



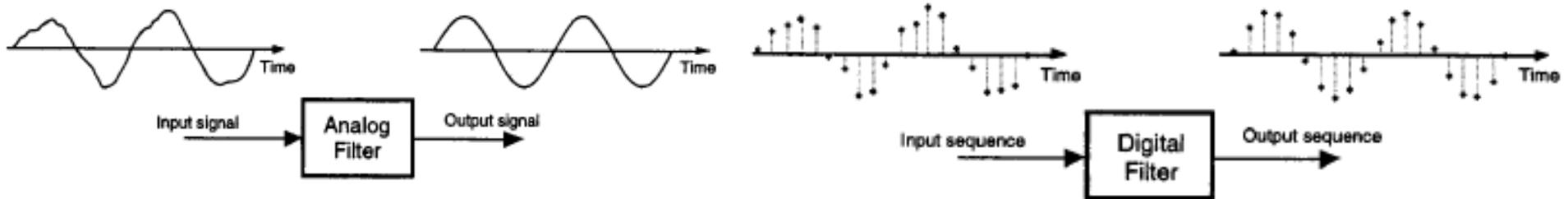
**Universidade Federal de Uberlândia  
Engenharia Eletrônica e de Telecomunicações**

**- Processamento digital de sinais –  
Capítulo 5 – Filtros FIR**

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# 1) Introdução filtros FIR

- Processo filtragem



- Ex.: filtro média móvel

$$y(n) = \frac{1}{5} [x(n-4) + x(n-3) + \dots + x(n)]$$

$$y(n) = \frac{1}{5} \sum_{k=n-4}^n x(k)$$

ou

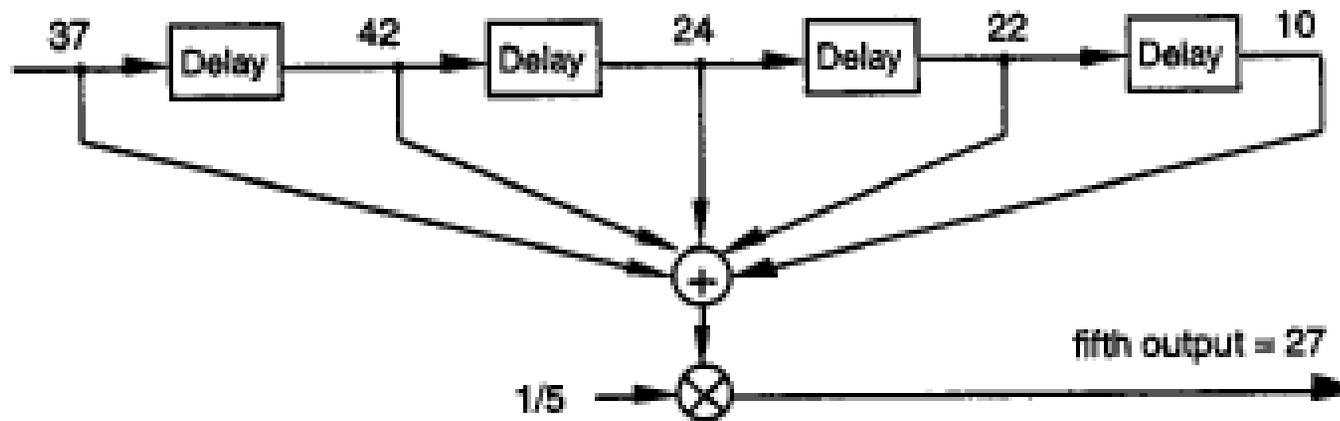
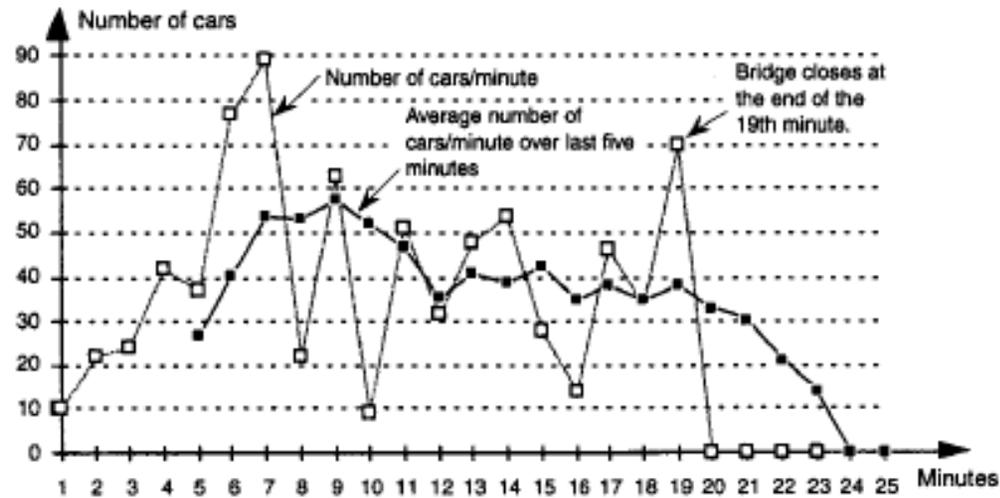
$$y(n) = h(4).x(n-4) + h(3).x(n-3) + \dots + h(0).x(n)$$

$$y(n) = \sum_{k=0}^{M-1} h(k).x(n-k)$$

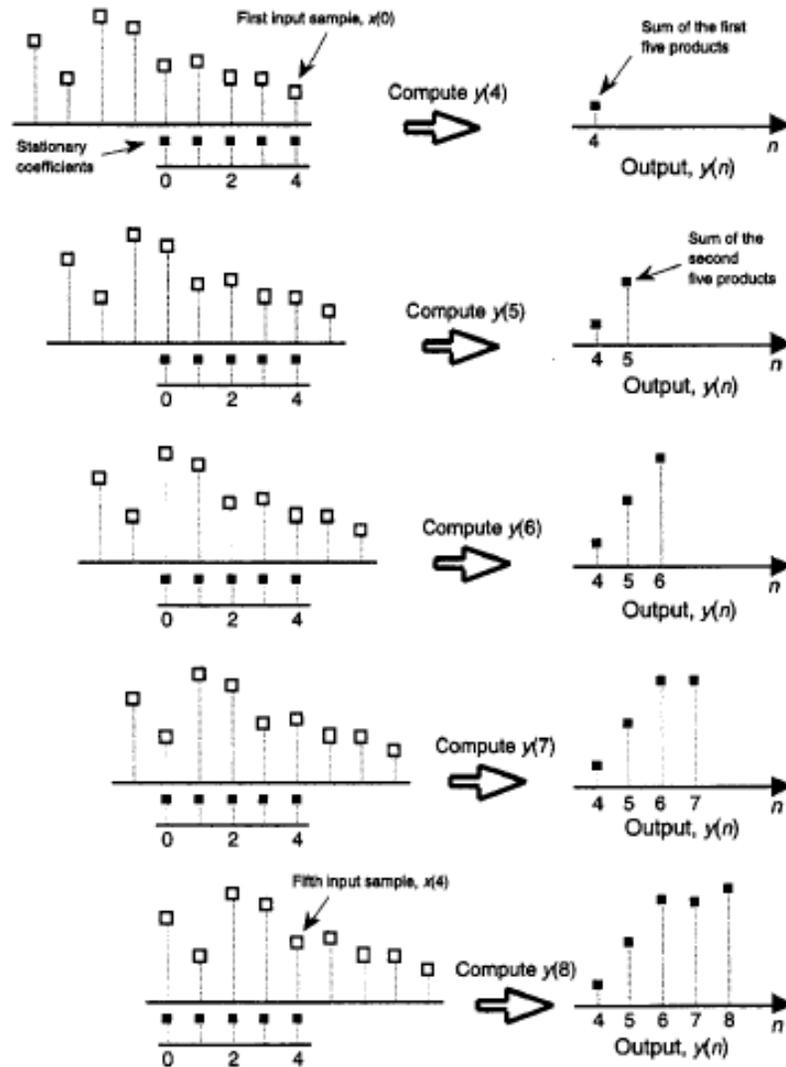
<i>Minute index</i>	<i>Number of cars/minute over the last minute</i>	<i>Number of cars/minute averaged over the last five minutes</i>
1	10	-
2	22	-
3	24	-
4	42	-
5	37	27
6	77	40.4
7	89	53.8
8	22	53.4
9	63	57.6
10	9	52



- Estrutura e resultados:



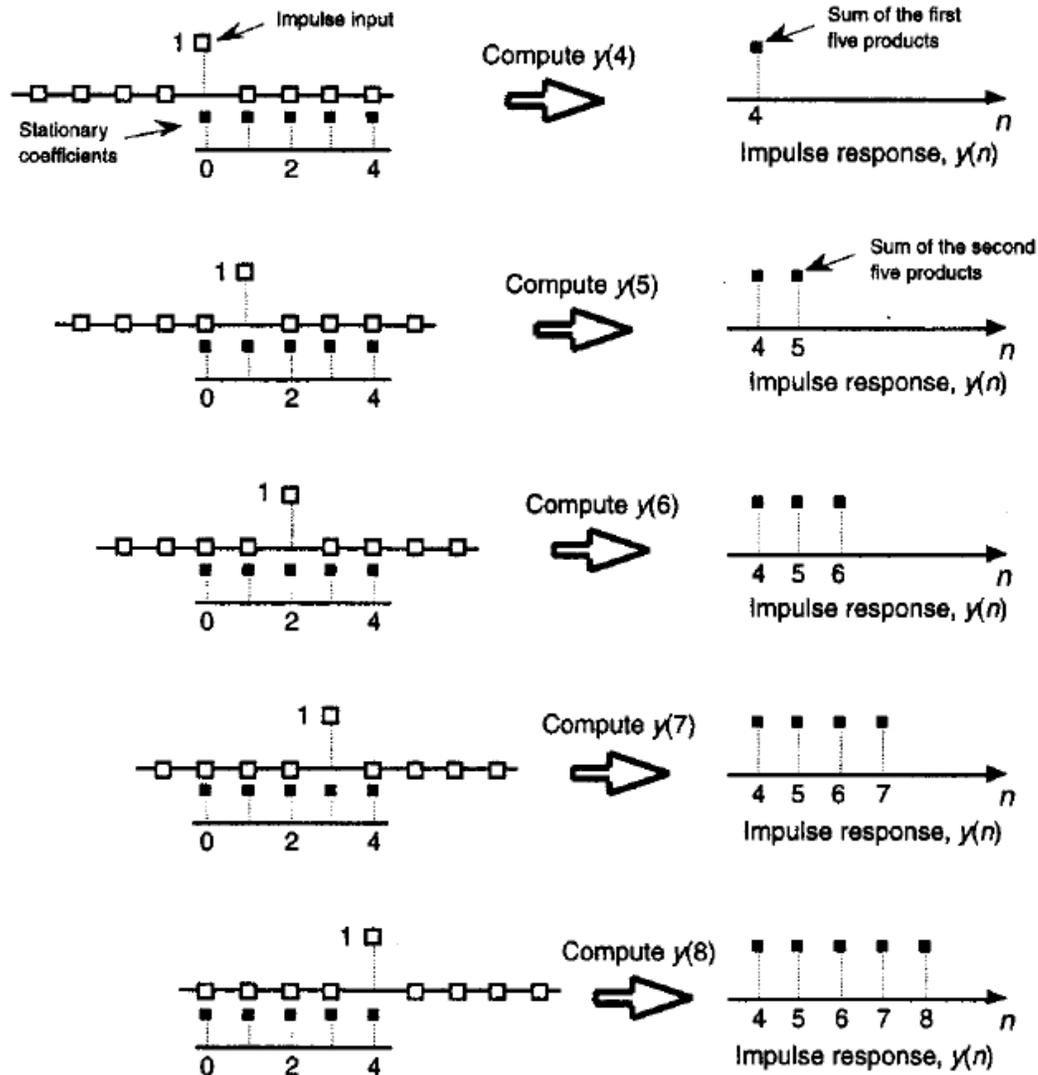
- Convolução em filtros:



$$h(k) * x(n) \xleftrightarrow{DFT / IDFT} H(m) \cdot X(m)$$



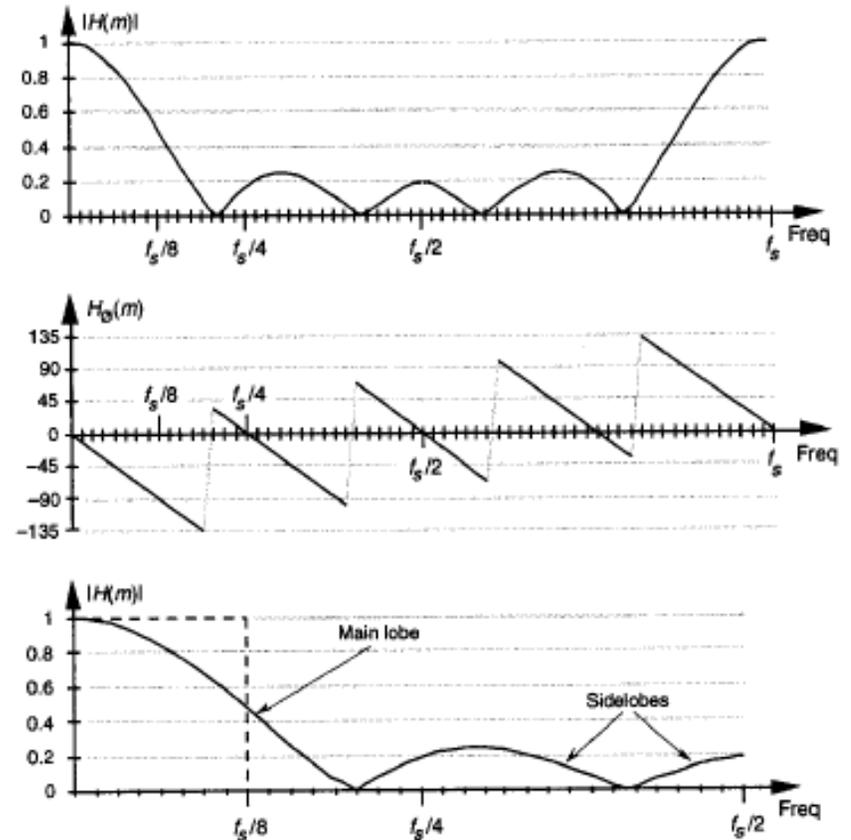
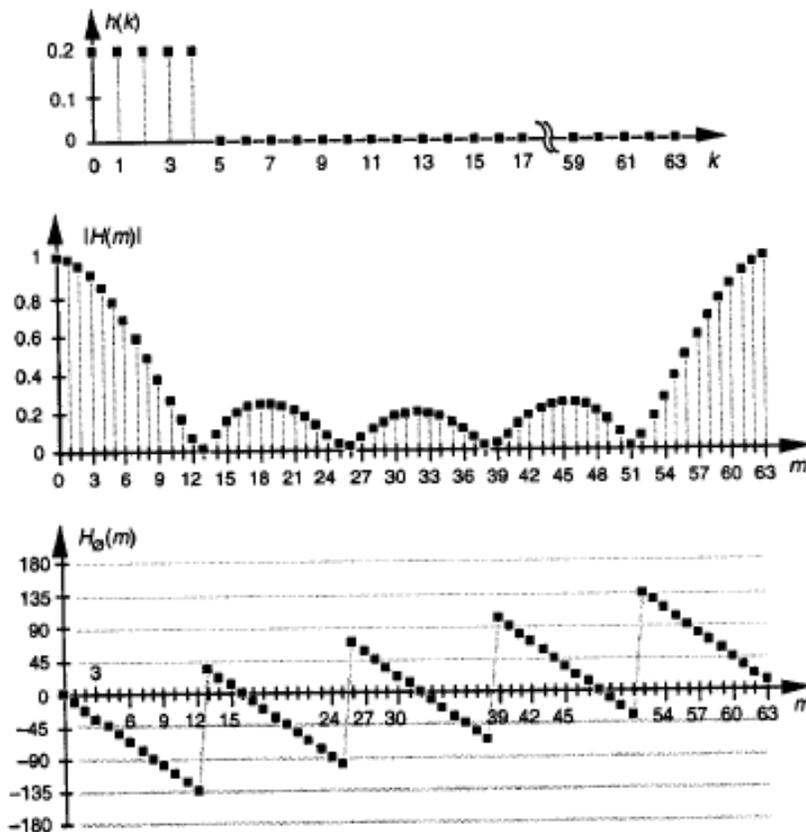
- Resposta impulsiva filtro

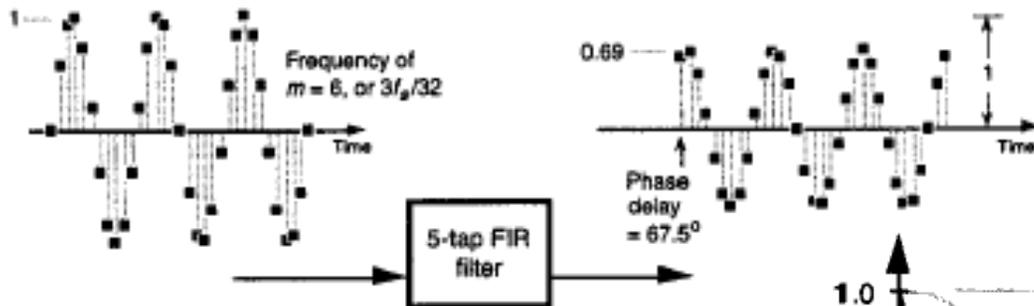
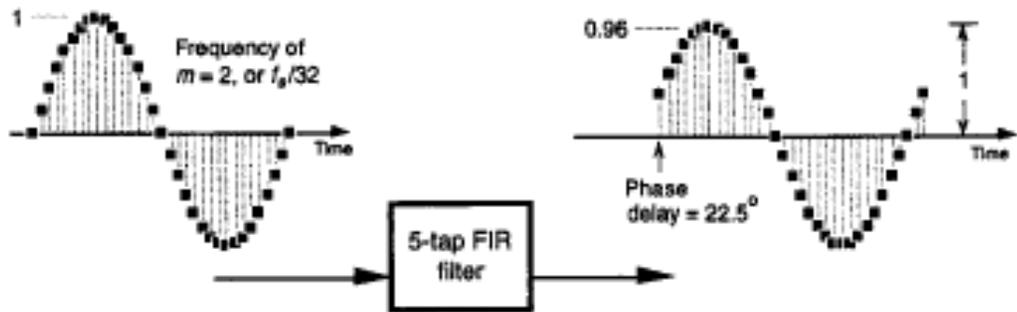


**Coef. Filtro FIR = resposta impulsiva**

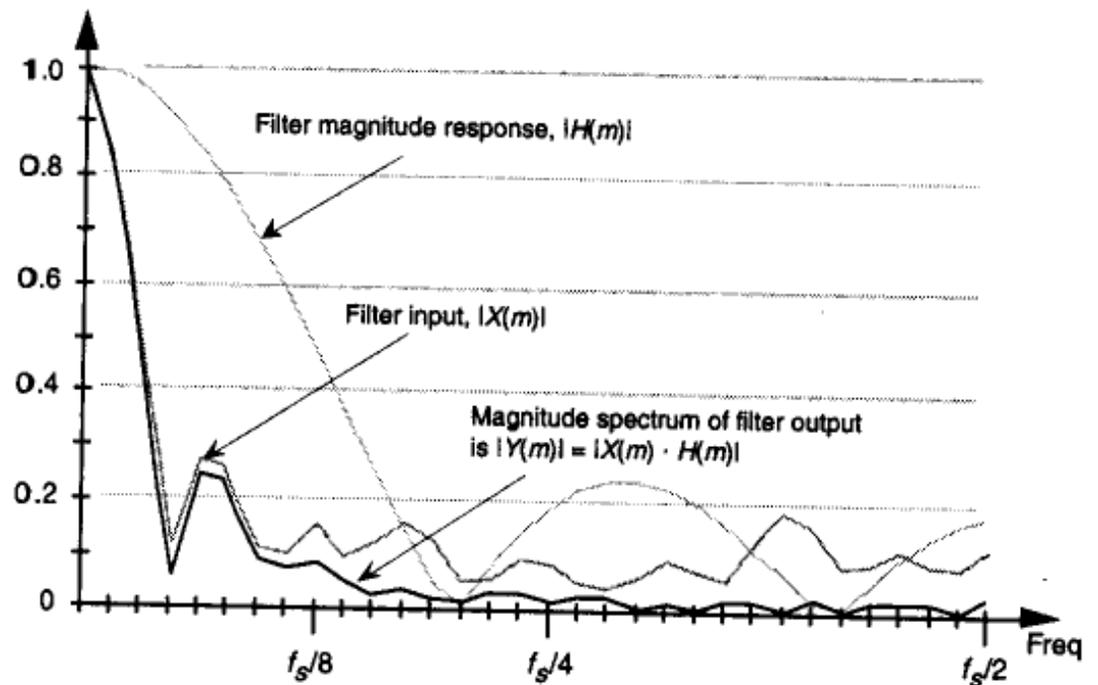


- Comportamento frequência filtro:
  - análise DFT coeficientes filtro!
- Ex.: filtro média móvel: 5 amostras + 59 zeros





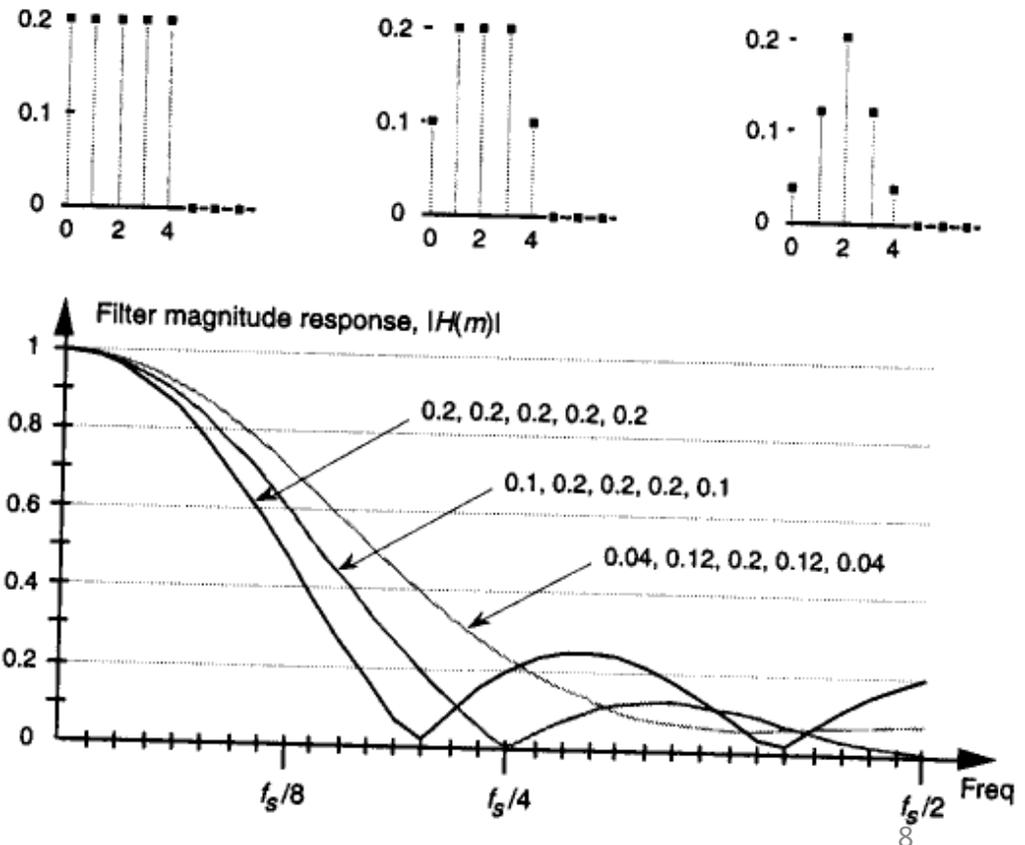
- Espectro:



- Pontos importantes:

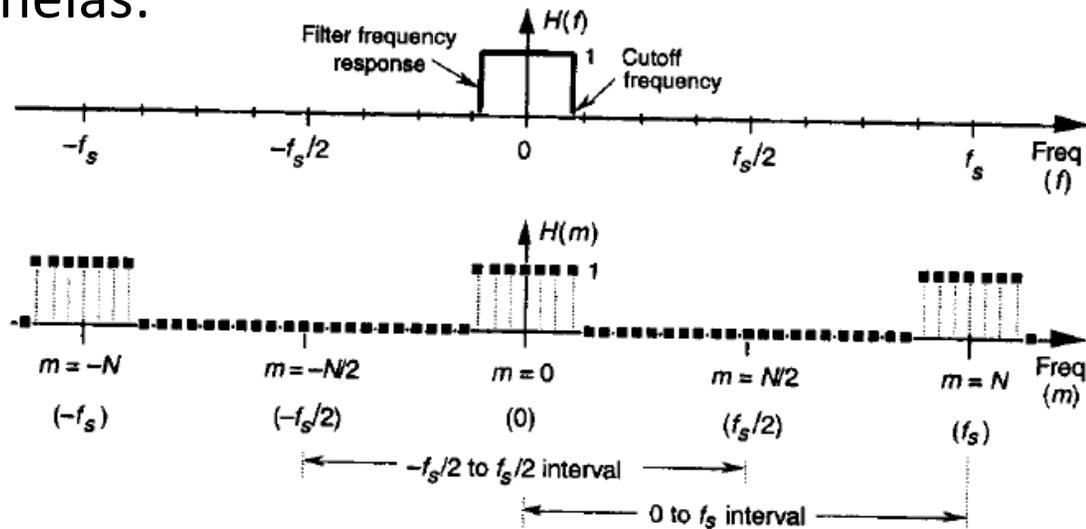
- saída do filtro FIR é a convolução da entrada e os coeficientes do filtro;
- a resposta em frequência do filtro FIR é a DFT da resposta impulsiva do filtro;
- o espectro de saída é o produto do espectro de entrada e a resposta em frequência do filtro.

- Alterando coeficientes do filtro:

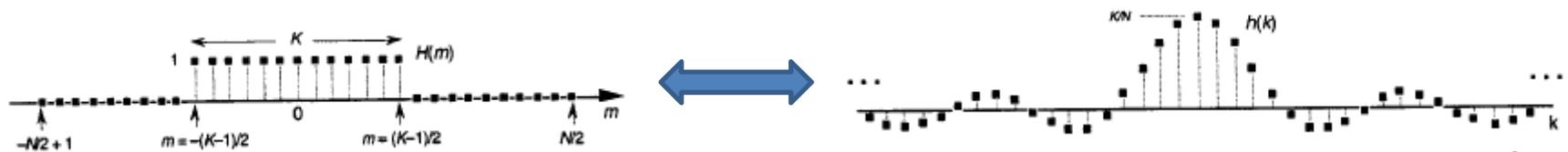


## 2) Projetos filtros FIR passa-baixas

- Dois métodos: (i) janelas e (ii) ótimo (Parks-McClellan).
- Método janelas:

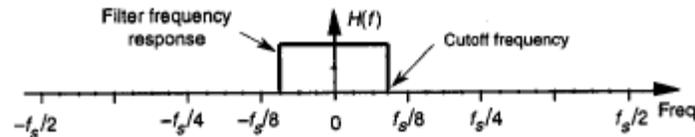


$$h(k) = \frac{1}{N} \sum_{m=-(N/2)+1}^{N/2} H(m) \cdot e^{j2\pi mk / N}$$

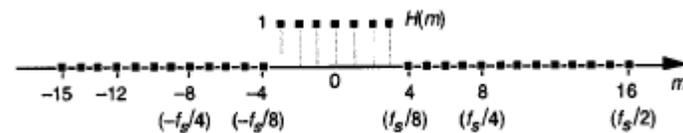


- Passos:

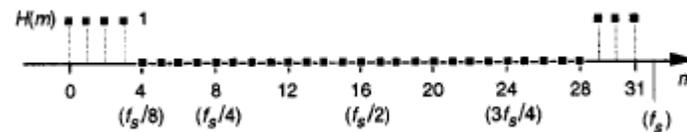
- A) esboce a resposta ideal



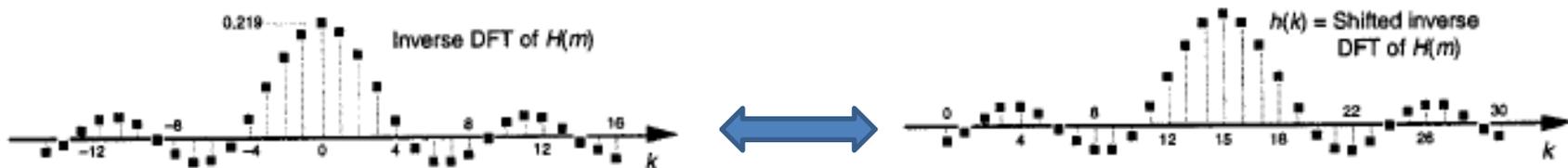
- B) discretize a resposta ideal



- C) coloque na forma necessária para refazer as assimetrias e núm. Pts.

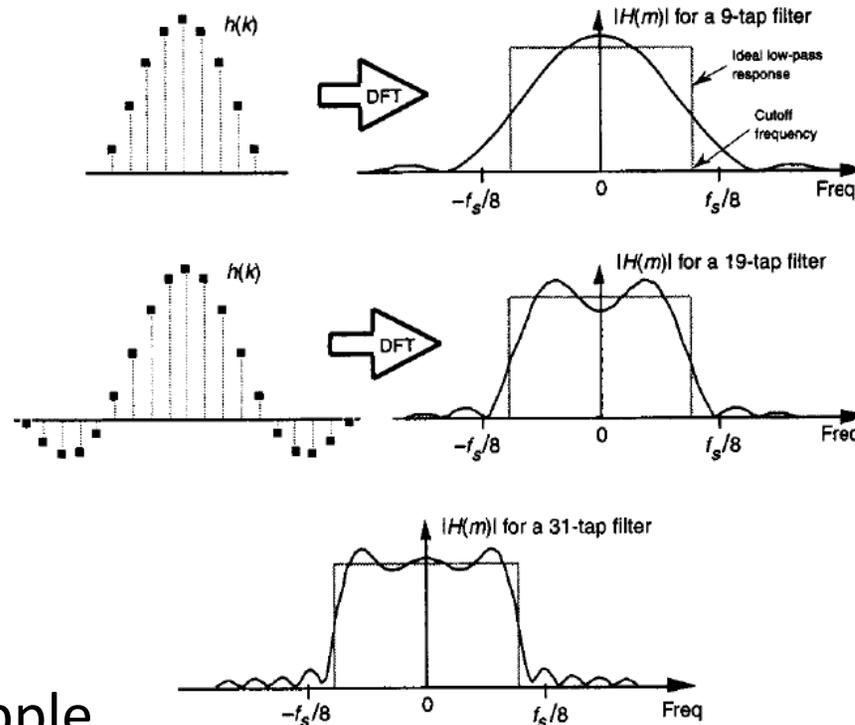


- D) Calcule a IDFT



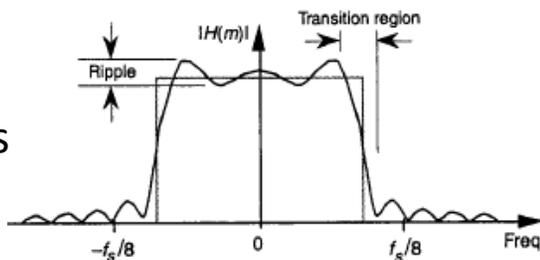
- Resposta em frequência x num pontos

- Melhora atenuação

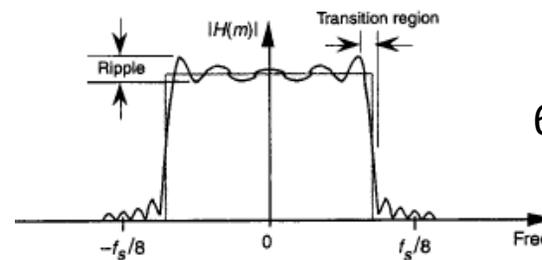


- Mantém ripple

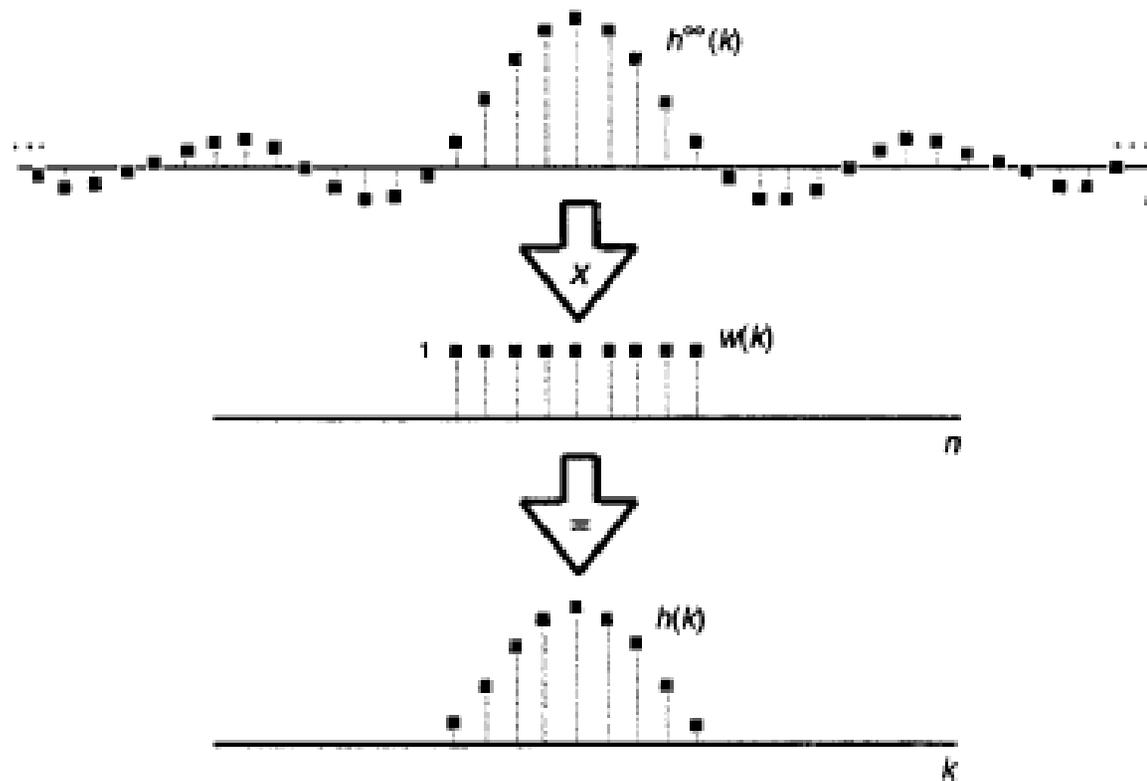
31 pts



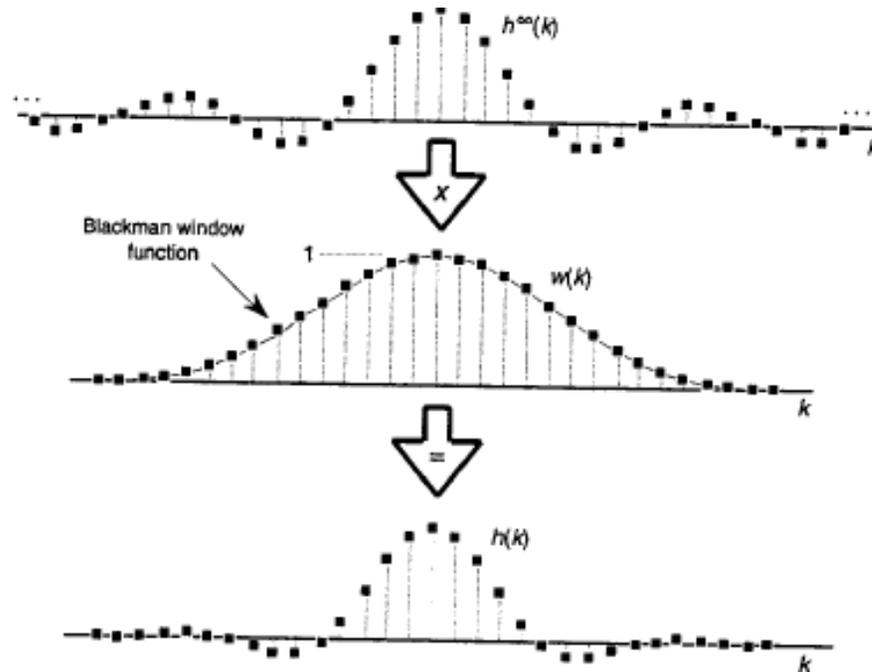
63 pts



- “Janelamento” dos coeficientes:
  - Grande efeito no ripple do filtro



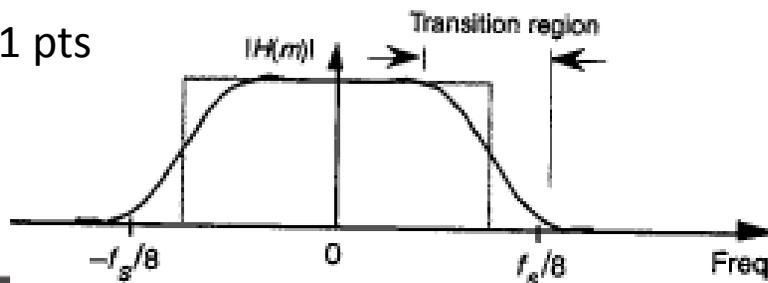
- Adicionando janelas



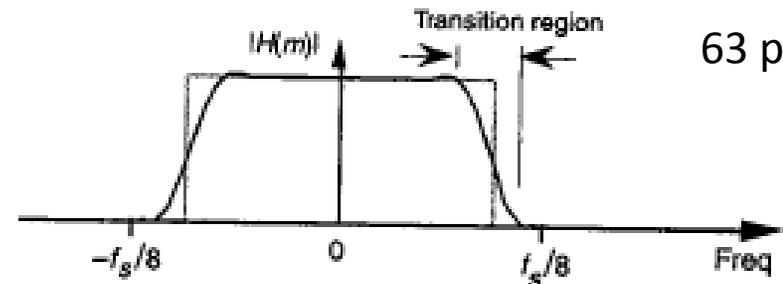
- Efeitos:

- Decaimento mais atenuado e estabilização do ripple

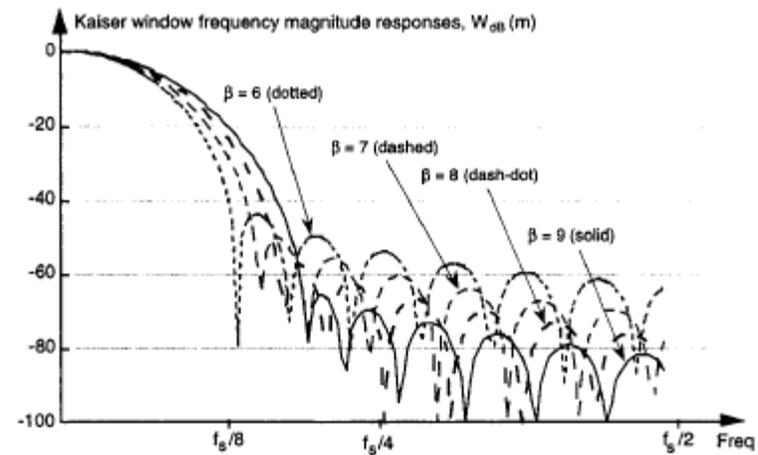
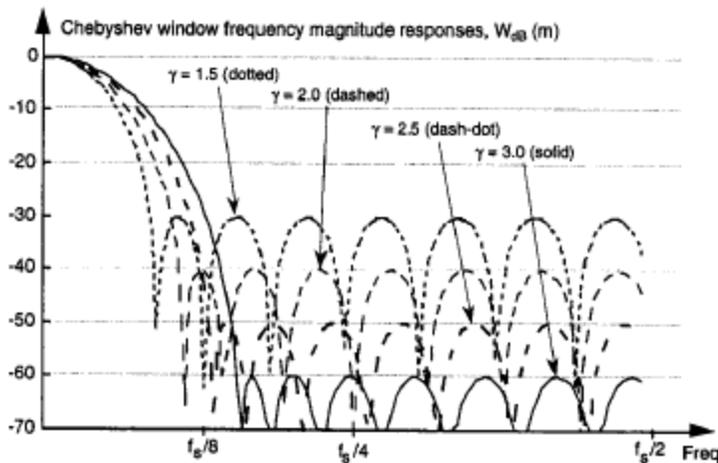
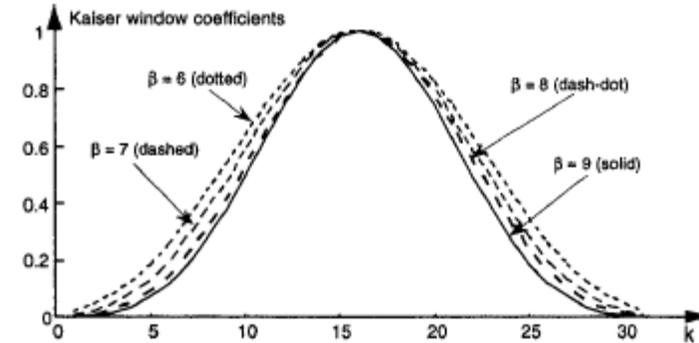
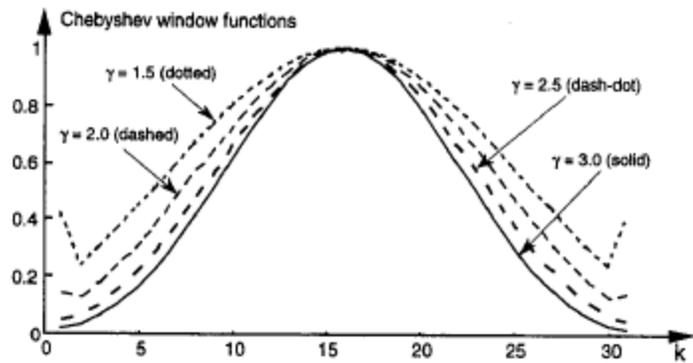
31 pts



63 pts

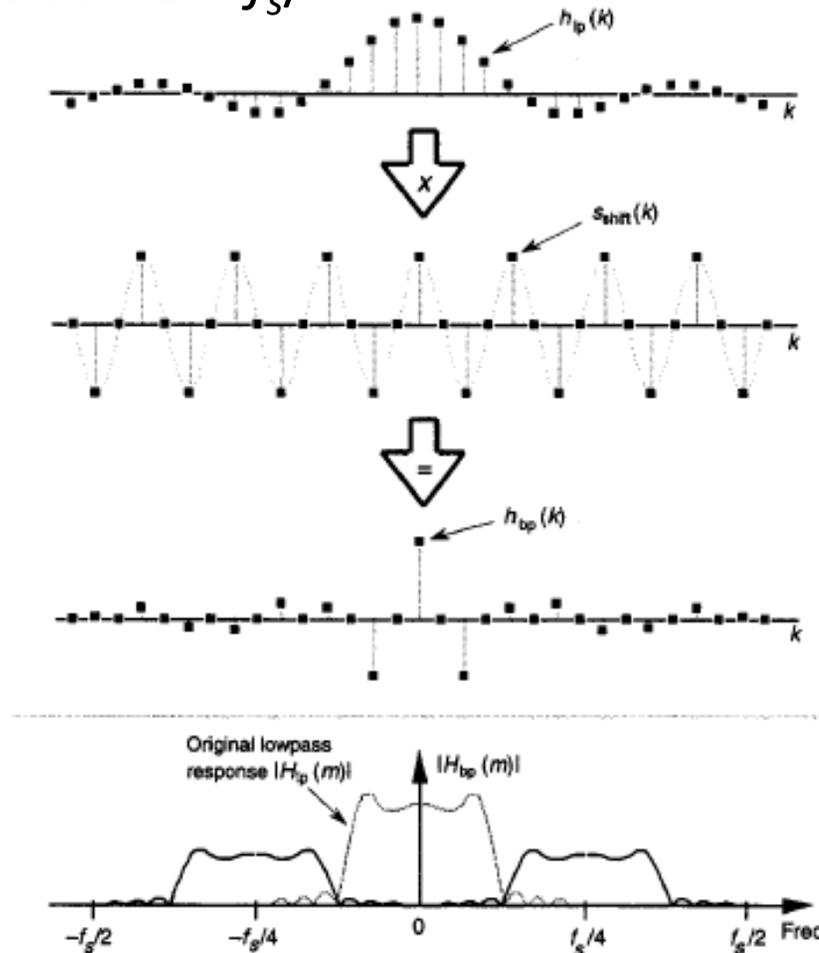


- Modelos de janelas para filtros:



# 3) Projetos filtros FIR passa-bandas

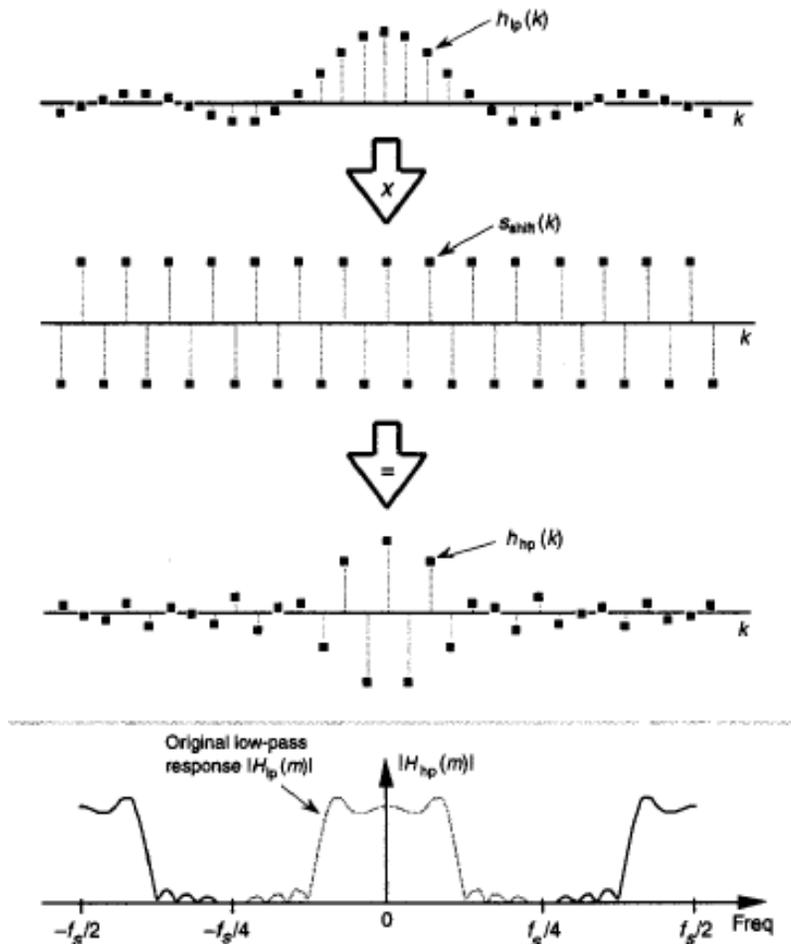
- Filtro passa-baixas deslocado  $h_{bp}(k) = h_{Lp}(k) \cdot s_{shift}(k)$ 
  - Ex.: filtro centrado em  $f_s/4$ .



## 4) Projetos filtros FIR passa-altas

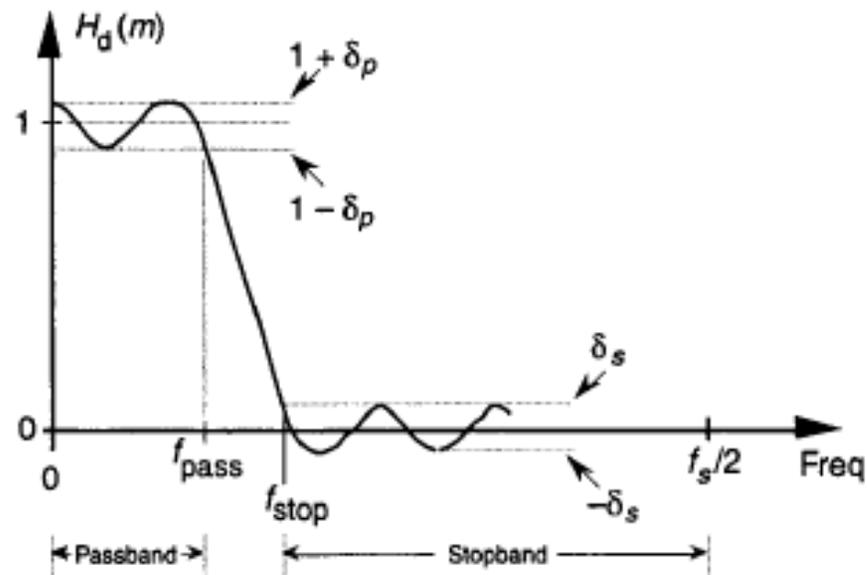
- Filtro passa-baixas deslocado por  $f_s/2$ .

$$h_{hp}(k) = h_{LP}(k) \cdot s_{shift}(k) = h_{LP}(k) \cdot (1, -1, 1, -1, 1, -1, \dots)$$



# 5) Projetos filtros FIR por Parks-McClellan

- Feito por computador
  - Ripple passa-banda:  $20\log_{10}(1 + \delta_p)$
  - Ripple banda rejeição:  $20\log_{10}(\delta_s)$



- Matlab: `firpm` e `firgr`