EESC6360

Project 2 – FIR and IIR Filtering

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Question 1:

Write a MATLAB Program to compute and display the poles and zeros, to compute and display the factor form, and to generate the pol-zero plot of the z-transform that is a ratio of two polynomials in z^{-1}. Using this program, analyze the z-transform G(z) of Equation 1.

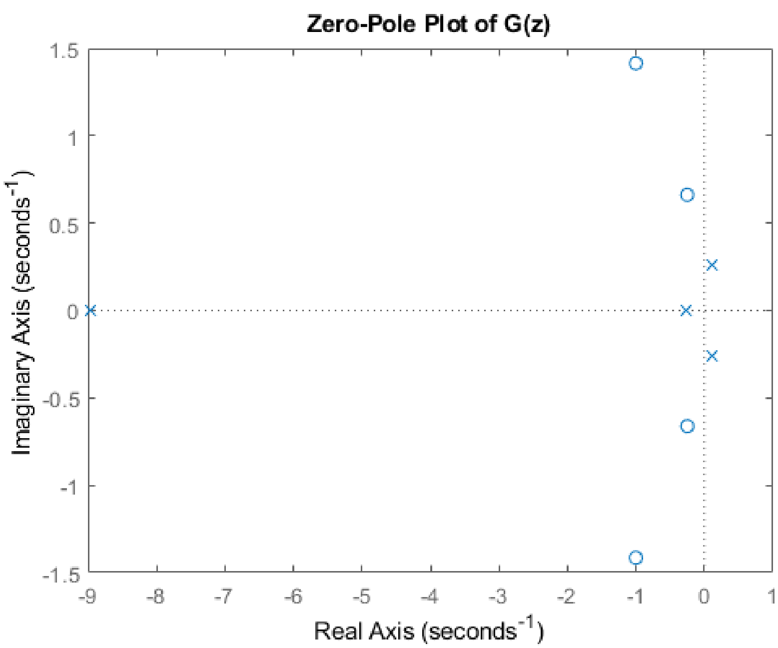
$$G(Z) = \frac{2 + 5z^{-1} + 9z^{-2} + 5z^{-3} + 3z^{-4}}{5 + 45z^{-1} + 2z^{-2} + z^{-3} + z^{-4}} \tag{1}$$

Solution:

```
% CODE:
num = [2,5,9,5,3];
den = [5,45,2,1,1];
[p_i1,z_i1] = question1(num,den,"G(z)");

function [poleG,zeroG] = question1(num,den,str)
syms z
poleG = roots(den);
zeroG = zeros(length(den)-1,1);
zeroG(1:length(num)-1,1) = roots(num);
disp("Zeros:")
disp(zeroG');
pause(1)
disp("Poles:");
disp(poleG');
pause(1)
denz = 1;
numz = 1;
for i = 1:length(zeroG)
    numz = numz * ( 1 - zeroG(i)*z^-1);
end
for j = 1:length(poleG)
    denz = denz * ( 1 - poleG(j)*z^-1);
end
disp("Factored G(z)")
pretty(numz);
if den ~= 1
    disp("----------------------------------------------------------------------------------------------------------")
    pretty(denz);
end
s = tf('s');
Gs = tf(num,den);
figure
pzplot(Gs*s^(length(den)-length(num)));
title("Zero-Pole Plot of " + str)
end
```

Output:

```
Zeros:
  -1.0000 - 1.4142i  -1.0000 + 1.4142i  -0.2500 - 0.6614i  -0.2500 + 0.6614i

Poles:
  -8.9576 + 0.0000i  -0.2718 + 0.0000i   0.1147 - 0.2627i   0.1147 + 0.2627i

Factored G(z)
                                                 / sqrt(7) 1i   1     \
                                                 | ---------- - -     |
/ - 1 + sqrt(2) 1i     \ / 1 + sqrt(2) 1i     \ |      4       4     |
| ---------------- - 1 | | -------------- + 1 | | -------------- - 1 |
\         z            / \        z           / \        z           /

   / sqrt(7) 1i   1     \
   | ---------- + -     |
   |      4       4     |
   | -------------- + 1 |
   \        z           /
```



Question 2:

Write a MATLAB program to compute and display the rational z-transform from its zeros, poles, and gain constant. Using this program, determine the rational form of a z-transform with the given zeros, poles, and gain constant.

Solution:

```
% CODE:
z_i = [0.3,2.5,-0.2+1j*0.4,-0.2-1j*0.4];
p_i = [0.5,-0.75,0.6+1j*0.7,0.6-1j*0.7];
b0 = 3.9;
[b,a] = question2(z_i,p_i,b0)


function [b,a] = question2(z_i,pi,b0)
syms z
numz = 1;
denz = 1;
for i = 1:length(z_i)
    numz = numz*(z-z_i(i));
end
numz = expand(numz);
for j = 1:length(pi)
    denz = denz*(z-pi(j));
end
denz = expand(denz);
disp("G(z) = ");
pretty(b0*numz/denz)
b = sym2poly(numz);
a = sym2poly(denz);
end
```

Output:

```
G(z) =
        4         3         2
    39 z     234 z     663 z     507 z    117
  - ----- + ------ + ------ + ----- - ---
      10       25       1000      500     200
- ---------------------------------------
                3       2
        4    19 z     7 z     53 z     51
       z   - ----- + ---- + ---- - ---
               20      40      80     160


b =

    3.9000   -9.3600   -0.6630   -1.0140    0.5850


a =

    1.0000   -0.9500    0.1750    0.6625   -0.3187
```

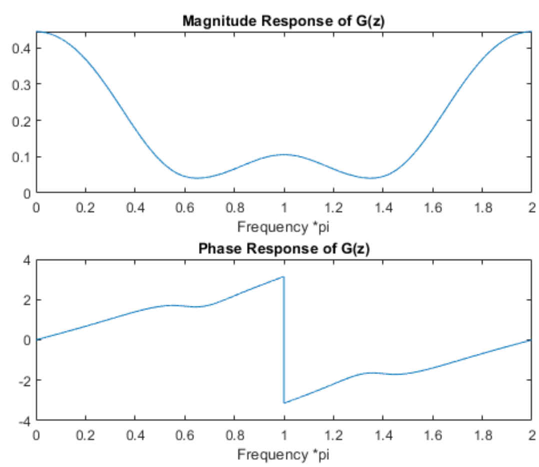
Question 3:

Write a MATLAB program to compute and display the magnitude and phase response of a filter with rational z-transform. Use this program to display the magnitude and phase response for G(z).

Solution:

```
% CODE:
```

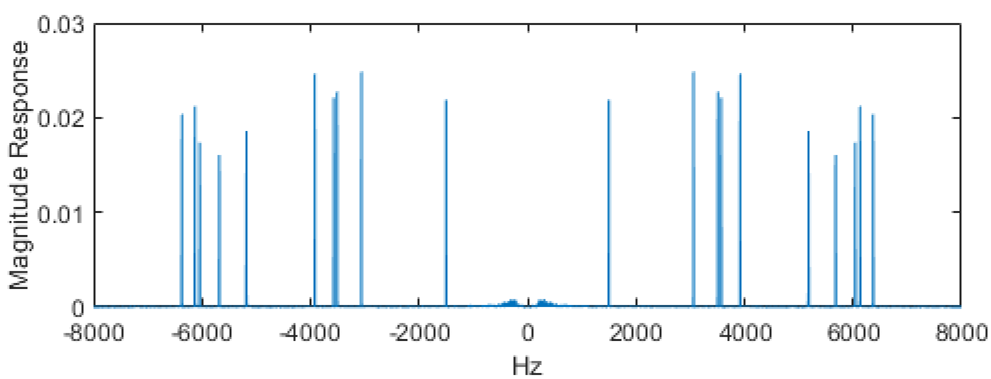
```
num = [2,5,9,5,3];
den = [5,45,2,1,1];
question3(num,den,"G(z)");

function question3(num,den,str)
w = 0:0.001:2*pi;
numw = 0;
denw = 0;
for i = 1:length(num)
    numw = numw + num(i).*exp(1j*w*(i-1));
end
for i = 1:length(den)
    denw = denw + den(i).*exp(1j*w*(i-1));
end

figure
subplot(211)
Hw = numw./denw;
plot(w/pi,abs(Hw))
xlabel('Frequency *pi')
title("Magnitude Response of " + str)

subplot(212)
plot(w/pi,angle(Hw))
xlabel('Frequency *pi')
title("Phase Response of " + str)

end
```

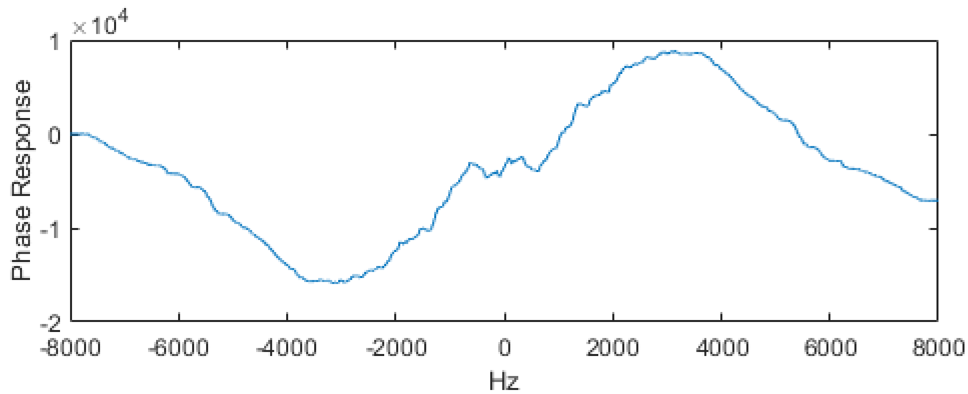


Question 4:

The audio signal in http://tinyurl.com/ja5vxce has been contaminated with multiple additive noisy signals with narrow spectral content. The goal of this project is to clean the audio by designing different notch filters

a. Plot the magnitude and phase response of the audio file. Discuss the results.





We can see 10 highly distinct peaks in the positive portion of the frequency response. Since the human voice typically is around 400-4kHz and usually is wideband, we expect every one of these peaks to correspond to additive noise. We will design notch filters to cancel out these frequencies.

b. Determine the spectral location associated with the noise. Give your results in the discrete time domain (normalizes frequencies) and continuous time domain (in Hz).

Frequencies of Noise (kHz):
Columns 1 through 10

1.5000 3.0600 3.5100 3.5699 3.9200 5.1800 5.6799 6.0400 6.1299 6.3699

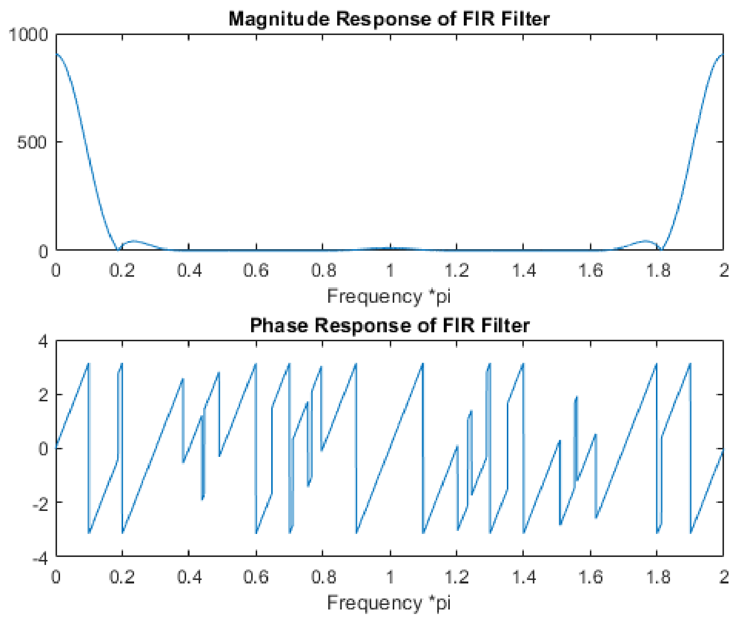
Discrete Normalized Frequencies of Noise:
Columns 1 through 10

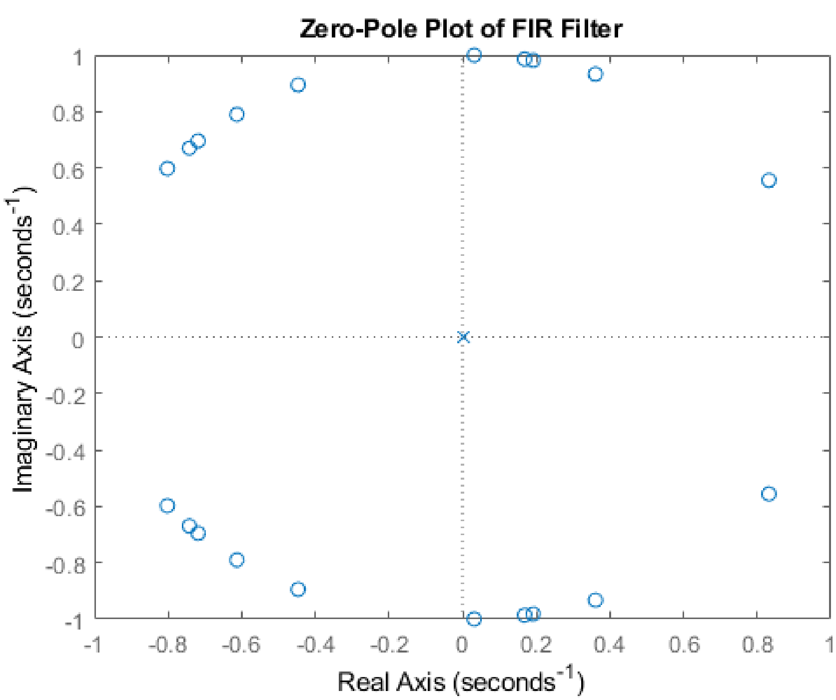
0.0937 0.1912 0.2194 0.2231 0.2450 0.3237 0.3550 0.3775 0.3831 0.3981

c. Design a notch FIR filter with only zeros. Plot the magnitude and phase response of the filter. Plot the magnitude response of the resulting signal. Create an audio file after filtering the signal.

Our FIR notch filter will have the following properties:

We will place zeros at the frequencies which contain noise and we desire to eliminate.





We can see that the zeros we placed at the normalized frequencies result in a 0 magnitude response of the filter at those normalized frequencies.

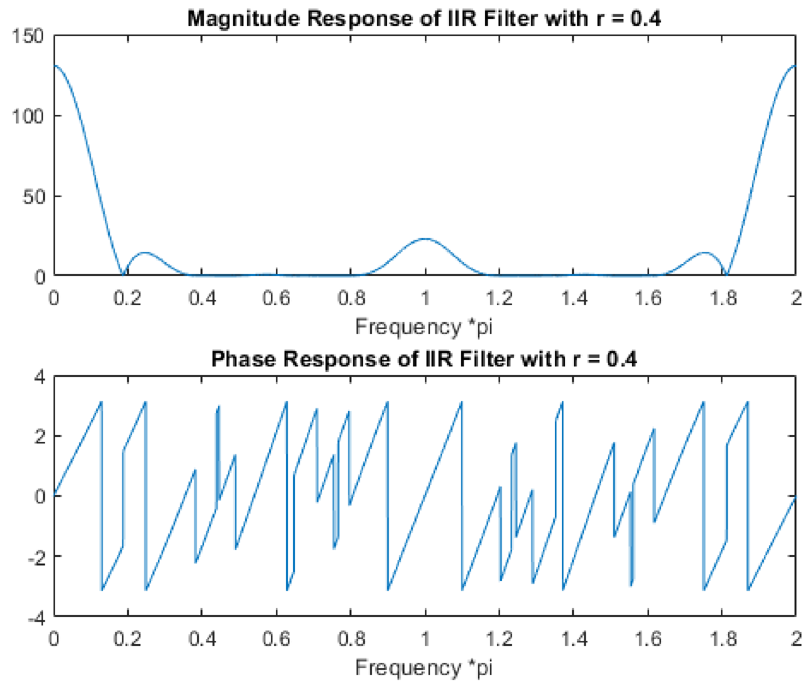
```
Zeros:
  Columns 1 through 4

   0.8315 - 0.5556i   0.8315 + 0.5556i   0.3608 - 0.9326i   0.3608 + 0.9326i

  Columns 5 through 8

   0.1912 - 0.9815i   0.1912 + 0.9815i   0.1681 - 0.9858i   0.1681 + 0.9858i

  Columns 9 through 12

   0.0314 - 0.9995i   0.0314 + 0.9995i  -0.4470 - 0.8945i  -0.4470 + 0.8945i

  Columns 13 through 16

  -0.8020 - 0.5973i  -0.8020 + 0.5973i  -0.7423 - 0.6701i  -0.7423 + 0.6701i

  Columns 17 through 20

  -0.7181 - 0.6959i  -0.7181 + 0.6959i  -0.6129 - 0.7902i  -0.6129 + 0.7902i

Factored G(z)
/  566085731962705    9002750976819333      \
| ----------------- - ----------------i     |
| 18014398509481984   9007199254740992      |
| ------------------------------------- - 1 |
\                   z                       /

   /  566085731962705    9002750976819333      \
   | ----------------- + ----------------i     |
   | 18014398509481984   9007199254740992      |
   | ------------------------------------- - 1 |
   \                   z                       /

   / 5520343083264219   3558632133896769      \
   | ---------------- - ----------------i     |
   | 9007199254740992   4503599627370496      |
   | ------------------------------------ + 1 |
   \                   z                      /

   / 5520343083264219   3558632133896769      \
   | ---------------- + ----------------i     |
   | 9007199254740992   4503599627370496      |
   | ------------------------------------ + 1 |
   \                   z                      /

   / 1513968334038139   4439525264545937      \
   | ---------------- - ----------------i     |
   | 9007199254740992   4503599627370496      |
   | ------------------------------------ - 1 |
   \                   z                      /

   / 1513968334038139   4439525264545937      \
   | ---------------- + ----------------i     |
   | 9007199254740992   4503599627370496      |
   | ------------------------------------ - 1 |
   \                   z                      /

   / 234039014659009   2502038957673595      \
   | --------------- - ----------------i     |
   | 281474976710656   4503599627370496      |
   | ----------------------------------- - 1 |
   \                  z                      /

   / 234039014659009   2502038957673595      \
   | --------------- + ----------------i     |
   | 281474976710656   4503599627370496      |
   | ----------------------------------- - 1 |
   \                  z                      /

   / 6685597574028107   6035927724275377      \
   | ---------------- - ----------------i     |
   | 9007199254740992   9007199254740992      |
   | ------------------------------------ + 1 |
   \                   z                      /
```

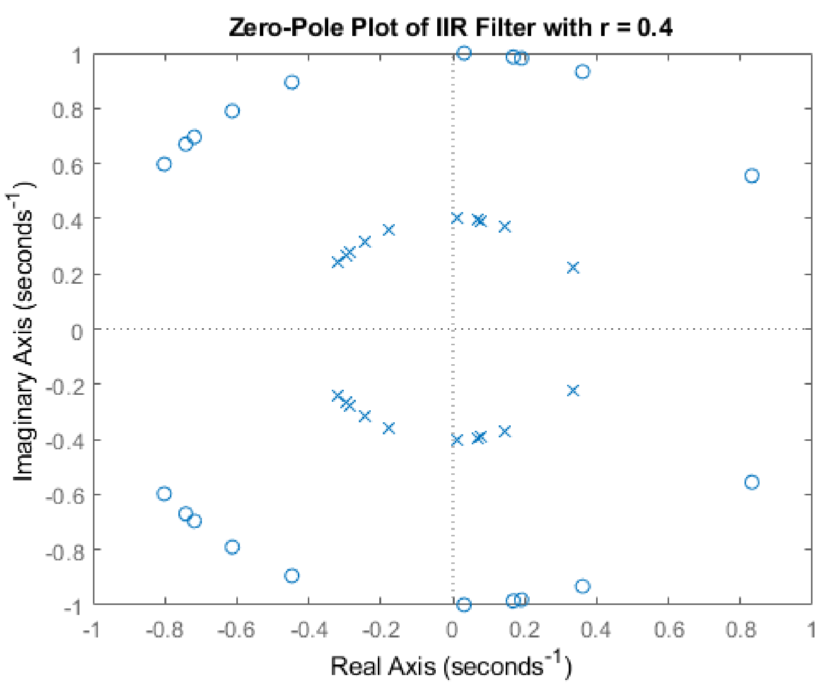
```
/ 6685597574028107   6035927724275377     \
| ---------------- + ----------------i    |
| 9007199254740992   9007199254740992     |
| ---------------------------------- + 1 |
\                  z                      /

/  3445177072878327   8840946055072791     \
| ----------------- - ----------------i    |
| 18014398509481984   9007199254740992     |
| ----------------------------------- - 1 |
\                  z                       /

/  3445177072878327   8840946055072791     \
| ----------------- + ----------------i    |
| 18014398509481984   9007199254740992     |
| ----------------------------------- - 1 |
\                  z                       /

/ 6468296862995579   6268235326380601     \
| ---------------- - ----------------i    |
| 9007199254740992   9007199254740992     |
| ---------------------------------- + 1 |
\                  z                      /

/ 6468296862995579   6268235326380601     \
| ---------------- + ----------------i    |
| 9007199254740992   9007199254740992     |
| ---------------------------------- + 1 |
\                  z                      /

/ 2013000991858733   8057353563157265     \
| ---------------- - ----------------i    |
| 4503599627370496   9007199254740992     |
| ---------------------------------- + 1 |
\                  z                      /

/ 2013000991858733   8057353563157265     \
| ---------------- + ----------------i    |
| 4503599627370496   9007199254740992     |
| ---------------------------------- + 1 |
\                  z                      /

/  812504570253995   4200208911103973     \
| ---------------- - ----------------i    |
| 2251799813685248   4503599627370496     |
| ---------------------------------- - 1 |
\                  z                      /

/  812504570253995   4200208911103973     \
| ---------------- + ----------------i    |
| 2251799813685248   4503599627370496     |
| ---------------------------------- - 1 |
\                  z                      /

/ 3611975720343689   5379978066609391     \
| ---------------- - ----------------i    |
| 4503599627370496   9007199254740992     |
| ---------------------------------- + 1 |
\                  z                      /

/ 3611975720343689   5379978066609391     \
| ---------------- + ----------------i    |
| 4503599627370496   9007199254740992     |
| ---------------------------------- + 1 |
\                  z                      /
```

d. Design a notch IIR filter with zeros and poles. Set the magnitude of the poles to r = 0.4 (pk = r*e^(jw_k)). Plot the magnitude and phase response of the filter. Plot the magnitude response of the resulting signal. Create an audio file after filtering the signal.

Our IIR notch filter will have the following properties:

We will keep the zeros in the same locations as for the FIR filter, but we will at poles at the same frequencies to narrow the bandwidth of the notch. For this IIR filter, we will place our poles at a radial distance of 0.4 from the origin of the z-plane.





By adding poles at the same normalized frequencies as the zeroes, we increase the quality factor (decrease the bandwidth) of the notch filter at each of the normalized frequencies.

```
Zeros:
  Columns 1 through 4

   0.8315 - 0.5556i   0.8315 + 0.5556i   0.3608 - 0.9326i   0.3608 + 0.9326i

  Columns 5 through 8

   0.1912 - 0.9815i   0.1912 + 0.9815i   0.1681 - 0.9858i   0.1681 + 0.9858i

  Columns 9 through 12

   0.0314 - 0.9995i   0.0314 + 0.9995i  -0.4470 - 0.8945i  -0.4470 + 0.8945i

  Columns 13 through 16

  -0.8020 - 0.5973i  -0.8020 + 0.5973i  -0.7423 - 0.6701i  -0.7423 + 0.6701i

  Columns 17 through 20

  -0.7181 - 0.6959i  -0.7181 + 0.6959i  -0.6129 - 0.7902i  -0.6129 + 0.7902i

Poles:
  Columns 1 through 4

   0.3326 - 0.2222i   0.3326 + 0.2222i   0.1443 - 0.3731i   0.1443 + 0.3731i

  Columns 5 through 8

   0.0765 - 0.3926i   0.0765 + 0.3926i   0.0672 - 0.3943i   0.0672 + 0.3943i

  Columns 9 through 12

   0.0126 - 0.3998i   0.0126 + 0.3998i  -0.1788 - 0.3578i  -0.1788 + 0.3578i

  Columns 13 through 16

  -0.3208 - 0.2389i  -0.3208 + 0.2389i  -0.2969 - 0.2680i  -0.2969 + 0.2680i

  Columns 17 through 20

  -0.2873 - 0.2784i  -0.2873 + 0.2784i  -0.2452 - 0.3161i  -0.2452 + 0.3161i

Factored G(z)
/  566085731962705    9002750976819333      \
| ----------------- - ----------------i     |
| 18014398509481984   9007199254740992      |
| ------------------------------------- - 1 |
\                  z                        /

   /  566085731962705    9002750976819333      \
   | ----------------- + ----------------i     |
   | 18014398509481984   9007199254740992      |
   | ------------------------------------- - 1 |
   \                  z                        /

   / 5520343083264219   3558632133896769      \
   | ---------------- - ----------------i     |
   | 9007199254740992   4503599627370496      |
   | ------------------------------------ + 1 |
   \                  z                       /

   / 5520343083264219   3558632133896769      \
   | ---------------- + ----------------i     |
   | 9007199254740992   4503599627370496      |
   | ------------------------------------ + 1 |
   \                  z                       /

   / 1513968334038139   4439525264545937      \
   | ---------------- - ----------------i     |
   | 9007199254740992   4503599627370496      |
   | ------------------------------------ - 1 |
   \                  z                       /
```

$$\left(\frac{\frac{1513968334038139}{9007199254740992} + \frac{4439525264545937}{4503599627370496} i}{z} - 1 \right)$$

$$\left(\frac{\frac{234039014659009}{281474976710656} - \frac{2502038957673595}{4503599627370496} i}{z} - 1 \right)$$

$$\left(\frac{\frac{234039014659009}{281474976710656} + \frac{2502038957673595}{4503599627370496} i}{z} - 1 \right)$$

$$\left(\frac{\frac{6685597574028107}{9007199254740992} - \frac{6035927724275377}{9007199254740992} i}{z} + 1 \right)$$

$$\left(\frac{\frac{6685597574028107}{9007199254740992} + \frac{6035927724275377}{9007199254740992} i}{z} + 1 \right)$$

$$\left(\frac{\frac{3445177072878327}{18014398509481984} - \frac{8840946055072791}{9007199254740992} i}{z} - 1 \right)$$

$$\left(\frac{\frac{3445177072878327}{18014398509481984} + \frac{8840946055072791}{9007199254740992} i}{z} - 1 \right)$$

$$\left(\frac{\frac{6468296862995579}{9007199254740992} - \frac{6268235326380601}{9007199254740992} i}{z} + 1 \right)$$

$$\left(\frac{\frac{6468296862995579}{9007199254740992} + \frac{6268235326380601}{9007199254740992} i}{z} + 1 \right)$$

$$\left(\frac{\frac{2013000991858733}{4503599627370496} - \frac{8057353563157265}{9007199254740992} i}{z} + 1 \right)$$

$$\left(\frac{\frac{2013000991858733}{4503599627370496} + \frac{8057353563157265}{9007199254740992} i}{z} + 1 \right)$$

$$\left(\frac{\frac{812504570253995}{2251799813685248} - \frac{4200208911103973}{4503599627370496} i}{z} - 1 \right)$$

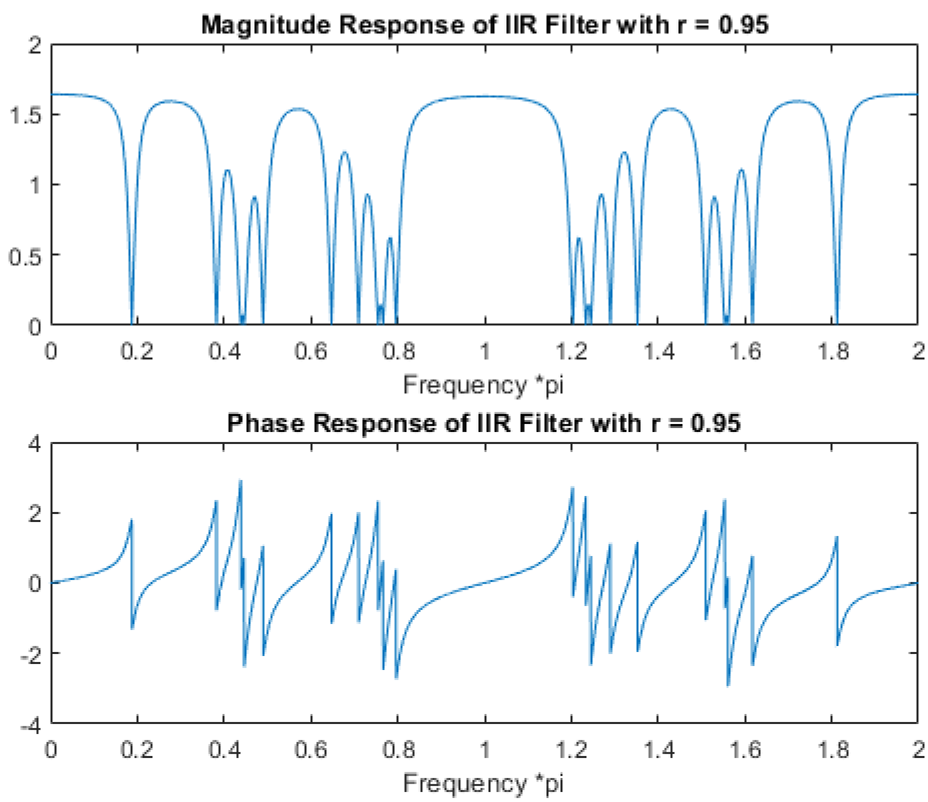
$$\left(\frac{812504570253995}{2251799813685248} + \frac{4200208911103973}{4503599627370496} i \right.$$

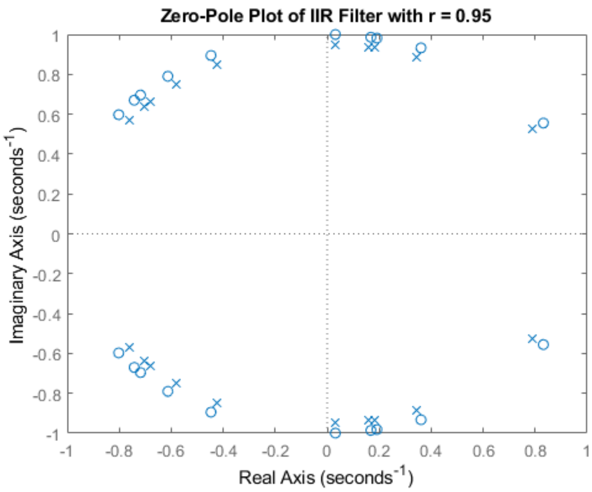
```
| ----------------------------------- - 1 |
\                  z                      /

/ 3611975720343689   5379978066609391     \
| ---------------- - ----------------i    |
| 4503599627370496   9007199254740992     |
| ---------------------------------- + 1 |
\                  z                      /

/ 3611975720343689   5379978066609391     \
| ---------------- + ----------------i    |
| 4503599627370496   9007199254740992     |
| ---------------------------------- + 1 |
\                  z                      /
```

e. Repeat part (d) with r = 0.95

Our IIR notch filter will have the following properties:

We will keep the zeros in the same locations as for the FIR filter, but we will at poles at the same frequencies to narrow the bandwidth of the notch. For this IIR filter, we will place our poles at a radial distance of 0.4 from the origin of the z-plane.





By increasing the radial magnitude of the poles and placing them closer to the unit circle, we can see that the quality factor is drastically increased and the notch filter stops the desired normalized frequencies and allows other frequencies to pass.

```
Zeros:
  Columns 1 through 4

   0.8315 - 0.5556i   0.8315 + 0.5556i   0.3608 - 0.9326i   0.3608 + 0.9326i

  Columns 5 through 8

   0.1912 - 0.9815i   0.1912 + 0.9815i   0.1681 - 0.9858i   0.1681 + 0.9858i

  Columns 9 through 12

   0.0314 - 0.9995i   0.0314 + 0.9995i  -0.4470 - 0.8945i  -0.4470 + 0.8945i

  Columns 13 through 16

  -0.8020 - 0.5973i  -0.8020 + 0.5973i  -0.7423 - 0.6701i  -0.7423 + 0.6701i

  Columns 17 through 20

  -0.7181 - 0.6959i  -0.7181 + 0.6959i  -0.6129 - 0.7902i  -0.6129 + 0.7902i

Poles:
  Columns 1 through 4

   0.7899 - 0.5278i   0.7899 + 0.5278i   0.3428 - 0.8860i   0.3428 + 0.8860i

  Columns 5 through 8

   0.1817 - 0.9325i   0.1817 + 0.9325i   0.1597 - 0.9365i   0.1597 + 0.9365i

  Columns 9 through 12

   0.0299 - 0.9495i   0.0299 + 0.9495i  -0.4246 - 0.8498i  -0.4246 + 0.8498i

  Columns 13 through 16

  -0.7619 - 0.5674i  -0.7619 + 0.5674i  -0.7051 - 0.6366i  -0.7051 + 0.6366i

  Columns 17 through 20

  -0.6822 - 0.6611i  -0.6822 + 0.6611i  -0.5822 - 0.7507i  -0.5822 + 0.7507i

Factored G(z)
```

$$\left(\frac{\frac{566085731962705}{18014398509481984} - \frac{9002750976819333}{9007199254740992} i}{z} - 1 \right)$$

$$\left(\frac{\frac{566085731962705}{18014398509481984} + \frac{9002750976819333}{9007199254740992} i}{z} - 1 \right)$$

$$\left(\frac{\frac{5520343083264219}{9007199254740992} - \frac{3558632133896769}{4503599627370496} i}{z} + 1 \right)$$

$$\left(\frac{\frac{5520343083264219}{9007199254740992} + \frac{3558632133896769}{4503599627370496} i}{z} + 1 \right)$$

$$\left(\frac{\frac{1513968334038139}{9007199254740992} - \frac{4439525264545937}{4503599627370496} i}{z} - 1 \right)$$

$$\left(\frac{\frac{1513968334038139}{9007199254740992} + \frac{4439525264545937}{4503599627370496} i}{z} - 1 \right)$$

$$\left(\frac{\frac{234039014659009}{281474976710656} - \frac{2502038957673595}{4503599627370496} i}{z} - 1 \right)$$

$$\left(\frac{\frac{234039014659009}{281474976710656} + \frac{2502038957673595}{4503599627370496} i}{z} - 1 \right)$$

$$\left(\frac{\frac{6685597574028107}{9007199254740992} - \frac{6035927724275377}{9007199254740992} i}{z} + 1 \right)$$

$$\left(\frac{\frac{6685597574028107}{9007199254740992} + \frac{6035927724275377}{9007199254740992} i}{z} + 1 \right)$$

$$\left(\frac{\frac{3445177072878327}{18014398509481984} - \frac{8840946055072791}{9007199254740992} i}{z} - 1 \right)$$

$$\left(\frac{\frac{3445177072878327}{18014398509481984} + \frac{8840946055072791}{9007199254740992} i}{z} - 1 \right)$$

$$\left(\frac{6468296862995579}{9007199254740992} - \frac{6268235326380601}{9007199254740992} i \right.$$

```
| ------------------------------------ + 1 |
\                   z                    /

/ 6468296862995579   6268235326380601      \
| ---------------- + ----------------i      |
| 9007199254740992   9007199254740992       |
| ------------------------------------ + 1 |
\                   z                    /

/ 2013000991858733   8057353563157265      \
| ---------------- - ----------------i      |
| 4503599627370496   9007199254740992       |
| ------------------------------------ + 1 |
\                   z                    /

/ 2013000991858733   8057353563157265      \
| ---------------- + ----------------i      |
| 4503599627370496   9007199254740992       |
| ------------------------------------ + 1 |
\                   z                    /

/  812504570253995   4200208911103973      \
| ---------------- - ----------------i      |
| 2251799813685248   4503599627370496       |
| ------------------------------------ - 1 |
\                   z                    /

/  812504570253995   4200208911103973      \
| ---------------- + ----------------i      |
| 2251799813685248   4503599627370496       |
| ------------------------------------ - 1 |
\                   z                    /

/ 3611975720343689   5379978066609391      \
| ---------------- - ----------------i      |
| 4503599627370496   9007199254740992       |
| ------------------------------------ + 1 |
\                   z                    /

/ 3611975720343689   5379978066609391      \
| ---------------- + ----------------i      |
| 4503599627370496   9007199254740992       |
| ------------------------------------ + 1 |
\                   z                    /
```

Code for question 4:

```
[y,Fs] = audioread('project2audio.wav');
[y_new,y_new1,y_new2] = question4(y,Fs,0.4,0.95);
soundsc(y_new2,Fs)

function [y_new,y_new1,y_new2] = question4(y,Fs,r1,r2)
L = length(y);
yf = fftshift(fft(y))/L;
f = -Fs/2:Fs/L:Fs/2-Fs/L;
figure
subplot(211);
plot(f,abs(yf));
ylabel('Magnitude Response')
xlabel('Hz')
% plot phase
subplot(212);
plot(f,unwrap(angle(yf)));
ylabel('Phase Response')
xlabel('Hz')
```

```
[peaks,noi_loc] = findpeaks(abs(yf( (length(yf)+1)/2 : length(yf) ) ),f( (length(yf)+1)/2 :
length(yf) ),'MinPeakHeight',0.01);

disp("Frequencies of Noise (Hz):")
disp(noi_loc);
disp("Discrete Normalized Frequencies of Noise:")
disp(noi_loc/Fs);

syms z
% Make an FIR filter with zeros at noise frequencies
numz = 1;
%noi_loc = mean(noi_loc);
for i = 1:length(noi_loc)
   numz = numz .* (z^2-2*cos(2*pi*noi_loc(i)/Fs)*z+1);
end
numHz = sym2poly(numz);

question3(numHz,1,"FIR Filter");
question1(numHz,1,"FIR Filter");

y_new = filter(numHz,1,y);

% Make an IIR filter with r1
denz = 1;
for i = 1:length(noi_loc)
   denz = denz .* (z^2-2*r1*cos(2*pi*noi_loc(i)/Fs)*z+r1^2);
end
denHz1 = sym2poly(denz);

question3(numHz,denHz1,"IIR Filter with r = 0.4");
question1(numHz,denHz1,"IIR Filter with r = 0.4");

y_new1 = filter(numHz,denHz1,y);

% Make an IIR filter with r2
denz = 1;
for i = 1:length(noi_loc)
   denz = denz .* (z^2-2*r2*cos(2*pi*noi_loc(i)/Fs)*z+r2^2);
end
denHz2 = sym2poly(denz);

question3(numHz,denHz2,"IIR Filter with r = 0.95");
question1(numHz,denHz2,"IIR Filter with r = 0.95");

y_new2 = filter(numHz,denHz2,y);
end
function question3(num,den,str)
w = 0:0.001:2*pi;
numw = 0;
denw = 0;
for i = 1:length(num)
    numw = numw + num(i).*exp(1j*w*(i-1));
end
```

```
for i = 1:length(den)
    denw = denw + den(i).*exp(1j*w*(i-1));
end

figure
subplot(211)
Hw = numw./denw;
plot(w/pi,abs(Hw))
xlabel('Frequency *pi')
title("Magnitude Response of " + str)

subplot(212)
plot(w/pi,angle(Hw))
xlabel('Frequency *pi')
title("Phase Response of " + str)

end

function [poleG,zeroG] = question1(num,den,str)
syms z
poleG = roots(den);
zeroG = zeros(length(den)-1,1);
zeroG(1:length(num)-1,1) = roots(num);
disp("Zeros:")
disp(zeroG');
pause(1)
disp("Poles:");
disp(poleG');
pause(1)
denz = 1;
numz = 1;
for i = 1:length(zeroG)
    numz = numz * ( 1 - zeroG(i)*z^-1);
end
for j = 1:length(poleG)
    denz = denz * ( 1 - poleG(j)*z^-1);
end
disp("Factored G(z)")
pretty(numz);
if den ~= 1
    disp("---------------------------------------------------------------------------------
-------------")
    pretty(denz);
end
s = tf('s');
Gs = tf(num,den);
figure
pzplot(Gs*s^(length(den)-length(num)));
title("Zero-Pole Plot of " + str)
end
```

```
% Audiofiles written
```

```
Audiowrite("FIRaudio.wav",y_new/length(y_new),Fs)
```