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
  - Mπlog
  - 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

- $M\pi log + \text{Volterra Series (SPI 2010)}$
  - Each submodel represented by Volterra Series
  - Exact static behavior not guaranteed
- $M\pi log + \text{Volterra Series + Constraints (SPI 2011)}$
  - 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

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

\[
\bar{v}_{n_l,i_l [k]} = (v_{n_l} * \phi_{n_l,i_l})[k], n_l = 1,2
\]
New approach: theoretical framework

\[
i_{2}[k] = \sum_{i_{1}=0}^{I_{1}-1} C_{1,1,i_{1},i_{1}} \vbar_{1,i_{1}}[k] + \sum_{i_{1}=0}^{I_{1}-1} C_{1,2,i_{1},i_{1}} \vbar_{2,i_{1}}[k]
\]

\[
+ \sum_{i_{1}=0}^{I_{2}-I_{2}-1} \sum_{i_{2}=0}^{I_{2}-I_{2}-1} C_{2,1,1,i_{1},i_{2}} \vbar_{1,i_{1}}[k] \vbar_{1,i_{1}}[k] + \sum_{i_{1}=0}^{I_{2}-I_{2}-1} \sum_{i_{2}=0}^{I_{2}-I_{2}-1} C_{2,2,1,i_{1},i_{2}} \vbar_{2,i_{1}}[k] \vbar_{2,i_{1}}[k]
\]

\[
+ \sum_{i_{1}=0}^{I_{2}-I_{2}-1} \sum_{i_{2}=0}^{I_{2}-I_{2}-1} C_{2,2,2,i_{1},i_{2}} \vbar_{2,i_{1}}[k] \vbar_{2,i_{1}}[k] + \sum_{i_{1}=0}^{I_{2}-I_{2}-1} \sum_{i_{2}=0}^{I_{2}-I_{2}-1} C_{2,2,2,i_{1},i_{2}} \vbar_{2,i_{1}}[k] \vbar_{2,i_{1}}[k] + \ldots
\]
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

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

![Graph showing a periodic signal with time in seconds on the x-axis and voltage in volts on the y-axis. The signal oscillates between 0 and 1 volt.]
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