Leveraging IBIS Capabilities for Multi-Gigabit Interfaces

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Overview

- In writing EDI CON paper “Signal Integrity Methodology for Double-Digit Multi-Gigabit Interfaces”, different IBIS modeling techniques were applied
- Wanted to share some of the IBIS modeling methods we’ve been using

Agenda

- [External Model]
- AMI equalization adaptation
- Backchannel training
- Applying IBIS-AMI to DDR applications

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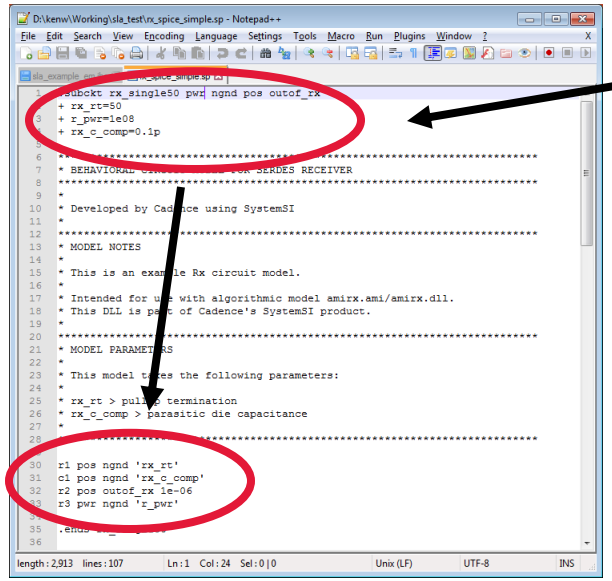
Preliminary IBIS Modeling

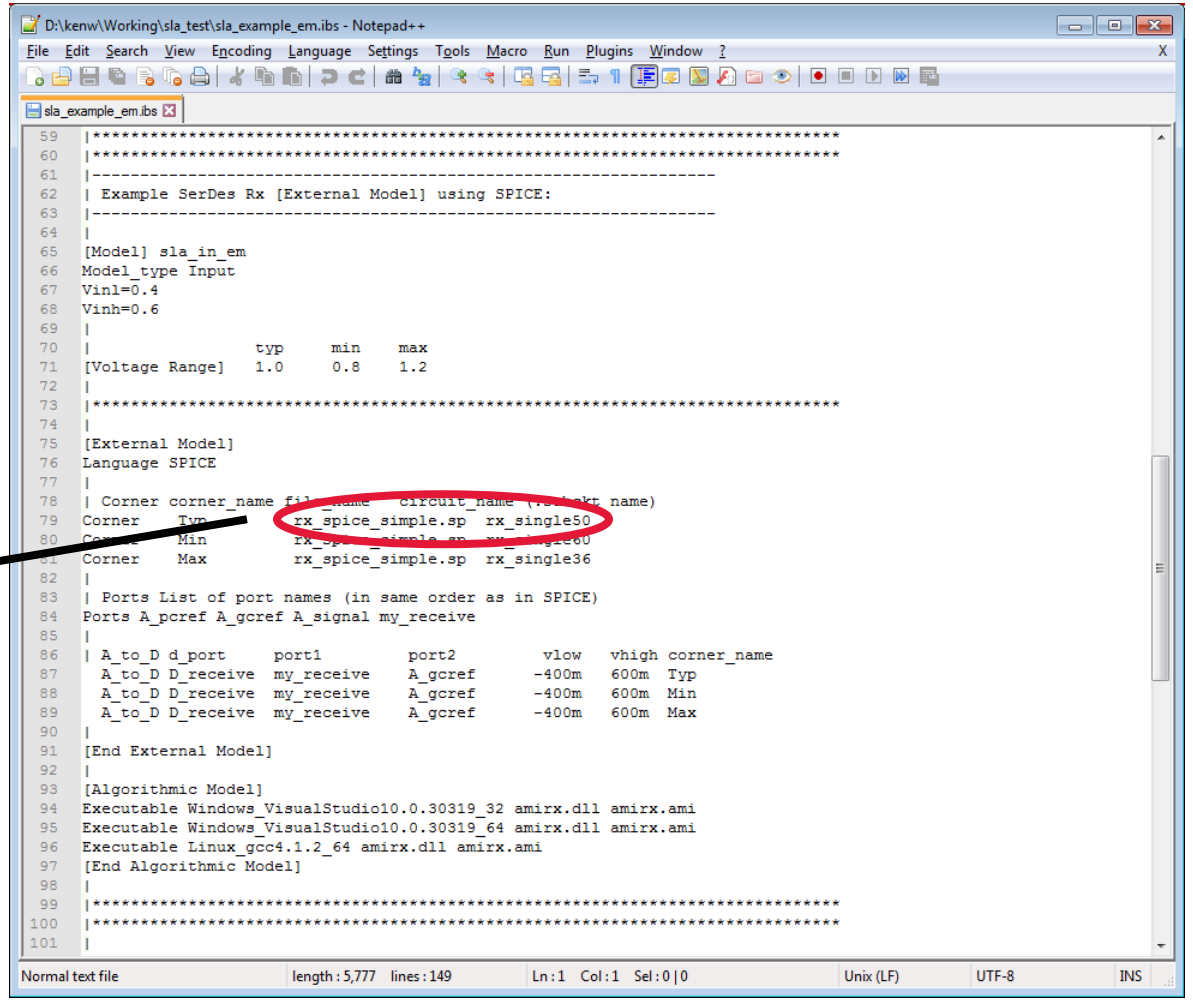
- Can get started with:
  - Voltage swing
  - Pad capacitance
  - Output impedance
  - Rise time
- Even easier to model using [External Model] syntax

```
|
[Model]     pcie4_out
Model_type  Output
Polarity Non-Inverting
Vmeas =     0.5
|
|
| variable                                  typ         min         max
C_comp                                      0.50pF      0.50pF      0.50pF
[Temperature Range]                         20          80          -50
[Voltage range]                             1.0         1.0         1.0
|
|*****************************************************************************
[Pulldown]
|
|                         Voltage             I(typ)      I(min)      I(max)
|
                         -1.0000e+00          -2.0000e-02 -2.0000e-02 -2.0000e-02
                          0.0000e-00           0.0000e-00  0.0000e-00  0.0000e-00
                          1.0000e+00           2.0000e-02  2.0000e-02  2.0000e-02
|
|*****************************************************************************
[Pullup]
|
|                         Voltage             I(typ)      I(min)      I(max)
|
                         -1.0000e+00           2.0000e-02  2.0000e-02  2.0000e-02
                          0.0000e-00           0.0000e-00  0.0000e-00  0.0000e-00
                          1.0000e+00          -2.0000e-02 -2.0000e-02 -2.0000e-02
|
|*****************************************************************************
[Ramp]
|
| variable          typ                 min                 max
dV/dt_r        0.60/0.020n   0.60/0.020n   0.60/0.020n
dV/dt_f        0.60/0.020n   0.60/0.020n   0.60/0.020n
|
R_load = 50
|
```

External Model

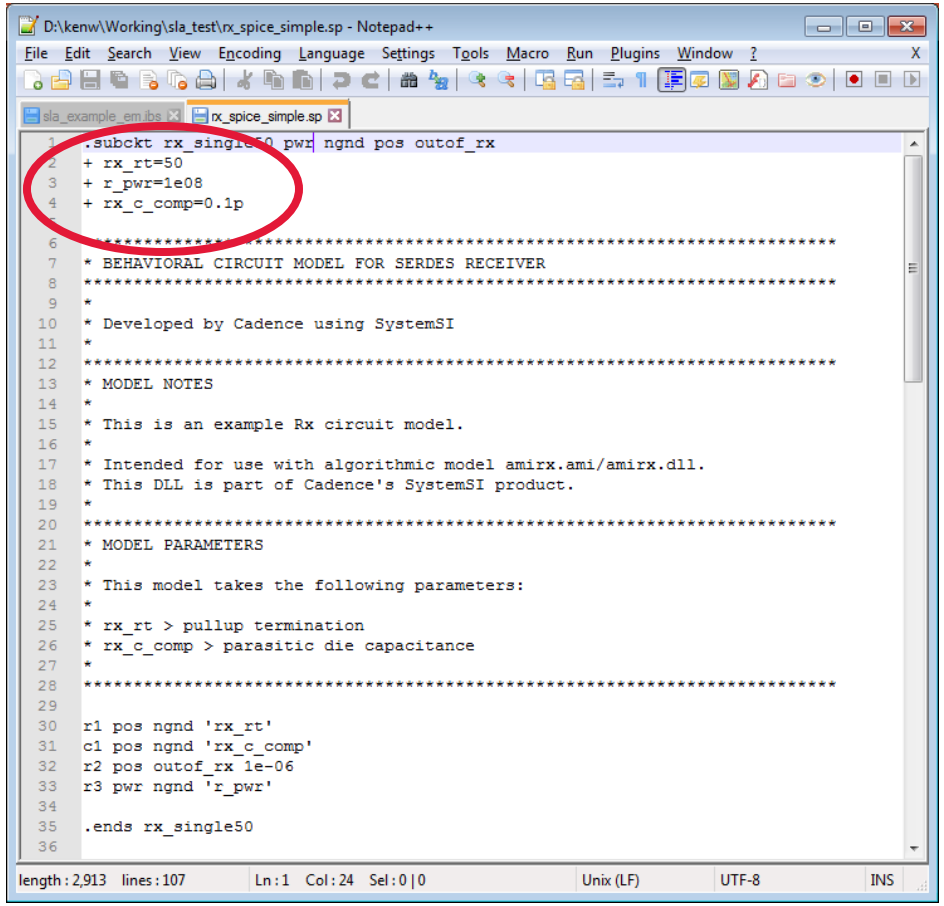
- Originally introduced in IBIS 4.1 !
- Enabled VHDL, Verilog-A, and Spice syntax to be used for buffer models instead of VI/VT table syntax
- Spice syntax has proven very useful to us





Spice [External Model]s Convenient for Early Feasibility

- Sometimes the IBIS model you want is not available for preliminary / pre-design analysis
- Easy to write (or use) simple parameterized Spice subcircuits for IO buffers when IBIS availability does not align with your project schedule
- Can sweep parameters and cover a big portion of the design space quickly and easily



Analog Buffer Model Extensions

- Incorporated into IBIS 6.0

```
[External Model]
Language IBIS-ISS
|
| Corner corner_name file_name circuit_name (.subckt name)
Corner    Typ         cdnstxrx.cir   tx_subckt
|
| List of parameters
Parameters  TSFile1     = cdns_tx.param(CDNS_Tx(Model_Specific(Tstonefile)))
Parameters  Tx_Rseries      = cdns_tx.param(CDNS_Tx(Model_Specific(Tx_R)))
|
| List of converter parameters
Converter_Parameters  Vtx_h = cdns_tx.param(CDNS_Tx(Model_Specific(Tx_V)))
|
| Ports List of port names (in same order as in SPICE)
Ports A_signal_pos A_signal_neg my_driveP   A_pdref  A_puref
|
| D_to_A d_port port1 port2 vlow vhigh trise tfall corner_name polarity
D_to_A  D_drive  my_driveP  A_pdref  0  Vtx_h  0.05n  0.03n  Typ
|
|
[End External Model]
```

Tx/Rx Model described in external file

- Replaces the VI/VT curves
- Can now be parameterized when Language 'IBIS-ISS' is used

Parameter Definition is in a separate file

- Similar to AMI Parameters
- Can be in .ami or any other file
- User Selects Parameter Values from GUI

Parameter Value is passed to Simulator

- Using.param, the parameter value is passed to the simulator
- Converter_Parameters are used appropriately in the stimulus/D_to_A

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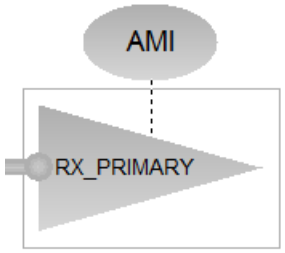
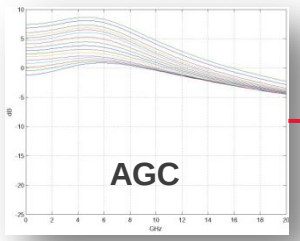
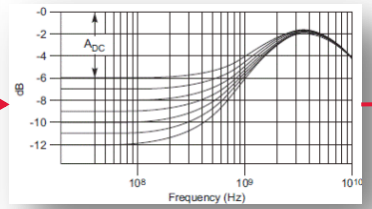
- ***AMI equalization adaptation***
- Backchannel training
- Applying IBIS-AMI to DDR applications

Anatomy of a Receiver AMI Model

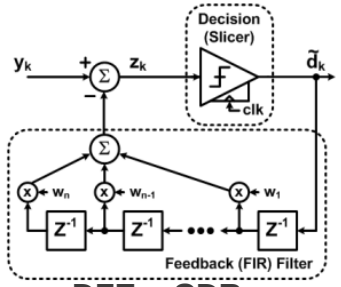
- These different modules typically adapt at different rates
- Initial modules usually adapt more slowly than later ones







CTLE



DFE + CDR

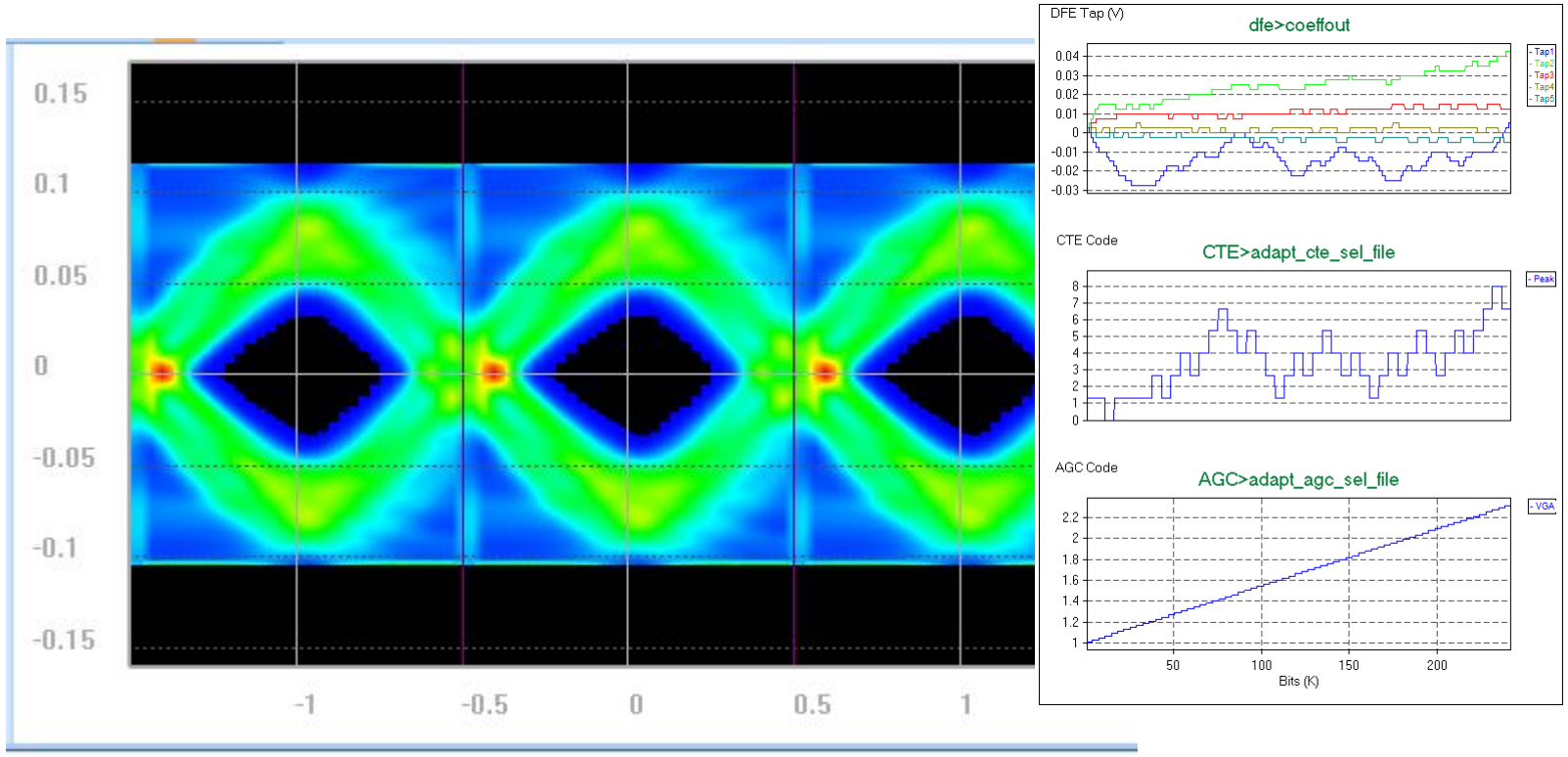
• Selective boosting at frequency of interest (high freq channel loss cancellation)
• Better for Area/Pwr considerations
• Noise and xtalk also gets boosted.
• Usually first order filter only

• Curve-based function to boost the incoming signal so that it could be detected at the output.
• Noise also gets boosted.

• Feeds back previous bit decisions to cancel post cursor ISI caused by them
• Can model non-linearity
• Adaptively tunes tap coeff.
• Level sensitive
• Cannot cancel pre-cursor
• Needs 'something' to work with → AGC/CTLE

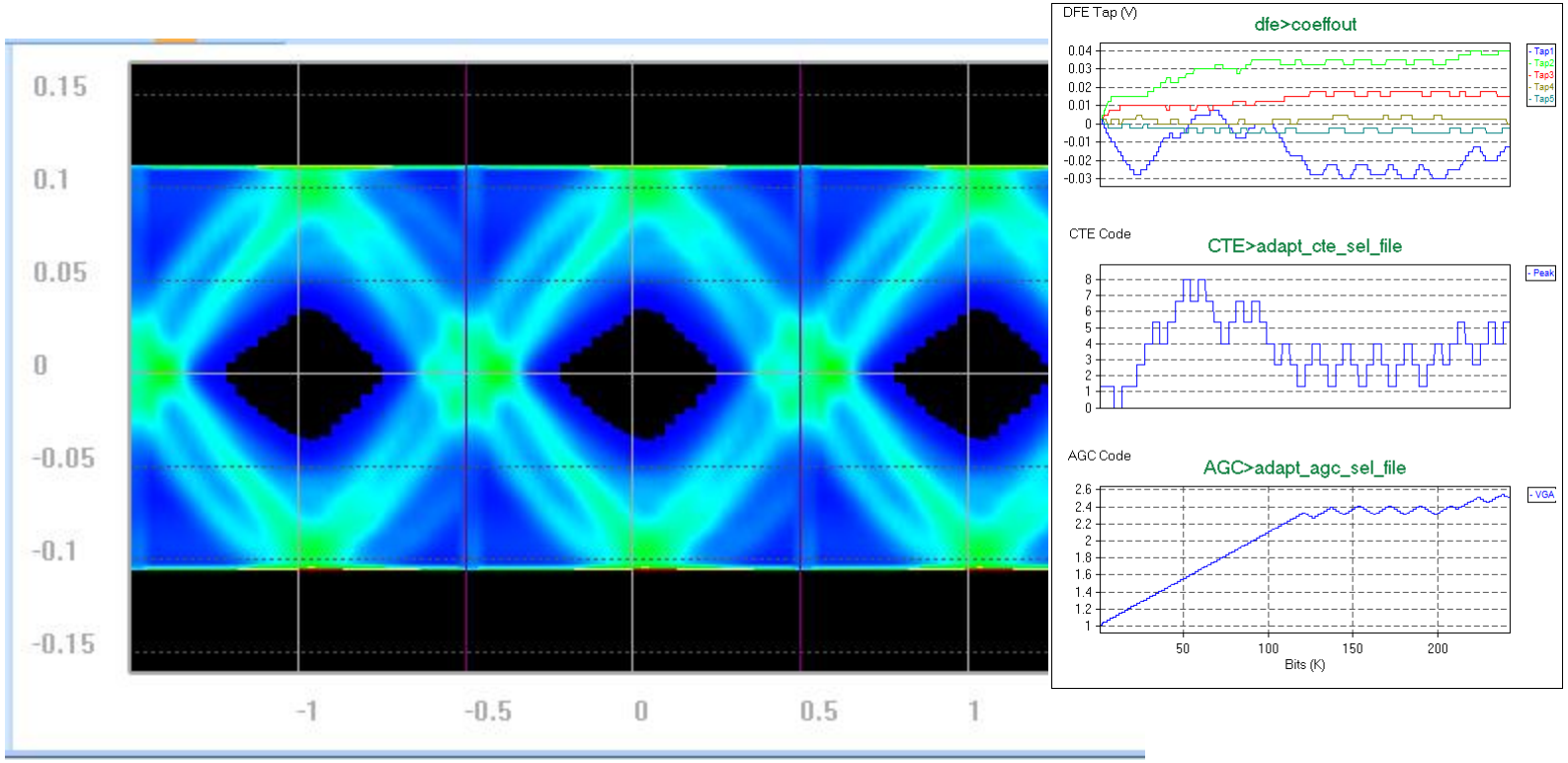
Rx With Default Adaptation

- Note that adaptation coefficients don’t converge



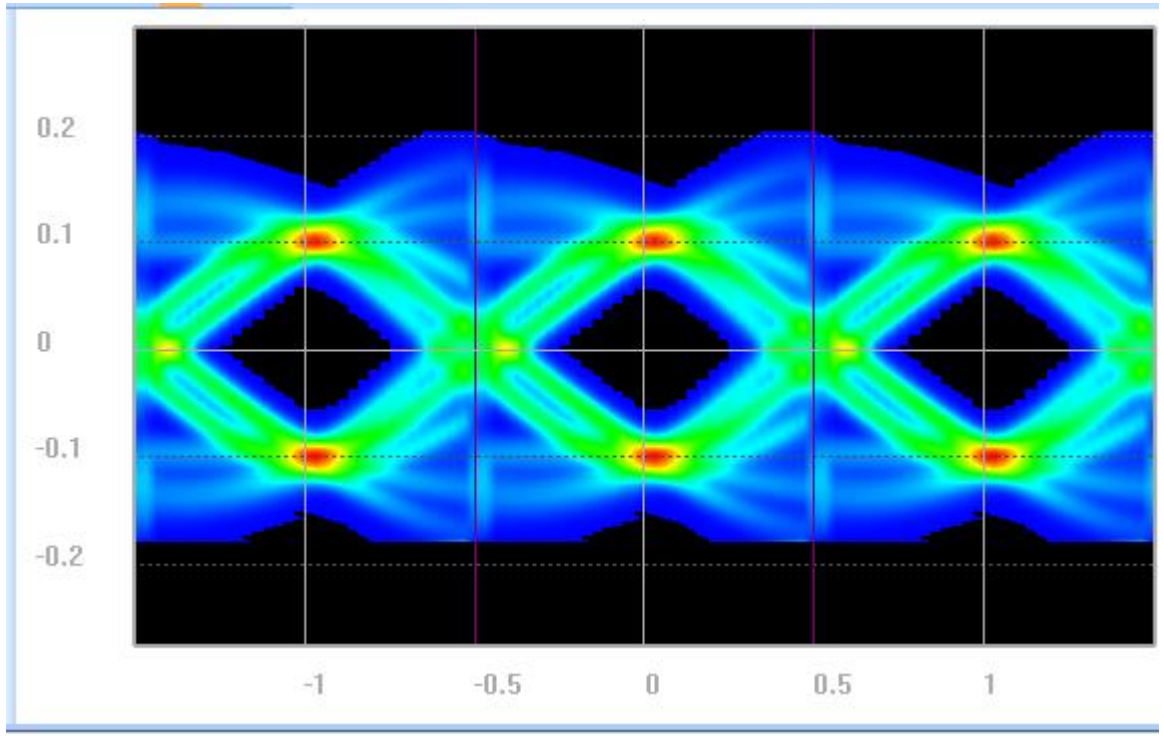
With Faster AGC Adaptation

- Coefficients converge, but after 150k bits of traffic are passed



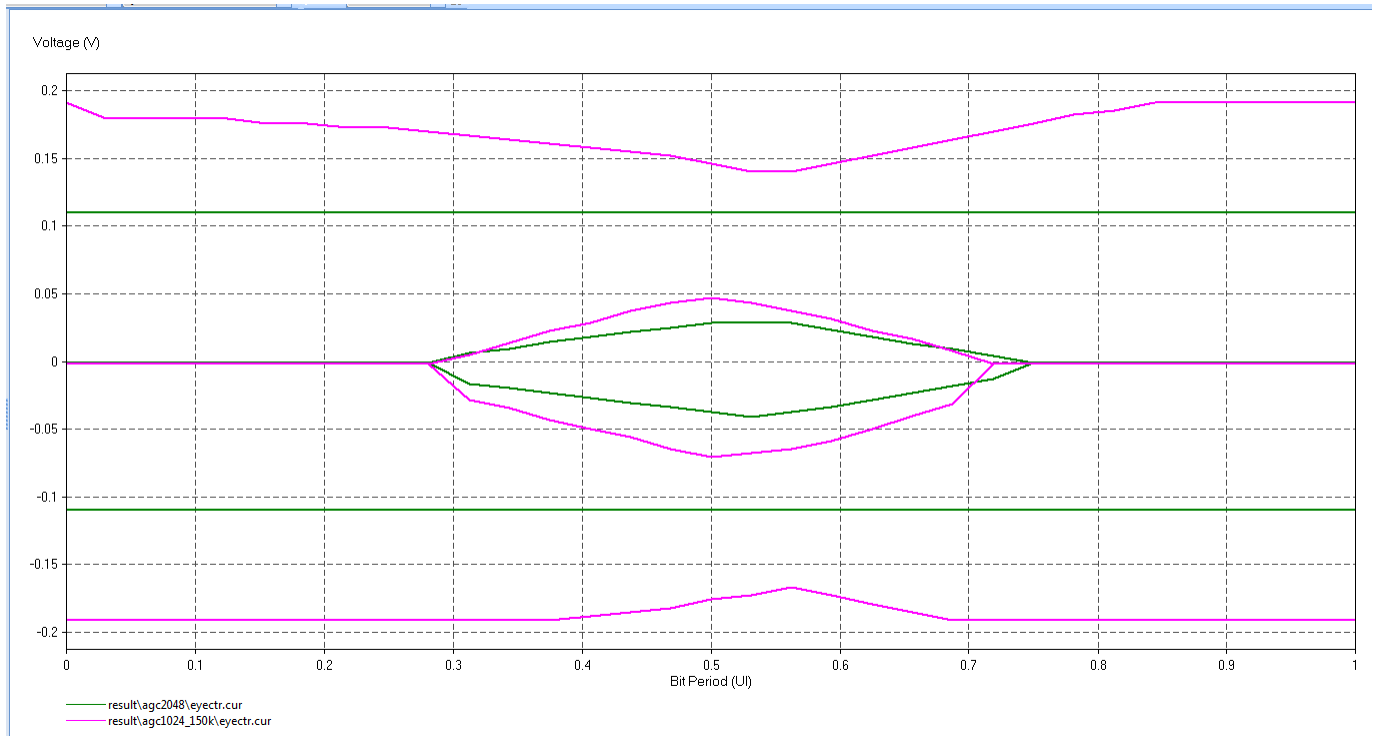
Ignoring the First 150k Bits

- Default was to ignore the first 40k bits
- Eliminates the noise from before coefficients converged
- Very important to be able to visualize how the adaptation is converging



Original Eye Contour vs. Final

- Adjusting AGC adaptation time and Ignore_Bits made a significant difference in eye height



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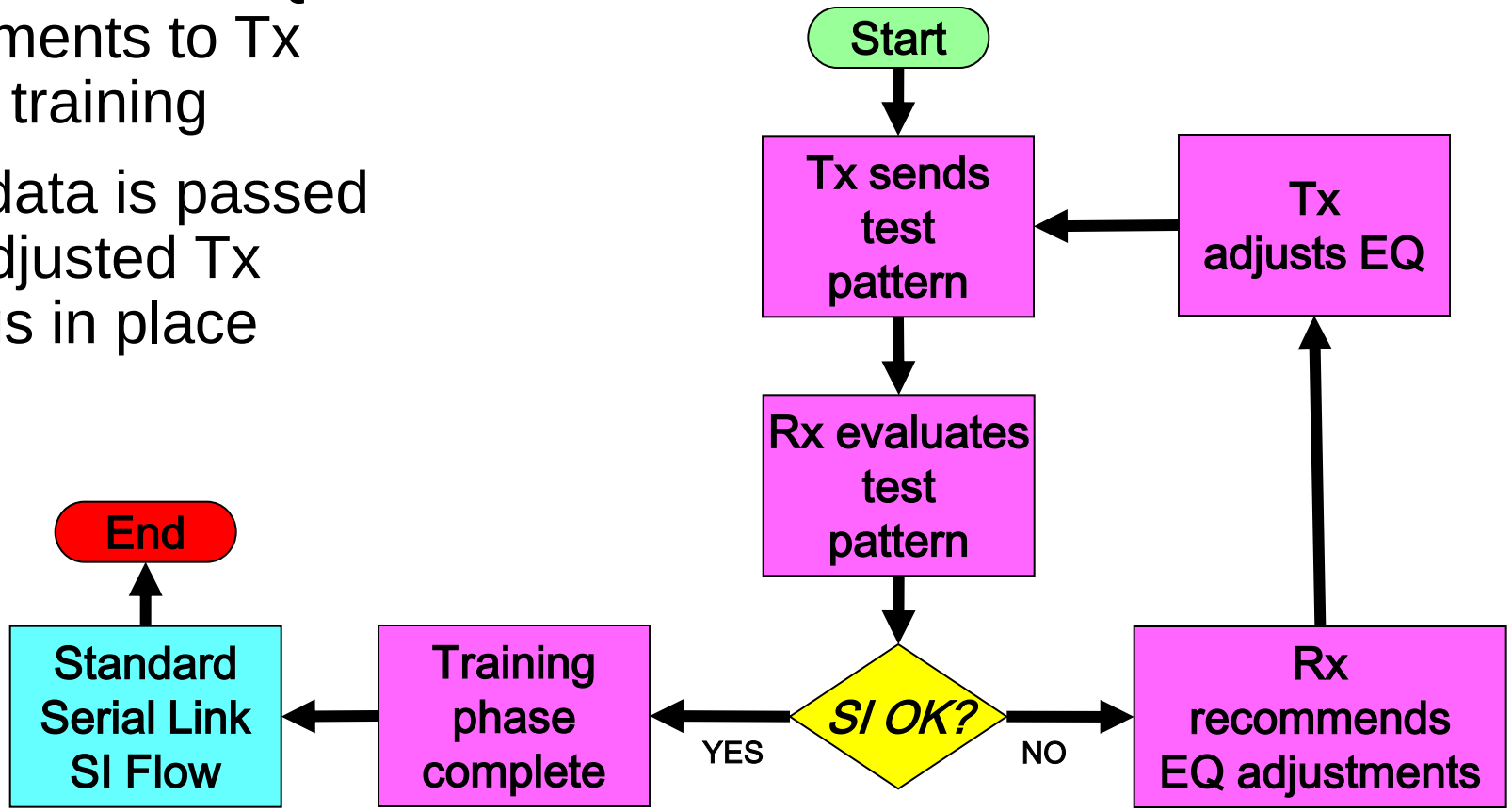
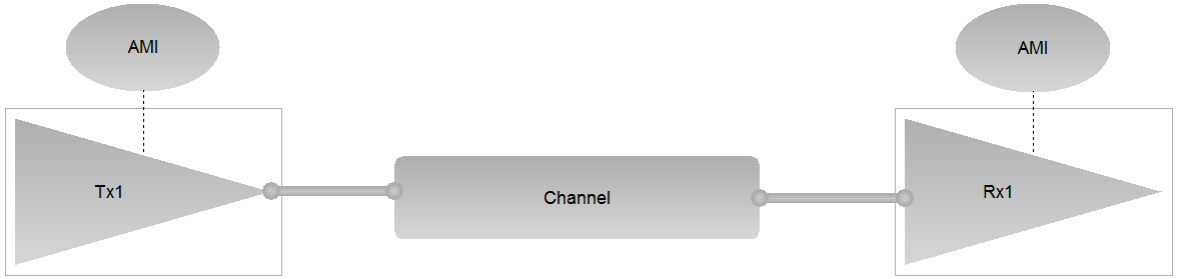
Backchannel Training (IBIS BIRD 147, in IBIS 7.0)

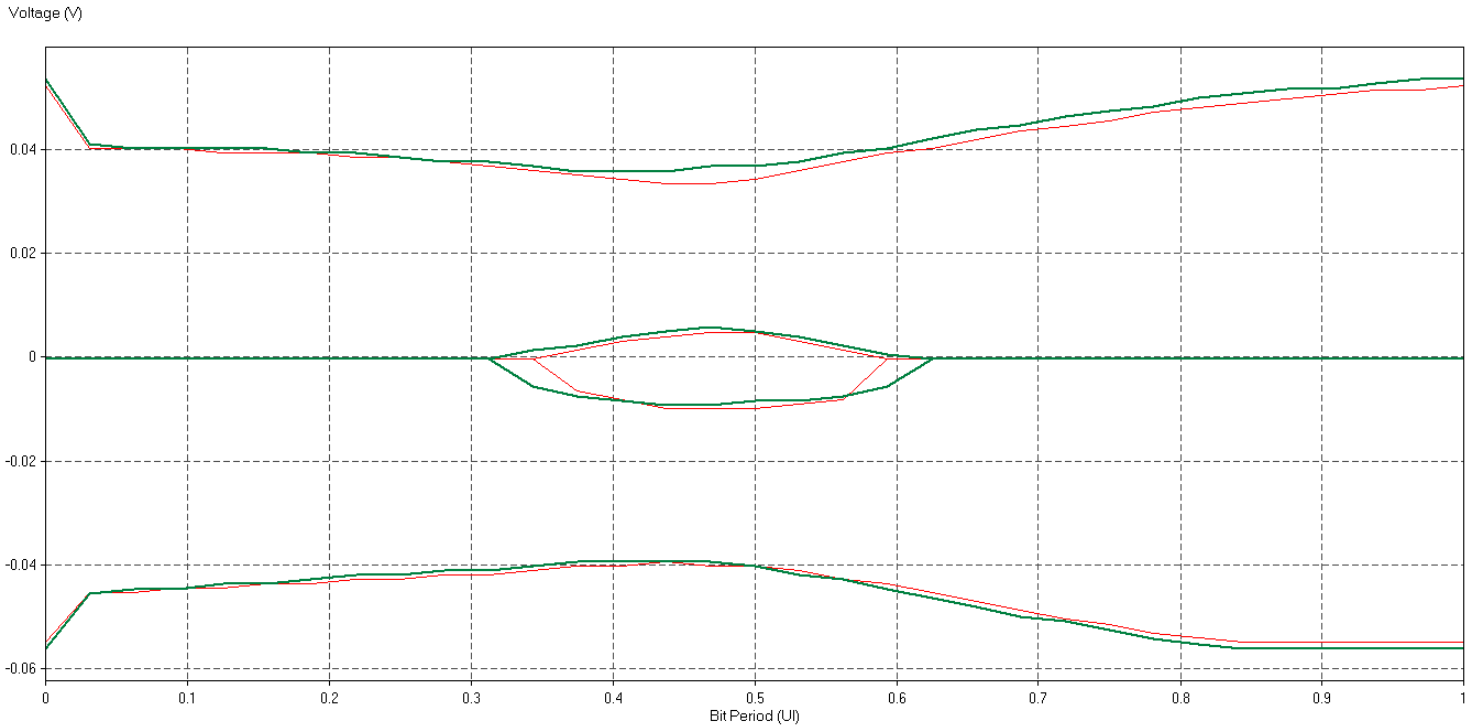
- Rx feeds back EQ adjustments to Tx during training
- Then data is passed with adjusted Tx settings in place



With and Without Backchannel

- Backchannel turned down Tx FFE settings somewhat
- Leaves more “heavy lifting” to Rx and its advanced adaptation
- Improves overall signal quality significantly





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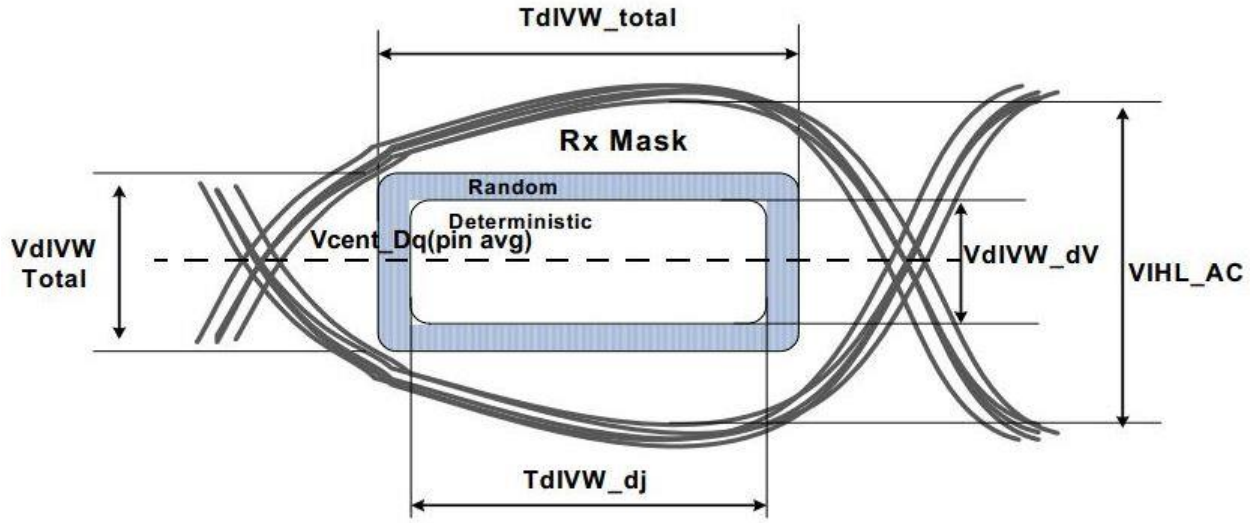
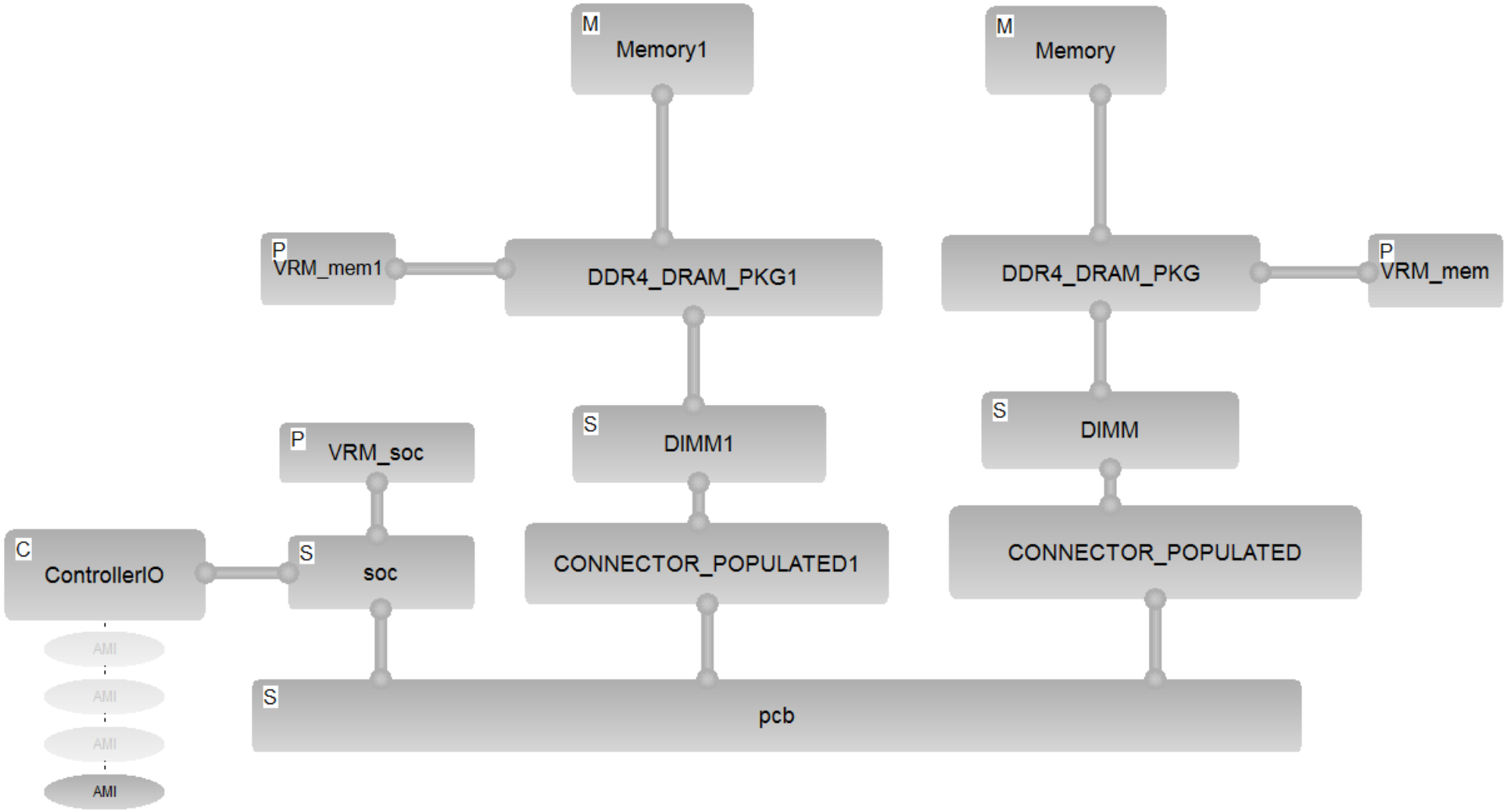
- ***Applying IBIS-AMI to DDR applications***

DDR4 Brought Some New Requirements

- Specified DQ mask compliance checking at a particular BER
- BER analysis requires extrapolation (bathtubs)
- Extrapolation requires a lot of traffic to be passed (need a lot of samples)
  - Channel simulation can be applied
- Started to see equalization used at Controller side
  - AMI modeling can be applied
- Worked with IP division to develop AMI model for DDR4 IP



Simulation Testbench

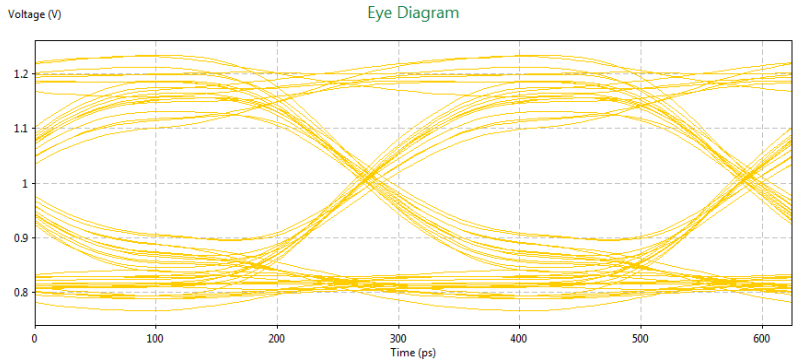


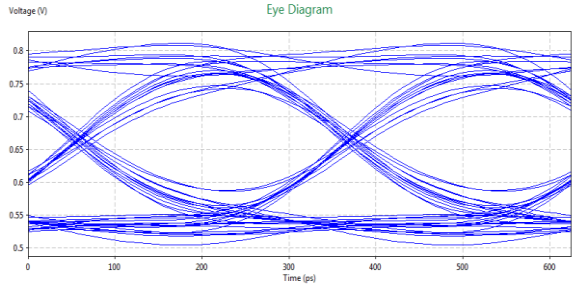
CTLE Correlation: 3200Mbps

Input of receiver @pad

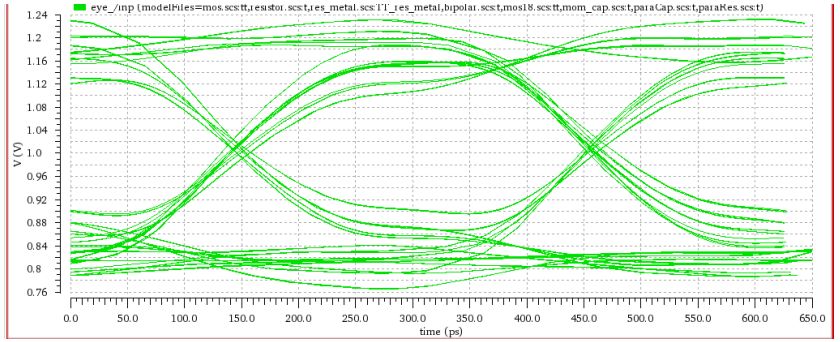
Output of CTLE

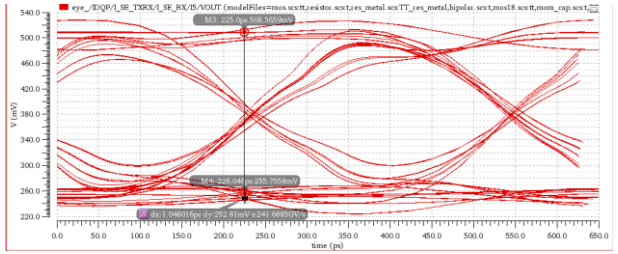
IBIS-AMI channel sim





Transistor-Level circuit sim





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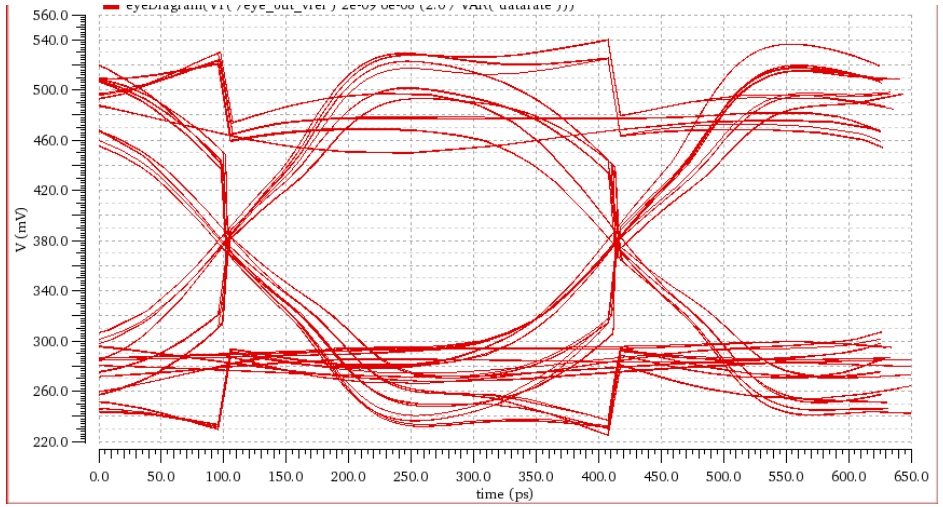
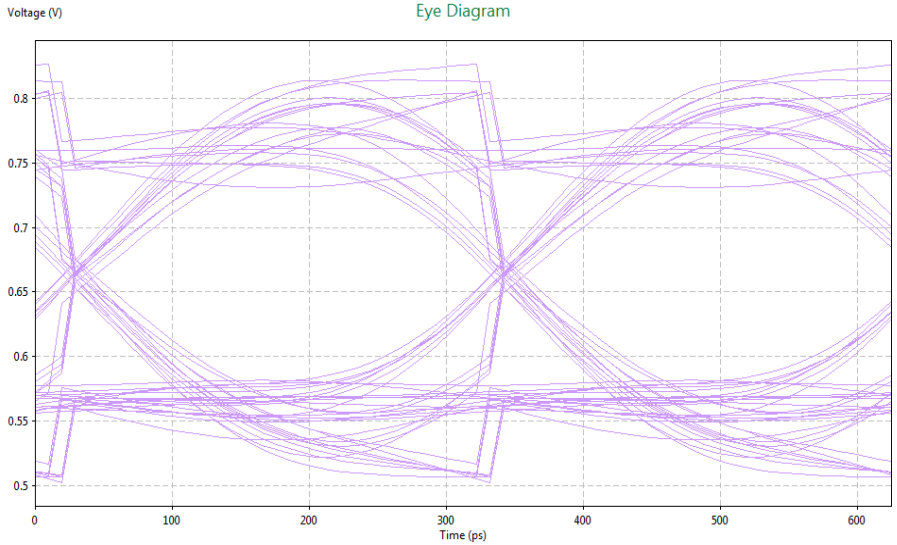
CTLE + DFE Correlation: 3200Mbps



Transistor-Level circuit sim



IBIS-AMI channel sim

Summary

- External Model syntax can be very useful for pre-design modeling, when detailed IBIS models are not available, and has had some recent additions in capability
- Building IBIS-AMI models is not the obstacle it used to be
- Adaptive equalization often has interplay between multiple sub-modules in real devices, and therefore also in AMI models
- If adaptive, understand if your EQ coefficients converge during simulation
- Backchannel training enables interplay between the Tx and Rx in simulation, and can produce more realistic results for devices that use backchannel
- Channel simulation and AMI modeling has been successfully applied to DDR4 IP (and more of this is expected with DDR5)