SPICE-BASED BEHAVIORAL MODELS OF IC BUFFERS VIA COMPACT KERNEL REGRESSIONS

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This summary outlines recent developments by the Torino "Elettronica" unit in the field of compact modeling techniques for digital IC buffers. The proposed methodology leverages kernel-based learning to build accurate and SPICE-compatible behavioral models, with a specific focus on reducing model complexity through data-driven compression strategies.

Accurate models of digital IC buffers are essential for signal and power integrity simulations. While IBIS (Input/Output Buffer Information Specification) is a standard in the field, alternative approaches can offer improved accuracy and simpler model generation. This work explores a method based on the kernel ridge regression (KRR), which allows the generation of SPICE-compatible models that are both accurate and compact [1]. The method includes the impact of power supply variation and employs model compression strategies to enhance efficiency.

The IC buffer is modeled as a nonlinear dynamic system using a NARX representation, where the port currents are predicted from past values of voltages and currents. The KRR method is adopted to learn this relationship from simulated data, and the resulting model is implemented in SPICE using controlled current sources. The model is tested on a commercial buffer (TI SN74ALVCH16973) under various load conditions and power supply variations. To reduce the computational burden, two compression techniques are explored: random sampling (RND) and Nyström approximation (NYS). The compressed models significantly reduce the number of expansion terms and simulation time while maintaining good accuracy. The comparison of the resulting output currents is shown in Fig. 1, highlighting the impact of each compression method.

Numerical tests in [1] demonstrate that the full KRR model achieves excellent accuracy but at the cost of longer SPICE simulation times. Compressed models, especially those based on the Nyström method, offer a good trade-off between accuracy and efficiency. Even with strong compression, the Nyström model closely follows the reference behavior. These results confirm the feasibility of using compact kernel-based models for IC buffers in practical signal and power integrity analysis workflows.

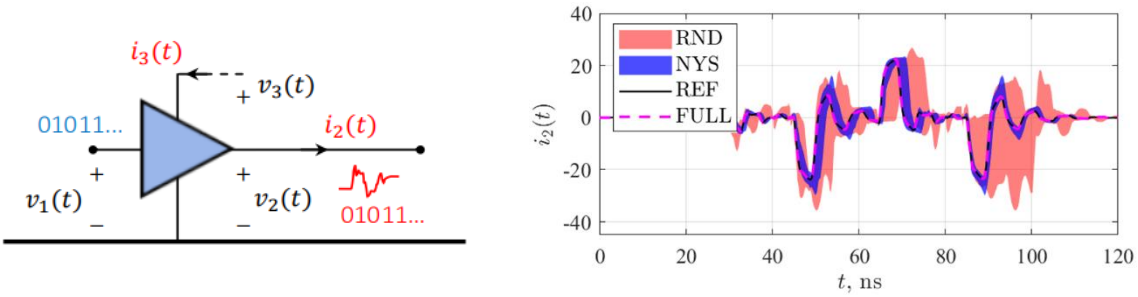

Fig.1. Output current $i_2(t)$ obtained from different KRR models under the same test condition. The figure shows the reference waveform and the output predicted by the full (uncompressed) model, overlaid with the results of five different compressed models for each technique—random sampling and Nyström. This visualization highlights the variability introduced by each compression strategy and their impact on model accuracy.

[1] M. Atlante et al., "SPICE-based Behavioral Models of IC Buffers via Compact Kernel Regressions", Proc. 29th IEEE Workshop on Signal and Power Integrity, Gaeta, Italy, May 11-14, 2025.