**Filters and their types:**

In digital signal processing (DSP), filters are used to modify or extract information from signals by selectively attenuating or amplifying certain frequency components. The types of digital filters can be categorized based on their purpose, design, and implementation.

**1. Based on Frequency Response**

**(a) Low-Pass Filter**

- Allows frequencies below a cutoff frequency to pass through.
- Attenuates frequencies above the cutoff.
- Common applications: Noise reduction, audio signal smoothing.

**(b) High-Pass Filter**

- Allows frequencies above a cutoff frequency to pass through.
- Attenuates frequencies below the cutoff.
- Common applications: Removing low-frequency noise, de-trending signals.

**(c) Band-Pass Filter**

- Allows frequencies within a specific range (band) to pass through.
- Attenuates frequencies outside the band.
- Common applications: Communication systems, channel selection.

**(d) Band-Stop (Notch) Filter**

- Attenuates frequencies within a specific range (band).
- Allows frequencies outside the band to pass through.
- Common applications: Eliminating power-line interference (e.g., 50/60 Hz), removing specific unwanted tones.

**2. Based on Impulse Response**

**(a) Infinite Impulse Response (IIR) Filters**

- Impulse response is of infinite duration due to feedback loops.
- Efficient, requires fewer coefficients to meet specifications.

- Examples: Butterworth, Chebyshev, Elliptic filters.

**(b) Finite Impulse Response (FIR) Filters**

- Impulse response is of finite duration.
- Always stable and can achieve exact linear-phase response.
- Common design methods: Windowing, Parks-McClellan algorithm.

**3. Based on Design**

**(a) Analog-to-Digital Conversion Filters**

- Designed by converting analog filter prototypes to digital filters.
- Methods: Bilinear transformation, Impulse invariance.

**(b) Direct Design Filters**

- Designed directly in the digital domain using optimization or frequency sampling.

**4. Based on Implementation**

**(a) Recursive Filters**

- Output depends on past outputs and inputs (e.g., IIR filters).
- Efficient but requires careful stability analysis.

**(b) Non-Recursive Filters**

- Output depends only on current and past inputs (e.g., FIR filters).
- Always stable and straightforward to implement.

**5. Based on Application**

**(a) Adaptive Filters**

- Filters that change their characteristics dynamically based on the input signal.
- Applications: Echo cancellation, noise suppression.

**(b) Multirate Filters**

- Used in systems where signals are upsampled or downsampled.

- Applications: Sample rate conversion.

**6. Based on Characteristics**

**(a) Linear Phase Filters**

- Maintain a constant phase shift across all frequencies.
- Common in FIR filters.

**(b) Minimum Phase Filters**

- Designed to minimize phase distortion.

**(c) All-Pass Filters**

- Pass all frequencies with equal gain but alter the phase.

**When to Use FIR Filters**

1. **Linear Phase Response Required:**
    - FIR filters can achieve an exact linear phase, ensuring no phase distortion.
    - Useful in applications like audio processing, image processing, and data communications where preserving waveform shape is critical.
2. **Stability is Crucial:**
    - FIR filters are inherently stable because they have no feedback loops.
    - Suitable for safety-critical applications like biomedical signal processing.
3. **Multirate Processing:**
    - FIR filters are ideal for interpolation, decimation, and sample rate conversion due to their predictable phase response.
4. **Arbitrary Frequency Response:**
    - FIR filters can be designed to approximate any desired frequency response, including non-standard responses.
5. **Finite Precision Systems:**

- FIR filters handle quantization and rounding errors better than IIR filters, making them suitable for fixed-point arithmetic.

6. **Low Latency Not Critical:**
   - FIR filters may require more coefficients and computation, making them less suitable for low-latency applications.

**When to Use IIR Filters**

1. **Efficiency in Computational Resources:**
   - IIR filters achieve similar frequency response characteristics as FIR filters with fewer coefficients.
   - Suitable for real-time applications with limited computational power, such as embedded systems.
2. **Sharp Roll-offs Required:**
   - IIR filters can achieve a steep transition band with lower filter order compared to FIR filters.
   - Common in applications like speech processing, equalizers, and communication systems.
3. **Analog Filter Approximation:**
   - IIR filters are preferred when mimicking analog filter characteristics (e.g., Butterworth, Chebyshev, Elliptic).
   - Useful in systems where analog-to-digital transitions are common.
4. **Low Latency Critical:**
   - IIR filters introduce less delay for the same filter specifications compared to FIR filters, making them suitable for low-latency applications like control systems.
5. **Memory-Constrained Environments:**
   - IIR filters require fewer coefficients and thus consume less memory.
6. **Nonlinear Phase Acceptable:**

- IIR filters introduce phase distortion, which is acceptable in applications like audio equalization where phase linearity is not a priority.