Experiences with driver schedules
Eckhard Lenski
DATE, Nice, France
19th April 2007
Agenda

Experiences with driver schedules

Summary

Driver schedules basics

CML- Pre-emphasis

GTL-like

Push-pull
Driver schedule basics...
A Multistage driver consists of several driver stages, which are switching at different times

Or different voltage levels
Or ....
parts of IBIS Multistage driver model

[Model]   3-Driver-schedule

Model_type    I/O
Vinl = 0.68V
Vinh = 0.88V
C_comp        1.5pF  1.0pF  2.0pF
[Voltage Range]  3.30V  3.1350V  3.4650V

[Driver Schedule]

<table>
<thead>
<tr>
<th>Model_name</th>
<th>Rise_on_dly</th>
<th>Rise_off_dly</th>
<th>Fall_on_dly</th>
<th>Fall_off_dly</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL_1</td>
<td>0s</td>
<td>NA</td>
<td>0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_2</td>
<td>0.5ns</td>
<td>NA</td>
<td>0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_3</td>
<td>1.0ns</td>
<td>2.5ns</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

[GND Clamp]  

[POWER Clamp] 

[Pulldown] 

[Pullup] 

3.00 0.00 0.00 0.00

[Ramp] 

dV/dt_r 1.00V/1.8ns 0.9V/2.50ns 1.1V/1.0ns

dV/dt_f 1.3V/1.5ns 1.1V/2.0ns 1.4V/0.9ns
top level model

C_comp
[Voltage Range] 3.30V
[GND Clamp]
[POWER Clamp]
[Pulldown]
[Pullup]
[Ramp]
dV/dt_r 1.00V/1.8ns
dV/dt_f 1.3V/1.5ns

For tools, which don’t understand the [Driver schedule] keyword, there is a description of the rough/approximate behavior of the output with normal IBIS keywords, (called top level model)
The Driver schedule contains the exact timing information about the time, when the different driver stages are used.

The switching behavior of each driver stage itself is described like that of a normal IBIS IO-model in a [Model] statement.
### scheduled models timing

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<th>Fall_off_dly</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL_1</td>
<td>1.0ns</td>
<td>2.5ns</td>
<td>0ns</td>
<td>NA</td>
</tr>
</tbody>
</table>

- **rising edge (L->H):**
  - turn on pullup-structure
  - turn off pullup-structure
  - turn off pulldown-structure
  - turn on pulldown-structure

- **falling edge (H->L):**
  - turn on pullup-structure
  - turn off pullup-structure
  - turn off pulldown-structure
  - turn on pulldown-structure
example timing schedule

[Driver Schedule]

<table>
<thead>
<tr>
<th>Model_name</th>
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<tbody>
<tr>
<td>MODEL_1</td>
<td>0.5ns</td>
<td>NA</td>
<td>0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_2</td>
<td>1.0ns</td>
<td>NA</td>
<td>0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_3</td>
<td>1.5ns</td>
<td>2.5ns</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
time schedule  \( t=0 \)

All 3 driver stages are switched off
Driver stage D1 is switched on
time schedule  \( t = 1 \)

Driver stage D2 is additionally switched on
Driver stage D3 is additionally switched on
Driver stage D3 is switched off

time schedule  \( t = 2.5 \)
Driver schedules with push-pull (CMOS) Models
IBIS push pull driver schedule

MODEL_1

MODEL_2

Push-pull
Experiences with two IO-Models and no top level model information

<table>
<thead>
<tr>
<th>Model_name</th>
<th>Rise_on_dly</th>
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</tr>
</thead>
<tbody>
<tr>
<td>MODEL_1</td>
<td>2.00ns</td>
<td>NA</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_2</td>
<td>2.50ns</td>
<td>NA</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
</tbody>
</table>

………
IO-models stand alone

MODEL_1 stand alone

MODEL_2 stand alone

Testload was a 3 inch transmission line (open)

Driver   End of line
3 test cases

( examples show only rising edge )

<table>
<thead>
<tr>
<th>Model_name</th>
<th>Rise_on_dly</th>
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<tbody>
<tr>
<td>MODEL_1</td>
<td>0.00ns</td>
<td>NA</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_2</td>
<td>0.00ns</td>
<td>NA</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_1</td>
<td>2.00ns</td>
<td>NA</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_2</td>
<td>2.50ns</td>
<td>NA</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
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<td>MODEL_1</td>
<td>2.00ns</td>
<td>NA</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_2</td>
<td>2.50ns</td>
<td>NA</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
</tbody>
</table>
## Results

<table>
<thead>
<tr>
<th>Model_name</th>
<th>Rise_on_dly</th>
<th>Rise_off_dly</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL_1</td>
<td>0.00ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_2</td>
<td>0.00ns</td>
<td>2.50ns</td>
</tr>
</tbody>
</table>

Testload was a 3 inch transmission line (open).

![Graphs showing voltage over time for different models with labels for 'Driver' and 'End of line'.]
results with comments

Both drivers starting at time 0ns

One driver starts at t=0ns, the second driver starts at 2.5ns

Both drivers starting with delaytime 2ns

Testload was a 3 inch transmission line (open)

Driver  End of line
GTL-like driver schedules
IO models

Example with two IO-Models and with top level model information
### IBIS gtl driver schedule

**[Driver schedule]**

<table>
<thead>
<tr>
<th>Model name</th>
<th>Rise on dly</th>
<th>Rise off dly</th>
<th>Fall on dly</th>
<th>Fall off dly</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL_OPSINK</td>
<td>0.00ns</td>
<td>NA</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_OPSOURCE</td>
<td>0.00ns</td>
<td>2.0ns</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

**[pullup]**

- 0.0V 0mA

**[pulldown]**

- 0.0V 0mA
- 2.0 35mA

**[powerclamp]**

- 0.0V 0mA
- 2.0V -10mA

**[ramp]** 0.5V/0.45ns
3 test cases

( here only rising edge shown )

Pulldown

Power clamp

Ramp

<table>
<thead>
<tr>
<th>Model_name</th>
<th>Rise_on_dly</th>
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<th>Fall_off_dly</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL_1</td>
<td>0.00ns</td>
<td>NA</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_2</td>
<td>0.00ns</td>
<td>2.0ns</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
</tbody>
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<tr>
<td>MODEL_1</td>
<td>0.00ns</td>
<td>NA</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_2</td>
<td>0.00ns</td>
<td>2.0ns</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
</tbody>
</table>
models overview for testcases

Case 1 top level
- Power clamp
- V
- I
- Po
- Vout
- Iout
- High/pullup
- Low/pulldown

Case 2 Main only
- Vcc
- V1
- GND
- V2

Case 3 scheduled
- Vcc
- V2

GTL-like
results

<table>
<thead>
<tr>
<th>Model name</th>
<th>Rise on dly</th>
<th>Rise off dly</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL_1</td>
<td>0.0ns</td>
<td>NA</td>
</tr>
</tbody>
</table>

Pulldown

Power clamp

Testload was a 3 inch transmission line with Rload 50 to 1P2V

Driver  | End of line
results with comments

1. Ramp only
   no accurate rising

2. Rising behavior from external termination

3. Additional swing by open source driver

Test load was a 3 inch transmission line with Rload 50 to 1P2V

Driver

End of line

GTL-like
CML pre-emphasis
IO models

Example with two IO-Models and with wrong top level model information
IBIS cml driver schedule

<table>
<thead>
<tr>
<th>Model_name</th>
<th>Rise_on_dly</th>
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<th>Fall_on_dly</th>
<th>Fall_off_dly</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL_OPSINKMAIN</td>
<td>0.00ns</td>
<td>NA</td>
<td>2.0ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_OPSINKBOOST</td>
<td>0.00ns</td>
<td>0.8ns</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

[pullup]

0.0V  0mA

[pulldown]

0.0V  0mA
2.0V  0mA

[powerclamp]

0.0V  0mA
2.0V  -10mA

[ramp]  0.4V/37ps
### 3 test cases

( here only rising edge shown )

<table>
<thead>
<tr>
<th>Pulldown</th>
</tr>
</thead>
</table>

1. **Power clamp**

2. **Ramp**

<table>
<thead>
<tr>
<th>Model name</th>
<th>Rise on dly</th>
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<th>Fall on dly</th>
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</tr>
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<tbody>
<tr>
<td>MODEL_MAIN</td>
<td>0.00 ns</td>
<td>NA</td>
<td>2.0 ns</td>
<td>NA</td>
</tr>
<tr>
<td>MODEL_BOOST</td>
<td>0.00 ns</td>
<td>0.8 ns</td>
<td>2.0 ns</td>
<td>NA</td>
</tr>
</tbody>
</table>

3. **Pulldown Power clamp Ramp**

<table>
<thead>
<tr>
<th>Model name</th>
<th>Rise on dly</th>
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<td>0.00 ns</td>
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<td>MODEL_BOOST</td>
<td>0.00 ns</td>
<td>0.8 ns</td>
<td>2.0 ns</td>
<td>NA</td>
</tr>
</tbody>
</table>

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models for test cases

Case 1  top level

Case 2  Main only

Case 3  scheduled
Testload was a 3 inch transmission line with Rload 50 to 1P5V

Driver       | End of line
---           |---

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</tr>
<tr>
<td>MODEL_2</td>
<td>0.0ns</td>
<td>0.8ns</td>
</tr>
</tbody>
</table>
results with comments

1. No switching at all

2. Switches up to 1.5V
Correct level, but no pre-emphasis?

3. Shows Pre-emphasis behavior, but then goes back to 1.4V ??

Testload was a 3 inch transmission line with Rload 50 to 1P5V

Driver  |  End of line
Summary

• Timing dependant drivers works fine

• Voltage dependant drivers should be possible with [submodel] and 'fall-back'

• Pre-emphasis modeling is possible, but only with fixed 'Pre-emphasis'

• Pattern dependant 'Pre-emphasis' with VHDL-AMS

• Check of combined static and dynamic waveforms necessary

• Driver schedule models have to be carefully checked
Thank You

• Questions ?