Modeling Formats and Procedures at Intel

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JEITA IBIS Conference
March 24, 2005
Agenda

- Introduction and Disclaimer
- Modeling Flow
- Formats Used for External Distribution
- Future Direction and Investigations
- Evaluating Model Formats
- Key Questions for the Industry
A Disclaimer

- The following information is presented as the opinion of one person at Intel. This presentation does not necessarily represent Intel policy, commitments or preferences.

- This is not presented on behalf of the IBIS Open Forum and does not represent the official IBIS Open Forum direction.
General Modeling Flow

Conversion to Customer Distribution Format

Internal Buffer Design Format

Correlation Between Formats or to Silicon

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Modeling Flow

- **Buffer Design**
  - Internal SPICE-like format
  - Internal tool also supports IBIS, AMS languages

- **Conversion to External Formats**
  - IBIS is majority model type supported
    - Data generated directly from internal format
    - Other proprietary behavioral formats on case-by-case basis
  - Encrypted HSPICE used for one group of customers
    - Process file conversion used for model generation

- **Correlation Over Process, Voltage, Temperature**
  - I-V curve-tracing performed to correlate IBIS
  - Time- and frequency-domain analysis of systems
  - “Silicon-to-Simulation” correlation of process files to factory production data

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Curve-Tracing Example

- IBIS defines “envelope” for silicon data
  - **Weakest IBIS should be weaker than silicon, etc.**

![Pullup Curve - IBIS vs. Silicon](image)

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External Formats

- Different divisions use different formats
  - Format choices based on customer demand and capabilities, internal technical analysis

- Reasons for use of proprietary SPICE
  - Control over buffer features (example: impedance)
  - Latch-to-latch: more ps from timings at core!

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Transistor-Level SPICE Modeling

Why are transistor models popular?
- Familiar to users
- More detail seen as more accuracy (misconception)
- Behavioral models add some effort, burden
  - Encrypted transistor very simple to distribute – just include everything and send files to customers
  - Behavioral models require conversion, correlation
- Transistor simulation faster as computer speed increases
  - PI, SSO still very difficult at transistor-level
- Behavioral methods sometimes difficult to use
  - Example: impedance control in IBIS
- Latch-to-latch detail not seen in behavioral models
  - AMS is promising here

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Studies of Behavioral Modeling Types

- Intel team is studying formats
  - Behavioral Modeling Workgroup meets weekly
  - **Mission:** develop methods for IBIS, AMS modeling; analyze new proposals (ex. SPICE macromodeling)

- Key goals
  - Develop standardized methods, templates for AMS
  - Add features: latch-to-latch, new controls (ex. impedance)
  - Correlate AMS against internal format, proprietary SPICE

- Ideal: a single format that can be used company-wide
  - Short term: IBIS, encrypted HSPICE remain
  - Longer term: IBIS divisions will move to AMS+IBIS
    - Teams using encrypted HSPICE will evaluate AMS capabilities, consult with customers
  - No compelling case for SPICE macromodeling yet

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How to Evaluate A Model Format

- **Seven** basic desires for a modeling solution
  - “I want it to be accurate”
  - “I want it to be fast in my simulator”
  - “I want it to protect my IP”
  - “I want it to be standardized”
    - *Works for more than one tool*
  - “I want it available soon”
  - “I want it easy to use/implement/automate”
  - “I want maximum flexibility in describing my buffer design’s behavior”

- A “perfect” solution can only meet **six** desires (so far)

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**Customer Solutions and the 7 Rules**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Proprietary Encrypted SPICE</th>
<th>IBIS 3.2/4.0</th>
<th>IBIS + AMS</th>
<th>IBIS + Macromodeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>**</td>
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<td>*</td>
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<tr>
<td>Availability</td>
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<td>Ease of use/implementation</td>
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<td>Flexibility</td>
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<td>IP Protection</td>
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<tr>
<td>Speed</td>
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<tr>
<td>Standardization</td>
<td></td>
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</tr>
</tbody>
</table>

* can change, depending on tool support/committee efforts  
** depends on model implementation

- **Meets all of need**  
- **Meets most or some of need**  
- **Meets most or some of need, with difficulty**  
- **Cannot meet need**

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Questions for Industry

- Transistor encrypted SPICE is very popular
  - Is either AMS or Macromodeling more compelling?
- Will customers support behavioral modeling?
  - Behavioral models are faster in simulation, but take more effort to generate
  - Can customers be convinced they are accurate?
- What is the best long-term industry solution?
  - Macromodeling standardization will take time
  - Should we develop macromodeling specification or educate industry about AMS usage?
- How will IP be protected?
  - Behavioral modeling uses algorithms, not process details or design netlists
  - Some design algorithms may be sensitive
  - Behavioral encryption may require standardization

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BACKUP
What is the greatest use for IBIS?

IBIS originally consisted of two parts
- Device model behavioral data: V-t, I-V tables, etc.
  - “Snapshot” at certain conditions (Temp, etc.)
- Interface specs, for user automation: Vinh, Vmeas, etc.
- Power supply information fits in both categories

With AMS or Macromodeling, some of IBIS redundant
- Behavioral modeling under IBIS very limited (no equations)
- Both alternatives are much more flexible than IBIS

IBIS interface specifications are still very useful
- AMS, Macromodeling describe device design behavior
- Still a need for a standardized SI “wrapper” around behavior
- Includes evaluation criteria
- Would help user judge device performance in system
- IBIS serves this need! Evaluation parameters for SI
- Need IBIS-based user-defined specs, measurements

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Solutions and the 7 Rules

- **IBIS 3.2/4.0**
  - **Advantages**
    - Fast, IP protecting, standard, easy to use/implement
    - Available immediately in tools
  - **Disadvantages**
    - Not accurate for certain functions (e.g., freq. dep. C)
    - Not flexible (table-based, not equation-based)

- **AMS + IBIS**
  - **Advantages**
    - Flexible, standardized, can be fast
    - Can be accurate, depending on correlation effort
  - **Disadvantages**
    - Greater challenges to implementation
    - Additional learning for users, model authors
      - Templates would reduce this problem
    - Not available in tools yet
    - IP protection?

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Solutions and the 7 Rules

- SPICE Macromodeling
  - Advantages:
    - EDA tools already support controlled sources
    - Low barriers to use by behavioral experts
    - Has flexibility beyond native IBIS
  - Disadvantages:
    - Obstacles to standards development
      - Creating a standardized SPICE syntax
      - Can this be done is less than two years?
    - New features still require creation of new keywords
      - Same development delay as in traditional IBIS
      - Can controlled sources cover all equations?
    - Still behavioral!
      - More value than transistor-level models?
      - Behavioral modeling expertise required!

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