N-1}{2}\right)} \frac{\sin\left(\left(\omega + \frac{2\pi}{N-1}\right)\left(\frac{N}{2}\right)\right)}{\sin\left(\left(\omega + \frac{2\pi}{N-1}\right)\left(\frac{1}{2}\right)\right)}$$

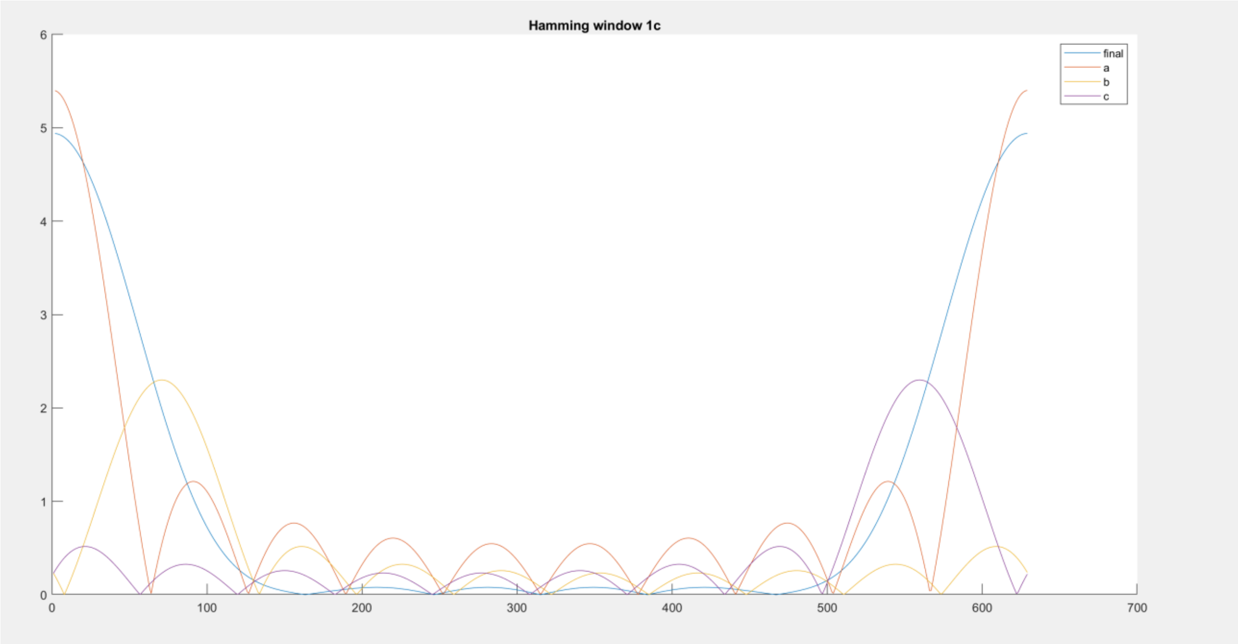
$$\Rightarrow W_4(e^{j\omega}) = +e^{-j\frac{\omega(N-1)}{2}} \left[0.54 \frac{\sin(\omega N/2)}{\sin(\omega/2)} + 0.23 \frac{\sin\left(\left(\omega - \frac{2\pi}{N-1}\right)\left(\frac{N}{2}\right)\right)}{\sin\left(\left(\omega - \frac{2\pi}{N-1}\right)\left(\frac{1}{2}\right)\right)} + 0.23 \frac{\sin\left(\left(\omega + \frac{2\pi}{N-1}\right)\left(N/2\right)\right)}{\sin\left(\left(\omega + \frac{2\pi}{N-1}\right)\left(1/2\right)\right)} \right]$$

becomes +ve as $e^{-j\pi} = \cos\pi - i\sin\pi$

Plots on matlab.


MAgnitude responce 1a where value of a=0.9
MAgnitude responce 1a where value of a=2


Rectangular function 1b



Hamming window 1c
final
a
b
c
0
1
2
3
4
5
6
0
100
200
300
400
500
600
700

(2) a) $\tilde{X}(k) = \sum_{-\infty}^{\infty} x[m]\, e^{-j\frac{2\pi}{N}km} \rightarrow (1)$

$$\tilde{x}[n] = \frac{1}{N}\sum_{k=0}^{N-1} \tilde{X}(k)\, e^{j\frac{2\pi}{N}kn} \rightarrow (2)$$

Substitute (1) in (2)

$$\tilde{x}[n] = \frac{1}{N}\sum_{k=0}^{N-1}\left[\sum_{-\infty}^{\infty} x[m]\, e^{-j\frac{2\pi}{N}km}\right] e^{j\frac{2\pi}{N}kn}$$

$$= \frac{1}{N}\sum_{k=0}^{N-1}\sum_{-\infty}^{\infty} x[m]\, e^{-j\frac{2\pi}{N}k(n-m)}$$

Using Poisson summation formula

$$\frac{1}{N}\sum_{k=0}^{N-1} e^{-j\frac{2\pi k}{N}(n-m)} = \sum_{r=-\infty}^{\infty} \delta(n-m-rN)$$

$$\tilde{x}(n) = \underbrace{\sum_{r=-\infty}^{\infty}\sum_{m=-\infty}^{\infty} x(m)\,\delta(m-(n+rN))}$$

$$= \sum_{r=-\infty}^{\infty} x(n+rN)$$

b) Signal should be bandlimited to $\frac{\omega_0}{2}$ and sampling interval $\Delta\omega \; 7/\!\!=\; \frac{2\pi}{m}$

$$\Rightarrow m \geq \frac{2\pi}{\Delta\omega} \; 7/\!\!= \frac{2\pi}{\Omega}$$

c) $y(n) = x[nm]$

Let $v(n) = x[n]\,p(n)$ $\qquad p[n] = \sum_{r=-\infty}^{\infty} \delta[n+rm]$

DFT of $v(n)$

$$V(k) = \sum_{n=0}^{m-1} v[n]\; e^{-j\frac{\omega n}{m}}$$

$$V(k) = \sum_{n=0}^{m-1} x(n)\, p(n)\, e^{-\frac{j\omega n}{m}}$$ ③

$$p(n) = \sum_{-\infty}^{\infty} \delta(n+rm)$$

can be written as

$$p(n) = \frac{1}{m}\sum_{0}^{m-1} e^{-j\frac{2\pi k n}{m}}$$ (Poisson summation)

$$V(k) = \sum_{n=0}^{m-1} x(n)\, \frac{1}{m} \sum_{k=0}^{m-1} e^{\frac{-j2\pi k n}{m}}\; e^{\frac{-j\omega n}{m}}$$

$$= \frac{1}{m} \sum_{n=0}^{m-1} \sum_{k=0}^{m-1} \underbrace{x(nm)}_{\text{downsampling}}\; e^{\frac{-jn}{m}(\omega - 2\pi k)}$$

$$\Rightarrow V(k) = \frac{1}{m} \sum_{k=0}^{M-1} X\left(e^{j(\omega - 2\pi k)/m}\right)$$

d) Signal should be bandlimited.

$$\Rightarrow \omega_s > 2\omega_m \quad \text{(bandwidth)}$$

sampling frequency

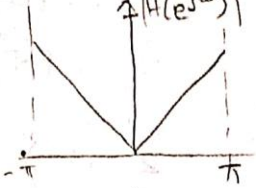
$$\omega_s = \frac{2\pi}{N}$$

$$\Rightarrow \omega_s \geq \frac{2\pi}{N}$$

③ Rabiner 2.9

$H(e^{j\omega}) = j\omega \, e^{-j\omega\tau}$ $\qquad -\pi \le \omega \le \pi$ (period 2π)

a) $|H(e^{j\omega})| = |\omega|$

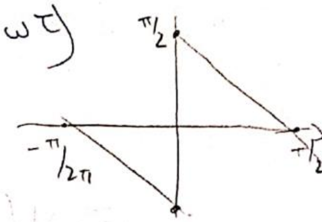


Phase responce

$\arg(H(e^{j\omega})) = \arg(j\omega e^{-j\omega\tau})$

$= \arg(j\omega) \quad \arg(e^{-j\omega\tau})$

$= \arctan\omega \quad (\omega\tau)$



b) $h(n) = \frac{1}{2\pi}\int H(e^{j\omega}) e^{j\omega n} d\omega$

$= \frac{1}{2\pi}\int j\omega \, e^{-j\omega\tau} e^{j\omega n} d\omega$

$= \frac{1}{2\pi}\int j\omega \, e^{-j\omega(n+\tau)} d\omega$

by using integral solver

$= \frac{j}{2\pi}\left[\frac{e^{-j\omega(\tau-n)}}{(-j\tau - n)^2}\left[j\omega(\tau-n)+1\right]_{-\pi}^{\pi}\right]$

$= \frac{j}{2\pi}\left[\frac{e^{-j\pi(\tau-n)}}{(\tau-n)^2}\left[(j\pi(\tau-n)+1)\right] + \frac{e^{j\pi(\tau-n)}}{(\tau-n)^2}\left(j\pi(\tau-n) - 1\right)\right]$

$= \frac{j}{2\pi(\tau-n)^2}\left[j\pi(\tau-n)\left[e^{-j\pi(\tau-n)} + e^{j\pi(\tau-n)}\right] + \left[e^{-j\pi(\tau-n)} - e^{j\pi(\tau-n)}\right]\right]$

$= \frac{j^2 \cancel{\pi}(\tau-n)}{\cancel{2}\cancel{\pi}(\tau-n)^{\cancel{2}}} \cos(\pi(n-\tau)) \times \cancel{2} + \frac{j}{\cancel{2}\pi(\tau-n)^2}\sin(\pi(\tau-n)) \times \cancel{2}j$

eulers form

$$h(n) = -\frac{\cos(\pi(n-\tau))}{(\tau-n)} - \frac{\sin(\pi(n-\tau))}{\pi(\tau-n)^2}$$

$$h(n) = \frac{\cos(\pi(n-\tau))}{(n-\tau)} - \frac{\sin(\pi(n-\tau))}{\pi(\tau-n)^2}$$

c) $\tau = \frac{N-1}{2}$ $\frac{N-1}{2}$ and N are odd

$\Rightarrow$ if τ is odd $\Rightarrow$ sin function becomes $\underline{0}$.

$$\Rightarrow h(n) = \frac{\cos\left(\pi\left(n-\left(\frac{N-1}{2}\right)\right)\right]}{\left[n-\left(\frac{N-1}{2}\right)\right]}$$

let $N = \underline{11}$

$$= \frac{\cos(\pi(n-5))}{(n-5)}$$

we can see $(n-5)$ in denominator

$\Rightarrow$ ideal responce becomes $\left(\frac{1}{n}\right)$

d) $\tau = \frac{N-1}{2}$ $\frac{N-1}{2}$ and N are even

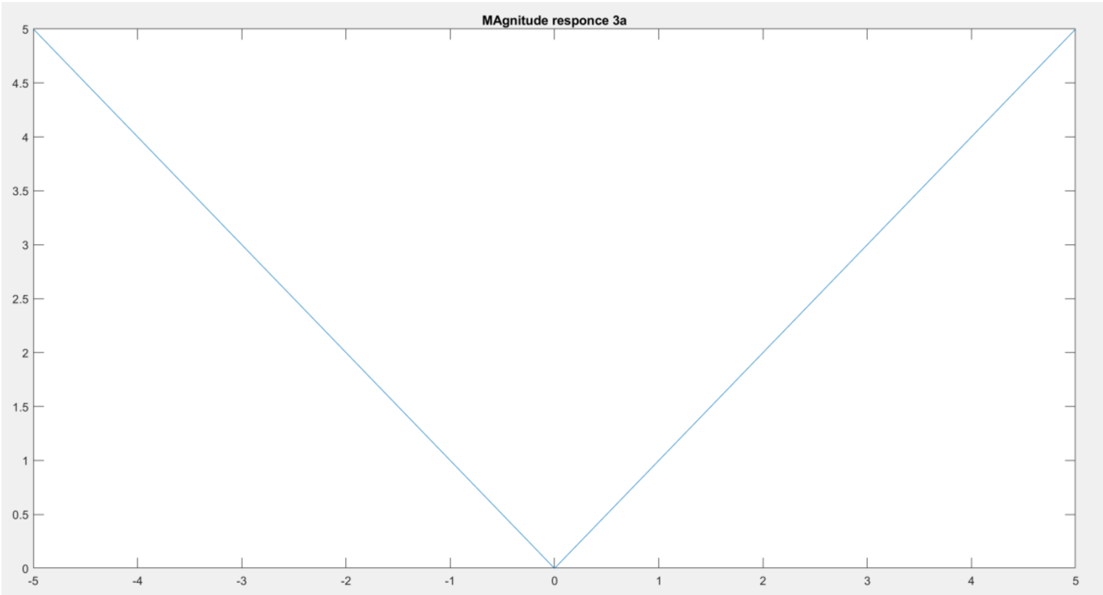
$\Rightarrow$ τ is even $\Rightarrow$ cos function becomes $\underline{0}$.

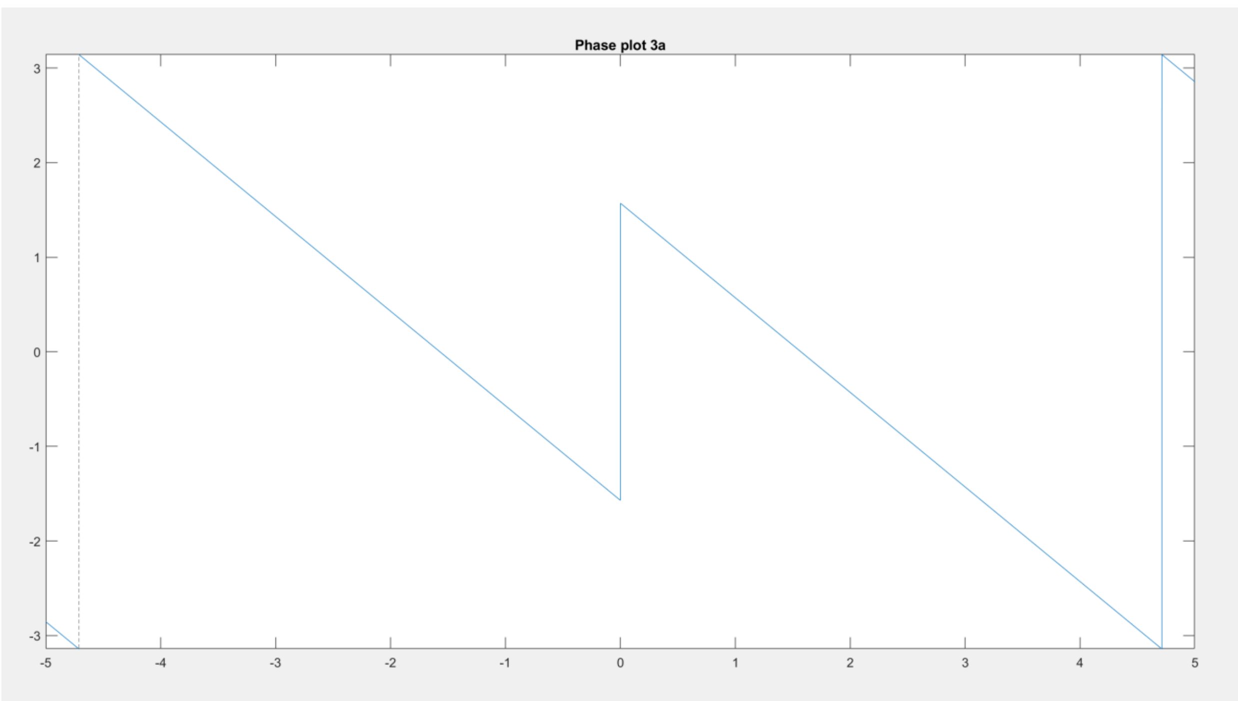
$$\Rightarrow h(n) = -\frac{\sin\left[\pi\left(n-\left(\frac{N-1}{2}\right)\right)\right]}{\pi\left(n-\left(\frac{N-1}{2}\right)\right)^2}$$ Let $N=10$

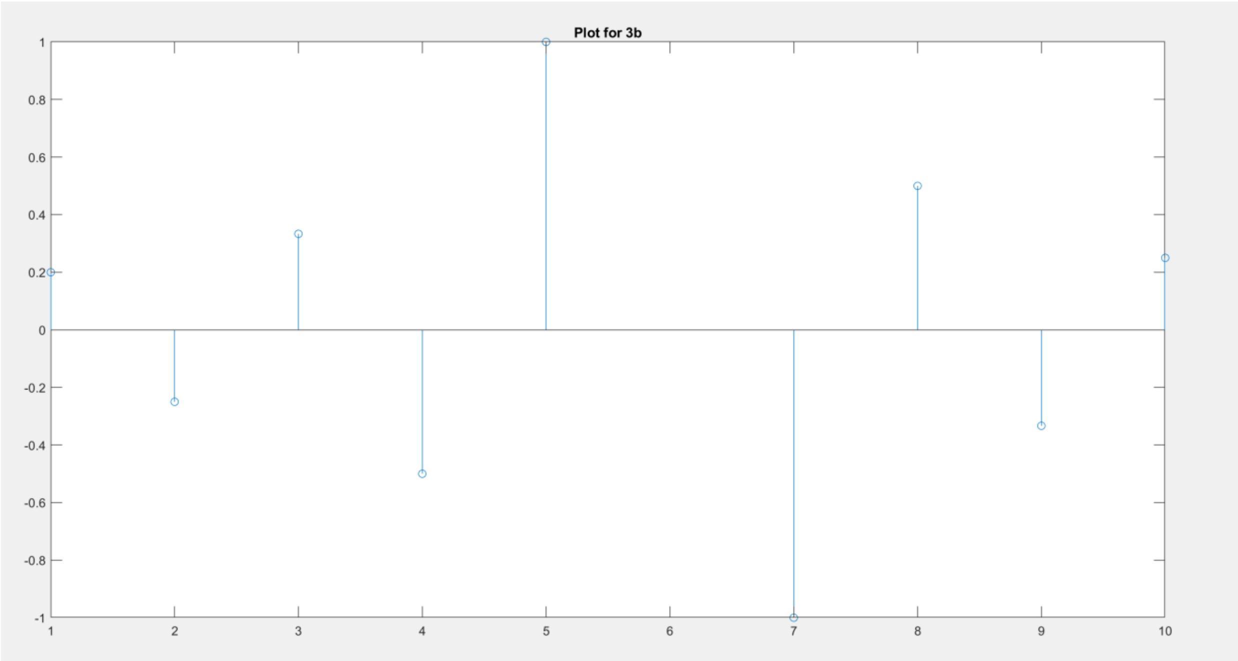
$$= -\frac{\sin(\pi(n-9/2))}{\pi(n-9/2)^2}$$

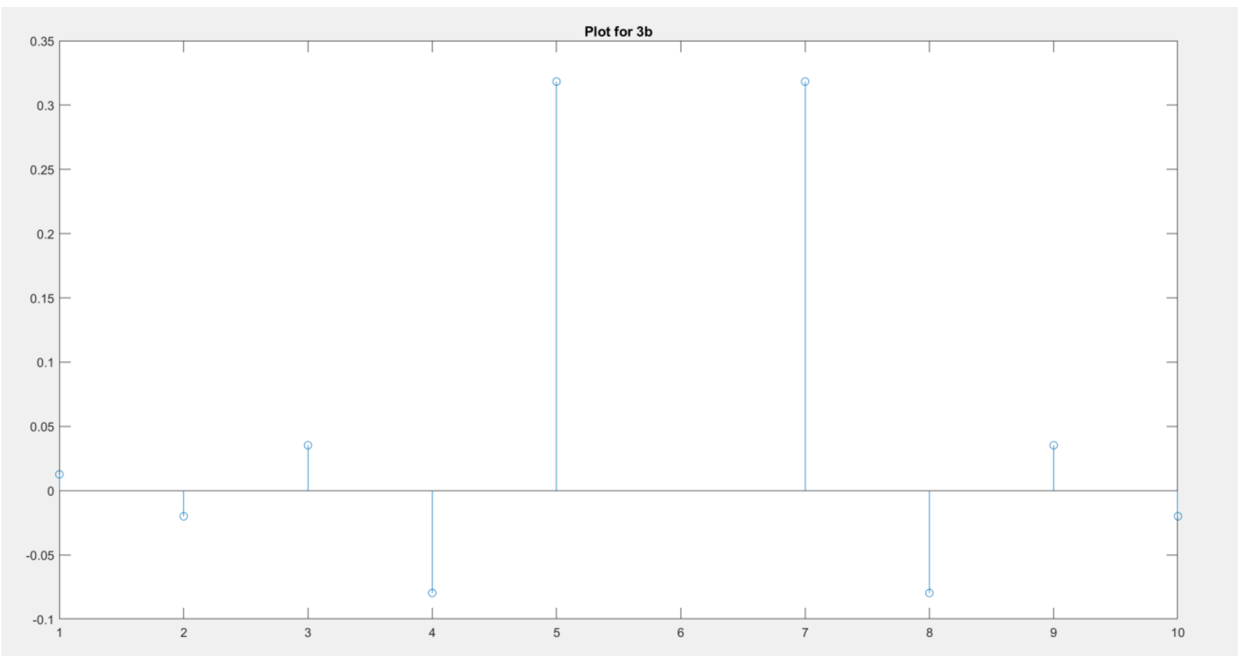
denominator is $(n-9/2)^2$

$\Rightarrow$ we can see ideal responce becomes $\left(\frac{1}{n^2}\right)$


MAgnitude responce 3a
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5


Phase plot 3a
3
2
1
0
-1
-2
-3
-5
-4
-3
-2
-1
0
1
2
3
4
5


Plot for 3b
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
1
2
3
4
5
6
7
8
9
10


Plot for 3b
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
1
2
3
4
5
6
7
8
9
10

4) Rabiner 2.12

$y(n) = x(n) - \frac{1}{4} x(n-1) + \frac{1}{3} y(n-1)$

a) $Y(z) = X(z) - \frac{1}{4} X(z) z^{-1} + \frac{1}{3} Y(z) z^{-1}$

$Y(z) - \frac{1}{3} Y(z) z^{-1} = X(z) - \frac{1}{4} X(z) z^{-1}$

$Y(z)\left(1 - \frac{1}{3} z^{-1}\right) = X(z)\left(1 - \frac{1}{4} z^{-1}\right)$

$$H(z) = \frac{Y(z)}{X(z)} = \frac{\left(1 - \frac{1}{4} z^{-1}\right)}{\left(1 - \frac{1}{3} z^{-1}\right)}$$

ROC $|z| > \frac{1}{3}$

b) $$H(z) = \frac{1 - \frac{1}{4} z^{-1}}{1 - \frac{1}{3} z^{-1}} = \frac{1 - \frac{1}{4z}}{1 - \frac{1}{3z}}$$

$$= \frac{4z - 1}{3z - 1} \times \frac{3z}{4z} = \frac{12z - 3}{12z - 4}$$

$z = \frac{1}{4}$ is pole, $z = \frac{1}{3}$ is zero

c) $x(n) = u(n)$

$$X(z) = \frac{1}{1 - z^{-1}}$$

$$\frac{Y(z)}{X(z)} = \frac{\left(1 - \frac{1}{4} z^{-1}\right)}{\left(1 - \frac{1}{3} z^{-1}\right)} = \frac{X(z)\left(1 - \frac{1}{4} z^{-1}\right)}{\left(1 - \frac{1}{3} z^{-1}\right)}$$

$$= \frac{\left(1 - \frac{1}{4} z^{-1}\right)}{\left(1 - z^{-1}\right)\left(1 - \frac{1}{3} z^{-1}\right)}$$

Using splitting

(5)

$$\frac{(1-\frac{1}{4}z^{-1})}{(1-z^{-1})(1-\frac{1}{3}z^{-1})} = \frac{A}{(1-z^{-1})} + \frac{B}{(1-\frac{1}{3}z^{-1})}$$

$$A+B = 1 \qquad -\frac{A}{3} - B = -\frac{1}{4}$$

$$A + 3B = 3/4$$
$$A + B = 1$$

$$2B = -1/4$$

$$B = -1/8 \, , \, A = 9/8$$

$$H(z) = \frac{9/8}{(1-z^{-1})} + \frac{-1/8}{(1-\frac{1}{3}z^{-1})}$$ Taking inverse z tranform

$$= \frac{9}{8}u(n) - \frac{1}{8}\left(\frac{1}{3}\right)^n u(n)$$

d) $$Hi(z) = \frac{1}{H(z)} = \frac{1-\frac{1}{3}z^{-1}}{1-\frac{1}{4}z^{-1}}$$

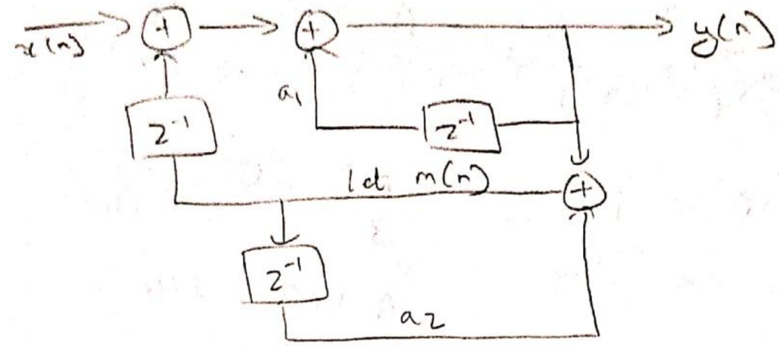
$$= \frac{1}{1-\frac{1}{4}z^{-1}} + \frac{-\frac{1}{3}z^{-1}}{1-\frac{1}{4}z^{-1}}$$

ROC $|z| > \frac{1}{4}$

$$h_i(n) = \left(\frac{1}{4}\right)^n u(n) - \frac{1}{3}\left(\frac{1}{4}\right)^{n-1} u(n-1)$$

$$= \left(\frac{1}{4}\right)^n u[n] - \left(\frac{1}{3}\right)\left(\frac{1}{4}\right)^{n-1} u(n-1)$$

⑤ Rabiner 2.21



a) $y(n) = x(n) + a_1 y(n-1) + m(n-1) \rightarrow ①$

$m(n) = y(n) + a_2\, m(n-1) \rightarrow ②$

b) System function

$$H(z) = \frac{Y(z)}{X(z)}$$

$① \Rightarrow \quad Y(z) = X(z) + a_1 Y(z) z^{-1} - m(z) z^{-1} \rightarrow ③$

$② \Rightarrow \quad m(z) = Y(z) + a_2\, m(z) z^{-1}$

$$m(z)(1 - a_2 z^{-1}) = Y(z)$$

$$m(z) = \frac{Y(z)}{(1 - a_2 z^{-1})} \rightarrow ④$$

Sub ④ in ③

$$Y(z) = X(z) + a_1 Y(z) z^{-1} + \frac{Y(z)}{(1 - z^{-1})} z^{-1}$$

$$Y(z)\left(1 - a_1 z^{-1} - \frac{z^{-1}}{1 - a_2 z^{-1}}\right) = X(z)$$

$$\frac{Y(z)}{X(z)} = H(z) = \frac{1}{\left(1 - a_1 z^{-1} - \frac{z^{-1}}{1 - a_2 z^{-1}}\right)}$$

$$H(z) = \frac{1 - a_2 z^{-1}}{1 - a_2 z^{-1} - a_1 z^{-1}(\cancel{z^{-1}}\, 1 - a_2 z^{-1}) - z^{-1}}$$

$$= \frac{1 - a_2 z^{-1}}{1 - a_2 z^{-1} - a_1 z^{-1} + a_1 a_2 z^{-2} - z^{-1}}$$

$$= \frac{1 - a_2 z^{-1}}{1 + a_1 a_2 z^{-2} + (-1 - a_2 - a_1) z^{-1}}$$

Set $z = e^{j\omega}$

$$\boxed{\Rightarrow H(e^{j\omega}) = \frac{1 - a_2 e^{-j\omega}}{1 + a_1 a_2 e^{-2j\omega} + (-1 - a_1 - a_2) e^{-j\omega}}}$$

b) $y(n) =$

6) Rabiner 2.29(b)

$y(n) = (x(n))^3$

$y_2(n) = r^n \cos(\omega_0 n)\, u(n) \quad |r| < 1$

$y_2(n) = (r^n \cos(\omega_0 n))^3$

$= r^{3n} \cos^3(\omega_0 n)$

$\cos 3\theta = \cos(2\theta + \theta)$

$= \cos 2\theta \cos\theta - \sin 2\theta \sin\theta$

$= (2\cos^2\theta - 1)\cos\theta - 2\sin\theta\cos\theta\sin\theta$

$= 2\cos^3\theta - \cos\theta - 2\sin^2\theta\cos\theta$

$= 2\cos^3\theta - \cos\theta - 2(1-\cos^2\theta)\cos\theta$

$= 2\cos^3\theta - \cos\theta - 2\cos\theta + 2\cos^3\theta$

$\cos 3\theta = 4\cos^3\theta - 3\cos\theta$

$\cos^3\theta = \frac{\cos 3\theta + 3\cos\theta}{4}$

if we take fourier transform

$\cos 3\theta = \frac{e^{3j\omega} + e^{-3j\omega}}{2}$

$\rightarrow$ fourier transform $(\cos 3\theta) = \frac{1}{8}\left[\delta(\omega - 3\omega_0) + \delta(\omega + 3\omega_0)\right]$

$\cos\theta = \frac{e^{j\omega} + e^{-j\omega}}{2}$

fourier transform $(\cos\theta) = \frac{1}{8}\left[\delta(\omega - \omega_0) + \delta(\omega + \omega_0)\right]$

fourier transfor of $r^{3n} = \frac{1}{1 - r^3 e^{-j\omega}}$

$\Rightarrow Y_2(e^{j\omega}) = \text{fourier transform of } (r^{3n} \cos^3(\omega_0 n))$ (7)

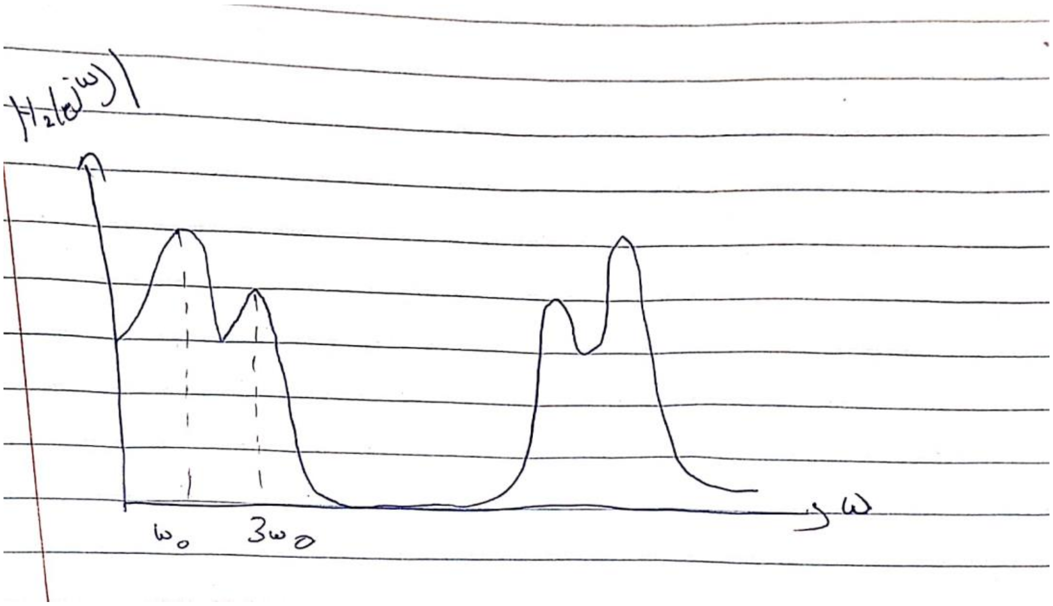
$$= \frac{1}{1-r^3 e^{-j\omega}} \text{ fourier transform} \left(\frac{\cos 3\theta + 3\cos\theta}{4} \right)$$

$$= \frac{1}{1-r^3 e^{-j\omega}} * \left[\frac{1}{4} \left[\frac{1}{2} [\delta(\omega - 3\omega_0) + \delta(\omega + 3\omega_0)] + \frac{3}{2} [\delta(\omega - \omega_0) + \delta(\omega + \omega_0)] \right] \right]$$

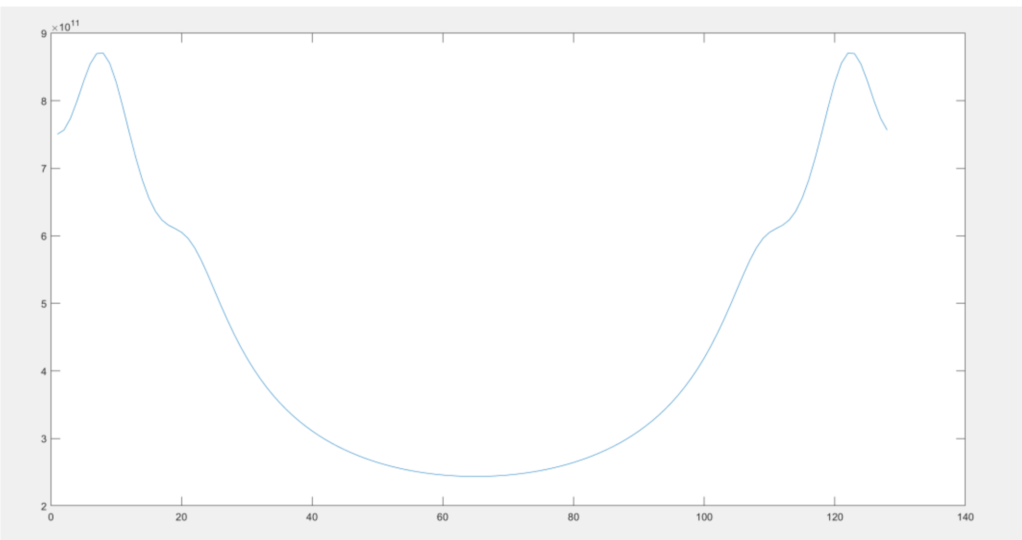
$$= \frac{1}{1-r^3 e^{-j\omega}} * \left[\frac{1}{8} [\delta(\omega - 3\omega_0) + \delta(\omega + 3\omega_0)] + \frac{3}{8} [\delta(\omega - \omega_0) + \delta(\omega + \omega_0)] \right]$$

$\omega_0 = 2\pi \, 500/F_s$ $\qquad r \simeq 0.9$ $\qquad$ plot on matlab

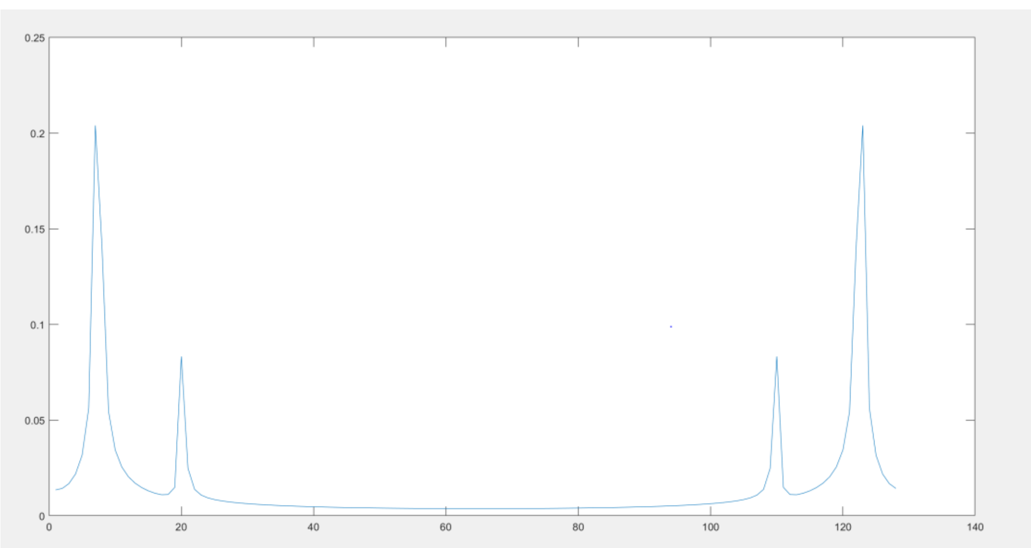
$F_s = 10000$ Hz



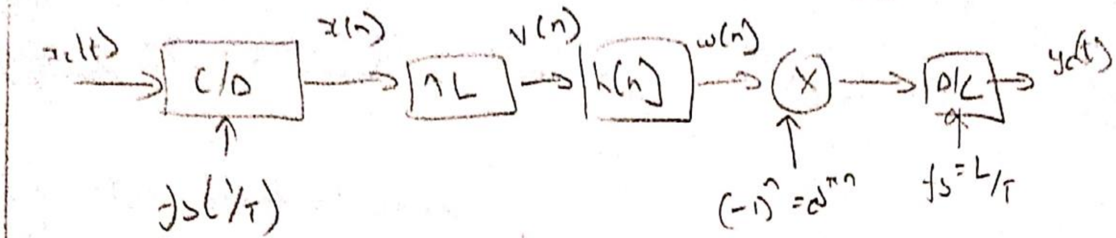
$|H_2(e^{j\omega})|$
ω_0
$3\omega_0$
ω



×10^11
9
8
7
6
5
4
3
2
0
20
40
60
80
100
120
140



0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120
140

7) 

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

$x_c(t)$ is ~~fty~~ fourier transform $\underline{X_c(j\Omega)}$

now conversion to discrete.

$\Rightarrow X(e^{j\omega})$ is range $|\omega| < \frac{\pi}{T} \times T \Rightarrow |\omega| \le \pi$

Now upsampling by factor L

$\Rightarrow X(e^{j\omega})$ in range $|\omega| < \pi/L = V(e^{j\omega})$

So $h(n)$ is frequency domain is LPF in range $|\omega| < \pi/L$

$w(e^{j\omega}) = V(e^{j\omega})$

$\Rightarrow V(e^{j\omega}) = X(e^{j\omega}) \quad |\omega| < \pi/L$

Now multiplying by $e^{j\pi n}$

$w(e^{j\omega}) \times e^{j\pi n} = X(e^{j\omega})\, e^{j\pi n}$

$= X(e^{j(\omega - \pi)}) \quad |\omega| < \pi/L$

in forms of continuous frequency

$= \frac{1}{T} X\left(j\left(\Omega - \frac{\pi}{T}\right)\right)$

$\Rightarrow X\left(e^{j(\Omega - \pi/T)T}\right) = X\left(e^{j(\omega - \pi)}\right)$

Now conversion to continous time domain (8)

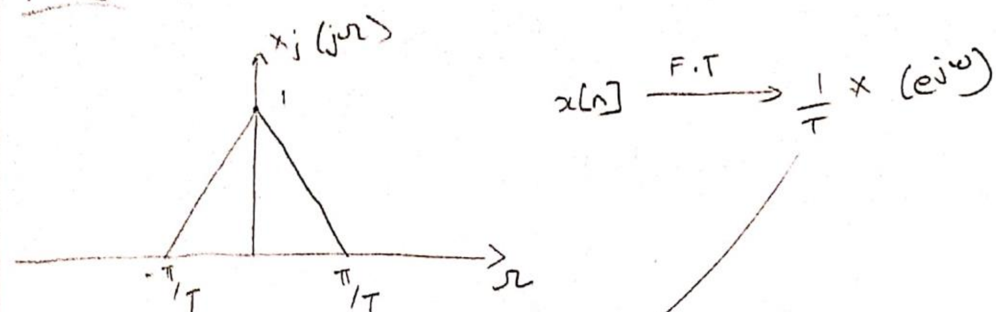
$$Y(e^{j\omega\Omega}) = Y(\omega\Omega T) = \frac{1}{T} X\left(j\left(\Omega - \pi/T\right)\right)$$

$$y_c(t) = \frac{1}{T} X\left(j\left(\Omega - \pi/T\right)\right) \times \frac{T}{L} \quad |\omega| < \frac{\pi}{L} \times \frac{4}{T}$$

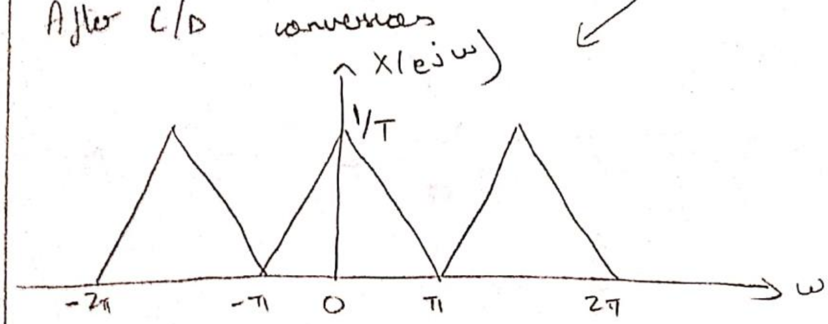
$$= \frac{1}{L} X\left(j\left(\Omega - \pi/T\right)\right) \quad |\omega| < \pi/T$$

plots on matlab

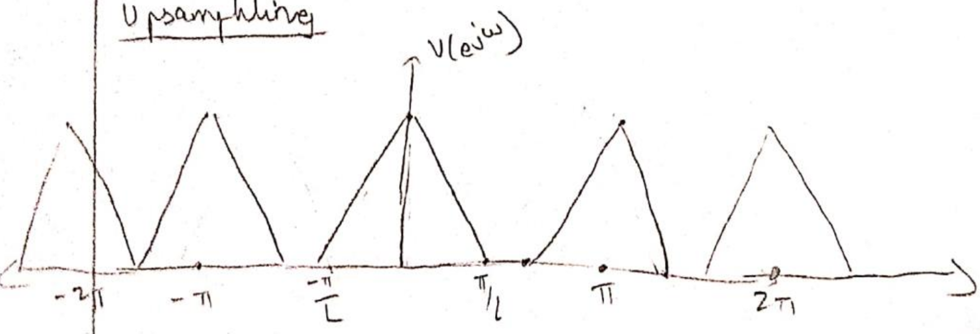
Plots



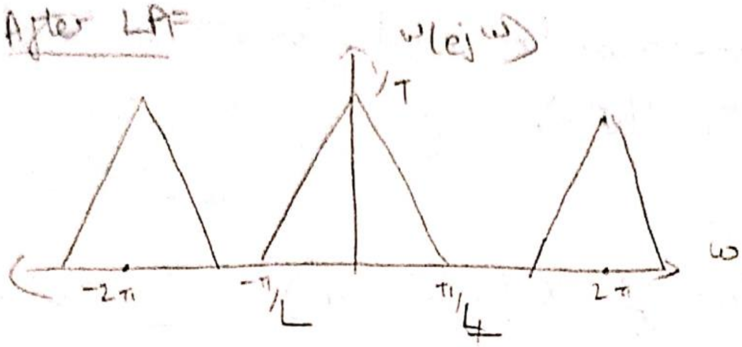
After C/D conversion



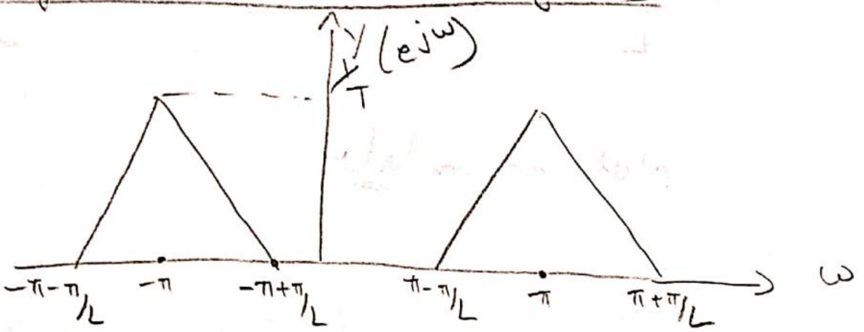
Upsamphling



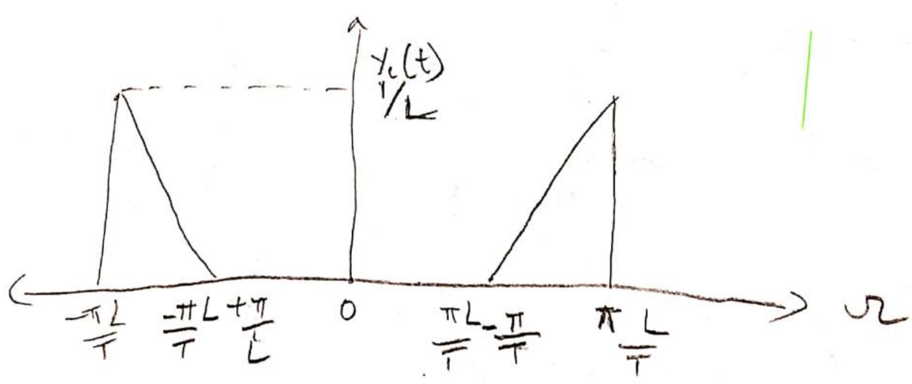
After LPF



After modulation (Shifting)



D/C converter



Question 8 code)

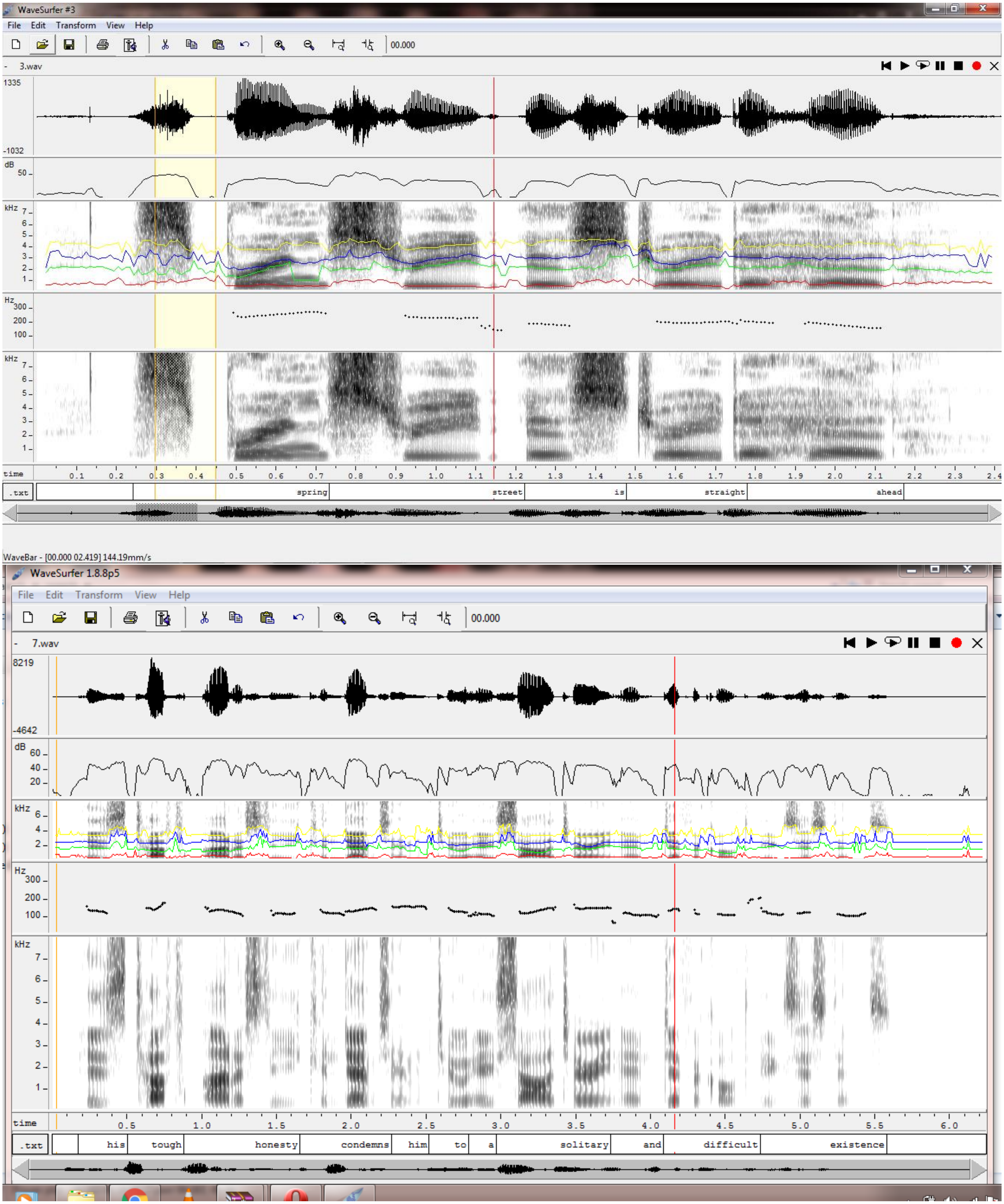
```
clc;clear all; close all;
%8b downsample by 4 and save
[wave4, F_4] = audioread('4.wav');
wav4downby4 = downsample(wave4,4);
[wave8, F_8] = audioread('8.wav');
wav8downby4 = downsample(wave8,4);
audiowrite('4_downsampled.wav',wav4downby4,F_4);
audiowrite('8_downsampled.wav',wav8downby4,F_8);

%8c filter and then downsample by 4.. Cut off frequency choosen 2000Hz. In
%ellip filter I have used as 0.25.
[wave3,F_3] = audioread('3.wav');
[wave7,F_7] = audioread('7.wav');
[b,a] = ellip(6,0.1,40,.25);
f3_filtered = filter(b,a,wave3);
f7_filtered = filter(b,a,wave7);

filterWav3downby4 = downsample(f3_filtered,4);
filterWav7downby4 = downsample(f7_filtered,4);
audiowrite('3_filter_downsampled.wav',filterWav3downby4,F_3);
audiowrite('7_filter_downsampled.wav',filterWav7downby4,F_7);

%8d resample to 3000hz and downsample by 4.
p=3000;%final frquecy
q=16000;%inital sampled frequency
resampledWav3_3000 = resample(wave3,p,q);
resampledWav7_3000 = resample(wave7,p,q);
down3 = downsample(resampledWav3_3000,4);
down7 = downsample(resampledWav7_3000,4);
audiowrite('3_3000_down.wav',down3,3000);
audiowrite('7_3000_down.wav',down7,3000);
```

8a)


WaveSurfer #3
File Edit Transform View Help
00.000
3.wav
spring
street
is
straight
ahead
WaveBar - [00.000 02.419] 144.19mm/s
WaveSurfer 1.8.8p5
File Edit Transform View Help
00.000
7.wav
his
tough
honesty
condemns
him
to
a
solitary
and
difficult
existence

8b)

When the original signal is compared to the down sampled signal , the amplitude is almost the same just there is a quality loss due to not filtering in the beginning. Aliasing occurs due to presence of both high and low frequencies. Rest we can hear the differences in the voices in both cases.(code has been attached)

8c)

This is better than the case in b. Since we have used a low pass filter at frequency of 2000Hz so all high frequency sounds have been eliminated which would cause the loss like in step b.

So after down sampling the voice is clearly heard and also the clarity has not deteriorated.

8d) Since after resampling it to 3000Hz, there are still high frequencies left in the signal. Due to which when we further down sample the signal, there are losses due to aliasing but the voice is recognizable with poor quality and low amplitude.

8e)

vowel, semi-vowel, nasal, fricative & stop

Vowel- Since Vowels are mostly low frequency, the sounds are clearly heard and not deteriorated enough by filtering or resampling to 3000Hz.

Semi-vowel- Since these are combination with vowels, they have high frequency parts as well, which get cut off in case of filtering and deteriorated in case of resampling. So, identifying them creates a small problem.

Nasal- these are low frequency so they are heard clearly.

Fricative- Since these are high frequency, these get eliminated or semi eliminated.

Stop- Remains same as low frequency.

Code for all plots:

```
clear all; close all; clc;
%1a
N=10;
% w=-pi:0.01:pi;
w=0:0.01:2*pi
a=0.9;
num=(1-((a^N)*exp(-j*w*N)))
den= (1-(a*exp(-j*w)))
afunc=(num./den)
a=2;
num=(1-((a^N)*exp(-j*w*N)))
den= (1-(a*exp(-j*w)))
afunc1=(num./den)
figure();
subplot(2,1,1);
plot(abs(afunc));
title('MAgnitude responce 1a where value of a=0.9');
subplot(2,1,2);
plot(abs(afunc1));
title('MAgnitude responce 1a where value of a=2');
pic1= sin(w*N/2)./sin(w/2)
figure();
plot(abs(pic1))
% a= @(w) 0.54*sin(w*N/2)/sin(w/2)
% b=@(w) 0.23*sin((N/2)*(w-((2*pi)/(N-1))))/sin((1/2)*(w-((2*pi)/(N-1))))
% c=@(w) 0.23*sin((N/2)*(w+((2*pi)/(N-1))))/sin((1/2)*(w+((2*pi)/(N-1))))
a=  0.54*sin(w*N/2)./sin(w/2)
b=0.23*sin((N/2)*(w-((2*pi)/(N-1))))./sin((1/2)*(w-((2*pi)/(N-1))))
c=0.23*sin((N/2)*(w+((2*pi)/(N-1))))./sin((1/2)*(w+((2*pi)/(N-1))))
title('Rectangular function 1b');
%  pic2=@(w) 0.54*sin(w*N/2)/sin(w/2) + 0.23*sin((N/2)*(w-((2*pi)/(N-1))))/sin((1/2)*(w-((2*pi)/(N-1)))) +
0.23*sin((N/2)*(w+((2*pi)/(N-1))))/sin((1/2)*(w+((2*pi)/(N-1))))
pic2=0.54*sin(w*N/2)./sin(w/2) + 0.23*sin((N/2)*(w-((2*pi)/(N-1))))./sin((1/2)*(w-((2*pi)/(N-1)))) + 0.23*sin((N/2)*(w+((2*pi)/(N-
1))))./sin((1/2)*(w+((2*pi)/(N-1))))
figure();
hold on;

plot(abs(pic2))
plot(abs(a))
plot(abs(b))
plot(abs(c))
legend('final','a','b','c')
title('Hamming window 1c')
% n=-pi:0.01:pi;

pic= @(w) abs(j*w*exp(-j*w));
figure();
fplot(pic);
title('MAgnitude responce 3a');
pic1221= @(w) angle(j*w*exp(-j*w));
figure();
fplot(pic1221);
title('Phase plot 3a');

for n= 0:9
   y(n+1)=(-1).^(n+1)/(n-5);
end
```

```
figure()
stem(y);
title('Plot for 3b');
for n= 0:9
    y(n+1)=(-1).^(n)/(pi*(n-5)^2);
end
figure()
stem(y);
title('Plot for 3b');
%6
r = 0.9;
omega_0 = 0.1*pi;
eqn = @(x) 0.25*(0.9.^(3*x)).*((cos(omega_0*x*3)) + 3*cos(omega_0*x));
n = [-100:1:100];
F_last = (1/128)*fft(eqn(n),128);
figure();
plot(abs(F_last))
title('Plot for 6');
```