Experiment - 7 **Date - 29 / 3 / 24**

Aim - Design the Infinite Impulse Response (IIR) digital filters for low pass ,

high pass , band pass , and band stop responses.

Laboratory Exercise

A) Design the Butterworth bandstop filter by running Program P7_1 . Write down the exact expression for the transfer function generated . What are the filter specifications ? Does your design meet the specifications ? Using MATLAB , compute and plot the filter's unwrapped phase response and the group delay response .

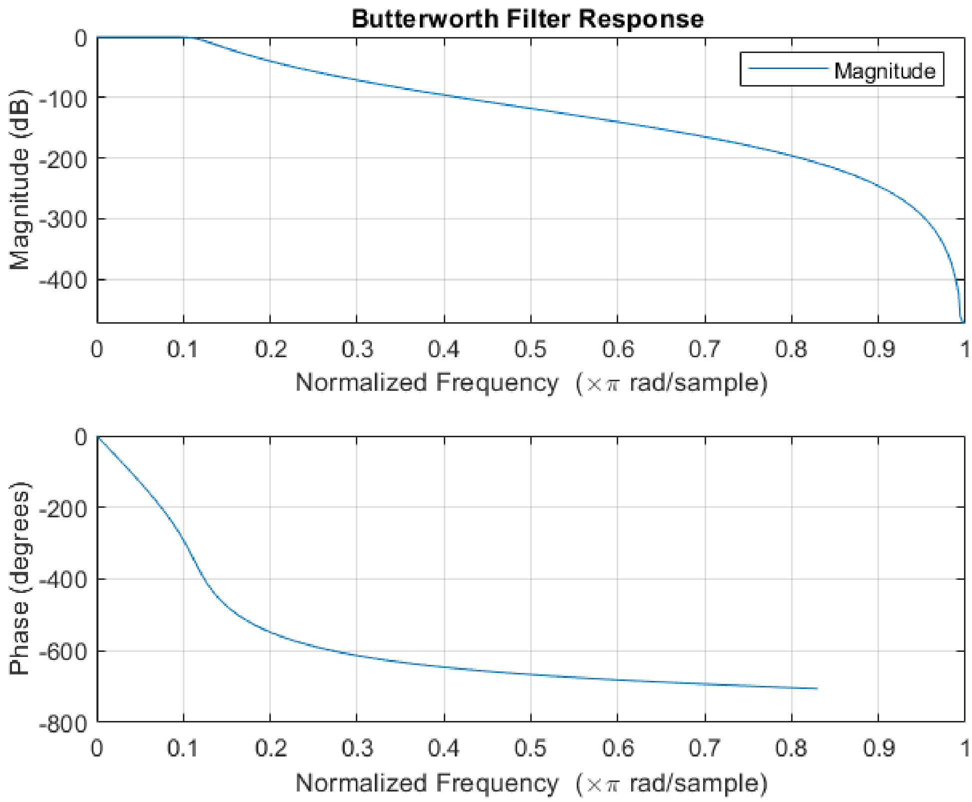
```
clc ; clear all ; close all ;

% [n,Wn] = buttord(Wp,Ws,Passband Ripple(db),Stopband Attenuation(db))
% where n = lowest possible order , Wn = normalized cutoff frequency
% [b,a] = butter(n,Wn)

% Butterworth
Wp = 4000 / 40000 ; Ws = 8000 / 40000 ; pr = 0.5 ; sa = 40 ;
[N , Wn] = buttord(Wp , Ws , pr , sa) ;
fprintf("Lowest Order is :- %d \n", N) ; fprintf("Normalised Cutoff Frequency :- %f
", Wn) ;
```

```
Lowest Order is :- 8
Normalised Cutoff Frequency :- 0.115052
```

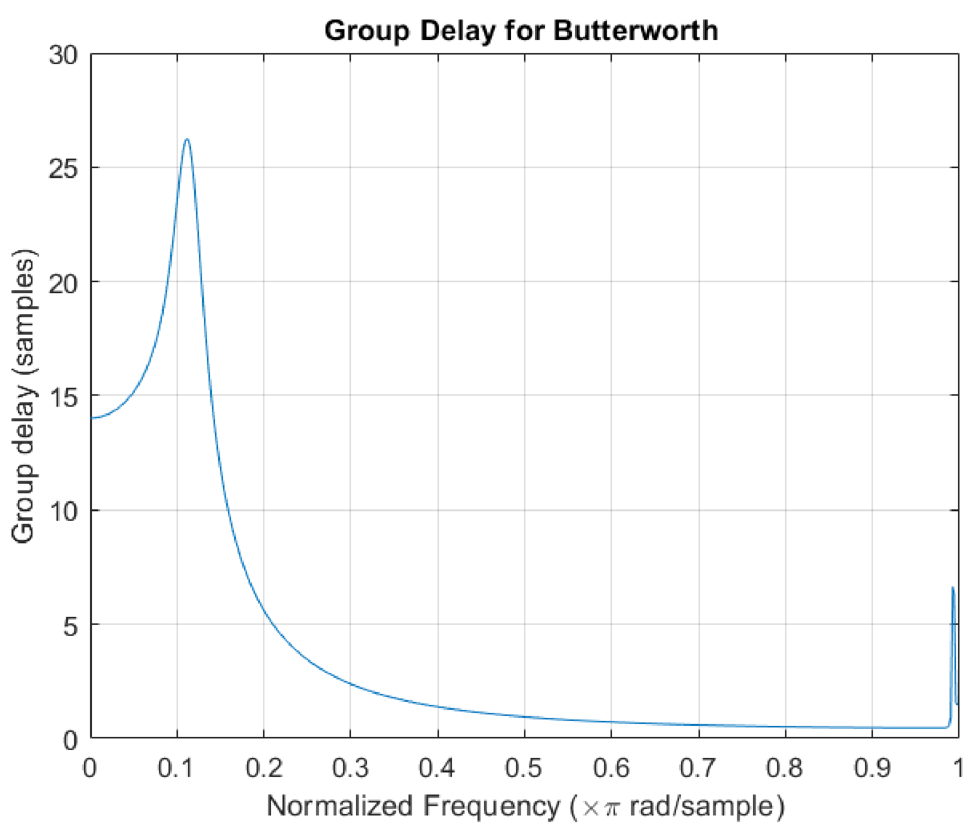
```
[b , a] = butter(N , Wn) ;
disp(b) ; disp(a) ;
```

```
   1.0e-04 *

    0.0049    0.0391    0.1368    0.2737    0.3421    0.2737    0.1368    0.0391    0.0049

    1.0000   -6.1483   16.7106  -26.1941   25.8774  -16.4864    6.6107   -1.5246    0.1548
```

```
freqz(b,a) ; grid on ; title("Butterworth Filter Response ") ; legend("Magnitude") ;
```




```
grpdelay(b , a) ; title("Group Delay for Butterworth ") ;
```



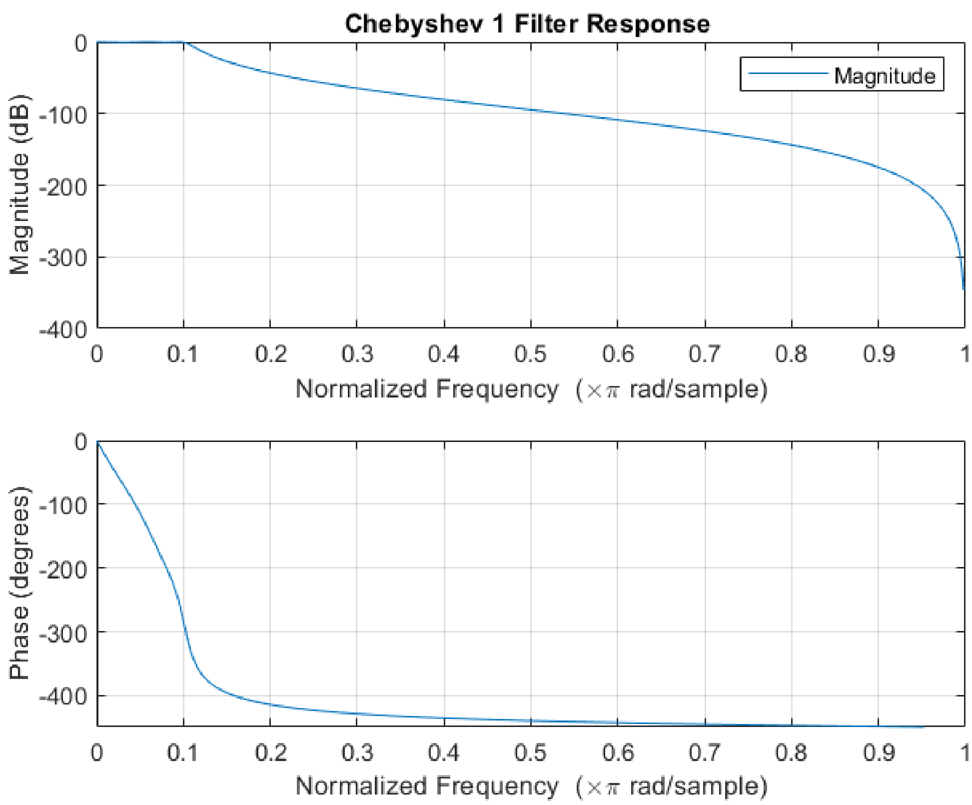
```
% Chebyshev1
[N1, Wn1] = cheb1ord(Wp, Ws, pr, sa) ;
fprintf("Lowest Order is :- %d \n", N1) ; fprintf("Normalised Cutoff Frequency :-
%f ", Wn1) ;
```

```
Lowest Order is :- 5
Normalised Cutoff Frequency :- 0.100000
```

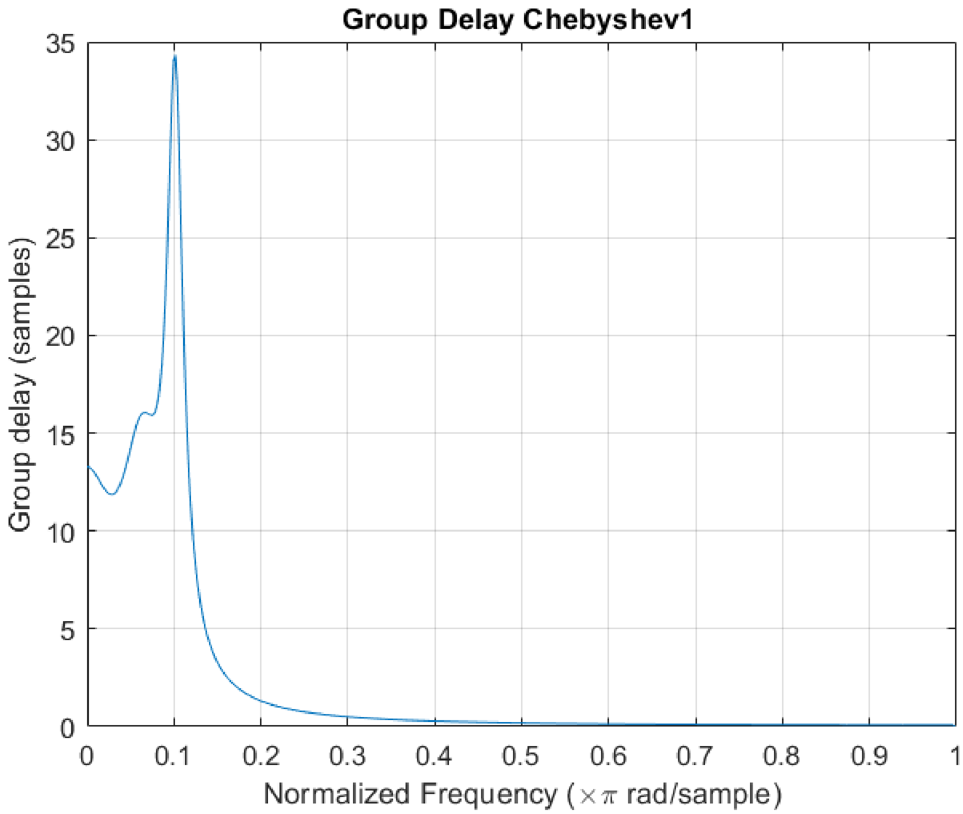
```
[b1 , a1] = cheby1(N1 , pr , Wn1 ,'low') ;
disp(b1) ; disp(a1) ;
```

```
   1.0e-03 *

    0.0144    0.0719    0.1438    0.1438    0.0719    0.0144

    1.0000   -4.5153    8.2782   -7.6956    3.6253   -0.6921
```

```
freqz(b1,a1) ; grid on ; title("Chebyshev 1 Filter Response ") ;
legend("Magnitude") ;
```




```
grpdelay(b1 , a1) ; title("Group Delay Chebyshev1 ") ;
```



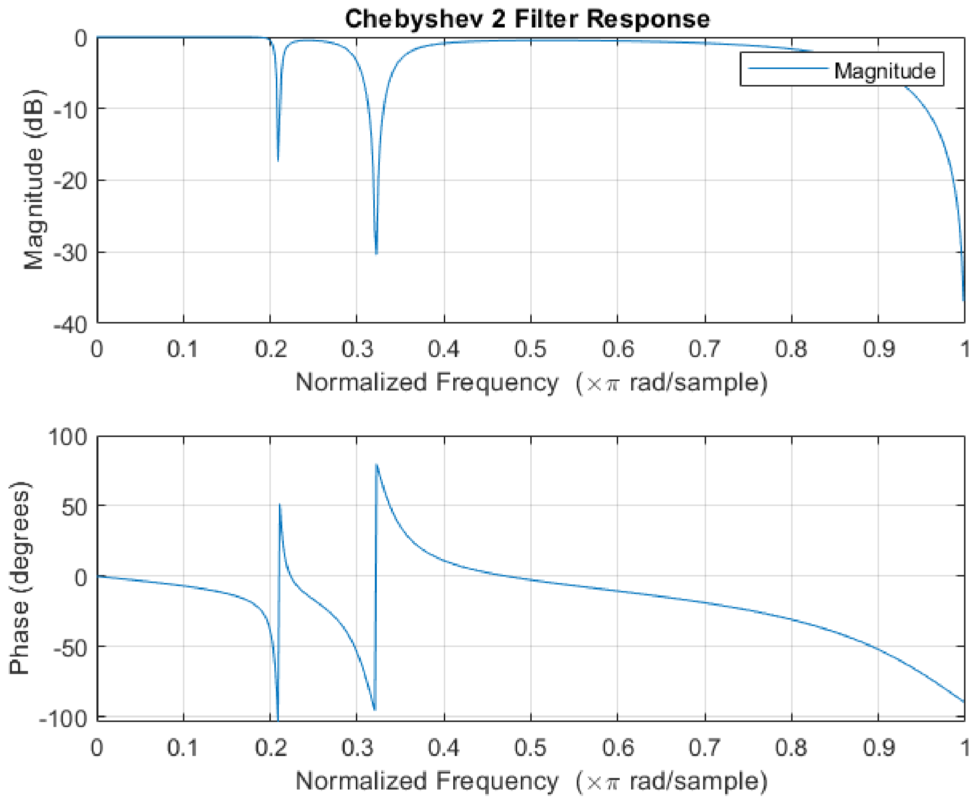

```
%Chebyshev2
[N2, Wn2] = cheb2ord(Wp, Ws, pr, sa) ;
fprintf("Lowest Order is :- %d \n", N2) ; fprintf("Normalised Cutoff Frequency :-
%f ", Wn2) ;
```

```
Lowest Order is :- 5
Normalised Cutoff Frequency :- 0.200000
```

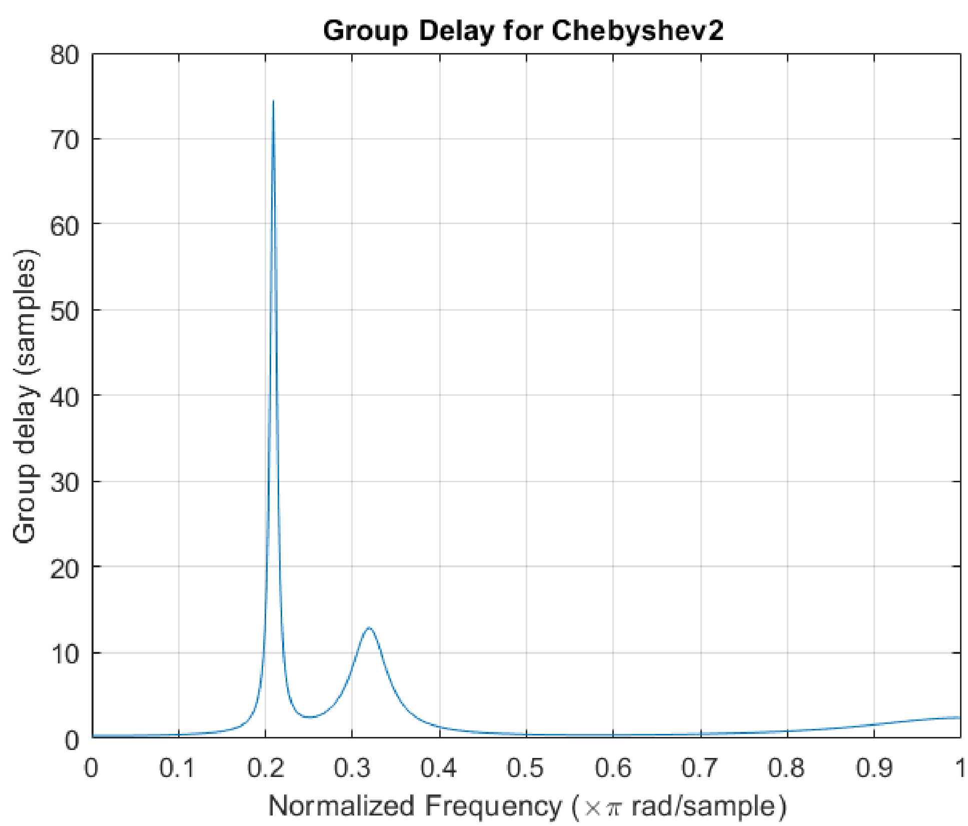
```
[b2 , a2] = cheby2(N2 , pr , Wn2 ,'low') ;
disp(b2) ; disp(a2) ;
```

```
    0.7437   -1.2240    0.7713    0.7713   -1.2240    0.7437

    1.0000   -1.9059    1.7150   -0.0990   -0.6690    0.5411
```

```
freqz(b2,a2) ; grid on ; title("Chebyshev 2 Filter Response ") ;
legend("Magnitude") ;
```




```
grpdelay(b2 , a2) ; title("Group Delay for Chebyshev2 ") ;
```



Inference :- In this exercise , we observed that different types of Low Pass filters like Butterworth Filter , Chebyshev 1 and Chebyshev 2 , their phase response . We also observed that the Group Delay is almost constant for the Passband Frequency for all the filter types .

Here , we found the lowest order possible to design a filter with the above given specifications and further calculated the Cutoff - Frequency to get the coefficients of b and a to apply the freqz() function and observe the Magnitude and Phase Spectrum .We have also used grpdelay() function to plot the Group Delay plot.

B) Design an elliptic bandpass filter meeting the specification given in Question Q7.3 . Write down the exact expression for the transfer function generated . Does your design meet the specifications ? Using MATLAB , compute and plot the filter's unwrapped phase response and the group delay response .

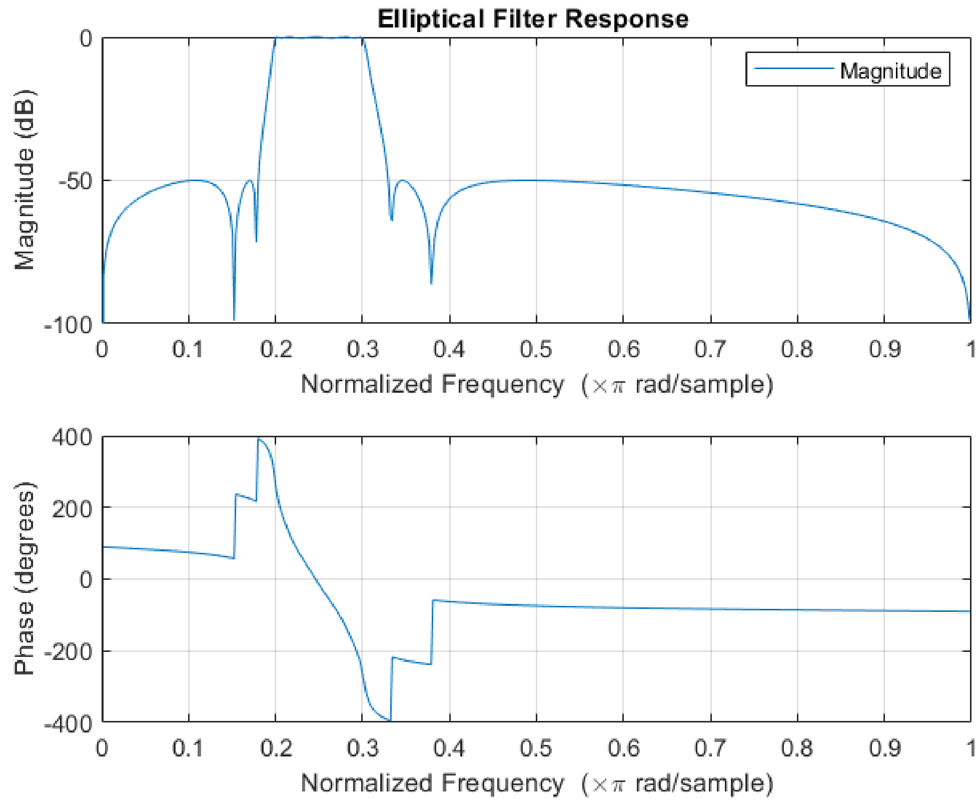
```
clc ; clear all ; close all ;

%Elliptical
Wp = [(1400 / 7000) , (2100 / 7000)] ; Ws = [(1050 / 7000) , (2450 / 7000)] ; pr =
0.4 ; sa = 50 ;
[N , Wn] = ellipord(Wp , Ws , pr , sa) ;
fprintf("Lowest Order is :- %d \n", N) ; fprintf("Normalised Cutoff Frequency :- %f
", Wn) ;
```

```
Lowest Order is :- 5
Normalised Cutoff Frequency :- 0.200000 Normalised Cutoff Frequency :- 0.300000
```

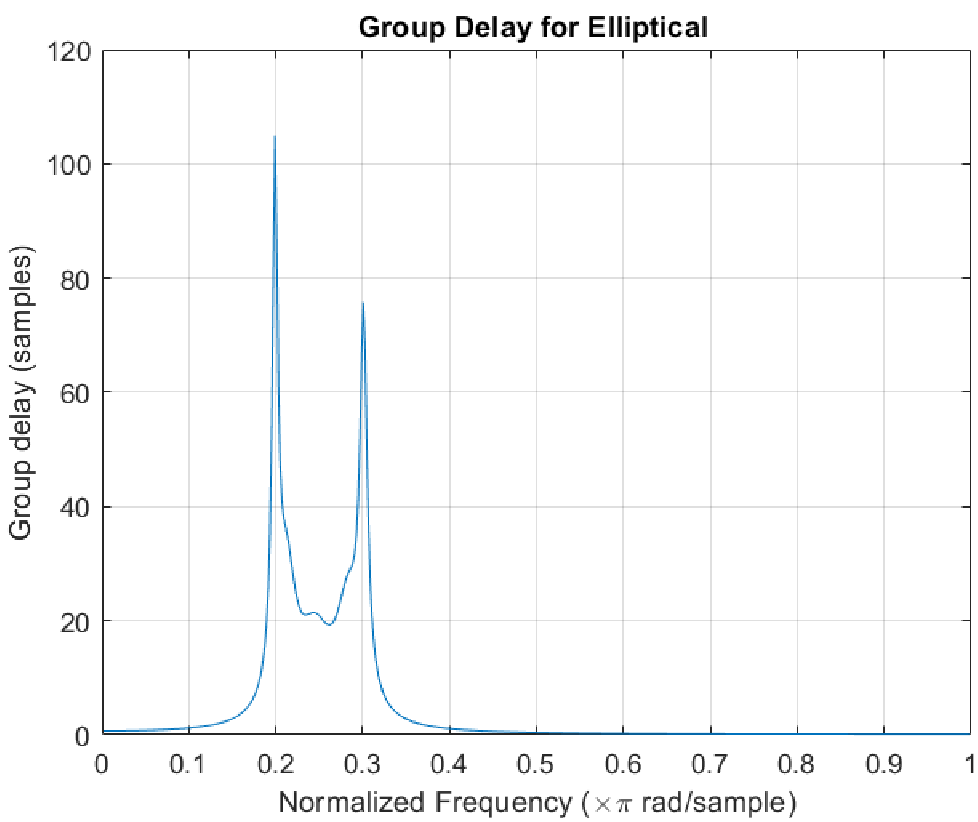
```
[b , a] = ellip(N , pr , sa , Wn ) ;
disp(b) ; disp(a) ;
```

```
    0.0032   -0.0165    0.0406   -0.0578    0.0445    0.0000   -0.0445    0.0578   -0.0406    0.0165   -0.0032

    1.0000   -6.7920   23.0078  -49.9145   76.2211  -85.1956   70.5315  -42.7390   18.2281   -4.9788    0.6785
```

```
freqz(b , a) ; grid on ; title("Elliptical Filter Response ") ;
legend("Magnitude") ;
axis([0 1 -100 0]) ; % x axis to 0 to 1 % y axis to -100 to 0
```




```
grpdelay(b , a) ; title("Group Delay for Elliptical ") ;
```



Inference :- Similar to the above question , we calculate the Lowest Possible Order and Cutoff Frequency for the given specifications for the Band Pass filter using the ellipord() function . Then , we calculate the coefficients of b and a by using the ellip() function . Further we use the freqz() function to plot the Magnitude and Phase Response . We also plot the the Group Delay plot usig grpdelay() function which has some ripples in the Passband Region due to the Elliptic Filter .

C) Design lowpass IIR Filter with the following specifications :

-- Filter Order = 2 , Butterworth Type

-- Cut-off Frequency = 800 Hz

-- Sampling Rate = 8000 Hz

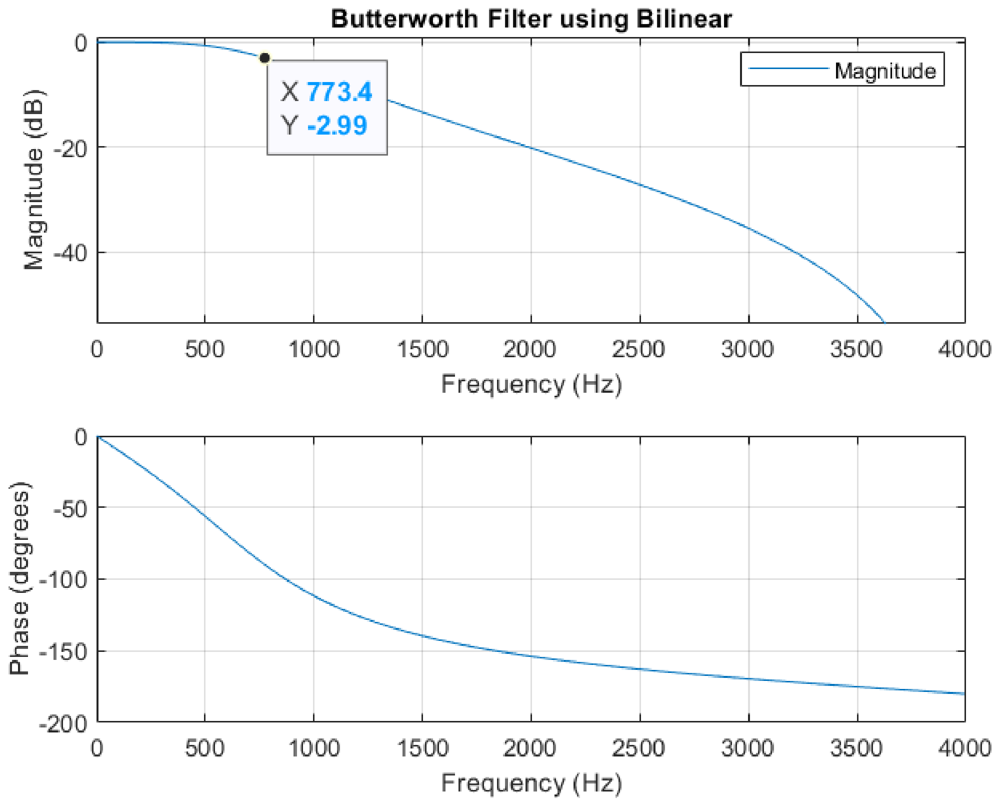
-- Design using the bilinear z - transform design method . Plot the frequency responses using MATLAB .

Hint : freqz(bLP,aLP,512,8000) ; axis([0 4000 -40 1]) ; 'Label and print your graph . What are the filter gains for the stopband at the cut - off frequency and 2000Hz and the passband at 50Hz based on the plot of the magnitude frequency response ?

```
clc ; clear all ; close all ;

Ord = 2 ; Fs = 8000 ; Fc = 800 ; Wc = (2 * pi * Fc) / Fs ;
[b , a] = butter(Ord , Wc , 's') ; [bz , az] = bilinear(b , a , 1) ;

disp(b) ; disp(a) ; disp(bz) ; disp(az) ;
```

```
         0         0    0.3948

    1.0000    0.8886    0.3948

    0.0640    0.1279    0.0640

    1.0000   -1.1683    0.4241
```

```
freqz(bz , az , 512 , 8000); axis([0 4000 -40 1]) ; title("Butterworth Filter using Bilinear") ; legend("Magnitude") ;
```




```
%Filter Gain at Fc(800 Hz) = -3.371
%Filter Gain at 2000 Hz = -20.16
%Filter Gain at Pass Band at 50 Hz = -9.489 * 10^-5
```

Inference :- Here , we designed a 2nd Order Butterworth Low Pass Filter for the give specifications using bilinear Z - Transform Method . Firstly , we use the butter() function to get the coefficients of b and a . Further , we use the bilinear() function for the Mathematical Mapping of the coefficients and then we use the freqz() function to plot the Magnitude and Phase Response . Further we also measured the Filter Gain at Fc(800Hz) = -3.371 , at 2000Hz = -20.16 and at 50Hz = -9.489 * 10 ^ -5 using the data tips .

Conclusion :- From this experiment , we get a brief idea about the designing of IIR Filters of different types and observing their Group Delay Plot as well as the Phase Response . We also learnt to find the lowest possible order for the given specifications of the Filter .