



Chapter 4: Types of Windows — Choosing the Right Edge Fader

4.1 Why Different Windows Exist

- FFT assumes **repeating signals**.
- Abrupt edges → **spectral leakage**.
- Different windows **shape the edges differently**, trading off:
 - i. **Leakage reduction** (clean FFT peak)
 - ii. **Main lobe width** (frequency resolution)
 - iii. **Side lobe amplitude** (spurious frequencies)

Think of each window as a **different “fade-in/fade-out curve”**.

4.2 Common Window Types

Window	Shape / Behavior	When to Use / Intuition
Rectangular	Flat (no fade)	Best frequency resolution, poor leakage; like no ramp .
Hanning / Hann	Smooth, symmetric $0 \rightarrow 1 \rightarrow 0$	Most commonly used; balances leakage and resolution.
Hamming	Similar to Hanning, slightly higher edges	Reduces side-lobes more; good for audio signals.
Blackman	Very smooth edges, wider main lobe	Best leakage reduction; slightly worse frequency resolution.
Bartlett / Triangular	Linear ramp up and down	Simple, good for quick experiments; moderate leakage.

Window	Shape / Behavior	When to Use / Intuition
Kaiser	Adjustable shape via parameter β	Flexible control: trade-off leakage vs resolution.

4.3 Headfirst Intuition

- **Edges define leakage:** higher fade \rightarrow less leakage.
- **Middle defines amplitude preservation:** flatter middle \rightarrow better energy retention.
- **Trade-off:** Narrow main lobe \rightarrow better frequency resolution; wider main lobe \rightarrow less leakage.
- Windows are **applied sample-by-sample**: same principle as Hanning.

Think of it like **choosing a slope for a ramp**: shallow slope = smooth transition (less leakage), steep slope = abrupt (more leakage).

4.4 Choosing a Window: Simple Rules

1. **Hanning:** default, general-purpose, audio/FFT.
2. **Hamming:** if you want slightly lower side-lobes.
3. **Blackman:** if spectral leakage is critical (e.g., measuring small signals near strong tones).
4. **Rectangular:** only if edges naturally align with zero or you want maximum frequency resolution.
5. **Kaiser:** when you want **custom control** over trade-offs.

4.5 Practical Example in Python

```
import numpy as np

N = 16
windows = {
    "Rectangular": np.ones(N),
    "Hanning": np.hanning(N),
    "Hamming": np.hamming(N),
    "Blackman": np.blackman(N)
}

for name, w in windows.items():
    print(f"{name} window: {np.round(w, 2)}")
```

Observation:

- Rectangular \rightarrow all ones \rightarrow no fade.
 - Hanning / Hamming \rightarrow smooth fade $0 \rightarrow 1 \rightarrow 0$.
 - Blackman \rightarrow even smoother edges, lower side-lobes.
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4.6 Key Takeaways

1. **Window = edge shaping tool**; different windows shape differently.
2. **Trade-offs**: leakage vs resolution vs side-lobe amplitude.
3. **Default**: Hanning \rightarrow safe and general-purpose.
4. **Remember**: Behavior matters more than internal formula.