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CHAPTER 3:
DIGITAL FILTER DESIGN

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Finite Impulse Response (FIR) Filter Design

- FIR filter design is a key technique in digital signal processing, used for filtering signals in the time domain.
- FIR filters are popular due to their inherent stability and linear phase properties, which means they do not introduce phase distortion, making them suitable for many applications, such as communication systems, audio processing, and control systems.

FIR Filter Design

Key Properties of FIR Filters

- ✓ Finite Impulse Response
- ✓ Linear Phase Response
- ✓ Stability

FIR Filter Design

FIR Filter Characteristics

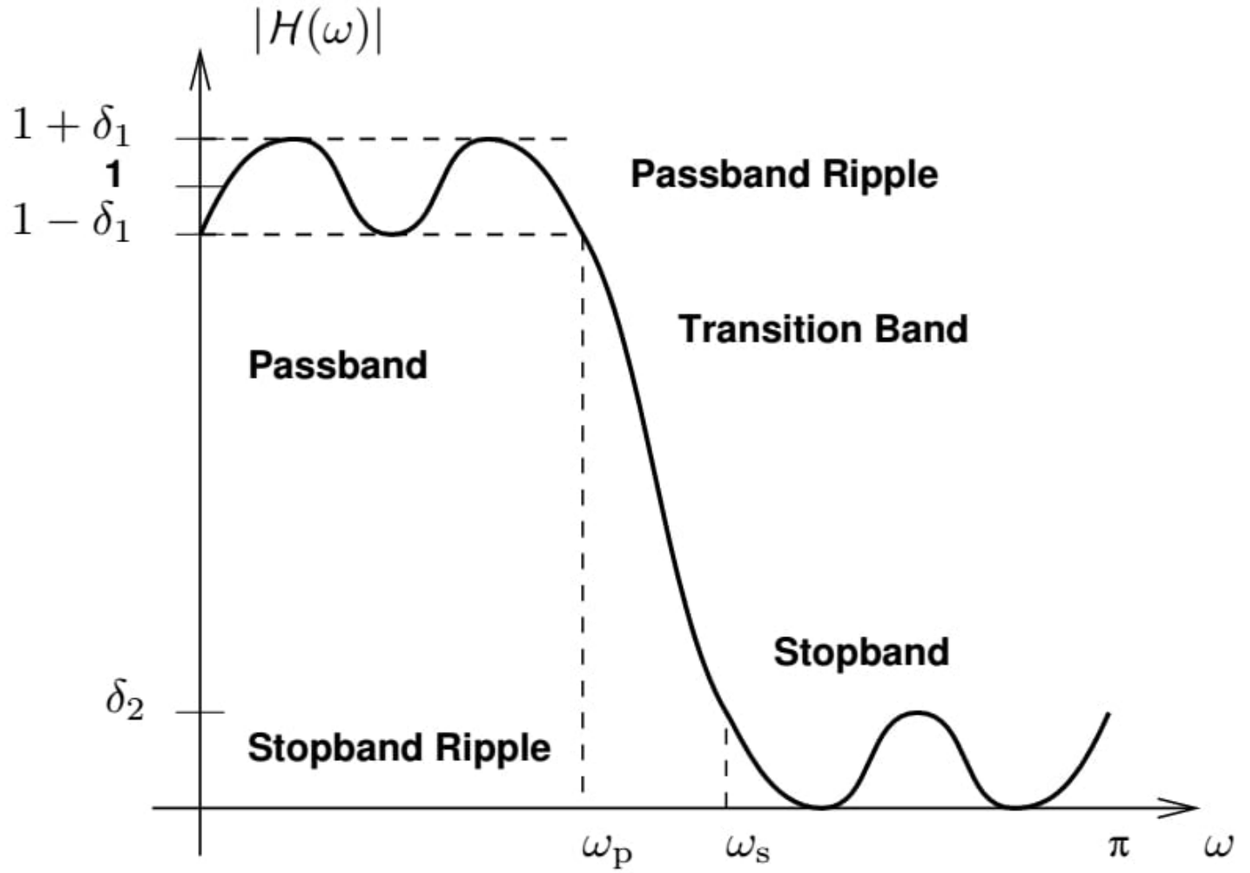
- ✓ An FIR filter is described by its impulse response h(n), which defines how the filter responds to each input sample. The filter output y(n) is a convolution of the input signal x(n) and the filter coefficients (impulse response) h(n).

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

FIR Filter Design

Specify the Filter Requirements

- ✓ Filter Type
- ✓ Cutoff Frequency
- ✓ Filter Order
- ✓ Transition Band
- ✓ Passband Ripple
- ✓ Stopband Ripple



FIR Filter Design

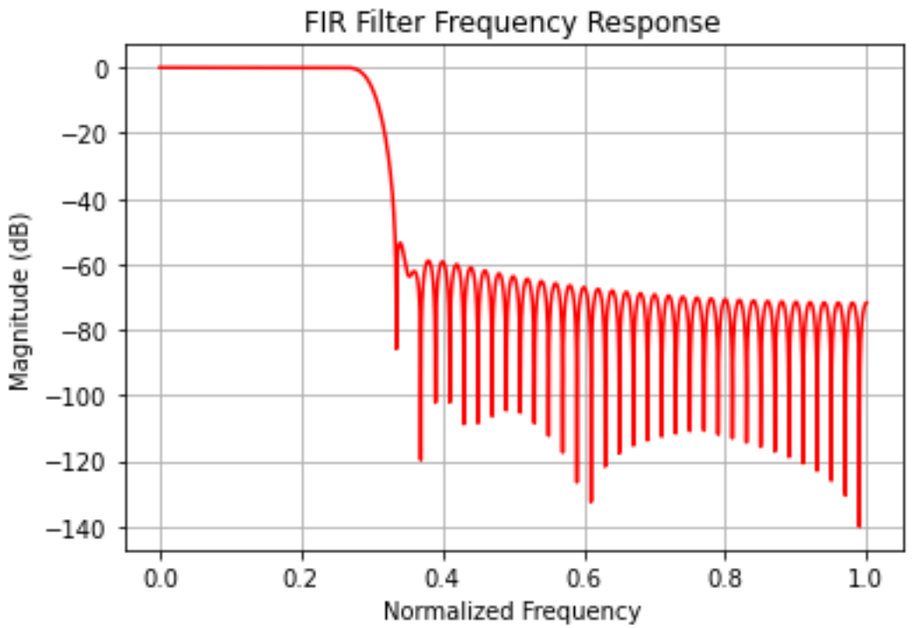
Common FIR Filter Design Methods

- ✓ Windowing Method
- ✓ Frequency Sampling Method
- ✓ Parks-McClellan Algorithm (Equi-ripple or Optimal Filter)
- ✓ Least-Squares Method

FIR Filter Design

Verify the Filter Design

- ✓ Frequency Response
- ✓ Impulse Response



FIR Filter Design

Advantages of FIR Filters

- ✓ Linear phase response
- ✓ Guaranteed stability
- ✓ Easier design for multi-band filters

Disadvantages of FIR Filters

- ✓ Higher computational complexity
- ✓ Larger filter order

Infinite Impulse Response (IIR) Filter Design

- Designing filters that can achieve a given frequency response with a lower filter order compared to FIR filters.
- IIR filters are commonly used in applications like audio processing, communications, and control systems, where real-time performance and low computational cost are important.

IIR Filter Design

Key Properties of IIR Filters

- ✓ Infinite Impulse Response
- ✓ Feedback
- ✓ Efficient for Narrowband Filtering
- ✓ Non-linear Phase Response

$$y(n) = \sum_{k=0}^{M} b_k x(n-k) - \sum_{k=1}^{N} a_k y(n-k)$$

$$H(z) = \frac{B(z)}{A(z)} = \frac{\sum_{k=0}^{M} b_k z^{-k}}{1 + \sum_{k=1}^{N} a_k z^{-k}}$$

IIR Filter Design

Common IIR Filter Design Methods

- ✓ Butterworth Filter
- ✓ Chebyshev Filter
- ✓ Elliptic (Cauer) Filter
- ✓ Bessel Filter
- ✓ Digital Design Using Bilinear Transform
- ✓ Impulse Invariant Method

IIR Filter Design

Advantages of IIR Filters

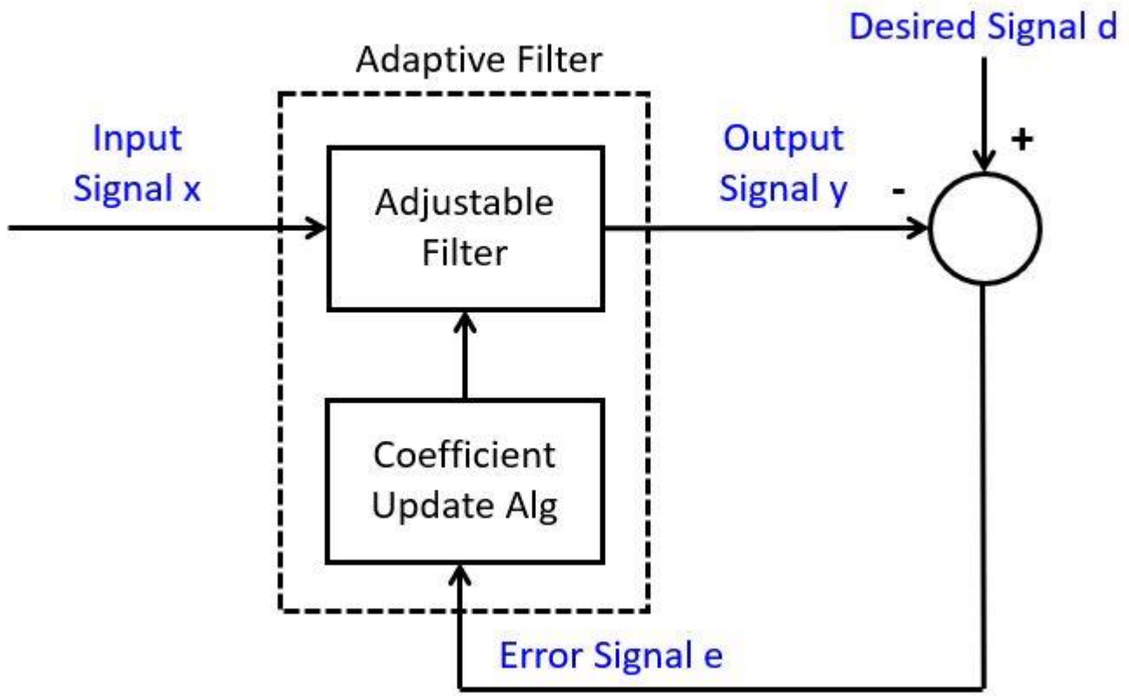
- ✓ Efficient for narrowband filters
- ✓ Low filter order
- ✓ Suited for real-time applications

Disadvantages of IIR Filters

- ✓ Non-linear phase response
- ✓ Stability issues
- ✓ More complex design

Adaptive Filter Design

- Adaptive filter design is the process of constructing a filter that can adjust its parameters dynamically to minimize the difference between its output and a desired signal in real-time.



Adaptive Filter Design

1. Choose Filter Structure

- ✓ FIR Filter (Finite Impulse Response)
- ✓ IIR Filter (Infinite Impulse Response)

Adaptive Filter Design

2. Select Adaptation Algorithm

- ✓ Least Mean Squares (LMS)
- ✓ Normalized Least Mean Squares (NLMS)
- ✓ Recursive Least Squares (RLS)
- ✓ Kalman Filter

Adaptive Filter Design

3. Define Performance Criterion

- ✓ Mean Squared Error (MSE)
- ✓ Weighted Least Squares (WLS)

Adaptive Filter Design

4. Choose Initialization

- ✓ The filter coefficients and other parameters must be initialized properly.
- ✓ In some cases, starting with all-zero coefficients works well, but in others, some prior knowledge about the system can be used to initialize the coefficients.

Adaptive Filter Design

5. Implement Update Mechanism

- ✓ Calculating the error between the desired and actual output.
- ✓ Adjusting the filter coefficients based on the adaptation algorithm and error.

Adaptive Filter Design

6. Evaluate Convergence and Stability

- ✓ A key factor in adaptive filter design is to ensure that the algorithm converges to an optimal solution and remains stable during operation.
- ✓ The step size and other tuning parameters must be chosen carefully to balance convergence speed with stability.