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Comparative Analysis of C_comp Extraction Techniques for High-Fidelity IBIS I/O Buffer Modeling

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2 Extraction Methods

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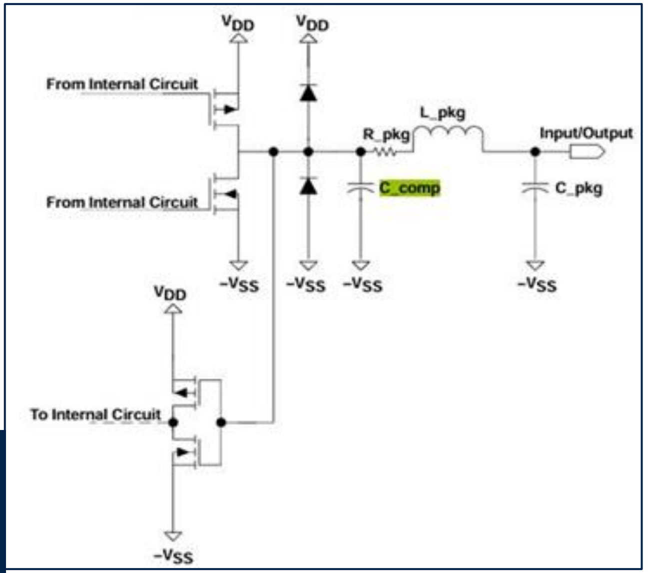
Introduction

- **C_comp** is the static equivalent die capacitance of an I/O buffer — capturing pad, on-die interconnect, and intrinsic transistor capacitances — excluding package parasitics.
- Strongly affects:
  - Signal rise/fall times and shape
  - Impedance matching & reflections
  - Timing margins and crosstalk
  - Power integrity and system performance

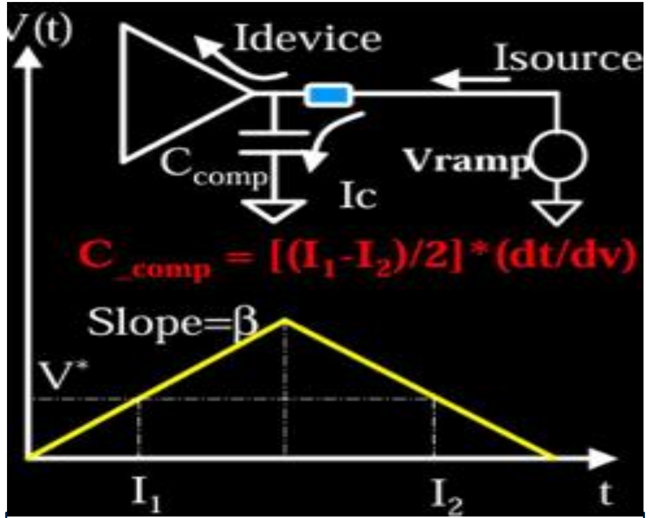


Accurate C_comp extraction improves early prediction of SI issues and enables reliable IBIS models for high-speed designs.

Challenge: C_comp is nonlinear and varies with voltage and frequency, making extraction difficult.

Extraction Methods (1/2)

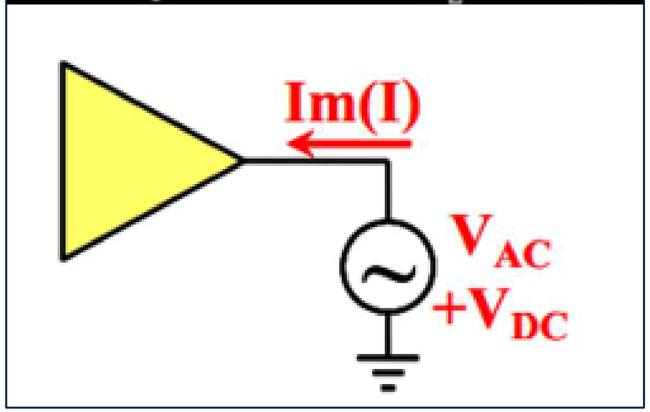
To satisfy the IBIS specification's requirement for a static C_comp entry, each technique described herein maps the buffer's nonlinear, bias- and frequency-dependent die capacitance onto a single representative scalar value.



❑ **Forced Saw Tooth technique**

$$C = (I_1 - I_2) / 2\beta$$

- ✓ Isolates capacitive current via differential measurement.
- ⚠ Sensitive to ramp slope; shows voltage but not frequency dependence.



❑ **AC / Frequency Sweep analysis**

$$\text{C\_comp} = -\mathrm{Im}(IAC) / (2\pi f \cdot VAC)$$

- ✓ Linearizes nonlinear circuits; black-box approach; stable scalar value.
- ⚠ Frequency ambiguity in direct sweep; mitigated by bias-point iteration.

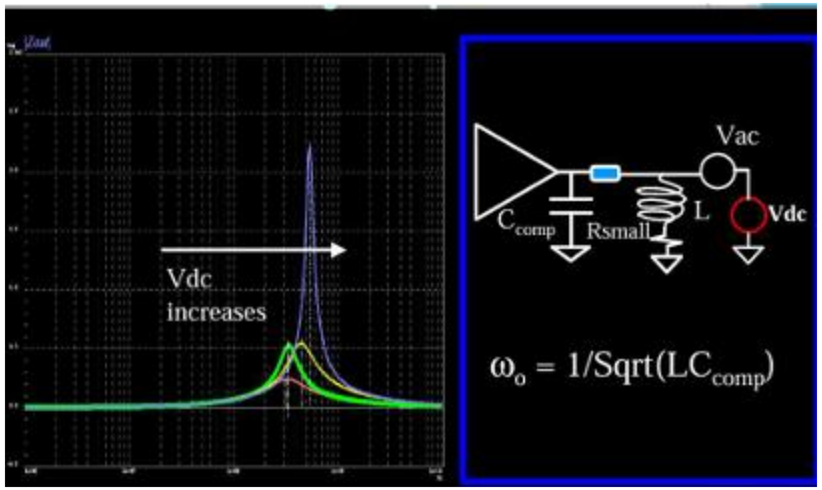
Extraction Methods (2/2)

☐ **Tank / Resonating circuit**

$$C\_comp = 1 / (\omega_o^2 \cdot L)$$

✓ Yields a single unambiguous scalar C_comp value.

⚠ Requires prior estimate of C_comp to select L; tuning difficulty.

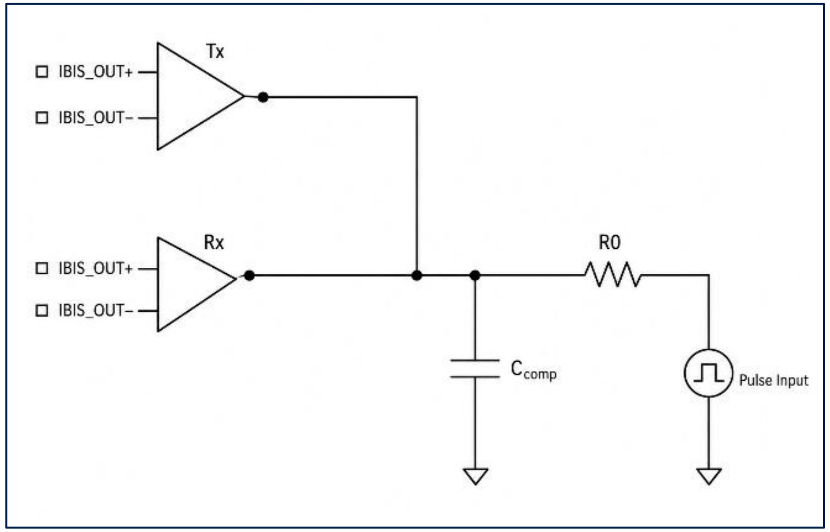


☐ **RC Time Constant method**

$$C\_comp = \tau / R = t(V_o=0.632Vs) / R$$

✓ Simple; directly measures time constant.

⚠ Corrupted by DC leakage; approximates dynamic C(V) as static.



Results

- C_comp value comparison

Methodology	C_comp — General-purpose Bidirectional IO	C_comp — Differential IO (LVDS)
Forced Sawtooth	3.2391 pF	1.0912 pF
AC / Frequency Sweep ★	**3.2071 pF**	**1.0800 pF**
Tank / Resonating Circuit	3.1904 pF	1.0174 pF
RC Time Constant	3.3604 pF	1.1429 pF

- Observations
  - RC Time Constant yields the highest values — inflated by DC leakage current corruption.
  - AC/Frequency Sweep produces the most consistent and linearized results across both I/O types.
  - C_comp Split delivers lowest values — most structurally accurate.
  - All methods converge within ~7% for BIDIR; divergence wider for complex LVDS structures.

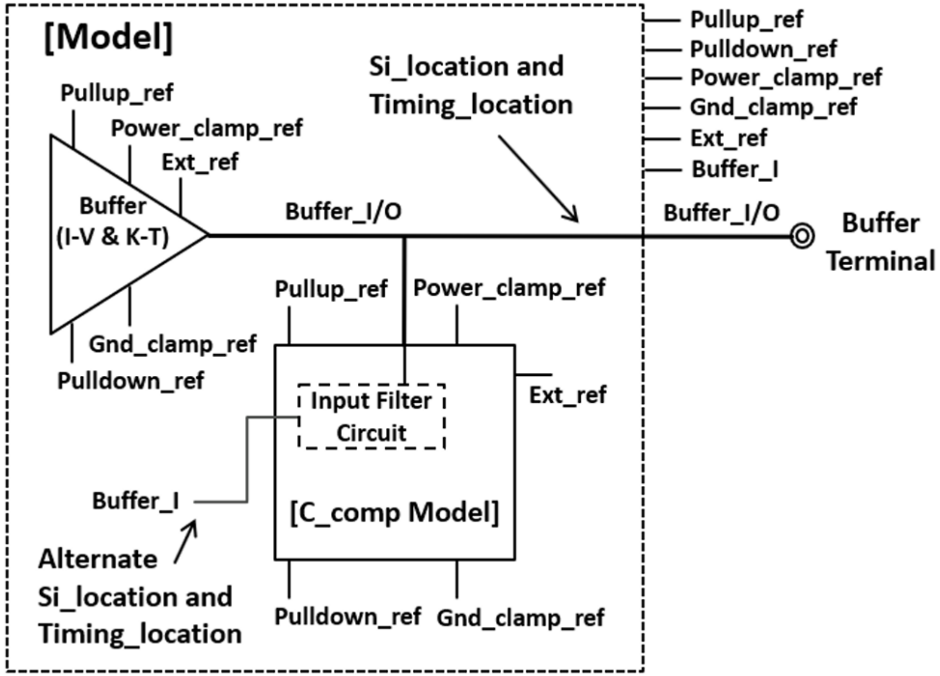
Conclusion & Summary

- C_comp extraction is essential for high-fidelity IBIS modeling.
- Time-domain and RC-based methods are faster but less robust.
- Tank method gives one value, but tuning is difficult.
- **Recommended approach: AC analysis / frequency sweep**
  - treats buffer as a black box
  - linearizes around a DC bias point
  - provides consistent scalar values
  - best suited for modern SI/PI analysis

For high-speed designs (typically above 1GHz signaling rates or where rise/fall times <500ps), AC analysis is the preferred standard for reliable IBIS modeling.

Future Work

- Extending the comparative analysis to advanced process nodes.
- Analyze the Impact of C_comp on SI/PI simulations.
- To Explore the [C Comp Model] keyword (BIRD200) keyword in IBIS 7.1,
  - allows for advanced, frequency-dependent, and voltage-dependent capacitance modeling of I/O buffers using IBIS-ISS subcircuits or Touchstone files.



[C_comp Model structure]

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