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Versatile surrogate models for IC buffers

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Outline

- Introduction
- New approach: theoretical framework
- Identification
- Recent developments
- Examples
- Conclusion

Introduction

- Nonlinear behavior of IC buffers
  - Fading memory
  - Highly nonlinear
    - Switching feature
    - Saturation
- Behavioral modeling techniques
  - IBIS
  - MπTlog
  - Neural networks, etc…

Introduction

- 2-piece model (IBIS or Mπlog)
  - Black box modeling of buffers
  - Output buffer port modeled in respect to input state (High or Low)
  - Transitions between states modeled through weighting functions
  - Output port relations, two submodels scheme

Introduction

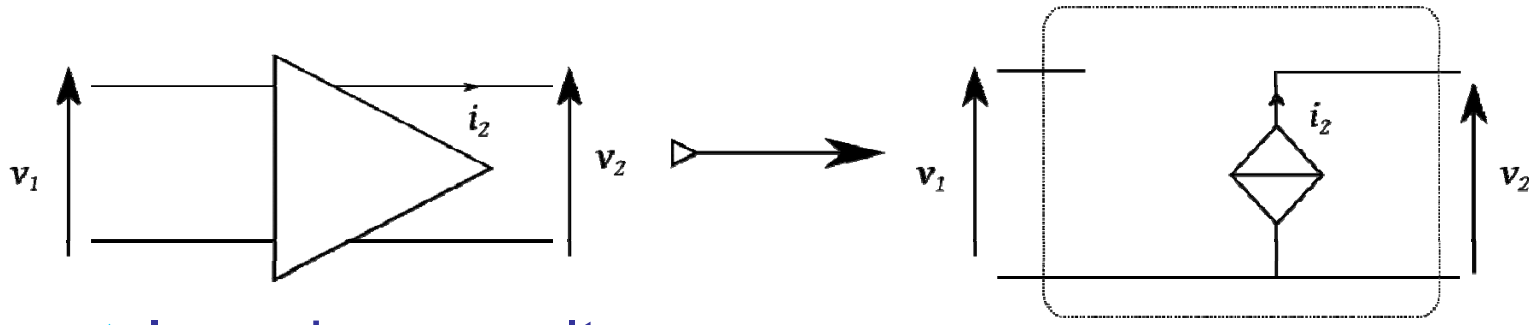
- MπLog + Volterra Series (SPI 2010)
  - Each submodel represented by Volterra Series
  - Exact static behavior not guaranteed
- MπLog + Volterra Series + Constraints (SPI 2011)
  - A posteriori mathematical constraints to improve static behavior

New approach: theoretical framework

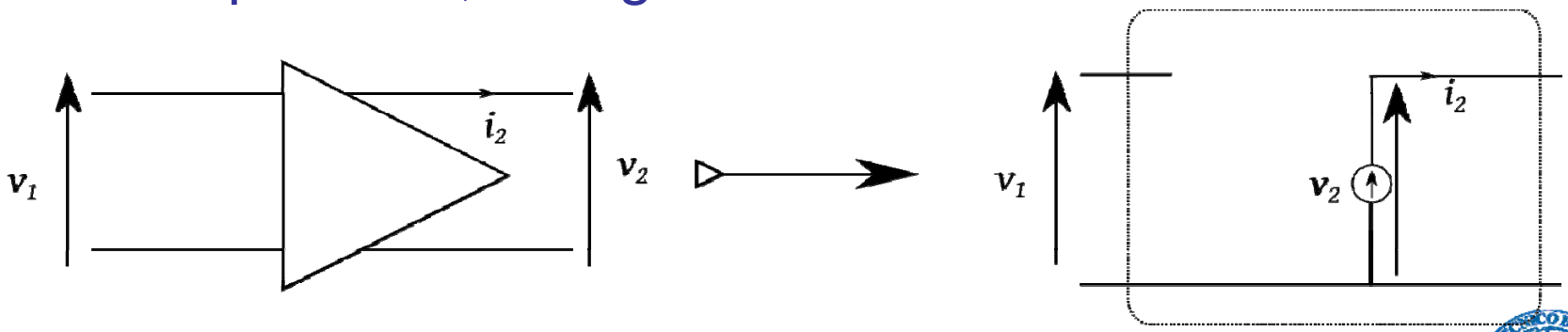
- I/O behavioral modeling method is :
  - Versatile
    - wide range of loads
    - working for a wide range of frequencies
  - Surrogate
    - Mathematical models
    - Based on Very high order Volterra-Laguerre Series

New approach: theoretical framework

- Modeling strategy
  - Admittance, current source



  - Impedance, voltage source



New approach: theoretical framework

- I/O Relations, “admittance”, $i_2[k] = f(v_1, v_2, [k])$, “impedance” $v_2[k] = f(v_1, i_2, [k])$
- High order Volterra-Laguerre series

$$Z\left(\phi_{n_l, i_l}[k]\right)(z) = \sqrt{1 - a_{n_l}{}^2}\,\frac{z}{z-a}\left(\frac{1 - a_{n_l} z}{z-a}\right)^{i_l}$$

$$\bar{v}_{n_l, i_l}[k] = \left(v_{n_l} * \bar{\phi}_{n_l, i_l}\right)[k], n_l = 1,2$$

New approach: theoretical framework

$$i_2[k] = \sum_{i_1=0}^{I_1-1} C_{1,1,i_1}\,\bar{v}_{1,i_1}[k] + \sum_{i_1=0}^{I_1-1} C_{1,2,i_1}\,\bar{v}_{2,i_1}[k]$$

$$+ \sum_{i_1=0}^{I_2-1}\sum_{i_2=0}^{I_2-1} C_{2,1,1,i_1,i_2}\,\bar{v}_{1,i_1}[k]\bar{v}_{1,i_1}[k] + \sum_{i_1=0}^{I_2-1}\sum_{i_2=0}^{I_2-1} C_{2,1,2,i_1,i_2}\,\bar{v}_{1,i_1}[k]\bar{v}_{2,i_1}[k]$$

$$+ \sum_{i_1=0}^{I_2-1}\sum_{i_2=0}^{I_2-1} C_{2,2,1,i_1,i_2}\,\bar{v}_{2,i_1}[k]\bar{v}_{1,i_1}[k] + \sum_{i_1=0}^{I_2-1}\sum_{i_2=0}^{I_2-1} C_{2,2,2,i_1,i_2}\,\bar{v}_{2,i_1}[k]\bar{v}_{2,i_1}[k]$$

$$+ \ldots$$

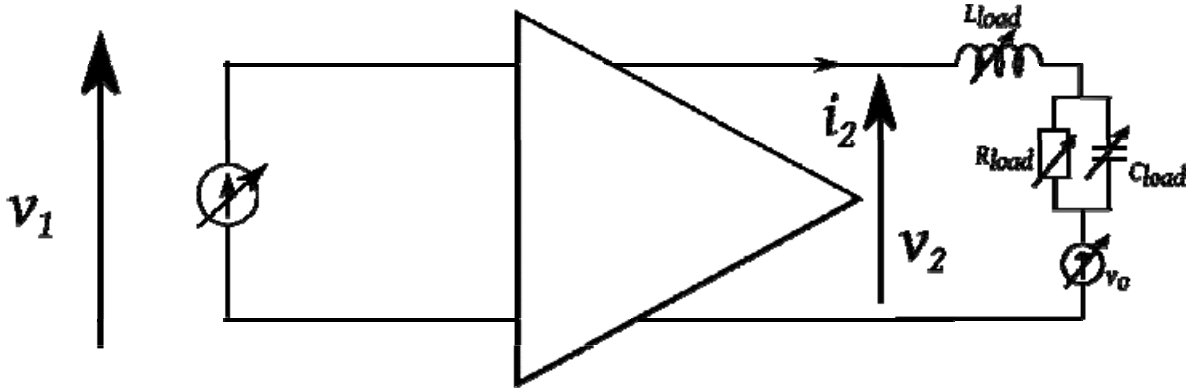
Identification

- Apply a well-chosen identification sequence to the driver.
- Extract voltages(v_1, v_2) and output current (i_2)
- By least squares find C coefficients that satisfied best the Volterra-Laguerre relation

$$i_2[k] = \sum_{m=1}^{M} \sum_{n_1=1}^{2} \cdots \sum_{n_m=1}^{2} \sum_{i_1=0}^{I_m-1} \cdots \sum_{i_m=0}^{I_m-1} C_{m,n_1,\ldots,n_m,i_1,\ldots,i_m} \prod_{l=1}^{m} \bar{v}_{n_l,i_l}[k]$$

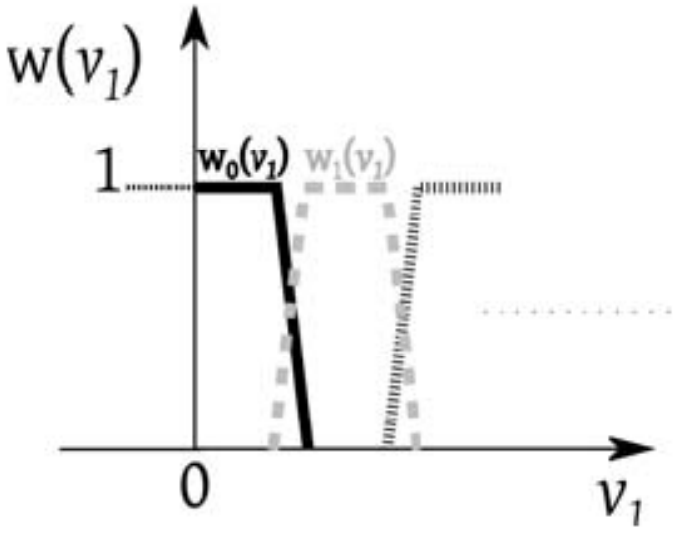
Identification

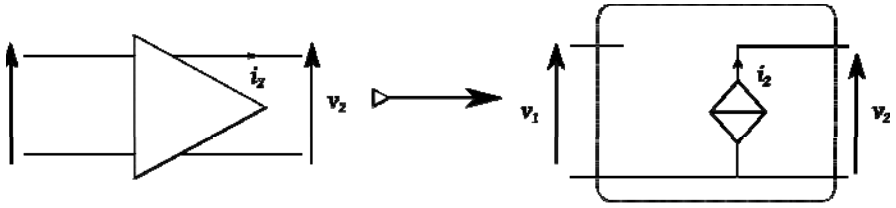
- Variable identification load
  - Allowing a good static exploration
  - Dynamic exploration of (i_2,v_2) trajectories resulting from interconnects reactive elements



Recent developments

- Piece-wise approach → reduce complexity
- Output relation

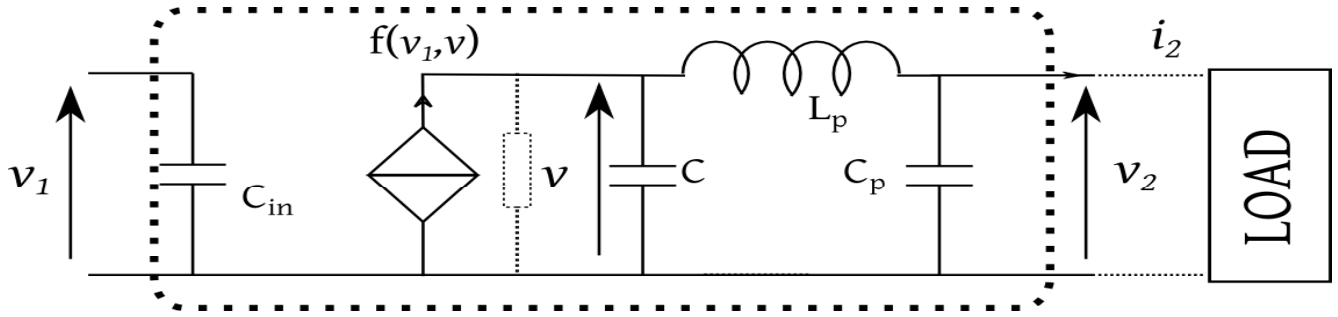




$$i_2[k] = \sum_{i=1}^{I} W_i(v_1) i_{2,i}[k]$$

Application

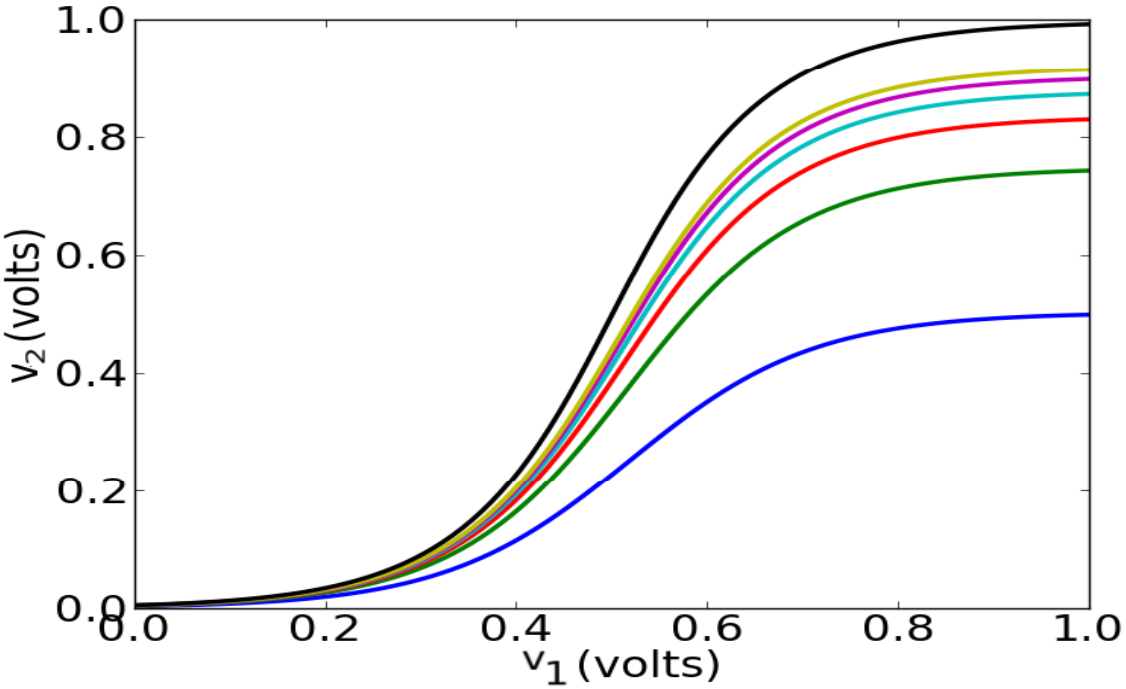
- Test vehicle: tunable synthetic system mimicking single ended non inverting driver



- $f(v_1,v)$ nonlinear current source
- Dynamic by reactive components

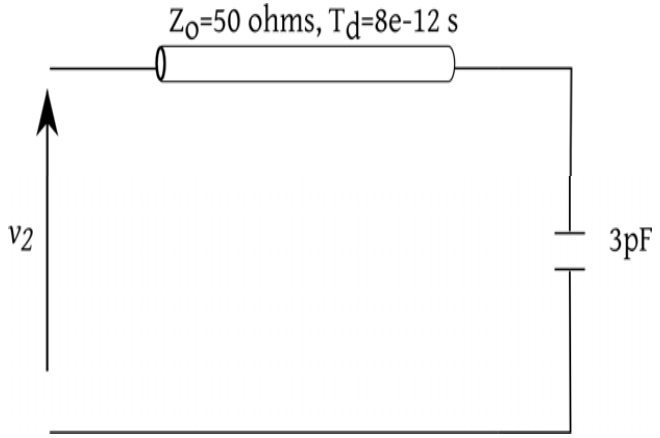
Application

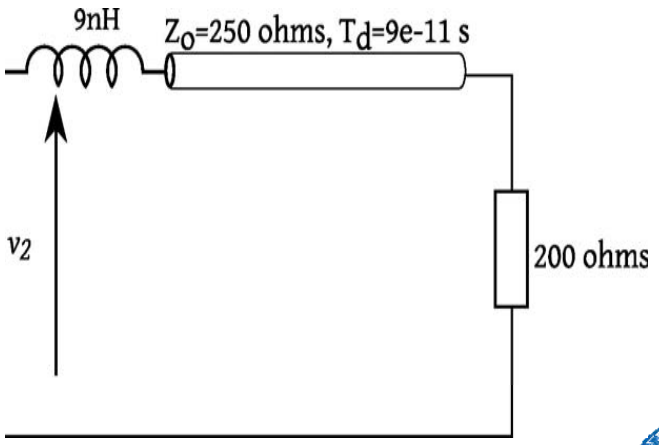
- Input/Output Characteristic



Application

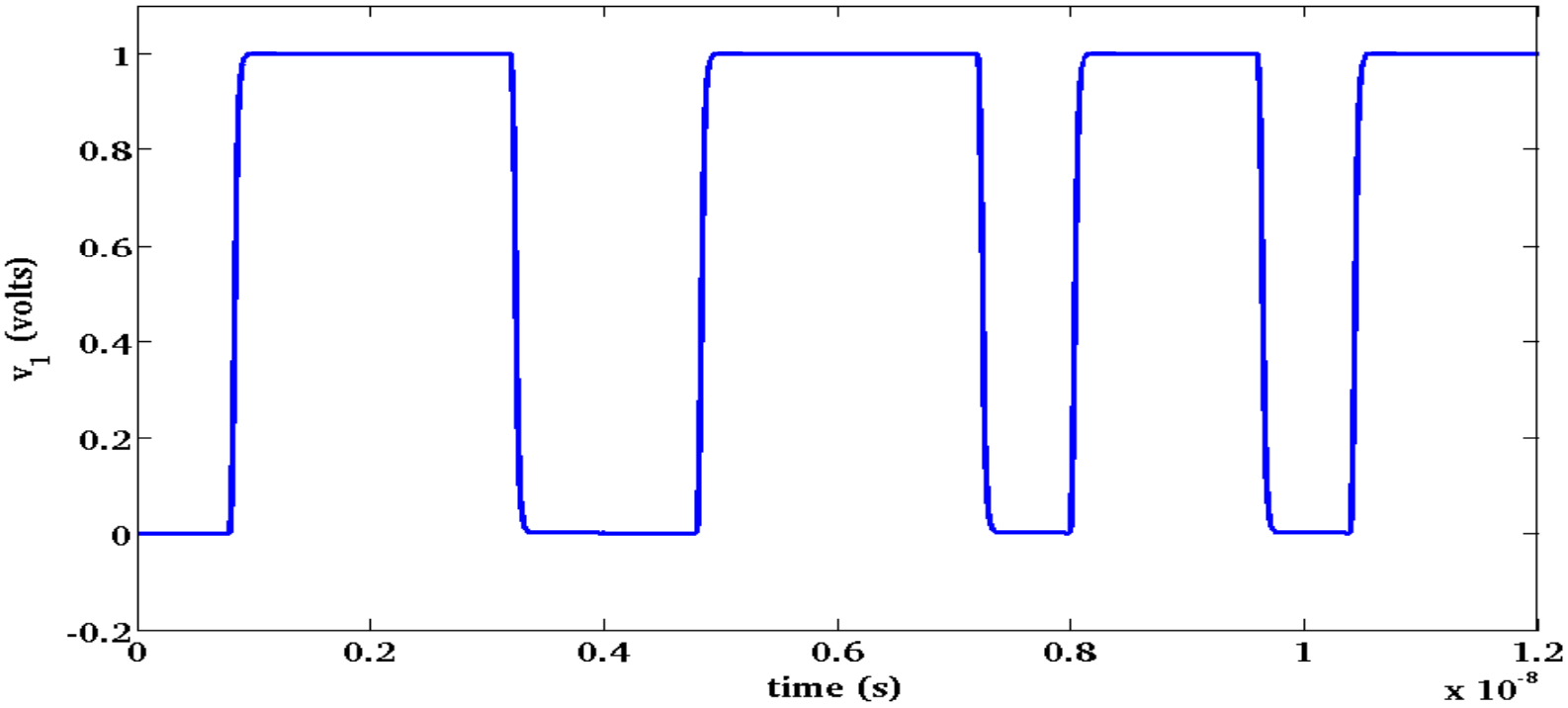
- System is identified through the described procedure
- The Volterra-Laguerre model is implemented in SPICE
- Validation
  - Input validation signal
  - On two load configurations





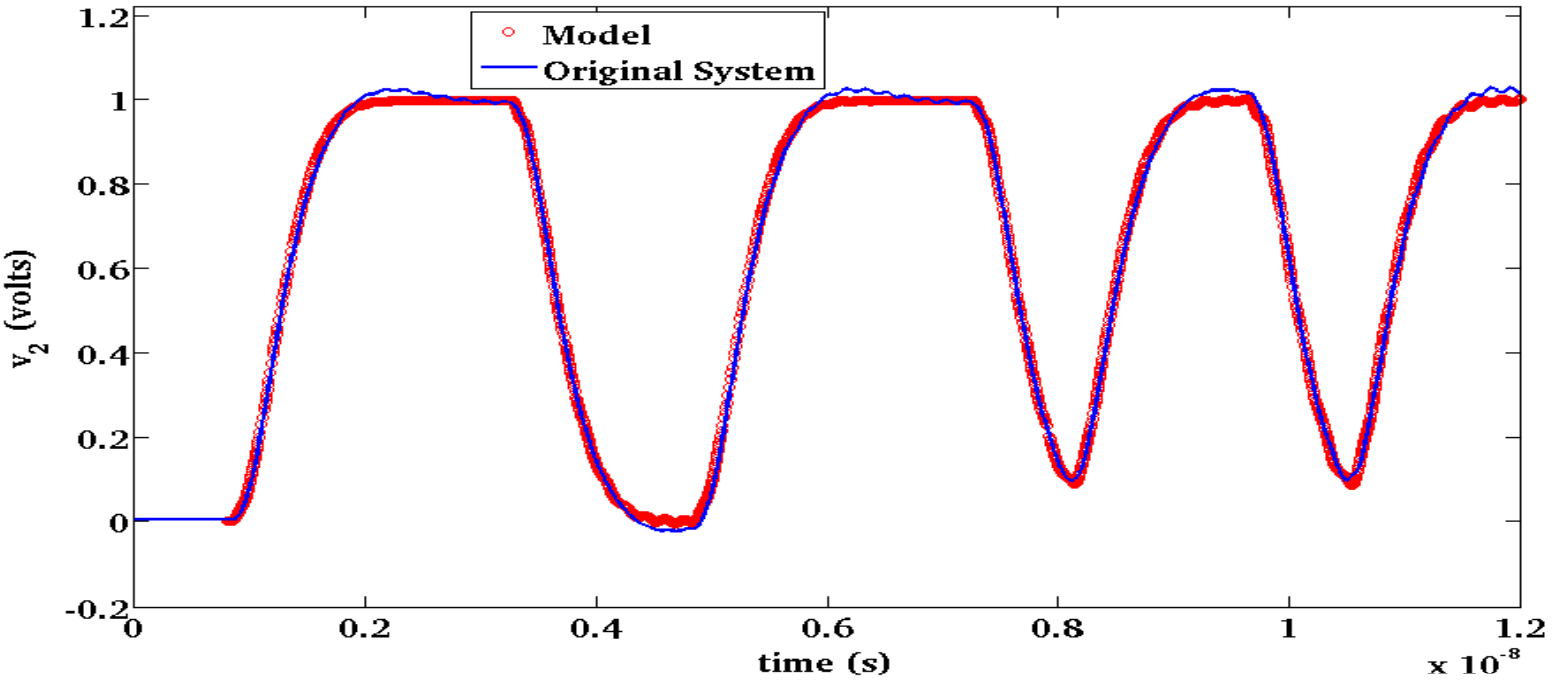
Application

- Input validation signal



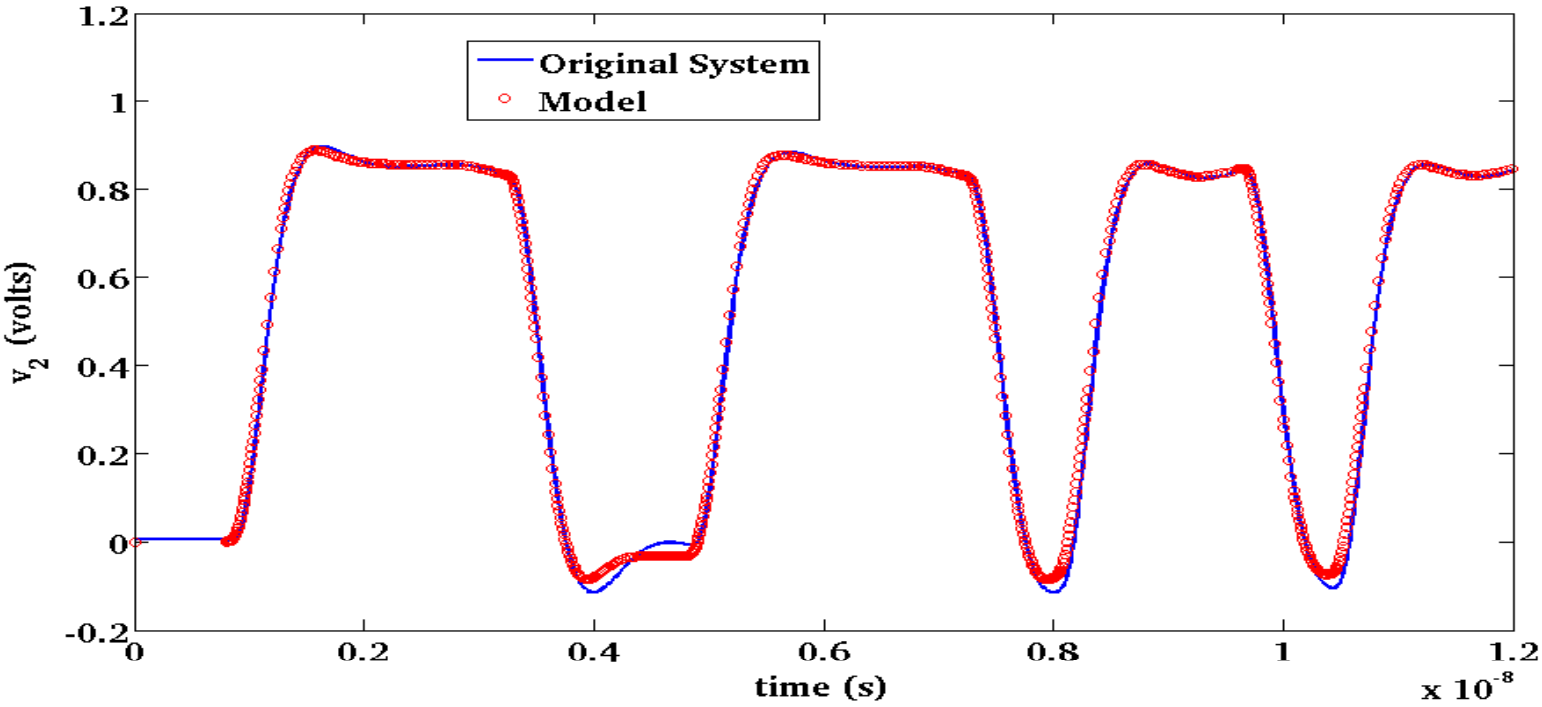
Application

- First Load



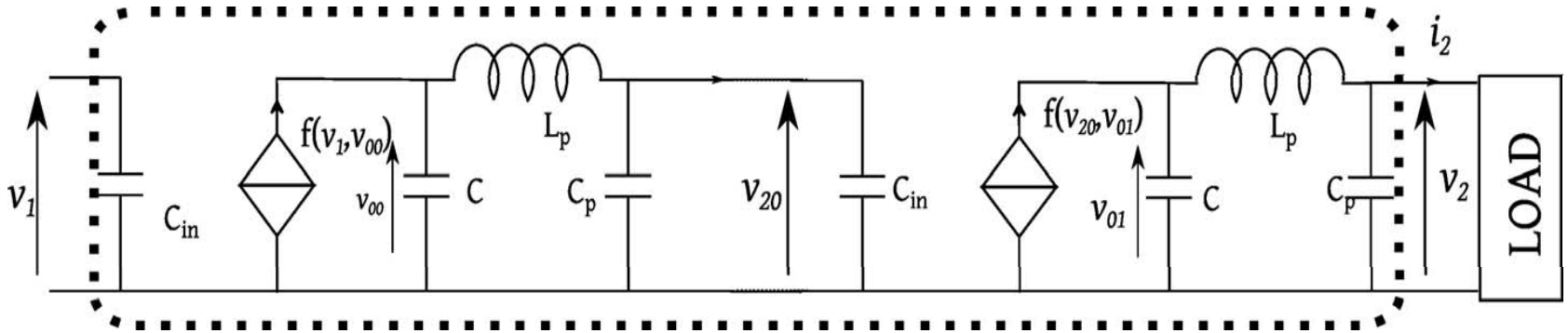
Application

- Second Load



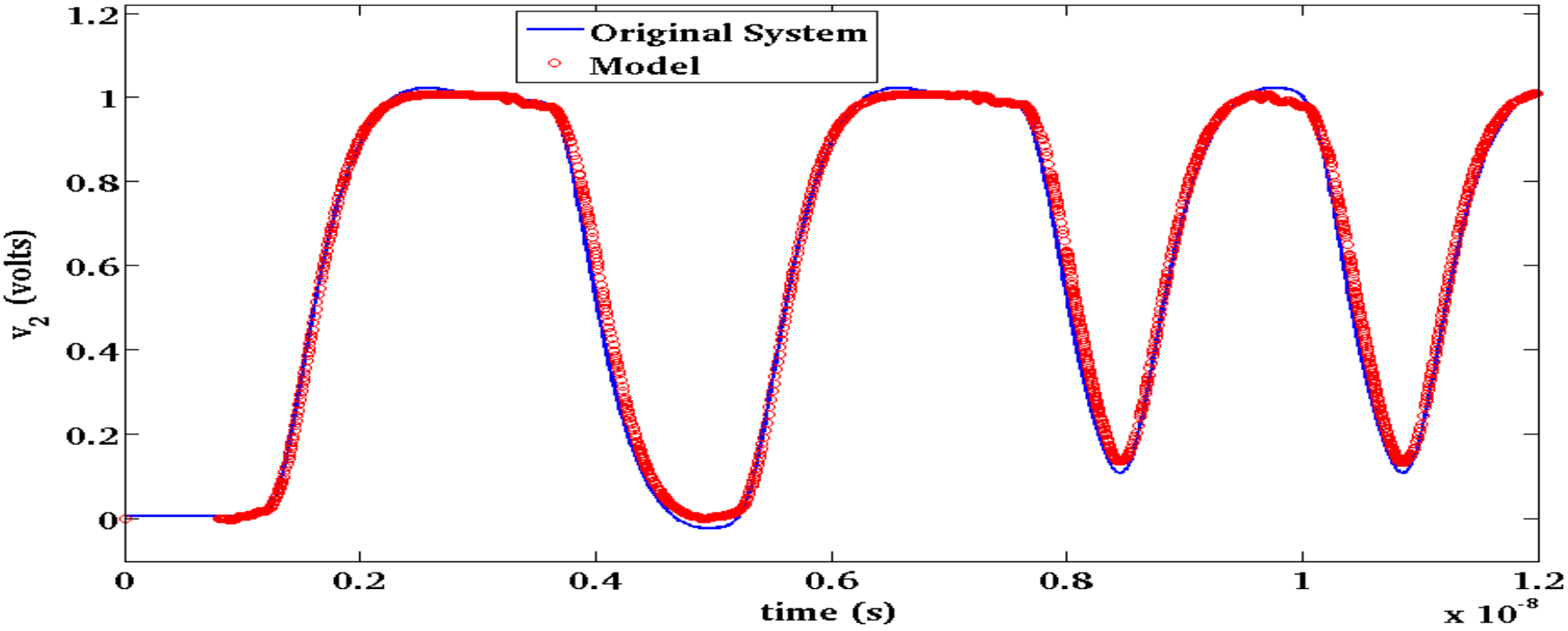
Application

- Cascaded drivers



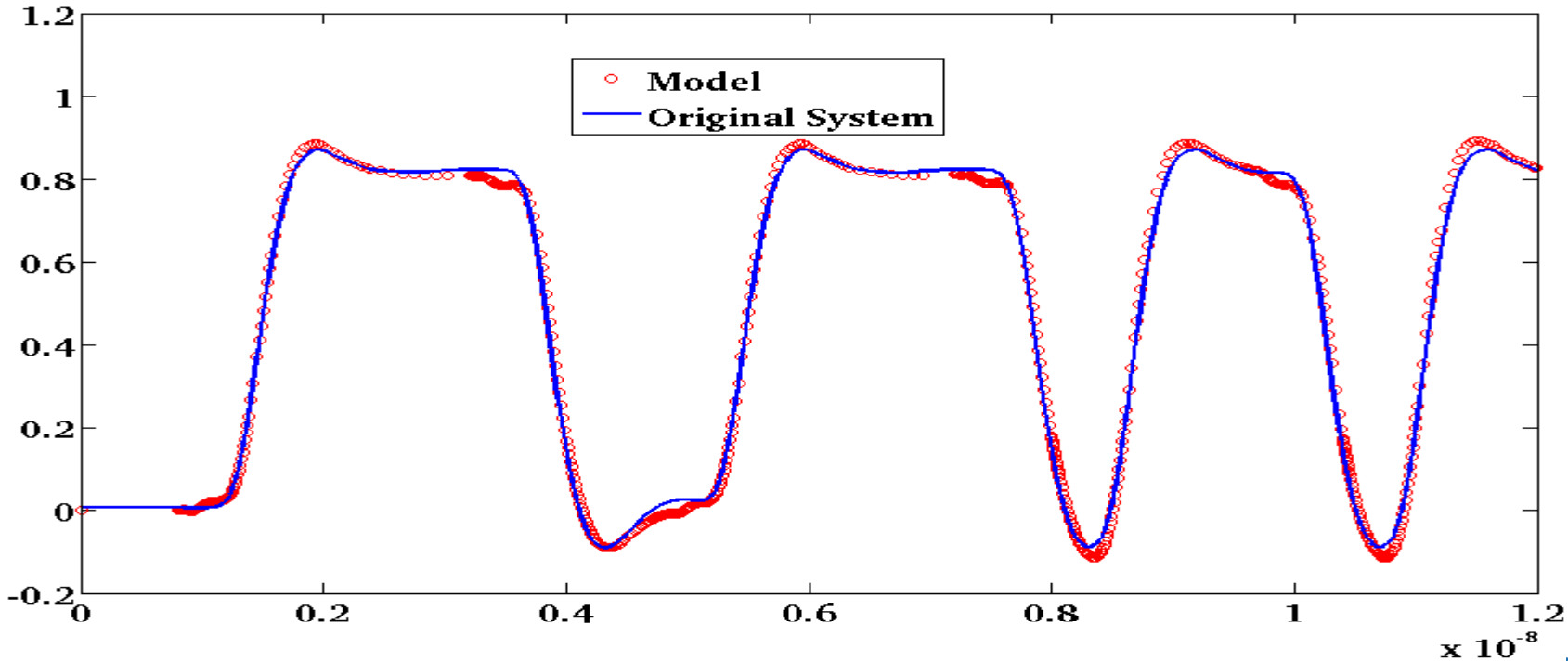
Application

- First Load



Application

- Second Load



Conclusion

- A new approach to IC buffer modeling seeking more general, versatile models
- Ongoing research on more complex, recent buffers
- Tuning the method on the needs of the industry