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EE 274 Digital Signal Processing 1 Lab Activity 2

A. DIFFERENCE EQUATIONS IN MATLAB

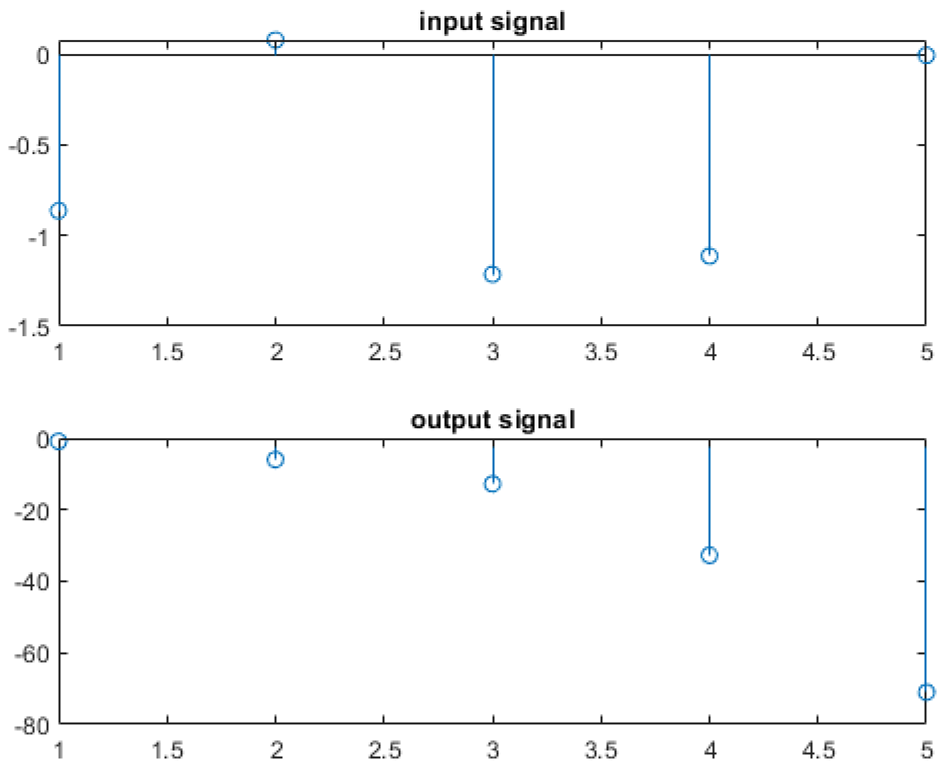
Discrete time systems can be represented using block diagrams and difference equation. Shown below is an example of a discrete time ARMA system:

$$y[n] = x[n] + 5x[n-1] + 2y[n-1]$$

B. SYSTEM RESPONSE CALCULATION

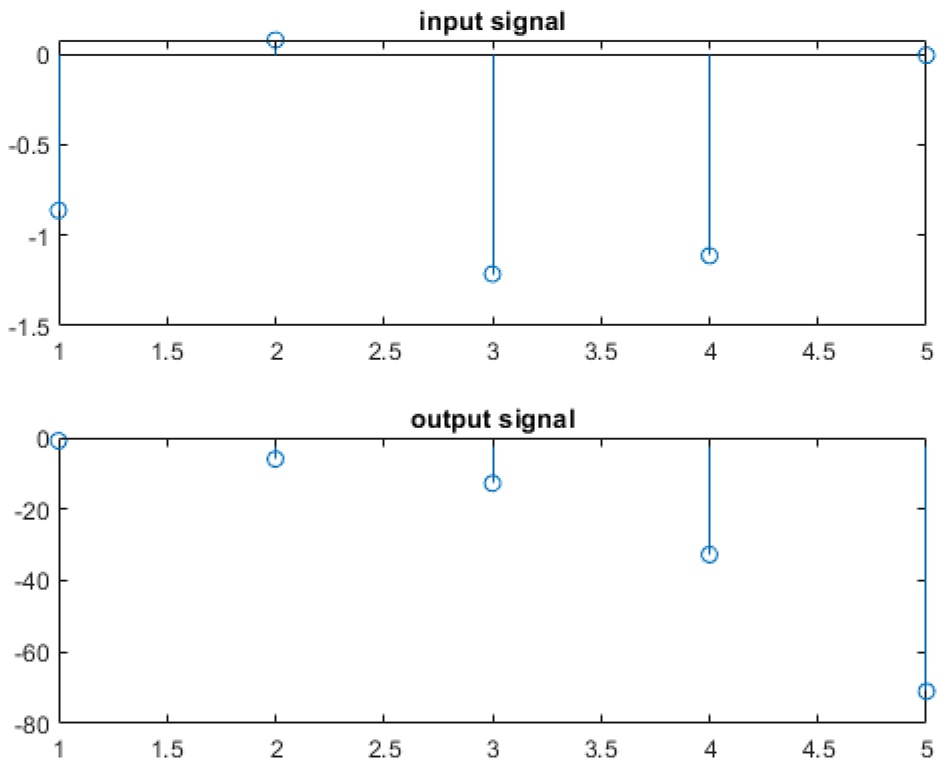
1. Using recursion We can simulate the recursion using the for loop function. FOr the code below, the simulation runs on the entire domain of n: $y[n] = x[n] + 5x[n-1] + 2y[n-1]$

```
x = randn(1,5); %random input signal x
y = zeros(1,length(x)); %initialize output signal y
for n = 1:length(x) %5 time indices
if n<2
y(n) = x(n);
else
y(n) = x(n) + 5*x(n-1) + 2*y(n-1);
end
end
figure;
subplot 211
stem(1:5,x); title('input signal');
subplot 212
stem(1:5,y); title('output signal');
```



1. Using the impulse response and DT convolution We can also simulate response using the **impz ()** function and * conv ();*

```
b = [1 5]; a = [1 -2];
h = impz(b,a); %impulse response
y = conv(h,x);
figure;
subplot 211
stem(1:5,x(1:5)); title('input signal');
subplot 212
stem(1:5,y(1:5)); title('output signal');
```



C. EXERCISES

Given the following discrete time systems: # System 1 $y[n] = 0.5x[n] + 0.5x[n-1]$ # System 2 $y[n] = x[n] - 2y[n-1] - 2y[n-2]$ # System 3 $y[n] = 1.5x[n] + 0.5x[n-1] - 2y[n-1] - 2y[n-2]$ # System 4 $y[n] = x[n] + 0.5y[n-L] + 0.5y[n-L-1]$

For each system, determine the following using MATLAB:

Create a function file (M-file) that returns a vector y from a given input x. (Make sure the lengths are the same and are using the same sampling period). For systems 1&2, perform the recursive method. For systems 3&4, use the impulse response method. System 4, should have an extra input L. Assume zero initial conditions.

```
*Format:* y = dt_1(x), y = dt_2(x), y = dt_3(x), y = dt_4(x,L)
```

Load Input Signals Input Signals

```
[x1,fs1] = audioread('inputs/x1.wav');
%divide x1 signal into two channel for computational convenience
x1_c1 = x1(:,1);
x1_c2 = x1(:,2);
[x2,fs2] = audioread('inputs/x2.wav');
```

```
[x3,fs3] = audioread('inputs/x3.wav');

[x4,fs4] = audioread('inputs/x4.wav');

[x5,fs5] = audioread('inputs/x5.wav');
```

Simulate System 1 [<system1.png](system1.png)>

```
y1_c1=dt_1(x1_c1);
y1_c2=dt_1(x1_c2);

y1_2=dt_1(x2);
y1_3=dt_1(x3);
y1_4=dt_1(x4);
y1_5=dt_1(x5);
```

combine y1_1 channels

```
y1_1 = [y1_c1(:),y1_c2(:)];
```

Simulate System 2 [<system2.png](system2.png)>

```
y2_c1=dt_2(x1_c1);
y2_c2=dt_2(x1_c2);

y2_2=dt_2(x2);
y2_3=dt_2(x3);
y2_4=dt_2(x4);
y2_5=dt_2(x5);

%combine y2_1
y2_1 = [y2_c1(:),y2_c2(:)];
```

Simulate System 3 [<system3.png](system3.png)>

```
y3_c1=dt_3(x1_c1);
y3_c2=dt_3(x1_c2);
y3_2=dt_3(x2);
y3_3=dt_3(x3);
y3_4=dt_3(x4);
y3_5=dt_3(x5);
```

combine y3_1

```
y3_1 = [y3_c1(:),y3_c2(:)];

%Simulate System 4
% <<system4.png>>
L1=50;
L2=100;
L3=400;

y4_c1_L1=dt_4(x1_c1,L1);
y4_c1_L2=dt_4(x1_c1,L2);
```

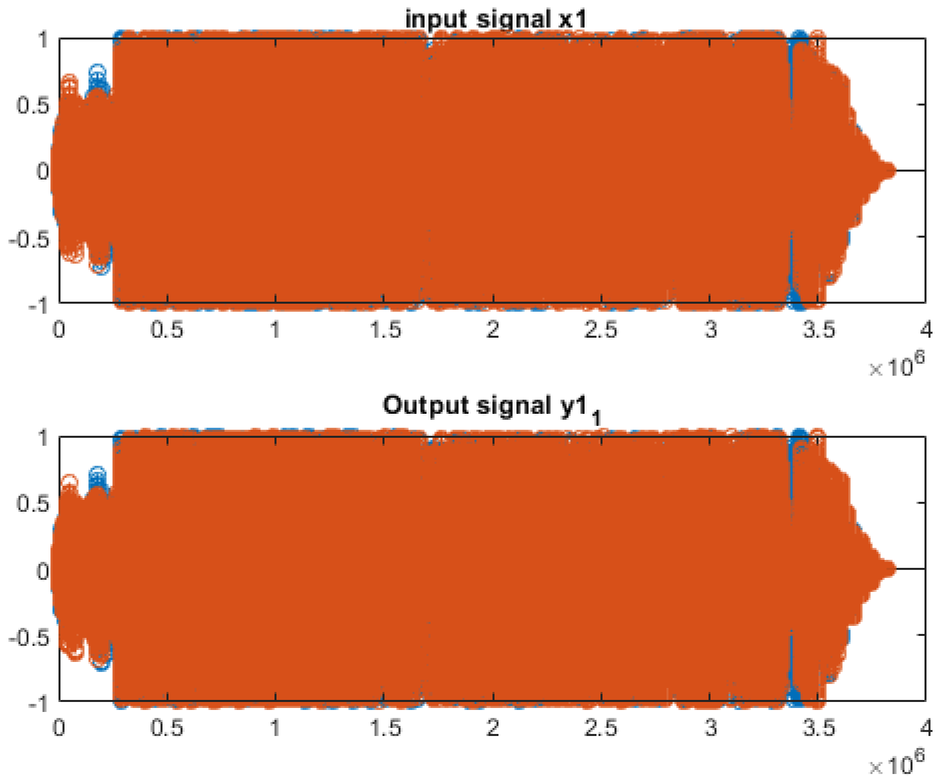
```
y4_c1_L3=dt_4(x1_c1,L3);

y4_c2_L1=dt_4(x1_c1,L1);
y4_c2_L2=dt_4(x1_c1,L2);
y4_c2_L3=dt_4(x1_c1,L3);

y4_2_L1=dt_4(x2,L1);
y4_2_L2=dt_4(x2,L2);
y4_2_L3=dt_4(x2,L3);

y4_3_L1=dt_4(x3,L1);
y4_3_L2=dt_4(x3,L2);
y4_3_L3=dt_4(x3,L3);

y4_4_L1=dt_4(x4,L1);
y4_4_L2=dt_4(x4,L2);
y4_4_L3=dt_4(x4,L3);

y4_5_L1=dt_4(x5,L1);
y4_5_L2=dt_4(x5,L2);
y4_5_L3=dt_4(x5,L3);


a =

  Columns 1 through 7

...

%combine y4_1_L1
%combine y4_1_L2
%combine y4_1_L3
y4_1_L1 = [y4_c1_L1(:),y4_c2_L1(:)];
y4_1_L2 = [y4_c1_L2(:),y4_c2_L2(:)];
y4_1_L3 = [y4_c1_L3(:),y4_c2_L3(:)];
```

2.Investigate the output response from the given input signals. Use **figure()** and **subplot()** to compare the domain plot of x versus y. For system 4, try L = 100.

3. Compare the input and output signals by listening using **soundsc(y,fs)**. For system 4, try the following values of L = 50, 100, 400.

System 1 Input X1

```
figure;
subplot 211
stem(1:length(x1),x1);
title(' input signal x1');
subplot 212
stem(1:length(y1_1),y1_1);
title('Output signal y1_1');
```



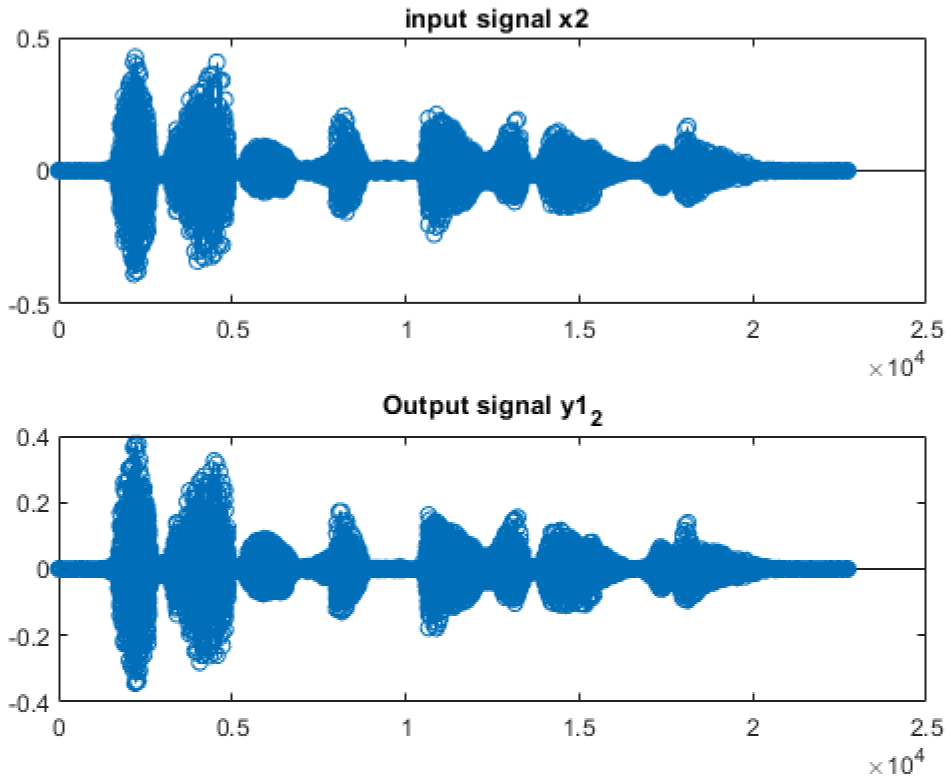
System 1 X1

```
soundsc(x1,fs1)
soundsc(y1_1,fs1)
```

Observation: Base from the graph of System 1 with input X1, there is a small difference between the input and output of audio x1 although the difference cannot be distinguish through hearing.

System 1 Input X2

```
figure;
subplot 211
stem(1:length(x2),x2);
title(' input signal x2')
subplot 212
stem(1:length(y1_2),y1_2);
title('Output signal y1_2')
```



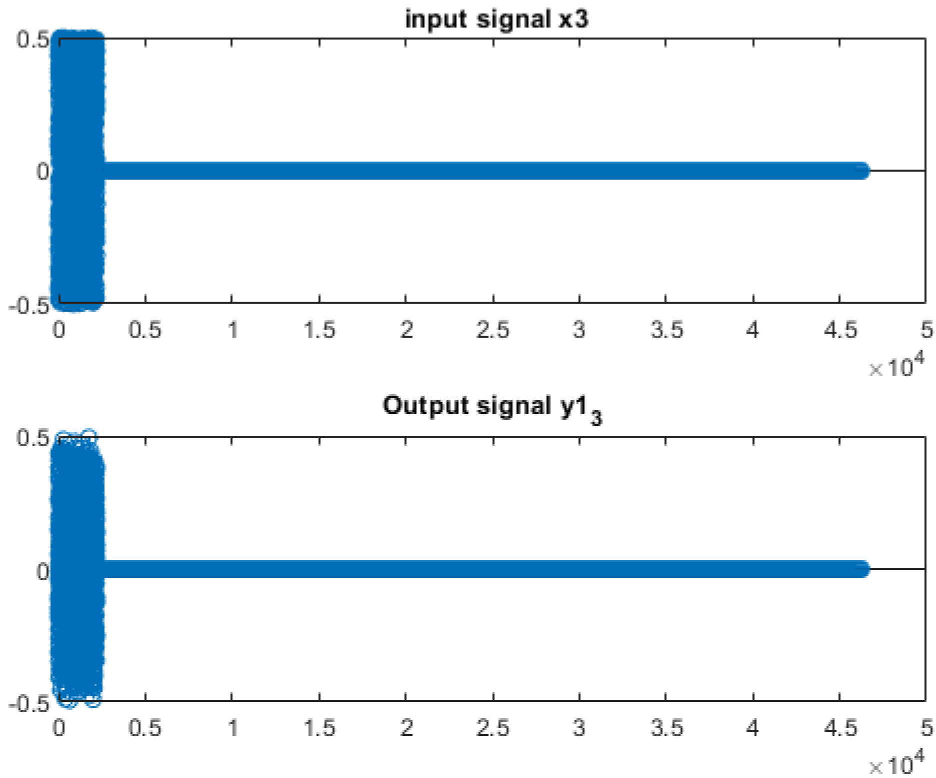
System 1 X2

```
soundsc(x2,fs2)
soundsc(y1_2,fs2)
```

Observation: Base from the graph of System 1 with input X2, there is a small difference between the input and output of speech x2 although the difference cannot be distinguish through hearing.

System 1 Input X3

```
figure;
subplot 211
stem(1:length(x3),x3);
title(' input signal x3')
subplot 212
stem(1:length(y1_3),y1_3);
title('Output signal y1_3')
```



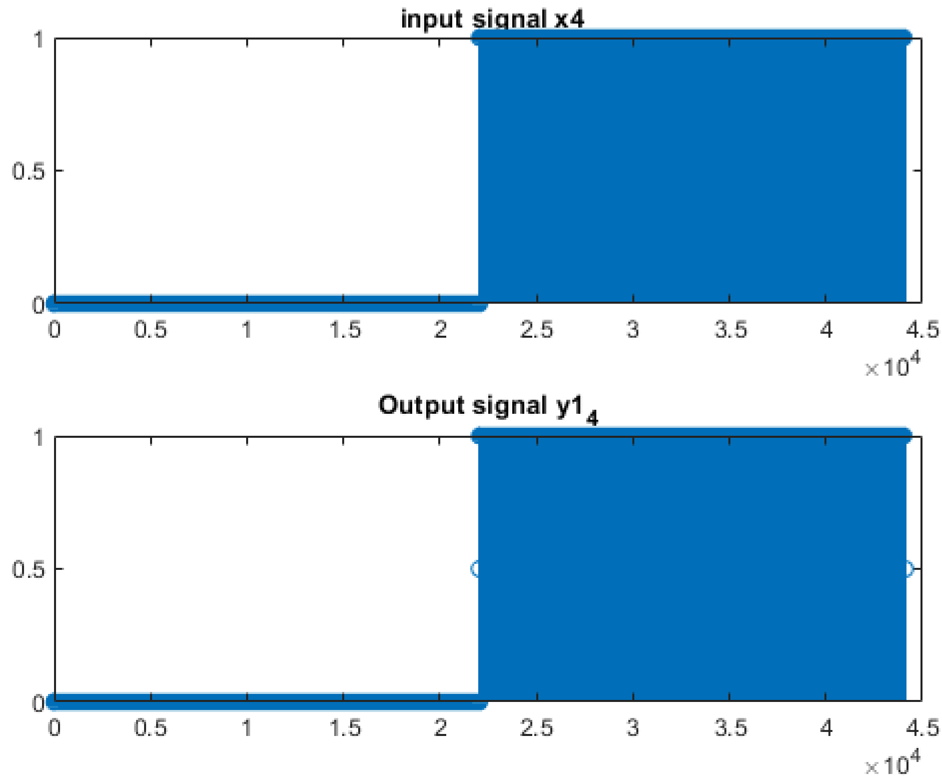
System 1 X3

```
soundsc(x3,fs3)
soundsc(y1_3,fs3)
```

Observation: Base from the graph of System 1 with input X3, there is a small difference between the input and output of audio x3 although the difference cannot be distinguish through hearing.

System 1 Input X4

```
figure;
subplot 211
stem(1:length(x4),x4);
title(' input signal x4')
subplot 212
stem(1:length(y1_4),y1_4);
title('Output signal y1_4')
```



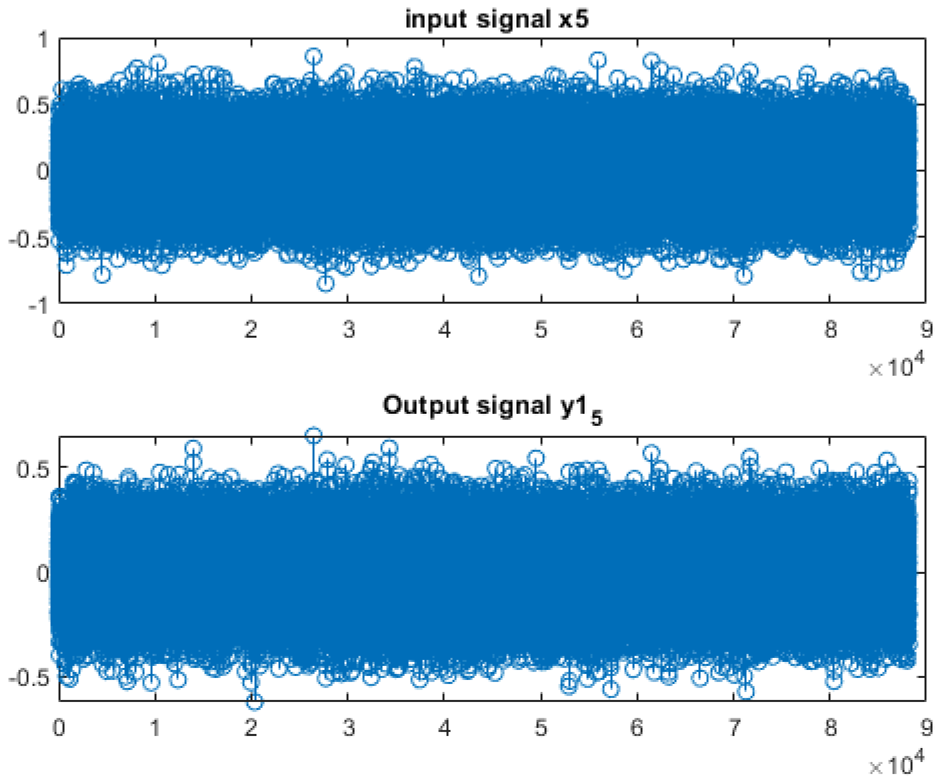
System 1 X4

```
soundsc(x4,fs4)
soundsc(y1_4,fs4)
```

Observation: Base from the graph of System 1 with input X4, there is a small difference between the input and output of audio x4 although the difference cannot be distinguish through hearing.

System 1 Input X5

```
figure;
subplot 211
stem(1:length(x5),x5);
title(' input signal x5')
subplot 212
stem(1:length(y1_5),y1_5);
title('Output signal y1_5')
```



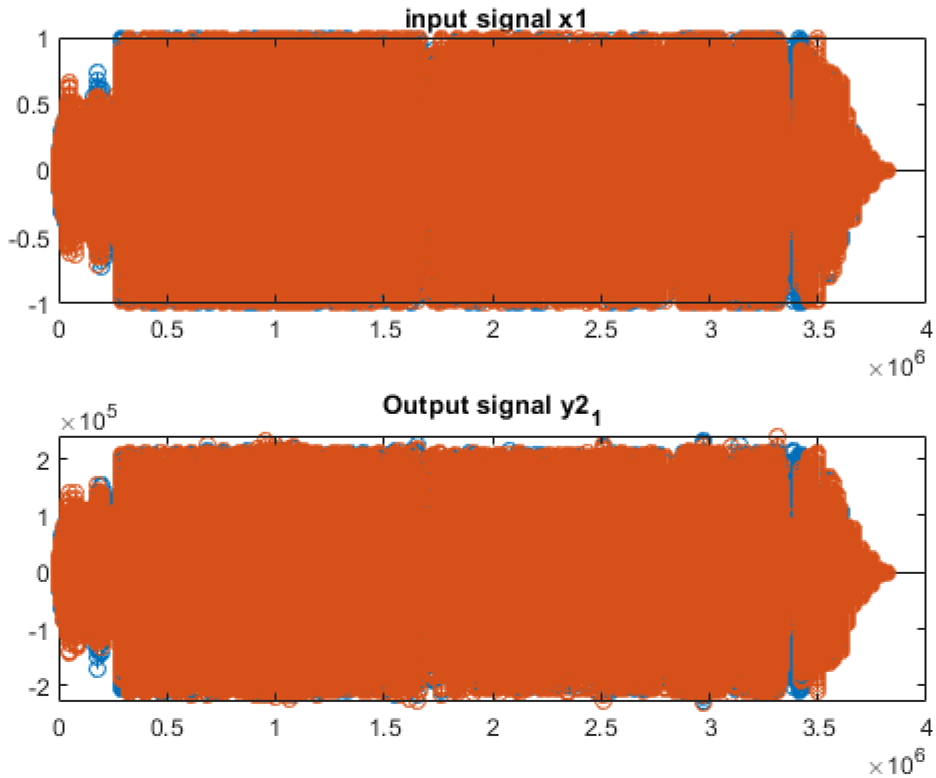
System 1 X5

```
soundsc(x5,fs5)
soundsc(y1_5,fs5)
```

Observation: Base from the graph of System 1 with input X5, there is a small difference between the input and output of audio x5 although the difference cannot be distinguish through hearing.

System 2 Input X1

```
figure;
subplot 211
stem(1:length(x1),x1);
title(' input signal x1')
subplot 212
stem(1:length(y2_1),y2_1);
title('Output signal y2_1')
```



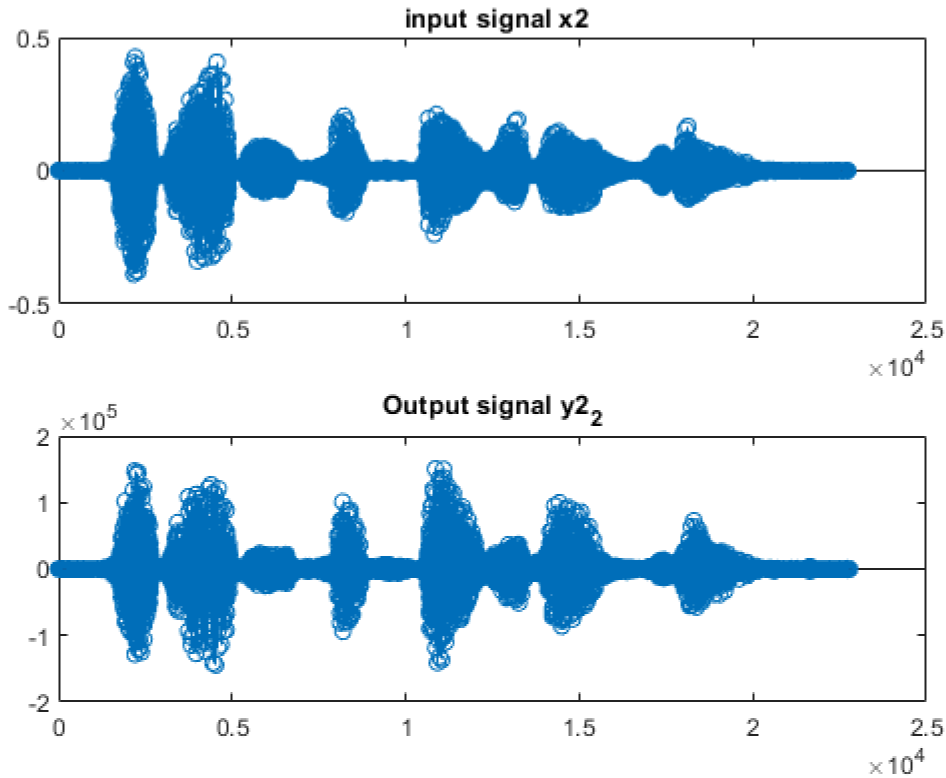
System 2 X1

```
soundsc(x1,fs1)
soundsc(y2_1,fs1)
```

Observation: Signal x1 become smoother after passing system 2

System 2 Input X2

```
figure;
subplot 211
stem(1:length(x2),x2);
title(' input signal x2')
subplot 212
stem(1:length(y2_2),y2_2);
title('Output signal y2_2')
```



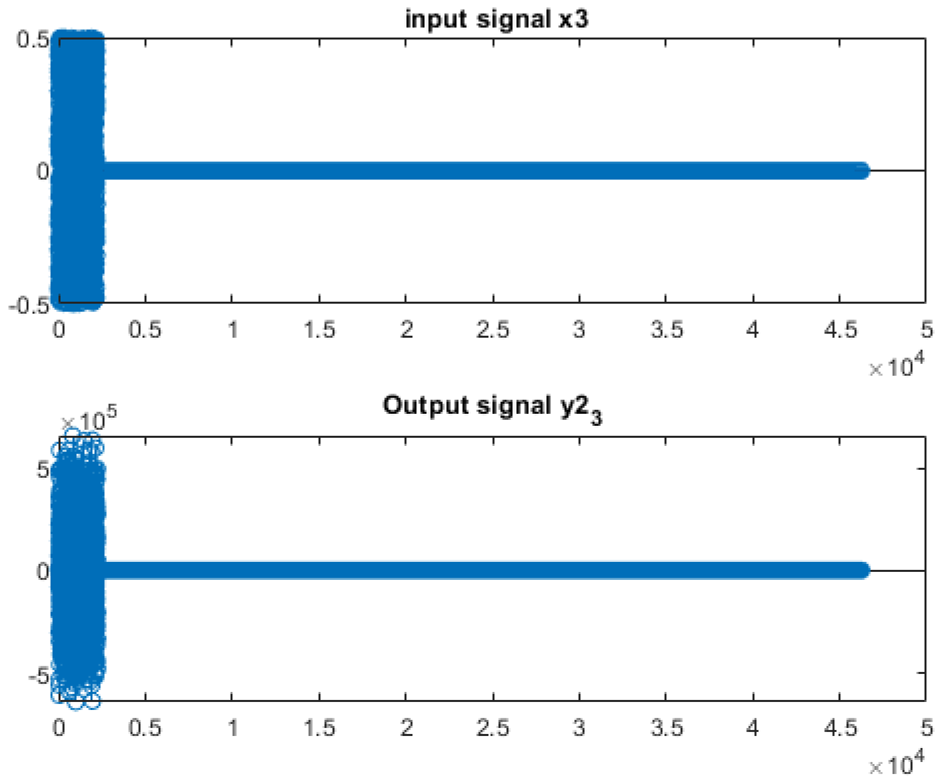
System 2 X2

```
soundsc(x2,fs2)
soundsc(y2_2,fs2)
```

Observation: Signal x2 become smoother after passing system 2

System 2 Input X3

```
figure;
subplot 211
stem(1:length(x3),x3);
title(' input signal x3')
subplot 212
stem(1:length(y2_3),y2_3);
title('Output signal y2_3')
```



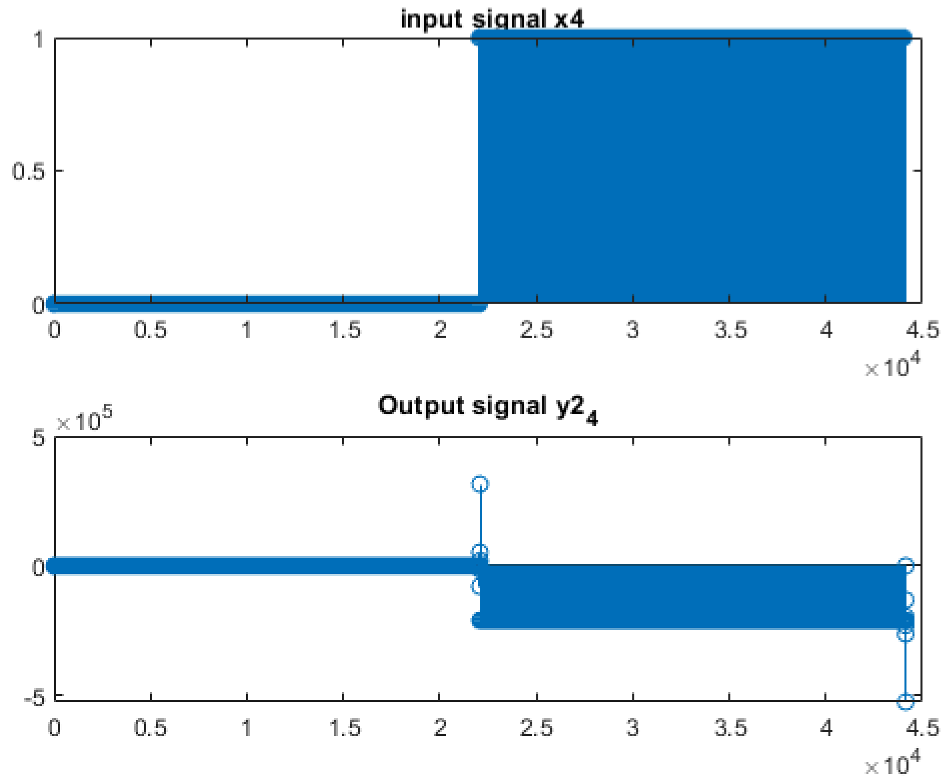
System 2 X3

```
soundsc(x3,fs3)
soundsc(y2_3,fs3)
```

Observation: Signal x3 become smoother after passing system 2

System 2 Input X4

```
figure;
subplot 211
stem(1:length(x4),x4);
title(' input signal x4')
subplot 212
stem(1:length(y2_4),y2_4);
title('Output signal y2_4')
```



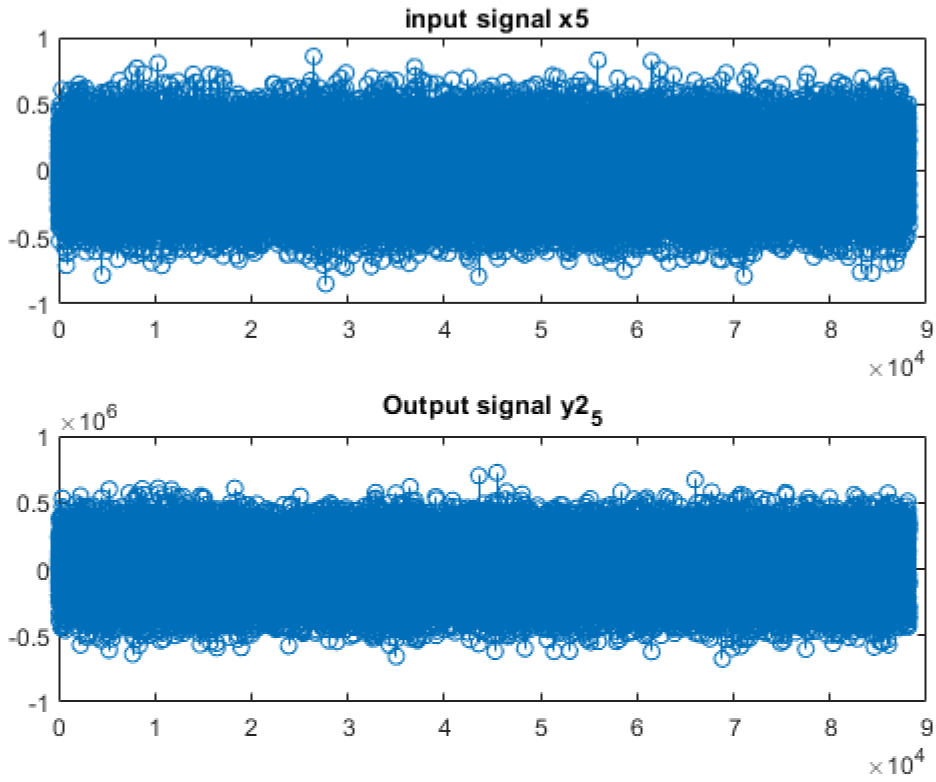
System 2 X4

```
soundsc(x4,fs4)
soundsc(y2_4,fs4)
```

Observation: Signal x4 become smoother after passing system 2

System 2 Input X5

```
figure;
subplot 211
stem(1:length(x5),x5);
title(' input signal x5')
subplot 212
stem(1:length(y2_5),y2_5);
title('Output signal y2_5')
```



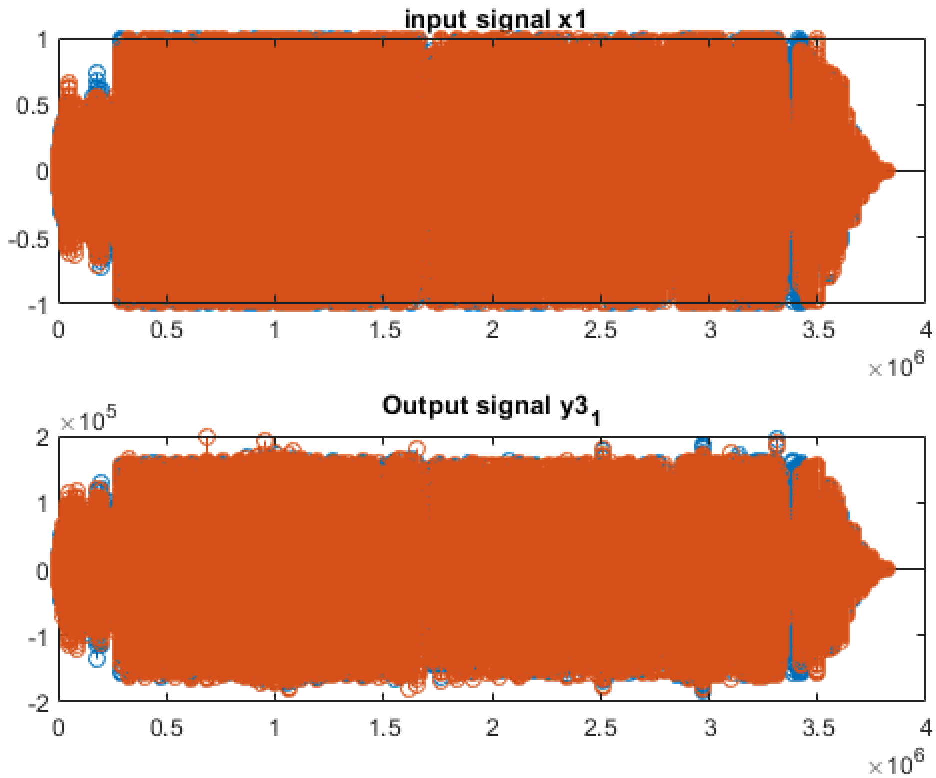
System 2 X5

```
soundsc(x5,fs5)
soundsc(y2_5,fs5)
```

Observation: Signal x5 become smoother after passing system 2

System 3 Input X1

```
figure;
subplot 211
stem(1:length(x1),x1);
title(' input signal x1')
subplot 212
stem(1:length(y3_1),y3_1);
title('Output signal y3_1')
```



System 3 X1

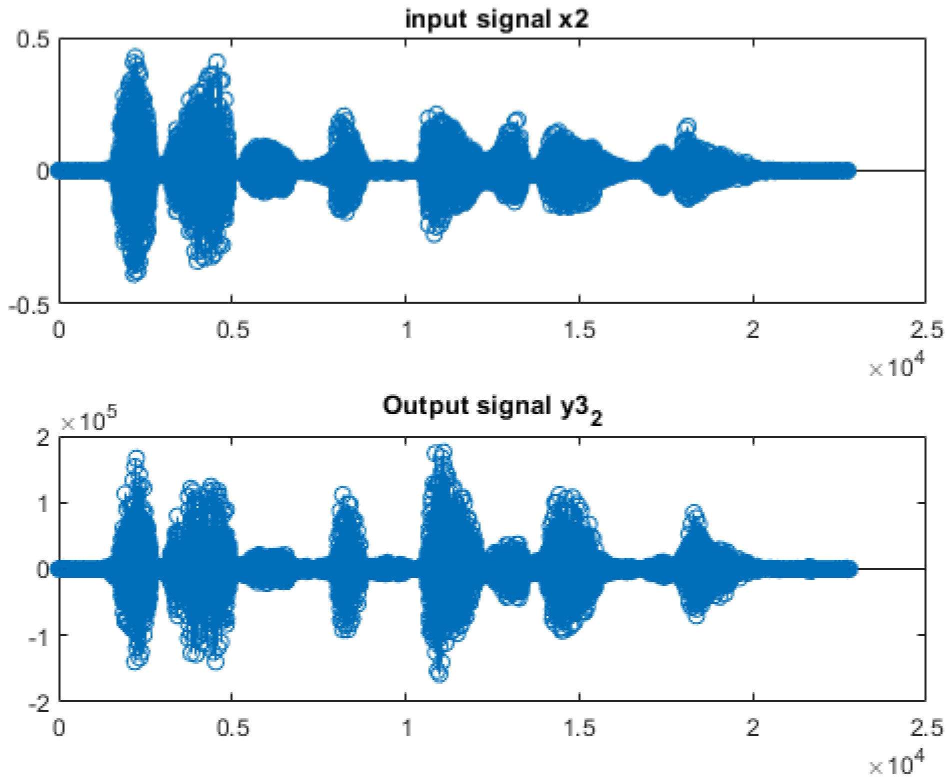
```
soundsc(x1,fs1)
soundsc(y3_1,fs1)
```

Observation: Signal x1 is smoother after passing system 3 as compared to

```
%system 2
```

System 3 Input X2

```
figure;
subplot 211
stem(1:length(x2),x2);
title(' input signal x2')
subplot 212
stem(1:length(y3_2),y3_2);
title('Output signal y3_2')
```

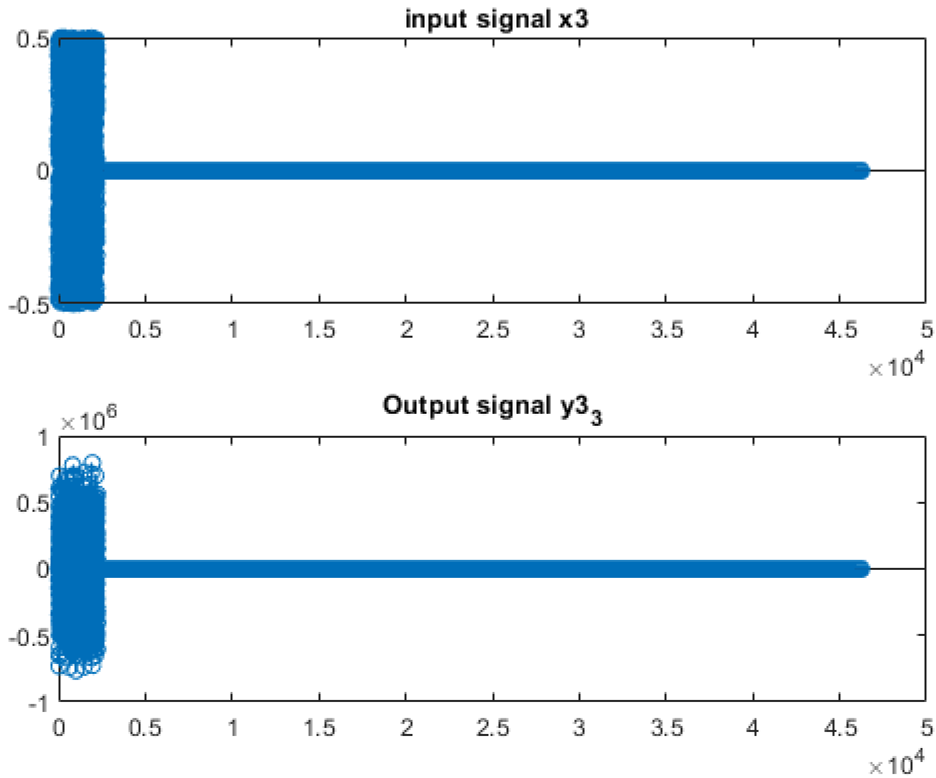


System 3 X2

```
soundsc(x2,fs2)
soundsc(y3_2,fs2)

%Observation: Signal x2 is smoother after passing system 3 as compared
%to system 2
```

System 3 Input X3

```
figure;
subplot 211
stem(1:length(x3),x3);
title(' input signal x3')
subplot 212
stem(1:length(y3_3),y3_3);
title('Output signal y3_3')
```



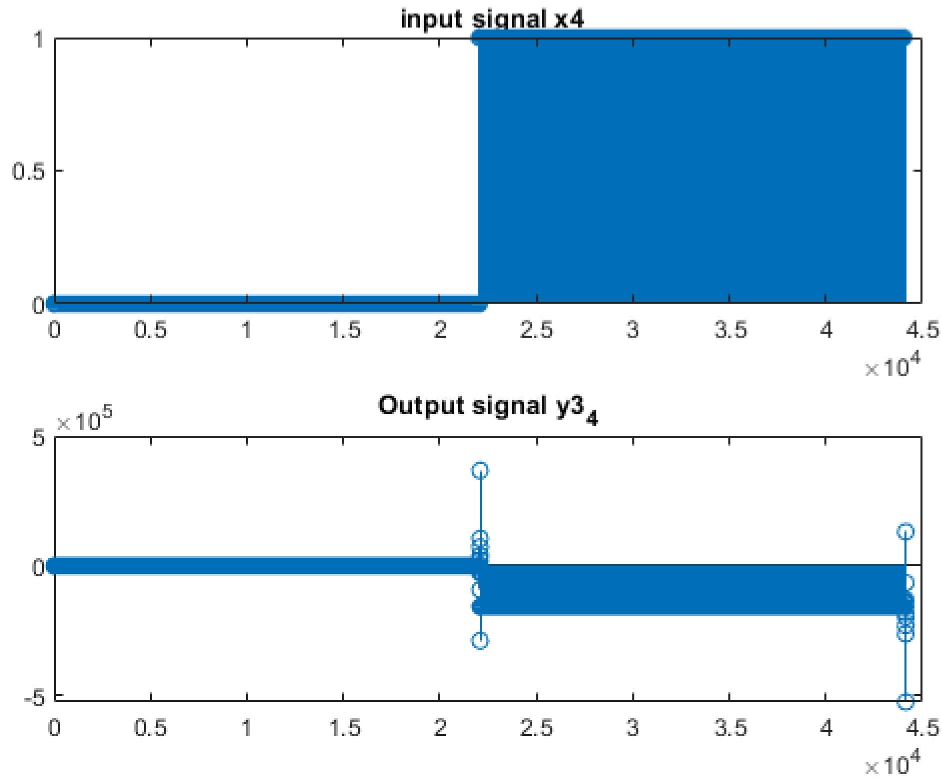
System 3 X3

```
soundsc(x3,fs3)
soundsc(y3_3,fs3)
```

Observation: Signal x3 is smoother after passing system 3 as compared to system 2

System 3 Input X4

```
figure;
subplot 211
stem(1:length(x4),x4);
title(' input signal x4')
subplot 212
stem(1:length(y3_4),y3_4);
title('Output signal y3_4')
```



System 3 X4

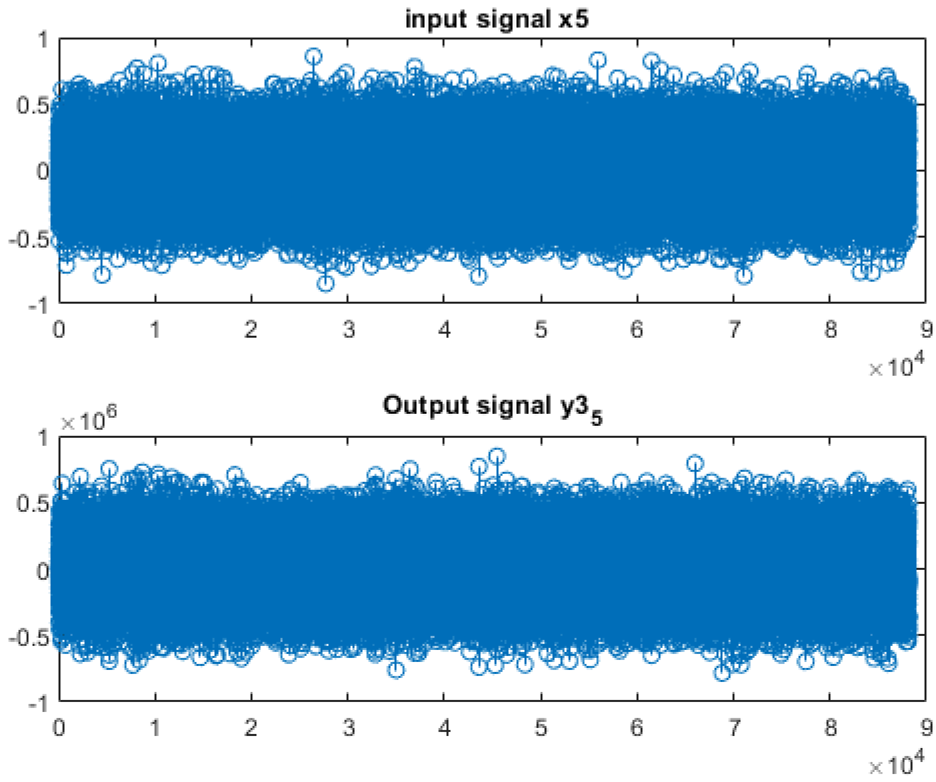
```
soundsc(x4,fs4)
soundsc(y3_4,fs4)
```

Observation: Signal x4 is smoother after passing system 3 as compared

```
%to system 2
```

System 3 Input X5

```
figure;
subplot 211
stem(1:length(x5),x5);
title(' input signal x5')
subplot 212
stem(1:length(y3_5),y3_5);
title('Output signal y3_5')
```



System 3 X5

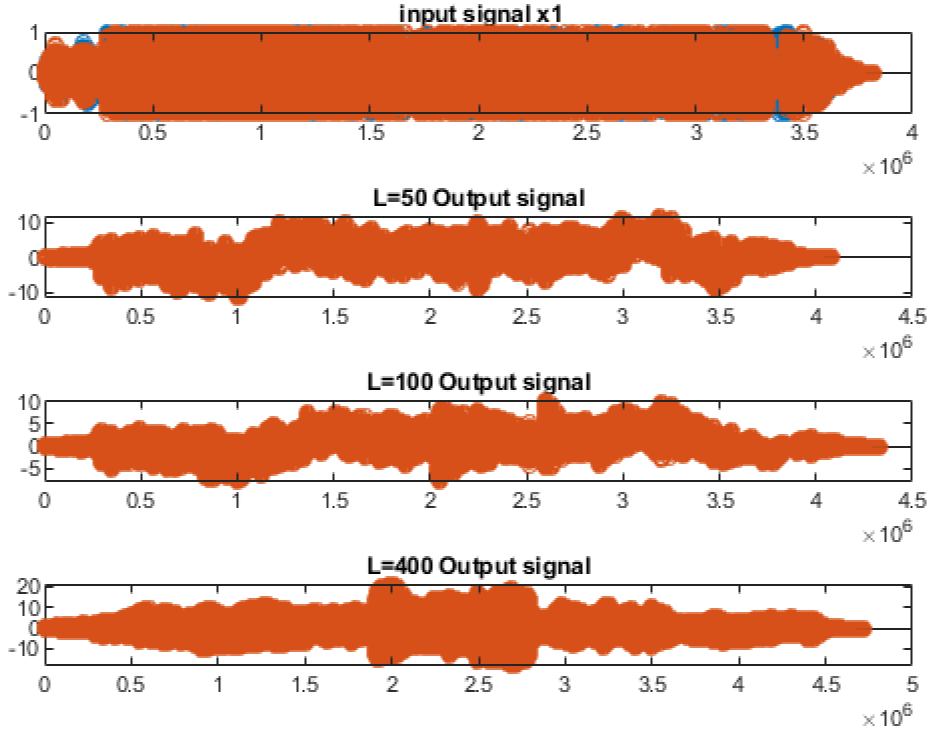
```
soundsc(x5,fs5)
soundsc(y3_5,fs5)
```

Observation: Signal x5 is smoother after passing system 3 as compared

```
%to system 2
```

System 4 Input X1

```
figure;
subplot 411
stem(1:length(x1),x1);
title(' input signal x1')
subplot 412
stem(1:length(y4_1_L1),y4_1_L1);
title('L=50 Output signal')
subplot 413
stem(1:length(y4_1_L2),y4_1_L2);
title('L=100 Output signal')
subplot 414
stem(1:length(y4_1_L3),y4_1_L3);
title('L=400 Output signal')
```



System 4 X1

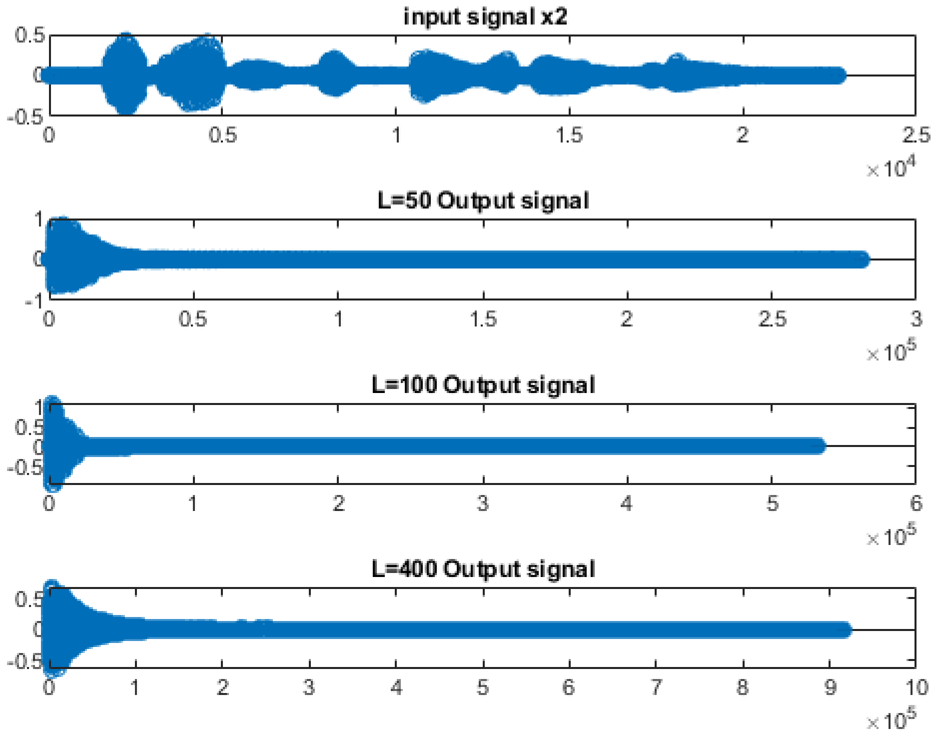
```
soundsc(x1,fs1)
soundsc(y4_1_L1,fs1)
soundsc(y4_1_L2,fs1)
soundsc(y4_1_L3,fs1)
```

As compared to the original signal, the signal x1 after passing system 4 appeared to be downsampled. Upon listening to the output of System 4 at L=50, the singer in the audio seems to be out of tempo with some echos in appearing in the background. Also the bell instrument become louder as compared to the singer. At L=100, the bell becomes more apparent and the delay in the singer's voice was longer. Finaly, at L=400, the audio cannot be heard clearly as there is a loud horn in the background.

System 4 Input X2

```
figure;
subplot 411
stem(1:length(x2),x2);
title(' input signal x2')
subplot 412
stem(1:length(y4_2_L1),y4_2_L1);
title('L=50 Output signal')
subplot 413
stem(1:length(y4_2_L2),y4_2_L2);
title('L=100 Output signal')
subplot 414
stem(1:length(y4_2_L3),y4_2_L3);
```

```
title('L=400 Output signal')
```



System 4 X2

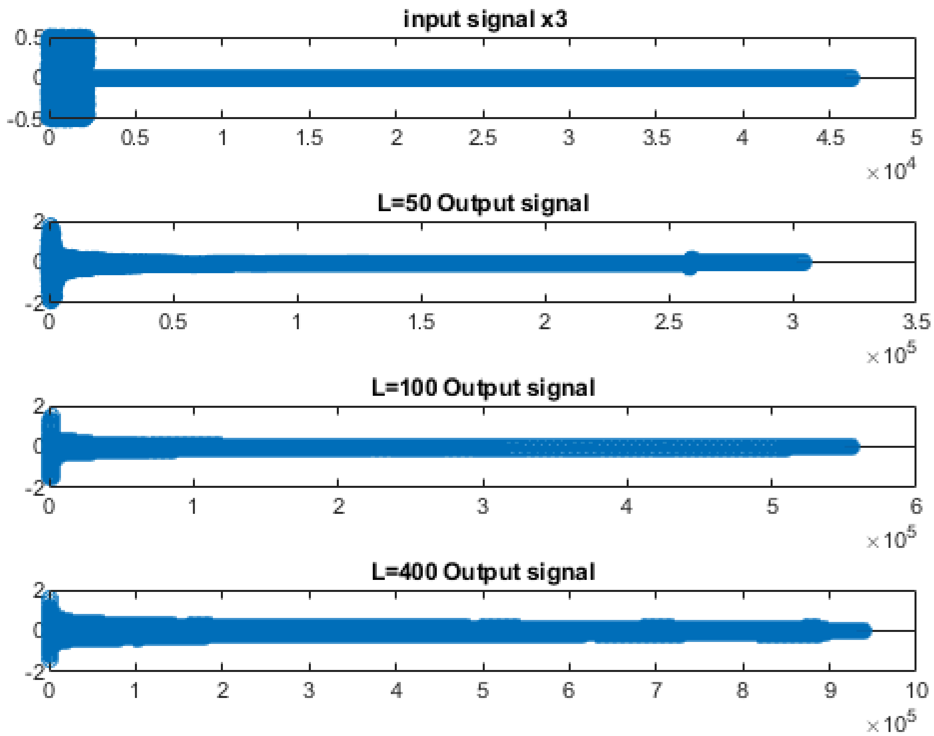
```
soundsc(x2,fs2)
soundsc(y4_2_L1,fs2) % distorted voice
soundsc(y4_2_L2,fs2) % robotic voice
soundsc(y4_2_L3,fs2) % voice distortion is intensified with a feedback
 similar to
```

At L=50, the voice becomes distorted with loud noise in the background, at L=100, the voice's pitch becomes lower making it sound like a male robot. Finally, At L=400, the pitch of the input signal is at the lowest compared to the previous L values.

System 4 Input X3

```
figure;
subplot 411
stem(1:length(x3),x3);
title(' input signal x3')
subplot 412
stem(1:length(y4_3_L1),y4_3_L1);
title('L=50 Output signal')
subplot 413
stem(1:length(y4_3_L2),y4_3_L2);
title('L=100 Output signal')
subplot 414
```

```
stem(1:length(y4_3_L3),y4_3_L3);
title('L=400 Output signal')
```

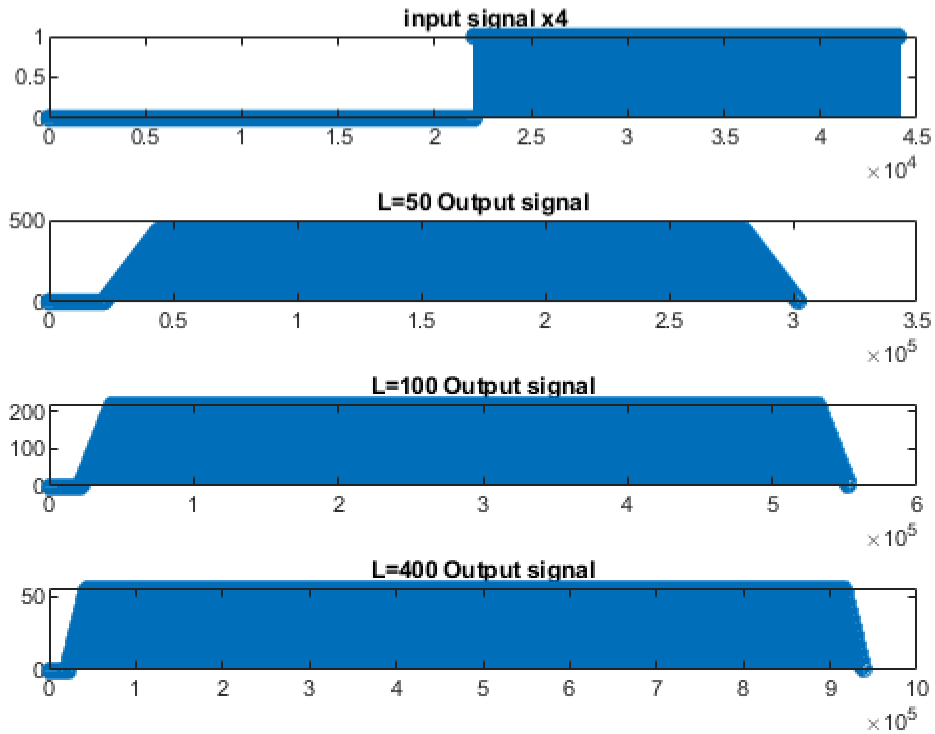


System 4 X3

```
soundsc(x3,fs3)
soundsc(y4_3_L1,fs3) %high pitch like piano key
soundsc(y4_3_L2,fs3) % guitar string
soundsc(y4_3_L3,fs3) %guitar string with lower chords
```

At L=50, the signal is heard as high pitch like piano key as compared to the input, at L=100, the sound is similar to a guitar string while at L=400, the sound becomes identical to the sound of base guitar string.

```
%System 4 Input X4
figure;
subplot 411
stem(1:length(x4),x4);
title(' input signal x4')
subplot 412
stem(1:length(y4_4_L1),y4_4_L1);
title('L=50 Output signal')
subplot 413
stem(1:length(y4_4_L2),y4_4_L2);
title('L=100 Output signal')
subplot 414
stem(1:length(y4_4_L3),y4_4_L3);
title('L=400 Output signal')
```

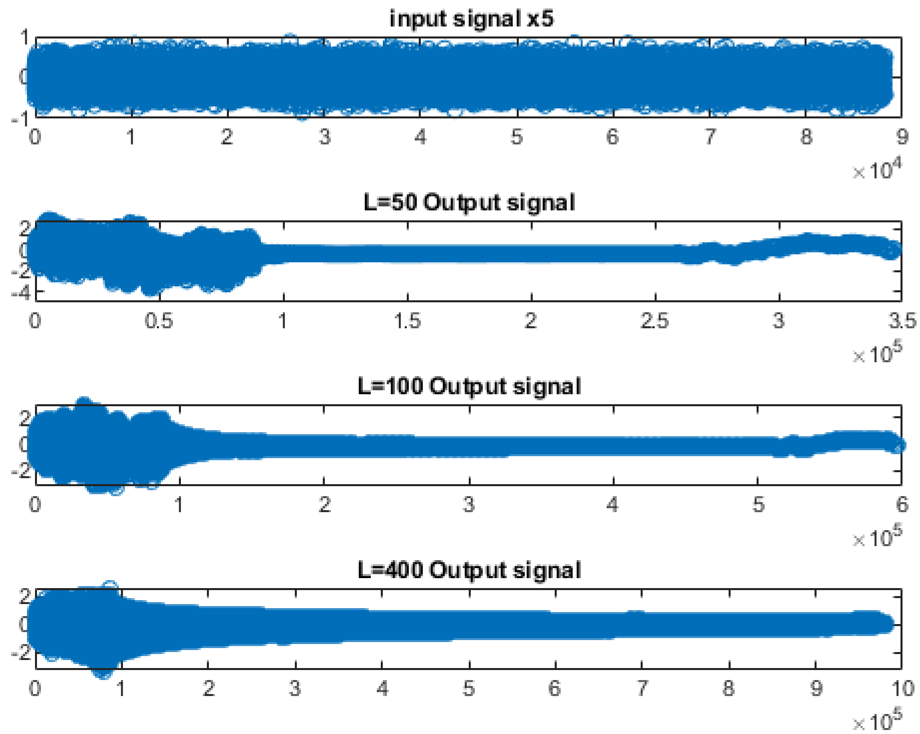


System 4 X4

```
soundsc(x4,fs4)
soundsc(y4_4_L1,fs4)
soundsc(y4_4_L2,fs4)
soundsc(y4_4_L3,fs4)
```

At L=50, the signal is heard as high pitch like piano key as compared to the input, at L=100, the sound is similar to a guitar string while at L=400, the sound becomes identical to the sound of base guitar string.

```
%System 4 Input X5
figure;
subplot 411
stem(1:length(x5),x5);
title(' input signal x5')
subplot 412
stem(1:length(y4_5_L1),y4_5_L1);
title('L=50 Output signal')
subplot 413
stem(1:length(y4_5_L2),y4_5_L2);
title('L=100 Output signal')
subplot 414
stem(1:length(y4_5_L3),y4_5_L3);
title('L=400 Output signal')
```



System 4 X5

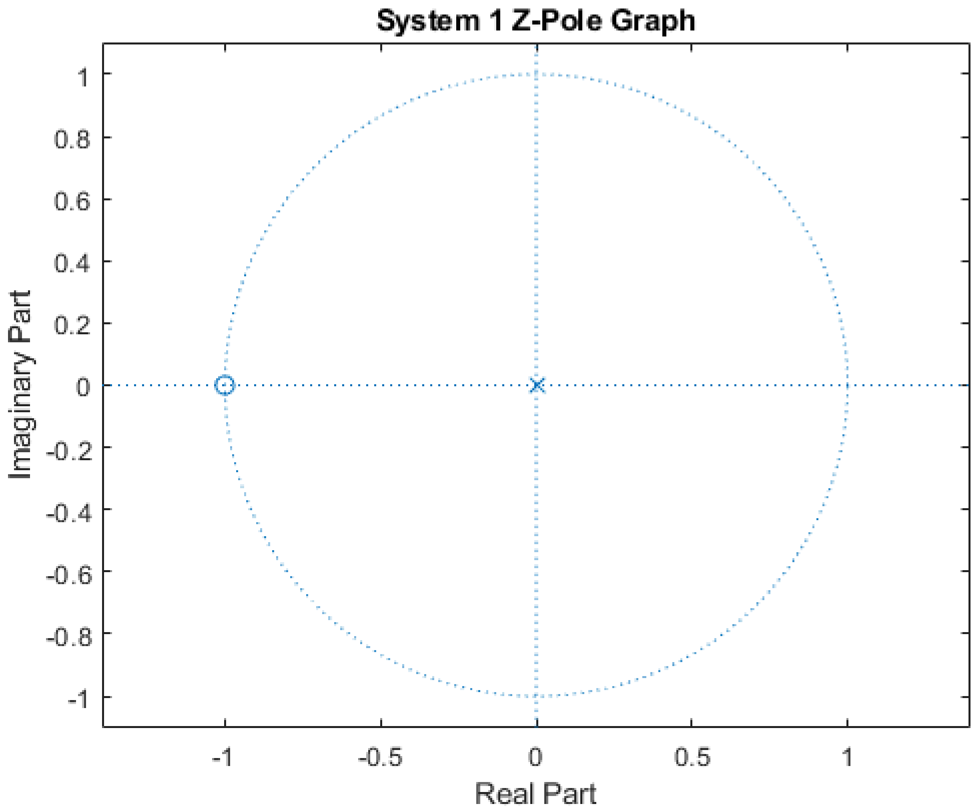
```
soundsc(x5,fs5)
soundsc(y4_5_L1,fs5) % high pitch alarm
soundsc(y4_5_L2,fs5) %train horn
soundsc(y4_5_L3,fs5) %ship horn
```

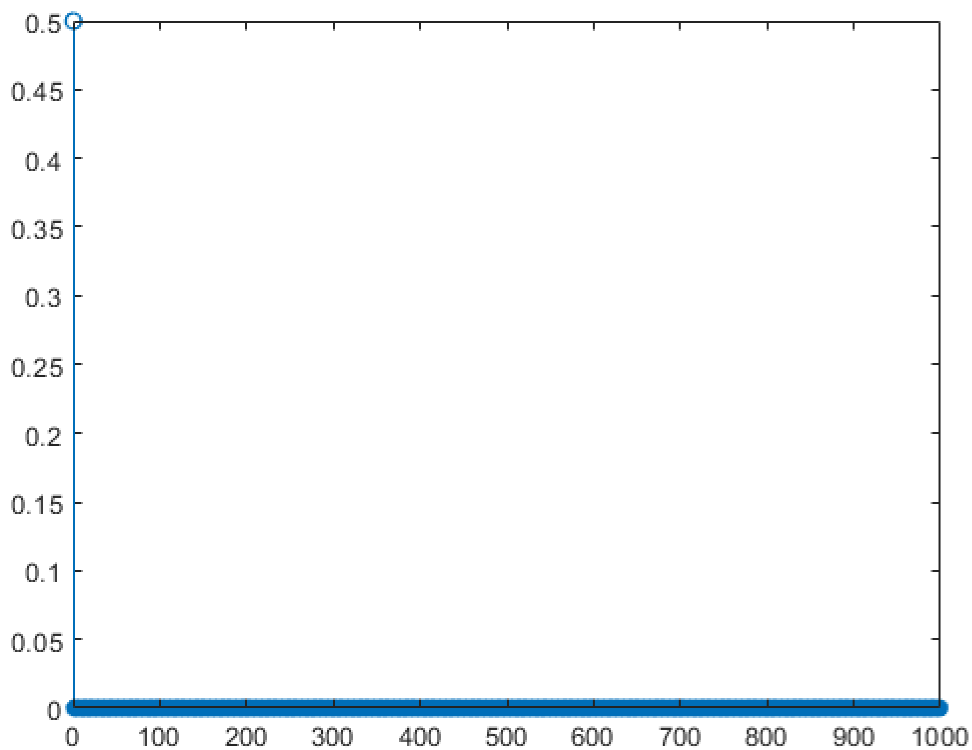
The audio is transformed from a rain like sound to a high pitch alarm at L=50. At L=100, the sound is intensified making it comparable to a train horn, and finally at L=400, it seems like a loud ship horn.

4.Answer the following questions (Use MATLAB to support your answer):

a. Is the system BIBO stable? (Hint: use impz ())

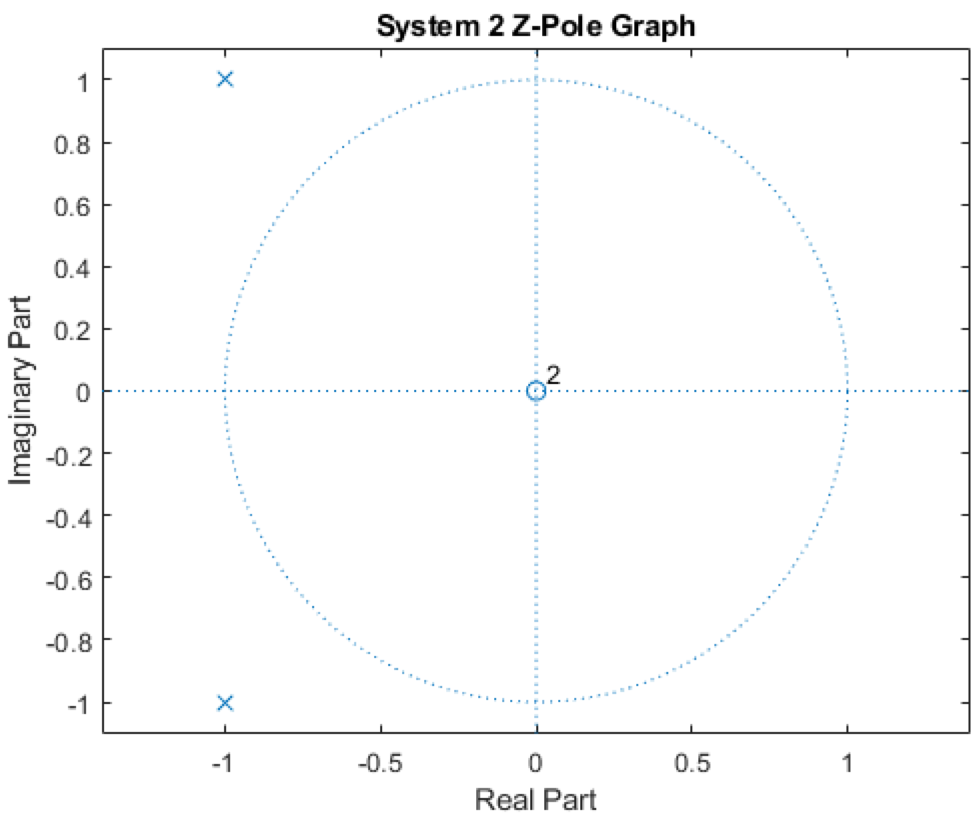
```
%# System 1
as1 = [1]; % output coefficient
bs1 = [0.5 0.5]; % system 1 input coef
figure();
zplane(bs1,as1); % system 1 Z pole
title('System 1 Z-Pole Graph')

s1N=1000;
s1n=0:s1N-1;
s1x = (s1n==0);
s1y=filter(bs1,as1,s1x);
figure();
stem(s1n,s1y);
```

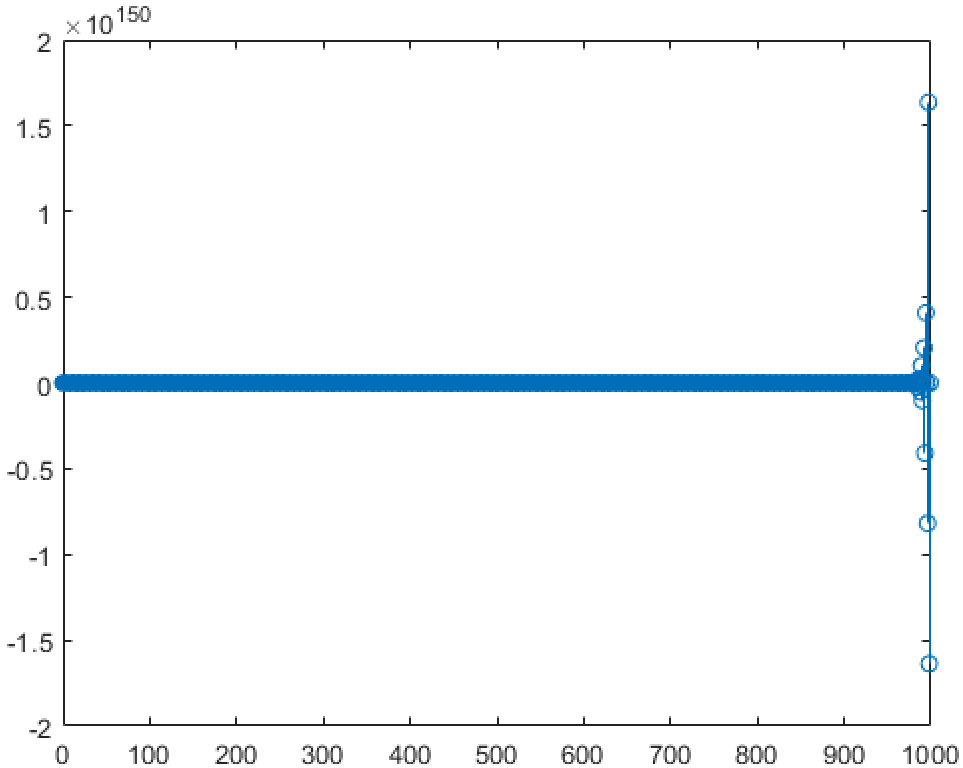

System 1 Z-Pole Graph
Imaginary Part
Real Part
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.5
0
0.5
1


0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
100
200
300
400
500
600
700
800
900
1000

System 1 is a BIBO stable system as poles are inside the boundary of the system as shown in the zplane. Also, impulse response graph of system 1 shows that it is finite thus, the values are bounded and does not change in value.

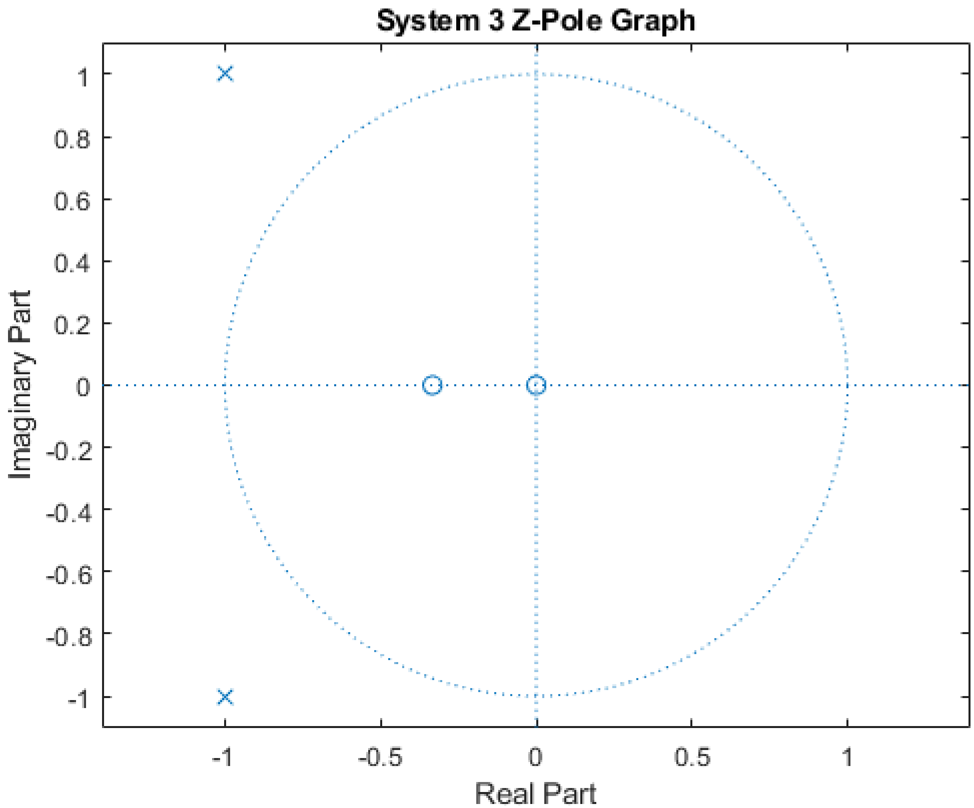
```
%# System 2
as2 = [1 2 2]; % system 2 output coef
bs2 = [1]; % system 2 input coef
figure();
zplane(bs2,as2); % generate z-pole of system 2;
title('System 2 Z-Pole Graph')

s2N=1000;
s2n=0:s2N-1;
s2x = (s2n==0);
s2y=filter(bs2,as2,s2x);
figure();
stem(s2n,s2y);
```

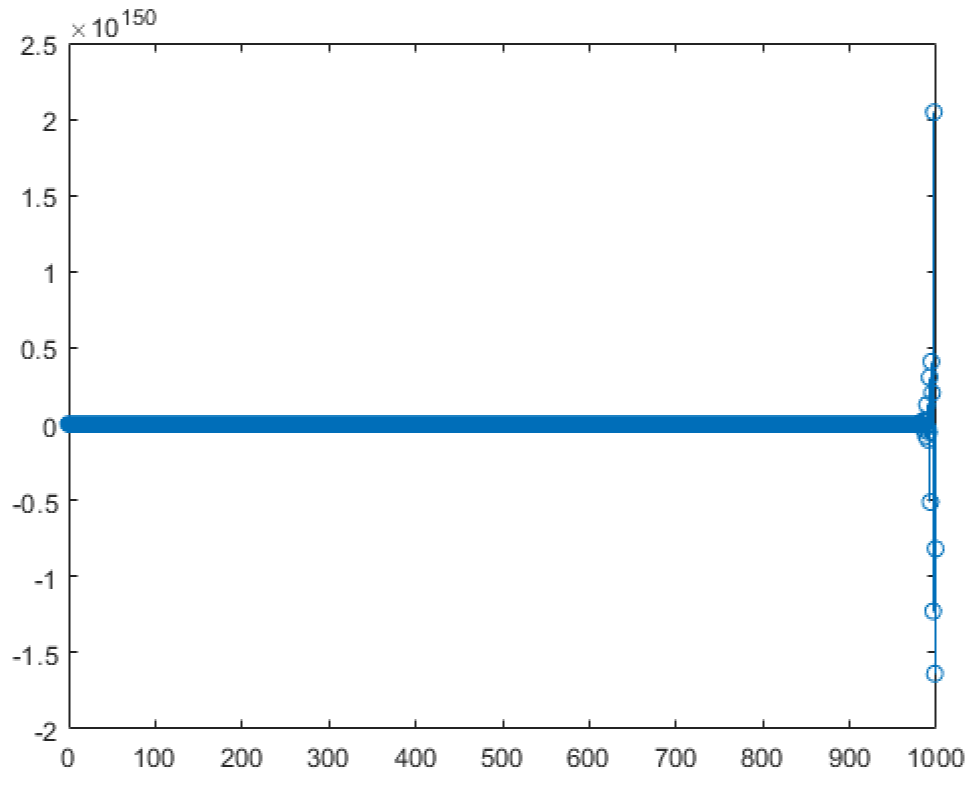




System 2 is NOT a BIBO stable system with its poles are outside of the system's circle as shown in the zplane. This is supported by the impulse response graph with its amplitude changes by near end of time.

```
%# System 3
as3 = [1 2 2]; % system 3 output coef
bs3 = [1.5 0.5]; % system 3 input coef
figure();
zplane(bs3,as3); % generate z-pole of system 3;
title('System 3 Z-Pole Graph')

s3N=1000;
s3n=0:s3N-1;
s3x = (s3n==0);
s3y=filter(bs3,as3,s3x);
figure();
stem(s3n,s3y);
```


System 3 Z-Pole Graph
Imaginary Part
Real Part
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.5
0
0.5
1


$\times 10^{150}$
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
100
200
300
400
500
600
700
800
900
1000

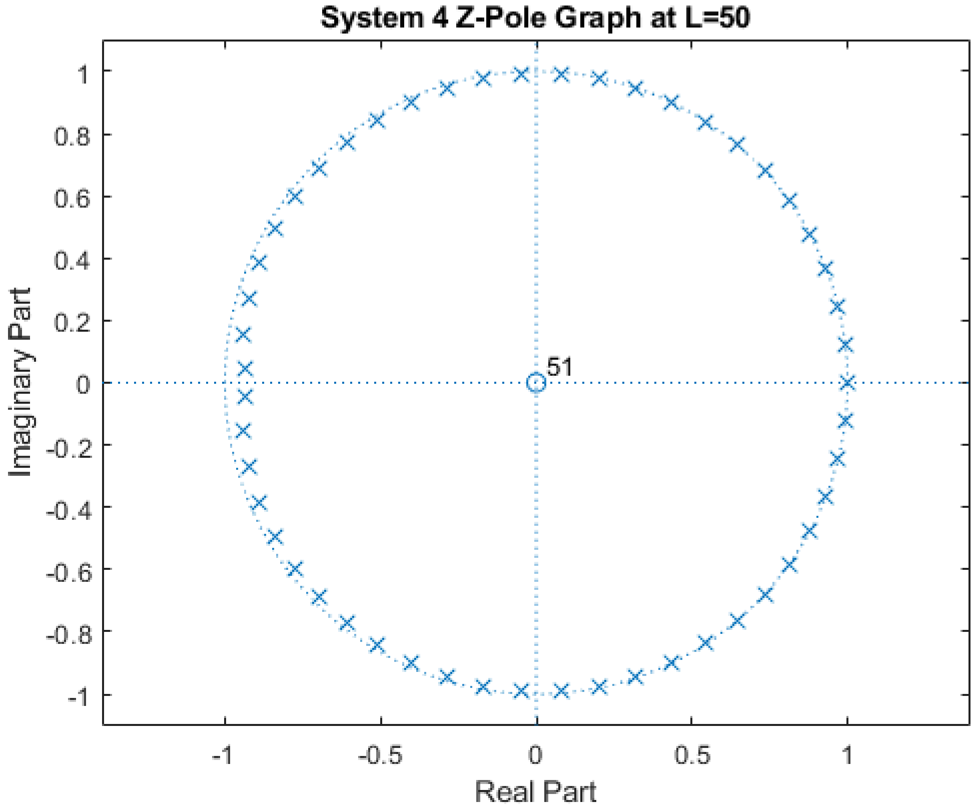
System 3 is NOT a BIBO stable system as its poles are outside of the system's circle as shown in the zplane. Similar to system 2, its impulse reponse graph shows that its amplitude chanegs by near end of time

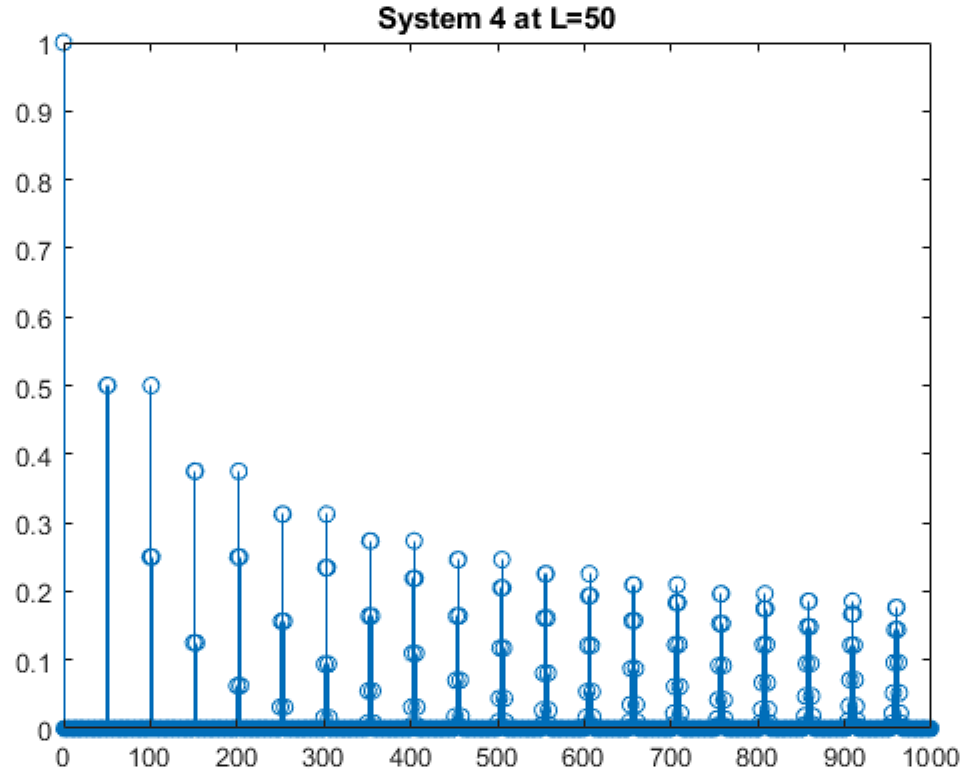
```
%# System 4
L=50
a_l = zeros(1,L-1);  %
as4 = [1 a_l -0.5 -0.5] % output coefficient n, n-L, n-L-1
bs4 = [1];  % input coefficient n
figure();
zplane(bs4,as4);
title('System 4 Z-Pole Graph at L=50')

s4N=1000;
s4n=0:s4N-1;
s4x = (s4n==0);
s4y=filter(bs4,as4,s4x);
figure();
stem(s4n,s4y);
title('System 4 at L=50')

L=100
a_l = zeros(1,L-1);  %
as4 = [1 a_l -0.5 -0.5] % output coefficient n, n-L, n-L-1
bs4 = [1];  % input coefficient n
figure();
zplane(bs4,as4);
title('System 4 Z-Pole Graph at L=100')

s4N=1000;
s4n=0:s4N-1;
s4x = (s4n==0);
s4y=filter(bs4,as4,s4x);
figure();
stem(s4n,s4y);
title('System 4 at L=100')

L=400
a_l = zeros(1,L-1);  %
as4 = [1 a_l -0.5 -0.5] % output coefficient n, n-L, n-L-1
bs4 = [1];  % input coefficient n
figure();
zplane(bs4,as4);
title('System 4 Z-Pole Graph at L=400')

s4N=1000;
s4n=0:s4N-1;
s4x = (s4n==0);
s4y=filter(bs4,as4,s4x);
figure();
stem(s4n,s4y);
title('System 4 at L=400')
```

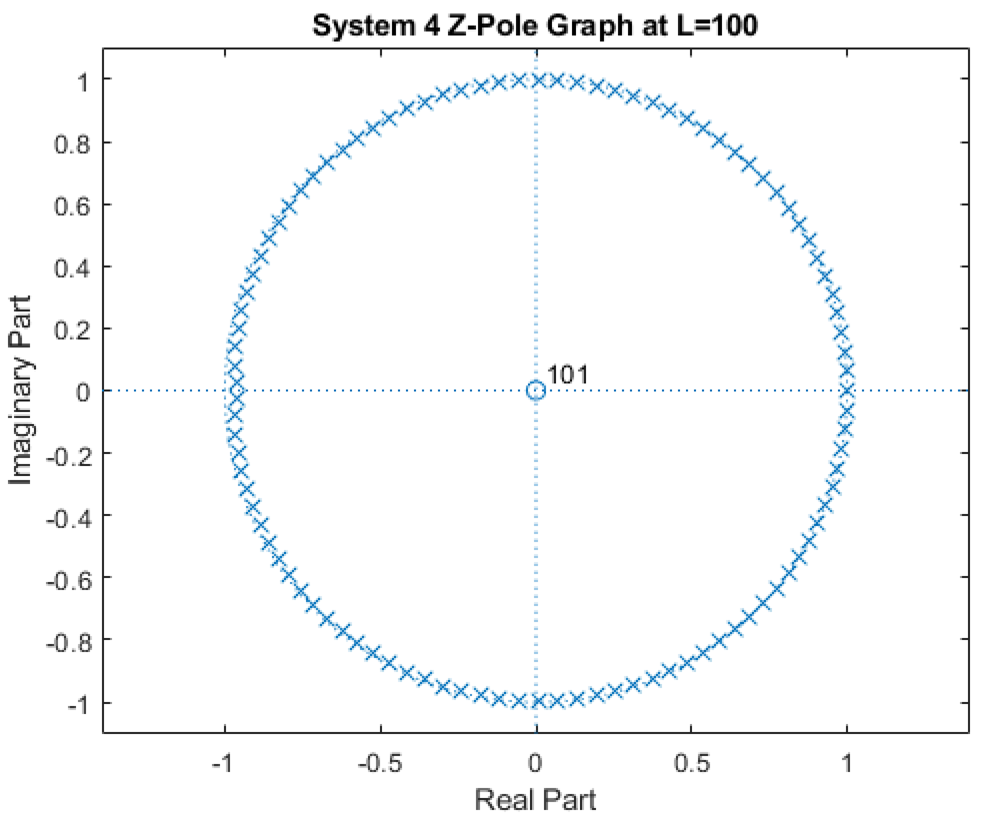
```
L =
```

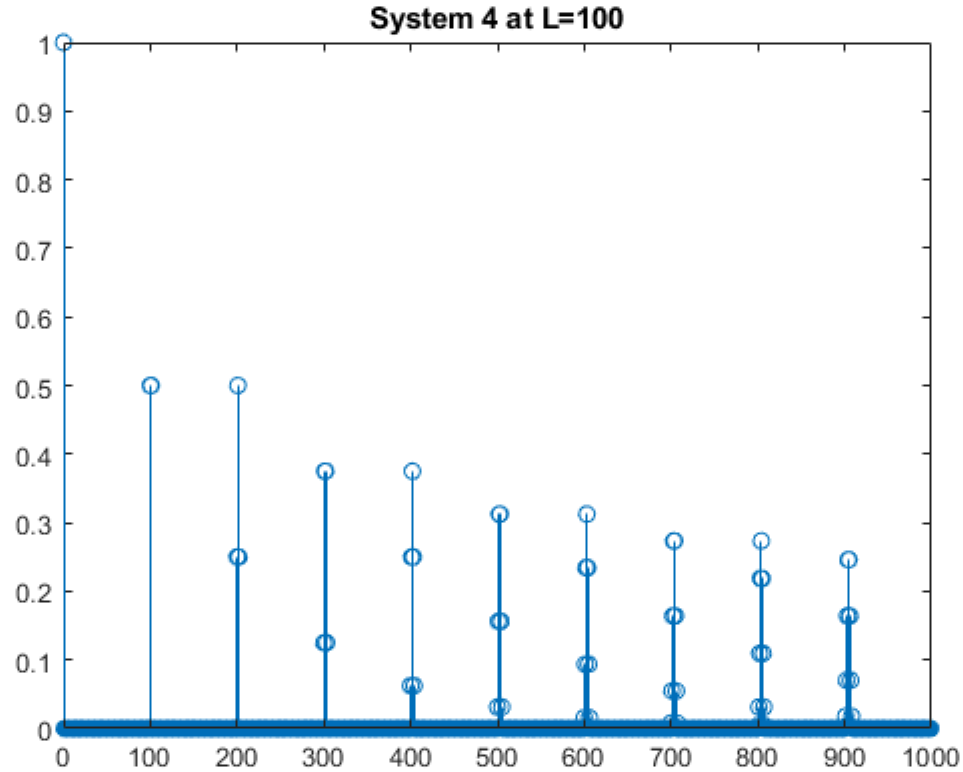
50

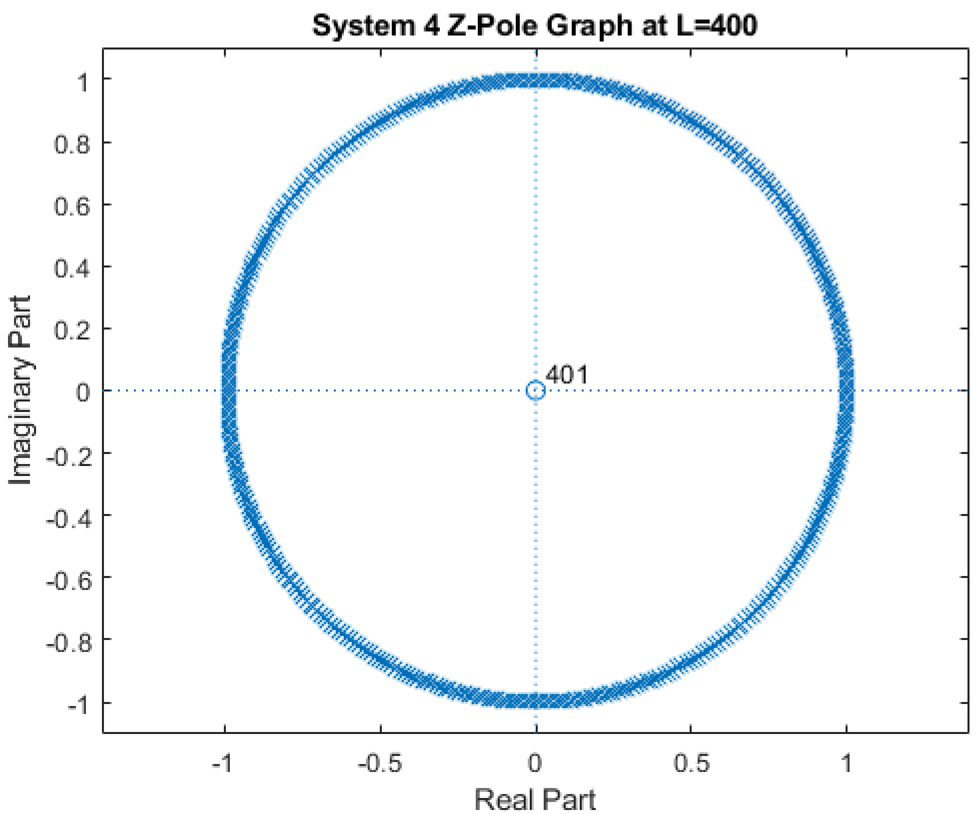
...

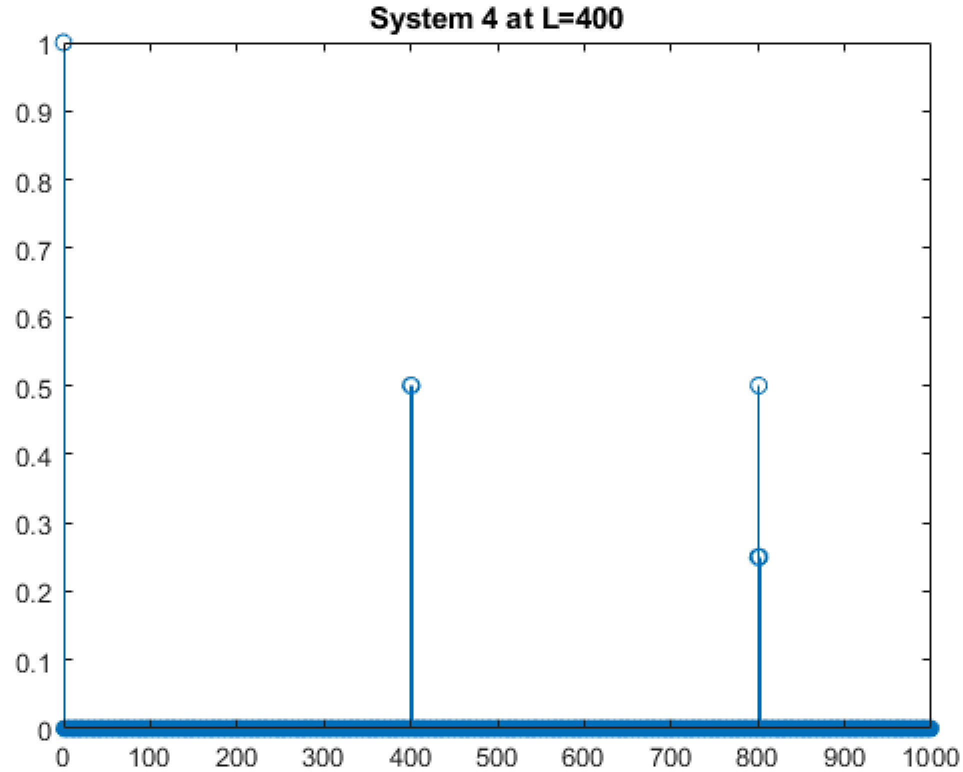

System 4 Z-Pole Graph at L=50
Imaginary Part
Real Part
51
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.5
0
0.5
1


System 4 at L=50
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
700
800
900
1000


System 4 Z-Pole Graph at L=100
Imaginary Part
Real Part
101
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.5
0
0.5
1


System 4 at L=100
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
700
800
900
1000


System 4 Z-Pole Graph at L=400
Imaginary Part
Real Part
401
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.5
0
0.5
1



System 4 is a BIBO stable system as poles are inside the endge of the

```
%boundary as shown in the zplane.
```

b. Is the system causal?

1. System 1 System 1 is causal as its output depends on the current and previous inputs. From the provided matlab implementation below, the values of y(n) depends on the past inputs n-1.

```
function y=dt_1(x)
y= zeros(1,length(x)); % zero initialization
for n=1:length(x);
    if n<2
        y(n) = x(n);
    else
        y(n) = 0.5*x(n) + 0.5*x(n-1)
    end
end
end
```

1. System 2 System 2 is a causal system as its output depends only on the past and present values of inputs and previous outputs as presented on the matlab implementation below. function y=dt_2(x) y= zeros(1,length(x));

```
for n=1:length(x);
    if n==1
        y(n) = x(n);
```

```
    elseif n==2
        y(n) = x(n) - 2*y(n-1);
    else
        y(n) = x(n) - 2*y(n-1) - 2*y(n-2)
    end
end
end
```

1. System 3 System 3 is a causal system as its output depends on the past and present values of inputs and previous output(inputs n, n-1, outputs n-1, n-2). The matlab implementation of system 3 is presented below. function y=dt_3(x) y= zeros(1,length(x)); b = [1.5 0.5]; %input coefficients n , n-1 a = [1 2 2]; % output coefficients n, n-1, n-2 h = impz(b,a); %impulse response y = conv(h,x); end

System 4 is also a causal system with its input is dependent on current and past inputs and past outputs. Its matlab implementation is presented below. function y=dt_4(x,L) y= zeros(1,length(x)); b = [1]; % input coefficient n a_l = zeros(1,L-1); % a = [1 a_l -0.5 -0.5] % output coefficient n, n-L, n-L-1 h = impz(b,a); %impulse response y = conv(h,x); end

1. Is the system FIR or IIR?

System 1: Since system 1 is causal and its pole is located at the boundary of the Z-pole graph(See the System 1 Z-Pole Graph) at X=-1, therefore system 1 is IIR.

System 2: Since system 2 is causal and its poles are beyond the boundary of the system nor the origin.

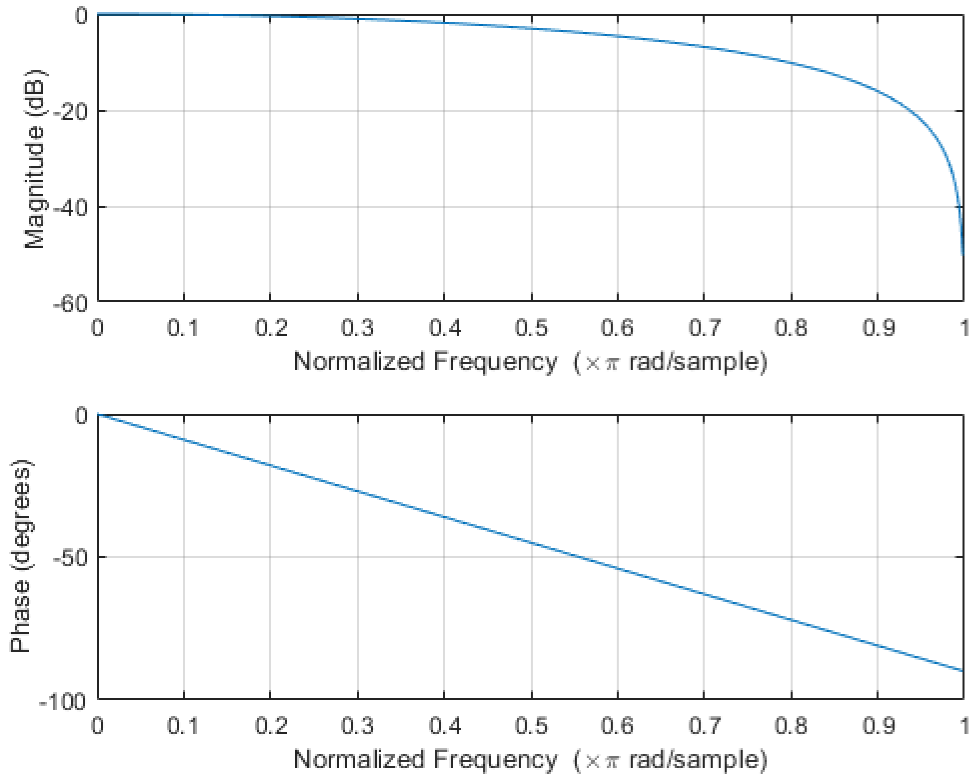
System 3: Since system 3 is causal and its poles are outside the boundary of the system nor the origin, it is an IIR.

System 4: Since system 4 is causal and its poles are not in the origin but within the boundary of the system, it is an IIR.

1. What does the system do? (Based from #2&#3, you may also use freqz(b,a) to have an insight on the filter / frequency response)

System 1

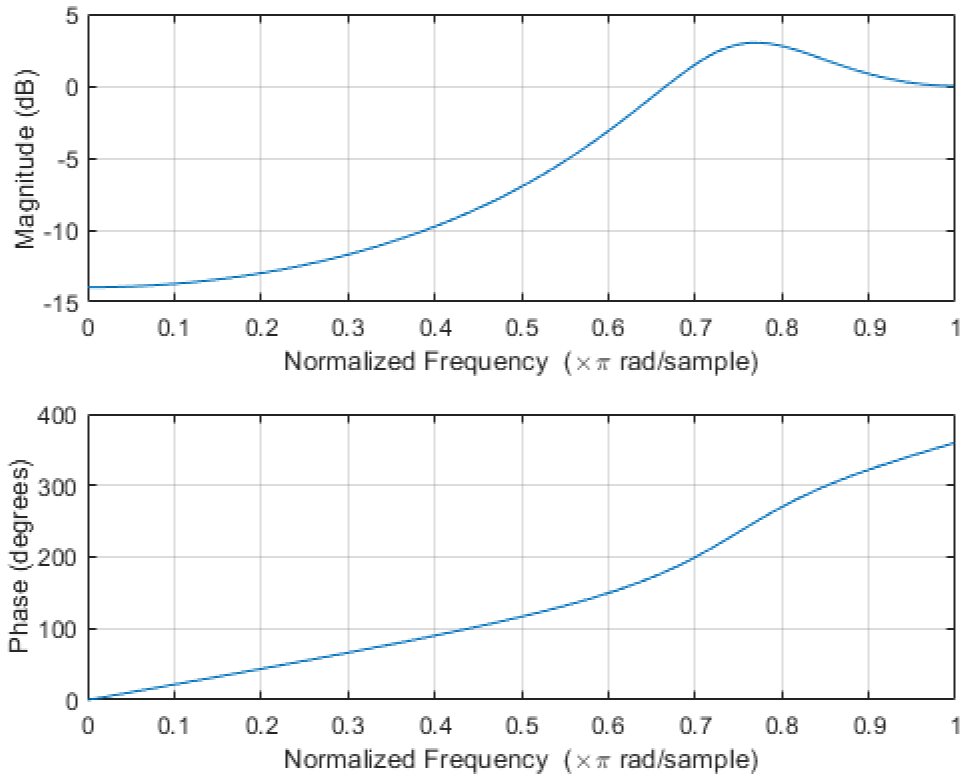
```
figure(); freqz(bs1,as1);
```



OBSERVATION: System 1 shifted the input signal from 0 to -50dB with a phase of 0 to -90 degrees per cycle.

System 2

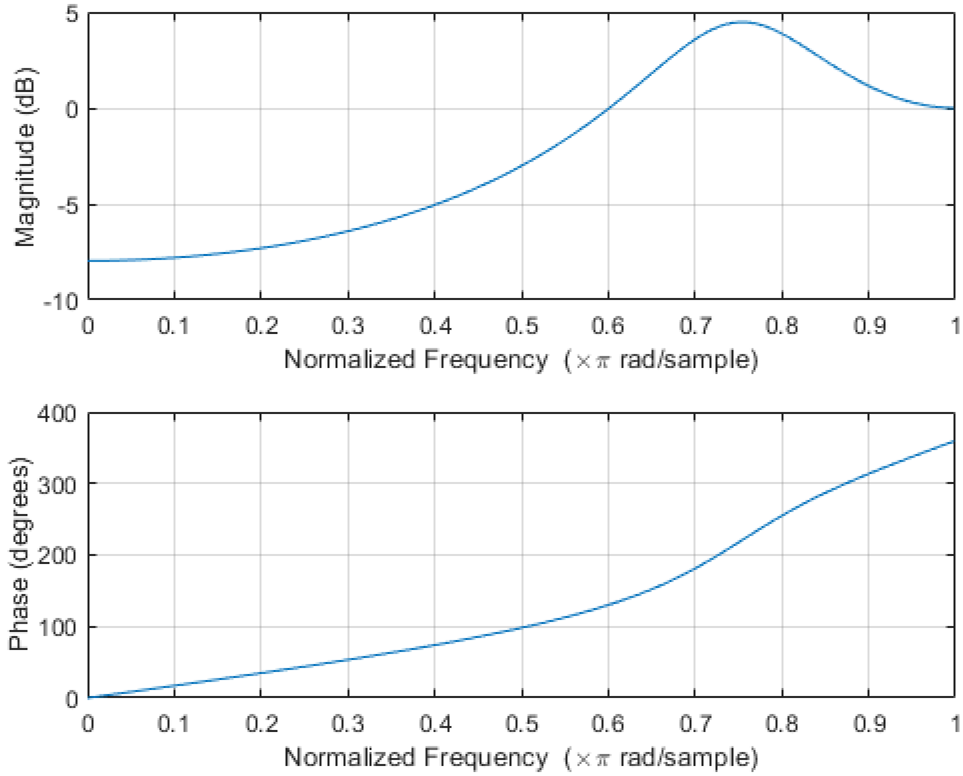
```
figure(); freqz(bs2,as2);
```



OBSERVATION: Sysem 2 shifted the magnitude of the input signal from -14 to 3dB with a phase of 0 to 350 degrees per cycle. This response makes the input audio smoother as compared to the input signal.

System 3

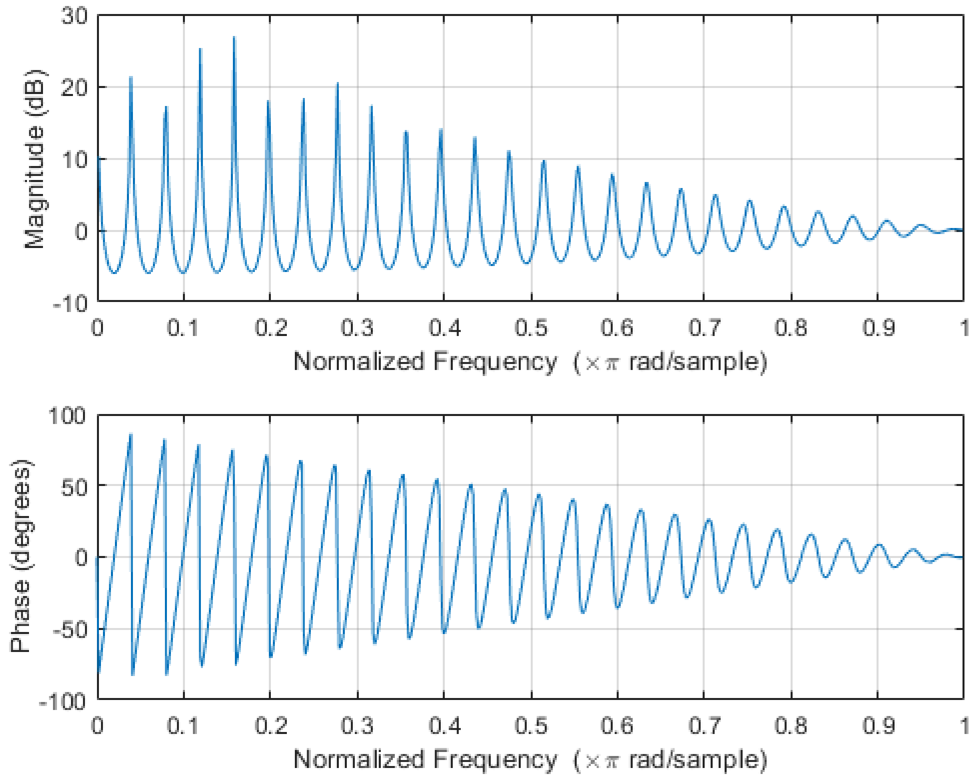
```
figure(); freqz(bs3,as3);
```



OBSERVATION: System 3 shifted the magnitude of the input signal from -8dB to 5dB with a phase of 0 to 360 degrees per cycle. This shift makes the input audio smoother as compared to system 2.

System 4

```
L=50
a_l = zeros(1,L-1);  %
as4 = [1 a_l -0.5 -0.5] % output coefficient n, n-L, n-L-1
bs4 = [1];  % input coefficient n
figure(); freqz(bs4,as4);


L =

    50

...
```



OBSERVATION: System 4 has a fluctuating frequency response, which explains the inaudible noise heard at various L values of the system.

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