Experiment No 08

BECS 32461

Paper E

INFINITE IMPULSE RESPONSE (IIR) FILTER DESIGN

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PROCEDURE

F01.

```matlab
alphap = 3;
alphas = 15;
fp = 500;
fs = 750;
f = 2000;

% Normalize the frequencies
omp = 2 * fp / f;
oms = 2 * fs / f;

% Determine the order and cutoff frequency
[N, Wn] = buttord(omp, oms, alphap, alphas);

% Display the order and cutoff frequency
disp('Order of the filter n =');
disp(N);
disp('Cutoff frequency Wn = ');
disp(Wn);

% Design Butterworth low-pass filter
[b, a] = butter(N, Wn, 'low');
% Display the filter coefficients
disp('Filter coefficients b =');
disp(b);
disp('Filter coefficients a =');
disp(a);

w = 0:0.01:pi; % Frequency ranges from 0 to π (normalized)
[h, om] = freqz(b, a, w, 'whole');% The frequency response
m = abs(h);
% Magnitude of the frequency response
an = angle(h); % Phase of the frequency response

[bz,az] = bilinear(b,a,f);

figure;
subplot(2,1,1);
plot(w/pi,mag2db(m),'-b','LineWidth',1);
xlabel('Normalized Frequency');
ylabel('Gain in dB');
title('Butterworth low-pass Filter Frequency Response');
grid on;

subplot(2,1,2);
plot(w/pi,an,'-b','LineWidth',1);
xlabel('Normalized Frequency');
ylabel('Phase in Radians');
title('Butterworth low-pass Filter Phase Response');
grid on;
```
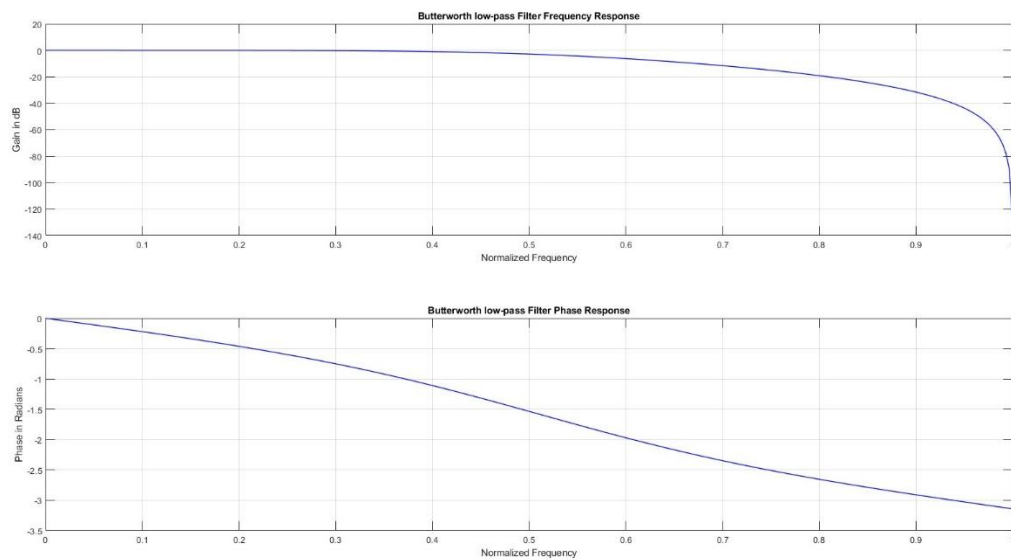
```
>> F01
Order of the filter n =
     2

Cutoff frequency Wn =
    0.5083

Filter coefficients b =
    0.3005    0.6011    0.3005

Filter coefficients a =
    1.0000    0.0304    0.1717

fx >>
```


Butterworth low-pass Filter Frequency Response

Butterworth low-pass Filter Phase Response

FO2.

```matlab
alphap = 3;
alphas = 15;
fp = 500;
fs = 750;
f = 2000;

% Normalize the frequencies
omp = 2 * fp / f;
oms = 2 * fs / f;

% Determine the order and cutoff frequency
[N, Wn] = buttord(omp, oms, alphap, alphas);

% Display the order and cutoff frequency
disp('Order of the filter n =');
```

```matlab
disp(N);
disp('Cutoff frequency Wn = ');
disp(Wn);

% Design Butterworth high-pass filter
[b, a] = butter(N, Wn, 'high');
% Display the filter coefficients
disp('Filter coefficients b =');
disp(b);
disp('Filter coefficients a =');
disp(a);

w = 0:0.01:pi; % Frequency ranges from 0 to π (normalized)
[h, om] = freqz(b, a, w, 'whole');% The frequency response
m = abs(h);
% Magnitude of the frequency response
an = angle(h); % Phase of the frequency response

[bz,az] = bilinear(b,a,f);

figure;
subplot(2,1,1);
plot(w/pi,mag2db(m),'-b','LineWidth',1);
xlabel('Normalized Frequency');
ylabel('Gain in dB');
title('Butterworth low-pass Filter Frequency Response');\
grid on;

subplot(2,1,2);
plot(w/pi,an,'-b','LineWidth',1);
xlabel('Normalized Frequency');
ylabel('Phase in Radians');
title('Butterworth low-pass Filter Phase Response');
grid on;
```

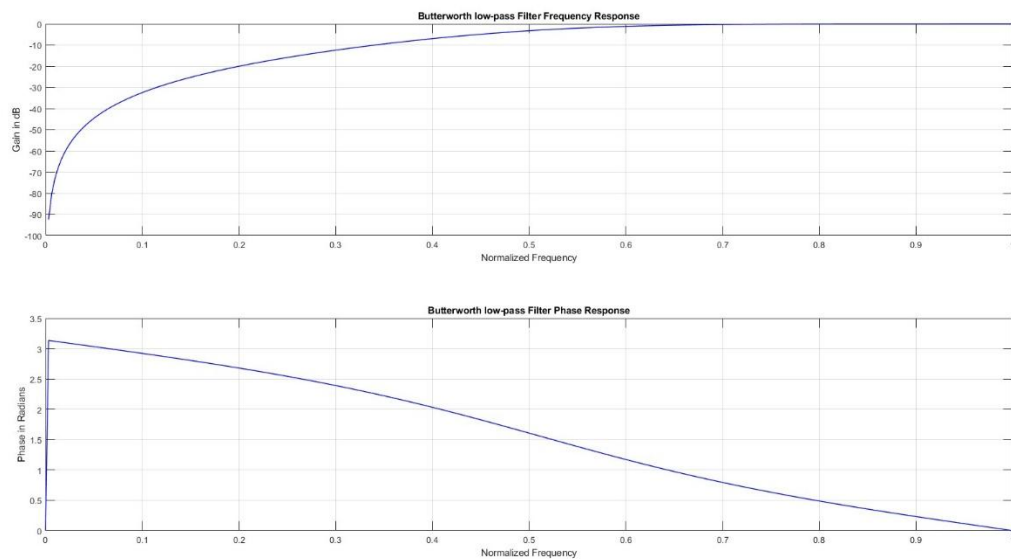```
>> F02
Order of the filter n =
     2

Cutoff frequency Wn =
     0.5083

Filter coefficients b =
     0.2853   -0.5707   0.2853

Filter coefficients a =
     1.0000   0.0304   0.1717

fx >>
```



Butterworth low-pass Filter Frequency Response



Butterworth low-pass Filter Phase Response

## EXERCISE

E01.

```
alphap = 2.5;
alphas = 40;
fp = 500;
fs = 900;
f = 3000;

% Normalize
omp = 2 * fp / f;
oms = 2 * fs / f;
```

```matlab
% Order & cutoff
[N, Wn] = cheb1ord(omp, oms, alphap, alphas);

disp('Order of the filter n =');
disp(N);
disp('Cutoff frequency Wn = ');
disp(Wn);

% Design Chebyshev Type I low-pass
[b, a] = cheby1(N, alphap, Wn, 'low');

disp('Filter coefficients b =');
disp(b);
disp('Filter coefficients a =');
disp(a);

w = 0:0.01:pi;
[h, om] = freqz(b, a, w, 'whole');
m = abs(h);
an = angle(h);

[bz, az] = bilinear(b, a, f);

figure;
subplot(2,1,1);
plot(w/pi, mag2db(m), '-b', 'LineWidth', 1);
xlabel('Normalized Frequency');
ylabel('Gain in dB');
title('Chebyshev Type I Low-pass Filter Frequency Response');
grid on;

subplot(2,1,2);
plot(w/pi, an, '-b', 'LineWidth', 1);
xlabel('Normalized Frequency');
ylabel('Phase in Radians');
title('Chebyshev Type I Low-pass Filter Phase Response');
grid on;
```
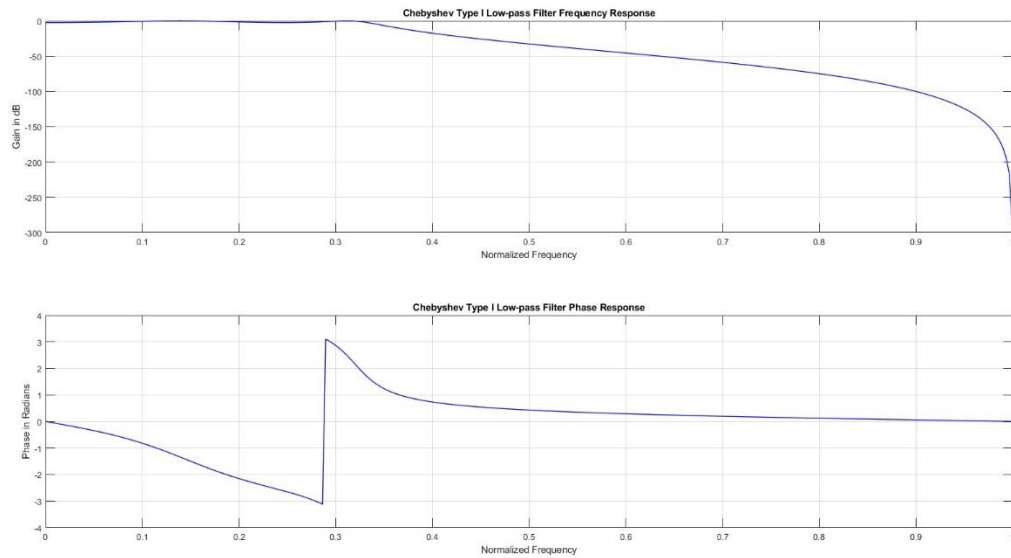
```
>> E01a
Order of the filter n =
     4

Cutoff frequency Wn =
    0.3333

Filter coefficients b =
    0.0084    0.0335    0.0502    0.0335    0.0084

Filter coefficients a =
    1.0000   -2.3833    2.8297   -1.7810    0.5132
```

Chebyshev Type I Low-pass Filter Frequency Response

Chebyshev Type I Low-pass Filter Phase Response

```matlab
alphap = 2.5;
alphas = 40;
fp = 500;
fs = 900;
f = 3000;

% Normalize
omp = 2 * fp / f;
oms = 2 * fs / f;

% Order & cutoff
[N, Wn] = cheb1ord(omp, oms, alphap, alphas);

disp('Order of the filter n =');
disp(N);
disp('Cutoff frequency Wn = ');
disp(Wn);

% Design Chebyshev Type I high-pass
[b, a] = cheby1(N, alphap, Wn, 'high');

disp('Filter coefficients b =');
disp(b);
disp('Filter coefficients a =');
disp(a);

w = 0:0.01:pi;
[h, om] = freqz(b, a, w, 'whole');
m = abs(h);
an = angle(h);

[bz, az] = bilinear(b, a, f);

figure;
```

```matlab
subplot(2,1,1);
plot(w/pi, mag2db(m), '-b', 'LineWidth', 1);
xlabel('Normalized Frequency');
ylabel('Gain in dB');
title('Chebyshev Type I High-pass Filter Frequency Response');
grid on;

subplot(2,1,2);
plot(w/pi, an, '-b', 'LineWidth', 1);
xlabel('Normalized Frequency');
ylabel('Phase in Radians');
title('Chebyshev Type I High-pass Filter Phase Response');
grid on;
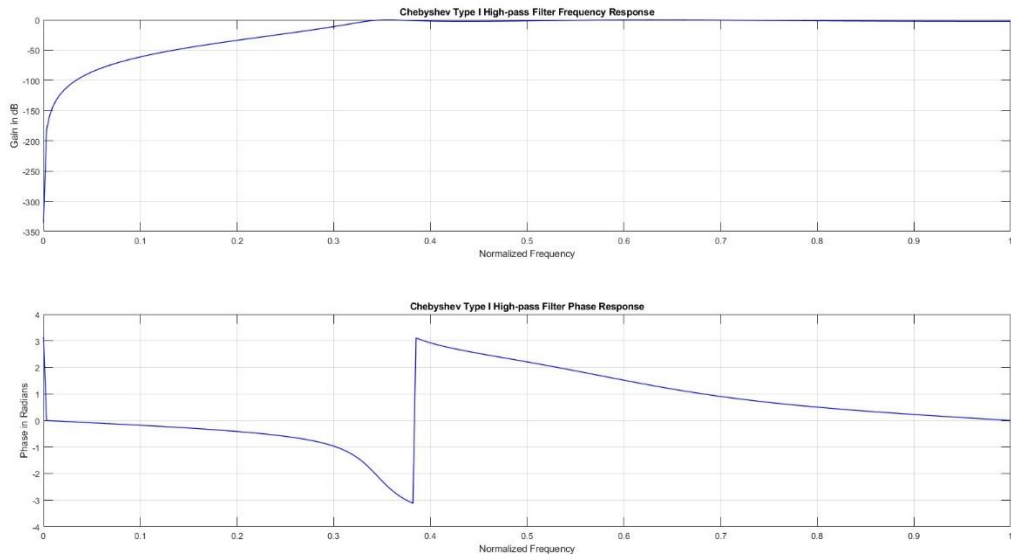```

```
>> E01c
Order of the filter n =
     4

Cutoff frequency Wn =
    0.3333

Filter coefficients b =
    0.1303   -0.5212    0.7818   -0.5212    0.1303

Filter coefficients a =
    1.0000   -0.5408    0.9163   -0.0319    0.2912
```

EO2.

```matlab
alphas = 25;
alphap = 1.2;
fp = 600;
fs = 1000;
f = 5000;

% Normalize
omp = 2 * fp / f;
oms = 2 * fs / f;

% Order & cutoff
[N, Wn] = cheb2ord(omp, oms, alphap, alphas);

disp('Order of the filter n =');
disp(N);
disp('Cutoff frequency Wn = ');
disp(Wn);

% Design Chebyshev Type II low-pass
[b, a] = cheby2(N, alphas, Wn, 'low');

disp('Filter coefficients b =');
disp(b);
disp('Filter coefficients a =');
disp(a);

w = 0:0.01:pi;
[h, om] = freqz(b, a, w, 'whole');
m = abs(h);
an = angle(h);

[bz, az] = bilinear(b, a, f);

figure;
subplot(2,1,1);
plot(w/pi, mag2db(m), '-y', 'LineWidth', 1);
xlabel('Normalized Frequency');
ylabel('Gain in dB');
title('Chebyshev Type II Low-pass Filter Frequency Response');
grid on;

subplot(2,1,2);
plot(w/pi, an, '-b', 'LineWidth', 1);
xlabel('Normalized Frequency');
ylabel('Phase in Radians');
title('Chebyshev Type II Low-pass Filter Phase Response');
grid on;
```
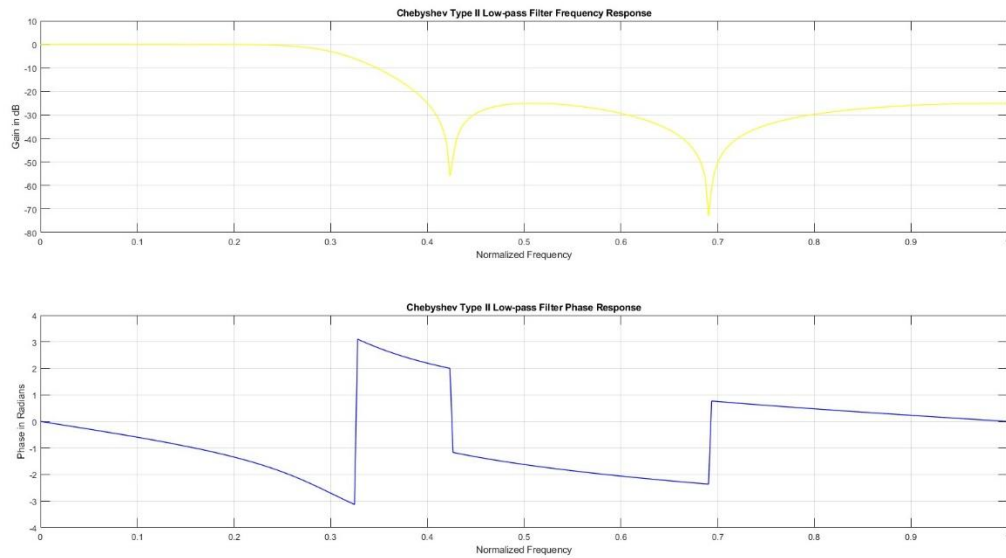
Chebyshev Type II Low-pass Filter Frequency Response

Chebyshev Type II Low-pass Filter Phase Response

```
>> E02a
Order of the filter n =
     4

Cutoff frequency Wn =
    0.4000

Filter coefficients b =
    0.1018    0.0672    0.1494    0.0672    0.1018

Filter coefficients a =
    1.0000   -1.3357    1.1188   -0.3649    0.0693
```

```
alphas = 25;
alphap = 1.2;
fp = 600;
fs = 1000;
f = 5000;

% Normalize
omp = 2 * fp / f;
oms = 2 * fs / f;

% Order & cutoff
[N, Wn] = cheb2ord(omp, oms, alphap, alphas);

disp('Order of the filter n =');
disp(N);
disp('Cutoff frequency Wn = ');
disp(Wn);
```

```matlab
% Design Chebyshev Type II high-pass
[b, a] = cheby2(N, alphas, Wn, 'high');

disp('Filter coefficients b =');
disp(b);
disp('Filter coefficients a =');
disp(a);

w = 0:0.01:pi;
[h, om] = freqz(b, a, w, 'whole');
m = abs(h);
an = angle(h);

[bz, az] = bilinear(b, a, f);

figure;
subplot(2,1,1);
plot(w/pi, mag2db(m), '-g', 'LineWidth', 1);
xlabel('Normalized Frequency');
ylabel('Gain in dB');
title('Chebyshev Type II High-pass Filter Frequency Response');
grid on;

subplot(2,1,2);
plot(w/pi, an, '-r', 'LineWidth', 1);
xlabel('Normalized Frequency');
ylabel('Phase in Radians');
title('Chebyshev Type II High-pass Filter Phase Response');
grid on;
```
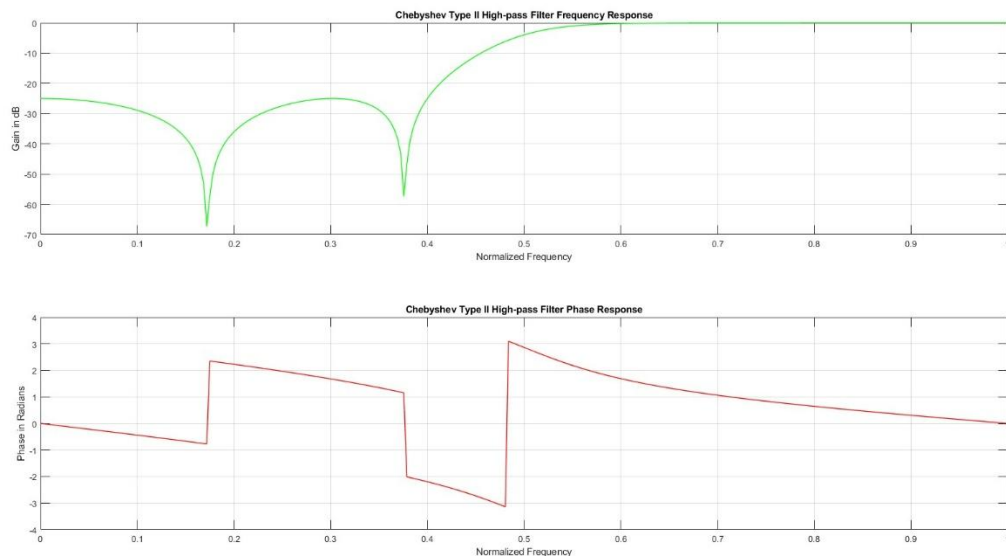
```
>> E02c
Order of the filter n =
      4

Cutoff frequency Wn =
    0.4000

Filter coefficients b =
    0.2044    -0.5049    0.6740    -0.5049    0.2044

Filter coefficients a =
    1.0000    -0.2566    0.6461    -0.1417    0.0483
```

E03.

```
alphap = 1.5;
alphas = 45;

fp1 = 140;
fs1 = 148;
fs2 = 152;
fp2 = 160;

f = 1200;

omp = [2*fp1/f 2*fp2/f];
oms = [2*fs1/f 2*fs2/f];

[N, Wn] = buttord(omp, oms, alphap, alphas);

disp('Order of filter =');
disp(N);
disp('Cutoff frequencies = ');
disp(Wn);

[b, a] = butter(N, Wn, 'stop');

disp('Filter coefficients b ='); disp(b);
disp('Filter coefficients a ='); disp(a);

w = 0:0.01:pi;
[h, om] = freqz(b, a, w, 'whole');
m = abs(h);
an = angle(h);

[bz, az] = bilinear(b, a, f);

figure;
subplot(2,1,1);
plot(w/pi, m, 'y-.', 'LineWidth', 1);
xlabel('Normalized Frequency');
```
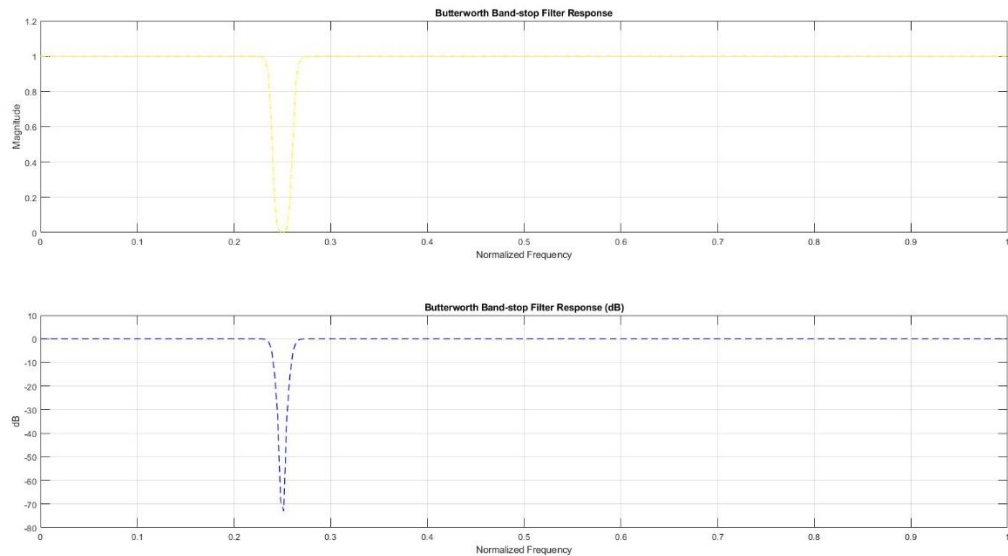
```matlab
ylabel('Magnitude');
title('Butterworth Band-stop Filter Response');
grid on;

subplot(2,1,2);
plot(w/pi, mag2db(m), 'b--', 'LineWidth', 1);
xlabel('Normalized Frequency');
ylabel('dB');
title('Butterworth Band-stop Filter Response (dB)');
grid on;
```



```
>> E03
Order of filter =
     4

Cutoff frequencies =
    0.2380    0.2624

Filter coefficients b =
  Columns 1 through 8

    0.9045    -5.1173    14.4747   -25.5886    30.7598   -25.5886    14.4747    -5.1173

  Column 9

    0.9045

Filter coefficients a =
  Columns 1 through 8

    1.0000    -5.5156    15.2098   -26.2172    30.7325   -24.9343    13.7577    -4.7448

  Column 9

    0.8182
```

EO4.

```matlab
alphap = 1;
alphas = 40;

fp1 = 800;
fp2 = 1800;

fs1 = 500;
fs2 = 2500;

f = 8000;

omp = [2*fp1/f 2*fp2/f];
oms = [2*fs1/f 2*fs2/f];

[N, Wn] = buttord(omp, oms, alphap, alphas);

disp('Order of filter =');
disp(N);
disp('Cutoff frequencies = ');
disp(Wn);

[b, a] = butter(N, Wn, 'bandpass');

disp('Filter coefficients b ='); disp(b);
disp('Filter coefficients a ='); disp(a);

w = 0:0.01:pi;
[h, om] = freqz(b, a, w, 'whole');
m = abs(h);

[bz, az] = bilinear(b, a, f);

figure;
plot(w/pi, mag2db(m), 'y', 'LineWidth', 1);
xlabel('Normalized Frequency');
ylabel('Gain in dB');
title('Butterworth Band-pass Filter Response');
grid on;

% Generate sonar signal
t = 0:1/f:1;
x = sin(2*pi*300*t) + sin(2*pi*1200*t) + sin(2*pi*3000*t);

% Filter the signal
y = filter(b, a, x);

figure;
subplot(2,1,1);
plot(t, x, 'b');
xlabel('Time (s)');
ylabel('Amplitude');
title('Original Sonar Signal');
grid on;
```
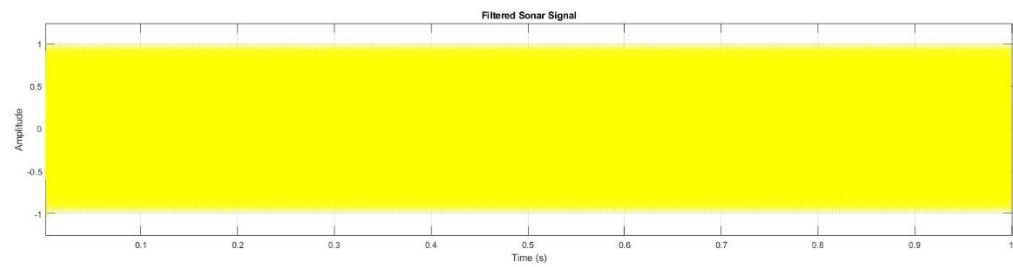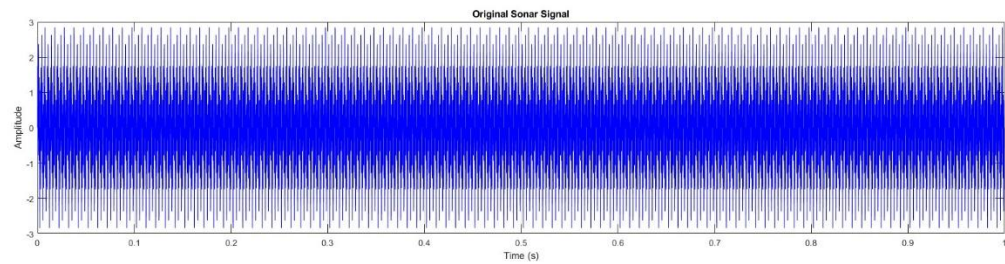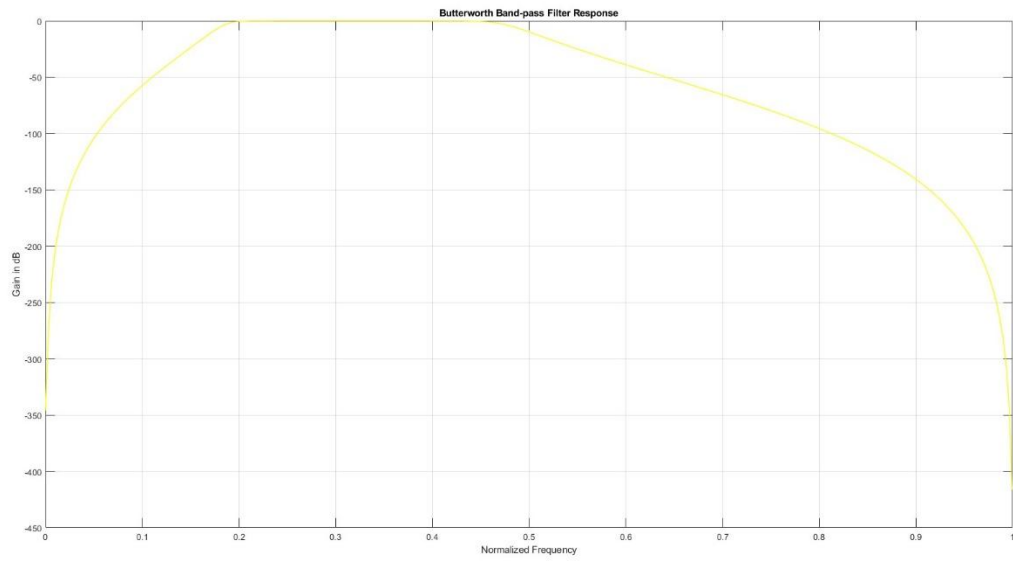
```matlab
subplot(2,1,2);
plot(t, y, 'y');
xlabel('Time (s)');
ylabel('Amplitude');
title('Filtered Sonar Signal');
grid on;
```


Butterworth Band-pass Filter Response

Original Sonar Signal

Filtered Sonar Signal

```
>> E04
Order of filter =
      7

Cutoff frequencies =
    0.1863    0.4738

Filter coefficients b =
  Columns 1 through 8

    0.0008         0   -0.0053         0    0.0158         0   -0.0264         0

  Columns 9 through 15

    0.0264         0   -0.0158         0    0.0053         0   -0.0008

Filter coefficients a =
  Columns 1 through 8

    1.0000   -5.6314   16.7459  -33.9753   52.1221  -63.4165   62.7735  -51.1516

  Columns 9 through 15

   34.4312  -19.0441    8.5385   -3.0200    0.8039   -0.1459    0.0143
```


Original Sonar Signal

Filtered Sonar Signal