$$\sum_{k=0}^{N} a_k y(n-k) = \sum_{k=0}^{M} b_k x(n-k)$$

$$y(n) = \sum b_k x(n-k) - \sum_{K=1}^{N} a_k y(n-k)$$

$N=0$

1

$$\frac{y(z)}{x(z)}$$

$$y(n) = \sum^{M} b_k x(n-k)$$

$$h(n) = \{ \quad \}$$

$$H(z) = \frac{\sum^{M} b_k z^{-k}}{1+\sum_{K=1}^{N} a_k z^{-k}}$$

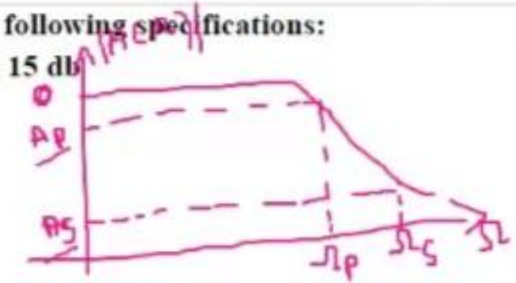
$$H(z) = \sum_{K=0}^{M} b_k z^{-K}$$

FIR

IIR

1. **Program to design Butterworth low/High pass filter for the following specifications:**
Pass band attenuation ≤ 1.25 db, Stopband attenuation ≥ 15 db
fpass =200Hz, fstop=300Hz, fsample=2kHz

MatLAB Program:




```
clc; clear all; close all;
% Given specifications
Ap=1.25;   As=15;  fpb=200;    fsb=300;    fs=2000;
% To find order (N)  and cutoff frequency (fc)
[N,fc]=buttord(200/(fs/2),300/(fs/2),Ap,As)
% Low pass filter
[b,a]=butter(N ,fc)
 % High pass filter
 %[b,a]=butter(N ,fc,'high')
[H,f]=freqz(b,a,256,fs);
subplot(3,1,1);    plot(f,abs(H));
title('Frequency response of  IIR digtial filter');
xlabel('Frequency in Hz');  ylabel('Magnitude');
%filtering operation on input signal having frequency 10Hz, 100Hz, 500Hz
n=0:1/fs:0.1;
s1=5*sin(2*pi*10*n);
s2=5*sin(2*pi*100*n
s3=5*sin(2*pi*500*n
```

$\Omega = 2\pi f$

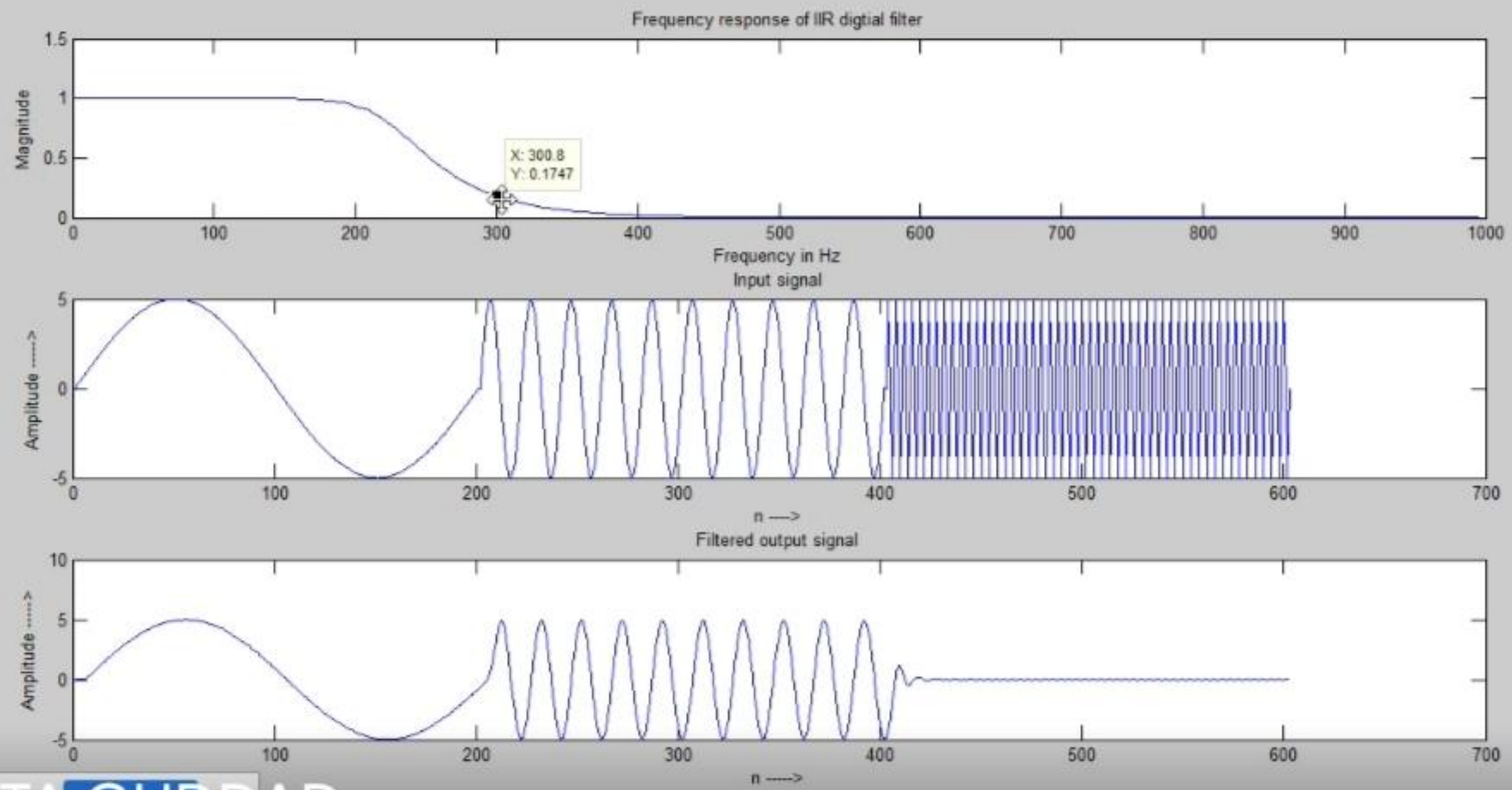
$H(s) = \frac{1}{B_N(s)}$

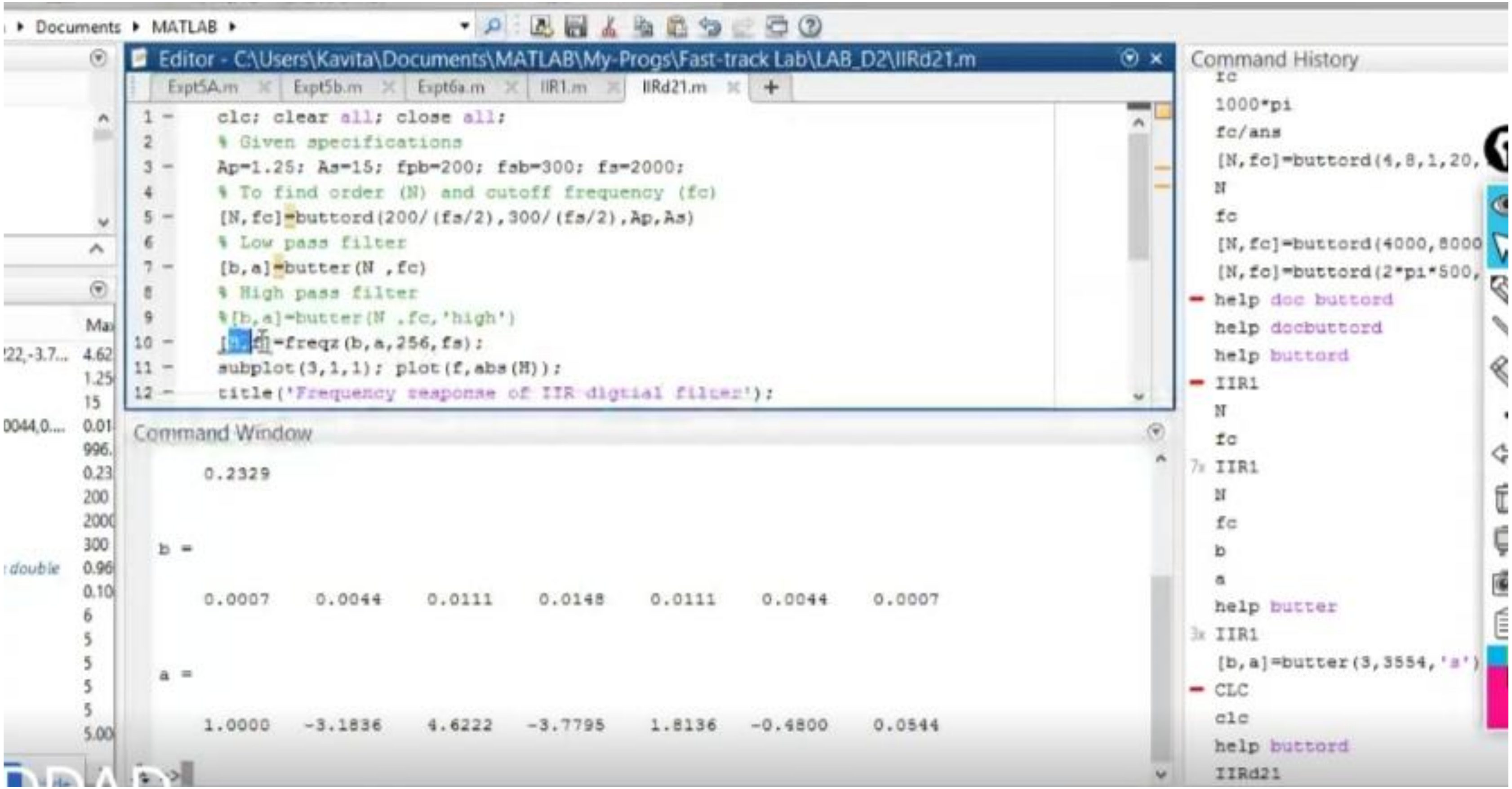
$|H(z)| = $

$z = e^{j\Omega}$

$\frac{f}{F/2}$

```
%[b,a]=butter(N ,fc,'high')
[H,f]=freqz(b,a,256,fs);
subplot(3,1,1);    plot(f,abs(H));
title('Frequency response of  IIR digtial filter');
xlabel('Frequency in Hz');  ylabel('Magnitude');
%filtering operation on input signal having frequency 10Hz, 100Hz, 500Hz
n=0:1/fs:0.1;
s1=5*sin(2*pi*10*n);
s2=5*sin(2*pi*100*n);
s3=5*sin(2*pi*500*n);
x=[s1 s2 s3];
subplot(3,1,2);    plot(x);
title('Input signal');  xlabel('n ---->'); ylabel('Amplitude ----->');
y=filter(b,a,x);
subplot(3,1,3);    plot(y);
```


Frequency response of IIR digtial filter
Magnitude
X: 300.8
Y: 0.1747
Frequency in Hz
Input signal
Amplitude ----->
n ----->
Filtered output signal
Amplitude ----->
n ----->


Documents ▸ MATLAB ▸
Editor - C:\Users\Kavita\Documents\MATLAB\My-Progs\Fast-track Lab\LAB_D2\IIRd21.m
Expt5A.m
Expt5b.m
Expt6a.m
IIR1.m
IIRd21.m
clc; clear all; close all;
% Given specifications
Ap=1.25; As=15; fpb=200; fsb=300; fs=2000;
% To find order (N) and cutoff frequency (fc)
[N,fc]=buttord(200/(fs/2),300/(fs/2),Ap,As)
% Low pass filter
[b,a]=butter(N ,fc)
% High pass filter
%[b,a]=butter(N ,fc,'high')
[h,f]=freqz(b,a,256,fs);
subplot(3,1,1); plot(f,abs(H));
title('Frequency response of IIR digtial filter');
Command Window
0.2329
b =
0.0007 0.0044 0.0111 0.0148 0.0111 0.0044 0.0007
a =
1.0000 -3.1836 4.6222 -3.7795 1.8136 -0.4800 0.0544
Command History
1000*pi
fc/ans
[N,fc]=buttord(4,8,1,20,
N
fc
[N,fc]=buttord(4000,8000
[N,fc]=buttord(2*pi*500,
help doc buttord
help docbuttord
help buttord
IIR1
N
fc
IIR1
N
fc
b
a
help butter
IIR1
[b,a]=butter(3,3554,'s')
CLC
clc
help buttord
IIRd21

Design a LP filter which has flat pass band & monotonic transition band for the following specifications.

i) Pass band & SB frequencies (cut off) of 500 r/s & 1000 r/s.

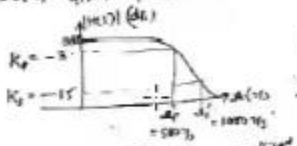
ii) Min pass band attenuation of -3 dB

& max stop — — of -15 dB.

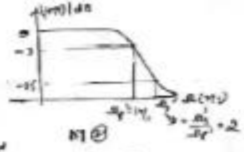
Soln. **Method - I**

using $H_N(s) \longrightarrow H_P(s) \longrightarrow H_a(s)$

Step 1) Given specification



Normalized map



Step 2) Find order (N) ① & normalized cutoff freq (Ω_{cn}) using N ②

$$N = \log\left[\frac{10^{-0.1K_p} - 1}{10^{-0.1K_s} - 1}\right] \div 2\log\left(\frac{\Omega_p}{\Omega_s}\right) =$$

$$= \log\left[\frac{10^{+0.3} - 1}{10^{1.5} - 1}\right] \div 2\log\left(\frac{1}{2}\right) = 2.4717$$

$\boxed{N = 3}$ Always approximate to higher integer

$$\Omega_{cn} = \frac{\Omega_p}{\left(10^{-0.1K_p} - 1\right)^{1/2N}} = \frac{1}{\left(10^{+0.3} - 1\right)^{1/6}}$$

$$\Omega_{cn} = 1 \text{ r/s}$$

i) Pass band & 3 dB frequencies ...

ii) Min pass band attenuation of −3 dB
& max stop — " — " — −15 dB.

Soln **Method − I**

using $H_N(s) \longrightarrow H_p(s) \longrightarrow H_a(s)$

Step 1> Given specification

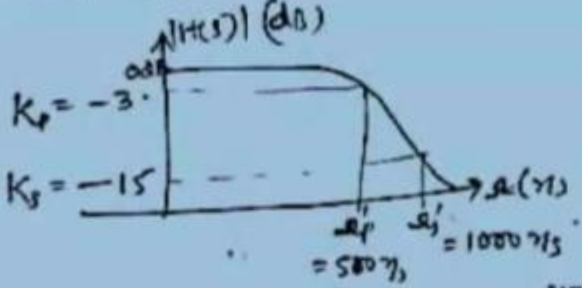


fig ①

Normalized resp

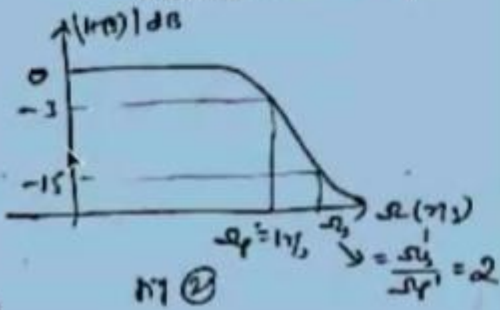
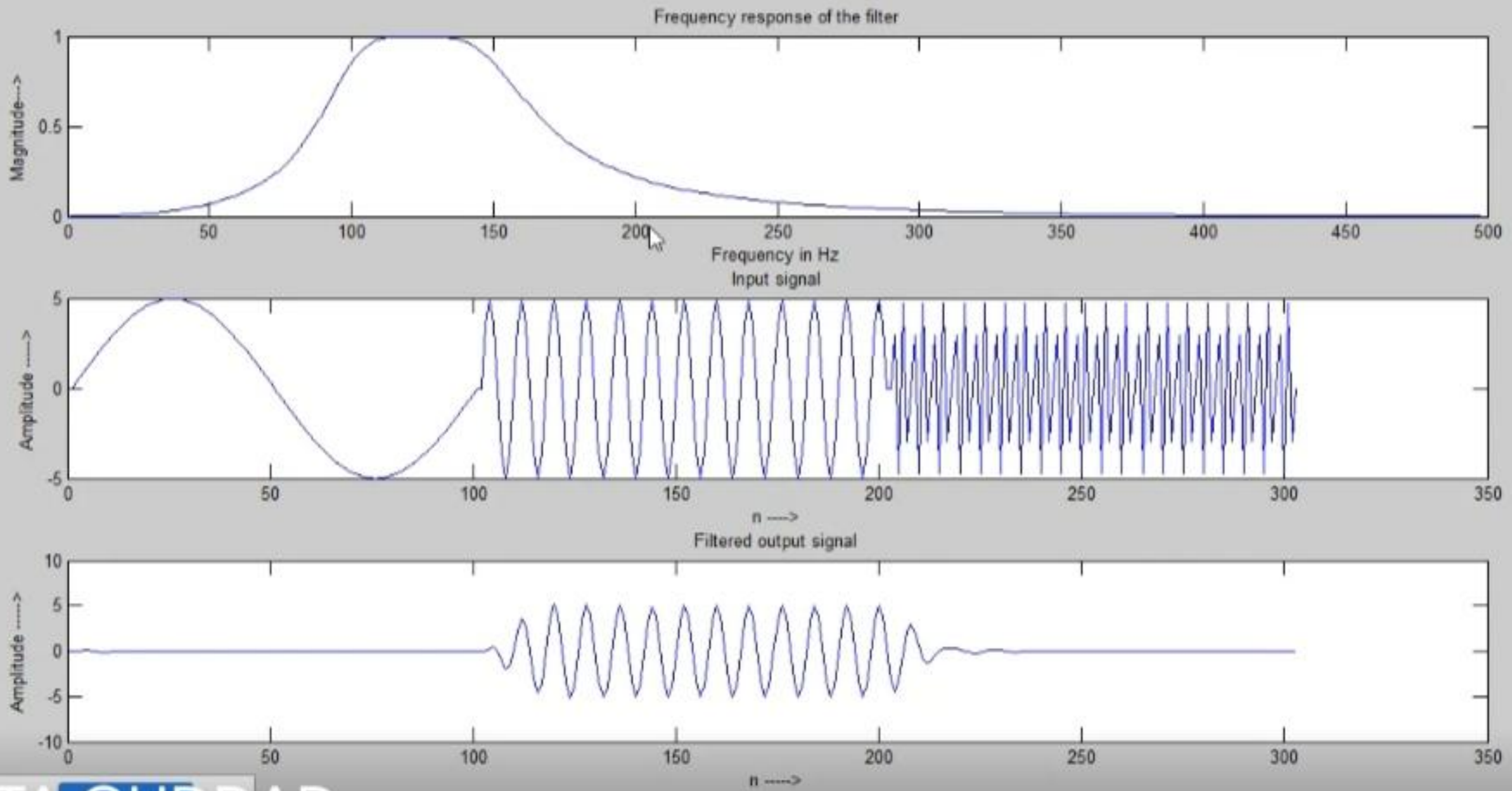


fig ②

Step 2> Find order (N) & normalized cutoff freq (Ω_{cn}) using fig ②

$$N = \log\left[\frac{10^{-0.1K_p}-1}{10^{-0.1K_s}-1}\right] \div 2\log\left(\frac{\Omega_p}{\Omega_s}\right) =$$


Frequency response of the filter
Magnitude--->
1
0.5
0
0
50
100
150
200
250
300
350
400
450
500
Frequency in Hz
Input signal
Amplitude ----->
5
0
-5
0
50
100
150
200
250
300
350
n ---->
Filtered output signal
Amplitude ----->
10
5
0
-5
-10
0
50
100
150
200
250
300
350
n ---->

Frequency response of the filter

3. Program to design Butterworth low pass filter for the following specifications:

N=2; fc=150Hz; fs=1000 Hz;

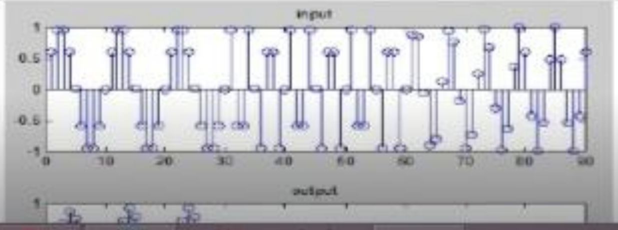
MATLab Program:

```
clc; clear all; close all;
N=2; fc= 150; f1=100; f2=300; f3=170; fs=1000;
[b,a]=butter(N, fc/(fs/2)) %% IIR filter  Nr and Dr coefficients
%generate simulated input of 100, 300 & 170 Hz, each of 30 points
n=1:30;
x1=sin(2*pi*n*f1/fs);
x2=sin(2*pi*n*f2/fs);
x3=sin(2*pi*n*f3/fs);
x=[x1 x2 x3];
subplot(2,1,1); stem(x);    title('input');
%generate o/p
y=filter(b,a,x);
subplot(2,1,2); stem(y);    title('output');
```

Result:

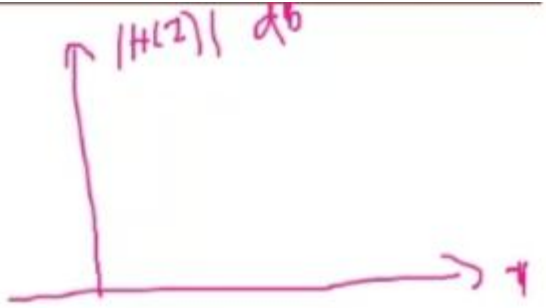
```
b =   0.1311   0.2622   0.1311

a =   1.0000  -0.7478   0.2722
```

...ws that 100 Hz is passed,



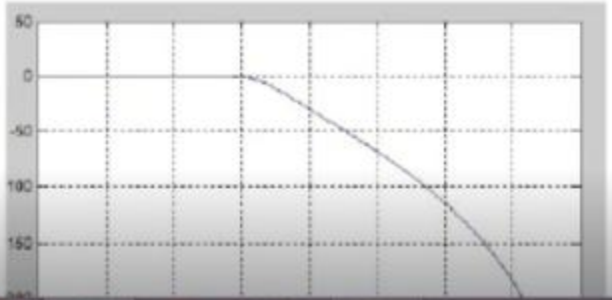
ITA GUDDAD

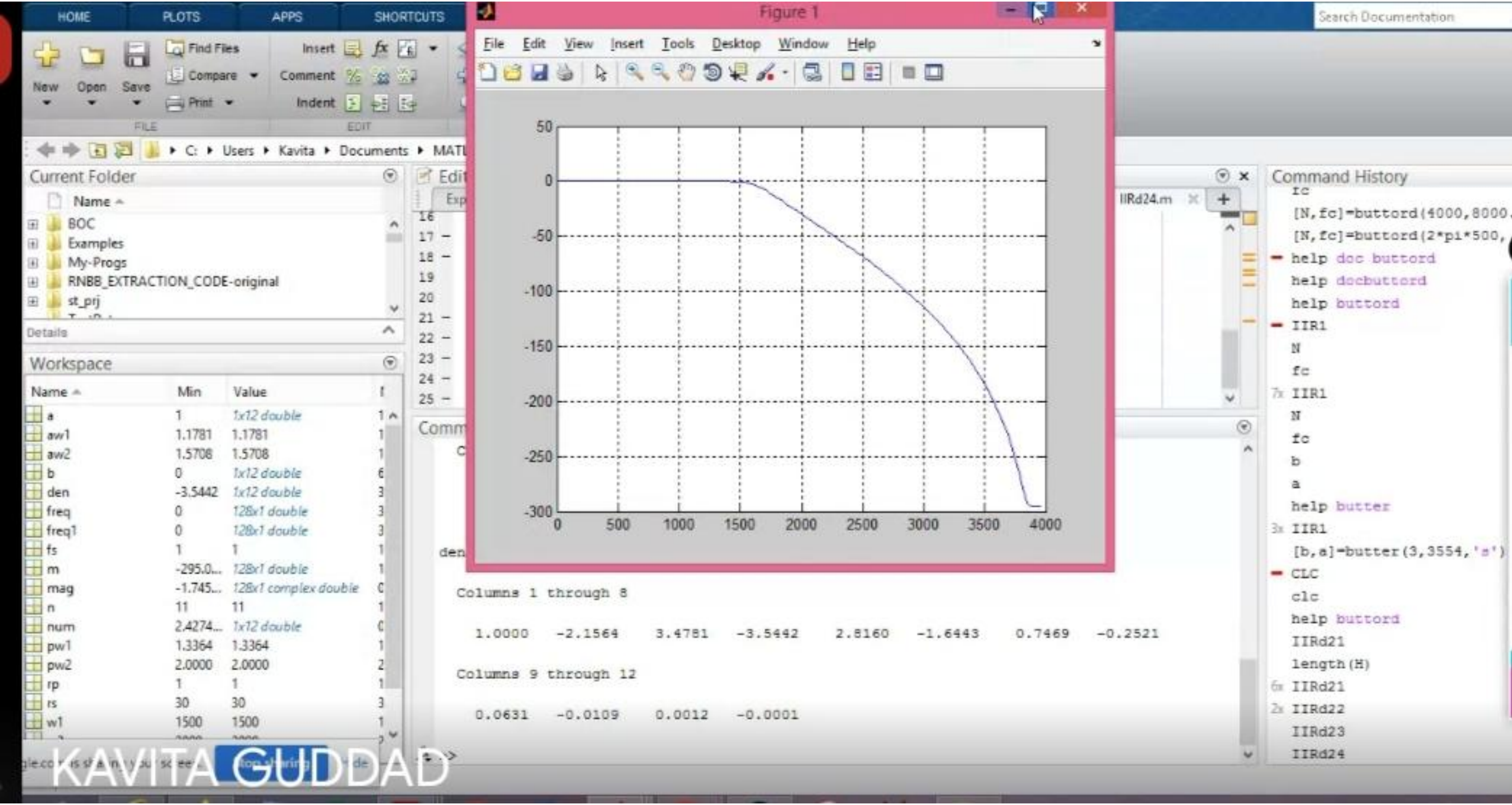
```
fs=1;
[num,den]= bilinear(b,a,fs)
% The num and den should match with H(z)
%plot the frequency response
[mag,freq1]=freqz(num,den,128);
freq=freq1*ws/(2*pi);
m = 20*log10(abs(mag));
plot(freq,m);
grid;
```



Result:

aw1 = 1.1781
aw2 = 1.5708
pw1 = 1.3364
pw2 = 2.0000
n = 11
wc = 1.4611
[illegible]02 0.0027 0.0134 0.0401
[illegible]1121 0.0801 0.0401




HOME
PLOTS
APPS
SHORTCUTS
Figure 1
File Edit View Insert Tools Desktop Window Help
50
0
-50
-100
-150
-200
-250
-300
0 500 1000 1500 2000 2500 3000 3500 4000
Search Documentation
Find Files
Compare
Print
New Open Save
Insert
Comment
Indent
FILE
EDIT
C: ▸ Users ▸ Kavita ▸ Documents ▸ MATL
Current Folder
Name
BOC
Examples
My-Progs
RNBB_EXTRACTION_CODE-original
st_prj
Details
Workspace
Name Min Value
a 1 1x12 double
aw1 1.1781 1.1781
aw2 1.5708 1.5708
b 0 1x12 double
den -3.5442 1x12 double
freq 0 128x1 double
freq1 0 128x1 double
fs 1 1
m -295.0... 128x1 double
mag -1.745... 128x1 complex double
n 11 11
num 2.4274... 1x12 double
pw1 1.3364 1.3364
pw2 2.0000 2.0000
rp 1 1
rs 30 30
w1 1500 1500
IIRd24.m
den
Columns 1 through 8
1.0000 -2.1564 3.4781 -3.5442 2.8160 -1.6443 0.7469 -0.2521
Columns 9 through 12
0.0631 -0.0109 0.0012 -0.0001
Command History
[N,fc]=buttord(4000,8000.
[N,fc]=buttord(2*pi*500,
help doc buttord
help docbuttord
help buttord
IIR1
N
fc
IIR1
N
fc
b
a
help butter
IIR1
[b,a]=butter(3,3554,'s')
CLC
clc
help buttord
IIRd21
length(H)
IIRd21
IIRd22
IIRd23
IIRd24
KAVITA GUDDAD

$\omega_{s1} = 2.\tan(\omega_{s/2})=1.998$

$N = \log[(10^{-0.1Ap}-1)/ (10^{-0.1As}-1)]/2\log[\omega'_{p/} \omega'_s] = 10.259 = 11$

$\omega_c = \omega'_{p/} (10^{-0.1Ap}-1)^{1/2N} = 1.42$

Programs for designing of IIR filters (to verify the above problem):

```
clc;   clear all; close all;
% Butterworth filter: Given Specifications:
rp=1; rs=30; w1=1500; w2=2000; ws=8000;
% Analog frequency
aw1=2*pi*w1/ws
aw2=2*pi*w2/ws
% Prewrapped frequency
pw1 = 2*tan(aw1/2)
pw2 = 2*tan(aw2/2)
%Calculate order and cutoff freq
[n,wc]= buttord (pw1,pw2,rp,rs,'s')
% The order n should match with corresponding theoretical value.
% analog filter transfer
[b,a] = butter(n,wc,'s');
% The b and a values should match with Ha(s)
%obtaining the digital filter using bilinear transformation
```