**PRACTICE 7**

**(PART A)**

**FREQUENCY-SELECTIVE FIR FILTERS**

**OBJECTIVE:**

1. Design FIR filters: Low-pass, High-pass and Band-pass filters.
2. Practical case: recovering a speech-signal.

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1. **Design selective-frequency FIR filters**

**EXAMPLE 1: THE MOVING AVERAGE SYSTEM (CAUSAL LTI SYSTEM)**

function [y,n] = lpf\_sma(x,n,L) % x is the input sequence, L is the number of the averaged samples and ac is a vector with the L-1 auxiliary conditions ac=[x[ni-1] … x[ni-(L-1)]]. Suppose ac=[0 … 0].

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| **lpf\_sma.m** |
| function [y,n] = lpf\_sma(x,n,L)  ac = zeros(1,L-1);  x\_aux = [ac x];  y = zeros(1,length(x));  for i = 1:length(x)  y(i) = (1/L)\*sum(x\_aux(i:i+L-1));  end  stem(n,y)  end |

The impulse response h[n] of this FIR system is:

For L=7 we have:

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| **PLOT h[n]** | **PLOT H(w) in [-pi,pi]** |
| [d,n] = delta(0,0,20);  [h,n] = lpf\_sma(d,n,7);  axis([-5 20 0 0.25])  NOTE: For us, we use Delta, not delta | H = MyDTFT(h,n); |

For L=15 we have:

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| **PLOT h[n]** | **PLOT H(w) in [-pi,pi]** |
| [d,n] = delta(0,0,20);  [h,n] = lpf\_sma(d,n,15);  axis([-5 20 0 0.15]) | H = MyDTFT(h,n); |

**EXAMPLE 2: THE RECTANGULAR WINDOW LOW-PASS FILTER (CAUSAL LTI SYSTEM)**

where:

function [y,n] = lpf\_r(x,n,L,wc) % x is the input sequence, L is the number of the weighted averaged samples and wc is the cut-off frequency. ac is a vector with the L-1 auxiliary conditions ac=[x[ni-1] … x[ni-(L-1)]]. Suppose ac=[0 … 0].

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| **lpf\_r.m** |
| function [y,n] = lpf\_r(x,n,L,wc)  % L is an odd number  ac = zeros(1,L-1);  x\_aux = [ac x];  y = zeros(1,length(x));    w\_r = ones(1,L);  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 = w\_r.\*hi;  for i = 1:length(x)  y(i) = sum(h.\*x\_aux(i:i+L-1));  end  stem(n,y)  end |

The impulse response h[n] of this FIR system is:

where:

For L=7 we have:

|  |  |
| --- | --- |
| **PLOT h[n]** | **PLOT H(w) in [-pi,pi]** |
| [d,n] = delta(0,0,20);  [h,n] = lpf\_r(d,n,7,0.5\*pi);  axis([-5 20 -0.15 0.6]) | H = MyDTFT(h,n); |

For L=15 we have:

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| **PLOT h[n]** | **PLOT H(w) in [-pi,pi]** |
| [d,n] = delta(0,0,20);  [h,n] = lpf\_r(d,n,15,0.5\*pi);  axis([-5 20 -0.15 0.6]) | H = MyDTFT(h,n); |

**EXAMPLE 3: THE HAMMING WINDOW LOW-PASS FILTER (CAUSAL LTI SYSTEM)**

where:

function [y,n] = lpf\_hm(x,n,L,wc) % x is the input sequence, L is the number of the weighted averaged samples and wc is the cut-off frequency. ac is a vector with the L-1 auxiliary conditions ac=[x[ni-1] … x[ni-(L-1)]]. Suppose ac=[0 … 0].

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| **lpf\_hm.m** |
| function [y,n] = lpf\_hm(x,n,L,wc)  % L is an odd number  ac = zeros(1,L-1);  x\_aux = [ac x];  y = zeros(1,length(x));    i = 0:L-1;  w\_h = 0.54-0.46\*cos(2\*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 = w\_h.\*hi;  for i = 1:length(x)  y(i) = sum(h.\*x\_aux(i:i+L-1));  end  stem(n,y)  end |

The impulse response h[n] of this FIR system is:

where:

For L=7 we have:

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| --- | --- |
| **PLOT h[n]** | **PLOT H(w) in [-pi,pi]** |
| [d,n] = delta(0,0,20);  [h,n] = lpf\_hm(d,n,7,0.5\*pi);  axis([-5 20 -0.15 0.6]) | H = MyDTFT(h,n); |

For L=15 we have:

|  |  |
| --- | --- |
| **PLOT h[n]** | **PLOT H(w) in [-pi,pi]** |
| [d,n] = delta(0,0,20);  [h,n] = lpf\_hm(d,n,15,0.5\*pi);  axis([-5 20 -0.15 0.6]) | H = MyDTFT(h,n); |

**EXAMPLE 4: THE BLACKMAN WINDOW LOW-PASS FILTER (CAUSAL LTI SYSTEM)**

where:

function [y,n] = lpf\_bm(x,n,L,wc) % x is the input sequence, L is the number of the weighted averaged samples and wc is the cut-off frequency. ac is a vector with the L-1 auxiliary conditions ac=[x[ni-1] … x[ni-(L-1)]]. Suppose ac=[0 … 0].

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| **lpf\_bm.m** |
| function [y,n] = lpf\_bm(x,n,L,wc) % x is the input sequence, L is the number of the weighted averaged samples and wc is the cut-off frequency. ac is a vector with the L-1 auxiliary conditions ac=[x[ni-1] … x[ni-(L-1)]]. Suppose ac=[0 … 0].  % L is an odd number  ac = zeros(1,L-1);  x\_aux = [ac x];  y = zeros(1,length(x));  k = 0:L-1;  w\_bm = 0.42-0.5\*cos(2\*pi\*k/(L-1)) + 0.08 \*cos(4\*pi\*k/(L-1));  % matlab doesn't have the same sense of scope as C  if mod (length(k),2) ~= 0 %sin(wc\*(k2-(L-1)/2)) == 1  % because for k = (L-1)/2, we have an indetermination 0/0:  % we calculate one side, then the other, and the max in the middle,  % then for k = (L-1)/2, we calculate by changing k to a continuous  % variable "p" and applying L'Hôpital, we get lim x->0 sin(p)/p -->  % cos(p)/1 ---> 1/1 = 1, then the sinc is wc/pi for that k    k2 = 0:((L-1)/2)-1;  hi1 = sin(wc\*(k2-(L-1)/2))./(pi\*(k2-(L-1)/2));  k3=((L-1)/2)+1:L-1;  hi2 = sin(wc\*(k3-(L-1)/2))./(pi\*(k3-(L-1)/2));  himax = wc/pi;  hi=[hi1 himax hi2];  else  % for even ones it's simpler, since we don't have the  % indetermination, we can just apply it normally.  k2 = 0:L-1;  hi1 = sin(wc\*(k2-(L-1)/2))./(pi\*(k2-(L-1)/2));  hi=[hi1];  end  h = w\_bm.\*hi;  for i = 1:length(x)  y(i) = sum(h.\*x\_aux(i:i+L-1));  end  stem(n,y)  end |

The impulse response h[n] of this FIR system is:

where:

For L=7 we have:

|  |  |
| --- | --- |
| **PLOT h[n]** | **PLOT H(w) in [-pi,pi]** |
| [d,n] = Delta(0,0,20);  [h,n] = lpf\_bm(d,n,7,0.5\*pi);  axis([-5 20 -0.15 0.6])  Gráfico, Gráfico de burbujas  Descripción generada automáticamente | H = MyDTFT(h,n);  **Gráfico, Gráfico de líneas  Descripción generada automáticamente** |

For L=15 we have:

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| **PLOT h[n]** | **PLOT H(w) in [-pi,pi]** |
| [d,n] = Delta(0,0,20);  [h,n] = lpf\_bm(d,n,15,0.5\*pi);  axis([-5 20 -0.15 0.6])  Gráfico, Gráfico de burbujas  Descripción generada automáticamente | H = MyDTFT(h,n);  **Gráfico  Descripción generada automáticamente** |

1. Compare graphically the log magnitude of the system frequency response for a Hamming low-pass filter and a Blackman low-pass filter with size windows L=35.

For L=35 we have:

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| **PLOT h\_hm[n]** | **PLOT H\_hm(w) in [-pi,pi]** |
| % important to increase impulse to more than 35  [d2,n2] = Delta(0,0,40);  [h2,n2] = lpf\_hm(d2,n2,35,0.5\*pi);  % do not forget to adjust the axis to the same  axis([-5 40 -0.15 0.6])  Gráfico  Descripción generada automáticamente | Hhm = MyDTFT(h2,n2);  Gráfico  Descripción generada automáticamente |

For L=35 we have:

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| **PLOT h\_bm[n]** | **PLOT H\_bm(w) in [-pi,pi]** |
| [d1,n1] = Delta(0,0,40);  [h1,n1] = lpf\_bm(d1,n1,35,0.5\*pi);  % do not forget to adjust the axis to the same  axis([-5 40 -0.15 0.6])  Gráfico  Descripción generada automáticamente | Hbm = MyDTFT(h1,n1);  **Gráfico  Descripción generada automáticamente** |

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| **PLOT TOGETHER GAIN OF H\_hm(w) AND H\_bm(w) in [-pi,pi]** |
| G\_H\_hm = 20 \* log10(abs(Hhm))  G\_H\_bm = 20 \* log10(abs(Hbm))  %G\_H\_hm = 20 \* log10(sqrt(real(Hhm).^2 + imag(Hhm).^2))  %G\_H\_bm = 20 \* log10(sqrt(real(Hbm).^2 + imag(Hbm).^2))  fplot(G\_H\_hm,[-pi,pi])  hold on  fplot(G\_H\_bm,[-pi,pi])  Gráfico, Histograma  Descripción generada automáticamente  G\_H\_hm is blue, G\_H\_bm is red, so while Hamming windowing is a bit better at having a greater fall immediately after the cutoff, Blackman window removes far more energy from those frequencies beyond the cutoff. |