CHAPTER 11

Design of IIR Filters

Tutorial Problems

1. (a) Solution:
   The frequency response is:

$$H\left(e^{j\omega}\right) = H(z)|_{z=e^{j\omega}} = \frac{e^{j\omega}}{(e^{j\omega}-0.8)(1-0.8e^{j\omega})} = \frac{1}{1.64-1.6\cos\omega}$$

   (b) Solution:
   Apply partial fraction expansion to system function:

$$H(z) = \frac{-1.25z^{-1}}{(1-0.8^{-1})(1-1.25z^{-1})} = \frac{25/9}{1-0.8z^{-1}} + \frac{-25/9}{1-1.25z^{-1}}$$

   where $0.8 \leq |z| \leq 1.25$, hence the impulse response is:

$$h[n] = \frac{25}{9}\cdot 0.8^n u[n] + \frac{25}{9}\cdot 1.25^n u[-n-1] = \frac{25}{9}\cdot 0.8^{|n|}$$

   (c) See plot below.
   MATLAB script:

```
% P1101: Illustration of usage of function 'filtfilt'
close all; clc
N = 30;
n = -N:N;
% Analytical Result:
hn1 = zeros(size(n));
ind = n >= 0;
hn1(ind) = 25/9*0.8.^n(ind);
ind = n < 0;
```

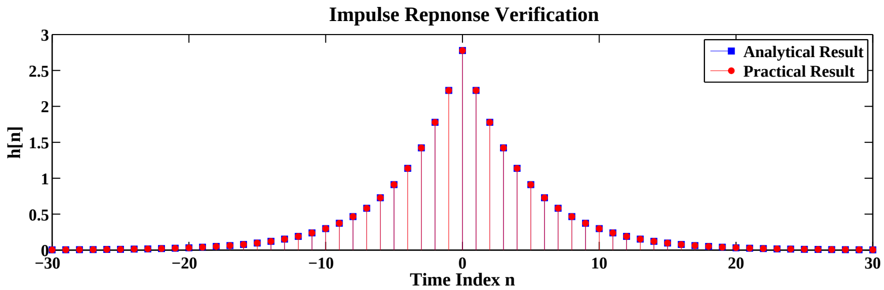

FIGURE 11.1: MATLAB verification of the impulse response of the filter using the `filtfilt` function.

```
hn1(ind) = 25/9*1.25.^n(ind);
% Practical Result:
deltan = zeros(size(n)); deltan(ceil(length(n)/2)) = 1;
b = [0 1];
a = [1 -0.8];
hn2 = filtfilt(b,a,deltan);
%% plot
hfa = figconfg('P1101a','long');
stem(n,hn1,'filled','marker','s','markersize',8); hold on
stem(n,hn2,'r','filled')
xlabel('Time Index n','fontsize',LFS)
ylabel('h[n]','fontsize',LFS)
title('Impulse Repnonse Verification','fontsize',TFS)
legend('Analytical Result','Practical Result','location','northeast')
```

2. (a) Solution:
   Pole locations of $H_c(s)$: $s_k = \sigma_k + j\Omega_s$, that is

$$\begin{cases} \sigma_k = \Omega_c \cos\theta_k, \\ \Omega_k = \Omega_c \sin\theta_k. \end{cases} \quad \text{where } \theta_k = \frac{\pi}{2} + \frac{2k-1}{2N}\pi, k = 1, 2, \ldots, 2N$$

   $\Omega_c = 40\pi$ rad/s, $N = 7$.

   (b) See plot below.

   (c) Solution:
   The frequencies are 27.77, 32.76, and 38.61 rad/s at which the attenuation is 20 dB, 30 dB, and 40 dB.

MATLAB script:

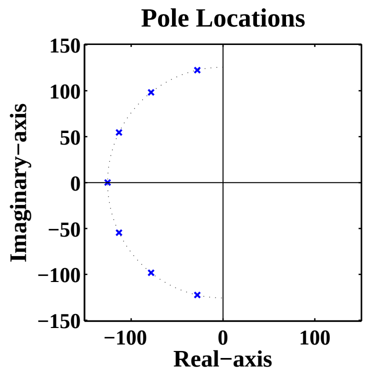

FIGURE 11.2: Pole locations of $H_c(s)$

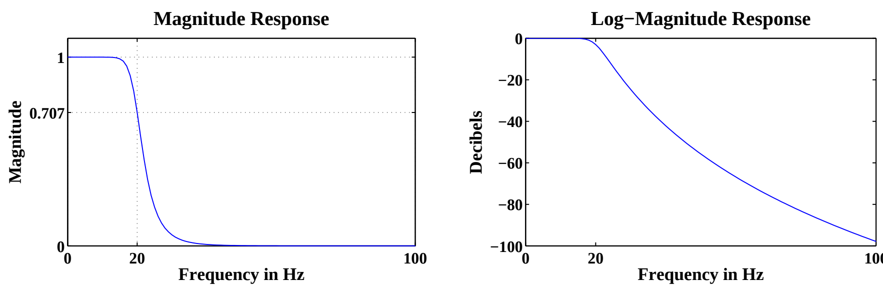

FIGURE 11.3: Magnitude and log-magnitude responses over $[0, 100]$ Hz range.

```
% P1102: Seventh order Butterworth low-pass filter
close all; clc
N = 7;
% Determine cutoff frequency
Hc = 20;
Omegac = Hc*2*pi;
% Determine zero locations
k = 1:N; thetak = pi/2+(2*k-1)*pi/2/N;
sigmak = Omegac*cos(thetak); Omegak = Omegac*sin(thetak);
sk = cplxpair(sigmak + 1j*Omegak);
% Compute system function
C = Omegac^N;
D = real(poly(sk));
Fmax = 100;
F = linspace(0,Fmax,101);
Om = F*2*pi;
```

```
H = freqs(C,D,F*2*pi);
Hmag = abs(H); Hpha = angle(H);
Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];
% Part c:
A = [3 20 30 40];
delta = (10.^(-A/20)).^2;
disp('Frequencies where attenuation is 3db, 20db, 30db, 40db')
F3 = (1./delta-1).^(1/2/N)*Hc,
%% Plot:
hfa = figconfg('P1102a','small');
plot(sigmak,Omegak,'bx','linewidth',1.5); hold on;
ff = 1.2; pc = ff*Omegac;
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
plot(Omegac*cos(0.5*pi*[1:0.01:3]),Omegac*sin(0.5*pi*[1:0.01:3]),'k:');
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfb = figconfg('P1102b','small');
plot(F,Hmag,'b','linewidth',1);
axis([0,Fmax,0,1.1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Hc,Fmax]);
set(gca,'ytick',[0,0.707,1]); grid;

hfc = figconfg('P1102c','small');
plot(F,Hdb,'b','linewidth',1);
axis([0,Fmax,-100,0]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Hc,Fmax]);
```

3. See plot below.

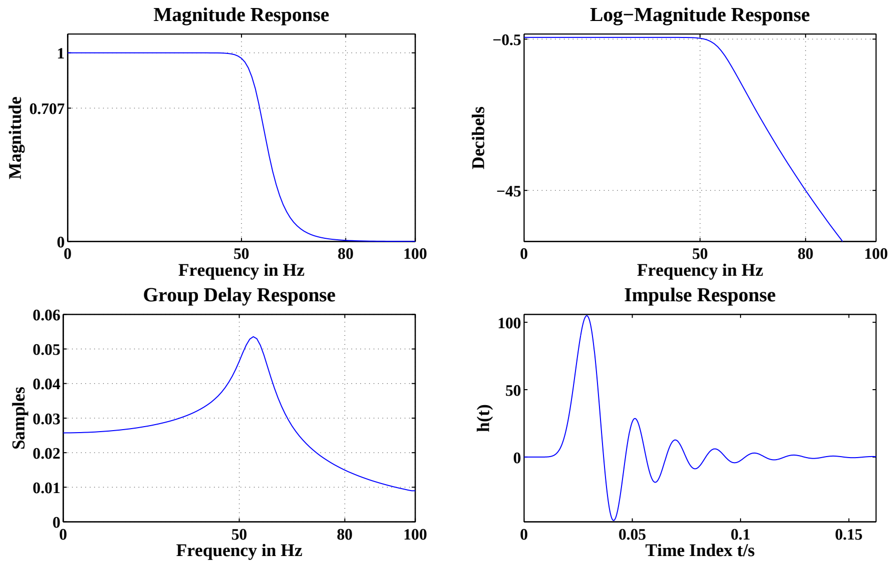

FIGURE 11.4: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

MATLAB script:

```
% P1103: Analog Butterworth lowpass filter design
clc; close all;
% Given Design Parameters
Fp = 50; Fs = 80; Ap = 0.5; As = 45;
Omegap = Fp*2*pi; Omegas = Fs*2*pi;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1);
A = 10^(0.05*As);
%% Design Steps
% Step-1: Calulation of N
alpha = Omegas/Omegap;
beta = (1/epsilon)*sqrt(A^2-1);
N = log(beta)/log(alpha);
N = ceil(N);
% Step-2: Calculation of Omegac
OmegacL = Omegap/(10^(0.1*Ap)-1)^(1/(2*N));
OmegacH = Omegas/(10^(0.1*As)-1)^(1/(2*N));
```

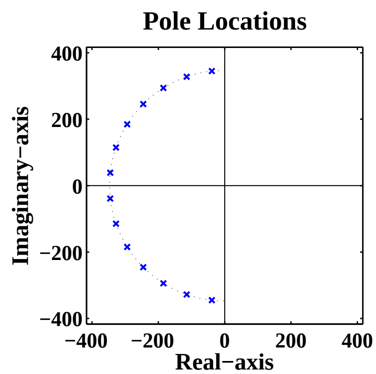

FIGURE 11.5: Pole-zero plot of the filter

```
Omegac = OmegacH;
Fc = Omegac/2/pi;
% Step-3: Calculations of Poles
k = 1:N; thetak = pi/2+(2*k-1)*pi/(2*N);
sigmak = Omegac*cos(thetak); Omegak = Omegac*sin(thetak);
sk = cplxpair(sigmak + 1j*Omegak);
% Step-4: Calculation of the system function
C = Omegac^N; D = real(poly(sk)); % Direct Form

% Design using SP Toolbox functions
% [N, Wn] = buttord(Omegap, Omegas, Ap, As, 's');
% [C,D] = butter(N,Wn,'s')

Fmax = 100;
F = linspace(0,Fmax,101);
Om = F*2*pi;
H = freqs(C,D,Om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];

% Impulse response:
trsys = tf(C,D);
[ht t] = impulse(trsys);

%% Design Plots
hfa = figconfg('P1103a','small'); % magnitude
```

```
plot(F,Hmag,'b','linewidth',1);
axis([0,Fmax,0,1.1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[0,0.707,1]); grid;

hfb = figconfg('P1103b','small'); % Log-Magnitude Plot in dB
plot(F,Hdb,'b','linewidth',1);
axis([0,Fmax,-60,1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[-As,-Ap]);grid

hfc = figconfg('P1103c','small'); % Group-Delay Plot in Samples
plot(F,Hgdl,'b','linewidth',1);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]); grid

hfd = figconfg('P1103d','small'); % Pole-zero Plot
plot(sigmak,Omegak,'bx','linewidth',1.5); hold on;
ff = 1.2; pc = ff*Omegac;
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
plot(Omegac*cos(0.5*pi*[1:0.01:3]),Omegac*sin(0.5*pi*[1:0.01:3]),'k:');
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfe = figconfg('P1103e','small'); % Impulse response
plot(t,ht,'linewidth',1)
axis([t(1) t(end) min(ht)-1 max(ht)+1])
xlabel('Time Index t/s','fontsize',LFS);
```

```
ylabel('h(t)','fontsize',LFS);
title('Impulse Response','fontsize',TFS);
```

4. Proof:
Repeat the definition of Chebyshev polynomial as below:

$$T_0(x) = 1, \quad T_1(x) = x, \quad T_{m+1}(x) = 2xT_m(x) - T_{m-1}(x),\ m > 1$$

Repeat $T_N(x)$ given by hyperbolic functions (11.29) as:

$$T_N(x) = \cosh(N \cosh^{-1} x), \quad |x| > 1$$

$$\cosh(x) \triangleq \frac{1}{2}(\mathrm{e}^x + \mathrm{e}^{-x}), \quad \cosh^{-1}(x) = \ln(x + \sqrt{x^2 - 1}) \qquad (11.29a)$$

$$\sinh(x) \triangleq \frac{1}{2}(\mathrm{e}^x - \mathrm{e}^{-x}), \quad \sinh^{-1}(x) = \ln(x + \sqrt{x^2 + 1}) \qquad (11.29b)$$

If $m = 0$, we have

$$T_0(x) = \cosh(0 \cdot \cosh^{-1} x) = \frac{1}{2}(\mathrm{e}^0 + \mathrm{e}{-}0) = 1.$$

If $m = 1$, we have

$$T_1(x) = \cosh(\cosh^{-1)x} = x.$$

If $m > 1$, we have

$$T_{m+1}(x) = \cosh[(m{+}1)\cosh^{-1} x] = x{\cdot}\cosh(m \cosh^{-1} x){+}\sinh(m \cosh^{-1} x)\sinh(\cosh^{-1} x)$$

$$T_{m-1}(x) = \cosh[(m{-}1)\cosh^{-1} x] = x{\cdot}\cosh(m \cosh^{-1} x){-}\sinh(m \cosh^{-1} x)\sinh(\cosh^{-1} x)$$

Hence,

$$T_{m+1}(x) + T_{m-1}(x) = 2x \cdot \cosh(m \cosh^{-1} x) = 2xT_m(x)$$

5. See plot below.

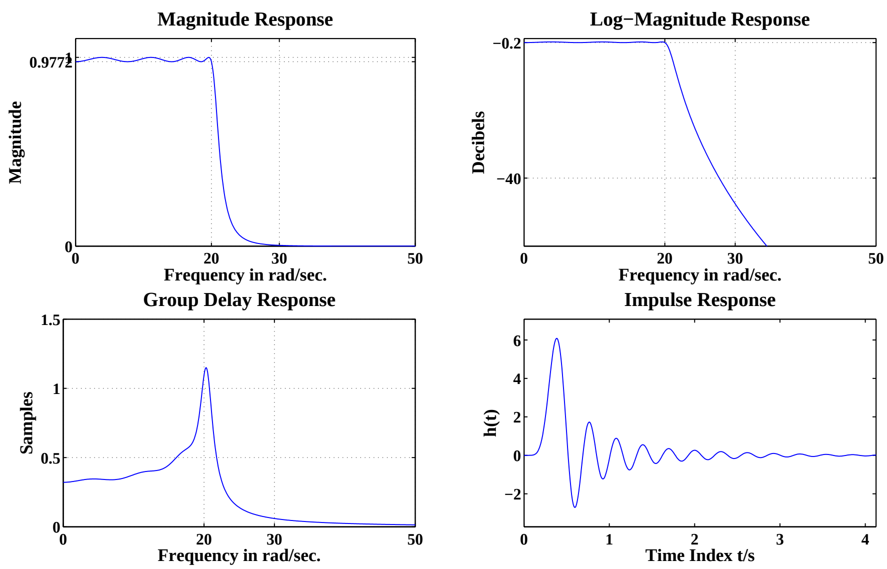

FIGURE 11.6: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

MATLAB script:

```
% P1105: Analog Chebyshev I lowpass filter design
clc; close all;
% Given Design Parameters
Omegap = 20; Omegas = 30; Ap = 0.2; As = 40;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);

%% Design Steps
% Step-1: Compute alpha and beta
alpha = Omegas/Omegap; beta = (1/epsilon)*sqrt(A^2-1);
% Step-2: Calulation of N
N = log(beta+sqrt(beta^2-1))/log(alpha+sqrt(alpha^2-1));
N = ceil(N);
% Step-3: Calculation of a and b
Omegac = Omegap;
gamma = (1/epsilon+sqrt(1+1/epsilon^2))^(1/N);
```

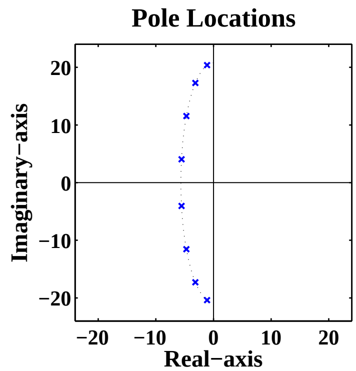

FIGURE 11.7: Pole-zero plot of the filter

```
a = 0.5*(gamma-1/gamma); b = 0.5*(gamma+1/gamma);
% Step-4: Calculations of Poles
k = 1:N; thetak = pi/2+(2*k-1)*pi/(2*N);
sigmak = (a*Omegac)*cos(thetak); Omegak = (b*Omegac)*sin(thetak);
sk = cplxpair(sigmak + 1j*Omegak);
% Step-5: Calculation of the system function
D = real(poly(sk)); % Direct Form
if mod(N,2) == 0
    G = D(end)*Rp; %1/sqrt(1+epsilon^2);
else
    G = D(end);
end
C = G;

%% Design using SP Toolbox functions
% [N, Wp] = cheb1ord(Omegap, Omegas, Ap, As, 's');
% [c,d] = cheby1(N,Ap, Wp,'s');

%% Frequency Response
Ommax = 50;
Om = linspace(0,Ommax,501);
H = freqs(C,D,Om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];

% Impulse response:
```

```
trsys = tf(C,D);
[ht t] = impulse(trsys);

%% Design Plots
hfa = figconfg('P1105a','small'); % magnitude
plot(Om,Hmag,'b','linewidth',1);
axis([0,Ommax,0,1.1]);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Omegac,Omegas,Ommax]);
set(gca,'ytick',[0,Rp,1]); grid;

hfb = figconfg('P1105b','small'); % Log-Magnitude Plot in dB
plot(Om,Hdb,'b','linewidth',1);
axis([0,Ommax,-60,1]);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]);
set(gca,'ytick',[-As,-Ap]);grid

hfc = figconfg('P1105c','small'); % Group-Delay Plot in Samples
plot(Om,Hgdl,'b','linewidth',1);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]); grid

hfd = figconfg('P1105d','small'); % Pole-zero Plot
plot(sigmak,Omegak,'bx','linewidth',1.5); hold on;
ff = 1.2; pc = ff*Omegac;
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
plot(a*Omegac*cos(0.5*pi*[1:0.01:3]),b*Omegac*sin(0.5*pi*[1:0.01:3]),'k:');
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);
```

```
hfe = figconfg('P1105e','small'); % Impulse response
plot(t,ht,'linewidth',1)
axis([t(1) t(end) min(ht)-1 max(ht)+1])
xlabel('Time Index t/s','fontsize',LFS);
ylabel('h(t)','fontsize',LFS);
title('Impulse Response','fontsize',TFS);
```

6. See plot below.

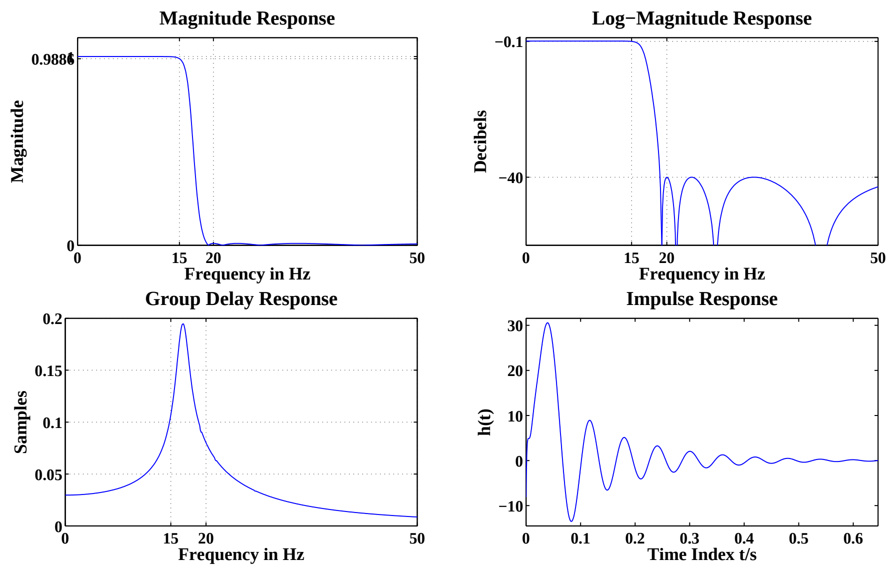

FIGURE 11.8: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

MATLAB script:

```
% P1106: Analog Chebyshev II lowpass filter design
clc; close all;
% Given Design Parameters
Fp = 15; Fs = 20; Ap = 0.1; As = 40;
Omegap = 2*pi*Fp; Omegas = 2*pi*Fs;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
```

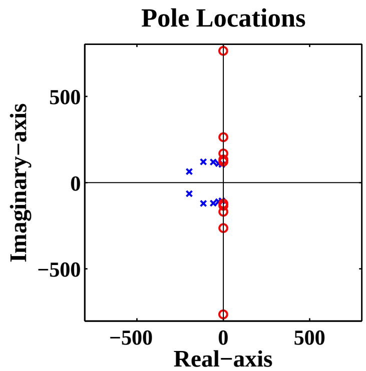

FIGURE 11.9: Pole-zero plot of the filter

```
% Plotting Parameters
Fmax = 50; Ommax = 2*pi*Fmax;
F = linspace(0,Fmax,501); Om = 2*pi*F;

% Chebyshev-II Approximation
disp('** Chebyshev-II **');
[N, Omegac] = cheb2ord(Omegap, Omegas, Ap, As, 's');
Fc = Omegac/(2*pi);
[C,D] = cheby2(N,As,Omegac,'s'); H = freqs(C,D,Om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
pk = roots(D); sigmapk = real(pk); Omegapk = imag(pk);
zk = roots(C); sigmazk = real(zk); Omegazk = imag(zk);

%% Impulse response:
trsys = tf(C,D);
[ht t] = impulse(trsys);

%% Design Plots
hfa = figconfg('P1106a','small'); % magnitude
plot(F,Hmag,'b','linewidth',1);
axis([0,Fmax,0,1.1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
```

```
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[0,Rp,1]); grid;

hfb = figconfg('P1106b','small'); % Log-Magnitude Plot in dB
plot(F,Hdb,'b','linewidth',1);
axis([0,Fmax,-60,1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[-As,-Ap]);grid

hfc = figconfg('P1106c','small'); % Group-Delay Plot in Samples
plot(F,Hgdl,'b','linewidth',1);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]); grid

hfd = figconfg('P1106d','small'); % Pole-zero Plot
plot(sigmapk,Omegapk,'bx','linewidth',1.5); hold on;
plot(sigmazk,Omegazk,'ro','linewidth',1.5);
ff = 1.05; pc = ff*max(abs([pk(:);zk(:)]));
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfe = figconfg('P1106e','small');  % Impulse response
plot(t,ht,'linewidth',1)
axis([t(1) t(end) min(ht)-1 max(ht)+1])
xlabel('Time Index t/s','fontsize',LFS);
ylabel('h(t)','fontsize',LFS);
title('Impulse Response','fontsize',TFS);
```

7. See plot below.

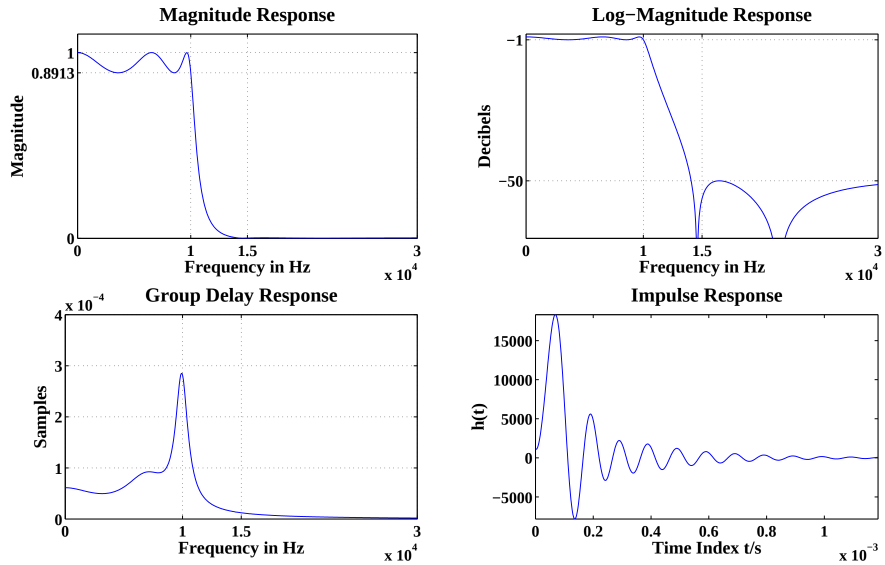

FIGURE 11.10: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

MATLAB script:

```
% P1107: Analog Elliptic low-pass filter design
clc; close all; %echo on;
% Given Design Parameters
Fp = 10e3; Fs = 15e3; Ap = 1; As = 50;
Omegap = 2*pi*Fp; Omegas = 2*pi*Fs;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
% Plotting Parameters
Fmax = 30e3; Ommax = 2*pi*Fmax;
F = linspace(0,Fmax,501); Om = 2*pi*F;
% Elliptic Approximation
disp('** Elliptic **');
[N, Omegac] = ellipord(Omegap, Omegas, Ap, As, 's');
[C,D] = ellip(N,Ap,As,Omegac,'s'); H = freqs(C,D,Om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];
```

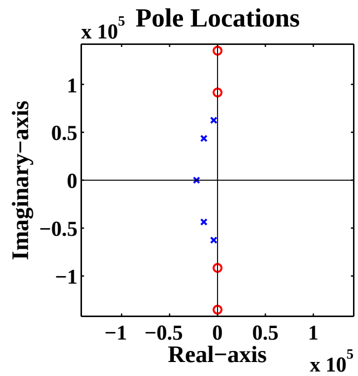

FIGURE 11.11: Pole-zero plot of the filter

```
Hgdl = medfilt1(Hgdl,3);
pk = roots(D); sigmapk = real(pk); Omegapk = imag(pk);
zk = roots(C); sigmazk = real(zk); Omegazk = imag(zk);

%% Impulse response:
trsys = tf(C,D);
[ht t] = impulse(trsys);

%% Design Plots
hfa = figconfg('P1107a','small'); % magnitude
plot(F,Hmag,'b','linewidth',1);
axis([0,Fmax,0,1.1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[0,Rp,1]); grid;

hfb = figconfg('P1107b','small'); % Log-Magnitude Plot in dB
plot(F,Hdb,'b','linewidth',1);
axis([0,Fmax,-70,1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[-As,-Ap]);grid
```

```
hfc = figconfg('P1107c','small'); % Group-Delay Plot in Samples
plot(F,Hgdl,'b','linewidth',1);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]); grid

hfd = figconfg('P1107d','small'); % Pole-zero Plot
plot(sigmapk,Omegapk,'bx','linewidth',1.5); hold on;
plot(sigmazk,Omegazk,'ro','linewidth',1.5);
ff = 1.05; pc = ff*max(abs([pk(:);zk(:)]));
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfe = figconfg('P1107e','small');  % Impulse response
plot(t,ht,'linewidth',1)
axis([t(1) t(end) min(ht)-1 max(ht)+1])
xlabel('Time Index t/s','fontsize',LFS);
ylabel('h(t)','fontsize',LFS);
title('Impulse Response','fontsize',TFS);
```

8. See plot below.

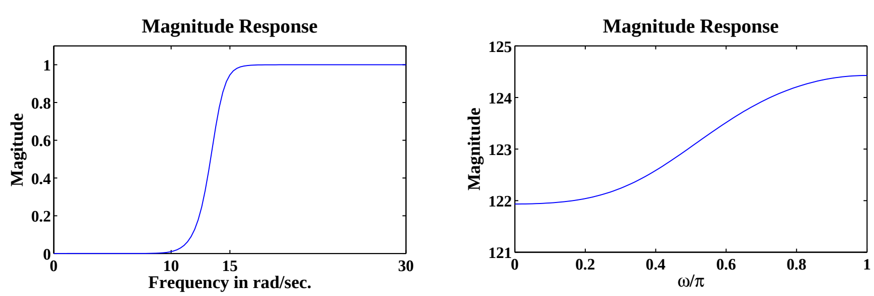

FIGURE 11.12: Plots of magnitude of analog and digital filters.

MATLAB script:

```
% P1108: High-pass analog filter by butterworth and transformation
%        using impulse invariance method
clc; close all;
%% Part a: Analog highpass filter design
Omegas = 10; Omegap = 15; As = 40; Ap = 1;
[N,Wn] = buttord(Omegap,Omegas,Ap,As,'s');
[b,a] = butter(N,Wn,'high','s');
Ommax = 30; Om = linspace(0,Ommax,101);
H = freqs(b,a,Om);
Hmag = abs(H); Hdb = 20*log10(Hmag);
%% Part b: Impulse-invariance transformation
Td = 1;
[B,A] = impinvar(b,a,1/Td);
w = linspace(0,1,101)*pi;
Hd = freqz(B,A,w);
Hdmag = abs(Hd); Hddb = 20*log10(Hdmag./max(Hdmag));

%% Design Plots
hfa = figconfg('P1108a','small'); % Magnitude Plot in dB
plot(Om,Hmag,'b','linewidth',1);
axis([0,Ommax,0,1.1]);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Magitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Omegas,Omegap,Ommax]);

hfb = figconfg('P1108b','small'); % Magnitude Plot in dB
plot(w/pi,Hdmag,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
```

9. (a) See plot below.

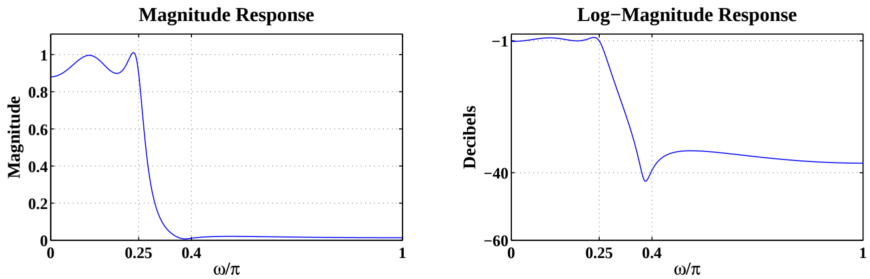

FIGURE 11.13: Plots of magnitude of analog and digital filters.

(b) See plot below.

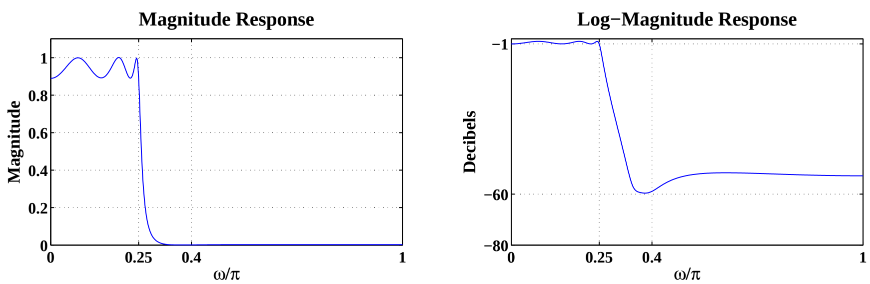

FIGURE 11.14: Plots of magnitude of analog and digital filters.

MATLAB script:

```
% P1109: Low-pass analog filter by elliptic and transformation
%         using impulse invariance method
clc; close all;
wp = 0.25*pi; ws = 0.4*pi; Ap = 1;
% As = 40; % part a
As = 60; % part b
Td = 1;
[N,Omegac] = ellipord(wp/Td,ws/Td,Ap,As,'s');
[b,a] = ellip(N,Ap,As,Omegac,'s');
[B,A] = impinvar(b,a,1/Td);
w = linspace(0,1,501)*pi;
Hd = freqz(B,A,w);
Hdmag = abs(Hd); Hddb = 20*log10(Hdmag./max(Hdmag));
```

```
%% Design Plots
hfa = figconfg('P1109a','small'); % Magnitude Plot
plot(w/pi,Hdmag,'b','linewidth',1);
axis([0,1,0,max(Hdmag)+0.1]);
set(gca,'xtick',[0 wp/pi ws/pi 1]); grid
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);

hfb = figconfg('P1109b','small'); % Log-Magnitude Plot in dB
plot(w/pi,Hddb,'b','linewidth',1);
axis([0,1,-As-20,1]);
set(gca,'ytick',[-As-20,-As,-Ap])
set(gca,'xtick',[0 wp/pi ws/pi 1]); grid
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
```

10. (a) See plot below.
    (b) See plot below.
    (c) See plot below.
    (d) tba.

    MATLAB script:

```
% P1110: Low-pass analog filter by butterworth and transformation
%        using impulse invariance method
clc; close all;
% Given Design Parameters
omegap = 0.25*pi; omegas = 0.4*pi; Ap = 1; As = 50;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
% Td = 1; % part a
% Td = 0.1; % part b
Td = 0.01; % part c
% Step-2: Compute Analog Edge Frequencies
```

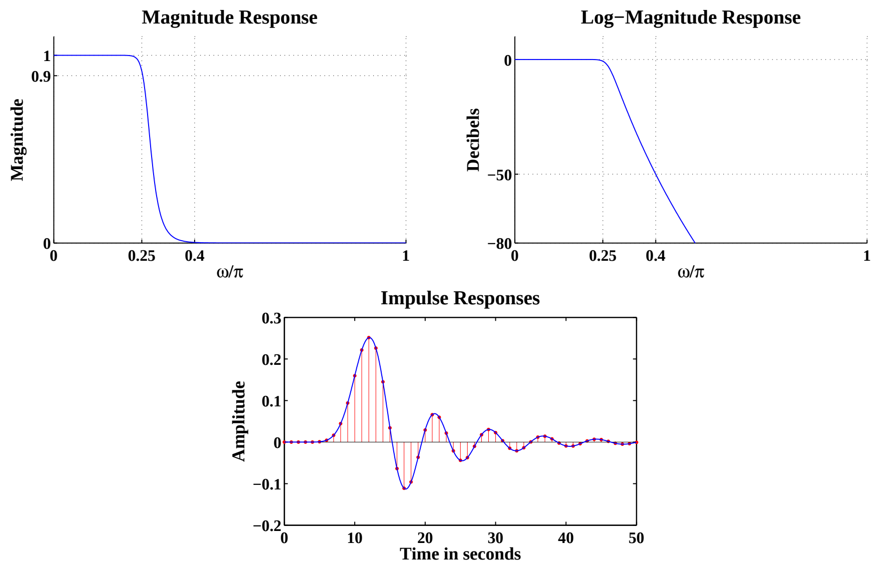

FIGURE 11.15: Plots of the magnitude, log-magnitude and impulse response of the digital filter superimposed on the impulse response of the analog prototype filter when $T_{\mathrm{d}} = 1$ sec..

```
Omegap = omegap/Td; Omegas = omegas/Td;
% Step-3: Design Analog Butterworth Approximation
[N,Omegac] = buttord(Omegap,Omegas,Ap,As,'s');
[C,D] = butter(N,Omegac,'s');
% Step-4: Obtain Digital Butterworth Filter
[B,A] = impinvar(C,D,1/Td);

% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);

%% Design Plots
hfa = figconfg('P1110a','small'); % magnitude
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
```

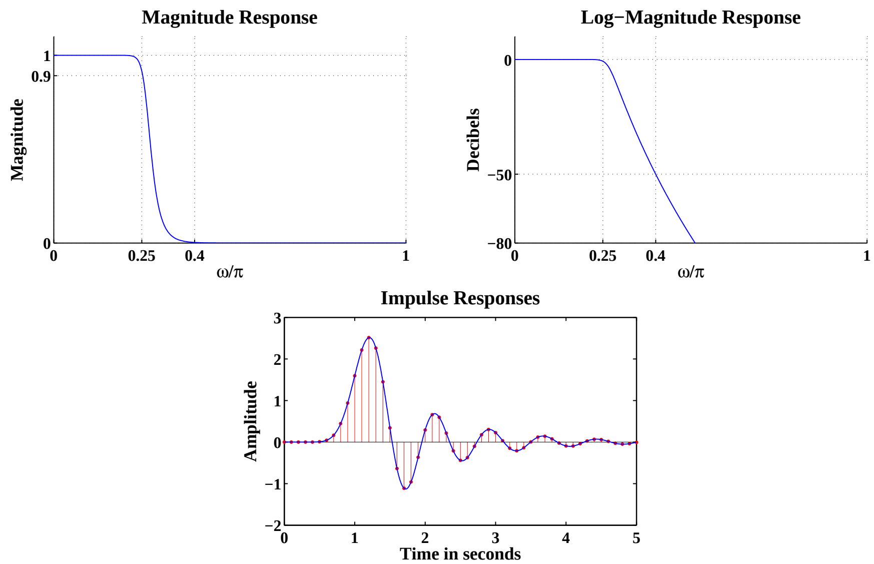

FIGURE 11.16: Plots of the magnitude, log-magnitude and impulse response of the digital filter superimposed on the impulse response of the analog prototype filter $T_{\mathrm{d}} = 0.1$ sec..

```
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[0,Rp,1],'yticklabel','0|0.9|1');
grid; box off;

hfb = figconfg('P1110b','small'); % Log-Magnitude Plot in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,0]); grid; box off;

hfc = figconfg('P1110c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
```

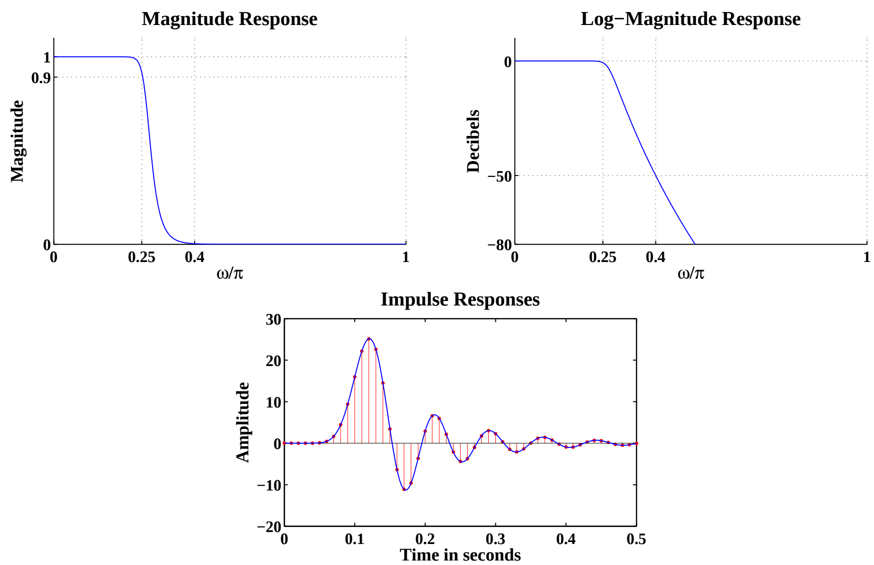

FIGURE 11.17: Plots of the magnitude, log-magnitude and impulse response of the digital filter superimposed on the impulse response of the analog prototype filter $T_{\text{d}} = 0.01$ sec..

```
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1110d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

11. See plot below.

    MATLAB script:

```
% P1111: Low-pass analog filter by Chebyshev I and transformation
%        using impulse invariance method
clc; close all;
% Given Design Parameters
omegap = 0.25*pi; omegas = 0.35*pi; Ap = 1; As = 50;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
```

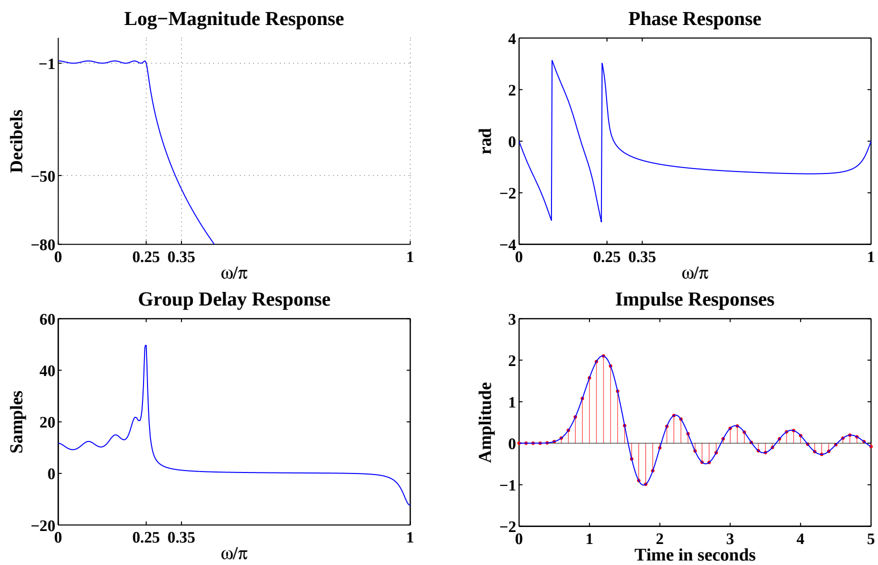

FIGURE 11.18: Plots of log-magnitude, phase, group, and impulse responses.

```
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
Td = 0.1;
% Step-2: Compute Analog Edge Frequencies
Omegap = omegap/Td; Omegas = omegas/Td;
% Step-3: Design Analog Chebyshev I Approximation
[N,Omegac] = cheb1ord(Omegap,Omegas,Ap,As,'s');
[C,D] = cheby1(N,Ap,Omegac,'s');
% Step-4: Obtain Digital Chebyshev I Filter
[B,A] = impinvar(C,D,1/Td);

% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);

%% Design Plots
```

```
hfa = figconfg('P1111a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1111b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1111c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1111d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

12. See plot below.

    MATLAB script:

```
% P1112: Lowpass filter design by Butterworth and tranformation
%        using bilinear method
clc; close all;
% Given Design Parameters
omegap = 0.25*pi; omegas = 0.35*pi; Ap = 1; As = 50;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
```

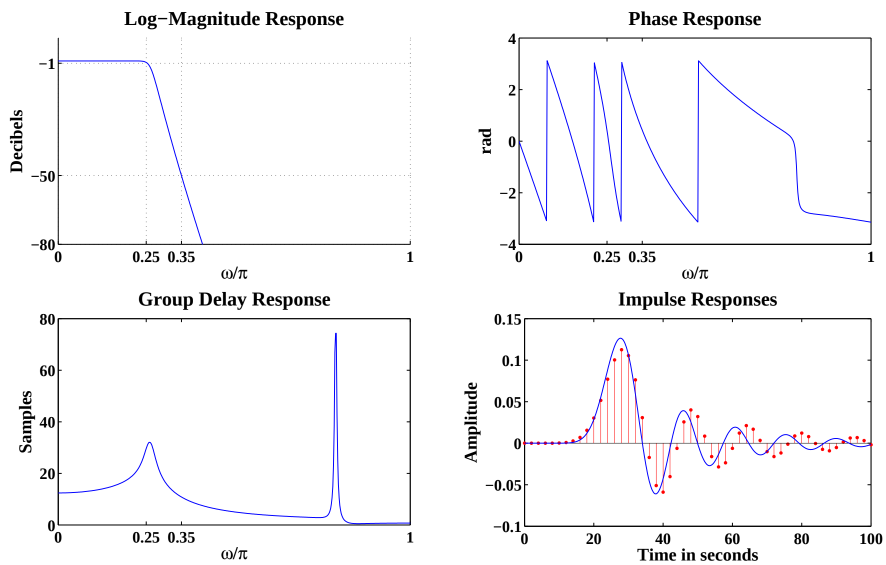

FIGURE 11.19: Plots of log-magnitude, phase, group, and impulse responses.

```
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
Td = 2;
% Step-2: Compute Analog Edge Frequencies
Omegap = 2/Td*tan(omegap/2); Omegas = 2/Td*tan(omegas/2);
% Step-3: Design Analog Butterworth Approximation
[N,Omegac] = buttord(Omegap,Omegas,Ap,As,'s');
[C,D] = butter(N,Omegac,'s');
% Step-4: Obtain Digital Butterworth Filter
[B,A] = bilinear(C,D,1/Td);
% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);
% Exact Frequency:
ind = find(Hdb < -Ap,1,'first'); om1 = om(ind)/pi; % Exact Passband Edge
ind = find(Hdb < -As,1,'first'); om2 = om(ind)/pi; % Exact Stopband Edge
%% Design Plots
```

```
hfa = figconfg('P1112a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1112b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1112c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1112d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

13. See plot below.

    MATLAB script:

```
% P1113: Lowpass filter design by Chebyshev I and tranformation
%        using bilinear method
clc; close all;
% Given Design Parameters
omegap = 0.2*pi; omegas = 0.3*pi; Ap = 1; As = 60;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
```

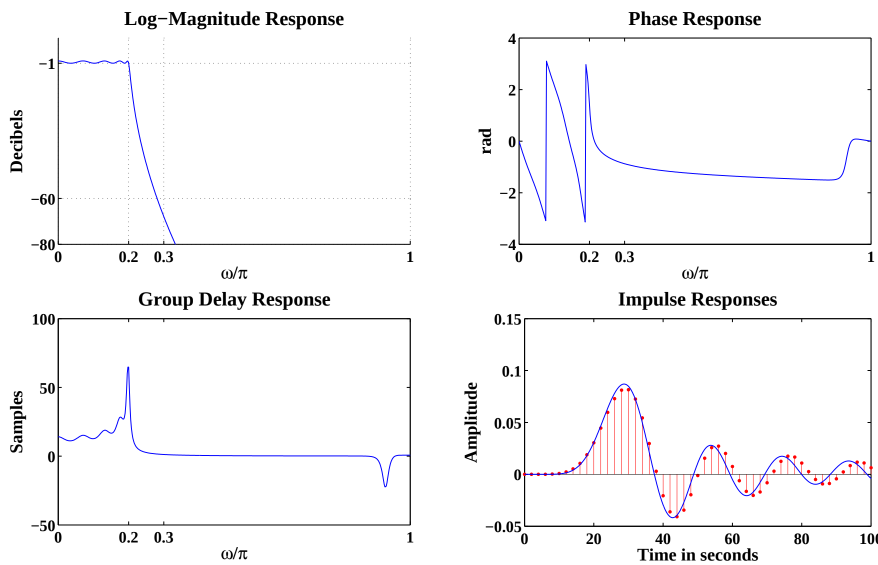

FIGURE 11.20: Plots of log-magnitude, phase, group, and impulse responses.

```
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
Td = 2;
% Step-2: Compute Analog Edge Frequencies
Omegap = 2/Td*tan(omegap/2); Omegas = 2/Td*tan(omegas/2);
% Step-3: Design Analog Chebyshev I Approximation
[N,Omegac] = cheb1ord(Omegap,Omegas,Ap,As,'s');
[C,D] = cheby1(N,Ap,Omegac,'s');
% Step-4: Obtain Digital Chebyshev I Filter
[B,A] = bilinear(C,D,1/Td);
[sos G] = tf2sos(B,A);
% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);
% Exact Frequency:
ind = find(Hdb < -Ap,1,'first'); om1 = om(ind)/pi; % Exact Passband Edge
ind = find(Hdb < -As,1,'first'); om2 = om(ind)/pi; % Exact Stopband Edge
```

```
%% Design Plots
hfa = figconfg('P1113a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1113b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1113c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1113d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

14. See plot below.

    MATLAB script:

```
% P1114: Lowpass filter design by Chebyshev II and tranformation
%        using bilinear method
clc; close all;
% Given Design Parameters
omegap = 0.5*pi; omegas = 0.6*pi; Ap = 2; As = 50;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
```

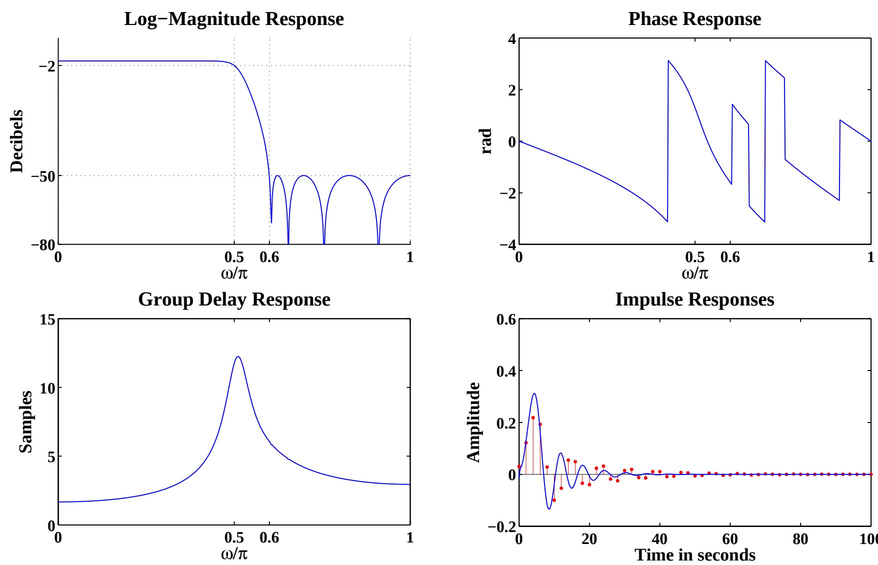

FIGURE 11.21: Plots of log-magnitude, phase, group, and impulse responses.

```
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
Td = 2;
% Step-2: Compute Analog Edge Frequencies
Omegap = 2/Td*tan(omegap/2); Omegas = 2/Td*tan(omegas/2);
% Step-3: Design Analog Chebyshev II Approximation
[N,Omegac] = cheb2ord(Omegap,Omegas,Ap,As,'s');
[C,D] = cheby2(N,As,Omegac,'s');
% Step-4: Obtain Digital Chebyshev II Filter
[B,A] = bilinear(C,D,1/Td);
[sos G] = tf2pf(B,A);
% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);
% Exact Frequency:
ind = find(Hdb < -Ap,1,'first'); om1 = om(ind)/pi; % Exact Passband Edge
```

```
ind = find(Hdb < -As,1,'first'); om2 = om(ind)/pi; % Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1114a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1114b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1114c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1114d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

15. See plot below.

    MATLAB script:

```
% P1115: Lowpass filter design by elliptic and tranformation
%        using bilinear method
clc; close all;
% Given Design Parameters
omegap = 0.1*pi; omegas = 0.2*pi; Ap = 0.5; As = 45;
% Analog Design Parameters (Eq. 10.9)
```

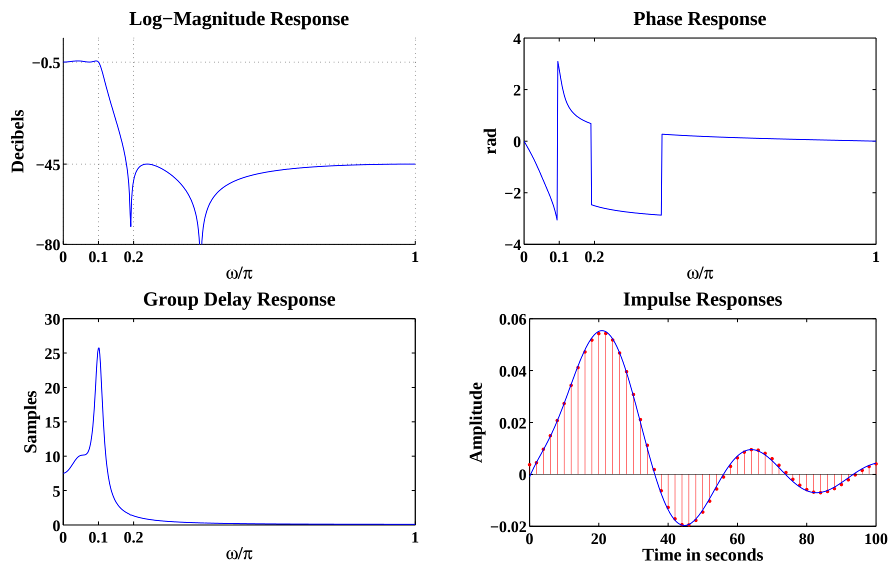

FIGURE 11.22: Plots of log-magnitude, phase, group, and impulse responses.

```
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
Td = 2;
% Step-2: Compute Analog Edge Frequencies
Omegap = 2/Td*tan(omegap/2); Omegas = 2/Td*tan(omegas/2);
% Step-3: Design Analog Elliptic Approximation
[N,Omegac] = ellipord(Omegap,Omegas,Ap,As,'s');
[C,D] = ellip(N,Ap,As,Omegac,'s');
% Step-4: Obtain Digital Elliptic Filter
[B,A] = bilinear(C,D,1/Td);
% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);
% Exact Frequency:
ind = find(Hdb < -Ap,2,'first'); om1 = om(ind(2))/pi; % Exact Passband Edge
```

```
ind = find(Hdb < -As,1,'first'); om2 = om(ind)/pi; % Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1115a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1115b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1115c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1115d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

16. See plot below.

    MATLAB script:

```
% P1116: Continuous-Time Frequency Transformation: Lowpass to Lowpass
close all; clc
C = 10; D = [1 1]; Omegac = 10; Td = 2;
[Bc,Ac] = lp2lp(C,D,Omegac); % continuous lowpass filter
[rc,pc,kc] = residue(Bc,Ac);
[B,A] = bilinear(Bc,Ac,1/Td); % digital lowpass filter
```

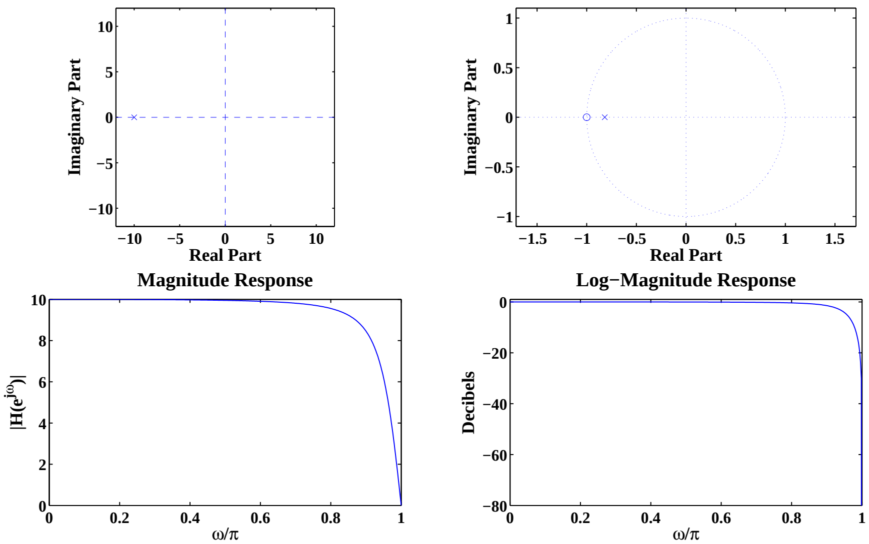

FIGURE 11.23: Plots of pole and zero locations for the analog lowpass filter and for the digital filter with $T_{\mathrm{d}} = 2$, magnitude response of the digital filter.

```
[r,p,k] = residuez(B,A);
om = linspace(0,1,501)*pi;
H = freqz(B,A,om); Hmag = abs(H); Hdb = 20*log10(Hmag/max(Hmag));

%% Plot
hfa = figconfg('P1116a','small'); % CT Pole-Zero plot
pv = abs(pc); pv = 1.2*pv;
plot(real(pc),imag(pc),'marker','x','color','b','markersize',8);hold on
plot([-pv pv],[0 0],'--b'); plot([0 0],[-pv pv],'--b'); axis square
axis([-pv pv -pv pv])
xlabel('Real Part','fontsize',LFS);
ylabel('Imaginary Part','fontsize',LFS);

hfb = figconfg('P1116b','small'); % DT Pole-Zero plot
zplane(B,A)
xlabel('Real Part','fontsize',LFS);
ylabel('Imaginary Part','fontsize',LFS);

hfc = figconfg('P1116c','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1);
```

```
xlabel('\omega/\pi','fontsize',LFS);
ylabel('|H(e^{j\omega})|','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);

hfd = figconfg('P1116d','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1);
axis([0,1,-80,1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
```

17. See plot below.

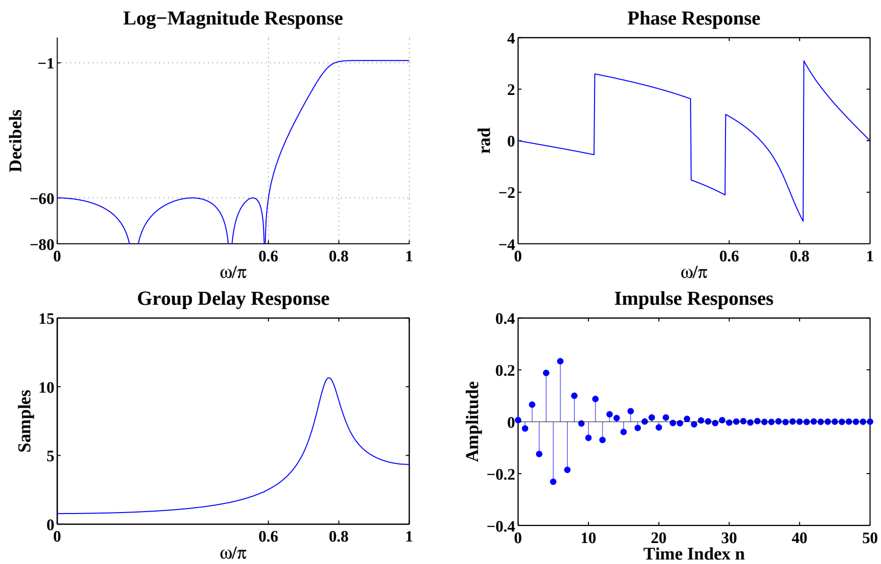

FIGURE 11.24: Plots of log-magnitude, phase, group, and impulse responses.

MATLAB script:

```
% P1117: Digital highpass filter design by Chebyshev II
close all; clc;
%% Filter Design
omegas = 0.6*pi; omegap = 0.8*pi; As = 60; Ap = 1; % Specification
[N,omegac] = cheb2ord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = cheby2(N,As,omegac,'high'); % coefficients
[sos G] = tf2sos(B,A); % cascade form
```

```
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb < -As,1,'last'); om1 = om(ind)/pi; % Exact stopband Edge
ind = find(Hdb > -Ap,1,'first'); om2 = om(ind)/pi; % Exact Passband Edge
%% Design Plots
hfa = figconfg('P1117a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1117b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);

hfc = figconfg('P1117c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);

hfd = figconfg('P1117d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

18. See plot below.

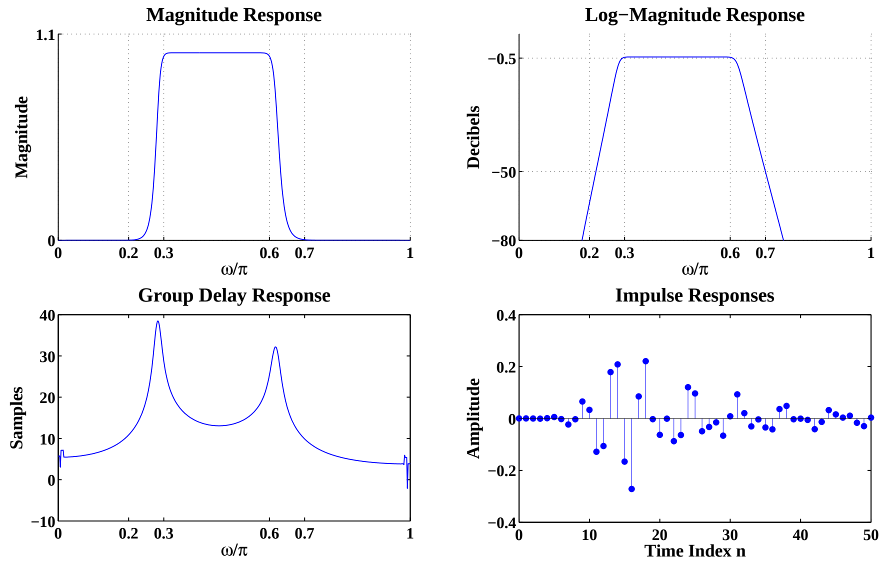

FIGURE 11.25: Plots of magnitude, log-magnitude, group, and impulse responses.

MATLAB script:

```
% P1118: Digital bandpass filter design by Butterworth
close all; clc;
%% Filter Design
omegas1 = 0.2*pi; omegap1 = 0.3*pi; omegap2 = 0.6*pi; omegas2 = 0.7*pi;
As1 = 40; Ap = 0.5; As2 = 50; % Specification
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; As = max(As1,As2);
[N,omegac] = buttord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = butter(N,omegac); % coefficients
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb > -Ap);
omp1 = om(ind(1))/pi; omp2 = om(ind(end))/pi;% Exact Passband Edge
ind = find(Hdb < -As); ind2 = find(om(ind)<omegap1,1,'last');
```

```
oms1 = om(ind(ind2))/pi; oms2 = om(ind(ind2+1))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1118a','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[0,1.1]); grid; box off;

hfb = figconfg('P1118b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfc = figconfg('P1118c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);

hfd = figconfg('P1118d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

19. See plot below.

    MATLAB script:

```
% P1119: Digital bandstop filter design by Chebyshev I
close all; clc;
%% Filter Design
omegap1 = 0.4*pi; omegas1 = 0.55*pi; omegas2 = 0.65*pi; omegap2 = 0.75*pi;
Ap1 = 1; As = 50; Ap2 = 1; % Specification
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; Ap = min(Ap1,Ap2);
```

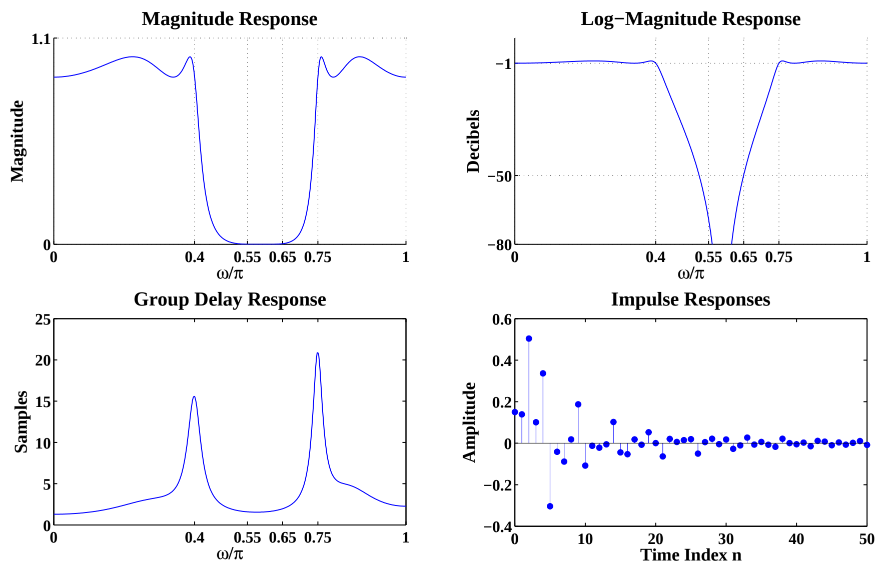

FIGURE 11.26: Plots of magnitude, log-magnitude, group, and impulse responses.

```
[N,omegac] = cheb1ord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = cheby1(N,Ap,omegac,'stop'); % coefficients
[sos G] = tf2pf(B,A); % parallel form
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb >= -Ap); ind2 = find(om(ind)<omegas1,1,'last');
omp1 = om(ind(ind2))/pi; omp2 = om(ind(ind2+1))/pi;% Exact Passband Edge
ind = find(Hdb <= -As);
oms1 = om(ind(1))/pi; oms2 = om(ind(end))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1119a','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
```

```
set(gca,'ytick',[0,1.1]); grid; box off;

hfb = figconfg('P1119b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfc = figconfg('P1119c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);

hfd = figconfg('P1119d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

Basic Problems

20. (a) Solution:
Follow the signal flow, we have

$$y[n] = x[n] * h[n] + x[-n] * h[n] = x[n] * h_{\mathrm{zp}}[n]$$

where

$$x[-n] * h[n] = \sum_{m=-\infty}^{\infty} x[-m]h[n-m] = \sum_{m=-\infty}^{\infty} x[m]h[n+m] = x[n] * h[-n]$$

Plug in the above result in, we have

$$y[n] = x[n] * h[n] + x[n] * h[-n] = x[n]\,(h[n] + h[-n])$$

thus,

$$h_{\mathrm{zp}}[n] = h[n] + h[-n]$$

(b) Solution:
The frequency response is:

$$H_{\mathrm{zp}}\big(\mathrm{e}^{\mathrm{j}\omega}\big) = H\big(\mathrm{e}^{\mathrm{j}\omega}\big) + H(\mathrm{e}^{-\mathrm{j}\omega}) = 2\mathrm{Re}[H\big(\mathrm{e}^{\mathrm{j}\omega}\big)]$$

(c) tba.

21. (a) See plot below.

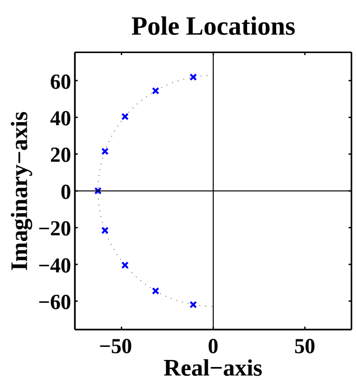

FIGURE 11.27: Pole locations of $H_{\mathrm{c}}(s)$

(b) See plot below.

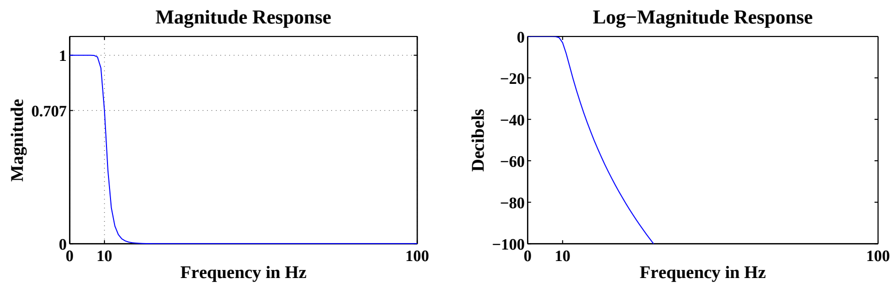

FIGURE 11.28: Magnitude and log-magnitude responses over $[0, 100]$ Hz range.

(c) Solution:
The frequencies are 14.68, 16.68, and 18.96 rad/s at which the attenuation is 30 dB, 40 dB, and 50 dB.

MATLAB script:

```
% P1121: Ninth order Butterworth low-pass filter
close all; clc
N = 9;
% Determine cutoff frequency
Hc = 10;
Omegac = Hc*2*pi;
% Determine zero locations
k = 1:N; thetak = pi/2+(2*k-1)*pi/2/N;
sigmak = Omegac*cos(thetak); Omegak = Omegac*sin(thetak);
sk = cplxpair(sigmak + 1j*Omegak);
% Compute system function
C = Omegac^N;
D = real(poly(sk));
Fmax = 100;
F = linspace(0,Fmax,101);
Om = F*2*pi;
H = freqs(C,D,F*2*pi);
Hmag = abs(H); Hpha = angle(H);
Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];
% Part c:
A = [3 30 40 50];
delta = (10.^(-A/20)).^2;
disp('Frequencies where attenuation is 3db, 30db, 40db, 50db')
```

```
F3 = (1./delta-1).^(1/2/N)*Hc,
%% Plot:
hfa = figconfg('P1121a','small');
plot(sigmak,Omegak,'bx','linewidth',1.5); hold on;
ff = 1.2; pc = ff*Omegac;
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
plot(Omegac*cos(0.5*pi*[1:0.01:3]),Omegac*sin(0.5*pi*[1:0.01:3]),'k:');
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfb = figconfg('P1121b','small');
plot(F,Hmag,'b','linewidth',1);
axis([0,Fmax,0,1.1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Hc,Fmax]);
set(gca,'ytick',[0,0.707,1]); grid;

hfc = figconfg('P1121c','small');
plot(F,Hdb,'b','linewidth',1);
axis([0,Fmax,-100,0]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Hc,Fmax]);
```

22. See plot below.

    MATLAB script:

```
% P1122: Analog Butterworth lowpass filter design
clc; close all;
% Given Design Parameters
Omegap = 10; Omegas = 15; Ap = 0.5; As = 40;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1);
```

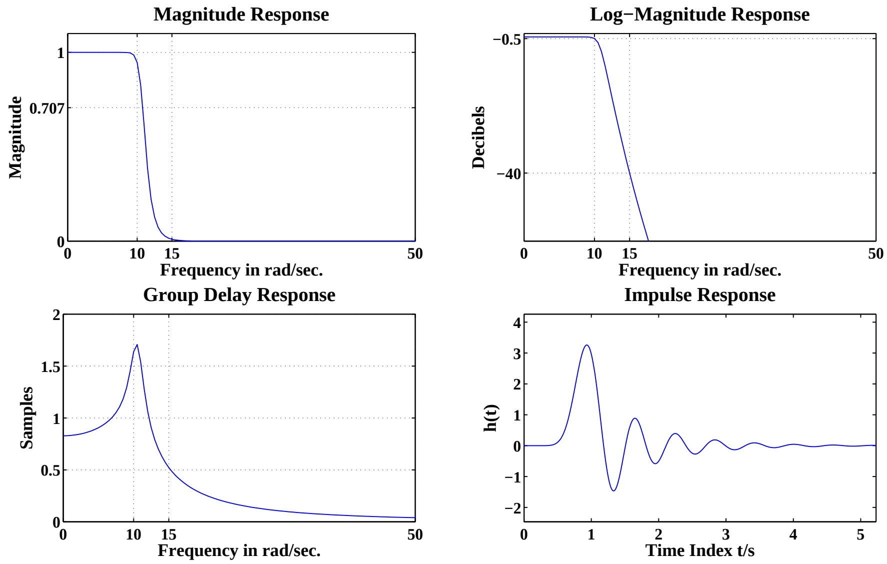

FIGURE 11.29: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

```
A = 10^(0.05*As);
%% Design Steps
% Step-1: Calulation of N
alpha = Omegas/Omegap;
beta = (1/epsilon)*sqrt(A^2-1);
N = log(beta)/log(alpha);
N = ceil(N);
% Step-2: Calculation of Omegac
OmegacL = Omegap/(10^(0.1*Ap)-1)^(1/(2*N));
OmegacH = Omegas/(10^(0.1*As)-1)^(1/(2*N));
Omegac = OmegacH;
Fc = Omegac/2/pi;
% Step-3: Calculations of Poles
k = 1:N; thetak = pi/2+(2*k-1)*pi/(2*N);
sigmak = Omegac*cos(thetak); Omegak = Omegac*sin(thetak);
sk = cplxpair(sigmak + 1j*Omegak);
% Step-4: Calculation of the system function
C = Omegac^N; D = real(poly(sk)); % Direct Form

% Design using SP Toolbox functions
```

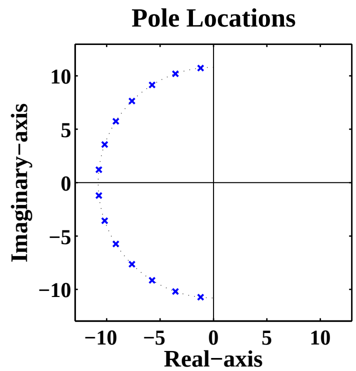

FIGURE 11.30: Pole-zero plot of the filter

```
% [N, Wn] = buttord(Omegap, Omegas, Ap, As, 's');
% [C,D] = butter(N,Wn,'s')

Ommax = 50;
Om = linspace(0,Ommax,101);
H = freqs(C,D,Om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];

% Impulse response:
trsys = tf(C,D);
[ht t] = impulse(trsys);

%% Design Plots
hfa = figconfg('P1122a','small'); % magnitude
plot(Om,Hmag,'b','linewidth',1);
axis([0,Ommax,0,1.1]);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]);
set(gca,'ytick',[0,0.707,1]); grid;

hfb = figconfg('P1122b','small'); % Log-Magnitude Plot in dB
plot(Om,Hdb,'b','linewidth',1);
axis([0,Ommax,-60,1]);
```

```
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]);
set(gca,'ytick',[-As,-Ap]);grid

hfc = figconfg('P1122c','small'); % Group-Delay Plot in Samples
plot(Om,Hgdl,'b','linewidth',1);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]); grid

hfd = figconfg('P1122d','small'); % Pole-zero Plot
plot(sigmak,Omegak,'bx','linewidth',1.5); hold on;
ff = 1.2; pc = ff*Omegac;
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
plot(Omegac*cos(0.5*pi*[1:0.01:3]),Omegac*sin(0.5*pi*[1:0.01:3]),'k:');
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfe = figconfg('P1122e','small'); % Impulse response
plot(t,ht,'linewidth',1)
axis([t(1) t(end) min(ht)-1 max(ht)+1])
xlabel('Time Index t/s','fontsize',LFS);
ylabel('h(t)','fontsize',LFS);
title('Impulse Response','fontsize',TFS);
```

23. See plot below.

    MATLAB script:

```
% P1123: Analog Chebyshev I lowpass filter design
clc; close all;
% Given Design Parameters
Fp = 2e3; Fs = 3.5e3; Ap = 1; As = 50;
Omegap = Fp*2*pi; Omegas = Fs*2*pi;
```

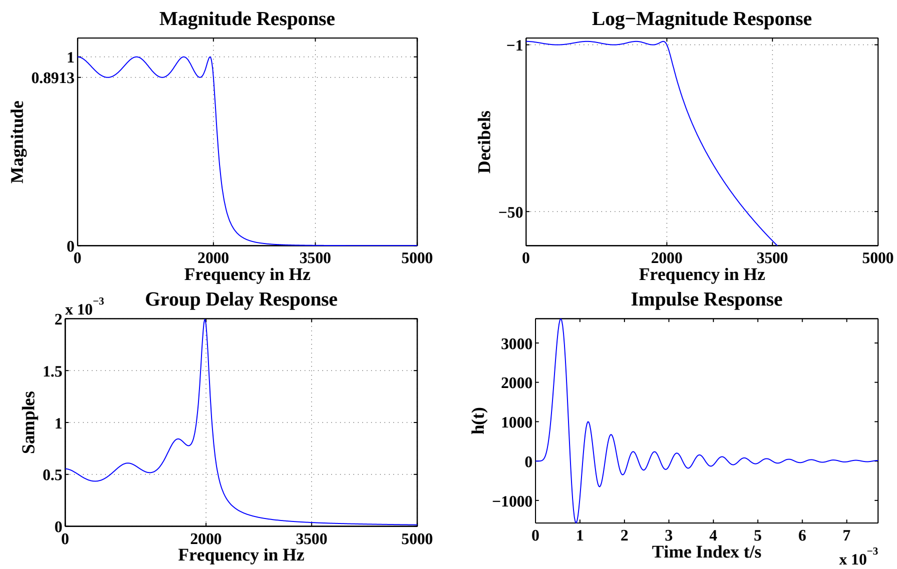

FIGURE 11.31: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

```
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);

%% Design Steps
% Step-1: Compute alpha and beta
alpha = Omegas/Omegap; beta = (1/epsilon)*sqrt(A^2-1);
% Step-2: Calulation of N
N = log(beta+sqrt(beta^2-1))/log(alpha+sqrt(alpha^2-1));
N = ceil(N);
% Step-3: Calculation of a and b
Omegac = Omegap;
gamma = (1/epsilon+sqrt(1+1/epsilon^2))^(1/N);
a = 0.5*(gamma-1/gamma); b = 0.5*(gamma+1/gamma);
% Step-4: Calculations of Poles
k = 1:N; thetak = pi/2+(2*k-1)*pi/(2*N);
sigmak = (a*Omegac)*cos(thetak); Omegak = (b*Omegac)*sin(thetak);
sk = cplxpair(sigmak + 1j*Omegak);
% Step-5: Calculation of the system function
D = real(poly(sk)); % Direct Form
```

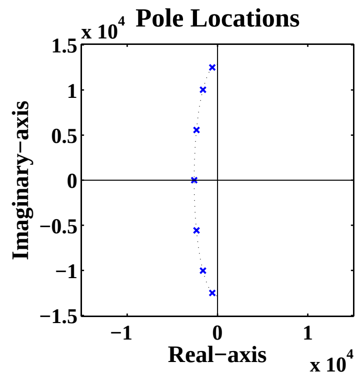

FIGURE 11.32: Pole-zero plot of the filter

```
if mod(N,2) == 0
    G = D(end)*Rp; %1/sqrt(1+epsilon^2);
else
    G = D(end);
end
C = G;

%% Design using SP Toolbox functions
% [N, Wp] = cheb1ord(Omegap, Omegas, Ap, As, 's');
% [c,d] = cheby1(N,Ap, Wp,'s');

%% Frequency Response
Fmax = 5e3;
F = linspace(0,Fmax,501);
Om = 2*pi*F;
H = freqs(C,D,Om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];

% Impulse response:
trsys = tf(C,D);
[ht t] = impulse(trsys);

%% Design Plots
hfa = figconfg('P1123a','small'); % magnitude
plot(F,Hmag,'b','linewidth',1);
```

```
axis([0,Fmax,0,1.1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[0,Rp,1]); grid;

hfb = figconfg('P1123b','small'); % Log-Magnitude Plot in dB
plot(F,Hdb,'b','linewidth',1);
axis([0,Fmax,-60,1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[-As,-Ap]);grid

hfc = figconfg('P1123c','small'); % Group-Delay Plot in Samples
plot(F,Hgdl,'b','linewidth',1);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]); grid

hfd = figconfg('P1123d','small'); % Pole-zero Plot
plot(sigmak,Omegak,'bx','linewidth',1.5); hold on;
ff = 1.2; pc = ff*Omegac;
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
plot(a*Omegac*cos(0.5*pi*[1:0.01:3]),b*Omegac*sin(0.5*pi*[1:0.01:3]),'k:');
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfe = figconfg('P1123e','small');  % Impulse response
plot(t,ht,'linewidth',1)
axis([t(1) t(end) min(ht)-1 max(ht)+1])
xlabel('Time Index t/s','fontsize',LFS);
ylabel('h(t)','fontsize',LFS);
```

```
title('Impulse Response','fontsize',TFS);
```

24. tba

25. See plot below.

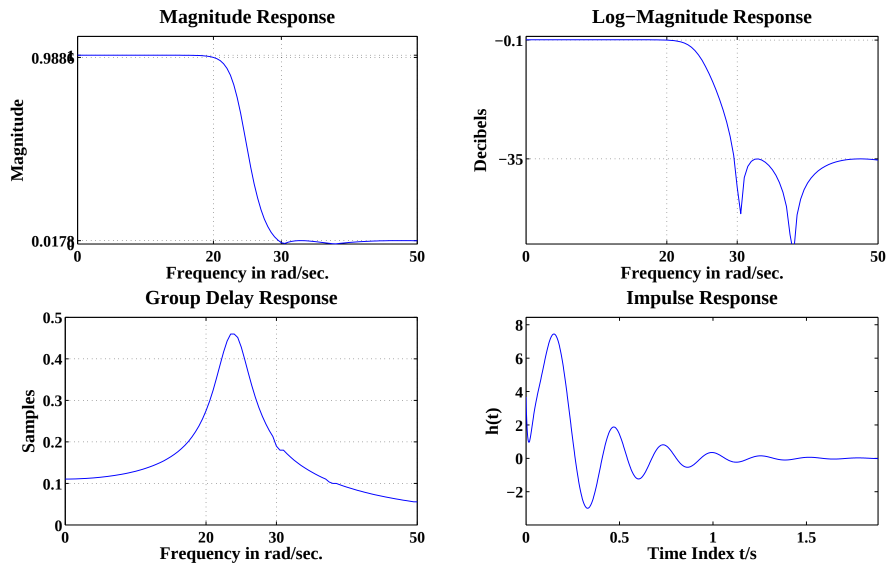

FIGURE 11.33: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

MATLAB script:

```
% P1125: Analog Chebyshev II lowpass filter design
clc; close all;
% Given Design Parameters
Omegap = 20; Omegas = 30; Ap = 0.1; As = 35;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);

%% Design Steps
% Step-1: Compute alpha and beta
alpha = Omegas/Omegap;
beta = (1/epsilon)*sqrt(A^2-1);
% Step-2: Calulation of N
```

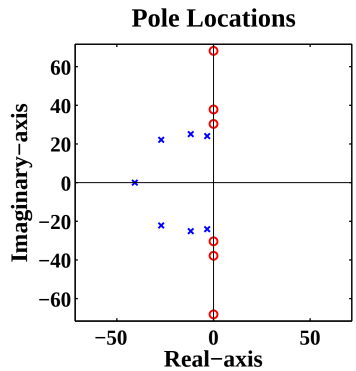

FIGURE 11.34: Pole-zero plot of the filter

```
N = log(beta+sqrt(beta^2-1))/log(alpha+sqrt(alpha^2-1));
N = ceil(N);
% Step-3; Calculation of exact Omegas
Ws = Omegap*cosh(acosh(beta)/N); Omegac = Ws;
% Step-3: Calculation of a and b
gamma = (A+sqrt(A^2-1))^(1/N);
a = 0.5*(gamma-1/gamma);
b = 0.5*(gamma+1/gamma);
% Step-4: Calculations of Poles
k = 1:N; thetak = pi/2+(2*k-1)*pi/(2*N);
sigmak = (a*Omegac)*cos(thetak); Omegak = (b*Omegac)*sin(thetak);
pk = (sigmak + 1j*Omegak);
pk = (Omegac^2)./pk;
sigmapk = real(pk); Omegapk = imag(pk);
% Step-5: Calculation of Zeros
thetak = (2*k-1)*pi/(2*N);
if mod(N,2) == 1
    thetak = [thetak(1:(N-1)/2),thetak((N+3)/2:N)];
end
zk = 1j*Omegac./cos(thetak);
sigmazk = real(zk); Omegazk = imag(zk);

% Step-5: Calculation of the system function
c = real(poly(zk)); % Direct Form
d = real(poly(pk));
c = [0,c]; c = d(end)*c/c(end);
```

```
%% Design using SP Toolbox functions
% [N, Ws] = cheb2ord(Omegap, Omegas, Ap, As, 's');
% [C,D] = cheby2(N,As, Ws,'s');

%% Frequency Response
Ommax = 50; Om = linspace(0,Ommax,101); H = freqs(c,d,Om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);

%% Impulse response:
trsys = tf(c,d);
[ht t] = impulse(trsys);

%% Design Plots
hfa = figconfg('P1125a','small'); % magnitude
plot(Om,Hmag,'b','linewidth',1);
axis([0,Ommax,0,1.1]);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]);
set(gca,'ytick',[0,1/A,Rp,1]); grid;

hfb = figconfg('P1125b','small'); % Log-Magnitude Plot in dB
plot(Om,Hdb,'b','linewidth',1);
axis([0,Ommax,-60,1]);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]);
set(gca,'ytick',[-As,-Ap]);grid

hfc = figconfg('P1125c','small'); % Group-Delay Plot in Samples
plot(Om,Hgdl,'b','linewidth',1);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]); grid
```

```
hfd = figconfg('P1125d','small'); % Pole-zero Plot
plot(sigmapk,Omegapk,'bx','linewidth',1.5); hold on;
plot(sigmazk,Omegazk,'ro','linewidth',1.5);
ff = 1.05; pc = ff*max(abs([pk(:);zk(:)]));
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfe = figconfg('P1125e','small');  % Impulse response
plot(t,ht,'linewidth',1)
axis([t(1) t(end) min(ht)-1 max(ht)+1])
xlabel('Time Index t/s','fontsize',LFS);
ylabel('h(t)','fontsize',LFS);
title('Impulse Response','fontsize',TFS);
```

26. See plot below.

    MATLAB script:

```
% P1126: Analog Elliptic low-pass filter design
clc; close all; %echo on;
% Given Design Parameters
Fp = 50; Fs = 60; Ap = 1; As = 30;
Omegap = 2*pi*Fp; Omegas = 2*pi*Fs;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
% Plotting Parameters
Fmax = 100; Ommax = 2*pi*Fmax;
F = linspace(0,Fmax,501); Om = 2*pi*F;
% Elliptic Approximation
disp('** Elliptic **');
[N, Omegac] = ellipord(Omegap, Omegas, Ap, As, 's');
[C,D] = ellip(N,Ap,As,Omegac,'s'); H = freqs(C,D,Om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];
```

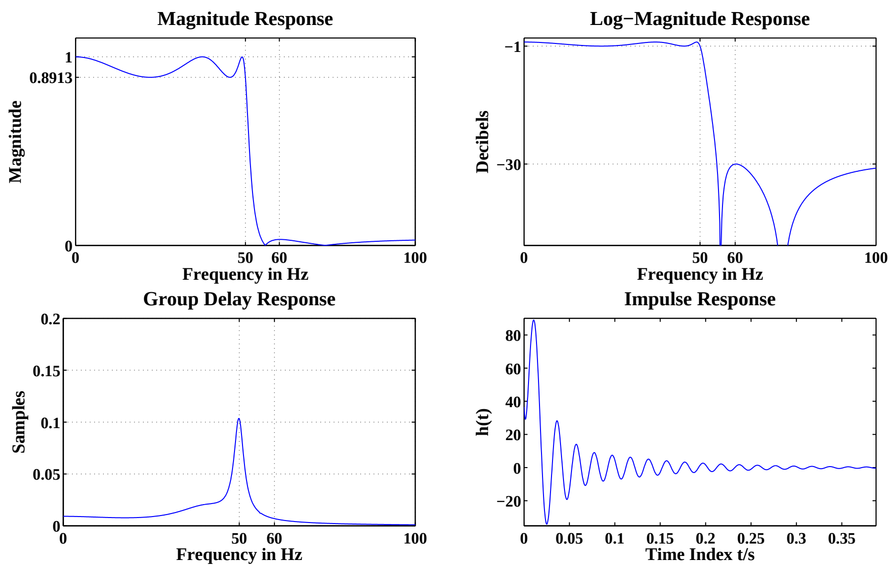

FIGURE 11.35: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

```
Hgdl = medfilt1(Hgdl,3);
pk = roots(D); sigmapk = real(pk); Omegapk = imag(pk);
zk = roots(C); sigmazk = real(zk); Omegazk = imag(zk);

%% Impulse response:
trsys = tf(C,D);
[ht t] = impulse(trsys);

%% Design Plots
hfa = figconfg('P1126a','small'); % magnitude
plot(F,Hmag,'b','linewidth',1);
axis([0,Fmax,0,1.1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[0,Rp,1]); grid;

hfb = figconfg('P1126b','small'); % Log-Magnitude Plot in dB
plot(F,Hdb,'b','linewidth',1);
```

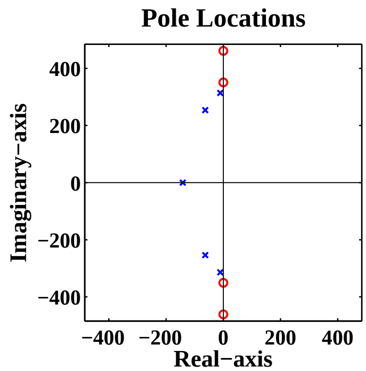

FIGURE 11.36: Pole-zero plot of the filter

```
axis([0,Fmax,-50,1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[-As,-Ap]);grid

hfc = figconfg('P1126c','small'); % Group-Delay Plot in Samples
plot(F,Hgdl,'b','linewidth',1);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]); grid

hfd = figconfg('P1126d','small'); % Pole-zero Plot
plot(sigmapk,Omegapk,'bx','linewidth',1.5); hold on;
plot(sigmazk,Omegazk,'ro','linewidth',1.5);
ff = 1.05; pc = ff*max(abs([pk(:);zk(:)]));
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);
```

```
hfe = figconfg('P1126e','small');  % Impulse response
plot(t,ht,'linewidth',1)
axis([t(1) t(end) min(ht)-1 max(ht)+1])
xlabel('Time Index t/s','fontsize',LFS);
ylabel('h(t)','fontsize',LFS);
title('Impulse Response','fontsize',TFS);
```

27. See plot below.

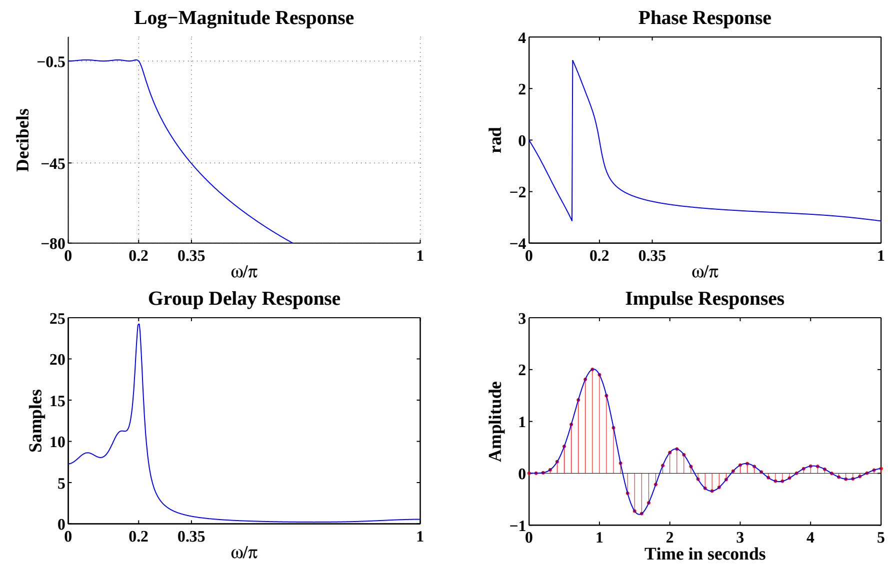

FIGURE 11.37: Plots of log-magnitude, phase, group, and impulse responses.

MATLAB script:

```
% P1127: Low-pass analog filter by Chebyshev I and transformation
%        using impulse invariance method
clc; close all;
% Given Design Parameters
omegap = 0.2*pi; omegas = 0.35*pi; Ap = 0.5; As = 45;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
Td = 0.1;
```

```
% Step-2: Compute Analog Edge Frequencies
Omegap = omegap/Td; Omegas = omegas/Td;
% Step-3: Design Analog Chebyshev I Approximation
[N,Omegac] = cheb1ord(Omegap,Omegas,Ap,As,'s');
[C,D] = cheby1(N,Ap,Omegac,'s');
% Step-4: Obtain Digital Chebyshev I Filter
[B,A] = impinvar(C,D,1/Td);

% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);

%% Design Plots
hfa = figconfg('P1127a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1127b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1127c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1127d','small'); % Impulse Response Plots
```

```
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

28. See plot below.

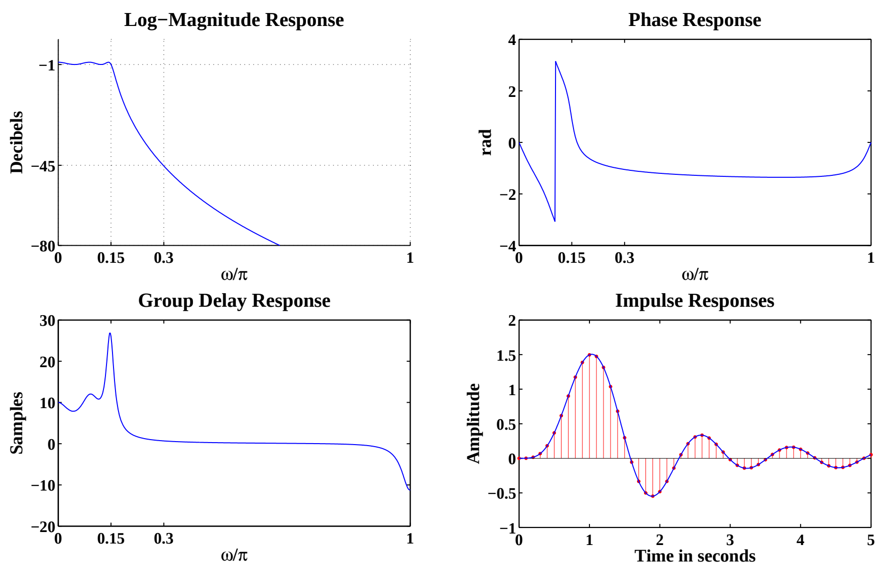

FIGURE 11.38: Plots of log-magnitude, phase, group, and impulse responses.

MATLAB script:

```
% P1128: Low-pass analog filter by Chebyshev I and transformation
%         using impulse invariance method
clc; close all;
% Given Design Parameters
omegap = 0.15*pi; omegas = 0.3*pi; Ap = 1; As = 45;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
Td = 0.1;
% Step-2: Compute Analog Edge Frequencies
```

```
Omegap = omegap/Td; Omegas = omegas/Td;
% Step-3: Design Analog Chebyshev I Approximation
[N,Omegac] = cheb1ord(Omegap,Omegas,Ap,As,'s');
[C,D] = cheby1(N,Ap,Omegac,'s');
% Step-4: Obtain Digital Chebyshev I Filter
[B,A] = impinvar(C,D,1/Td);

% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);

%% Design Plots
hfa = figconfg('P1128a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1128b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1128c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1128d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
```

```
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

29. (a) See plot below.

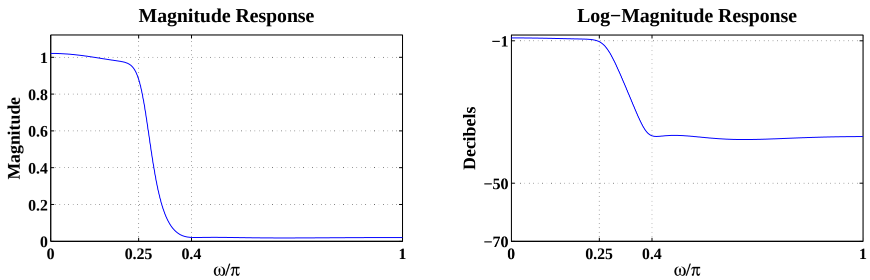

FIGURE 11.39: Plot the magnitude and log-magnitude responses when $As = 50$ dB.

(b) See plot below.

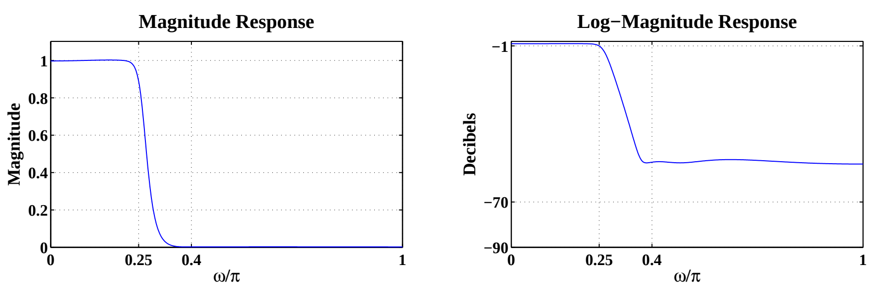

FIGURE 11.40: Plot the magnitude and log-magnitude responses when $As = 70$ dB.

MATLAB script:

```
% P1129: Low-pass analog filter by Chebyshev II and transformation
%        using impulse invariance method
clc; close all;
wp = 0.25*pi; ws = 0.4*pi; Ap = 1;
As = 50; % part a
% As = 70; % part b
```

```
Td = 1;
[N,Omegac] = cheb2ord(wp/Td,ws/Td,Ap,As,'s');
[b,a] = cheby2(N,As,Omegac,'s');
[B,A] = impinvar(b,a,1/Td);
w = linspace(0,1,501)*pi;
Hd = freqz(B,A,w);
Hdmag = abs(Hd); Hddb = 20*log10(Hdmag./max(Hdmag));

%% Design Plots
hfa = figconfg('P1129a','small'); % Magnitude Plot
plot(w/pi,Hdmag,'b','linewidth',1);
axis([0,1,0,max(Hdmag)+0.1]);
set(gca,'xtick',[0 wp/pi ws/pi 1]); grid
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);

hfb = figconfg('P1129b','small'); % Log-Magnitude Plot in dB
plot(w/pi,Hddb,'b','linewidth',1);
axis([0,1,-As-20,1]);
set(gca,'ytick',[-As-20,-As,-Ap])
set(gca,'xtick',[0 wp/pi ws/pi 1]); grid
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
```

30. See plot below.

MATLAB script:

```
% P1130: Lowpass filter design by Butterworth and tranformation
%        using bilinear method
clc; close all;
% Given Design Parameters
omegap = 0.25*pi; omegas = 0.45*pi; Ap = 1; As = 50;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
Td = 2;
```

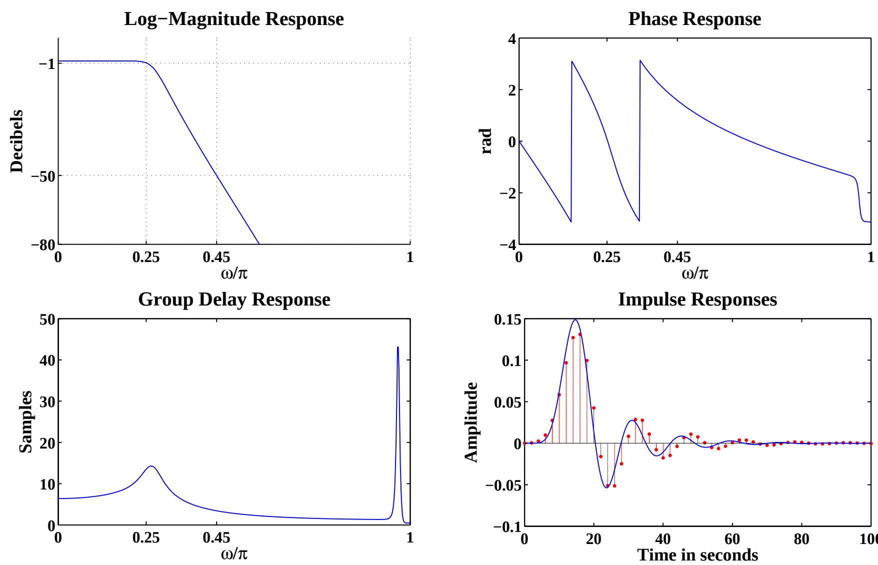

FIGURE 11.41: Plots of log-magnitude, phase, group, and impulse responses.

```
% Step-2: Compute Analog Edge Frequencies
Omegap = 2/Td*tan(omegap/2); Omegas = 2/Td*tan(omegas/2);
% Step-3: Design Analog Butterworth Approximation
[N,Omegac] = buttord(Omegap,Omegas,Ap,As,'s');
[C,D] = butter(N,Omegac,'s');
% Step-4: Obtain Digital Butterworth Filter
[B,A] = bilinear(C,D,1/Td);
[sos G] = tf2sos(B,A);
% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);
% Exact Frequency:
ind = find(Hdb < -Ap,1,'first'); om1 = om(ind)/pi; % Exact Passband Edge
ind = find(Hdb < -As,1,'first'); om2 = om(ind)/pi; % Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1130a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
```

```
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1130b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1130c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1130d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

31. See plot below.

    MATLAB script:

```
% P1131: Lowpass filter design by Chebyshev I and tranformation
%        using bilinear method
clc; close all;
% Given Design Parameters
omegap = 0.4*pi; omegas = 0.55*pi; Ap = 0.5; As = 50;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
```

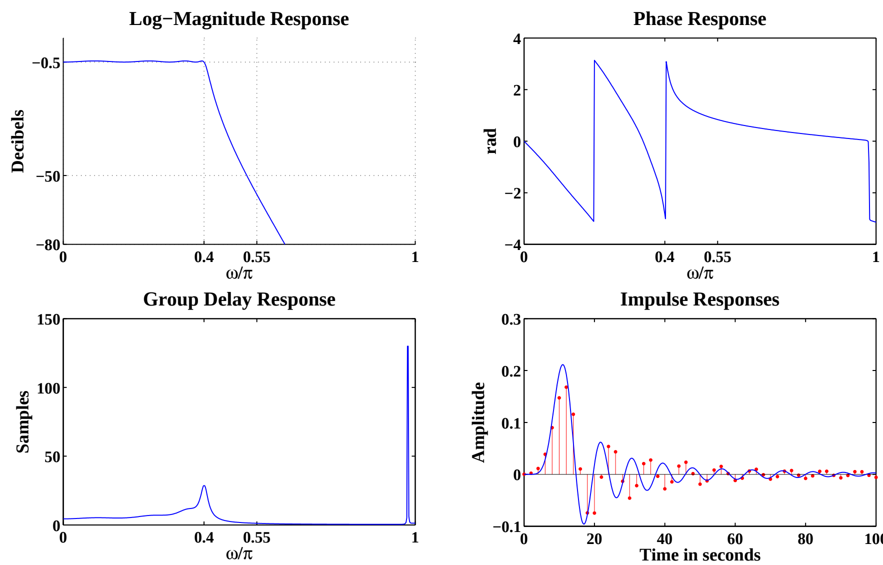

FIGURE 11.42: Plots of log-magnitude, phase, group, and impulse responses.

```
Td = 2;
% Step-2: Compute Analog Edge Frequencies
Omegap = 2/Td*tan(omegap/2); Omegas = 2/Td*tan(omegas/2);
% Step-3: Design Analog Chebyshev I Approximation
[N,Omegac] = cheb1ord(Omegap,Omegas,Ap,As,'s');
[C,D] = cheby1(N,Ap,Omegac,'s');
% Step-4: Obtain Digital Chebyshev I Filter
[B,A] = bilinear(C,D,1/Td);
% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);
% Exact Frequency:
ind = find(Hdb < -Ap,1,'first'); om1 = om(ind)/pi; % Exact Passband Edge
ind = find(Hdb < -As,1,'first'); om2 = om(ind)/pi; % Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1131a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
```

```
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1131b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1131c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1131d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

32. See plot below.

MATLAB script:

```
% P1132: Lowpass filter design by Chebyshev II and tranformation
%        using bilinear method
clc; close all;
% Given Design Parameters
omegap = 0.2*pi; omegas = 0.4*pi; Ap = 1; As = 50;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
```

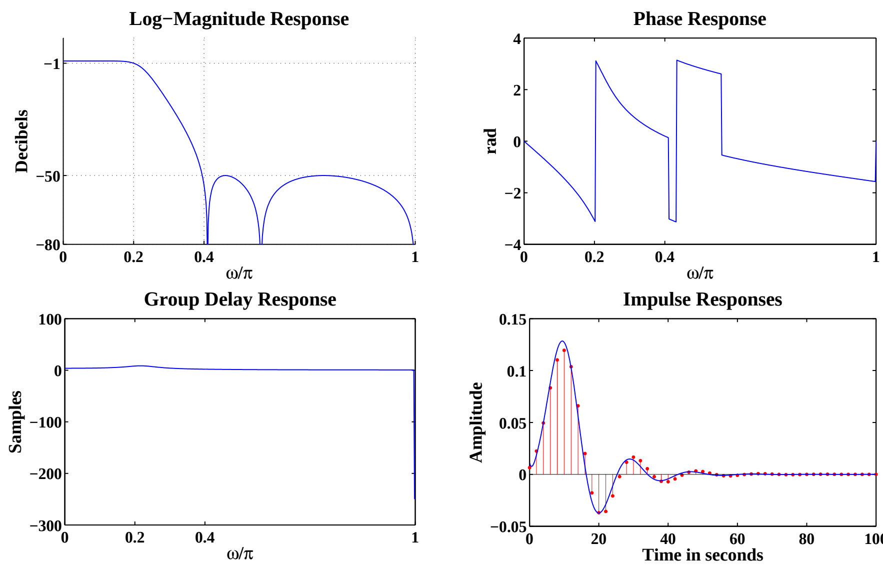

FIGURE 11.43: Plots of log-magnitude, phase, group, and impulse responses.

```
Td = 2;
% Step-2: Compute Analog Edge Frequencies
Omegap = 2/Td*tan(omegap/2); Omegas = 2/Td*tan(omegas/2);
% Step-3: Design Analog Chebyshev II Approximation
[N,Omegac] = cheb2ord(Omegap,Omegas,Ap,As,'s');
[C,D] = cheby2(N,As,Omegac,'s');
% Step-4: Obtain Digital Chebyshev II Filter
[B,A] = bilinear(C,D,1/Td);
[sos G] = tf2pf(B,A);
% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);
% Exact Frequency:
ind = find(Hdb < -Ap,1,'first'); om1 = om(ind)/pi; % Exact Passband Edge
ind = find(Hdb < -As,1,'first'); om2 = om(ind)/pi; % Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1132a','small'); % Log-Magnitude Response in dB
```

```
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1132b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1132c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1132d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

33. See plot below.

    MATLAB script:

```
% P1133: Lowpass filter design by elliptic and tranformation
%        using bilinear method
clc; close all;
% Given Design Parameters
omegap = 0.55*pi; omegas = 0.7*pi; Ap = 0.5; As = 50;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
```

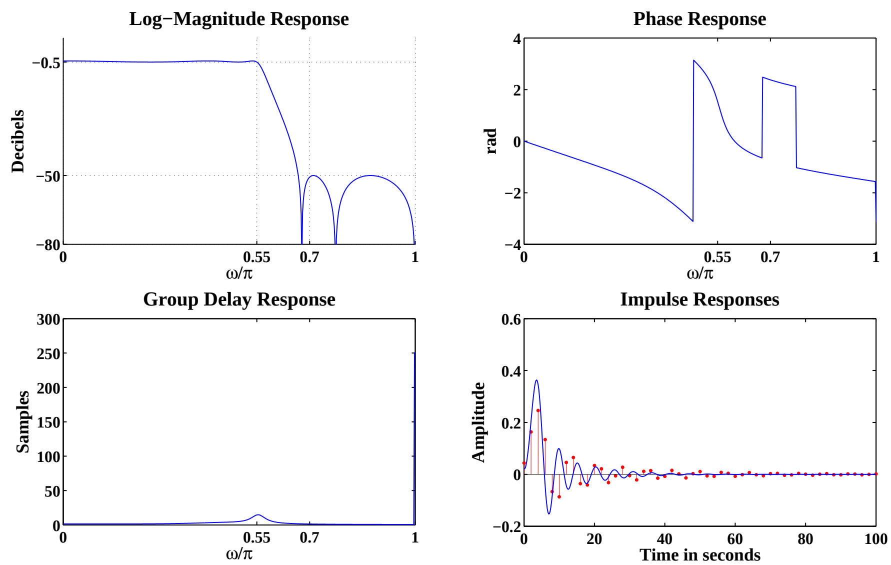

FIGURE 11.44: Plots of log-magnitude, phase, group, and impulse responses.

```
% Step-1: Choose Td
Td = 2;
% Step-2: Compute Analog Edge Frequencies
Omegap = 2/Td*tan(omegap/2); Omegas = 2/Td*tan(omegas/2);
% Step-3: Design Analog Elliptic Approximation
[N,Omegac] = ellipord(Omegap,Omegas,Ap,As,'s');
[C,D] = ellip(N,Ap,As,Omegac,'s');
% Step-4: Obtain Digital Elliptic Filter
[B,A] = bilinear(C,D,1/Td);
% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);
% Exact Frequency:
ind = find(Hdb < -Ap,1,'first'); om1 = om(ind)/pi; % Exact Passband Edge
ind = find(Hdb < -As,1,'first'); om2 = om(ind)/pi; % Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1133a','small'); % Log-Magnitude Response in dB
```

```
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1133b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1133c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1133d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

34. (a) See plot below.
    (b) See plot below.
    (c) See plot below.

    MATLAB script:

```
% P1134: Matched z-trasnformation
clc; close all
C = [1 10]; D = [1 2 101];
%% Part a:
rC = roots(C); rD  =roots(D);
% Td = 0.1;
```

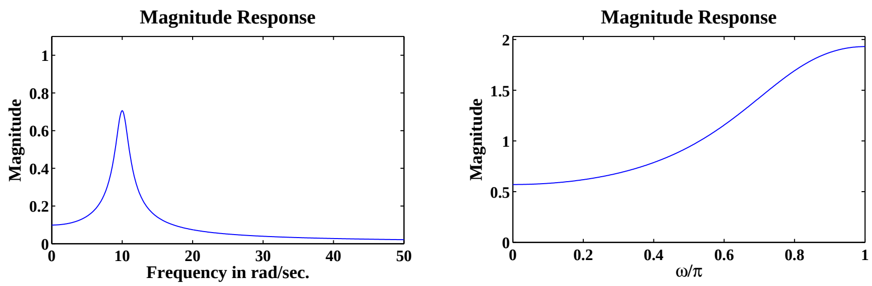

FIGURE 11.45: Plots of the magnitude of the frequency responses of $H_{c(s)}$ and $H(z)$.

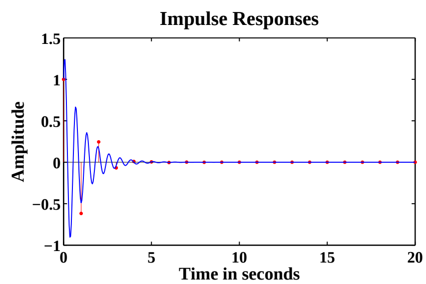

FIGURE 11.46: Impulse responses $h_c(t)$ and $h[n]$.

```
Td = 1;
B = poly(exp(rC*Td)); A = poly(exp(rD*Td));
%% Part b:
Ommax = 50; Om = linspace(0,Ommax,501);
Hc = freqs(C,D,Om); Hcmag = abs(Hc);
om = linspace(0,1,501)*pi;
H = freqz(B,A,om); Hmag = abs(H);
%% Part c:
NN = 20; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);

%% Design Plots
hfa = figconfg('P1134a','small'); % magnitude
plot(Om,Hcmag,'b','linewidth',1);
axis([0,Ommax,0,1.1]);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
```

```
title('Magnitude Response','fontsize',TFS);

hfb = figconfg('P1134b','small'); % Magnitude Plot
plot(om/pi,Hmag,'b','linewidth',1);
axis([0,1,0,max(Hmag)+0.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);

hfc = figconfg('P1134c','small'); % Impulse Response Plots
stem(n*Td,h,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

35. (a) See plot below.
    (b) See plot below.

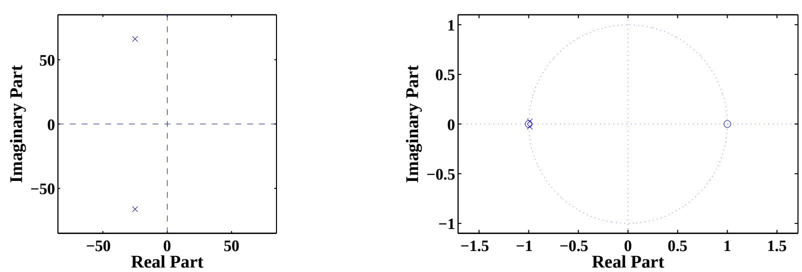

FIGURE 11.47: Plots of pole and zero locations for the analog bandpass filter and for the digital filter with $T_\mathrm{d} = 2$.

(c) See plot below.

MATLAB script:

```
% P1135: Continuous-Time Frequency Transformation: Lowpass to Bandpass
close all; clc
C = 10; D = [1 1]; Omegac1 = 50; Omegac2 = 100; Td = 2;
Omega0 = sqrt(Omegac1*Omegac2); BW = Omegac2 - Omegac1;
[Bc,Ac] = lp2bp(C,D,Omega0,BW); % continuous bandpass filter
[rc,pc,kc] = residue(Bc,Ac);
```

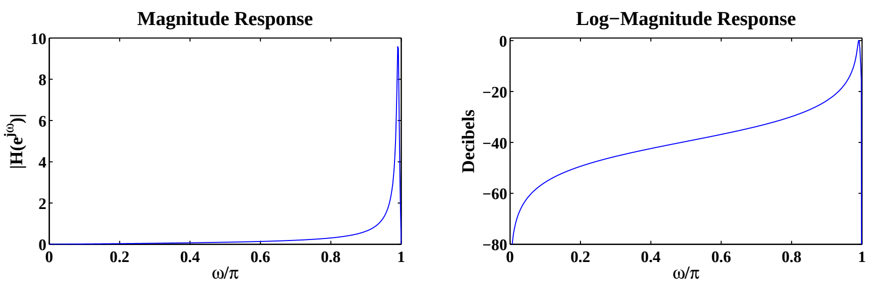

FIGURE 11.48: Plots of the magnitude response of the digital filter.

```
[B,A] = bilinear(Bc,Ac,1/Td); % digital bandpass filter
[r,p,k] = residuez(B,A);
om = linspace(0,1,501)*pi;
H = freqz(B,A,om); Hmag = abs(H); Hdb = 20*log10(Hmag/max(Hmag));

%% Plot
hfa = figconfg('P1135a','small'); % CT Pole-Zero plot
pv = max(abs(pc)); pv = 1.2*pv;
plot(real(pc),imag(pc),'x','markersize',8);hold on
plot([-pv pv],[0 0],'--b'); plot([0 0],[-pv pv],'--b'); axis square
axis([-pv pv -pv pv])
xlabel('Real Part','fontsize',LFS);
ylabel('Imaginary Part','fontsize',LFS);

hfb = figconfg('P1135ab','small'); % DT Pole-Zero plot
zplane(B,A)
xlabel('Real Part','fontsize',LFS);
ylabel('Imaginary Part','fontsize',LFS);

hfc = figconfg('P1135c','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('|H(e^{j\omega})|','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);

hfd = figconfg('P1135d','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1);
axis([0,1,-80,1]);
xlabel('\omega/\pi','fontsize',LFS);
```

```
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
```

36. Proof:
Repeat the most general allpass system as followed:

$$w^{-1} = G(z^{-1}) = \pm \prod_{k=1}^{N} \frac{z^{-1} - \alpha_k^*}{1 - \alpha_k z^{-1}}, \quad |\alpha_k| < 1. \tag{11.103}$$

The three constraints are:

(a) $G(z^{-1})$ should be a rational function of z^{-1}.
(b) The interior of the unit circle in the ω-plane must map to the interior of the unit circle in the z-plane.
(c) The unit circle of the ω-plane must map onto the unit circle of z-plane.

The first constraint is fulfilled since $G(z^{-1})$ is itself a rational function.
The third constraint is fulfilled since $|G(z^{-1})| = 1$?
Let us now prove the second constraint. Suppose $w = b \cdot \mathrm{e}^{\mathrm{j}\theta}$, and $0 < b < 1$, hence,

$$\left| \prod_{k=1}^{N} \frac{r^{-1}\mathrm{e}^{-\mathrm{j}\omega} - \alpha_k^*}{1 - \alpha_k r^{-1}\mathrm{e}^{-\mathrm{j}\omega}} \right| = \prod_{k=1}^{N} \left| \frac{r^{-1}\mathrm{e}^{-\mathrm{j}\omega} - \alpha_k^*}{1 - \alpha_k r^{-1}\mathrm{e}^{-\mathrm{j}\omega}} \right| = b^{-1} > 1$$

Since N is any positive integer, we have

$$\left| \frac{r^{-1}\mathrm{e}^{-\mathrm{j}\omega} - \alpha_k^*}{1 - \alpha_k r^{-1}\mathrm{e}^{-\mathrm{j}\omega}} \right| > 1$$

that is

$$(r^{-1}\mathrm{e}^{-\mathrm{j}\omega} - \alpha_k^*)(r^{-1}\mathrm{e}^{\mathrm{j}\omega} - \alpha_k) > (1 - \alpha_k r^{-1}\mathrm{e}^{-\mathrm{j}\omega})(1 - \alpha_k^* r^{-1}\mathrm{e}^{\mathrm{j}\omega})$$

After simply algebraic rearrangement, we have

$$(r^{-2} - 1)(1 - |\alpha_k|^2) > 0, \quad \text{given} \quad |\alpha_k| < 1$$

Hence, we conclude $0 < r < 1$.

37. tba.

38. See plot below.

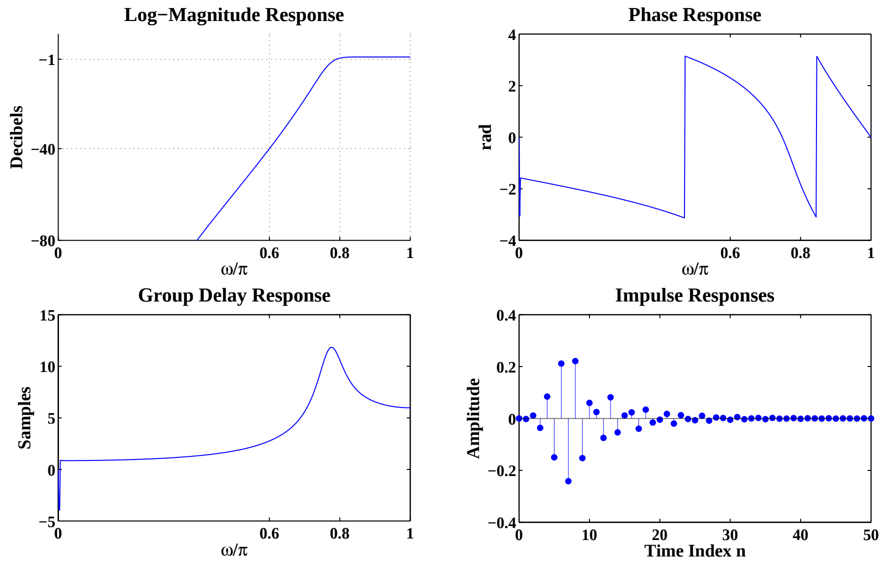

FIGURE 11.49: Plots of log-magnitude, phase, group, and impulse responses.

MATLAB script:

```
% P1138: Digital highpass filter design by Butterworth
close all; clc;
%% Filter Design
omegas = 0.6*pi; omegap = 0.8*pi; As = 40; Ap = 1; % Specification
[N,omegac] = buttord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = butter(N,omegac,'high'); % coefficients
[sos G] = tf2sos(B,A); % cascade form
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb < -As,1,'last'); om1 = om(ind)/pi; % Exact stopband Edge
ind = find(Hdb > -Ap,1,'first'); om2 = om(ind)/pi; % Exact Passband Edge
%% Design Plots
hfa = figconfg('P1138a','small'); % Log-Magnitude Response in dB
```

```
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1138b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);

hfc = figconfg('P1138c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
% axis([0,1,0,15]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);

hfd = figconfg('P1138d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

39. See plot below.

    MATLAB script:

```
% P1139: Digital highpass filter design by Chebyshev II
close all; clc;
%% Filter Design
omegas = 0.55*pi; omegap = 0.7*pi; As = 50; Ap = 1; % Specification
[N,omegac] = cheb2ord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = cheby2(N,As,omegac,'high'); % coefficients
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
```

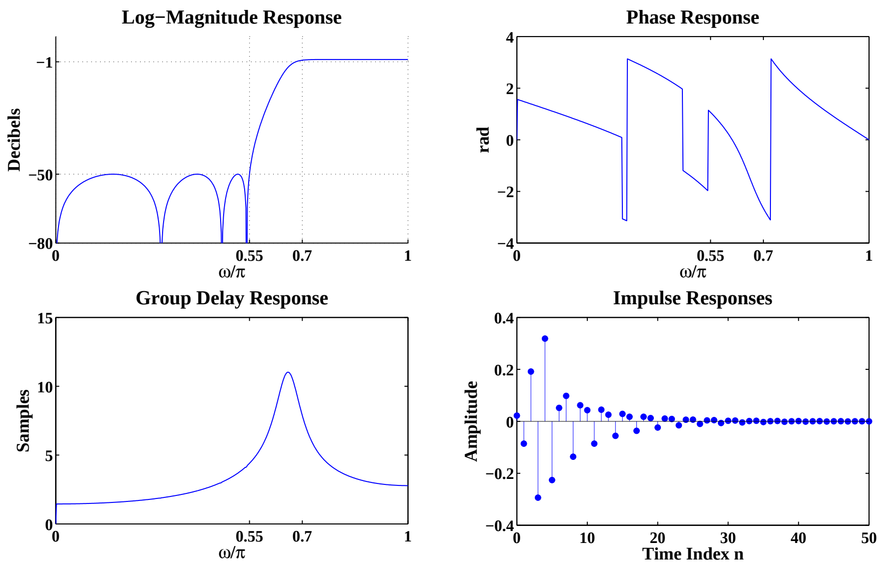

FIGURE 11.50: Plots of log-magnitude, phase, group, and impulse responses.

```
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb < -As,1,'last'); om1 = om(ind)/pi; % Exact stopband Edge
ind = find(Hdb > -Ap,1,'first'); om2 = om(ind)/pi; % Exact Passband Edge
%% Design Plots
hfa = figconfg('P1139a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1139b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);
```

```
hfc = figconfg('P1139c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);

hfd = figconfg('P1139d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

40. See plot below.

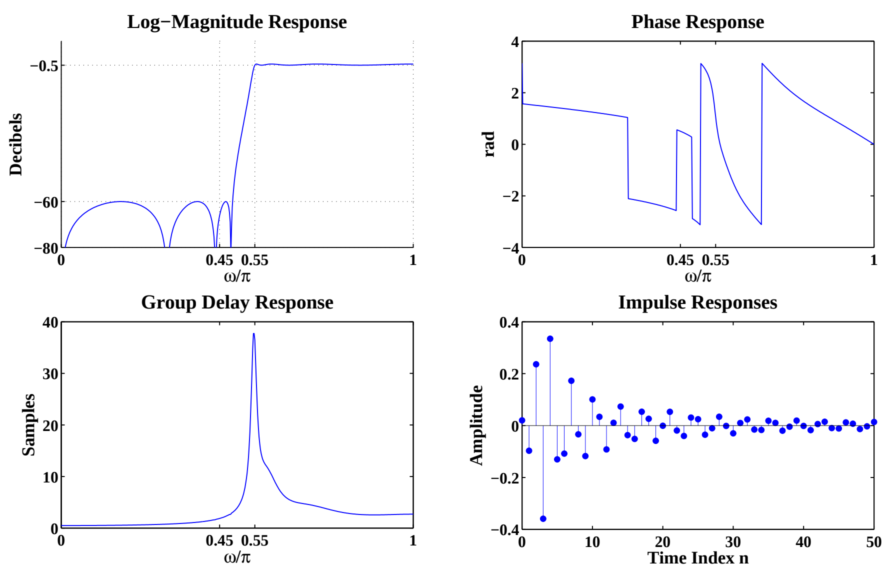

FIGURE 11.51: Plots of log-magnitude, phase, group, and impulse responses.

MATLAB script:

```
% P1140: Digital highpass filter design by elliptic
close all; clc;
%% Filter Design
omegas = 0.45*pi; omegap = 0.55*pi; As = 60; Ap = 0.5; % Specification
```

```
[N,omegac] = ellipord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = ellip(N,Ap,As,omegac,'high'); % coefficients
[sos G] = tf2sos(B,A); % parallel form
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb < -As,1,'last'); om1 = om(ind)/pi; % Exact stopband Edge
ind = find(Hdb > -Ap,1,'first'); om2 = om(ind)/pi; % Exact Passband Edge
%% Design Plots
hfa = figconfg('P1140a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1140b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);

hfc = figconfg('P1140c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);

hfd = figconfg('P1140d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

41. See plot below.

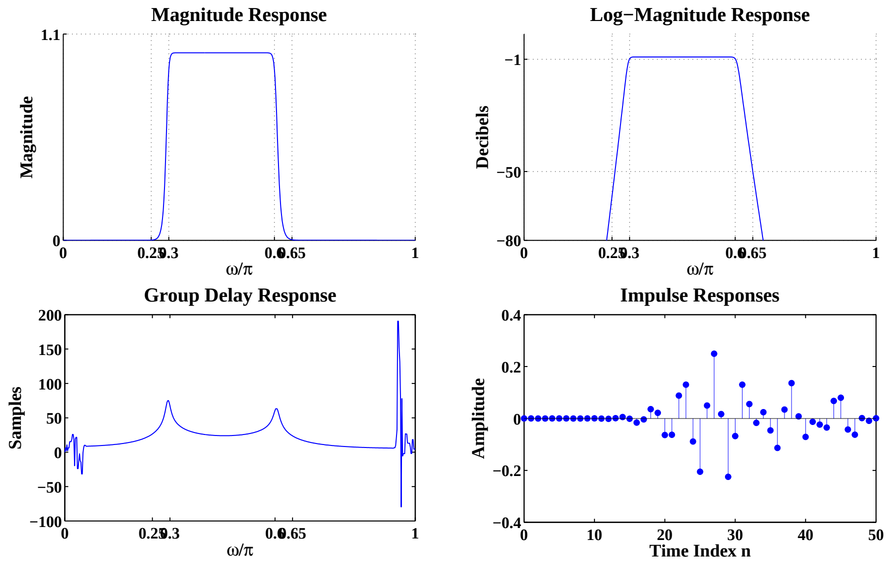

FIGURE 11.52: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

MATLAB script:

```
% P1141: Digital bandpass filter design by Butterworth
close all; clc;
%% Filter Design
omegas1 = 0.25*pi; omegap1 = 0.3*pi; omegap2 = 0.6*pi; omegas2 = 0.65*pi;
As1 = 40; Ap = 1; As2 = 50; % Specification
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; As = max(As1,As2);
[N,omegac] = buttord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = butter(N,omegac); % coefficients
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb > -Ap);
omp1 = om(ind(1))/pi; omp2 = om(ind(end))/pi;% Exact Passband Edge
```

```
ind = find(Hdb < -As); ind2 = find(om(ind)<omegap1,1,'last');
oms1 = om(ind(ind2))/pi; oms2 = om(ind(ind2+1))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1141a','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[0,1.1]); grid; box off;

hfb = figconfg('P1141b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfc = figconfg('P1141c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);

hfd = figconfg('P1141d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

42. See plot below.

    MATLAB script:

```
% P1142: Digital bandstop filter design by elliptic
close all; clc;
%% Filter Design
omegap1 = 0.2*pi; omegas1 = 0.3*pi; omegas2 = 0.55*pi; omegap2 = 0.7*pi;
Ap1 = 0.5; As = 50; Ap2 = 1; % Specification
```

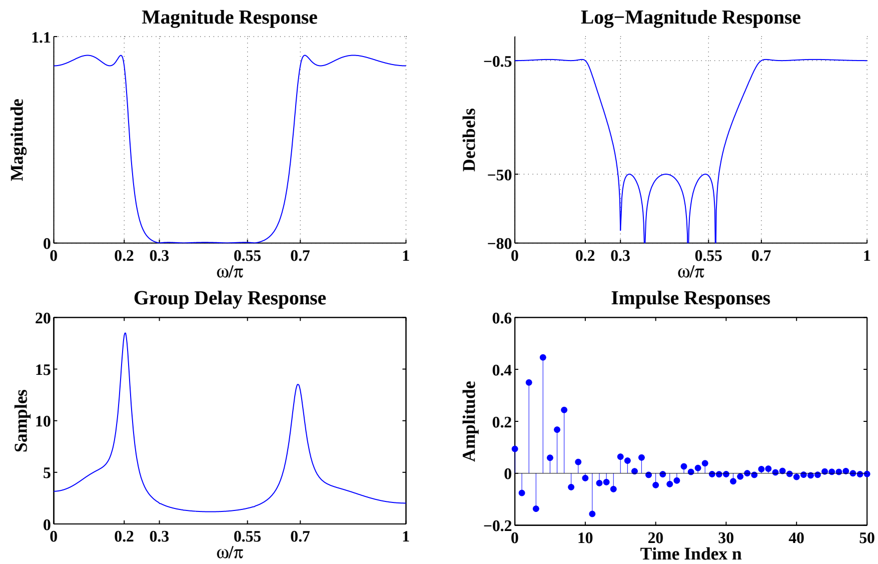

FIGURE 11.53: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

```
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; Ap = min(Ap1,Ap2);
[N,omegac] = ellipord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = ellip(N,Ap,As,omegac,'stop'); % coefficients
[sos G] = tf2sos(B,A); % cascade form
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb >= -Ap); ind2 = find(om(ind)<omegas1,1,'last');
omp1 = om(ind(ind2))/pi; omp2 = om(ind(ind2+1))/pi;% Exact Passband Edge
ind = find(Hdb <= -As);
oms1 = om(ind(1))/pi; oms2 = om(ind(end))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1142a','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
```

```
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
set(gca,'ytick',[0,1.1]); grid; box off;

hfb = figconfg('P1142b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfc = figconfg('P1142c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);

hfd = figconfg('P1142d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

43. See plot below.

    MATLAB script:

```
% P1143: Digital bandpass filter design by Chebyshev II
close all; clc;
%% Filter Design
omegas1 = 0.3*pi; omegap1 = 0.4*pi; omegap2 = 0.5*pi; omegas2 = 0.6*pi;
As1 = 50; Ap = 1; As2 = 50; % Specification
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; As = max(As1,As2);
[N,omegac] = cheb2ord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = cheby2(N,As,omegac); % coefficients
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
```

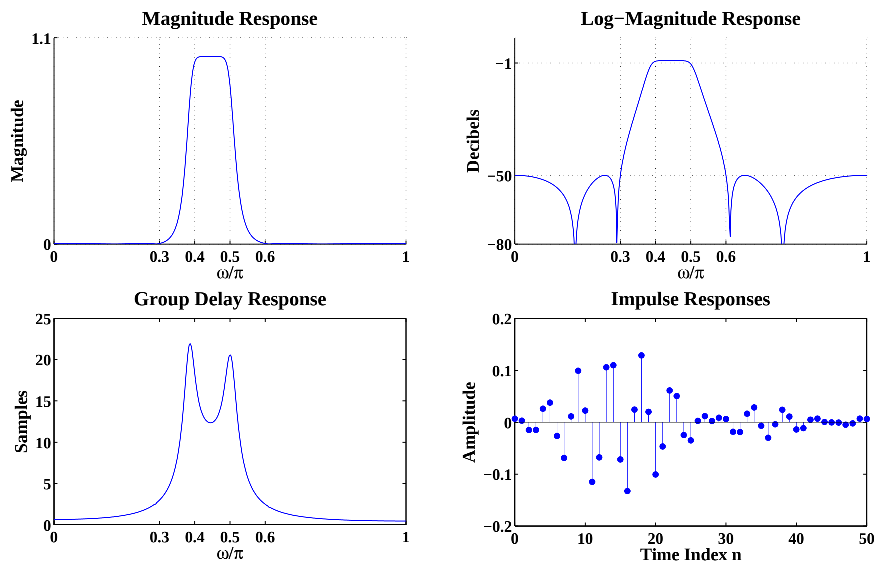

FIGURE 11.54: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

```
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb > -Ap);
omp1 = om(ind(1))/pi; omp2 = om(ind(end))/pi;% Exact Passband Edge
ind = find(Hdb < -As); ind2 = find(om(ind)<omegap1,1,'last');
oms1 = om(ind(ind2))/pi; oms2 = om(ind(ind2+1))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1143a','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[0,1.1]); grid; box off;

hfb = figconfg('P1143b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
```

```
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfc = figconfg('P1143c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);

hfd = figconfg('P1143d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

44. See plot below.

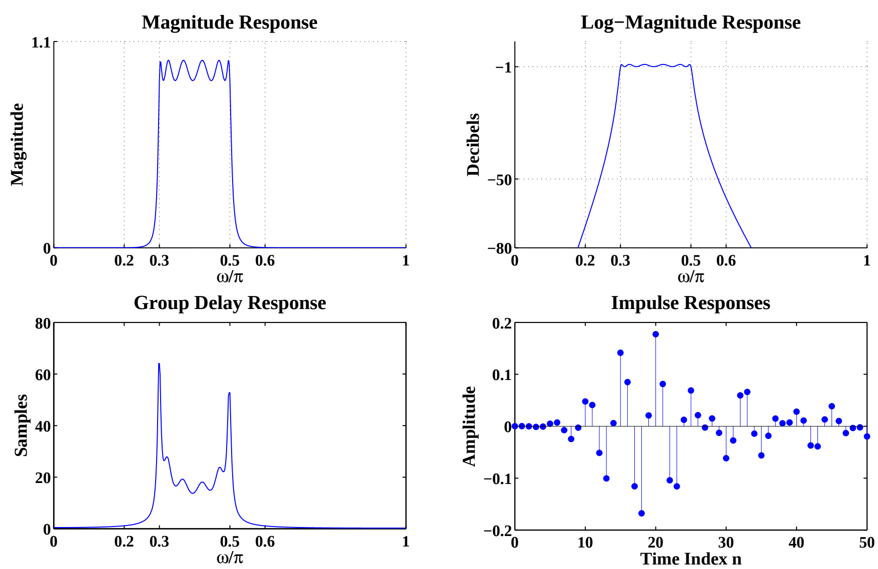

FIGURE 11.55: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

MATLAB script:

```
% P1144: Digital bandpass filter design by Chebyshev I
```

```
close all; clc;
%% Filter Design
omegas1 = 0.2*pi; omegap1 = 0.3*pi; omegap2 = 0.5*pi; omegas2 = 0.6*pi;
As1 = 40; Ap = 1; As2 = 50; % Specification
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; As = max(As1,As2);
[N,omegac] = cheb1ord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = cheby1(N,Ap,omegac); % coefficients
[sos G] = tf2pf(B,A); % parallel form
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb > -Ap);
omp1 = om(ind(1))/pi; omp2 = om(ind(end))/pi;% Exact Passband Edge
ind = find(Hdb < -As); ind2 = find(om(ind)<omegap1,1,'last');
oms1 = om(ind(ind2))/pi; oms2 = om(ind(ind2+1))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1144a','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[0,1.1]); grid; box off;

hfb = figconfg('P1144b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfc = figconfg('P1144c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
```

```
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);

hfd = figconfg('P1144d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

45. See plot below.

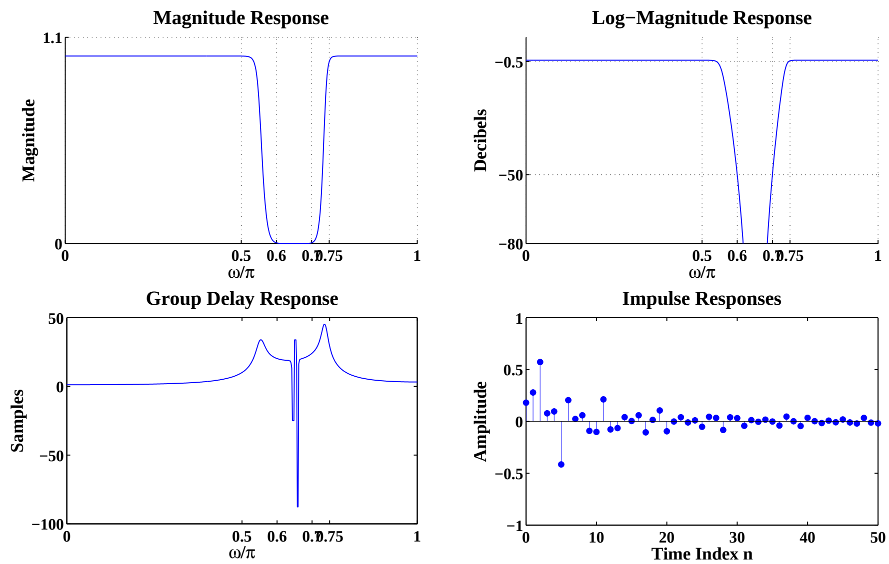

FIGURE 11.56: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

MATLAB script:

```
% P1145: Digital bandstop filter design by Butterworth
close all; clc;
%% Filter Design
omegap1 = 0.5*pi; omegas1 = 0.6*pi; omegas2 = 0.7*pi; omegap2 = 0.75*pi;
Ap1 = 0.5; As = 50; Ap2 = 0.5; % Specification
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; Ap = min(Ap1,Ap2);
[N,omegac] = buttord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = butter(N,omegac,'stop'); % coefficients
```

```
[sos G] = tf2sos(B,A); % cascade form
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb >= -Ap); ind2 = find(om(ind)<omegas1,1,'last');
omp1 = om(ind(ind2))/pi; omp2 = om(ind(ind2+1))/pi;% Exact Passband Edge
ind = find(Hdb <= -As);
oms1 = om(ind(1))/pi; oms2 = om(ind(end))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1145a','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
set(gca,'ytick',[0,1.1]); grid; box off;
hfb = figconfg('P1145b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;
hfc = figconfg('P1145c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
hfd = figconfg('P1145d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

Assessment Problems

46. See plot below.

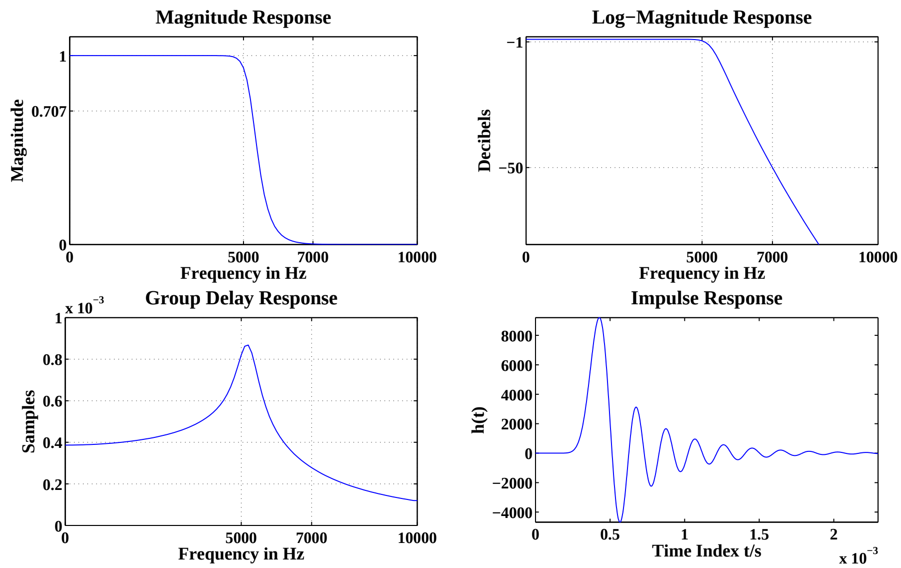

FIGURE 11.57: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

MATLAB script:

```
% P1146: Analog Butterworth lowpass filter design
clc; close all;
% Given Design Parameters
Fp = 5e3; Fs =7e3; Ap = 1; As = 50;
Omegap = Fp*2*pi; Omegas = Fs*2*pi;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1);
A = 10^(0.05*As);
%% Design Steps
% Step-1: Calulation of N
alpha = Omegas/Omegap;
beta = (1/epsilon)*sqrt(A^2-1);
N = log(beta)/log(alpha);
N = ceil(N);
% Step-2: Calculation of Omegac
```

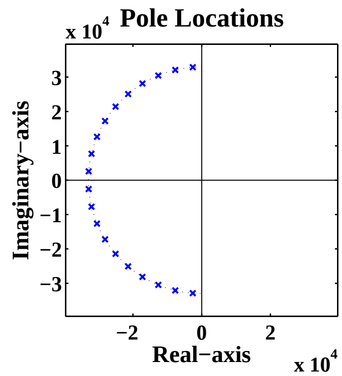

FIGURE 11.58: Pole-zero plot of the filter

```
OmegacL = Omegap/(10^(0.1*Ap)-1)^(1/(2*N));
OmegacH = Omegas/(10^(0.1*As)-1)^(1/(2*N));
Omegac = OmegacH;
Fc = Omegac/2/pi;
% Step-3: Calculations of Poles
k = 1:N; thetak = pi/2+(2*k-1)*pi/(2*N);
sigmak = Omegac*cos(thetak); Omegak = Omegac*sin(thetak);
sk = cplxpair(sigmak + 1j*Omegak);
% Step-4: Calculation of the system function
C = Omegac^N; D = real(poly(sk)); % Direct Form

% Design using SP Toolbox functions
% [N, Wn] = buttord(Omegap, Omegas, Ap, As, 's');
% [C,D] = butter(N,Wn,'s')

Fmax = 10e3;
F = linspace(0,Fmax,101);
Om = F*2*pi;
H = freqs(C,D,Om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];

% Impulse response:
trsys = tf(C,D);
[ht t] = impulse(trsys);
```

```
%% Design Plots
hfa = figconfg('P1146a','small'); % magnitude
plot(F,Hmag,'b','linewidth',1);
axis([0,Fmax,0,1.1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[0,0.707,1]); grid;

hfb = figconfg('P1146b','small'); % Log-Magnitude Plot in dB
plot(F,Hdb,'b','linewidth',1);
axis([0,Fmax,-80,1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[-As,-Ap]);grid

hfc = figconfg('P1146c','small'); % Group-Delay Plot in Samples
plot(F,Hgdl,'b','linewidth',1);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]); grid

hfd = figconfg('P1146d','small'); % Pole-zero Plot
plot(sigmak,Omegak,'bx','linewidth',1.5); hold on;
ff = 1.2; pc = ff*Omegac;
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
plot(Omegac*cos(0.5*pi*[1:0.01:3]),Omegac*sin(0.5*pi*[1:0.01:3]),'k:');
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfe = figconfg('P1146e','small'); % Impulse response
plot(t,ht,'linewidth',1)
```

```
axis([t(1) t(end) min(ht)-1 max(ht)+1])
xlabel('Time Index t/s','fontsize',LFS);
ylabel('h(t)','fontsize',LFS);
title('Impulse Response','fontsize',TFS);
```

47. (a) See plot below.

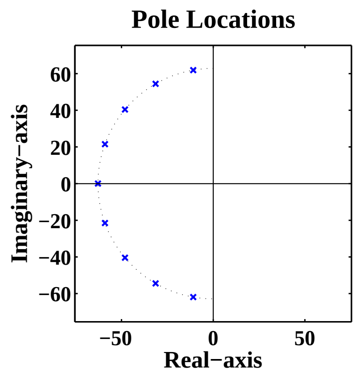

FIGURE 11.59: Pole locations of $H_c(s)$

(b) See plot below.

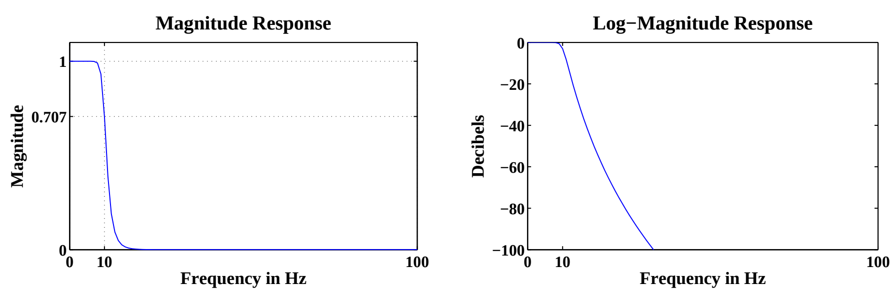

FIGURE 11.60: Magnitude and log-magnitude responses over $[0, 100]$ Hz range.

(c) Solution:
The frequencies are 15.02, 18.03, and 21.99 rad/s at which the attenuation is 30 dB, 40 dB, and 50 dB.

MATLAB script:

```
% P1147: Fifth order Chebyshev I low-pass filter
close all; clc
N = 5;
```

```
% Determine cutoff frequency
Hc = 10;
Omegac = Hc*2*pi;
Ap = 1;
epsilon = sqrt(10^(0.1*Ap)-1);
Rp = 1/sqrt(1+epsilon^2);
% Determine zero locations
gamma = (1/epsilon+sqrt(1+1/epsilon^2))^(1/N);
a = 0.5*(gamma-1/gamma); b = 0.5*(gamma+1/gamma);
k = 1:N; thetak = pi/2+(2*k-1)*pi/(2*N);
sigmak = (a*Omegac)*cos(thetak); Omegak = (b*Omegac)*sin(thetak);
sk = cplxpair(sigmak + 1j*Omegak);
% Compute system function
D = real(poly(sk)); % Direct Form
if mod(N,2) == 0
    G = D(end)*Rp; %1/sqrt(1+epsilon^2);
else
    G = D(end);
end
C = G;

Fmax = 100;
F = linspace(0,Fmax,101);
Om = F*2*pi;
H = freqs(C,D,F*2*pi);
Hmag = abs(H); Hpha = angle(H);
Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];
% Part c:
A = [30 40 50];
delta = (10.^(-A/20)).^2;
disp('Frequencies where attenuation is 30db, 40db, 50db')
F3 = cosh(acosh(sqrt((1./delta-1)./(epsilon^2)))/N)*Hc,
%% Plot:
hfa = figconfg('P1147a','small');
plot(sigmak,Omegak,'bx','linewidth',1.5); hold on;
ff = 1.2; pc = ff*Omegac;
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
plot(a*Omegac*cos(0.5*pi*[1:0.01:3]),b*Omegac*sin(0.5*pi*[1:0.01:3]),'k:');
```

```
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfb = figconfg('P1147b','small');
plot(F,Hmag,'b','linewidth',1);
axis([0,Fmax,0,1.1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Hc,Fmax]);
set(gca,'ytick',[0,Rp,1]); grid;

hfc = figconfg('P1147c','small');
plot(F,Hdb,'b','linewidth',1);
axis([0,Fmax,-100,0]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Hc,Fmax]);
set(gca,'ytick',[-100:20:-20,-1]); grid;
```

48. See plot below.

MATLAB script:

```
% P1148: Analog Chebyshev I lowpass filter design
clc; close all;
% Given Design Parameters
Omegap = 4; Omegas = 5; Ap = 1; As = 40;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);

%% Design Steps
% Step-1: Compute alpha and beta
alpha = Omegas/Omegap; beta = (1/epsilon)*sqrt(A^2-1);
% Step-2: Calulation of N
N = log(beta+sqrt(beta^2-1))/log(alpha+sqrt(alpha^2-1));
```

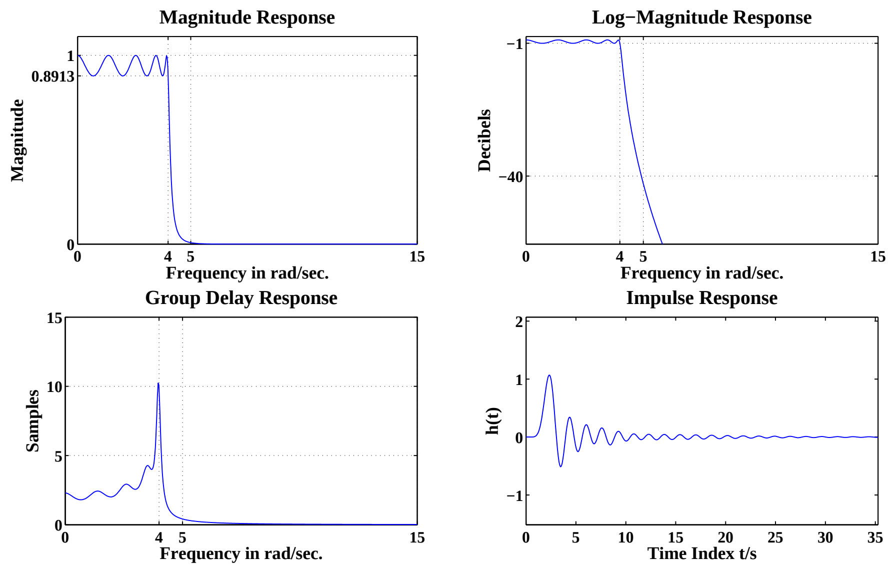

FIGURE 11.61: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

```
N = ceil(N);
% Step-3: Calculation of a and b
Omegac = Omegap;
gamma = (1/epsilon+sqrt(1+1/epsilon^2))^(1/N);
a = 0.5*(gamma-1/gamma); b = 0.5*(gamma+1/gamma);
% Step-4: Calculations of Poles
k = 1:N; thetak = pi/2+(2*k-1)*pi/(2*N);
sigmak = (a*Omegac)*cos(thetak); Omegak = (b*Omegac)*sin(thetak);
sk = cplxpair(sigmak + 1j*Omegak);
% Step-5: Calculation of the system function
D = real(poly(sk)); % Direct Form
if mod(N,2) == 0
    G = D(end)*Rp; %1/sqrt(1+epsilon^2);
else
    G = D(end);
end
C = G;

%% Design using SP Toolbox functions
% [N, Wp] = cheb1ord(Omegap, Omegas, Ap, As, 's');
```

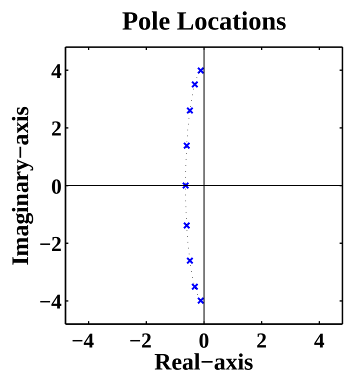

FIGURE 11.62: Pole-zero plot of the filter

```
% [c,d] = cheby1(N,Ap, Wp,'s');

%% Frequency Response
Ommax = 15;
Om = linspace(0,Ommax,501);
H = freqs(C,D,Om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];

%% Impulse response:
trsys = tf(C,D);
[ht t] = impulse(trsys);

%% Design Plots
hfa = figconfg('P1148a','small'); % magnitude
plot(Om,Hmag,'b','linewidth',1);
axis([0,Ommax,0,1.1]);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Omegac,Omegas,Ommax]);
set(gca,'ytick',[0,Rp,1]); grid;

hfb = figconfg('P1148b','small'); % Log-Magnitude Plot in dB
plot(Om,Hdb,'b','linewidth',1);
axis([0,Ommax,-60,1]);
```

```
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]);
set(gca,'ytick',[-As,-Ap]);grid

hfc = figconfg('P1148c','small'); % Group-Delay Plot in Samples
plot(Om,Hgdl,'b','linewidth',1);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]); grid

hfd = figconfg('P1105d','small'); % Pole-zero Plot
plot(sigmak,Omegak,'bx','linewidth',1.5); hold on;
ff = 1.2; pc = ff*Omegac;
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
plot(a*Omegac*cos(0.5*pi*[1:0.01:3]),b*Omegac*sin(0.5*pi*[1:0.01:3]),'k:');
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfe = figconfg('P1148e','small'); % Impulse response
plot(t,ht,'linewidth',1)
axis([t(1) t(end) min(ht)-1 max(ht)+1])
xlabel('Time Index t/s','fontsize',LFS);
ylabel('h(t)','fontsize',LFS);
title('Impulse Response','fontsize',TFS);
```

49. (a) See plot below.

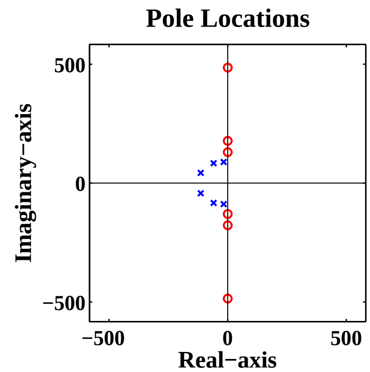

FIGURE 11.63: Pole locations of $H_c(s)$

(b) See plot below.

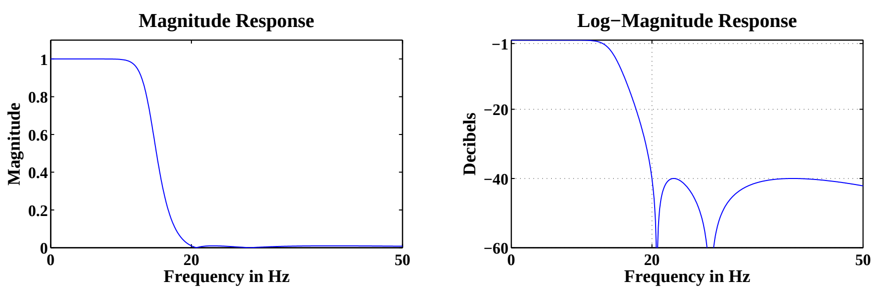

FIGURE 11.64: Magnitude and log-magnitude responses over $[0, 50]$ Hz range.

(c) Solution:
The frequencies are 17.39, 18.49, and 18.91 rad/s at which the attenuation is 0.1 dB, 0.5 dB, and 1 dB.

MATLAB script:

```
% P1149: Sixth order Chebyshev II low-pass filter
close all; clc
N = 6;
% Determine cutoff frequency
Hc = 20;
Omegac = Hc*2*pi;
As = 40;
```

```
A = 10^(0.05*As);
% Ap = 1;
% epsilon = sqrt(10^(0.1*Ap)-1);

gamma = (A+sqrt(A^2-1))^(1/N);
a = 0.5*(gamma-1/gamma);
b = 0.5*(gamma+1/gamma);
% Step-4: Calculations of Poles
k = 1:N; thetak = pi/2+(2*k-1)*pi/(2*N);
sigmak = (a*Omegac)*cos(thetak); Omegak = (b*Omegac)*sin(thetak);
pk = (sigmak + 1j*Omegak);
pk = (Omegac^2)./pk;
sigmapk = real(pk); Omegapk = imag(pk);
% Step-5: Calculation of Zeros
thetak = (2*k-1)*pi/(2*N);
if mod(N,2) == 1
    thetak = [thetak(1:(N-1)/2),thetak((N+3)/2:N)];
end
zk = 1j*Omegac./cos(thetak);
sigmazk = real(zk); Omegazk = imag(zk);

% Step-5: Calculation of the system function
C = real(poly(zk)); % Direct Form
D = real(poly(pk));
C = [0,C]; C = D(end)*C/C(end);

Fmax = 50;
F = linspace(0,Fmax,501);
Om = F*2*pi;
H = freqs(C,D,F*2*pi);
Hmag = abs(H); Hpha = angle(H);
Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];
% Part c: NOT COMPLETE
A = [0.1 0.5 1];
delta = (10.^(-A/20)).^2;
disp('Frequencies where attenuation is 0.1db, 0.5db, 1db')
F3 = Hc./cosh(acosh(sqrt((1./(1-delta)-1)./(epsilon^2)))/N),
%% Plot:
hfa = figconfg('P1149a','small');
```

```
plot(sigmapk,Omegapk,'bx','linewidth',1.5); hold on;
plot(sigmazk,Omegazk,'ro','linewidth',1.5);
ff = 1.2; pc = ff*max(abs([pk(:);zk(:)]));
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfb = figconfg('P1149b','small');
plot(F,Hmag,'b','linewidth',1);
axis([0,Fmax,0,1.1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Hc,Fmax]);

hfc = figconfg('P1149c','small');
plot(F,Hdb,'b','linewidth',1);
axis([0,Fmax,-60,0]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Hc,Fmax]);
set(gca,'ytick',[-60:20:-20,-1]); grid;
```

50. See plot below.

    MATLAB script:

```
% P1150: Analog Chebyshev II lowpass filter design
clc; close all;
% Given Design Parameters
Fp = 25; Fs = 30; Ap = 1; As = 40;
Omegap = 2*pi*Fp; Omegas = 2*pi*Fs;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
```

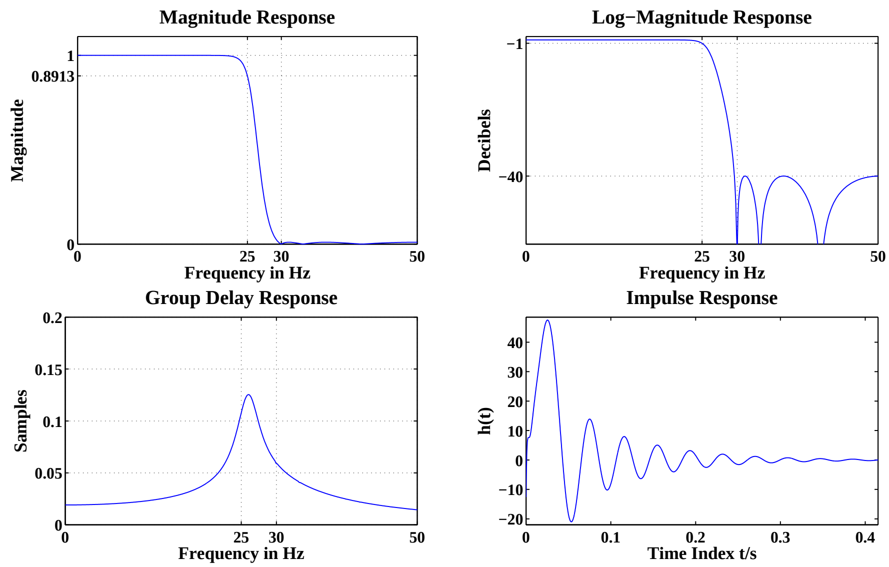

FIGURE 11.65: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

```
% Plotting Parameters
Fmax = 50; Ommax = 2*pi*Fmax;
F = linspace(0,Fmax,501); Om = 2*pi*F;

% Chebyshev-II Approximation
disp('** Chebyshev-II **');
[N, Omegac] = cheb2ord(Omegap, Omegas, Ap, As, 's');
Fc = Omegac/(2*pi);
[C,D] = cheby2(N,As,Omegac,'s'); H = freqs(C,D,Om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
pk = roots(D); sigmapk = real(pk); Omegapk = imag(pk);
zk = roots(C); sigmazk = real(zk); Omegazk = imag(zk);

%% Impulse response:
trsys = tf(C,D);
[ht t] = impulse(trsys);

%% Design Plots
```

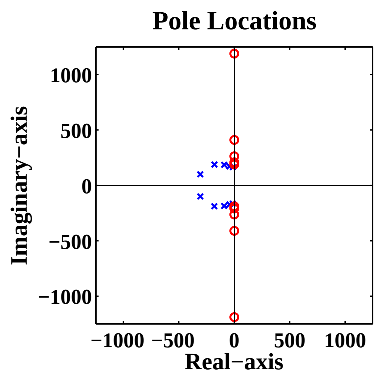

FIGURE 11.66: Pole-zero plot of the filter

```
hfa = figconfg('P1150a','small'); % magnitude
plot(F,Hmag,'b','linewidth',1);
axis([0,Fmax,0,1.1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[0,Rp,1]); grid;

hfb = figconfg('P1150b','small'); % Log-Magnitude Plot in dB
plot(F,Hdb,'b','linewidth',1);
axis([0,Fmax,-60,1]);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]);
set(gca,'ytick',[-As,-Ap]);grid

hfc = figconfg('P1150c','small'); % Group-Delay Plot in Samples
plot(F,Hgdl,'b','linewidth',1);
xlabel('Frequency in Hz','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,Fp,Fs,Fmax]); grid

hfd = figconfg('P1150d','small'); % Pole-zero Plot
```

```
plot(sigmapk,Omegapk,'bx','linewidth',1.5); hold on;
plot(sigmazk,Omegazk,'ro','linewidth',1.5);
ff = 1.05; pc = ff*max(abs([pk(:);zk(:)]));
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfe = figconfg('P1150e','small'); % Impulse response
plot(t,ht,'linewidth',1)
axis([t(1) t(end) min(ht)-1 max(ht)+1])
xlabel('Time Index t/s','fontsize',LFS);
ylabel('h(t)','fontsize',LFS);
title('Impulse Response','fontsize',TFS);
```

51. See plot below.

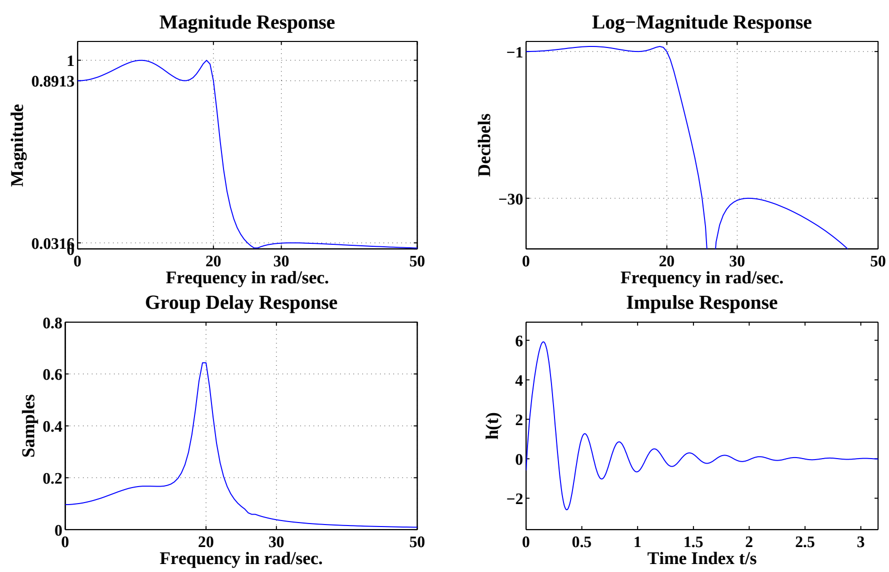

FIGURE 11.67: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

MATLAB script:

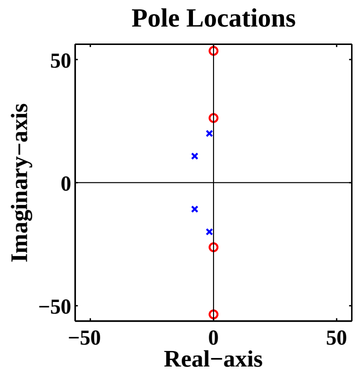

FIGURE 11.68: Pole-zero plot of the filter

```
% P1151: Analog Elliptic low-pass filter design
clc; close all; %echo on;
% Given Design Parameters
Omegap = 20; Omegas = 30; Ap = 1; As = 30;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
% Elliptic Approximation
disp('** Elliptic **');
[N, Omegac] = ellipord(Omegap, Omegas, Ap, As, 's');
[C,D] = ellip(N,Ap,As,Omegac,'s');
Ommax = 50; Om = linspace(0,Ommax,101); H = freqs(C,D,Om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(Om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
pk = roots(D); sigmapk = real(pk); Omegapk = imag(pk);
zk = roots(C); sigmazk = real(zk); Omegazk = imag(zk);

%% Impulse response:
trsys = tf(C,D);
[ht t] = impulse(trsys);

%% Design Plots
hfa = figconfg('P1151a','small'); % magnitude
plot(Om,Hmag,'b','linewidth',1);
axis([0,Ommax,0,1.1]);
```

```
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]);
set(gca,'ytick',[0,1/A,Rp,1]); grid;

hfb = figconfg('P1151b','small'); % Log-Magnitude Plot in dB
plot(Om,Hdb,'b','linewidth',1);
axis([0,Ommax,-40,1]);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]);
set(gca,'ytick',[-As,-Ap]);grid

hfc = figconfg('P1151c','small'); % Group-Delay Plot in Samples
plot(Om,Hgdl,'b','linewidth',1);
xlabel('Frequency in rad/sec.','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,Omegap,Omegas,Ommax]); grid

hfd = figconfg('P1151d','small'); % Pole-zero Plot
plot(sigmapk,Omegapk,'bx','linewidth',1.5); hold on;
plot(sigmazk,Omegazk,'ro','linewidth',1.5);
ff = 1.05; pc = ff*max(abs([pk(:);zk(:)]));
plot([-pc,pc],[0,0],'k','linewidth',0.75);
plot([0,0],[-pc,pc],'k','linewidth',0.75);
axis([-pc,pc,-pc,pc]);
axis square;
xlabel('Real-axis','fontsize',LFS);
ylabel('Imaginary-axis','fontsize',LFS);
title('Pole Locations','fontsize',TFS);

hfe = figconfg('P1151e','small');  % Impulse response
plot(t,ht,'linewidth',1)
axis([t(1) t(end) min(ht)-1 max(ht)+1])
xlabel('Time Index t/s','fontsize',LFS);
ylabel('h(t)','fontsize',LFS);
title('Impulse Response','fontsize',TFS);
```

52. (a) Solution:
Applying the Laplace transform property, that is

$$\frac{t^n}{n!}\mathrm{e}^{-at}u(t) \overset{\mathrm{LT}}{\longleftrightarrow} \frac{1}{(s+a)^{n+1}}, \quad \mathrm{Re}\{s\} > -a$$

The impulse response $h_\mathrm{c}(t)$ is:

$$h_\mathrm{c}(t) = t\mathrm{e}^{\alpha t} \cdot u(t)$$

Sample it at $t = nT_\mathrm{d}$, we have

$$h[n] = h_\mathrm{c}(nT_\mathrm{d}) = T_\mathrm{d} \cdot n \cdot \mathrm{e}^{\alpha T_\mathrm{d} \cdot n} \cdot u[n]$$

(b) Solution:
Applying z-transform pair of $a[n] = \mathrm{e}^{\alpha T_\mathrm{d} \cdot n} \cdot u[n]$, we have

$$A(z) = \frac{1}{1 - \mathrm{e}^{\alpha T_\mathrm{d}} z^{-1}}, \quad |z| > |\mathrm{e}^{\alpha T_\mathrm{d}}|$$

Applying z-transform property that

$$n \cdot a[n] \overset{\mathrm{ZT}}{\longleftrightarrow} (-z)\, \frac{\mathrm{d}\, A(z)}{\mathrm{d}\, z}$$

Hence, we compute $H(z)$ as:

$$H(z) = T_\mathrm{d} \cdot (-z) \cdot \frac{\mathrm{d}\, A(z)}{\mathrm{d}\, z} = T_\mathrm{d} \cdot \frac{\mathrm{e}^{\alpha T_\mathrm{d}} z^{-1}}{(1 - \mathrm{e}^{\alpha T_\mathrm{d}} z^{-1})^2}$$

(c) tba.

53. See plot below.

MATLAB script:

```
% P1153: Low-pass analog filter by butterworth and transformation
%        using impulse invariance method
clc; close all;
% Given Design Parameters
omegap = 0.4*pi; omegas = 0.5*pi; Ap = 0.5; As = 40;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
```

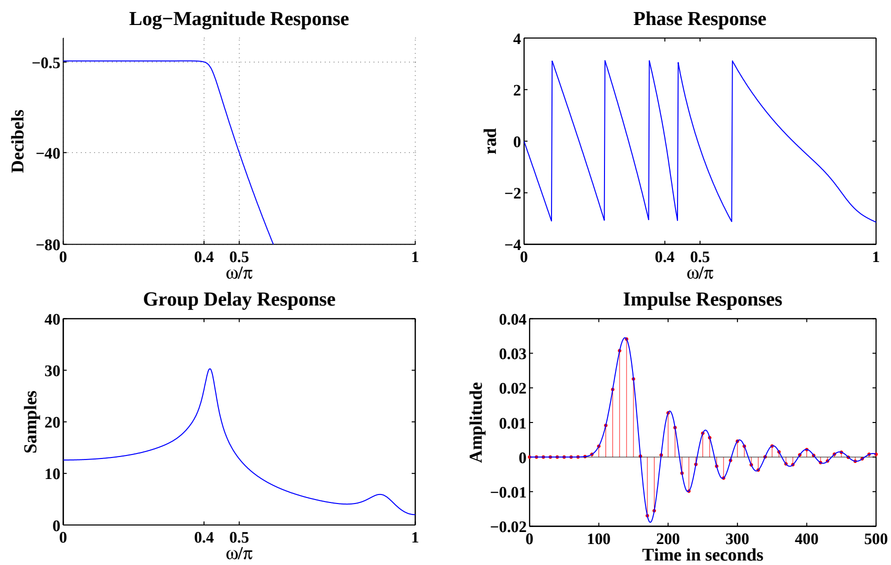

FIGURE 11.69: Plots of log-magnitude, phase, group, and impulse responses.

```
% Step-1: Choose Td
Td = 10;
% Step-2: Compute Analog Edge Frequencies
Omegap = omegap/Td; Omegas = omegas/Td;
% Step-3: Design Analog Butterworth Approximation
[N,Omegac] = buttord(Omegap,Omegas,Ap,As,'s');
[C,D] = butter(N,Omegac,'s');
% Step-4: Obtain Digital Butterworth Filter
[B,A] = impinvar(C,D,1/Td);

% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);

%% Design Plots
hfa = figconfg('P1153a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
```

```
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1153b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1153c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1153d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

54. See plot below.

MATLAB script:

```
% P1154: Low-pass analog filter by Chebyshev I and transformation
%        using impulse invariance method
clc; close all;
% Given Design Parameters
omegap = 0.25*pi; omegas = 0.35*pi; Ap = 0.5; As = 50;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
```

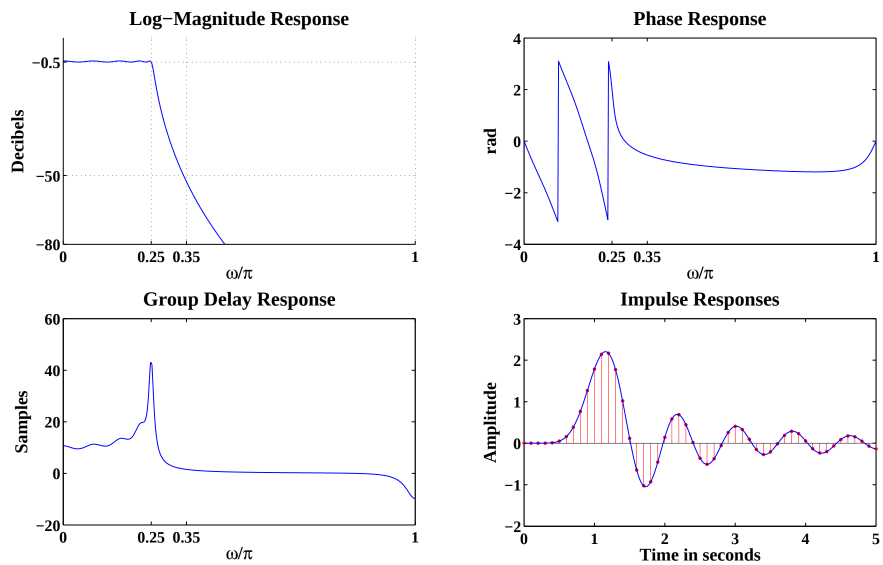

FIGURE 11.70: Plots of log-magnitude, phase, group, and impulse responses.

```
Td = 0.1;
% Step-2: Compute Analog Edge Frequencies
Omegap = omegap/Td; Omegas = omegas/Td;
% Step-3: Design Analog Chebyshev I Approximation
[N,Omegac] = cheb1ord(Omegap,Omegas,Ap,As,'s');
[C,D] = cheby1(N,Ap,Omegac,'s');
% Step-4: Obtain Digital Chebyshev I Filter
[B,A] = impinvar(C,D,1/Td);

% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);

%% Design Plots
hfa = figconfg('P1154a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
```

```
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1154b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1154c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1154d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

55. (a) See plot below.

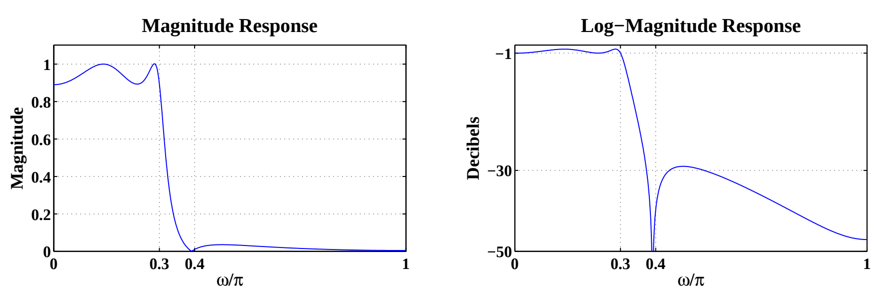

FIGURE 11.71: Plot the magnitude and log-magnitude responses when $As = 50$ dB.

(b) See plot below.

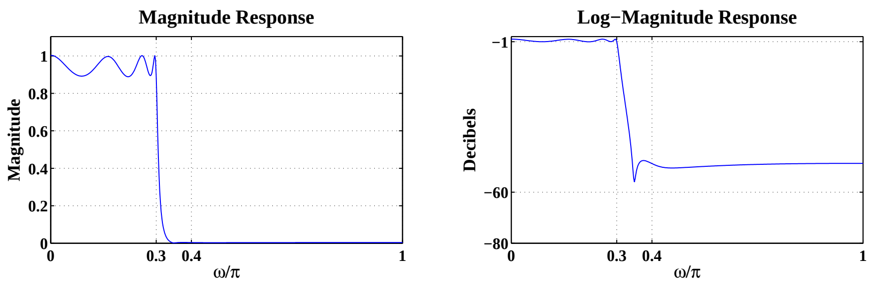

FIGURE 11.72: Plot the magnitude and log-magnitude responses when $As = 70$ dB.

MATLAB script:

```
% P1155: Low-pass analog filter by elliptic and transformation
%        using impulse invariance method
clc; close all;
wp = 0.3*pi; ws = 0.4*pi; Ap = 1;
As = 30; % part a
% As = 60; % part b
Td = 2;
[N,Omegac] = ellipord(wp/Td,ws/Td,Ap,As,'s');
[b,a] = ellip(N,Ap,As,Omegac,'s');
[B,A] = impinvar(b,a,1/Td);
w = linspace(0,1,501)*pi;
Hd = freqz(B,A,w);
Hdmag = abs(Hd); Hddb = 20*log10(Hdmag./max(Hdmag));

%% Design Plots
hfa = figconfg('P1155a','small'); % Magnitude Plot
plot(w/pi,Hdmag,'b','linewidth',1);
axis([0,1,0,max(Hdmag)+0.1]);
set(gca,'xtick',[0 wp/pi ws/pi 1]); grid
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);

hfb = figconfg('P1155b','small'); % Log-Magnitude Plot in dB
plot(w/pi,Hddb,'b','linewidth',1);
axis([0,1,-As-20,1]);
```

```
set(gca,'ytick',[-As-20,-As,-Ap])
set(gca,'xtick',[0 wp/pi ws/pi 1]); grid
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
```

56. See plot below.

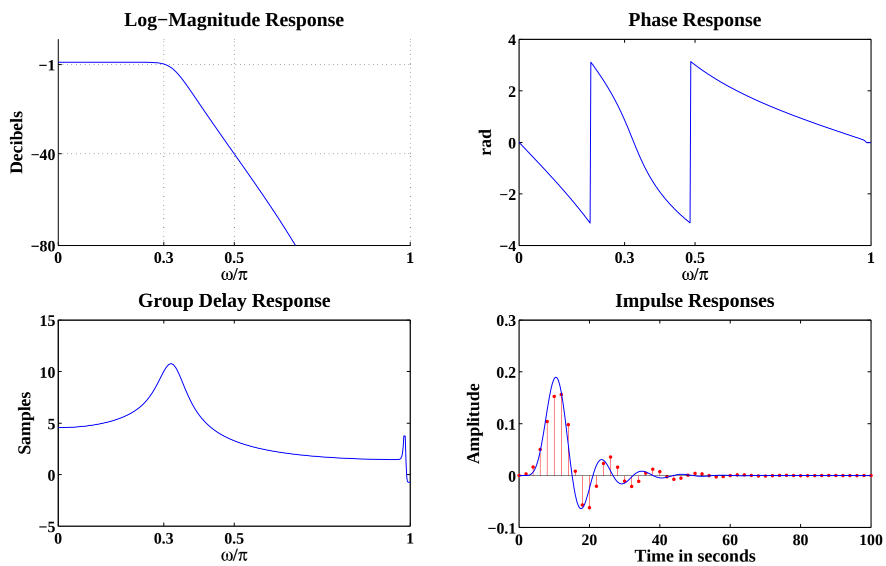

FIGURE 11.73: Plots of log-magnitude, phase, group, and impulse responses.

MATLAB script:

```
% P1156: Lowpass filter design by Butterworth and tranformation
%        using bilinear method
clc; close all;
% Given Design Parameters
omegap = 0.3*pi; omegas = 0.5*pi; Ap = 1; As = 40;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
Td = 2;
% Step-2: Compute Analog Edge Frequencies
```

```
Omegap = 2/Td*tan(omegap/2); Omegas = 2/Td*tan(omegas/2);
% Step-3: Design Analog Butterworth Approximation
[N,Omegac] = buttord(Omegap,Omegas,Ap,As,'s');
[C,D] = butter(N,Omegac,'s');
% Step-4: Obtain Digital Butterworth Filter
[B,A] = bilinear(C,D,1/Td);
[sos G] = tf2sos(B,A);
% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);
% Exact Frequency:
ind = find(Hdb < -Ap,1,'first'); om1 = om(ind)/pi; % Exact Passband Edge
ind = find(Hdb < -As,1,'first'); om2 = om(ind)/pi; % Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1156a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1156b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1156c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
```

```
hfd = figconfg('P1156d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

57. (a) See script below.
    (b) See plot below.
    (c) Solution:
    The exact band-edge frequencies are 0.2π and 0.396π.

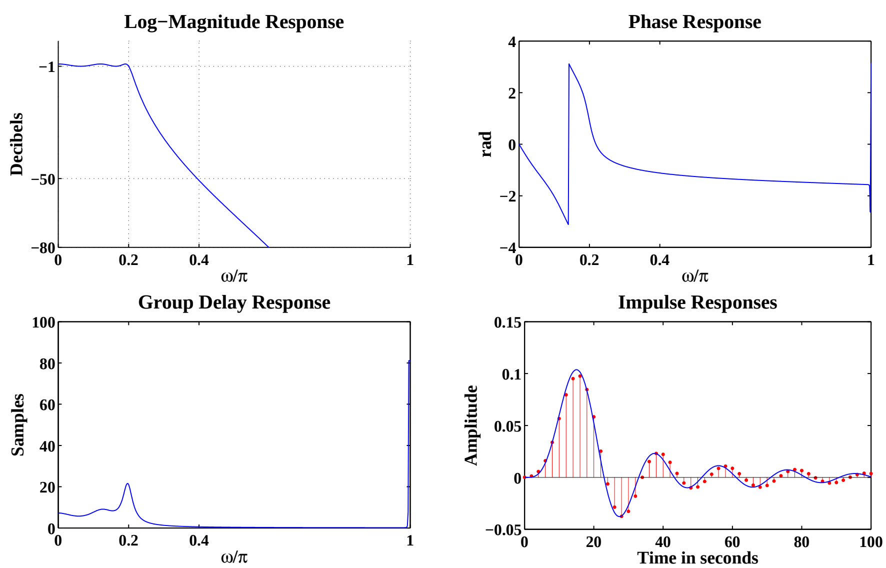

FIGURE 11.74: Plots of log-magnitude, phase, group, and impulse responses.

MATLAB script:

```
% P1157: Lowpass filter design by Chebyshev I and tranformation
%        using bilinear method
clc; close all;
% Given Design Parameters
omegap = 0.2*pi; omegas = 0.4*pi; Ap = 1; As = 50;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
```

```
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
Td = 2;
% Step-2: Compute Analog Edge Frequencies
Omegap = 2/Td*tan(omegap/2); Omegas = 2/Td*tan(omegas/2);
% Step-3: Design Analog Chebyshev I Approximation
[N,Omegac] = cheb1ord(Omegap,Omegas,Ap,As,'s');
[C,D] = cheby1(N,Ap,Omegac,'s');
% Step-4: Obtain Digital Chebyshev I Filter
[B,A] = bilinear(C,D,1/Td);
[sos G] = tf2pf(B,A);
% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);
% Exact Frequency:
ind = find(Hdb < -Ap,1,'first'); om1 = om(ind)/pi; % Exact Passband Edge
ind = find(Hdb < -As,1,'first'); om2 = om(ind)/pi; % Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1157a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1157b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1157c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
```

```
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1157d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

58. (a) See script below.
    (b) See plot below.
    (c) Solution:
    The exact band-edge frequencies are 0.452π and 0.548π.

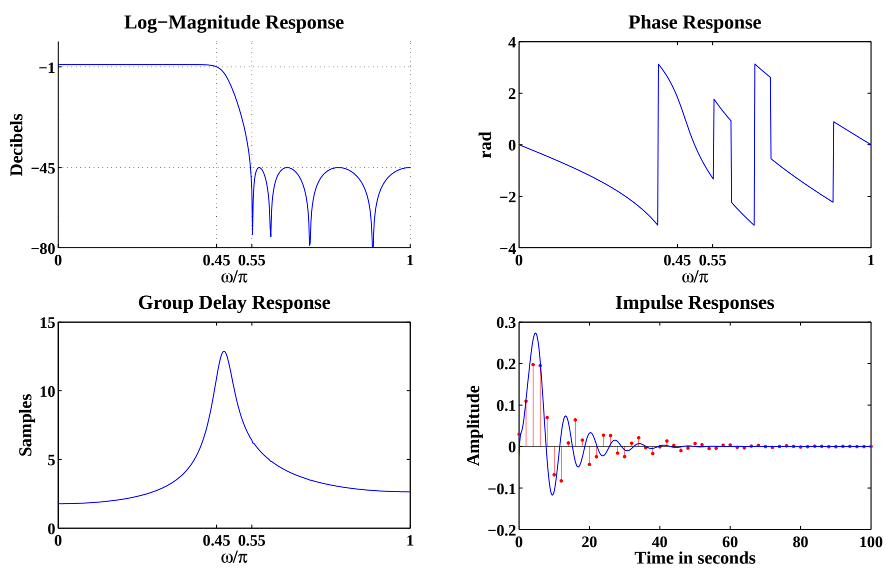

FIGURE 11.75: Plots of log-magnitude, phase, group, and impulse responses.

MATLAB script:

```
% P1158: Lowpass filter design by Chebyshev II and tranformation
%        using bilinear method
clc; close all;
% Given Design Parameters
```

```
omegap = 0.45*pi; omegas = 0.55*pi; Ap = 1; As = 45;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
Td = 2;
% Step-2: Compute Analog Edge Frequencies
Omegap = 2/Td*tan(omegap/2); Omegas = 2/Td*tan(omegas/2);
% Step-3: Design Analog Chebyshev II Approximation
[N,Omegac] = cheb2ord(Omegap,Omegas,Ap,As,'s');
[C,D] = cheby2(N,As,Omegac,'s');
% Step-4: Obtain Digital Chebyshev II Filter
[B,A] = bilinear(C,D,1/Td);
[sos G] = tf2pf(B,A);
% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);
% Exact Frequency:
ind = find(Hdb < -Ap,1,'first'); om1 = om(ind)/pi; % Exact Passband Edge
ind = find(Hdb < -As,1,'first'); om2 = om(ind)/pi; % Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1158a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1158b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
```

```
hfc = figconfg('P1158c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1158d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

59. (a) See script below.
    (b) See plot below.
    (c) Solution:
    The exact band-edge frequencies are 0.2π and 0.318π.

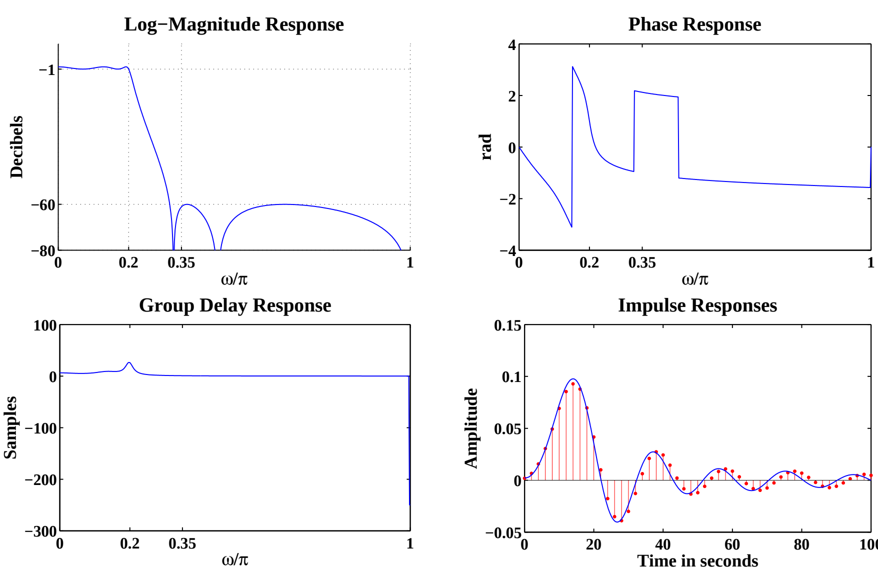

FIGURE 11.76: Plots of log-magnitude, phase, group, and impulse responses.

MATLAB script:

```
% P1159: Lowpass filter design by elliptic and tranformation
%        using bilinear method
clc; close all;
% Given Design Parameters
omegap = 0.2*pi; omegas = 0.35*pi; Ap = 1; As = 60;
% Analog Design Parameters (Eq. 10.9)
epsilon = sqrt(10^(0.1*Ap)-1); A = 10^(0.05*As);
Rp = 1/sqrt(1+epsilon^2);
%% Step by Step Impulse Invariance Design
% Step-1: Choose Td
Td = 2;
% Step-2: Compute Analog Edge Frequencies
Omegap = 2/Td*tan(omegap/2); Omegas = 2/Td*tan(omegas/2);
% Step-3: Design Analog Elliptic Approximation
[N,Omegac] = ellipord(Omegap,Omegas,Ap,As,'s');
[C,D] = ellip(N,Ap,As,Omegac,'s');
% Step-4: Obtain Digital Elliptic Filter
[B,A] = bilinear(C,D,1/Td);
[sos G] = tf2pf(B,A);
% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
t = linspace(0,NN*Td,501); hc = impulse(C,D,t);
% Exact Frequency:
ind = find(Hdb < -Ap,1,'first'); om1 = om(ind)/pi; % Exact Passband Edge
ind = find(Hdb < -As,1,'first'); om2 = om(ind)/pi; % Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1159a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1159b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
```

```
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfc = figconfg('P1159c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap,omegas,pi]/pi);

hfd = figconfg('P1159d','small'); % Impulse Response Plots
stem(n*Td,h/Td,'filled','markersize',3,'color','r'); hold on;
plot(t,hc,'b','linewidth',1);
xlabel('Time in seconds','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

60. (a) See plot below.

    (b) See plot below.

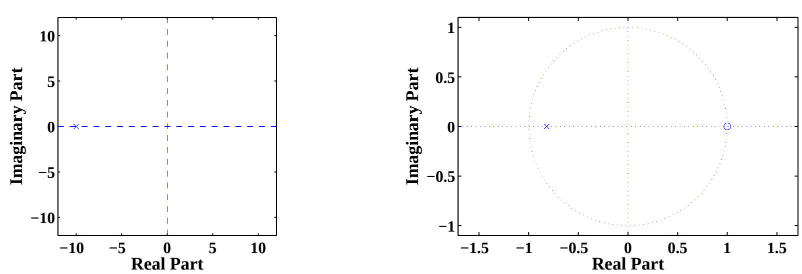

FIGURE 11.77: Plots of pole and zero locations for the analog bandpass filter and for the digital filter with $T_{\text{d}} = 2$.

    (c) See plot below.

MATLAB script:

```
% P1160: Continuous-Time Frequency Transformation: Lowpass to Highpass
close all; clc
C = 10; D = [1 1]; Omegac = 10; Td = 2;
```

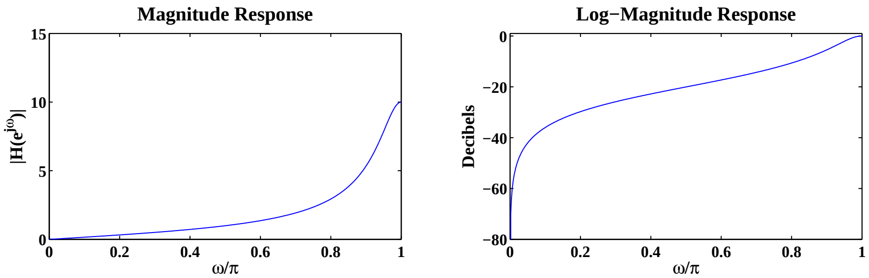

FIGURE 11.78: Plots of the magnitude response of the digital filter.

```
[Bc,Ac] = lp2hp(C,D,Omegac); % continuous highpass filter
[rc,pc,kc] = residue(Bc,Ac);
[B,A] = bilinear(Bc,Ac,1/Td); % digital highpass filter
[r,p,k] = residuez(B,A);
om = linspace(0,1,501)*pi;
H = freqz(B,A,om); Hmag = abs(H); Hdb = 20*log10(Hmag/max(Hmag));

%% Plot
hfa = figconfg('P1160a','small'); % CT Pole-Zero plot
pv = abs(pc); pv = 1.2*pv;
plot(real(pc),imag(pc),'marker','x','color','b','markersize',8);hold on
plot([-pv pv],[0 0],'--b'); plot([0 0],[-pv pv],'--b'); axis square
axis([-pv pv -pv pv])
xlabel('Real Part','fontsize',LFS);
ylabel('Imaginary Part','fontsize',LFS);

hfb = figconfg('P1160b','small'); % DT Pole-Zero plot
zplane(B,A)
xlabel('Real Part','fontsize',LFS);
ylabel('Imaginary Part','fontsize',LFS);

hfc = figconfg('P1160c','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('|H(e^{j\omega})|','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);

hfd = figconfg('P1160d','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1);
```

```
axis([0,1,-80,1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
```

61. (a) See plot below.
    (b) See plot below.

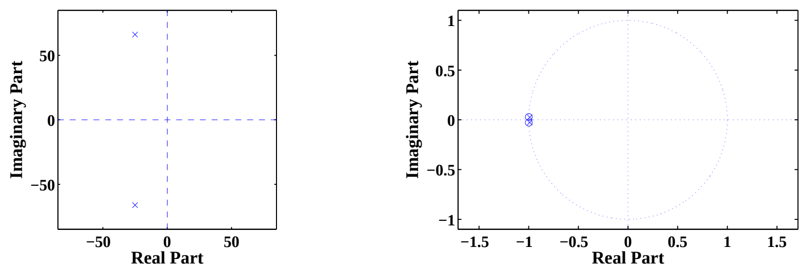

FIGURE 11.79: Plots of pole and zero locations for the analog bandpass filter and for the digital filter with $T_{\mathrm{d}} = 2$.

(c) See plot below.

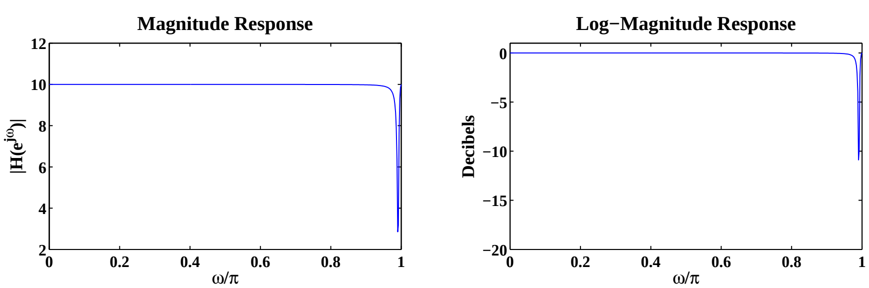

FIGURE 11.80: Plots of the magnitude response of the digital filter.

MATLAB script:

```
% P1161: Continuous-Time Frequency Transformation: Lowpass to Bandstop
close all; clc
C = 10; D = [1 1]; Omegac1 = 50; Omegac2 = 100; Td = 2;
Omega0 = sqrt(Omegac1*Omegac2); BW = Omegac2 - Omegac1;
[Bc,Ac] = lp2bs(C,D,Omega0,BW); % continuous bandstop filter
[rc,pc,kc] = residue(Bc,Ac);
```

```
[B,A] = bilinear(Bc,Ac,1/Td); % digital bandstop filter
[r,p,k] = residuez(B,A);
om = linspace(0,1,501)*pi;
H = freqz(B,A,om); Hmag = abs(H); Hdb = 20*log10(Hmag/max(Hmag));

%% Plot
hfa = figconfg('P1161a','small'); % CT Pole-Zero plot
pv = max(abs(pc)); pv = 1.2*pv;
plot(real(pc),imag(pc),'x','markersize',8);hold on
plot([-pv pv],[0 0],'--b'); plot([0 0],[-pv pv],'--b'); axis square
axis([-pv pv -pv pv])
xlabel('Real Part','fontsize',LFS);
ylabel('Imaginary Part','fontsize',LFS);

hfb = figconfg('P1161b','small'); % DT Pole-Zero plot
zplane(B,A)
xlabel('Real Part','fontsize',LFS);
ylabel('Imaginary Part','fontsize',LFS);

hfc = figconfg('P1161c','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('|H(e^{j\omega})|','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);

hfd = figconfg('P1161d','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1);
axis([0,1,-20,1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
```

62. (a) Solution:
Calculate the resulting zero and pole of $H_{\text{hp}}(z)$, we have

$$r_{\text{hp}} = -\frac{r_{\text{lp}} + \alpha}{1 + \alpha r_{\text{lp}}}$$

According to the formula above, we can compute the correspondent pole and zero as:

$$z_1^{\text{lp}} = -1 \longrightarrow z_1^{\text{hp}} = -\frac{-1+\alpha}{1-\alpha} = 1$$

$$p_1^{\text{lp}} = a \longrightarrow p_1^{\text{hp}} = -\frac{a+\alpha}{1+a\alpha}$$

(b) Solution:
Applying direct substitution of the transformation into $H_{\text{lp}}(z)$, we have

$$H_{\text{hp}}(z) = \frac{(1-\alpha) + (\alpha - 1)z^{-1}}{(1+a\alpha) + (\alpha + a)z^{-1}}$$

Compute its pole and zero, we have

$$z_1^{\text{hp}} = 1, \quad p_1^{\text{hp}} = -\frac{a+\alpha}{1+a\alpha}$$

63. (a) See script below.
(b) See plot below.
(c) Solution:
The exact band-edge frequencies are 0.698π and 0.898π.

MATLAB script:

```
% P1163: Digital highpass filter design by Butterworth
close all; clc;
%% Filter Design
omegas = 0.7*pi; omegap = 0.9*pi; As = 40; Ap = 0.5; % Specification
[N,omegac] = buttord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = butter(N,omegac,'high'); % coefficients
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
```

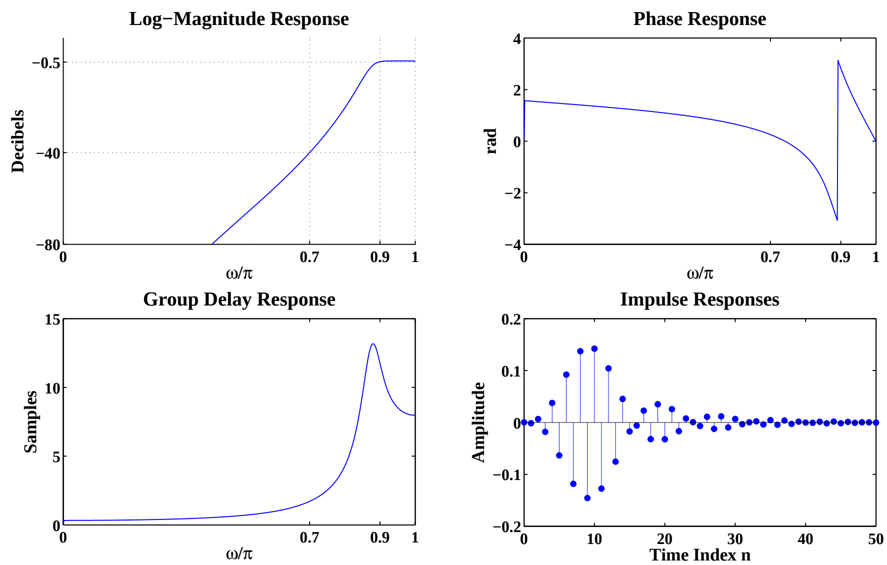

FIGURE 11.81: Plots of log-magnitude, phase, group, and impulse responses.

```
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb < -As,1,'last'); om1 = om(ind)/pi; % Exact stopband Edge
ind = find(Hdb > -Ap,1,'first'); om2 = om(ind)/pi; % Exact Passband Edge
%% Design Plots
hfa = figconfg('P1163a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1163b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);

hfc = figconfg('P1163c','small'); % Group-Delay Plot in Samples
```

```
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);

hfd = figconfg('P1163d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

64. (a) See script below.
    (b) See plot below.
    (c) Solution:
    The exact band-edge frequencies are 0.688π and 0.802π.

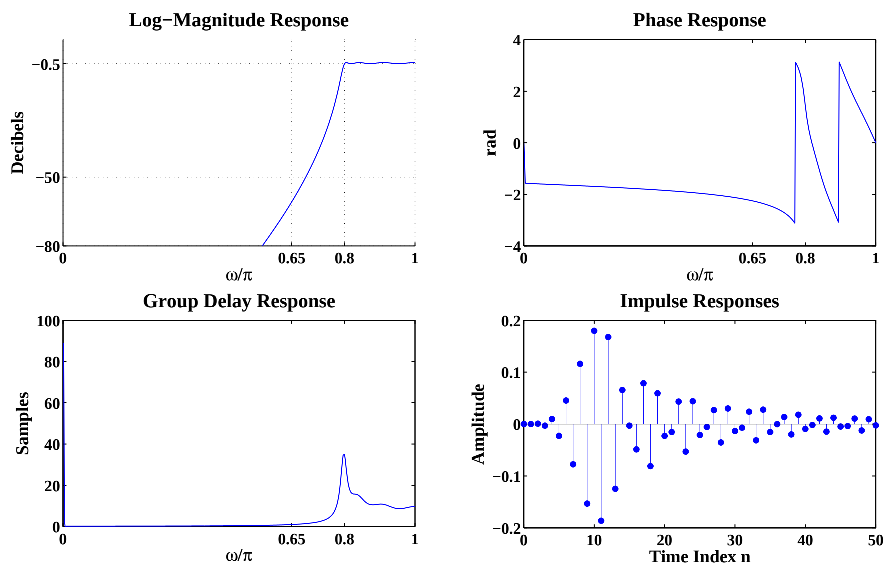

FIGURE 11.82: Plots of log-magnitude, phase, group, and impulse responses.

MATLAB script:

```
% P1164: Digital highpass filter design by Chebyshev I
close all; clc;
%% Filter Design
```

```
omegas = 0.65*pi; omegap = 0.8*pi; As = 50; Ap = 0.5; % Specification
[N,omegac] = cheb1ord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = cheby1(N,Ap,omegac,'high'); % coefficients
[sos G] = tf2sos(B,A); % cascade form
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb < -As,1,'last'); om1 = om(ind)/pi; % Exact stopband Edge
ind = find(Hdb > -Ap,1,'first'); om2 = om(ind)/pi; % Exact Passband Edge
%% Design Plots
hfa = figconfg('P1164a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;
hfb = figconfg('P1164b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);
hfc = figconfg('P1164c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);
hfd = figconfg('P1164d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

65. (a) See script below.
    (b) See plot below.
    (c) Solution:
    The exact band-edge frequencies are 0.736π and 0.802π.

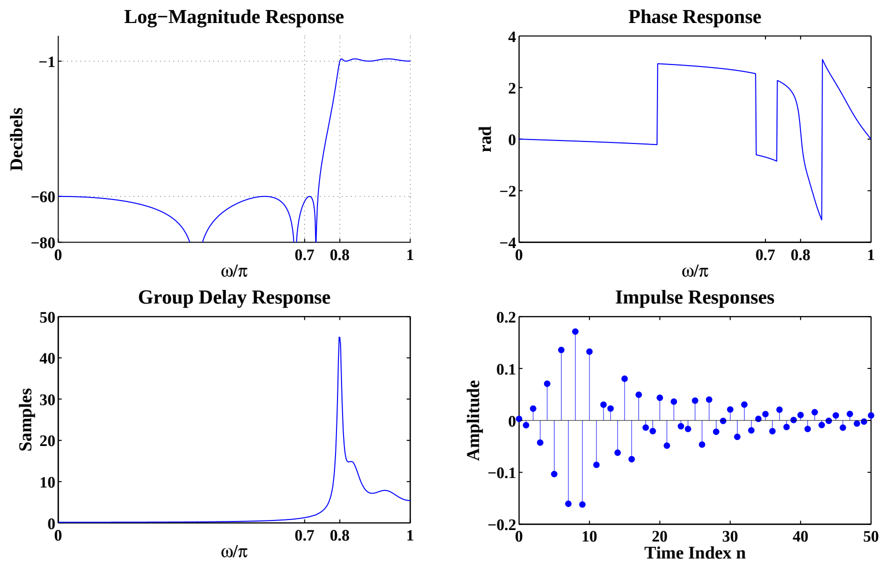

FIGURE 11.83: Plots of log-magnitude, phase, group, and impulse responses.

MATLAB script:

```
% P1165: Digital highpass filter design by elliptic
close all; clc;
%% Filter Design
omegas = 0.7*pi; omegap = 0.8*pi; As = 60; Ap = 1; % Specification
[N,omegac] = ellipord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = ellip(N,Ap,As,omegac,'high'); % coefficients
[sos G] = tf2pf(B,A); % parallel form
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb < -As,1,'last'); om1 = om(ind)/pi; % Exact stopband Edge
```

```
ind = find(Hdb > -Ap,1,'first'); om2 = om(ind)/pi; % Exact Passband Edge
%% Design Plots
hfa = figconfg('P1165a','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfb = figconfg('P1165b','small'); % Phase Plot
plot(om/pi,Hpha,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('rad','fontsize',LFS);
title('Phase Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);

hfc = figconfg('P1165c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas,omegap,pi]/pi);

hfd = figconfg('P1165d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

66. (a) See script below.
    (b) See plot below.
    (c) Solution:
    The exact band-edge frequencies are 0.242π and 0.632π for passband and 0.35π and 0.5π for stopband.

MATLAB script:

```
% P1166: Digital bandstop filter design by Butterworth
close all; clc;
```

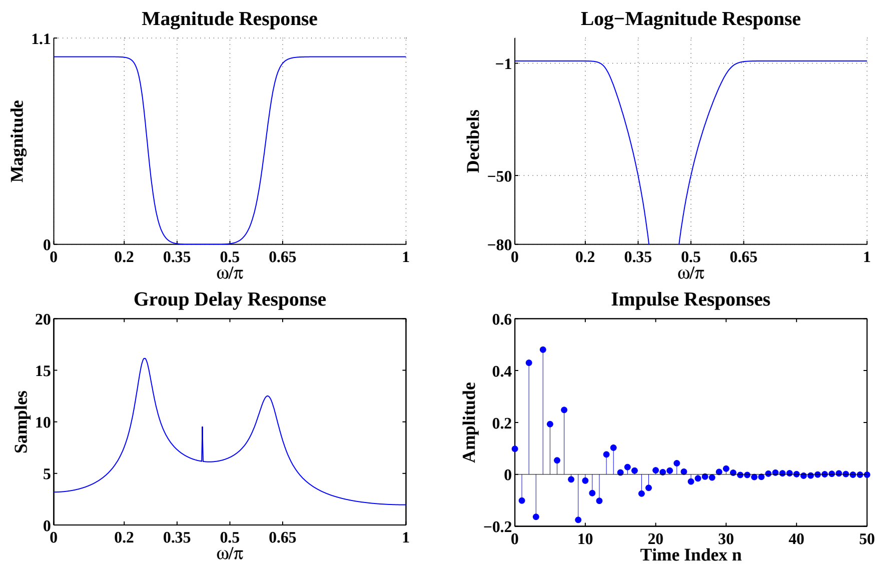

FIGURE 11.84: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

```
%% Filter Design
omegap1 = 0.2*pi; omegas1 = 0.35*pi; omegas2 = 0.5*pi; omegap2 = 0.65*pi;
Ap1 = 1; As = 50; Ap2 = 1; % Specification
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; Ap = min(Ap1,Ap2);
[N,omegac] = buttord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = butter(N,omegac,'stop'); % coefficients
[sos G] = tf2sos(B,A); % cascade form
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb >= -Ap); ind2 = find(om(ind)<omegas1,1,'last');
omp1 = om(ind(ind2))/pi; omp2 = om(ind(ind2+1))/pi;% Exact Passband Edge
ind = find(Hdb <= -As);
oms1 = om(ind(1))/pi; oms2 = om(ind(end))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1166a','small'); % Magnitude Response
```

```
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
set(gca,'ytick',[0,1.1]); grid; box off;

hfb = figconfg('P1166b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfc = figconfg('P1166c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);

hfd = figconfg('P1166d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

67. (a) See script below.
    (b) See plot below.
    (c) Solution:
    The exact band-edge frequencies are 0.452π and 0.548π for passband and 0.41π and 0.59π for stopband.

MATLAB script:

```
% P1167: Digital bandpass filter design by Chebyshev I
close all; clc;
%% Filter Design
omegas1 = 0.4*pi; omegap1 = 0.45*pi; omegap2 = 0.55*pi; omegas2 = 0.65*pi;
```

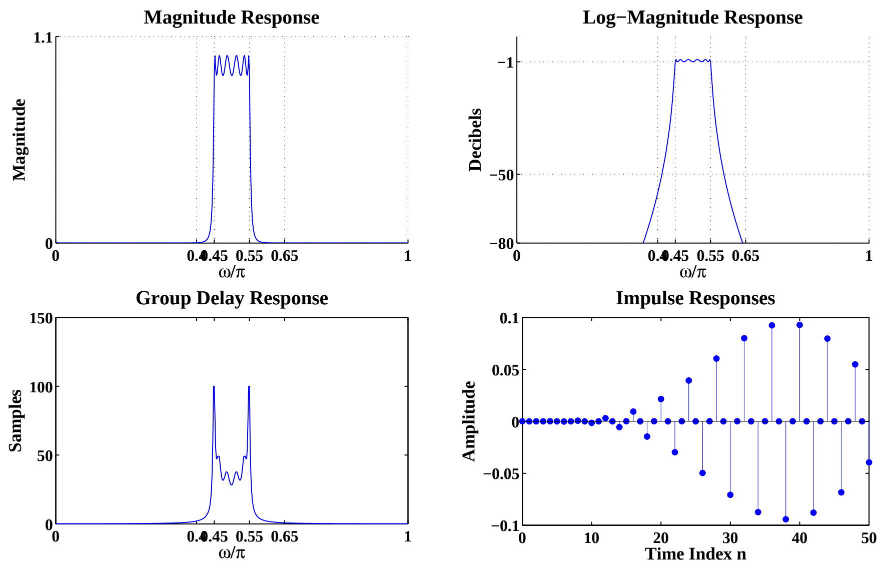

FIGURE 11.85: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

```
As1 = 40; Ap = 1; As2 = 50; % Specification
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; As = max(As1,As2);
[N,omegac] = cheb1ord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = cheby1(N,Ap,omegac); % coefficients
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb > -Ap);
omp1 = om(ind(1))/pi; omp2 = om(ind(end))/pi;% Exact Passband Edge
ind = find(Hdb < -As); ind2 = find(om(ind)<omegap1,1,'last');
oms1 = om(ind(ind2))/pi; oms2 = om(ind(ind2+1))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1167a','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
```

```
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[0,1.1]); grid; box off;

hfb = figconfg('P1167b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfc = figconfg('P1167c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);

hfd = figconfg('P1167d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

68. (a) See script below.
    (b) See plot below.
    (c) Solution:
    The exact band-edge frequencies are 0.198π and 0.652π for passband and 0.308π and 0.502π for stopband.

MATLAB script:

```
% P1168: Digital bandstop filter design by elliptic
close all; clc;
%% Filter Design
omegap1 = 0.2*pi; omegas1 = 0.35*pi; omegas2 = 0.5*pi; omegap2 = 0.65*pi;
Ap1 = 1; As = 60; Ap2 = 0.5; % Specification
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; Ap = min(Ap1,Ap2);
[N,omegac] = ellipord(omegap/pi,omegas/pi,Ap,As); % Order define
```

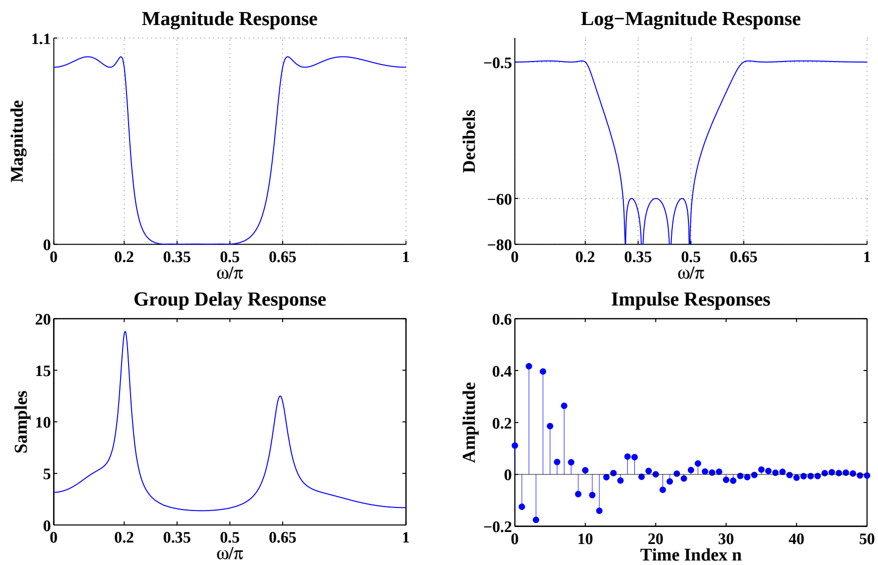

FIGURE 11.86: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

```
[B,A] = ellip(N,Ap,As,omegac,'stop'); % coefficients
[sos G] = tf2sos(B,A); % cascade form
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb >= -Ap); ind2 = find(om(ind)<omegas1,1,'last');
omp1 = om(ind(ind2))/pi; omp2 = om(ind(ind2+1))/pi;% Exact Passband Edge
ind = find(Hdb <= -As);
oms1 = om(ind(1))/pi; oms2 = om(ind(end))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1168a','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
```

```
set(gca,'ytick',[0,1.1]); grid; box off;

hfb = figconfg('P1168b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfc = figconfg('P1168c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);

hfd = figconfg('P1168d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

69. (a) See script below.
    (b) See plot below.
    (c) Solution:
    The exact band-edge frequencies are 0.458π and 0.594π for passband and 0.4π and 0.652π for stopband.

MATLAB script:

```
% P1169: Digital bandpass filter design by Chebyshev II
close all; clc;
%% Filter Design
omegas1 = 0.4*pi; omegap1 = 0.45*pi; omegap2 = 0.55*pi; omegas2 = 0.65*pi;
As1 = 40; Ap = 0.5; As2 = 50; % Specification
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; As = max(As1,As2);
[N,omegac] = cheb2ord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = cheby2(N,As,omegac); % coefficients
[sos G] = tf2pf(B,A); % parallel form
```

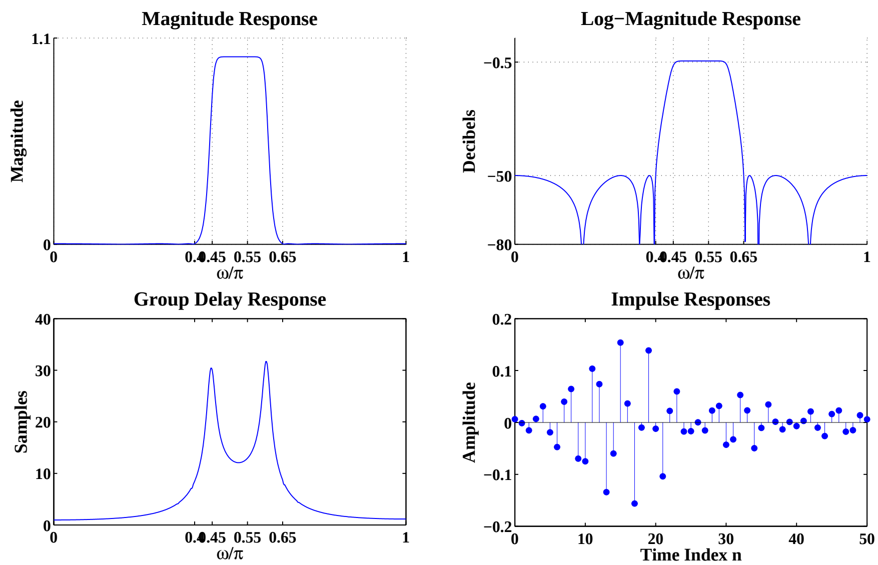

FIGURE 11.87: Plots of the magnitude, log-magnitude, group-delay, and impulse responses..

```
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
NN = 50; n = 0:NN; x = (n==0); h = filter(B,A,x);
%% Exact band-edge frequencies
ind = find(Hdb > -Ap);
omp1 = om(ind(1))/pi; omp2 = om(ind(end))/pi;% Exact Passband Edge
ind = find(Hdb < -As); ind2 = find(om(ind)<omegap1,1,'last');
oms1 = om(ind(ind2))/pi; oms2 = om(ind(ind2+1))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1169a','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[0,1.1]); grid; box off;
```

```
hfb = figconfg('P1169b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfc = figconfg('P1169c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);

hfd = figconfg('P1169d','small'); % Impulse Response Plots
stem(n,h,'filled');
xlabel('Time Index n','fontsize',LFS);
ylabel('Amplitude','fontsize',LFS);
title('Impulse Responses','fontsize',TFS);
```

Review Problems

70. tba.

71. (a) See plot below.

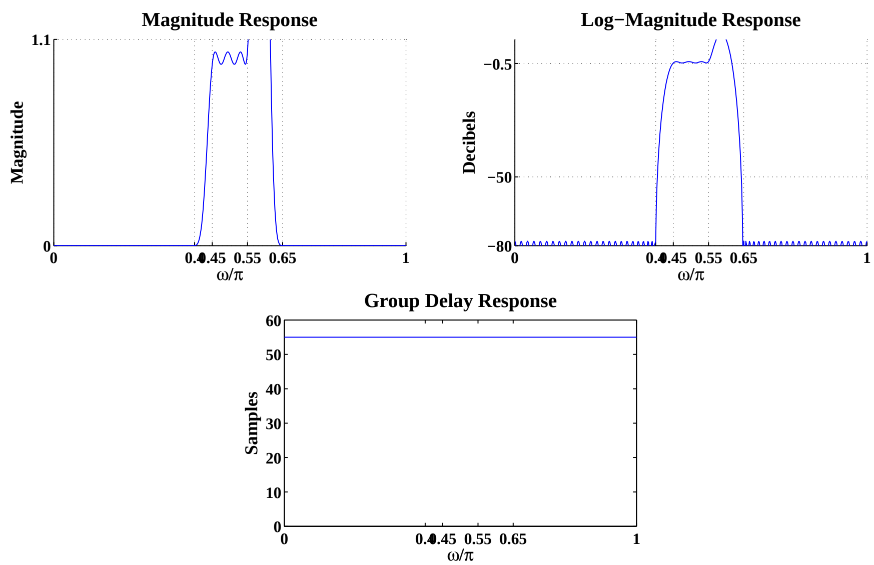

FIGURE 11.88: Plots of the magnitude, log-magnitude and group-delay responses of the FIR filter.

(b) See plot below.

(c) See script for details.

MATLAB script:

```
% P1171: Digital bandpass filter design comparison: FIR & IIR
close all; clc;
%% Specification
omegas1 = 0.4*pi; omegap1 = 0.45*pi; omegap2 = 0.55*pi; omegas2 = 0.65*pi;
As1 = 40; Ap = 0.5; As2 = 50;
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; As = max(As1,As2);
%% FIR filter design
% [deltap, deltas] = spec_convert(Ap,As,'rel','abs');
% [Mpm,fo,ao,W] = firpmord([omegas1,omegap1,omegap2,omegas2]/pi,[0,1,0],...
%     [deltas,deltap, deltas]);
% [B,delta] = firpm(Mpm,fo,ao,W); A = 1;
```

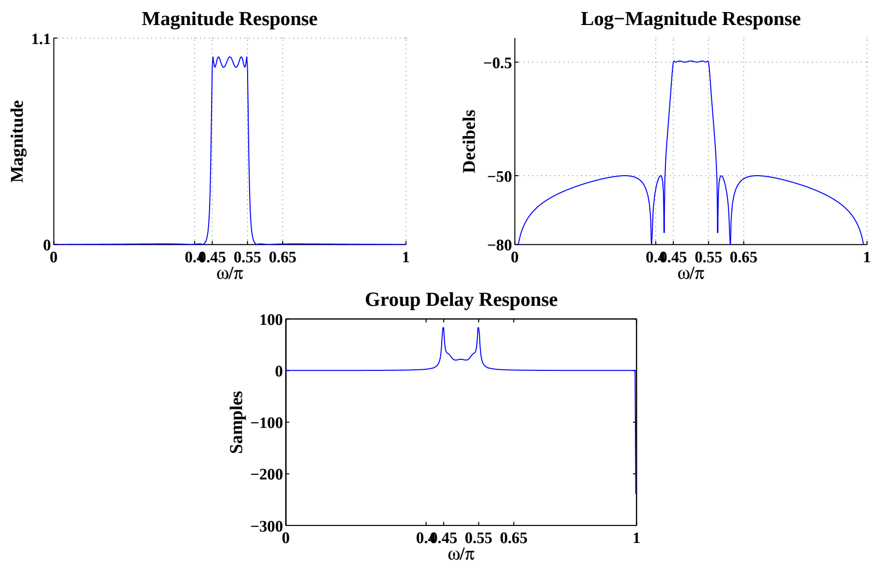

FIGURE 11.89: Plots of the magnitude, log-magnitude and group-delay responses of the IIR filter.

```
%% IIR filter design
[N,omegac] = ellipord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = ellip(N,Ap,As,omegac); % coefficients
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
%% Exact band-edge frequencies
ind = find(Hdb > -Ap);
omp1 = om(ind(1))/pi; omp2 = om(ind(end))/pi;% Exact Passband Edge
ind = find(Hdb < -As); ind2 = find(om(ind)<omegap1,1,'last');
oms1 = om(ind(ind2))/pi; oms2 = om(ind(ind2+1))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1171a','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Magnitude','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
```

```
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[0,1.1]); grid; box off;

hfb = figconfg('P1171b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfc = figconfg('P1171c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
% ylim([0 60])
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegas1,omegap1,omegap2,omegas2,pi]/pi);
```

72. (a) See plot below.
    (b) See plot below.
    (c) See script for details.

    MATLAB script:

```
% P1172: Multiband digital filter design: IIR vs. FIR
close all; clc;
%% Specification
ws1 = 0.1*pi; wp1 = 0.2*pi; wp2 = 0.5*pi; ws2 = 0.6*pi; ws3 = 0.7*pi;
wp3 = 0.8*pi;
H1 = 0; H2 = 0.475; H3 = 0; H4 = 0.975;
deltas1 = 0.01; deltap1 = 0.025; deltas2 = 0.01; deltap2 = 0.025;

%% FIR design:
% Bandpass
[M1,fo,ao,W] = firpmord([ws1,wp1,wp2,ws2]/pi,[0,1,0],...
    [deltas1,deltap1, deltas2]);
M1 = M1 + 2;
[B1,delta1] = firpm(M1,fo,ao,W);
% Highpass
```

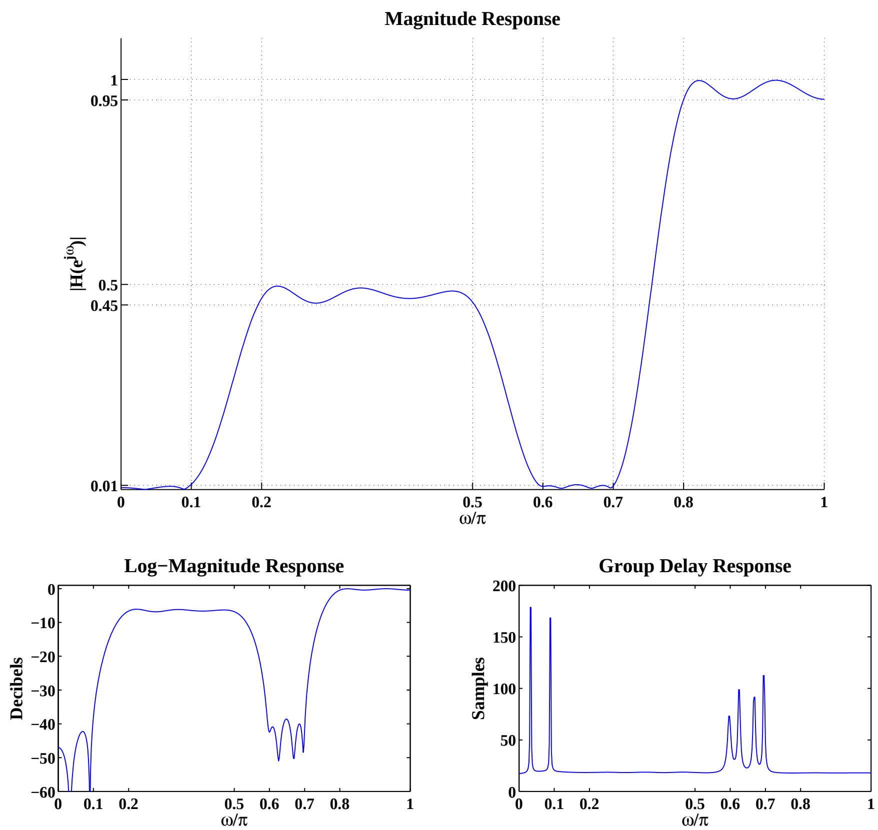

FIGURE 11.90: Plots of the magnitude, log-magnitude and group-delay responses of the FIR filter.

```
[M2,fo,ao,W] = firpmord([ws3,wp3]/pi,[0,1],[deltas2,deltap2]);
M2 = M2 + 2;
[B2,delta2] = firpm(M2,fo,ao,W);
% Combination
if M1 > M2
    B_fir = H2*B1; B_fir(end-M2:end) = B_fir(end-M2:end) + H4*B2;
else
    B_fir = H4*B2; B_fir(end-M1:end) = B_fir(end-M1:end) + H2*B1;
end
A_fir = 1;

%% IIR design:
```

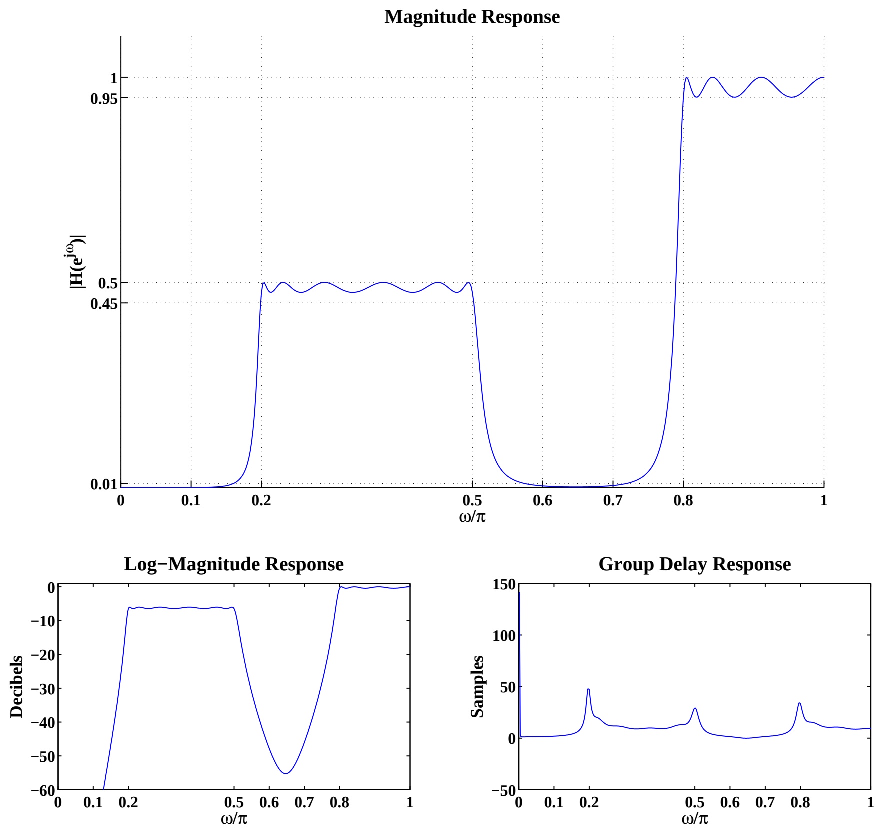

FIGURE 11.91: Plots of the magnitude, log-magnitude and group-delay responses of the IIR filter.

```
% Bandpass
[Ap1, As1] = spec_convert(deltap1,deltas1,'abs','rel');
[N1,omegac1] = cheb1ord([wp1 wp2]/pi,[ws1 ws2]/pi,Ap1,As1);
[B1,A1] = cheby1(N1,Ap1,omegac1);
% Highpass
[Ap2, As2] = spec_convert(deltap2,deltas2,'abs','rel');
[N2,omegac2] = cheb1ord(wp3/pi,ws3/pi,Ap2,As2);
N2 = N2 + 0;
[B2,A2] = cheby1(N2,Ap2,omegac2,'high');
[r1 p1 k1] = residuez(B1,A1); [r2 p2 k2] = residuez(B2,A2);
% [B_iir,A_iir] = residuez([H2*r1;H4*r2],[p1;p2],H2*k1+H4*k2);
[B_iir,A_iir] = residuez([0.5*r1;r2],[p1;p2],0.5*k1+k2);
```

```
%% Plotting Parameters and Filter Responses
B = B_fir; A = A_fir; % FIR
% B = B_iir; A = A_iir; % IIR
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);

%% Design Plots
hfa = figconfg('P1172a'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('|H(e^{j\omega})|','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,ws1,wp1,wp2,ws2,ws3,wp3,pi]/pi);
set(gca,'ytick',[0.01 0.45 0.5 0.95 1]); grid; box off;

hfb = figconfg('P1172b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1);
axis([0,1,-60,1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,ws1,wp1,wp2,ws2,ws3,wp3,pi]/pi);

hfc = figconfg('P1172c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,ws1,wp1,wp2,ws2,ws3,wp3,pi]/pi);
```

73. (a) See plot below.
    (b) See plot below.
    (c) See script for detail.

    MATLAB script:

```
% P1173: Multiband digital filter design: IIR vs. FIR
```

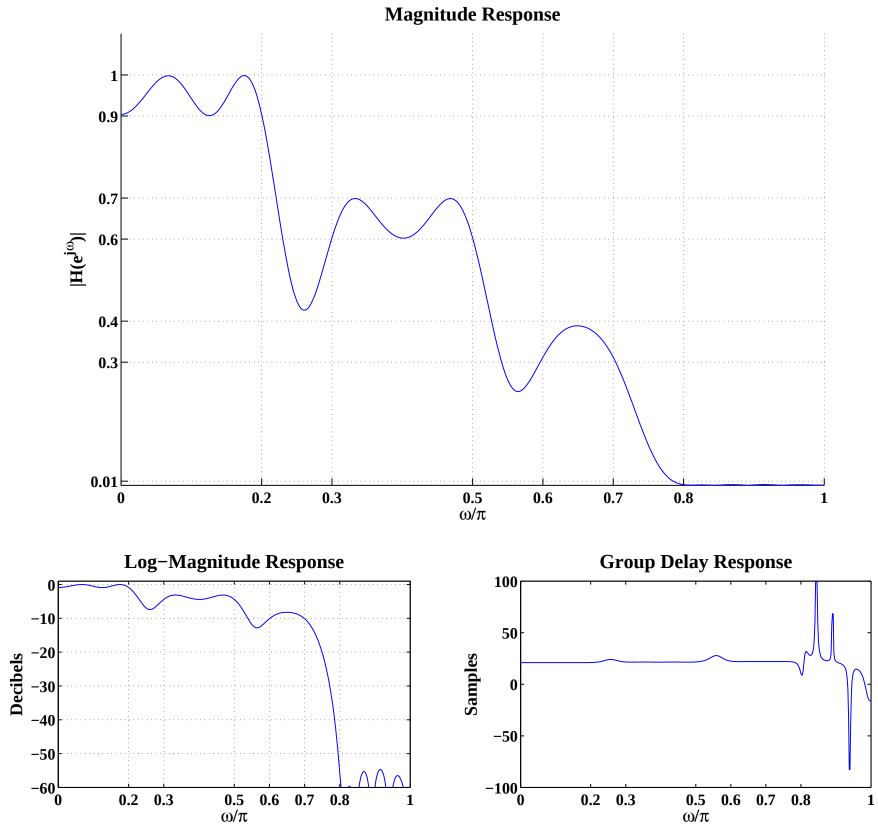

FIGURE 11.92: Plots of the magnitude, log-magnitude and group-delay responses of the FIR filter.

```
close all; clc;
%% Specification
wp1 = 0.2*pi; wp2 = 0.3*pi; wp3 = 0.5*pi; wp4 = 0.6*pi; wp5 = 0.7*pi;
ws = 0.8*pi;
H1 = 0.95; H2 = 0.65; H3 = 0.35; H4 = 0;
deltap1 = 0.05; deltap2 = 0.05; deltap3 = 0.05; deltas = 0.001;

%% FIR design:
% Lowpass
[M1,fo,ao,W] = firpmord([wp1,wp2]/pi,[1,0],[deltap1*0.75,deltas]);
[B1,delta1] = firpm(M1,fo,ao,W);
% Bandpass1
```

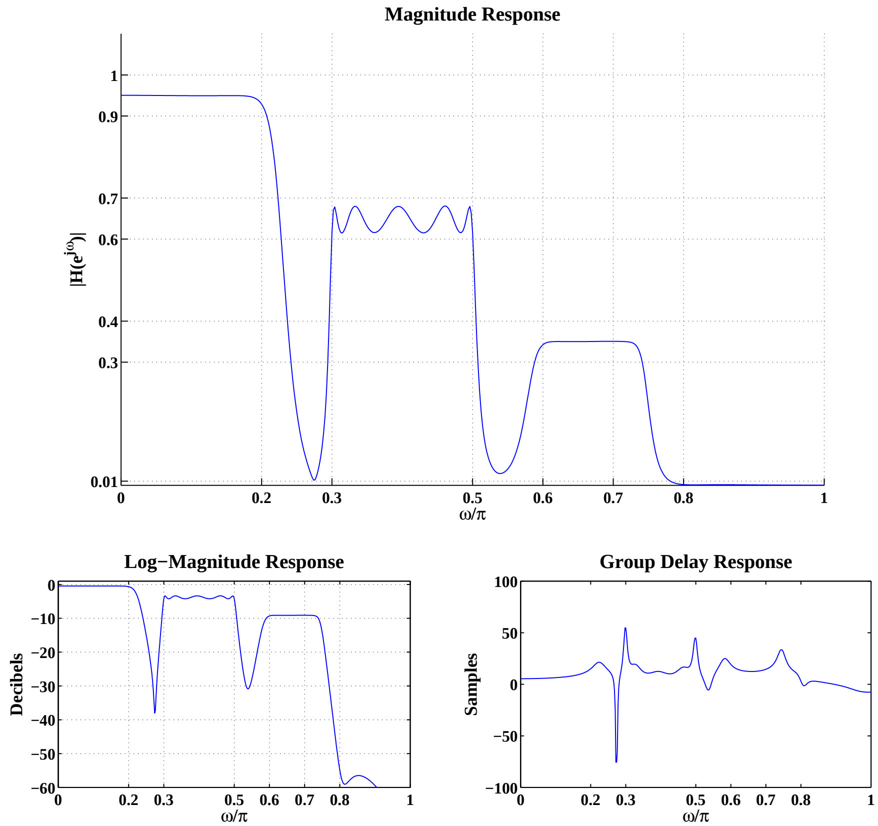

FIGURE 11.93: Plots of the magnitude, log-magnitude and group-delay responses of the IIR filter.

```
[M2,fo,ao,W] = firpmord([wp1,wp2,wp3,wp4]/pi,[0,1,0],...
    [deltas,deltap2*0.9, deltas]);
[B2,delta2] = firpm(M2,fo,ao,W);
% Bandpass2
[M3,fo,ao,W] = firpmord([wp3,wp4,wp5,ws]/pi,[0,1,0],...
    [deltas,deltap3, deltas]);
[B3,delta3] = firpm(M3,fo,ao,W);
% Combination
Mmax = max([M1,M2,M3]);
B1 = [zeros(1,Mmax-M1),B1];
B2 = [zeros(1,Mmax-M2),B2];
B3 = [zeros(1,Mmax-M3),B3];
```

```
B_fir = H1*B1 + H2*B2 + H3*B3;
A_fir = 1;

%% IIR design:
% Lowpass
[Ap1, As1] = spec_convert(deltap1,deltas,'abs','rel');
[N1,omegac1] = cheb2ord(wp1/pi,wp2/pi,Ap1,As1);
[B1,A1] = cheby2(N1,As1,omegac1);
% Bandpass1
[Ap2, As2] = spec_convert(deltap2,deltas,'abs','rel');
[N2,omegac2] = ellipord([wp2 wp3]/pi,[wp1 wp4]/pi,Ap2,As2);
[B2,A2] = ellip(N2,Ap2,As2,omegac2);
% Bandpass2
[Ap3, As3] = spec_convert(deltap1,deltas,'abs','rel');
[N3,omegac3] = cheb2ord([wp4 wp5]/pi-0.02,[wp3 ws]/pi,Ap3,As3);
[B3,A3] = cheby2(N3,As3,omegac3);

[r1 p1 k1] = residuez(B1,A1);
[r2 p2 k2] = residuez(B2,A2);
[r3 p3 k3] = residuez(B3,A3);
[B_iir,A_iir] = residuez([H1*r1;0.68*r2;0.35*r3],[p1;p2;p3],H1*k1+0.68*k2+0.35*k

%% Plotting Parameters and Filter Responses
B = B_fir; A = A_fir; % FIR
% B = B_iir; A = A_iir; % IIR
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
%% Design Plots
hfa = figconfg('P1173a'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('|H(e^{j\omega})|','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,wp1,wp2,wp3,wp4,wp5,ws,pi]/pi);
set(gca,'ytick',[0.01 0.3 0.4 0.6 0.7 0.9 1]); grid; box off;

hfb = figconfg('P1173b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1);
```

```
axis([0,1,-60,1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,wp1,wp2,wp3,wp4,wp5,ws,pi]/pi); grid

hfc = figconfg('P1173c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,wp1,wp2,wp3,wp4,wp5,ws,pi]/pi);
```

74. (a) See plot below.

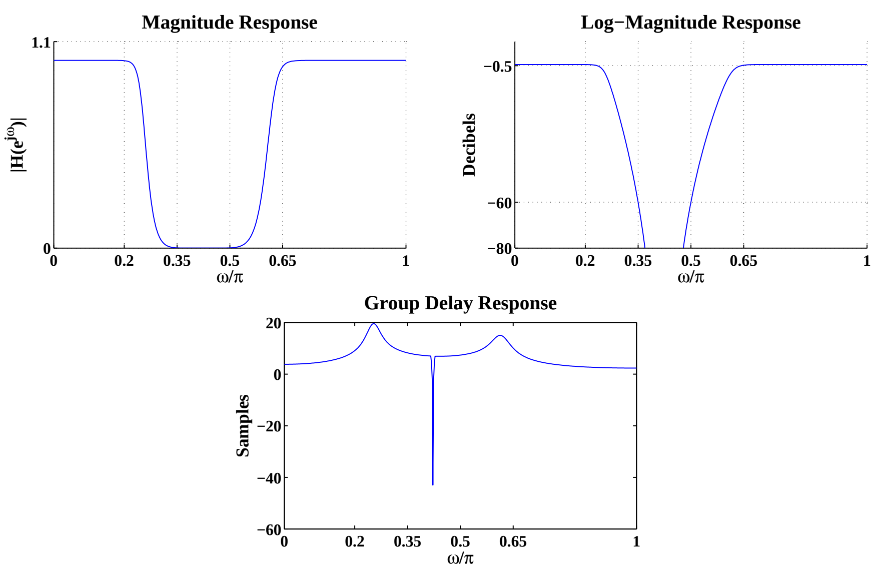

FIGURE 11.94: Plots of the magnitude, log-magnitude and group-delay responses of Butterworth filter.

(b) See plot below.

(c) See plot below.

(d) See plot below.

(e) See script for details.

MATLAB script:

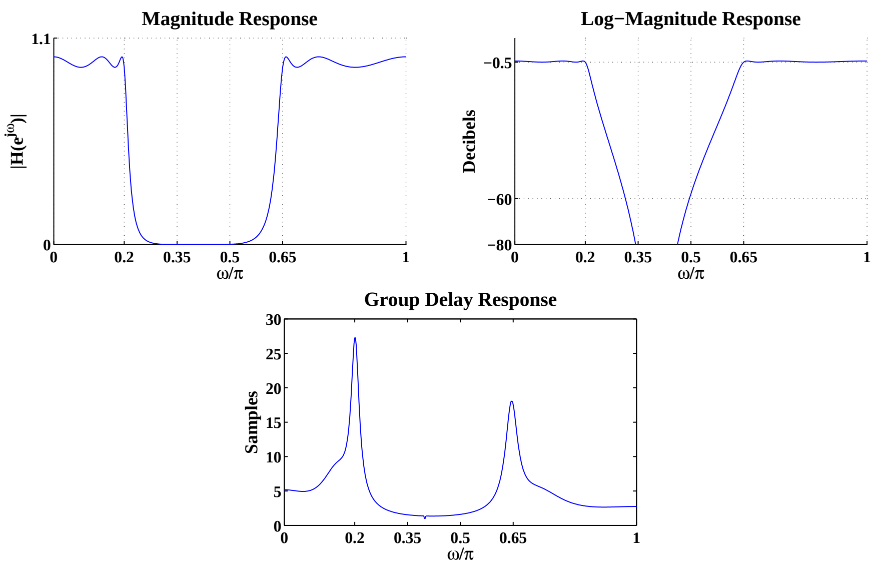

FIGURE 11.95: Plots of the magnitude, log-magnitude and group-delay responses of Chebyshev I filter.

```
% P1174: IIR filter design approximations comparison
close all; clc;
%% Specification
omegap1 = 0.2*pi; omegas1 = 0.35*pi; omegas2 = 0.5*pi; omegap2 = 0.65*pi;
Ap1 = 1; As = 60; Ap2 = 0.5;
omegap = [omegap1 omegap2]; omegas = [omegas1 omegas2]; Ap = min(Ap1,Ap2);
%% Butterworth
[N,omegac] = buttord(omegap/pi,omegas/pi,Ap,As); % Order define
[B,A] = butter(N,omegac,'stop'); % coefficients
%% Chebyshev I
% [N,omegac] = cheb1ord(omegap/pi,omegas/pi,Ap,As); % Order define
% [B,A] = cheby1(N,Ap,omegac,'stop'); % coefficients
%% Chebyshev II
% [N,omegac] = cheb2ord(omegap/pi,omegas/pi,Ap,As); % Order define
% [B,A] = cheby2(N,As,omegac,'stop'); % coefficients
%% Elliptic
% [N,omegac] = ellipord(omegap/pi,omegas/pi,Ap,As); % Order define
% [B,A] = ellip(N,Ap,As,omegac,'stop'); % coefficients
%% Plotting Parameters and Filter Responses
om = linspace(0,1,501)*pi; H = freqz(B,A,om);
```

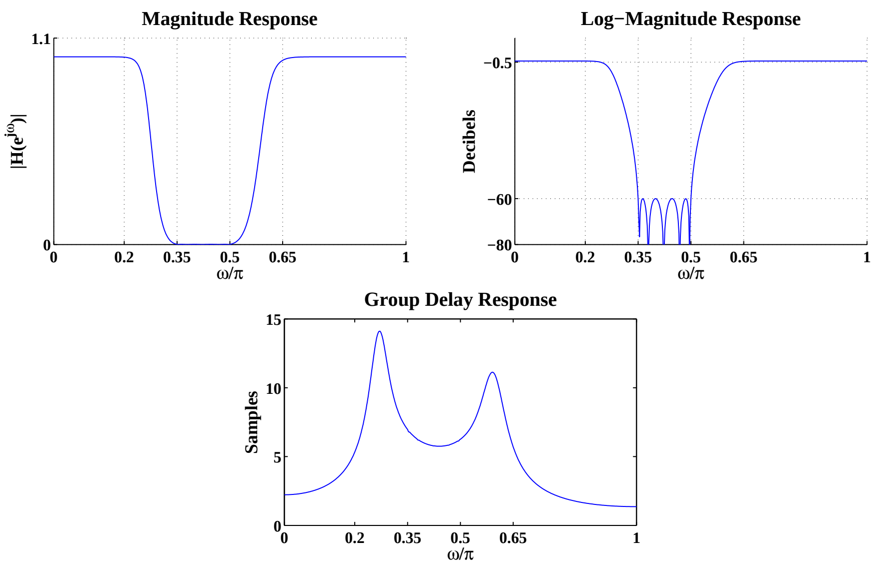

FIGURE 11.96: Plots of the magnitude, log-magnitude and group-delay responses of Chebyshev II filter.

```
Hmag = abs(H); Hpha = angle(H); Hdb = 20*log10(Hmag);
Hgdl = -diff(unwrap(Hpha))./diff(om); Hgdl = [Hgdl,Hgdl(end)];
Hgdl = medfilt1(Hgdl,3);
%% Exact band-edge frequencies
ind = find(Hdb >= -Ap); ind2 = find(om(ind)<omegas1,1,'last');
omp1 = om(ind(ind2))/pi; omp2 = om(ind(ind2+1))/pi;% Exact Passband Edge
ind = find(Hdb <= -As);
oms1 = om(ind(1))/pi; oms2 = om(ind(end))/pi;% Exact Stopband Edge
%% Design Plots
hfa = figconfg('P1174a','small'); % Magnitude Response
plot(om/pi,Hmag,'b','linewidth',1); axis([0,1,0,1.1]);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('|H(e^{j\omega})|','fontsize',LFS);
title('Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
set(gca,'ytick',[0,1.1]); grid; box off;

hfb = figconfg('P1174b','small'); % Log-Magnitude Response in dB
plot(om/pi,Hdb,'b','linewidth',1); axis([0,1,-80,10]);
xlabel('\omega/\pi','fontsize',LFS);
```

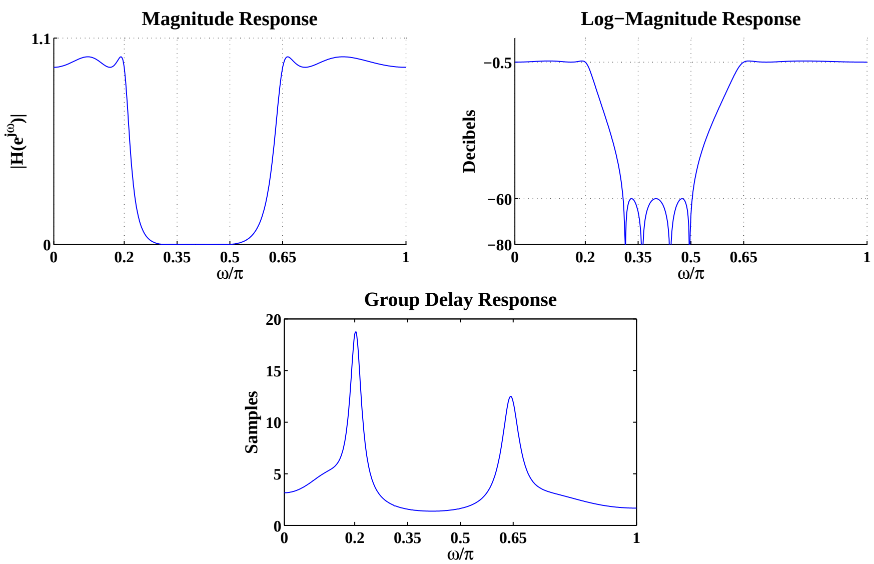

FIGURE 11.97: Plots of the magnitude, log-magnitude and group-delay responses of elliptic filter.

```
ylabel('Decibels','fontsize',LFS);
title('Log-Magnitude Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
set(gca,'ytick',[-80,-As,-Ap]); grid; box off;

hfc = figconfg('P1174c','small'); % Group-Delay Plot in Samples
plot(om/pi,Hgdl,'b','linewidth',1);
xlabel('\omega/\pi','fontsize',LFS);
ylabel('Samples','fontsize',LFS);
title('Group Delay Response','fontsize',TFS);
set(gca,'xtick',[0,omegap1,omegas1,omegas2,omegap2,pi]/pi);
```