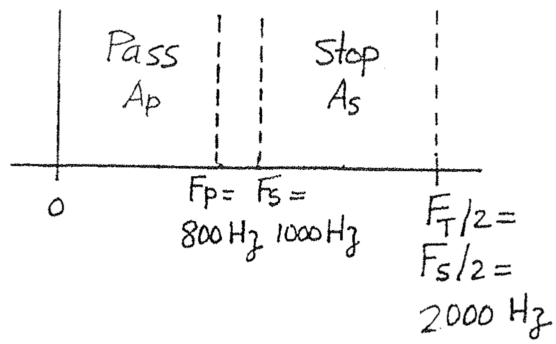
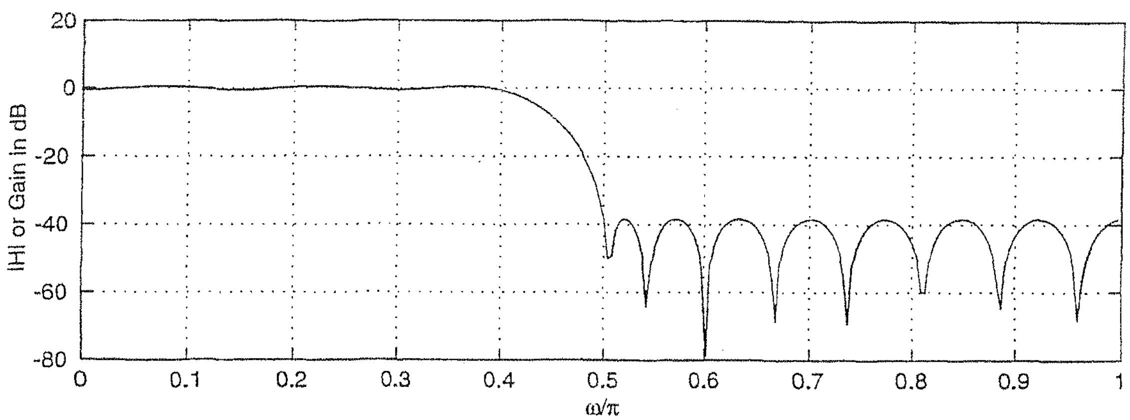
EE253 Prof. Essam Marouf
Matlab Handout #8

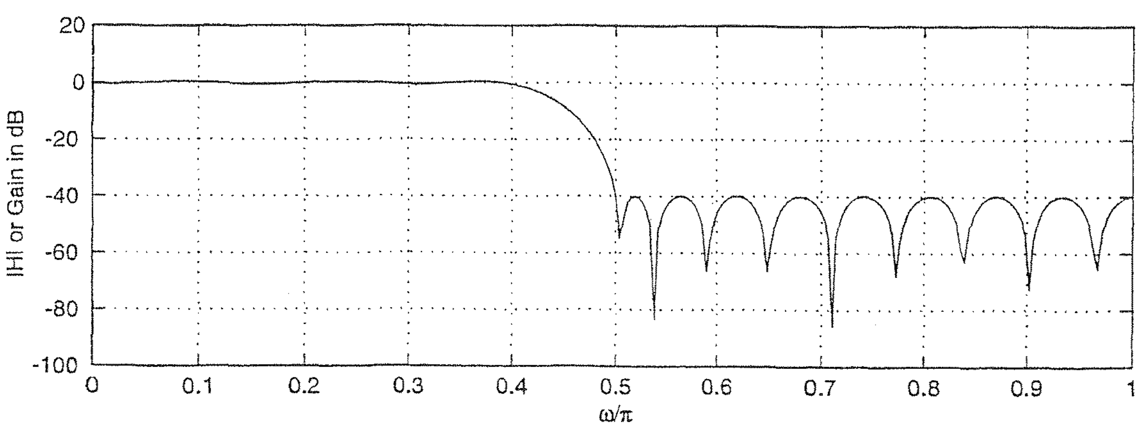
Example Linear Phase FIR Filter Design Using the Optimal Method (Mitra, 7.10)



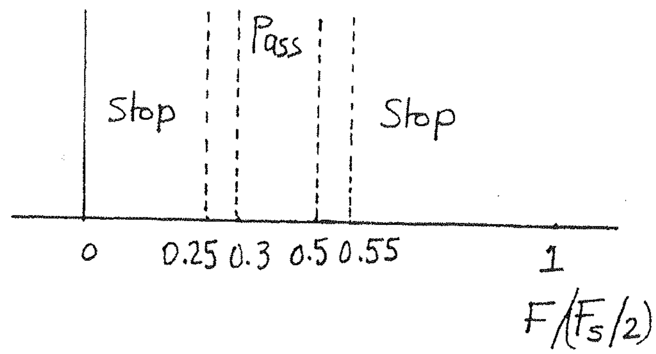

```
% Mitra, Example 7.27
% ---------------------
%
% Design of Lowpass Filter with the following specs
%
Ap = 0.5;          % passband ripple in dB
As = 40.0;         % stopband ripple in dB
Fp = 800.0;        % pass frquency in Hz
Fs = 1000.0;       % stop frquency in Hz
FT = 4000.0;       % sampling frquency in Hz
%
dp =1-10^(-Ap/20);  % delta_p, or delta_1 = 0.055939
ds=10^(-As/20);     % delta_s, or delta_2 = 0.01

dw=2*pi*(Fs-Fp)/FT;
%
% estimate filter order using empirical formula (Lec #17, p. 9)

M1= ceil( (-10.0*log10(dp*ds) -13.0) / (2.324*dw) ) % Gives M1 = 27 (Type 2)

% or estimate filter order using the more accurate remezord function

fedge =[Fp Fs];         % band edges in Hz
Hd  =[1  0] ;   % ideal Hd in each band
deltas=[dp ds];         % delta in each band

[M2, FN, Hmag, Wt] = remezord(fedge, Hd, deltas,FT)

% The output values prepare for the filter design using remez
% M2 is the filter order = 28 (a more accurate estimate; Type 1)
% FN = F/FT/2 of band edges (Matlab normalizes all frequencies by FT/2) = [0 0.4 0.5 1]
% Hmag is the desired magnitude vector at FN = [ 1  1  0 0]
% Wt is the weight vector = [1.0  5.5939];
%
% Design the filter using remez

b = remez(M2, FN, Hmag, Wt);
%
% Check the design
```

```
subplot(2,1,1)
[H,w]=freqz(b,1,256);
plot(w/pi, 20*log10(abs(H))), grid
xlabel('\omega/\pi'), ylabel('|H| or Gain in dB')

% Both Ap and As specs are not met (see also Fig. 7.33 of Mitra)
% need to increase the filter order and try again
%
M2= 30;
b = remez(M2, FN, Hmag, Wt);

subplot(2,1,2)
[H,w]=freqz(b,1,256);
plot(w/pi, 20*log10(abs(H))), grid
xlabel('\omega/\pi'), ylabel('|H| or Gain in dB')
subplot

% Looks Ok now (see also Mitra, Fig. 7.34)
```



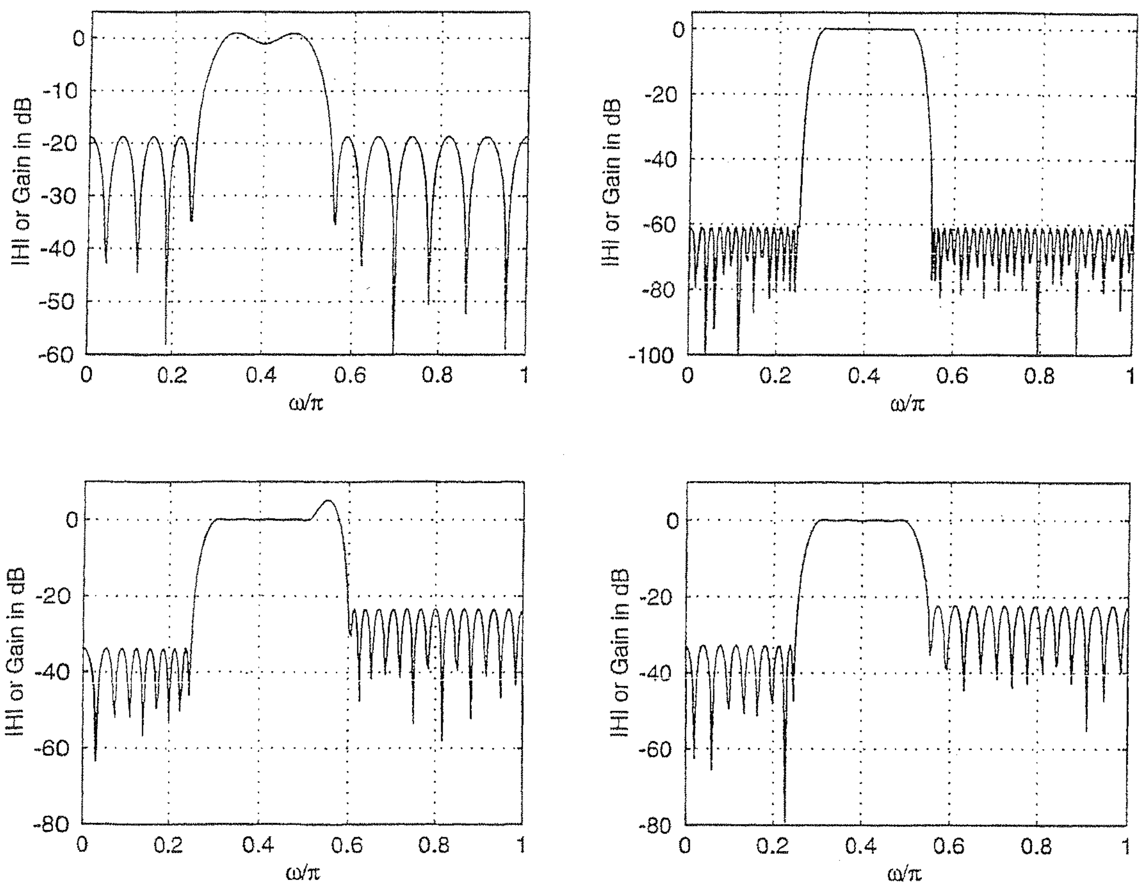


```
% Mitra 7.28 and 7.29.  Design of Bandpass Filter
% --------------------------------------------------------

M=26;  % compouted from specs using remezord (details skipped here)
FN=[0 0.25 0.3 0.5 0.55    1];        % Band edges F(Hz)/(FT(Hz)/2)
Hmag=[0    0  1   1   0    0];        % ideal H at frequence edges FN
Wt=[  1       1       1  ];           % weight vector in each band

b = remez(M, FN, Hmag, Wt);
```

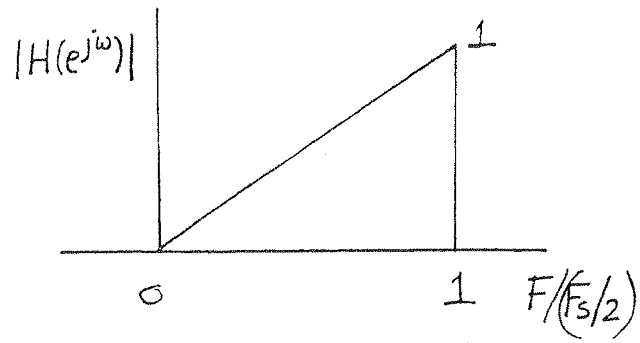



```
% Check the design
subplot(2,1,1)
[H,w]=freqz(b,1,256);
plot(w/pi, 20*log10(abs(H))), grid
axis([0 1 -60 5]);
xlabel('\omega/\pi'), ylabel('|H| or Gain in dB')

% Larger Filter order yields better performance
% largere stop band attenuation As and sharper transitions between bands
% Can also control deltas in different bands

M=110;
Wt = [ 1 0.1 1];
b = remez(M, FN, Hmag, Wt);

subplot(2,1,2)
[H,w]=freqz(b,1,256);
plot(w/pi, 20*log10(abs(H))), grid
axis([0 1 -100 5]);
subplot

% Unexpected behavior can occur in the transition bands ("don't care" regions)
M=60;
FN=[0 0.25 0.3 0.5 0.6   1];
Hmag=[0    0   1    1   0    0];
Wt=[  1       1       0.3];

b = remez(M, FN, Hmag, Wt);

subplot(2,2,3)
[H,w]=freqz(b,1,256);
plot(w/pi, 20*log10(abs(H))), grid
xlabel('\omega/\pi'), ylabel('|H| or Gain in dB')
axis([0 1 -80 10]);
subplot
```

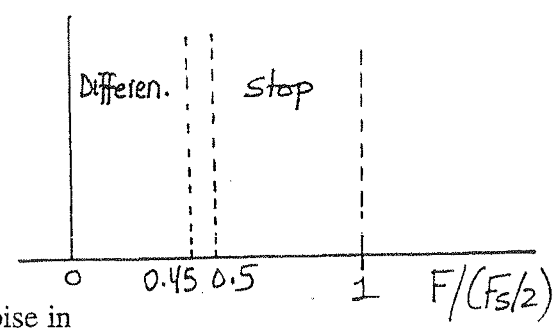
```
% A slight adjustment in filter order or band edges can yield acceptable behavior

FN=[0 0.25 0.3 0.5 0.55   1];          % 0.6 changed to 0.55 (sharper transition)
b = remez(M, FN, Hmag, Wt);

subplot(2,2,4)
[H,w]=freqz(b,1,256);
plot(w/pi, 20*log10(abs(H))), grid
xlabel('\omega/\pi'), ylabel('|H| or Gain in dB')
axis([0 1 -80 10]);
subplot
```



```
% Mitra Examples 7.30 and 7.31: Design of Differentiators
% -----------------------------------------------------------------------

clear, close all

M    = 11;                    % Type 4; has a zero at w = 0 which is OK
FN   = [0   1];
Hmag = pi*[0   1];

b=remez(M,FN,Hmag,'differentiator');

subplot(2,2,1)
[H,w]=freqz(b,1,256);
plot(w/pi, abs(H)), grid
xlabel('\omega/\pi'), ylabel('|H| or Gain')
title(['Type 4 LPhase FIR: M = ',num2str(M)])
axis([0 1 0 3.5]);
% See also Fig. 7.38 of Mitra
```

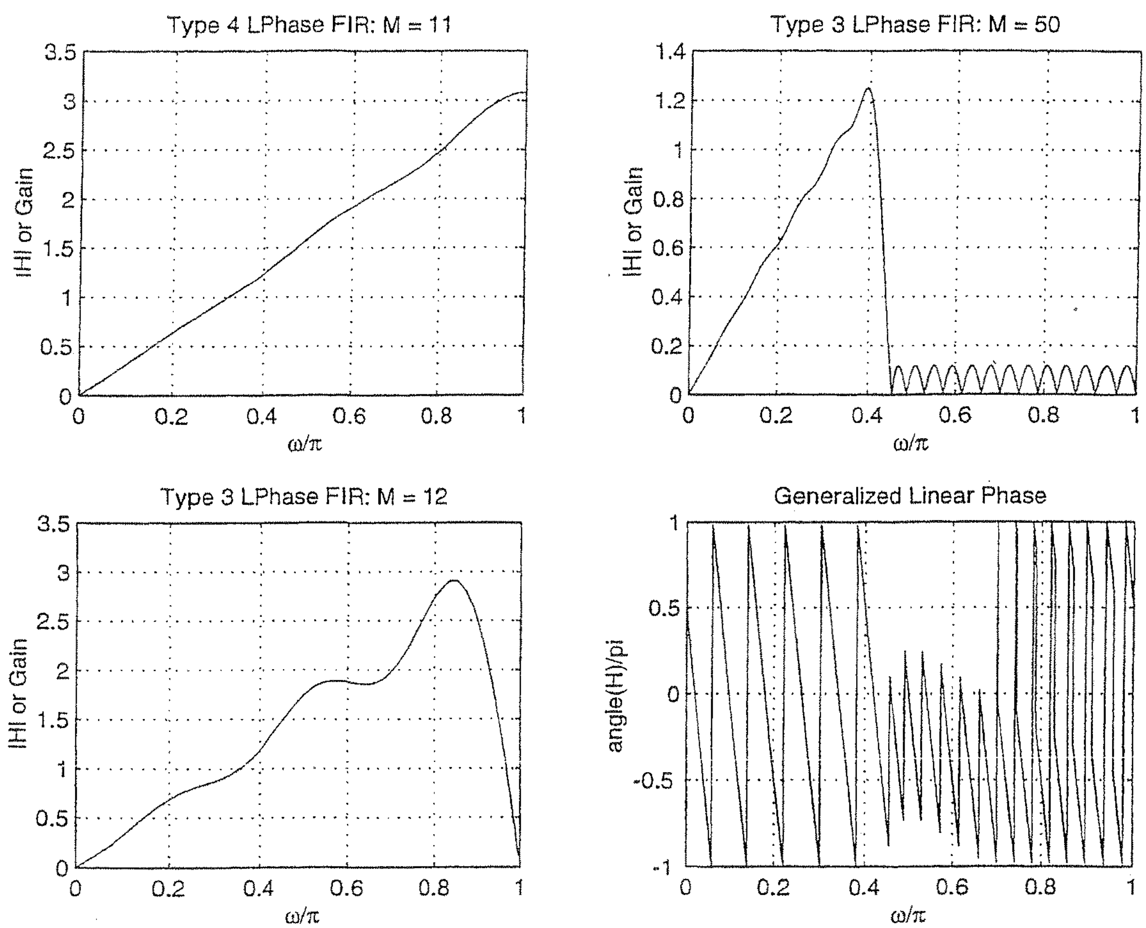



```
% Can use Type 3, but must accept a zero |H| at w = pi

M    = 12;                    % Type 3; has a zero at w = pi
FN   = [0   0.9];
Hmag = pi*[0   0.9];

b=remez(M,FN,Hmag,'differentiator');

subplot(2,2,2)
[H,w]=freqz(b,1,256);
plot(w/pi, abs(H)), grid
xlabel('\omega/\pi'), ylabel('|H| or Gain')
title(['Type 3 LPhase FIR: M = ',num2str(M)])
axis([0 1 0 3.5]);
```

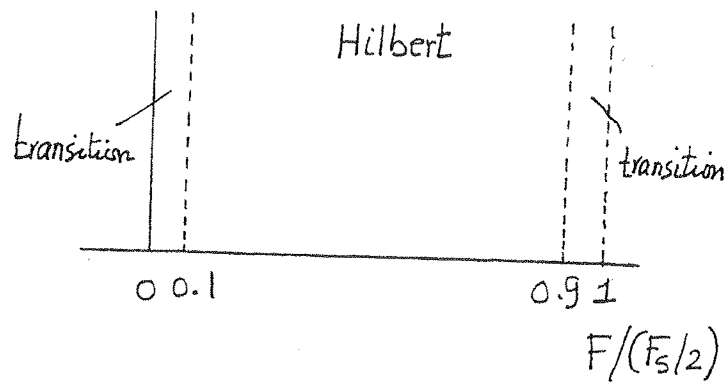



```
%
% For the case of noisy signals, differentiators amplify the noise in
% the high frequency band outside the signal bandwidth.  It's important
% therefore to limit a differentiator bandwidth to the signal bandwidth
%
M    = 50;         % a high order filter yields smaller fluctuations and sharper transition
FN   =    [0   0.4  0.45  1];   % 0.4 = (Matlab) Normalized bandwidth = B(Hz)/(FT(Hz)/2)
Hmag = pi*[0   0.4     0  0];

b=remez(M,FN,Hmag,'differentiator');
```

```
subplot(2,2,3)
[H,w]=freqz(b,1,1024);
plot(w/pi, abs(H)), grid
xlabel('\omega/\pi'), ylabel('|H| or Gain')
title(['Type 3 LPhase FIR: M = ',num2str(M)])
axis([0 1 0 1.4]);

subplot(2,2,4)
plot(w/pi, angle(H)/pi), grid
xlabel('\omega/\pi'), ylabel('angle(H)/pi ')
title(['Generalized Linear Phase'])
axis([0 1 -1  1]);
```



```
% Mitra Examples 7.32: Design of Hilbert Transformers
% ---------------------------------------------------------------
%
% Same Ideas
%

clear, close all

M    = 20;
FN   = [ 0.1   0.9];
Hmag = [ 1      1  ];

b=remez(M,FN,Hmag,'Hilbert');

subplot(2,2,1)
[H,w]=freqz(b,1,1024);
plot(w/pi, abs(H)), grid
xlabel('\omega/\pi'), ylabel('|H| or Gain')
title(['Hilbert Transformer'])
axis([0 1 0 1.2]);

subplot(2,2,3)
plot(w/pi, angle(H)/pi), grid
xlabel('\omega/\pi'), ylabel('angle(H)/pi ')
title(['Generalized Linear Phase'])
axis([0 1 -1  1]);

%
% Trying to force sharper transitions may yield larger ripples

M    = 20;
FN   = [ 0.05   0.95];
Hmag = [ 1      1  ];

b=remez(M,FN,Hmag,'Hilbert');

subplot(2,2,2)
[H,w]=freqz(b,1,1024);
plot(w/pi, abs(H)), grid
xlabel('\omega/\pi'), ylabel('|H| or Gain')
title(['Hilbert Transformer: Type 3'])
axis([0 1 0 1.2]);
```



```
% Will Type 4 filter also work?
% Note again that the optimal method does not control the bahavior of H
% over the transitions bands.

M    = 21;
FN   = [ 0.05   0.95];
Hmag = [ 1      1  ];

b=remez(M,FN,Hmag,'Hilbert');

subplot(2,2,4)
[H,w]=freqz(b,1,1024);
plot(w/pi, abs(H)), grid
xlabel('\omega/\pi'), ylabel('|H| or Gain')
title(['Hilbert Transformer: Type 4'])
axis([0 1 0 1.2]);
```