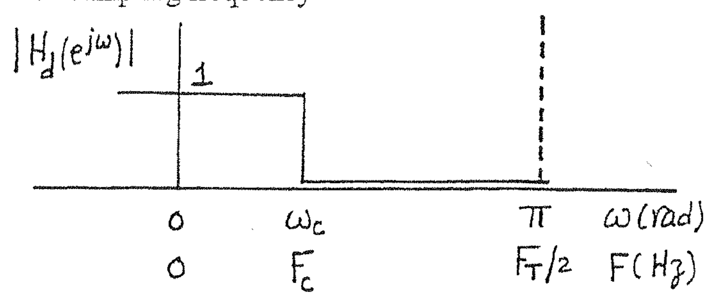
EE253 — Prof. Essam Marouf

FIR Filter Design: Window Method — Matlab Handout 5

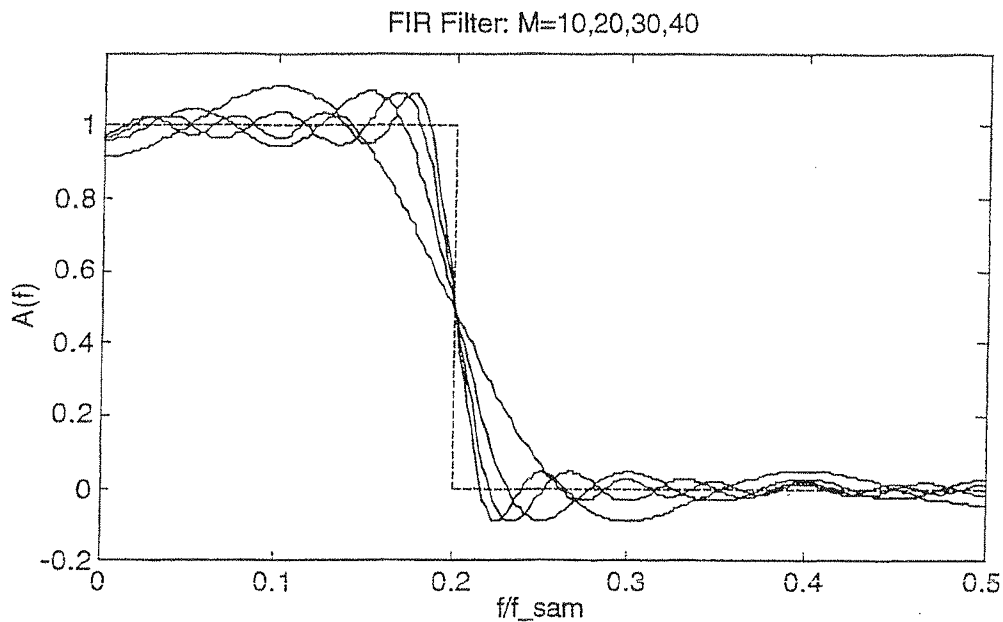
```
% Script File: FIRW_Ex1.m
% Demonstartes the Effect of Increasing Filter Order
% ---------------------------------------------------------
% fc=200 KHz; f_sam = 1 MHz; linear phase;
% i) Sketch H(e^jw) for M=10, 20, 30, 40 assuming rectangular window
%
% Initialize
j=sqrt(-1);
M=[10 20 30 40];                    % M = Filter order
fc=2E5;                             % cutoff of an ideal LPF
f_sam=1E6;                          % Sampling frequency
wc=2*pi*fc/f_sam;
%
% Plot the Ideal Response
Hd=[1 1 0 0];
wd=[0 wc wc pi];
plot(wd/(2*pi), Hd,'--b'),
axis([0 0.5 -.2 1.2]);
xlabel(' f/f_sam')
ylabel('A(f)')
hold on
%
% Loop Over 4 valus of M
for L=1:4,
n=[0:1:M(L)];                       % Sample index n, 0 <= n <= M
%
% Calculate causal impulse response
h= sin(wc*((n-M(L)/2)+1E-8))./(pi*((n-M(L)/2)+1E-8));    % Rectangular window
% Adding 1E-8 is the lazy man's way to avoid divide by zero.
%
% Compute the frequency response
nn=256;
a=1;
[H,w]=freqz(h,a,nn);
%
% Plot the results
plot(w/(2*pi), real(H.*exp(j*w*M(L)/2)),'-r');   % Remove linear phase from H(w) to get A(w)
end
title('FIR Filter: M=10,20,30,40')
hold off, pause
%
plot(w/(2*pi), angle(H)/pi,'-r');
axis([0 0.5 -1 1]);
xlabel('f/f_sam')
ylabel('ARG(H)/pi')
title('FIR Filter: M=40, Rectangular Window')     % Phase response for M=40
                                                  % is the only one plotted for clarity
```

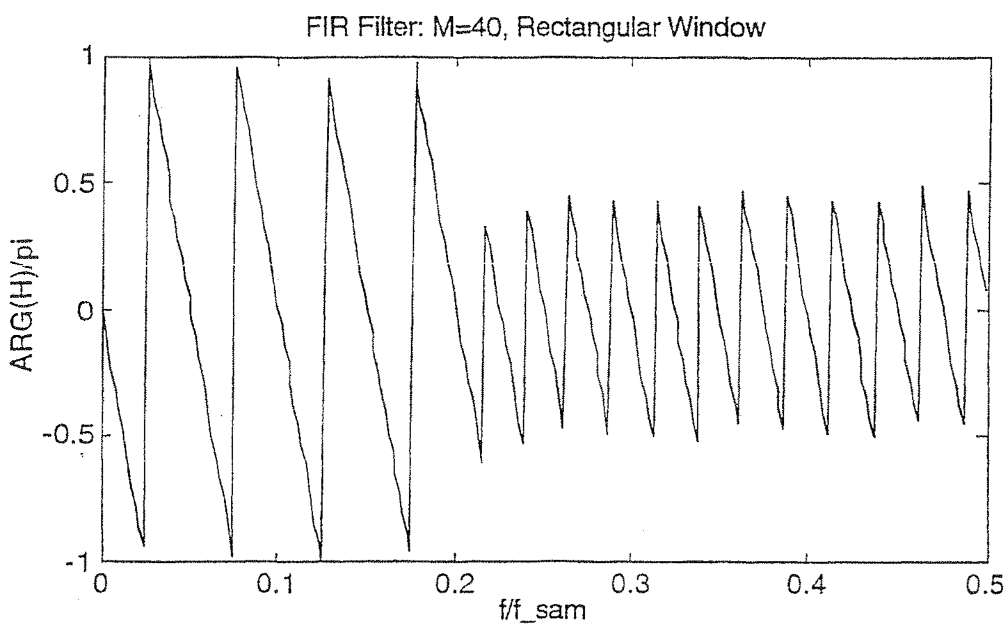


Output of FIRW_Ex1 and Comments

Note the decreasing transition width as M increases (1.8*pi/M) and Gibb's phenomenon (a 9% overshoot near the edges) .

Note that in all cases above the filter phase is linear as the plot for M=40 below demonstrates. The jumps from -1 to +1 in the passband correspond to phase jumps of 2*pi (phase wraping), while the smaller jumps in the stop band are phase jumps of pi at the zero crossings.

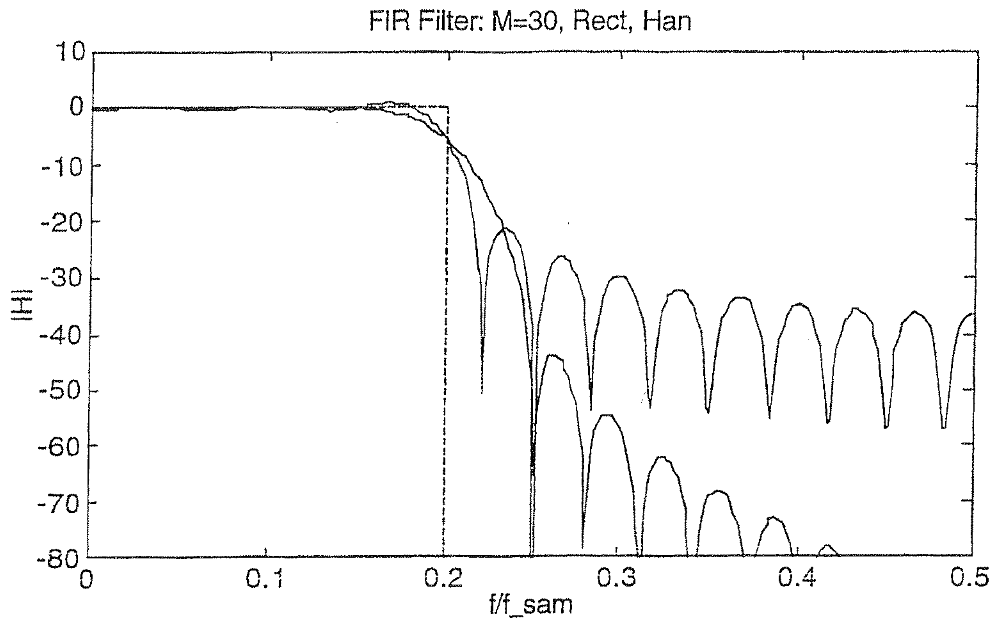


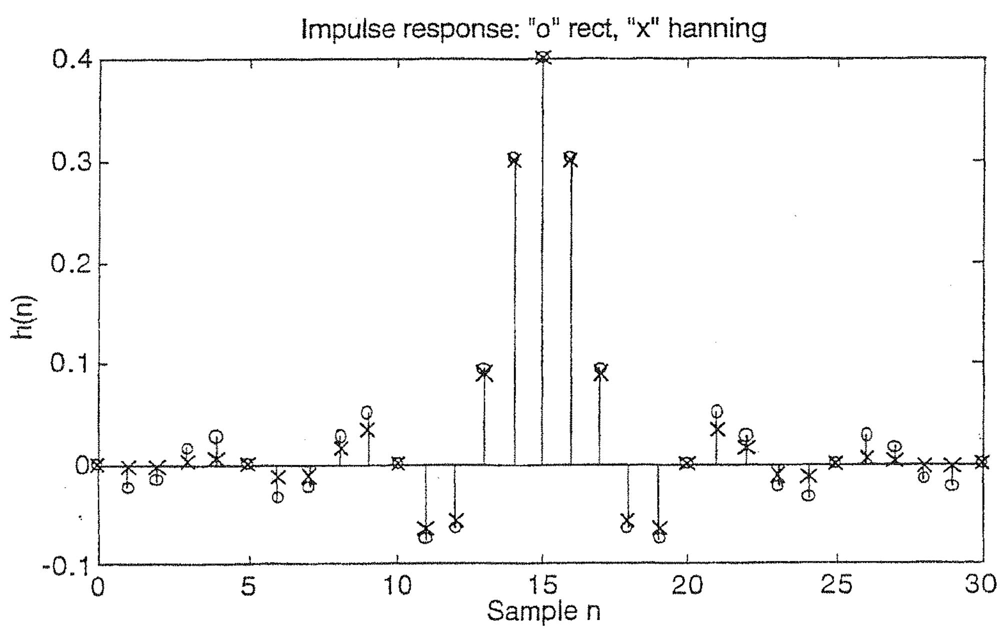


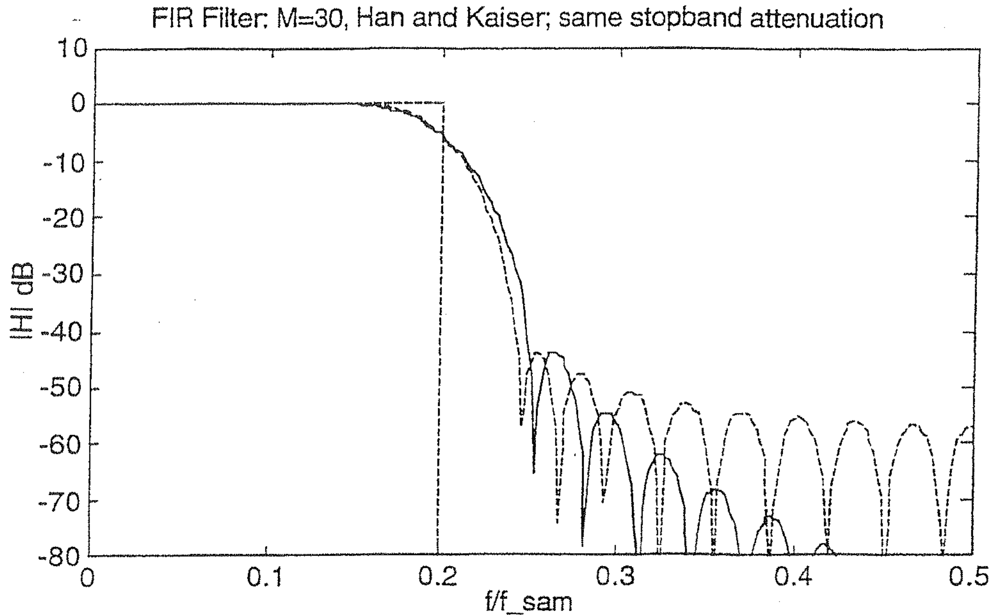
```
% Script File: FIRW_Ex2.m
% Demonstartes the Effect of Various Window Types on peak side-lobe
% and transition width
% ------------------------------------------------------------------------------
% Initialize
j=sqrt(-1); nn=256; a=1; M=30;
fc=2E5; f_sam=1E6;
wc=2*pi*fc/f_sam;
%
% Plot Ideal Response
clg
Hd=[0 0 -200 -200];                    % -200 dB is an artifitial off-scale value
wd=[0 wc wc pi];
plot(wd/(2*pi), Hd,'--b'),
xlabel(' f/f_sam'), ylabel('|H|')
title('FIR Filter: M=30, Rect, Han')
hold on,
%
n=[0:1:M];
h= sin(wc*((n-M/2)+1E-8))./(pi*((n-M/2)+1E-8));
% Compare Rectangular and Hanninig Windows
%
% Rectangular Window
[H,w]=freqz(h,a,nn);
plot(w/(2*pi), 20*log10(abs(H)),'-r');
% Hanning window
h1=h'.*hanning(M+1);
[H,w]=freqz(h1,a,nn);
plot(w/(2*pi), 20*log10(abs(H)),'-g');
axis([0 0.5 -80 10]); hold off
pause
%
% Here is how h(n) looks like for a ractangular and hanning windows
% ------------------------------------------------------------------------------
stem(n,h),hold on
plot(n, h'.*hanning(M+1),'xr')
xlabel(' Sample n'),
ylabel('h(n)')
title('Impulse response: "o" rect, "x" hanning'),
hold off, pause

% Compare response for a filter that uses a hanning window with that for a filter that uses
% a Kaiser window having the same stopband attenuation
% ------------------------------------------------------------------------------------------
Hd=[0 0 -200 -200]; wd=[0 wc wc pi];
plot(wd/(2*pi), Hd,'--b'),
axis([0 0.5 -80 10]);
xlabel(' f/f_sam')
ylabel('|H| dB')
title('FIR Filter: M=30, Han and Kaiser; same stopband attenuation')
hold on
%
h1=h'.*hanning(M+1);
[H,w]=freqz(h1,a,nn);
plot(w/(2*pi), 20*log10(abs(H)),'-r');
%
```

```
As=44;
beta=0.5842*(As-21)^0.4+0.07886*(As-21);
h1=h'.*kaiser(M+1,beta);
[H,w]=freqz(h1,a,nn);
plot(w/(2*pi), 20*log10(abs(H)),'--g');
hold off
% -----------------------------------------------------------------------
```

Output from FIRW_Ex2 and Comments







Note that the Kaiser window yields a better transition bandwidth for the same filter order and the same stopband attenuation. Vice versa, for any given transition width and stopband attenuation, the Kaiser window yields the smallest filter order M, compared to any other window type.

```
% Script File: FIRW_Ex3.m
% Demonstares Design of a High Pass Filter
% -----------------------------------------------
% Specifications
% ----------------
% fc=3E3 Hz, f_sam=1E4 Hz,          (cutoff and sampling frequencies (Hz))
% transition width df = 1E3 Hz
% stop band attenuation As = 50 dB
% ---------------------------------------------------------------------------
% Initialize
j=sqrt(-1);
As=50;  df=1E3;  fc=3E3;  f_sam=1E4;
dw=2*pi*df/f_sam;                                  % normalized frequencies
wc=2*pi*fc/f_sam;
%
% To achieve the required stop band attenuation, a hamming, or Kaiser,
% window could be used (see the Table in the lecture notes).
%
% Design 1: Hamming window
% -----------------------------
% Filter Order:
% Transitions width = 6.6*pi/M
%
M=ceil(6.6*pi/dw)                 % M= 33, or Type II, hence can not be a highpass filter
if(rem(M,2)~=0), M=M+1, end;      % if M is odd, increase M by one to make it even; M=34
% determine impulse response
n=[0:1:M];
h1= sin(wc*((n-M/2)+1E-8))./(pi*((n-M/2)+1E-8));          % Lowpass h
h1= sin(pi*((n-M/2)+1E-8))./(pi*((n-M/2)+1E-8)) - h1;     % highpass h
h1=h1'.* hamming(M+1);                                    % windowed highpass h
% Here is how h(n) looks like
```

```
stem(n,h1)
xlabel(' Sample n'),
ylabel('h(n)')
title('Impulse response: Highpass Filter'),
pause
%
% Design 2: Kaiser window
% --------------------------------
M=ceil((As-8)/(2.285*dw))                    % Filter order; see lecture notes (M=30)
if(rem(M,2)~=0), M=M+1, end;                 % ensure M is even
% Note that for the same dw, M is smaller in the kiaser case (30 instead of 34).
n=[0:1:M];
h2= sin(wc*((n-M/2)+1E-8))./(pi*((n-M/2)+1E-8));
h2= sin(pi*((n-M/2)+1E-8))./(pi*((n-M/2)+1E-8)) - h2;
beta=0.1102*(As-8.7);                        % see lecture notes (As >= 50)
h2=h2'.* kaiser(M+1, beta);
%
% We now plot and compare |H| in dB and compare
%
a=1; nn=256;
Hd=[-200 -200 0 0];
wd=[0 wc wc pi];
plot(wd/(2*pi), Hd,'--b'),
axis([0 0.5 -80 10]);
xlabel(' f/f_sam'), ylabel('|H|')
title('Highpass FIR Filter: solid: Hanning, dashed: Kaiser'), hold on
%
[H,w]=freqz(h1,a,nn);
plot(w/(2*pi), 20*log10(abs(H)),'-r');
[H,w]=freqz(h2,a,nn);
plot(w/(2*pi), 20*log10(abs(H)),'--g'), hold off
% ------------------------------------------------------------------------------------------------
```

Results of FIRW_Ex3.m

M =

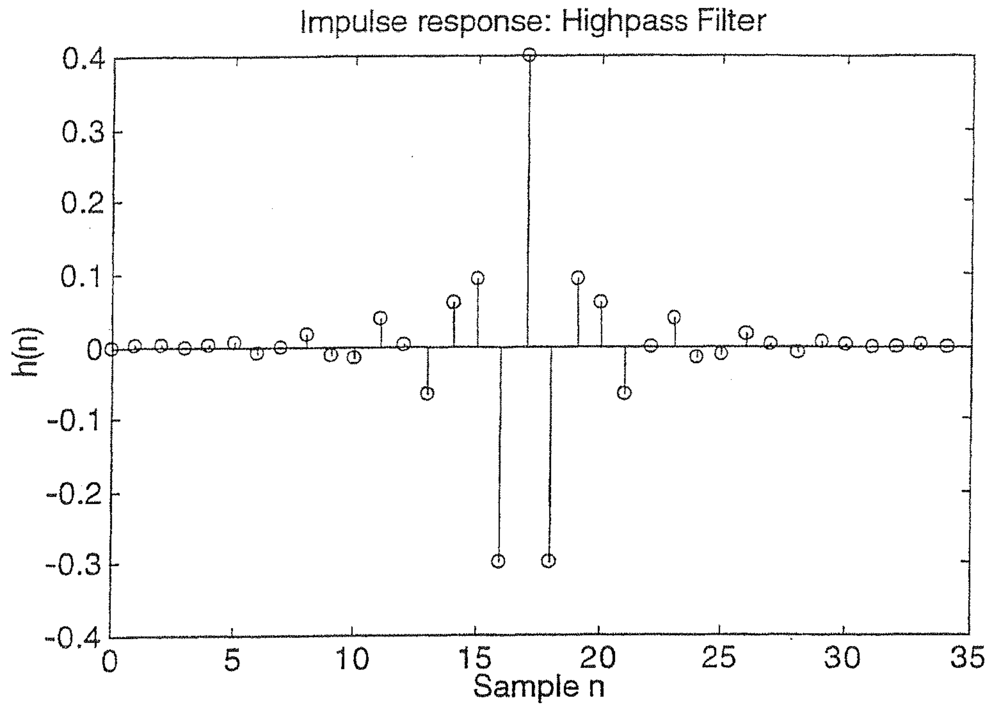
33

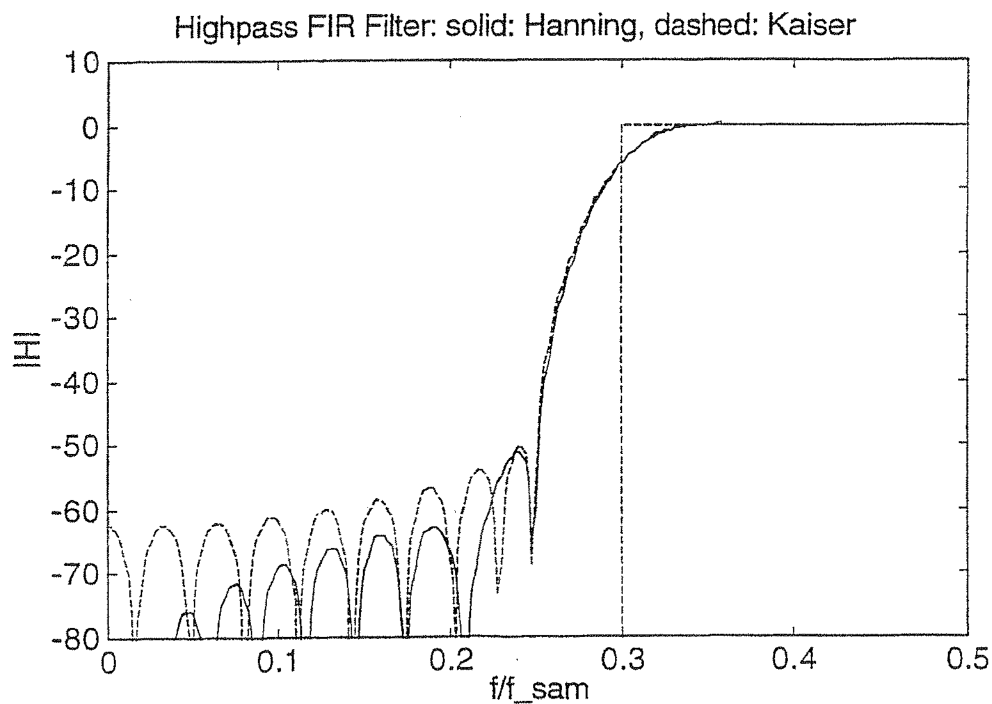
M =

34

M =

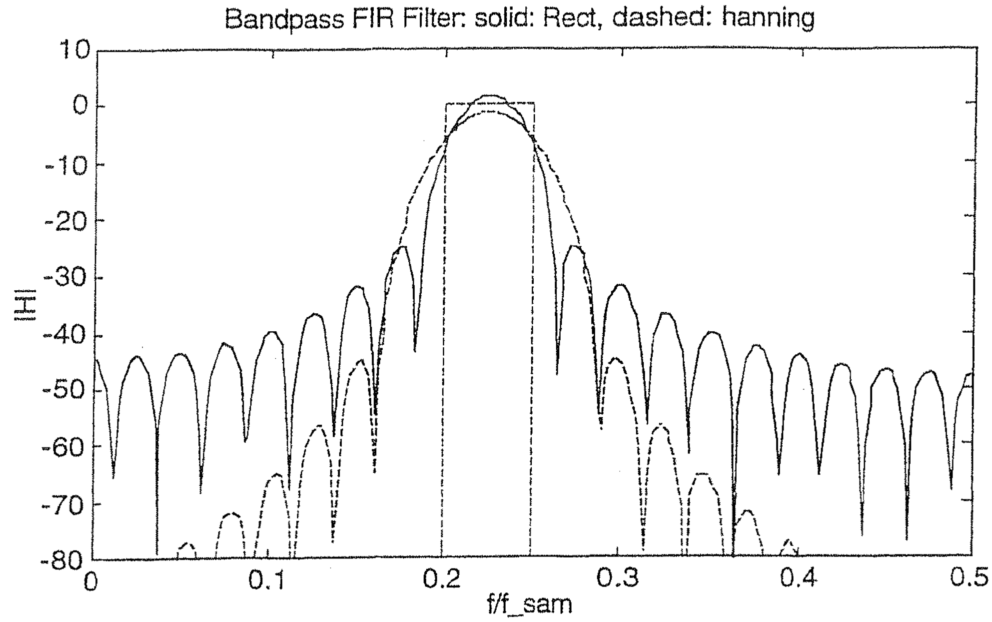
30

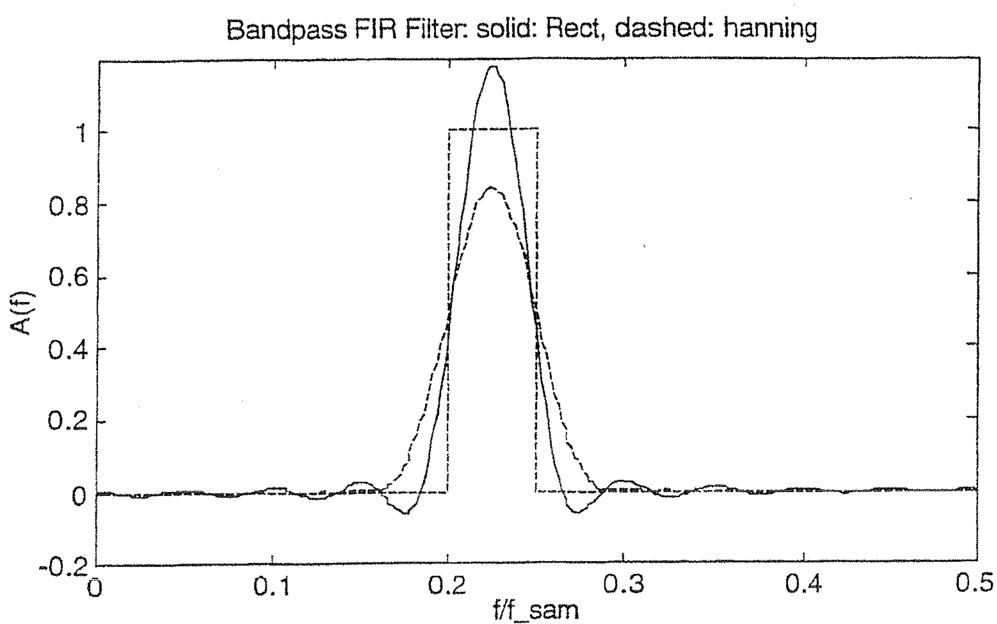




Note that the Hanning design yields fixed 53 dB stopband attenuation. The Kaiser design meets the 50 dB spec and gives a smaller M of 30 instead of 32.

```
% Script File: FIRW_Ex4.m
% Design of a bandpass filter (From Strum and Kirk, problem 9.7)
% ----------------------------------------------------------------------------
% Specifications
% ---------------
% f1=160 Hz, f2=200 Hz, f_sam=800 Hz;
% limit h(n) length to 50 msec;
% Compare transition width and stopband attenuation for
% rectangular and hanning windows
% ----------------------------------------------------------
f_sam=800; f1=160;  f2=200;
% Determine M from length of h(n)
M = ceil(f_sam*50E-3)                                    % M = 40
w1=2*pi*f1/f_sam;
w2=2*pi*f2/f_sam;
w0=(w1+w2)/2;
dw=(w2-w1)/2;                                            % Class B= 2*dw
n=[0:1:M];
% Rectangular window
% -----------------------
h1=sin(w1*((n-M/2)+1E-8))./(pi*((n-M/2)+1E-8));          % Lowpass filter
h1=sin(w2*((n-M/2)+1E-8))./(pi*((n-M/2)+1E-8)) - h1;     % Bandpass filter
%
% Hanning window
% ------------------
h2=h1'.*hanning(M+1);
%
% Plot and compare
axis([0 0.5 -80 10]);
Hd=[-200 -200 0 0 -200 -200];
wd=[0 w1 w1 w2 w2 pi];
plot(wd/(2*pi), Hd,'--b'),
axis([0 0.5 -80 10]);
xlabel(' f/f_sam'), ylabel('|H|')
title('Bandpass FIR Filter: solid: Rect, dashed: hanning'), hold on
%
% dB Plot
% ---------
a=1; nn=256;
[H,w]=freqz(h1,a,nn);
plot(w/(2*pi), 20*log10(abs(H)),'-r');
[H,w]=freqz(h2,a,nn);
plot(w/(2*pi), 20*log10(abs(H)),'--g');
hold off, pause
%
% Linear Plot
% --------------
Hd=[0 0 1 1 0 0];
wd=[0 w1 w1 w2 w2 pi];
plot(wd/(2*pi), Hd,'--b'),
axis([0 0.5 0 1.2]);
xlabel(' f/f_sam'), ylabel('|H|')
title('Bandpass FIR Filter: solid: Rect, dashed: hanning'), hold on
[H,w]=freqz(h1,a,nn); plot(w/(2*pi), abs(H),'-r');
[H,w]=freqz(h2,a,nn); plot(w/(2*pi), abs(H),'--g');
hold off
```


Bandpass FIR Filter: solid: Rect, dashed: hanning
10
0
-10
-20
-30
-40
-50
-60
-70
-80
|H|
0
0.1
0.2
0.3
0.4
0.5
f/f_sam


Bandpass FIR Filter: solid: Rect, dashed: hanning
1
0.8
0.6
0.4
0.2
0
-0.2
A(f)
0
0.1
0.2
0.3
0.4
0.5
f/f_sam