**PRACTICAL CASE**

**FREQUENCY-SELECTIVE FIR AND IIR FILTERS**

**OBJECTIVES:**

1. Design FIR and IIR filters: band-pass filters.
2. Practical case: recovering a message.
3. **Design selective-frequency FIR and IIR filters**

**EXAMPLE: THE BLACKMAN WINDOW BAND-PASS FILTER (CAUSAL LTI SYSTEM)**

where:

function [y,n] = bpf\_bm(x,n,L,wi,wf) % x is the input sequence, L is the number of the weighted averaged samples and wi and wf are the band-pass frequencies. ac is a vector with the L-1 auxiliary conditions ac=[x[ni-1] … x[ni-(L-1)]]. Suppose ac=[0 … 0].

|  |
| --- |
| **bpf\_bm.m** |
| function [y,n] = bpf\_bm(x,n,L,wi,wf)  % L is an odd number  ac = zeros(1,L-1);  x\_aux = [ac x];  y = zeros(1,length(x));  wc = (wf-wi)/2;  w0 = (wf+wi)/2;    i = 0:L-1;  w\_b = 0.42-0.5\*cos(2\*pi\*i/(L-1))+0.08\*cos(4\*pi\*i/(L-1));  m = 0:((L-1)/2)-1;  hi1 = sin(wc\*(m-(L-1)/2))./(pi\*(m-(L-1)/2));  himax = wc/pi;  m=((L-1)/2)+1:L-1;  hi2 = sin(wc\*(m-(L-1)/2))./(pi\*(m-(L-1)/2));  hi=[hi1 himax hi2];    h = 2\*cos(w0\*i).\*w\_b.\*hi;  for i = 1:length(x)  y(i) = sum(h.\*x\_aux(i:i+L-1));  end  stem(n,y)  end |

Compare graphically the log magnitude of the system frequency responses for a **FIR-Blackman** and **IIR-elliptic** band-pass filters:

For L=61 we have:

|  |  |
| --- | --- |
| **PLOT h\_fir[n]** | **PLOT H\_fir(w) in [-pi,pi]** |
| N = 101;  [d,n] = Delta(0,0,N-1);  [h\_fir,n] = bpf\_bm(d,n,61,1.5,2.5); | H\_fir = MyDTFT(h\_fir,n); |

For order=7 we have:

|  |  |
| --- | --- |
| **PLOT h\_iir[n]** | **PLOT H\_iir(w) in [-pi,pi]** |
| [d,n] = Delta(0,0, N-1);  [b,a]=ellip(7,0.25,50,[1.5/pi 2.5/pi],'bandpass');  h\_iir = filter(b,a,d);  stem(n, h\_iir, '. ') | H\_iir = MyDTFT(h\_iir,n); |

[b,a] = ellip(n,Rp,Rs, [w1 w2],'bandpass')

Returns the transfer function coefficients of an nth-order bandpass digital elliptic filter with normalized lower edge frequency w1 and higher edge frequency w2. The resulting filter has Rp decibels of peak-to-peak passband ripple and Rs decibels of stopband attenuation down from the peak passband value.

|  |
| --- |
| **PLOT TOGETHER THE GAIN OF H\_fir(w) AND H\_iir(w) in [-pi,pi]** |
| G\_H\_fir = 20\*log10(abs(H\_fir));  G\_H\_iir = 20\*log10(abs(H\_iir));  fplot(G\_H\_fir,[-pi,pi])  hold on  fplot(G\_H\_iir,[-pi,pi])  legend('FIR Blackman','IIR Elliptic') |

1. **Practical case: recovering a message.**

load('Message.mat')

load('Signal.mat')

load('H\_message.mat')

Ts = 0.2; % sampled period of 0.2

t = 0:Ts:40;

N = 201; % number of sampled values

n = 0:N-1;

m0 = n\*2\*pi/N;

m = m0(1:((N-1)/2)+1);

1. **The signal and the message:**

subplot(2,1,1)

x\_ip = interp(xs,1/Ts);

t\_ip = linspace(0,40,length(x\_ip)-4);

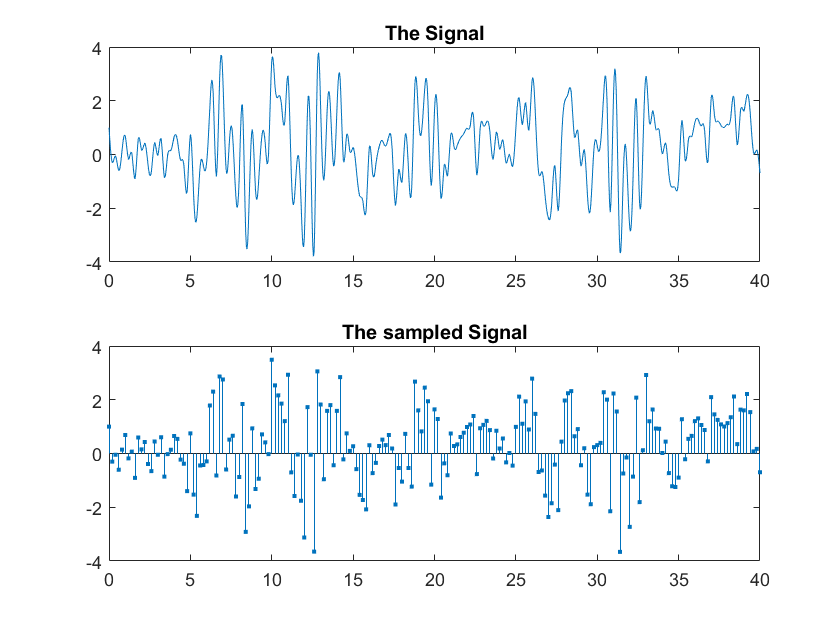
plot(t\_ip,x\_ip(1:end-4))

title('The Signal')

subplot(2,1,2)

stem(t,xs,'.')

title('The sampled Signal')



subplot(2,1,1)

x\_ip = interp(msg,1/Ts);

t\_ip = linspace(0,40,length(x\_ip)-4);

plot(t\_ip,x\_ip(1:end-4))

title('The Message')

subplot(2,1,2)

x\_ip = interp(xs,1/Ts);

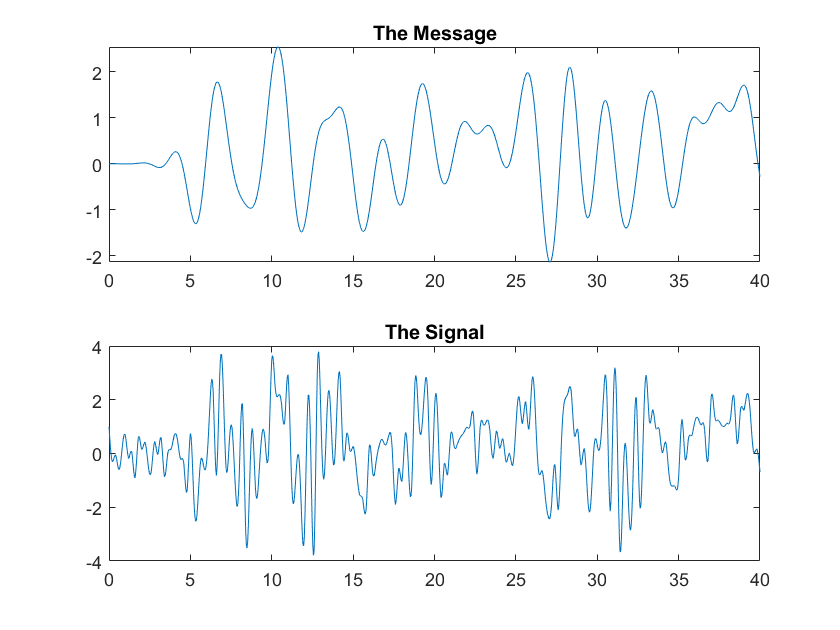
t\_ip = linspace(0,40,length(x\_ip)-4);

plot(t\_ip,x\_ip(1:end-4))

title('The Signal')

% ON THIS SIGNAL THERE’S A HIDDEN MESSAGE IN A BAND WE CANNOT HEAR: THE 0-5 BAND WHICH IS ULTRASONIC TO OUR EARS

% THE OBJECTIVE IS TO FIRST OBTAIN THE MESSAGE AND THEN OBTAIN THE HIDDEN MESSAGE.



1. **The frequency response of the signal:**

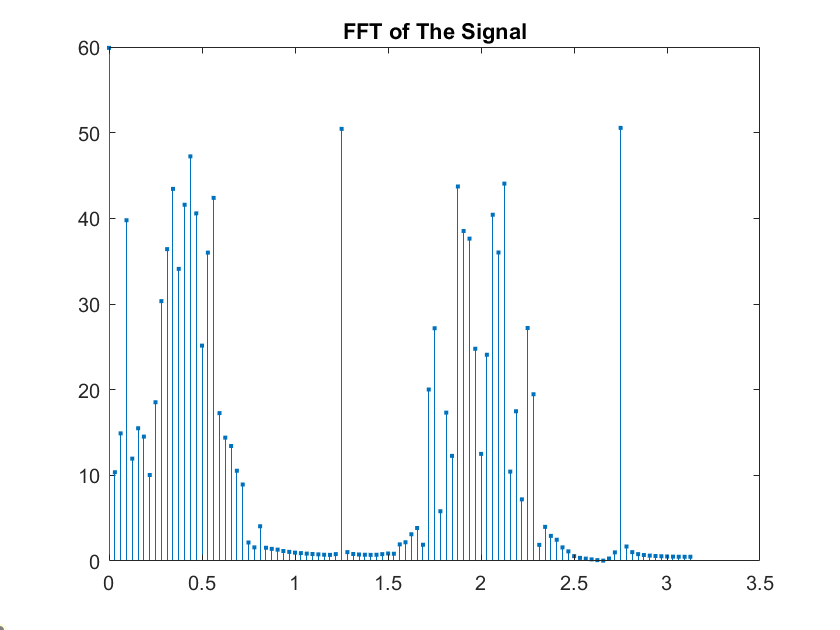
Xs = fft(xs);

Xs\_1= Xs(1:((N-1)/2)+1);

stem(m,abs(Xs\_1),'.')

title('FFT of the Signal')

% The range from 1.3 and beyond and both pulses (carriers) are not noise because they may be indicators, real noise is not so steep. They are beacons, in-between there’s hidden information. First we’ll get the info from 0 to the first beacon (the visible message)



1. **Recovering the message:**

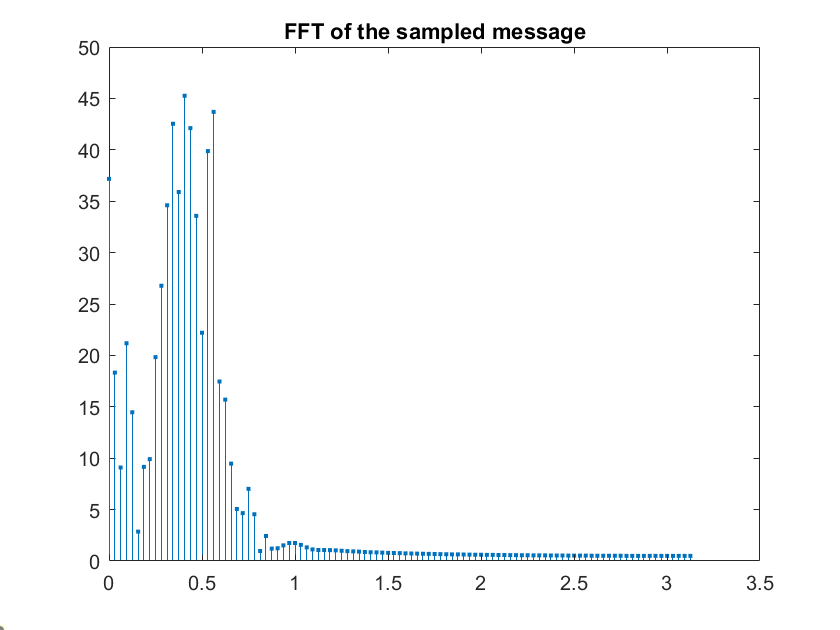
[ys,n] = lpf\_bm(xs,n,55,0.3\*pi); % wc = 0.9425

Ys = fft(ys);

Ys\_1= Ys(1:((N-1)/2)+1);

stem(m,abs(Ys\_1),'.')

title('FFT of the sampled message')



subplot(2,1,1)

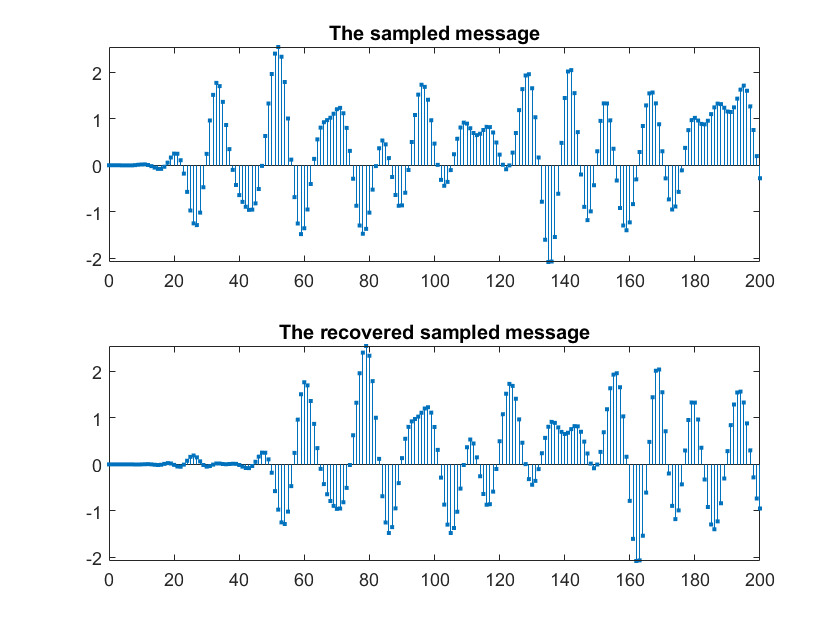
stem(n,msg,'.')

title('The sampled message')

subplot(2,1,2)

stem(n,ys,'.')

title('The recovered sampled message')



There’s a delay because the FIR has a linear phase, which gives a grouped delay, the derivative of the phase.

1. **Recovering the hidden message:**

% we use bandpass filter to remove the extra info outside the area, including the beacons. “b” and “a” are the coefficients of the transfer function.

[b,a] = ellip(7,0.25,50,[1.5/pi 2.5/pi],'bandpass');

% filter is calculating the output of this impulse response; we could design our personal function.

yhs = filter(b,a,xs);

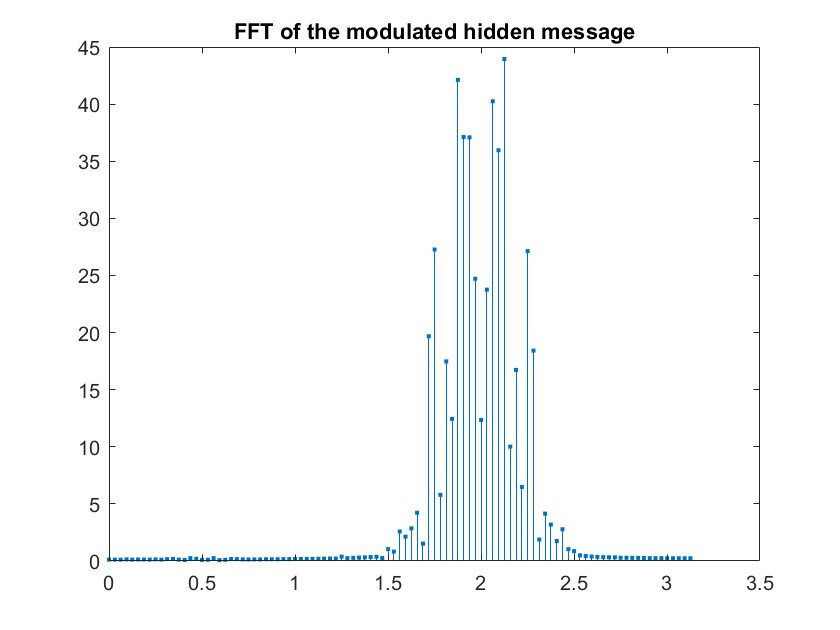
Yhs = fft(yhs);

Yhs\_1= Yhs(1:((N-1)/2)+1);

stem(m,abs(Yhs\_1),'.')

title('FFT of the modulated hidden message')

% these sounds are still ultrasonic, we need to move it to a low frequency band, by shifting in frequency, but multiplied by cos(ωon), and not 2\*cos(ωon) because that would give us twice the energy due to a replicated value).



syms t

ph(t) = cos(10\*t);

Ts = 0.2;

t = 0:Ts:40;

Ph = double(ph(t));

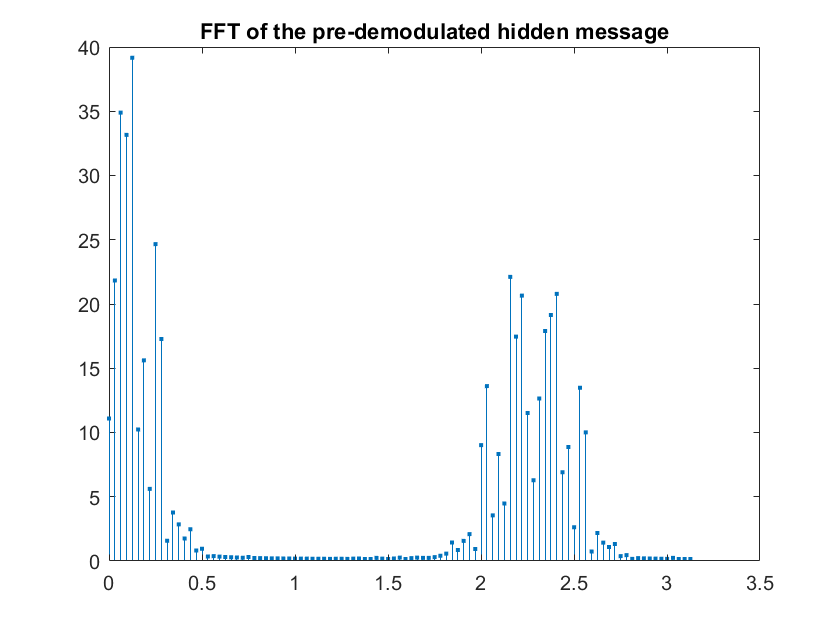
yhi = yhs.\*Ph;

Yhi = fft(yhi);

Yhi\_1= Yhi(1:((N-1)/2)+1);

stem(m,abs(Yhi\_1),'.')

title('FFT of the pre-demodulated hidden message')



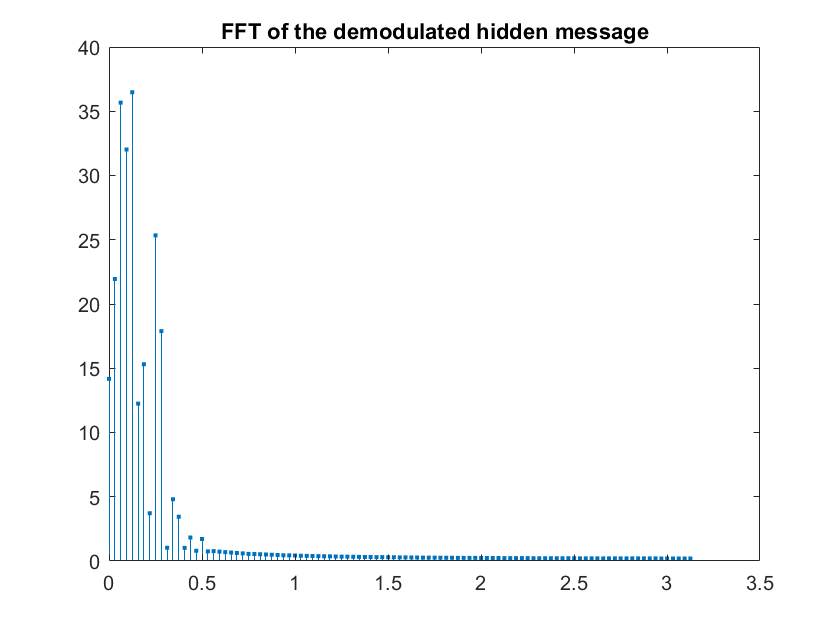
[y,n] = lpf\_bm(yhi,n,55,0.7);

Y = fft(y);

Y\_1= Y(1:((N-1)/2)+1);

stem(m,abs(Y\_1),'.')

title('FFT of the demodulated hidden message')



subplot(2,1,1)

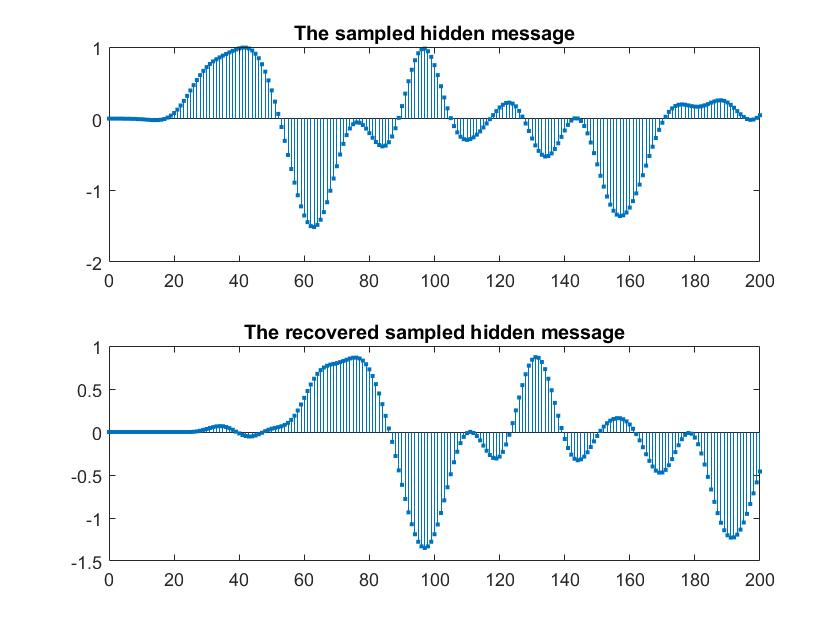
stem(n,msgh,'.')

title('The sampled hidden message')

subplot(2,1,2)

stem(n,y,'.')

title('The recovered sampled hidden message')



% the recovered signal has some loss due to the filter, I could improve the result with some gain amplifier