FINAL PROJECT - ECES 631

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DISCRETE TIME MODELS FOR THE SPEECH SIGNAL

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Part 3.3 a

Exponential model

```
a=0.91;
Npts=51;
Nfreq=6;
[gE,GE,w_E] = glottalE(a,Npts,Nfreq);
% figure,plot(gE), title('Exponential Model');

% Rosenberg Model
N1=40;
N2=10;
[gR,GR,w_R] = glottalR(N1,N2,Nfreq);
```

Part 3.3 b

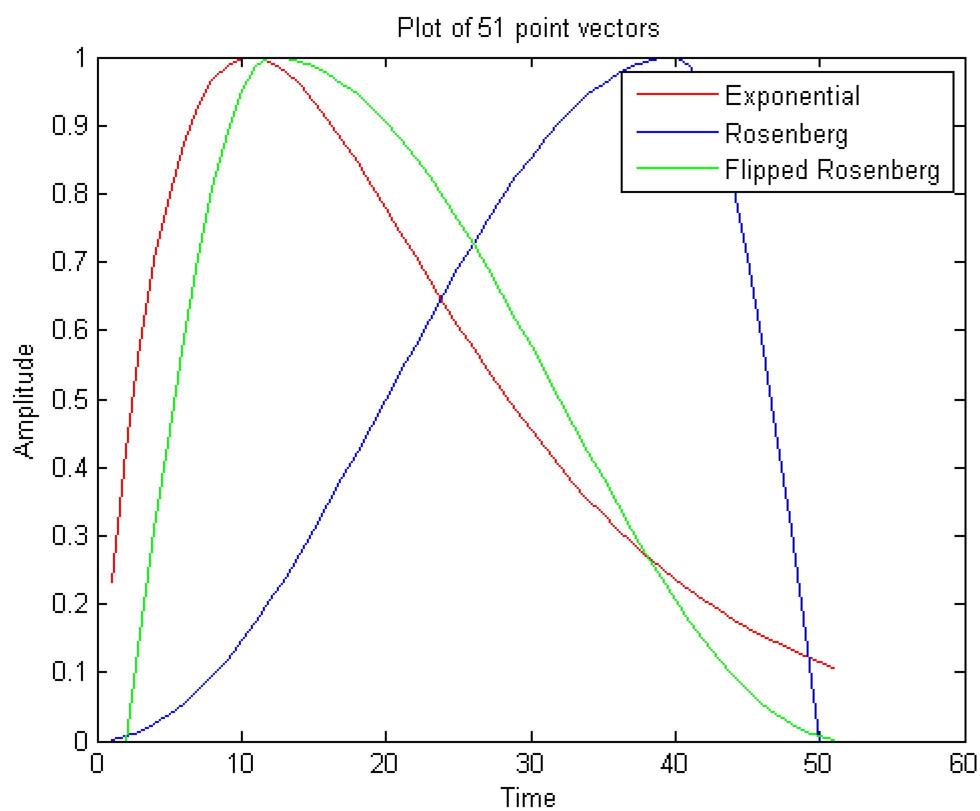
FLIPPED ROSENBERG

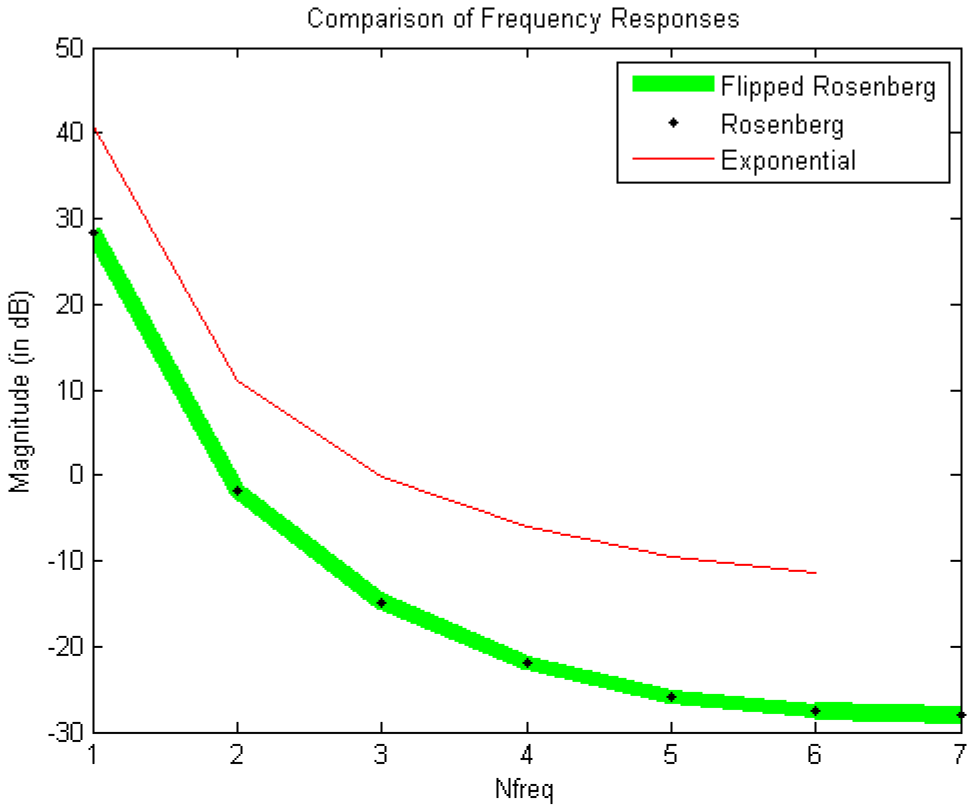
```
gRflip = fliplr(gR);
GR_flip=zeros(1,length(w_R));

for p=1:length(w_R)
    win=w_R(p);
    for l=1:N1+N2
        cmn=0;
%         cmn=gRflip(l)*exp((1i)*p*2*pi/Nfreq)*l;
        cmn=gR(l)*exp(-(1i)*win*l);
        GR_flip(p)=GR_flip(p) + cmn;
    end
end
```

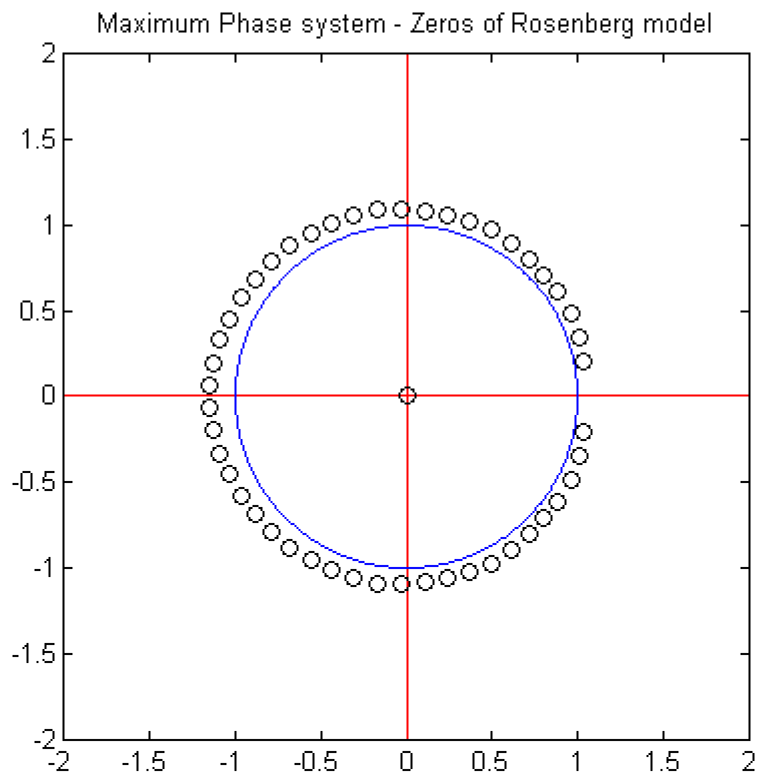
Part 3.3c

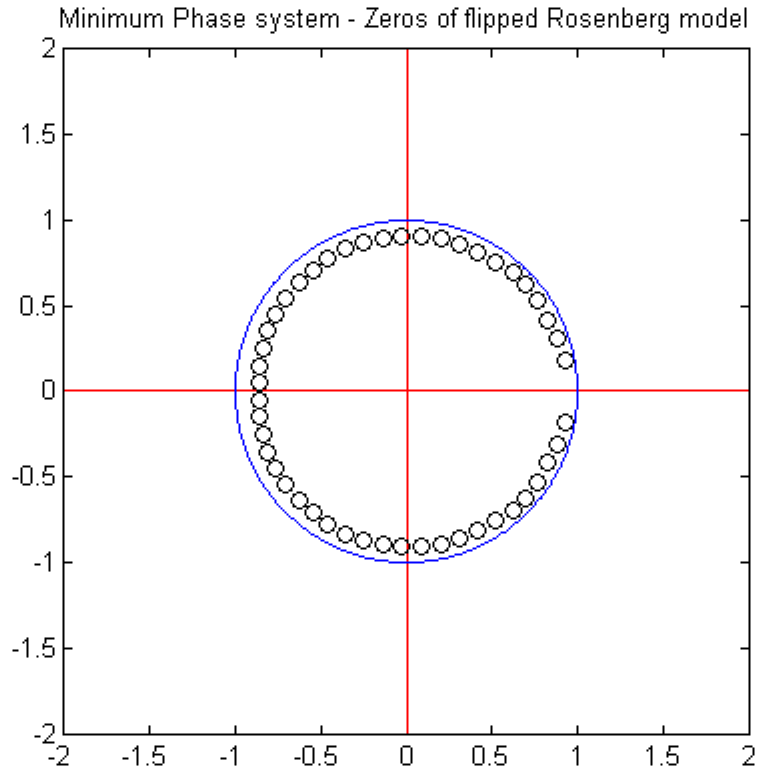
```
gE=gE/max(gE);
```

```
figure, plot(gE,'r');
hold on, plot(gR,'b');
hold on, plot(gRflip,'g');
title('Plot of 51 point vectors')
legend('Exponential','Rosenberg','Flipped Rosenberg');
xlabel('Time'), ylabel('Amplitude');
%Frequency plots
figure,plot(20*log10(abs(GR_flip)),'g','linewidth',6);
hold on, plot(20*log10(abs(GR)),'k.'), title('Comparison of Frequency Responses');
plot(20*log10(abs(GE)),'r');
legend('Flipped Rosenberg','Rosenberg','Exponential');
xlabel('Nfreq'), ylabel('Magnitude (in dB)');


%%Part 3.3d

% For the rosenberg model, since there is a zero at z = 0, when we flip it,
% then the zero goes to infinity. So skipping the first zero and plotting
% the rest of the zeros for the flipped rosenberg model
roo1=roots(gR);
figure,zpl(roo1,[]),title('Maximum Phase system - Zeros of Rosenberg model');


roo2=roots(gRflip);
figure,zpl(roo2(2:end),[]),title('Minimum Phase system - Zeros of flipped Rosenber
```




Comparison of Frequency Responses
Flipped Rosenberg
Rosenberg
Exponential
Magnitude (in dB)
Nfreq
50
40
30
20
10
0
-10
-20
-30
1
2
3
4
5
6
7


Maximum Phase system - Zeros of Rosenberg model
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2



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```
function [gE,GE,w_E] = glottalE(a,Npts,Nfreq)
% gE is the exponential glottal waveform vector of length Npts
% GE is the frequency response at Nfreq frequencies between 0  and pi
% radians
gE=[];
GE=[];

x=1:Npts;
gE=[gE x.*a.^x];

% G(z) = az^-1 /(1-2az^-1+a^2z^-2) => b=a, a=[1 -2a a^2]

b = [0 a];
a0 = [1 -2*a a^2];
[GE,w_E]=freqz(b,a0,Nfreq);
end
```

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```
function [gR,GR,w_R] = glottalR(N1,N2,Nfreq)
% gR is the Rosenberg Glottal waveform vector of length N1+N2+1
% GR is the frequency response at Nfreq frequencies w_R between 0 and pi
% radians

gR=[];
%Generation of glottal waveform
for n=1:N1+N2+1
    if(n<=N1)
    gR(n)=0.5*(1-cos(pi*(n)/N1));
    elseif(n<=N1+N2)
    gR(n)=cos(pi*(n-N1)/(2*N2));
    else
    gR(n) = 0;
    end
end
%Frequency response of the glottal waveform using Fourier transform formula
w_R = 0:pi/Nfreq:pi;
GR=zeros(1,length(w_R));

for p=1:length(w_R)
    win=w_R(p);
    for l=1:N1+N2
        cmn=0;
%         cmn=gR(l)*exp(-(1i)*p*2*pi/Nfreq)*l;
         cmn=gR(l)*exp(-(1i)*win*l);
        GR(p)=GR(p) + cmn;
    end
end

end
```

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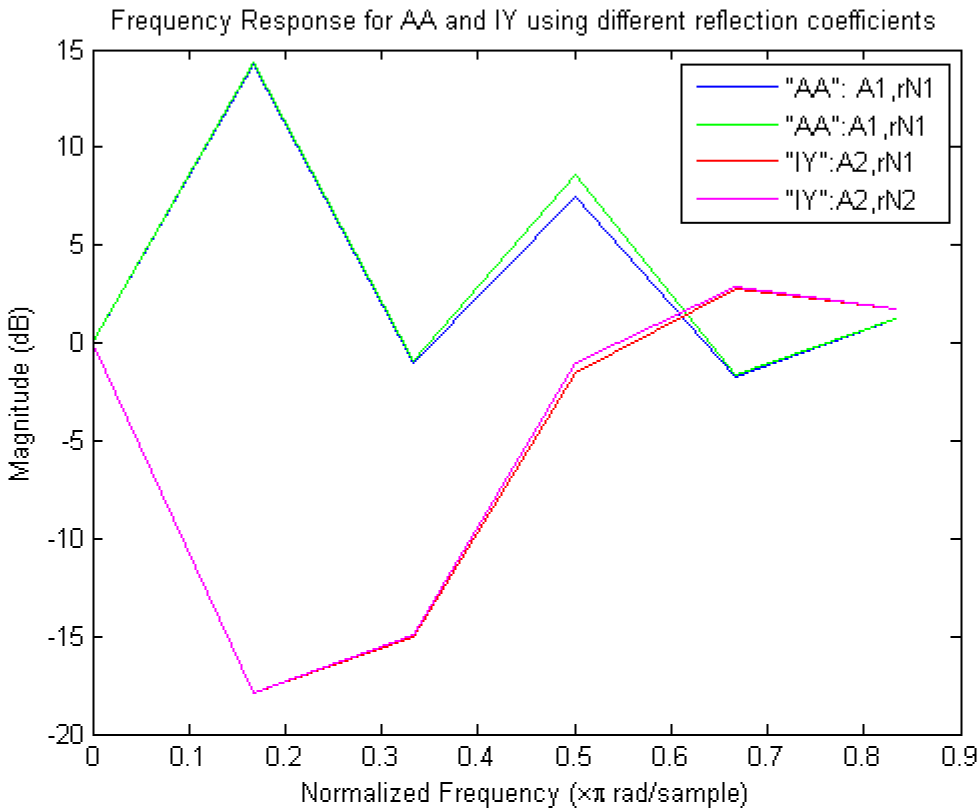
Part 4.1

Frequency response plots

```
Nfreq = 6;
A1=[1.6,2.6,0.65,1.6,2.6,4.0,6.5,8.0,7.0,5.0];
A2=[2.6,8.0,10.5,10.5,8.0,4.0,0.65,0.65,1.3,3.2];

rN1=0.71;
rN2=1.0;

[r1,D1,G1]=atov(A1,rN1);
[h1,w1]=freqz(G1,D1,Nfreq);
figure,plot(w1/pi,20*log10(abs(h1)));
hold on;

[r2,D2,G2]=atov(A1,rN2);
[h2,w2]=freqz(G2,D2,Nfreq);
plot(w2/pi,20*log10(abs(h2)),'g');


[r3,D3,G3]=atov(A2,rN1);
[h3,w3]=freqz(G3,D3,Nfreq);
plot(w3/pi,20*log10(abs(h3)),'r');

[r4,D4,G4]=atov(A2,rN2);
[h4,w4]=freqz(G4,D4,Nfreq);
plot(w4/pi,20*log10(abs(h4)),'m');

legend('"AA": A1,rN1','"AA":A1,rN1','"IY":A2,rN1','"IY":A2,rN2');
xlabel('Normalized Frequency (\times\pi rad/sample)');
ylabel('Magnitude (dB)');
title('Frequency Response for AA and IY using different reflection coefficients');
```

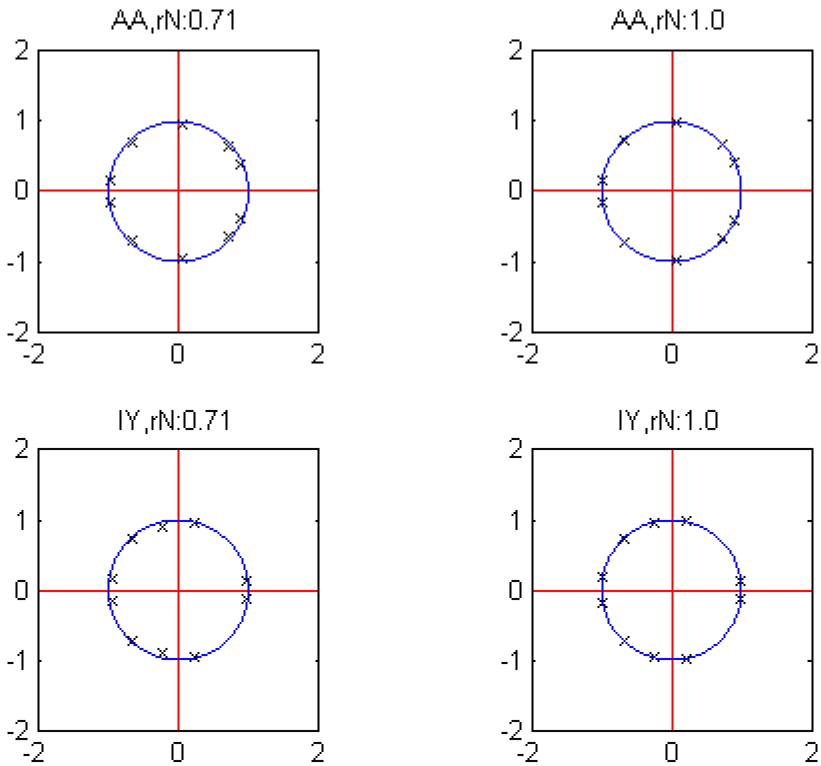


Part 4.1b

Pole plot

```
figure;
roo1 = roots(D1);
subplot(2,2,1), zpl([],roo1), title('AA,rN:0.71');

roo2 = roots(D2);
subplot(2,2,2), zpl([],roo2), title('AA,rN:1.0');


roo3 = roots(D3);
subplot(2,2,3), zpl([],roo3), title('IY,rN:0.71');

roo4 = roots(D4);
subplot(2,2,4), zpl([],roo4), title('IY,rN:1.0');

% FORMAT Frequencies
%Given T=1/1000;
Ts=1/1000;
ang1 = angle(roo1);
ang2 = angle(roo2);
ang3 = angle(roo3);
ang4 = angle(roo4);
```

```
fre1 = ang1/(2*pi*Ts);
fre2 = ang2/(2*pi*Ts);
fre3 = ang3/(2*pi*Ts);
fre4 = ang4/(2*pi*Ts);
```



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System Models

```
%Exponential glottal pulse
fs=10000;
b = [0 a];
a0 = [1 -2*a a^2];
sys_G_z = tf(b,a0,1/fs,'variable','z^-1');

% Vocal tract V(z)
sys_V_z1 = tf(G1,D1,1/fs,'variable','z^-1');
sys_V_z2 = tf(G2,D2,1/fs,'variable','z^-1');
sys_V_z3 = tf(G3,D3,1/fs,'variable','z^-1');
sys_V_z4 = tf(G4,D4,1/fs,'variable','z^-1');

%%Raditaion R(z) = (1-z^-1)
a=1;
b=[1 -1];
sys_R_z = tf(b,a,1/fs,'variable','z^-1');

% H(z)= G(z)*V(z)*R(z) for Exponential glottal model
H_z1 = sys_G_z*sys_V_z1*sys_R_z;
H_z2 = sys_G_z*sys_V_z2*sys_R_z;
H_z3 = sys_G_z*sys_V_z3*sys_R_z;
H_z4 = sys_G_z*sys_V_z4*sys_R_z;

%%Excitation signal e[n] = y1
f=100;
fs=10000;
y1=zeros(10000,1);
y1(1:fs/f:end)=1;
% stem(y1);

%Inverse Z-transform
imp1 = impz(H_z1.num{1},H_z1.den{1},10);
imp2 = impz(H_z2.num{1},H_z2.den{1},10);
imp3 = impz(H_z3.num{1},H_z3.den{1},10);
imp4 = impz(H_z4.num{1},H_z4.den{1},10);
%Convolution of input excitation signal with H(z)
soun_exp1=conv(y1,imp1);
soun_exp2=conv(y1,imp2);
soun_exp3=conv(y1,imp3);
soun_exp4=conv(y1,imp4);
```

```
% figure, subplot(2,2,1), plot(soun_exp1),title('AA,rN:0.71');
%Concatenate sounds into a single pulse.
song = cat(1,soun_exp1,zeros(1000,1),soun_exp2,zeros(1000,1),soun_exp3,zeros(1000,
%Listen to the sounds
soundsc(song,fs);

% Rosenberg  Glottal Pulse
%FOR "AA" sound
convolVR=sys_R_z*sys_V_z1;
%Inverse of convolVR_z
himp = impz(convolVR.num{1},convolVR.den{1},10);
ans_w=conv(himp,gR);
sou_n=conv(y1,ans_w);
soundsc(sou_n,fs);


%FOR 'IY' sound
convolVR3=sys_R_z*sys_V_z3;
%Inverse of convolVR_z
himp3 = impz(convolVR3.num{1},convolVR3.den{1},10);
ans_w3=conv(himp3,gR);
sou_n3=conv(y1,ans_w3);
soundsc(sou_n3,fs);
r_song = cat(1,sou_n,zeros(1000,1),sou_n3);
soundsc(r_song);
```

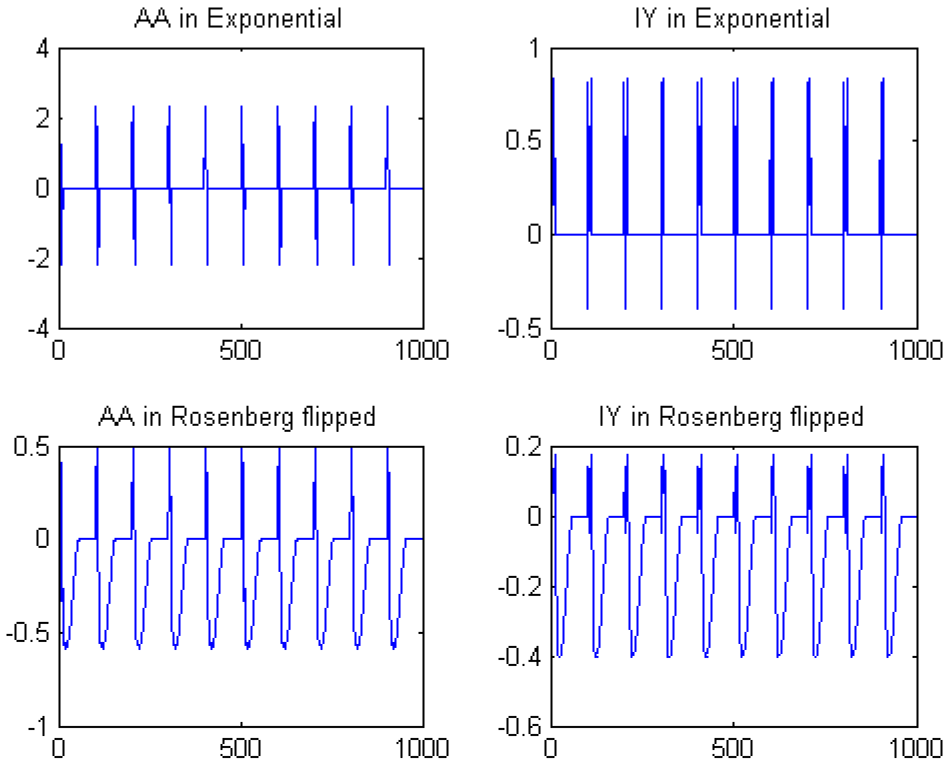
Rosenberg Flipped

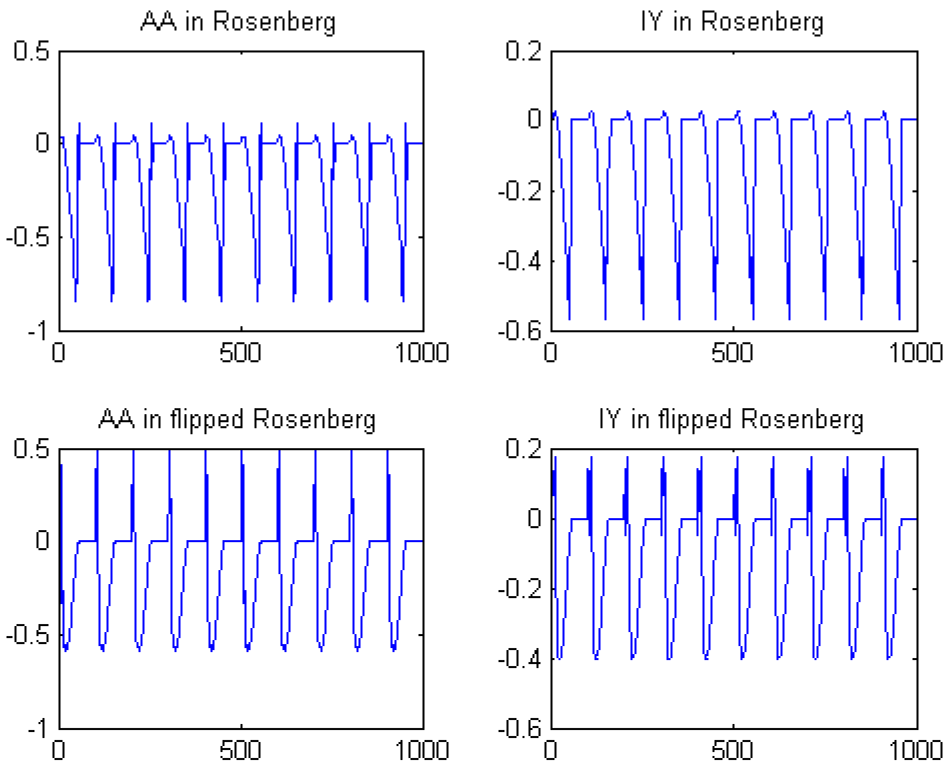
```
%FOR "AA" sound
ans_w_f=conv(himp,gRflip);
sou_nf=conv(y1,ans_w_f);
soundsc(sou_nf,fs);


%FOR 'IY' sound
ans_w3f=conv(himp3,gRflip);
sou_n3f=conv(y1,ans_w3f);
soundsc(sou_n3f,fs);
flr_song = cat(1,sou_n3,zeros(1000,1),sou_n3f);
soundsc(flr_song);
```

Part 5.1

```
figure, subplot(2,2,1), plot(soun_exp1(1:1000)), title('AA in Exponential');
subplot(2,2,2), plot(soun_exp3(1:1000)), title('IY in Exponential');
subplot(2,2,3), plot(sou_nf(1:1000)), title('AA in Rosenberg flipped');
subplot(2,2,4), plot(sou_n3f(1:1000)), title('IY in Rosenberg flipped');

figure, subplot(2,2,1), plot(sou_n(1:1000)), title('AA in Rosenberg');
subplot(2,2,2), plot(sou_n3(1:1000)), title('IY in Rosenberg');
subplot(2,2,3), plot(sou_nf(1:1000)), title('AA in flipped Rosenberg');
```

```
subplot(2,2,4), plot(sou_n3f(1:1000)), title('IY in flipped Rosenberg');
```

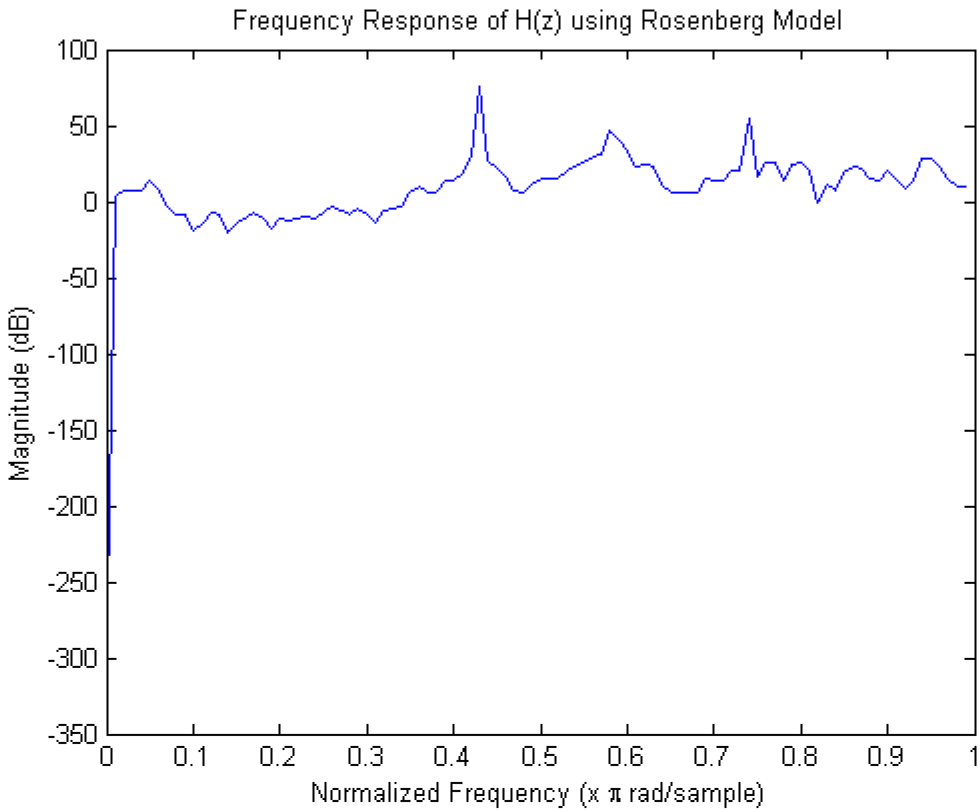




Part 5.2

TO find H(z) , first convert all the sytems into Z domain. Multiply V(z) , R(z) and G(z) to get H(z). After that plt the frequency response of H(z)

```
syms z n
G_z = symsum((0.5*(1-cos((pi*n)/40))*z^(-n)), n, 0, 40) + symsum(cos((pi*(n-40)/(2
R_z = 1-(1/z);
[r4, D4, G4]=atov(IY,rN2);
V_z = G4/ (D4(1)+D4(2)*(1/z) + D4(3)*(1/z^2)+ D4(4)*(1/z^3)+ D4(5)*(1/z^4)+ D4(6)*
Hz = G_z*V_z*R_z;
[NUME,DENO] = numden(Hz);

num_c = double(coeffs(NUME));
den_c = double(coeffs(DENO));

[mag, freq] = freqz(num_c, den_c, 100);
figure,plot(freq/pi,20*log10(abs(mag)))
xlabel('Normalized Frequency (x \pi rad/sample)');
ylabel('Magnitude (dB)');
title('Frequency Response of H(z) using Rosenberg Model');
```



Part 5.3

Listening to the output

```
%Rosenberg model
r_song = cat(1,sou_n,zeros(1000,1),sou_n3);
soundsc(r_song);
%Flipped rosenberg model
flr_song = cat(1,sou_n3,zeros(1000,1),sou_n3f);
soundsc(flr_song);
% The sounds can be distinctly differentiated into "AA" and "IY" vowels.
```

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EXERCISE 4.2

Part a]

Show that r_N is equal to co-efficient of z^{-N} in the denominator of $V(z)$ (ie) $r_N = -\alpha_N$

$D_0(z) = 1$

$D_K(z) = D_{K-1}(z) + r_K Z^{-K} D_{K-1}(z^{-1}) \rightarrow$ for $k = 1, 2, \dots N$

$D_1(z) = D_0(z) + r_1 z^{-1} . D_0(z^{-1})$

$D_1(z) = 1 + r_1 z^{-1} \Rightarrow [\because D_0(z^{-1}) = 1]$ — ①

$\Rightarrow r_1$ is co-efficient of z^{-1}

But $D(z) = 1 - \sum_{K=1}^{N} \alpha_K z^{-K}$

For $K=1$

$D_1(z) = 1 - \alpha_1 z^{-1}$ — ②

From ① + ②,

$\underline{\underline{r_1 = -\alpha_1}}$ — ③

For $K = 2$,

$D_2(z) = D_1(z) + r_2 z^{-2} D_1(z^{-1})$

$= 1 + r_1 z^{-1} + r_2 z^{-2} (1 + r_1 z)$

$= 1 + r_1 z^{-1} + r_2 z^{-2} + r_1 r_2 z^{-1}$ — ④

But

$D_2(z) = 1 - \alpha_1 z^{-1} - \alpha_2 z^{-2}$ — ⑤

From ④ + ⑤

$\Rightarrow \underline{\underline{r_2 = -\alpha_2}}$

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Similarly,

$$D_N(z) = 1 + r_{N-1} z^{-N+1} + r_N z^{-N} \quad r_{N-1} r_N z^{-N-1}$$

and also

$$D_N(z) = 1 - \alpha_1 z^{-1} - \alpha_2 z^{-2} + \dots - \alpha_N z^{-N}$$

$\therefore$ r_N is equal to co-efficient of z^{-N} in the denominator of $V(z)$

$$\boxed{r_N = -\alpha_N}$$

Part 4.2 b]

$$D_{k-1}(z) = \frac{D_k(z) - r_k z^{-k} D_k(z^{-1})}{1 - r_k^2}$$

$$[D_{k-1}(z)](1 - r_k^2) = D_k(z) - r_k z^{-k} D_k(z^{-1})$$

Using ⊛,

$$D_{k-2}(z) + r_{k-1} z^{-(k+1)} D_{k-2} z^{-1} [1 - r_k^2]$$

$$= \left[D_{k-1}(z) + r_k z^{-k} D_{k-1}(z^{-1})\right] - r_k z^{-k}\left[D_{k-1}(z^{-1}) + r_k z^{k} . D_{k-1}(z)\right]$$

$$D_{k-2}(z) + r_{k-1} z^{-(k+1)} D_{k-2}(z^{-1}) - r_k^2 D_{k-2}(z) - r_k^2 r_{k-1} z^{-(k+1)} . D_{k-2}(z^{-1})$$

$$= D_{k-1}(z) + r_k z^{-k} D_{k-1}(z^{-1}) - r_k z^{-k} D_{k-1}(z^{-1}) - r_k^2 D_{k-1}(z)$$

$$D_{k-1}(z)[1 - r_k^2] = D_{k-1}(z)[1 - r_k^2]$$

$\therefore$ LHS = RHS

4.2 PART c]

How would you find r_{k-1} from $D_{k-1}(z)$

From part b)

$$D_{k-1}(z) = \frac{D_k(z) - r_k z^{-k} D_k(z^{-1})}{1 - r_k^2} \qquad k = N, N-1, \dots 2$$

$$D_k(z) = D_{k-1}(z) + r_k z^{-k} D_{k-1}(z^{-1})$$

$$D_{k-1}(z) = D_{k-2}(z) + r_{k-1} z^{-k-1} D_{k-2}(z^{-1})$$

$$\therefore r_{k-1} = \frac{D_{k-2}(z) - D_{k-2}(z)}{z^{-k-1} D_{k-2}(z^{-1})}$$

4.2 PART D]

$$D_k(z) = D_{k-1}(z) + r_k z^{-k} D_{k-1}(z^{-1})$$

$$D_k - D_{k-1}(z) = r_k z^{-k} D_{k-1}(z^{-1})$$

$$\Rightarrow r_k = \frac{D_1(z) - D_0(z)}{z^{-1} D_0(z^{-1})}$$

$$r_N = \frac{D_N(z) - D_{N-1}(z)}{z^{-1} D_{N-1}(z^{-1})}$$

$$r_k = \frac{A_{k+1} - A_k}{A_{k+1} + A_k}$$

$$r_1 = \frac{2.6 - 1.6}{2.6 + 1.6} = \frac{1}{4.2} = 0.23$$

$$r_2 = \frac{A_3 - A_2}{A_3 + A_2} = \frac{0.65 - 2.6}{0.65 + 2.6} = \frac{1.95}{3.25} = 0.6$$

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Similarly $r_6 = \dfrac{6.5 - 4}{6.5 + 4} = \dfrac{2.5}{10.5} = 0.238$

~~4/3~~ r_6 is similar to r_1

4.3 PART a, b and c same as PART a, b, c of 4.2

4.3 PART d]

$r_K \Rightarrow k = 1, 2, \ldots N$

$A_K \Rightarrow K = 1, 2, \ldots N$

$[r, A] = \text{VtoA}(D, A_1)$

$$D(z) = 1 - 0.0460\, z^{-1} - 0.6232\, z^{-2} + 0.3814\, z^{-3} + 0.2443\, z^{-4} + 0.1973\, z^{-5}$$
$$+ 0.2873\, z^{-6} + 0.3655\, z^{-7} - 0.4806\, z^{-8} - 0.1153\, z^{-9} + 0.71\, z^{-10}$$