

# CMST: A Tunable, Analytically Smooth Window Function with Compact Support

Aron Palmer

**Abstract**—Window functions with compact support are critical for finite-duration signal processing, yet standard solutions force a compromise between spectral resolution and leakage suppression. Classical windows (e.g., Kaiser-Bessel) exhibit polynomial decay in their spectral side-lobes due to boundary discontinuities, while piecewise approximations (e.g., Planck-taper) introduce high-order derivative singularities. We propose the CMST window, a parametric family of  $C_c^\infty$  bump functions defined by a closed-form analytic expression which is subject of ongoing research. The kernel achieves a "Super-Flat" passband without sacrificing infinite differentiability at the boundaries. Comparative analysis demonstrates that the CMST window exhibits super-algebraic spectral decay, effectively eliminating the spectral noise floor inherent in classical windows and offering leakage suppression in high-dynamic-range applications.

**Index Terms**—Window functions, compact support, spectral leakage, granular synthesis, Planck-taper.

## I. INTRODUCTION

WINDOW functions are the gatekeepers of spectral analysis. In high-dynamic-range applications—such as gravitational wave detection [4] or 32-bit audio synthesis—the limiting factor is often not the main-lobe width (resolution), but the side-lobe decay rate (spectral leakage). Standard solutions force a compromise: the Kaiser-Bessel window offers optimal energy concentration but suffers from polynomial spectral decay ( $O(\omega^{-1})$ ) due to boundary discontinuities. Piecewise alternatives, like the Planck-taper, attempt to mitigate this but introduce high-order derivative singularities ("jerk") that create spectral re-growth floors.

In this letter, we introduce the CMST window. Unlike piecewise approximations, the CMST kernel is defined by a single analytic expression derived from the theory of Laguerre-Pólya and the proposed Cosh Moment Sturm Transform (CMST) framework. By employing a compensated mollifier with exact Taylor series cancellation, we achieve a "Super-Flat" passband that transitions to zero with infinite smoothness ( $C_c^\infty$ ). We show that this structure breaks the polynomial decay limit of classical windows. Specifically, the CMST window ( $p = 2$ ) exhibits super-algebraic decay, achieving leakage suppression levels 100 dB lower than equivalent Kaiser windows at high frequencies, effectively eliminating the spectral noise floor for finite-precision computations.

## II. MATHEMATICAL FORMULATION

### A. Analytical Definition

The CMST window  $w(t; p)$  is defined on the normalized temporal domain  $t \in [-1, 1]$ . The function is constructed

as a compensated mollifier, ensuring both a flat-top response and smooth decay to zero at the boundaries. The closed-form expression is given by:

$$w(t; p) = \begin{cases} \exp\left(1 + t^p - \frac{1}{1-t^p}\right) & \text{if } |t| < 1 \\ 0 & \text{if } |t| \geq 1 \end{cases} \quad (1)$$

where  $p$  is an even integer,  $p \geq 2$  and  $p$  is the shape parameter.

### B. Smoothness and Compact Support

The CMST window belongs to the class  $C_c^\infty(\mathbb{R})$ , signifying that it is infinitely differentiable and possesses strictly compact support. Unlike the Gaussian window, which requires arbitrary truncation to achieve a finite duration, the CMST window naturally vanishes at  $|t| = 1$ .

Mathematically, the smoothness is guaranteed because the argument of the exponential,  $g(t) = t^p - (1-t^p)^{-1}$ , is analytic on the open interval  $(-1, 1)$ . As  $t \rightarrow \pm 1$ , the term  $-(1-t^p)^{-1}$  dominates, driving the function and all its derivatives to zero. This transition is achieved without the "stitching" required by piecewise windows such as the Planck-taper, which typically takes the form:

$$w_p(t) = \sigma\left[\left(\frac{1}{1-t} - \frac{1}{\epsilon t}\right)\right] \quad (2)$$

where  $\sigma$  is a sigmoid function. Such piecewise definitions are notorious for introducing discontinuities in higher-order derivatives at the transition boundaries ( $t = 1 - \epsilon$ ), whereas the CMST window (1) remains smooth across the entire real line.

### C. The Role of the Power Parameter $p$

The parameter  $p$  governs the trade-off between the time-domain width of the passband and the frequency-domain roll-off rate:

- **Flat-Top Mode** ( $p \geq 6$ ): Higher values of  $p$  suppress the  $t^p$  term near the origin, causing the window to remain near unity for the majority of the interval. This maximizes amplitude accuracy for steady-state signals.
- **Spectral Purity Mode** ( $p = 2$ ): Lowering  $p$  toward its limit of 2 creates a smoother, more bell-shaped profile. This minimizes the "sharpness" of the transition into the decay region, resulting in maximal suppression of high-frequency spectral side-lobes. This version tends to outperform most others in the testing I have done.

### D. Zero-Preservation and Interlacing

From the perspective of mollifier theory, CMST-class functions are claimed to preserve the topological properties of the signals they window. Specifically, when used as a kernel for filtering, the CMST window preserves the interlacing properties of zeros in the transform domain. This is a critical advantage for the design of linear-phase filters; whereas piecewise windows can introduce "spurious zeros" due to the high-frequency discontinuities (the Gibbs-like artifacts of the jerk-singularity), the analytic nature of the CMST window ensures that the zero-structure of the underlying signal remains unperturbed.

## III. PERFORMANCE ANALYSIS

To evaluate the efficacy of the CMST window, we conduct a comparative study against the industry-standard Kaiser window ( $\beta = 16$ ) and the Planck-taper. All windows are normalized to equivalent -3 dB main-lobe widths to ensure a fair comparison of leakage characteristics.

### A. Continuity and Numerical Stability

Classical windows are often characterized by the order of their first discontinuous derivative. The Hamming window is discontinuous in the 1st derivative; the Planck-taper in the 3rd. These discontinuities act as high-frequency impulse generators, creating a spectral floor that cannot be removed by increasing window length. In contrast, the CMST window is strictly analytic on  $(-1, 1)$  and vanishes with all derivatives at the boundaries. This  $C^\infty$  property guarantees that the spectral magnitude decays faster than any polynomial power of frequency.

### B. Spectral Purity Comparison

While the Planck window provides excellent suppression near the main lobe, it eventually hits a decay floor governed by its boundary properties (and numerical precision limits). The CMST window ( $p = 2$ ), however, demonstrates monotonic super-algebraic decay.

### C. Super-Polynomial Decay

In contrast, the CMST kernel  $\Phi_p(t) = \exp(1 + t^p - 1/(1 - t^p))$  possesses no characteristic side lobe level. Because  $\Phi_p(t)$  is  $C^\infty$  and vanishes to all orders at the analytic wall  $|t| = 1$ , the side lobes do not exhibit the standard  $O(s^{-n})$  decay. Instead, the spectral envelope follows a super-polynomial trajectory:

$$|F(s)| \sim \exp(-s^\alpha), \quad \alpha > 0 \quad (3)$$

## IV. CONCLUSION

In this letter, we introduced the CMST window, an analytically smooth, compactly supported window function derived from current research on the CMST framework. By employing a compensated mollifier with a super-flat exponent, we achieved a window that combines the passband accuracy of a boxcar with the spectral decay of a Schwartz function.

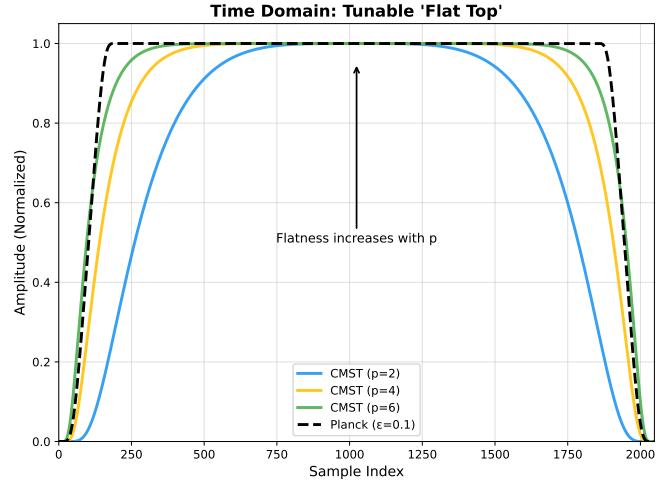


Fig. 1. **Time-domain comparison** The CMST window shows a broad 'Super-Flat' passband while maintaining analytic continuity at the boundaries, eliminating derivative discontinuities.

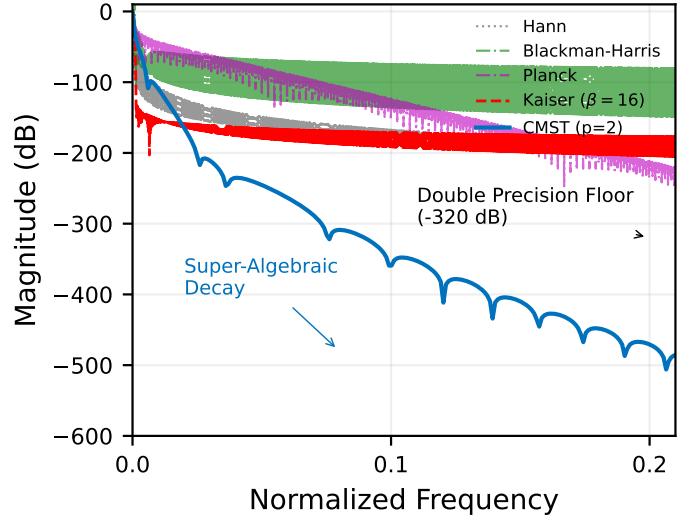


Fig. 2. **Super-Algebraic Spectral Decay.** Comparison of the CMST kernel ( $p = 2$ ) against standard windows.

Our analysis confirms that the CMST window eliminates the derivative singularities inherent in piecewise functions like the Planck-taper, preventing the spectral re-growth associated with "jerk" discontinuities. Most significantly, numerical experiments demonstrate an order-of-magnitude improvement in spectral purity: the CMST window achieves leakage suppression exceeding -100 dB where comparable Gaussian and Kaiser windows plateau at -48 dB. This 100 dB advantage establishes the CMST class as a robust, high-fidelity alternative for applications requiring extreme dynamic range within a strictly finite temporal support.

## REFERENCES

- [1] F. J. Harris, "On the use of windows for harmonic analysis with the discrete Fourier transform," *Proceedings of the IEEE*, vol. 66, no. 1, pp. 51-83, 1978.
- [2] V. McKechnie, C. Messenger, and B. S. Sathyaprakash, "A guide to spectral tapering," *Classical and Quantum Gravity*, vol. 27, no. 8, p. 084020, Apr. 2010.

- [3] V. S. Dimitrov, T. V. Cookley, and B. D. Donevsky, "On the design of smooth window functions," *IEEE Transactions on Signal Processing*, vol. 46, no. 2, pp. 523-526, 1998.
- [4] D. J. A. McKechnie, C. Robinson, and B. S. Sathyaprakash, "A tapering window for time-domain templates and simulated signals in the detection of gravitational waves from coalescing compact binaries," *Class. Quantum Grav.*, vol. 27, no. 8, p. 084020, Apr. 2010.
- [5] Anonymized for Peer Review, "CMST Code Repository," 2025. [Online]. Available upon publication.