Using Latency Insertion Method to Handle IBIS models

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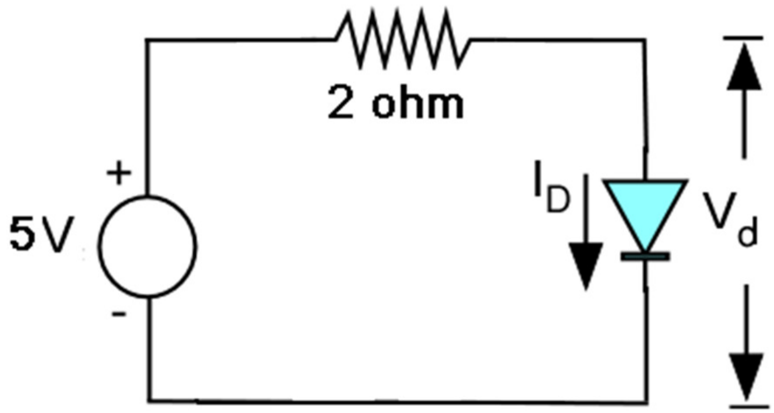
A simple non-linear Circuit



How to solve I_D and V_d?

Solve transcendental equations

$$I_d = 1pA \cdot \left[\exp\left(40 \cdot V_d\right) - 1 \right]$$

$$5 = V_d + 2 \cdot I_d$$

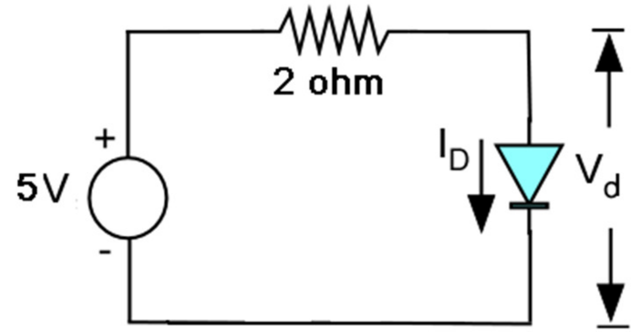
Using Newton-Raphson Method

$$X_{n+1} = X_n - \frac{f(X_n)}{f'(X_n)}$$

Newton-Raphson iterative process begins with an initial guess and terminates when the difference between successive guesses falls to zero.

$$I_d = 1pA \cdot \left[\exp(40 \cdot V_d) - 1 \right]$$

$$5 = V_d + 2 \cdot I_d$$

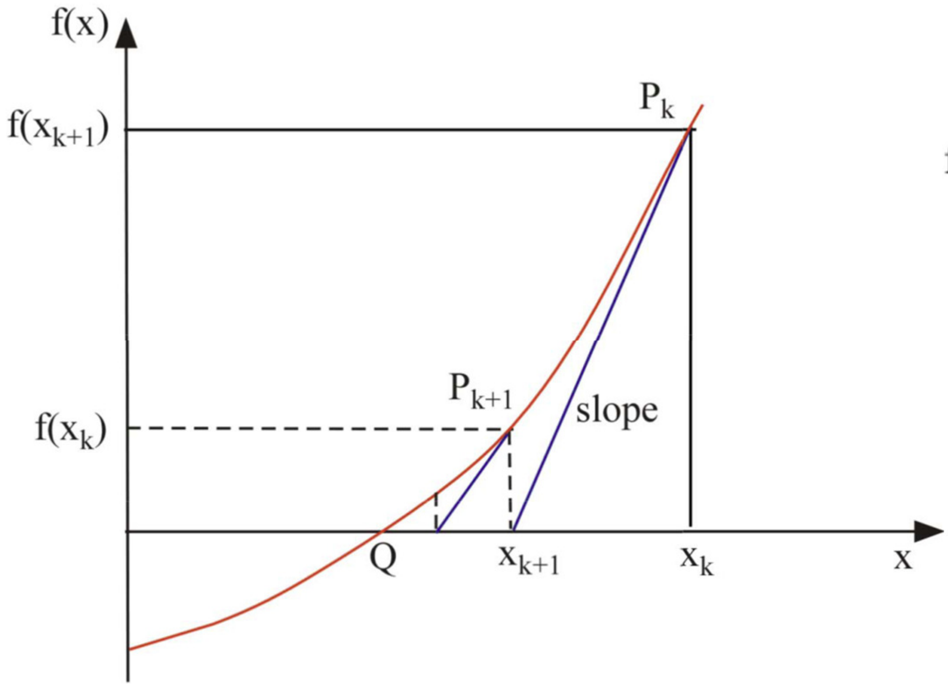


$$f(V_d) = -5 + V_d + 2pA \cdot \left[\exp(40 \cdot V_d) - 1 \right]$$

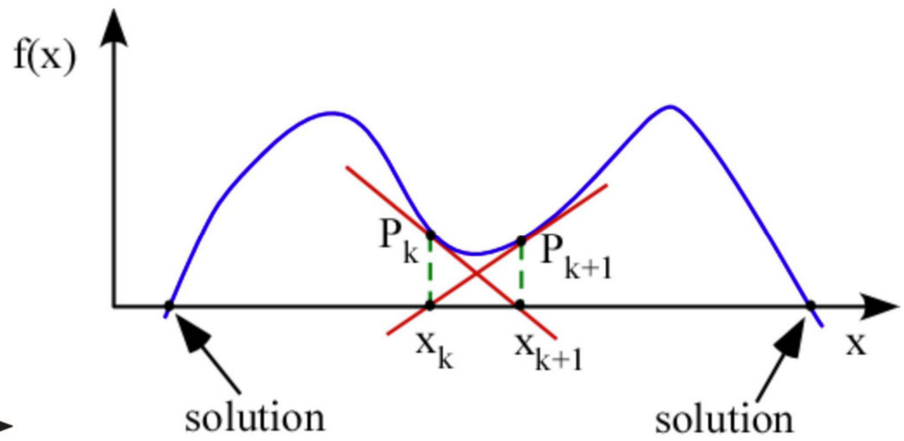
$$f'(V_d) = 0 + 1 + 80pA \cdot \exp(40 \cdot V_d)$$

$$V_d^{(n+1)} = V_d^{(n)} - \frac{-5 + V_d^{(n)} + 2pA \cdot \left[\exp\left(40 \cdot V_d^{(n)}\right) - 1 \right]}{1 + 80pA \cdot \exp\left(40 \cdot V_d^{(n)}\right)}$$

Newton-Raphson Method- Graphical Interpretation



Convergent



Divergent

Limitations*

- IBIS data can be unpredictable
- Transient response requires solution of nonlinear system
- Most simulators use Newton-Raphson (NR) technique combined with modified nodal analysis(MNA)
- NR may not converge
- NR may slow down simulation

* J. E. Schutt-Ainé, “IBIS modeling using Latency Insertion Method," European IBIS summit, Italy, May16, 2012.

Why LIM? *

- LIM does not iterate on nonlinear problems
- There is no convergence issue
- MNA has super-linear numerical complexity
- LIM has linear numerical complexity
- LIM uses no matrix formulation
- LIM has no matrix ill-conditioning problems
- LIM is much faster than MNA for large circuits

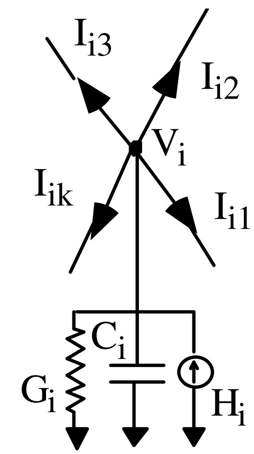
* J. E. Schutt-Ainé, “IBIS modeling using Latency Insertion Method," European IBIS summit, Italy, may16, 2012.

Latency Insertion Method**

- LIM is an efficient **time-domain** simulator for a large-scaled network
- Uses "**leapfrog**" scheme to solve node voltages and branch currents

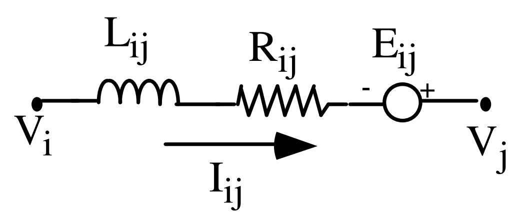
Nodes must have a shunt capacitor

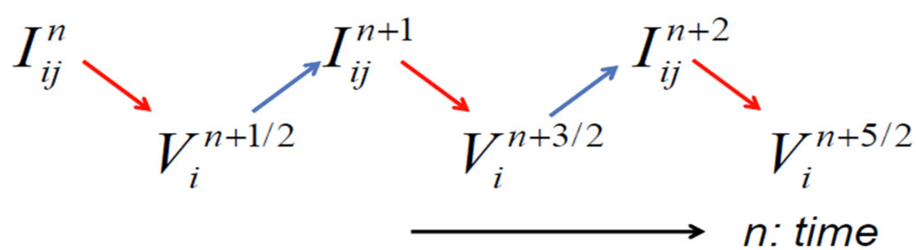
$$V_i^{n+1/2} = \frac{\frac{C_i V_i^{n-1/2}}{\Delta t} + H_i^n - \sum_{k=1}^{M_i} I_{ik}^n}{\frac{C_i}{\Delta t} + G_i}$$



Branches must have an inductor

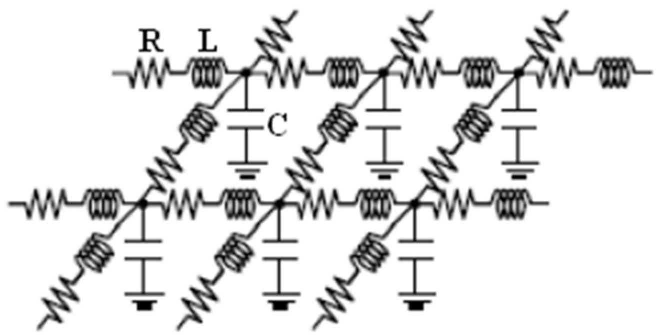
$$I_{ij}^{n+1} = I_{ij}^n + \frac{\Delta t}{L_{ij}}\left(V_i^{n+1/2} - V_j^{n+1/2} - R_{ij} I_{ij}^n + E_{ij}^{n+1/2}\right)$$

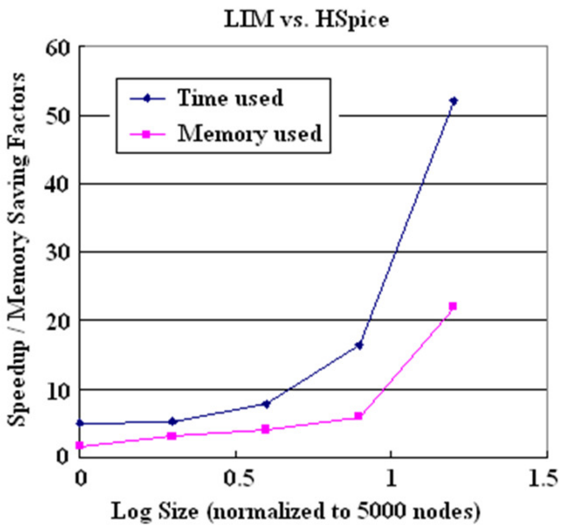




** J. E. Schutt-Ainé, "Latency Insertion Method for the Fast Transient Simulation of Large Networks," IEEE Trans. Circuit Syst., vol. 48, pp. 81-89, January 2001.

LIM is fast and get faster as circuit size increases





Number of Cells	HSPICE		LIM	
	Memory	Time	Memory	Time
200×200 cells	Memory overflow	abort	102M	1156 s
100×200 cells	320M	9361s	54M	573 s
100×100 cells	108M	2176s	28M	281 s
50×100 cells	53.3M	675s	16M	132 s
50×50 cells	12.4M	244s	9M	47 s

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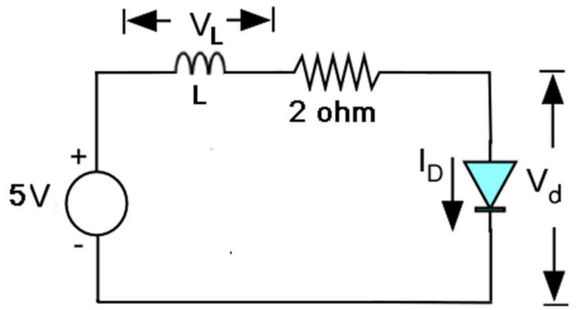
LIM has NO Convergence Issues



Introduce latency in diode circuit through a small L

$$V_L^{n+\frac{1}{2}} = L \cdot \frac{I_d^{n+1} - I_d^n}{\Delta t}$$

Use **Leapfrog:**

$$\left.\begin{aligned} V_L^{n+\frac{1}{2}} &= L \cdot \frac{I_d^{n+1} - I_d^n}{\Delta t} \\ V_L^{n+\frac{1}{2}} + 2 \cdot I_d^n + V_d^{n+\frac{1}{2}} &= 5 \end{aligned}\right\} \Rightarrow I_d^{n+1} = \frac{\Delta t}{L}\left(5 - 2 \cdot I_d^n - V_d^{n+\frac{1}{2}}\right) + I_d^n$$

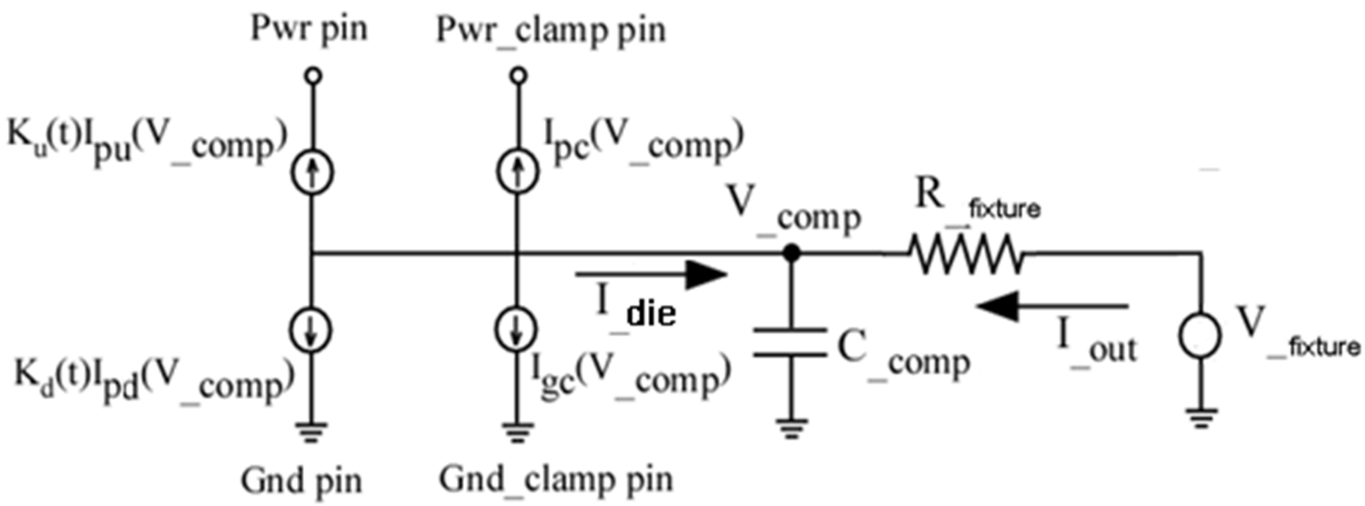
$$I_d^{n+1} = 1pA \cdot \left[\exp\left(40 \cdot V_d^{n+\frac{1}{2}}\right) - 1\right] \Rightarrow V_d^{n+\frac{1}{2}} = \frac{1}{40} \cdot \ln\left(\frac{I_d^n}{1pA} + 1\right)$$

Explicit!

Application LIM to IBIS

- Ku/Kd extraction
- LIM-IBIS formulation
- LIM-IBIS simulation results
- Extension to Bird98
- Extension to Bird95
- Conclusion

IBIS Ku/Kd Extraction



$$I^{n}_{out} = \left(V_{\_fixture} - \frac{V^{n+\frac{1}{2}}_{\_comp} + V^{n-\frac{1}{2}}_{\_comp}}{2} \right) / R_{\_fixture}$$

$$I^{n}_{\_comp} = C_{\_comp} \frac{V^{n+\frac{1}{2}}_{\_comp} - V^{n-\frac{1}{2}}_{\_comp}}{\Delta t}$$

$$I^{n}_{die} = I^{n}_{\_comp} - I^{n}_{out}$$

Find closest corresponding currents in static IV data

V_comp1 -> I_{pd1}, I_{pu1}, I_{gc1} and I_{pc1}

V_comp2 -> I_{pd2}, I_{pu2}, I_{gc2} and I_{pc2}

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IBIS Ku/Kd Extraction***

Two Equations Two Unknowns

$$-I_{die1}^{n} = K_{ur}^{n} I_{pu1}^{n} + K_{dr}^{n} I_{pd1}^{n} + I_{pc1}^{n} + I_{gc1}^{n}$$

$$-I_{die2}^{n} = K_{ur}^{n} I_{pu2}^{n} + K_{dr}^{n} I_{pd2}^{n} + I_{pc2}^{n} + I_{gc2}^{n}$$

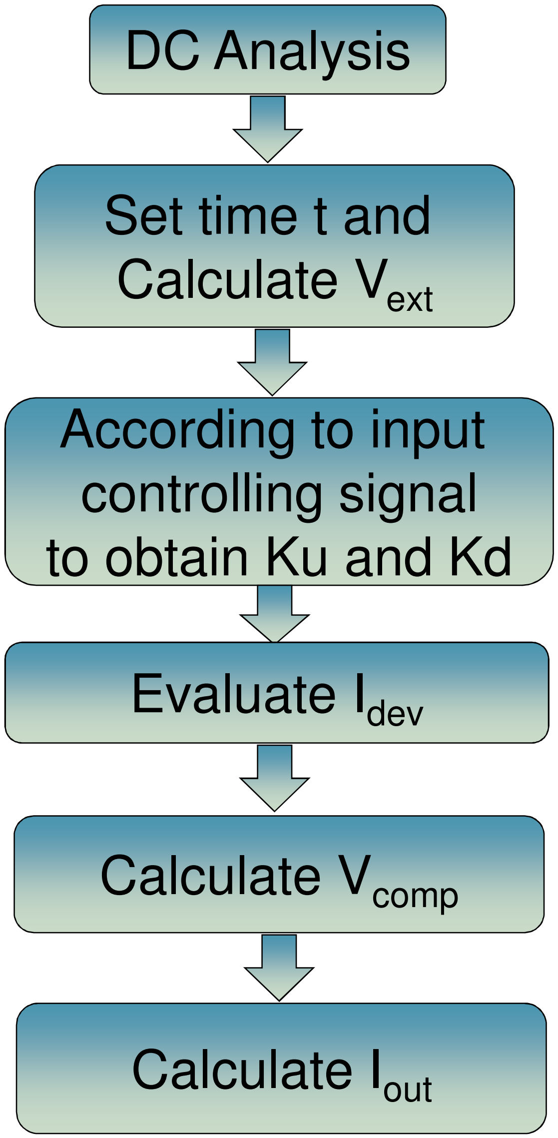
The solution is

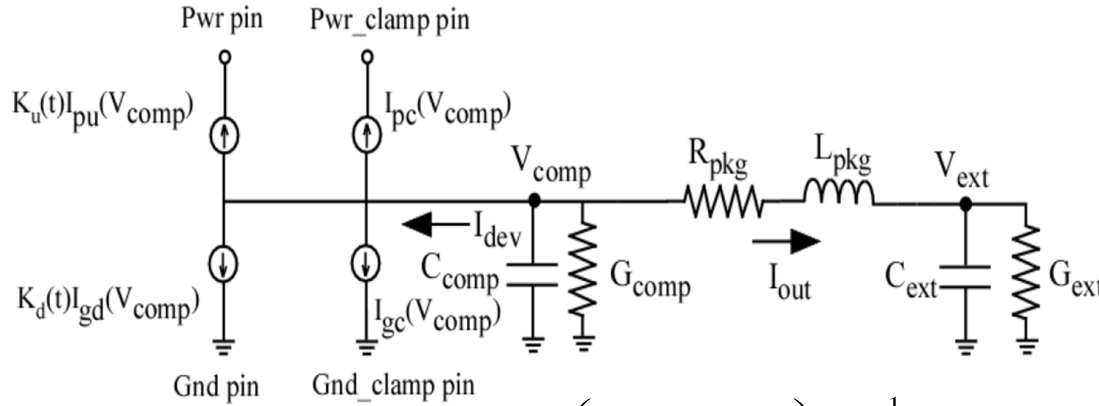
$$\begin{pmatrix} K_{ur}^{n} \\ K_{dr}^{n} \end{pmatrix} = \begin{pmatrix} I_{pu1}^{n} & I_{pd1}^{n} \\ I_{pu2}^{n} & I_{pd2}^{n} \end{pmatrix}^{-1} \begin{pmatrix} -I_{die1}^{n} - I_{pc1}^{n} - I_{gc1}^{n} \\ -I_{die2}^{n} - I_{pc2}^{n} - I_{gc2}^{n} \end{pmatrix}$$

The extraction of K_{uf} and K_{df} is similar.

*** Ying Wang, Han Ngee Tan "The Development of Analog SPICE Behavioral Model Based on IBIS Model", Proceedings of the Ninth Great Lakes Symposium on VLSI, GLS '99.

LIM-IBIS Simulation





$$V_{ext}^{n+\frac{1}{2}} = \frac{I_{out}^{n} + \left(\frac{C_{ext}}{\Delta t} - \frac{G_{ext}}{2}\right) V_{ext}^{n-\frac{1}{2}}}{\frac{C_{ext}}{\Delta t} + \frac{G_{ext}}{2}}$$

$$I_{dev}^{n} = K_{u}^{n} I_{pu}^{n}\left(V_{comp}\right) + K_{d}^{n} I_{pd}^{n}\left(V_{comp}\right) + I_{pc}^{n}\left(V_{comp}\right) + I_{gc}^{n}\left(V_{comp}\right)$$

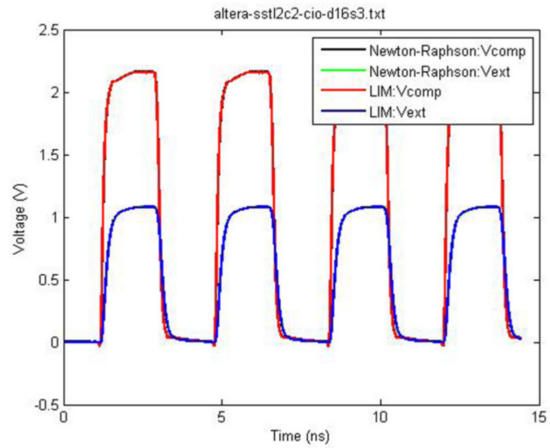
$$V_{comp}^{n+\frac{1}{2}} = \frac{-I_{out}^{n} - I_{dev}^{n} + \left(\frac{C_{comp}}{\Delta t} - \frac{G_{comp}}{2}\right) V_{comp}^{n-\frac{1}{2}}}{\left(\frac{C_{comp}}{\Delta t} + \frac{G_{comp}}{2}\right)}$$

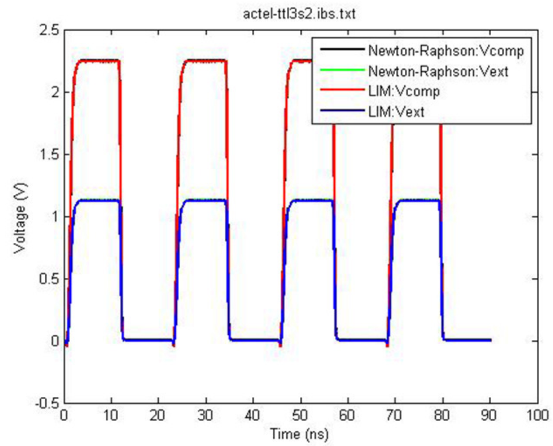
Explicit equations

$$I_{out}^{n+1} = \frac{\left(V_{comp}^{n+\frac{1}{2}} - V_{ext}^{n+\frac{1}{2}}\right) + I_{out}^{n}\left(\frac{L_{pkg}}{\Delta t} - \frac{R_{pkg}}{2}\right)}{\left(\frac{L_{pkg}}{\Delta t} + \frac{R_{pkg}}{2}\right)}$$

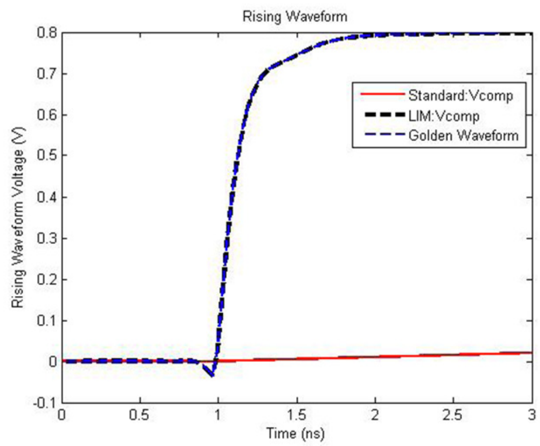
Transient Simulation Results*

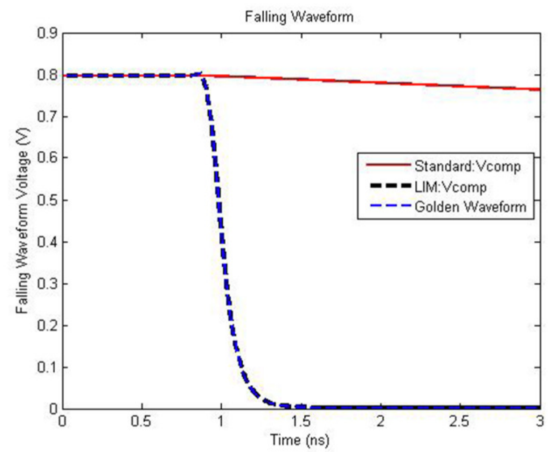
NR and LIM give the same results





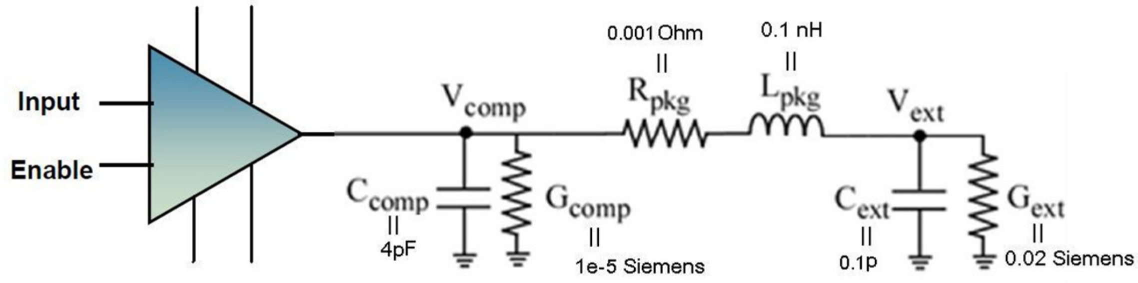
In some cases NR fails to converge

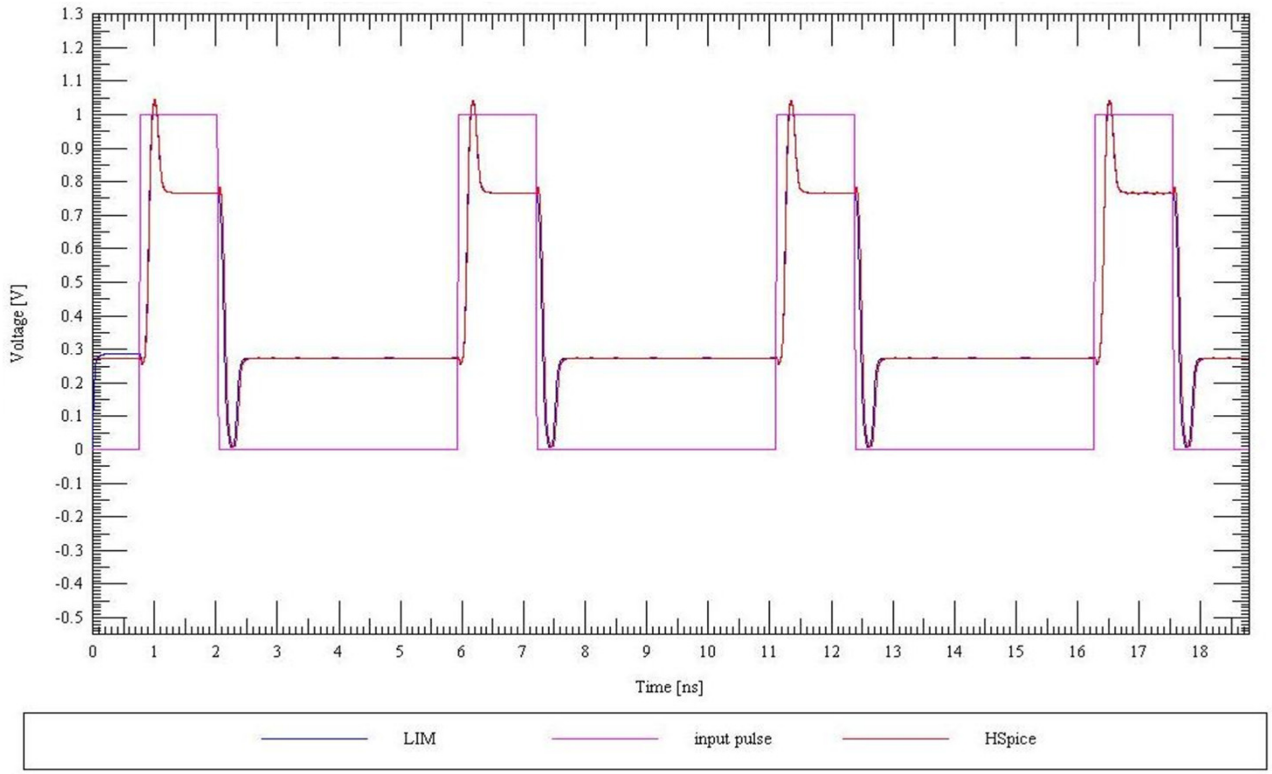




* J. E. Schutt-Ainé, “IBIS modeling using Latency Insertion Method," European IBIS summit, Italy, may16, 2012.

Comparison between LIM and HSPICE





AMI_TX model in ibisamiv2nodiff.ibs file

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Extension to Bird98

LIM-IBIS formulation can **easily be modified** to handle SSN problems

<u>Procedures:</u>

1. **use [ISSO PU] and [ISSO PD] tables (IV table) to generate Ksso_pd and Ksso_pu vectors** as follows:

   $$\mathit{Ksso\_pd}(\mathit{Vtable\_pd}) = \mathit{Isso\_pd}(\mathit{Vtable\_pd})/\mathit{Isso\_pd}(0)$$

   $$\mathit{Ksso\_pu}(\mathit{Vtable\_pu}) = \mathit{Isso\_pu}(\mathit{Vtable\_pu})/\mathit{Isso\_pu}(0)$$

2. **Add Ksso_pd and Ksso_pu coefficients to the equations**:

   $$\mathit{Ku}(t)\mathit{Ipu} \rightarrow \mathit{Ksso\_pu}(\mathit{Vtable\_pu}) * \mathit{Ku}(t)\mathit{Ipu}$$

   $$\mathit{Kd}(t)\mathit{Ipd} \rightarrow \mathit{Ksso\_pd}(\mathit{Vtable\_pd}) * \mathit{Ku}(t)\mathit{Ipd}$$

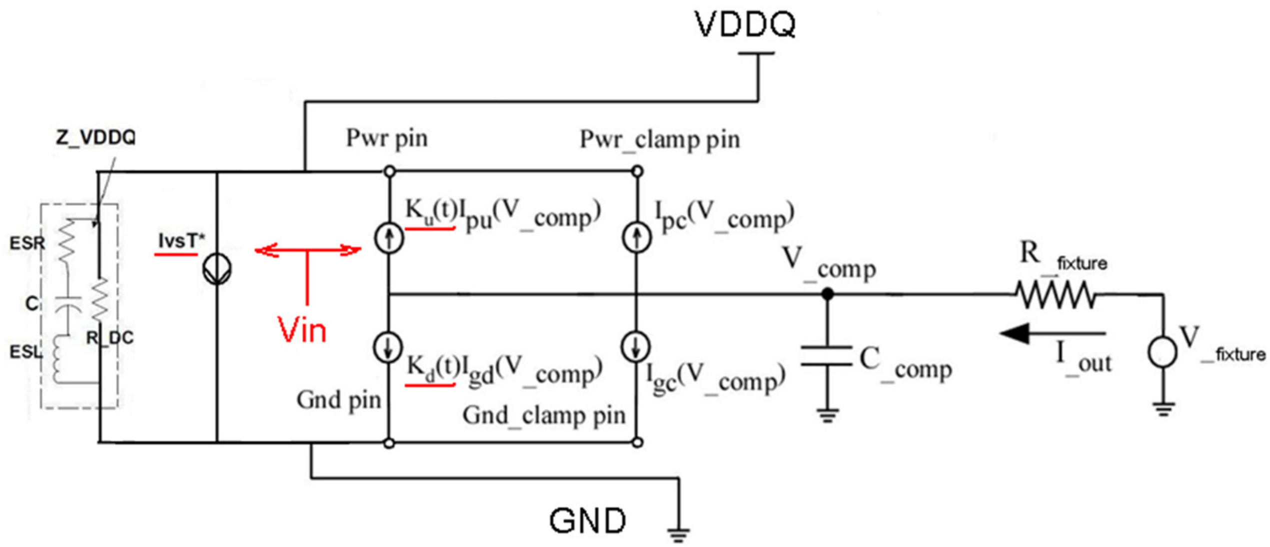
Extension to Bird95

Procedures:

1. Obtain composite currents **I_composite** from IBIS 5.0 file;
2. Obtain **I_B** from regular IBIS simulation during pre-simulation;
3. Obtain the pre-driver current **IvsT***, using

$$IvsT^{*}(t) = I\_composite(t) - I\_B(t)$$

4. Add **IvsT* (t)** as a voltage controlled current source (**VCCS**) in parallel with IBIS B element model.



Conclusions

- LIM can be used to simulate **IBIS based circuits** accurately;
- LIM does not suffer from **convergence** problems in handling nonlinear circuits;
- LIM can be extended to handle **IBIS 5.0** models;
- LIM is expected to be several orders of magnitude **faster** for large circuits containing a multitude of IBIS models.

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