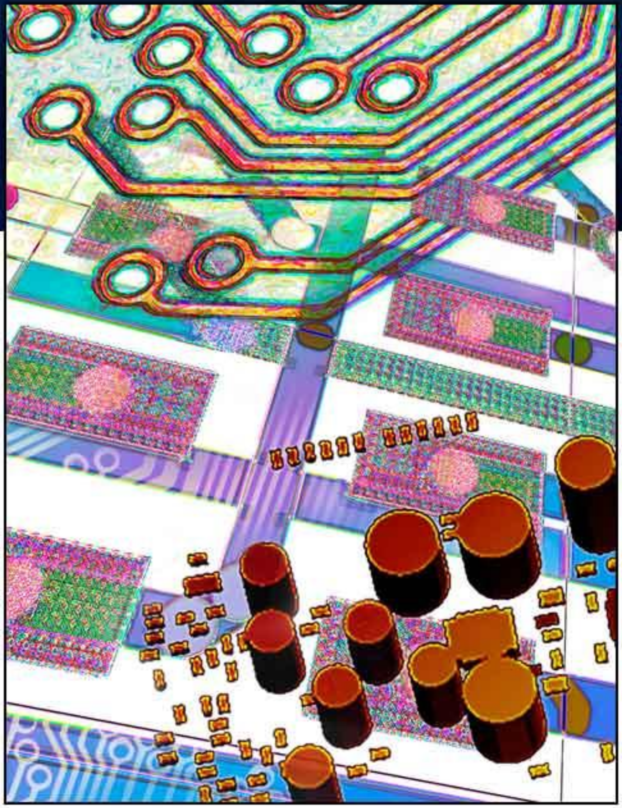

Analyzing Crosstalk's Impact on BER Performance: Methods and Solutions

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Topics

- Introduction
- The solutions best to be implemented in channel analysis environment
  - Correctly predict channel behavior
- Discussions on channel crosstalk responses
  - How to generate crosstalk response
  - How to include crosstalk response in time-domain and statistical analysis during channel simulation
- Simulation algorithms on channel crosstalk
  - Synchronous and asynchronous methods
  - Comparisons of advantages and limitations

Introduction

What is happening in high speed design world?

- In 2008, most of I/O interface works at the rates of 5 to 6Gbps
  - PCI Express Gen2 at 5Gbps for computer I/O buses
  - Optical Internetworking Forum (OIF) at 6Gbps for network communication
  - Serial Advanced Technology Attachment (SATA) III/SAS II at 6Gbps for storage area networks
- The following generation standards support data rates from 8 to 11Gbps
  - IEEE 10G Ethernet
  - PCIe Gen3 (8.0 Gbps) for computer I/O buses
- Data rates are approaching 20Gbps in 2015
  - According to the International Technology Roadmap, data rate of serial links doubles every 2-3 years
- New IEEE standard specifies design requirements for data rates at 25-28Gbps
  - See papers about 25-28Gbps designs from DesignCon in recent years

Facing the challenges

- Can the current device models accurately describe the behavior of SERDES components at data rates of 5Gbps or higher?
- Are the interconnect models accurate to capture material behaviors at high frequencies?

New device modeling methodology

- Recall why IBIS standard was introduced
  - Need a set of standard data to create behavioral models to
    - represent actual IO behaviors with reasonable accuracy
    - simplify interconnect simulation at boards level
      - Simulation of transistor based IO models with interconnects are very time consuming
    - protect circuit design knowledge from IC companies
  - Different simulators can use the same set of data
- Previous versions of IBIS show limitations in modeling advanced SERDES devices, but the original requirements to introduce and enhance IBIS standard remain unchanged
  - IP protection, interoperability, fast simulation for system interconnects

New device modeling methodology

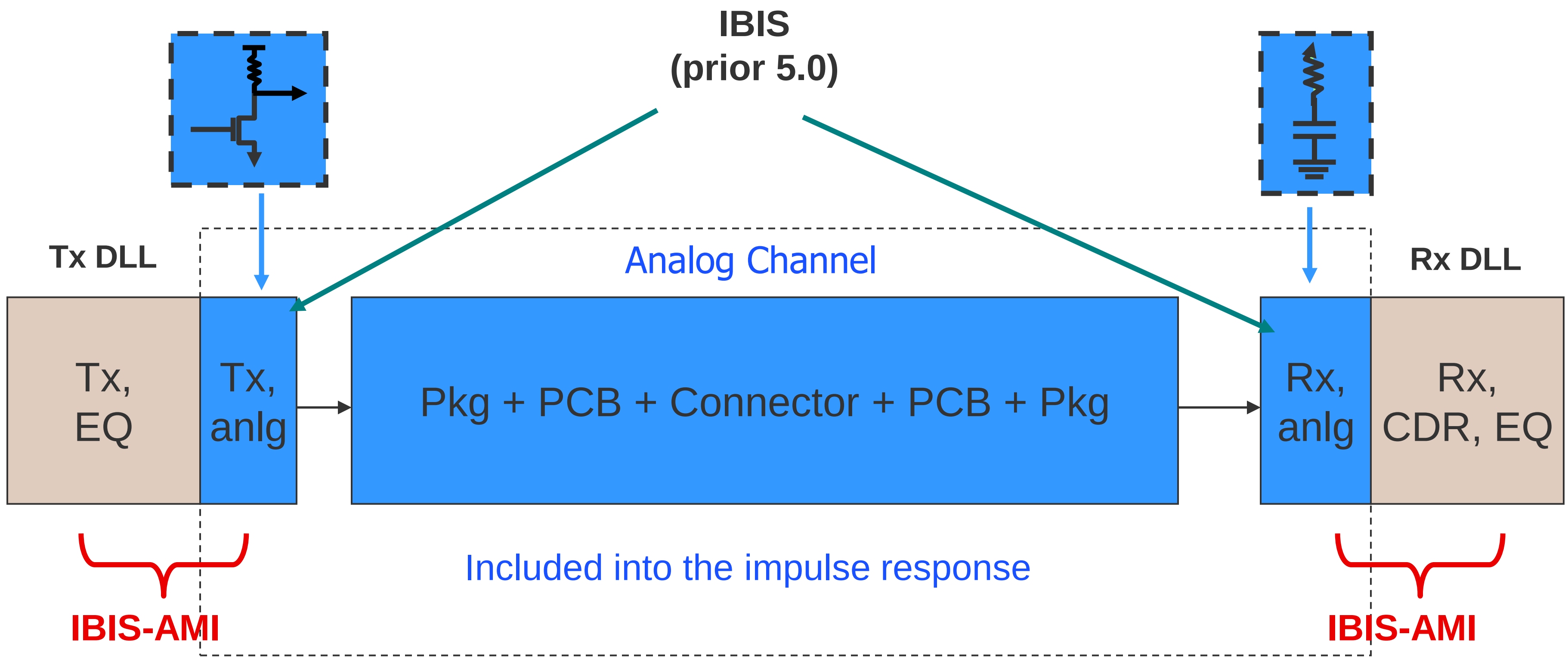
- Algorithmic Modeling Interface (AMI)
  - The method used by EDA tools to link compiled Algorithmic Models dynamically with IBIS buffer models and interconnects of a channel of SERDES design
    - DLL
    - Shared Object
- Best practice: making AMI as a standard

Algorithm Modeling Interface - IBIS 5.0

- Original proposal submitted in June 2006
- Reviewed and updated proposed AMI API working with IP vendors, EDA vendors and systems companies
- Progress in standardization
  - IBIS 5.0 approved on Aug 29, 2008
    - http://eda.org/pub/ibis/ver5.0/ver5_0.doc
  - IBIS 5.0 Parser available since December 2009
  - IBIS ATM committee continues to make the standard complete and fit into design and simulation flows
- AMI interoperability kits available on IBIS website to kick-start modeling process and to perform interoperability test
  - http://www.vhdl.org/pub/ibis/macromodel_wip/

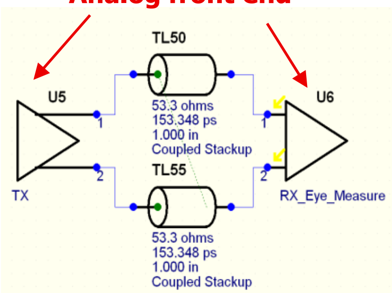
AMI in IBIS 5.0 – Channel model

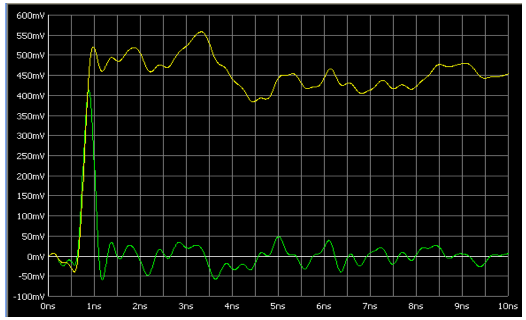
- IBIS-AMI: circuit models plus algorithmic models



Data flow of IBIS-AMI

Analog front end





Convolution with algorism models

Convolution in EDA tool

$h_{AC}(t) \otimes h_{TEI}(t) \otimes h_{REI}(t) \otimes b(t) \otimes p(t)$

$h_{AC}(t) \otimes h_{REI}(t) \otimes b(t) \otimes p(t)$

$h_{AC}(t) \otimes h_{TEI}(t) \otimes b(t) \otimes p(t)$

$h_{AC}(t) \otimes b(t) \otimes p(t)$

Tx GetWave call

$g_{TEG}[\, h_{AC}(t) \otimes h_{TEI}(t) \otimes h_{REI}(t) \otimes b(t) \otimes p(t) \,]$

$g_{TEG}[\, h_{AC}(t) \otimes h_{REI}(t) \otimes b(t) \otimes p(t) \,]$

$g_{TEG}[\, h_{AC}(t) \otimes h_{TEI}(t) \otimes b(t) \otimes p(t) \,]$

$g_{TEG}[\, h_{AC}(t) \otimes b(t) \otimes p(t) \,]$

Rx GetWave call

$g_{REG}\{\, g_{TEG}[\, h_{AC}(t) \otimes h_{TEI}(t) \otimes h_{REI}(t) \otimes b(t) \otimes p(t) \,] \,\}$

$g_{REG}\{\, g_{TEG}[\, h_{AC}(t) \otimes h_{REI}(t) \otimes b(t) \otimes p(t) \,] \,\}$

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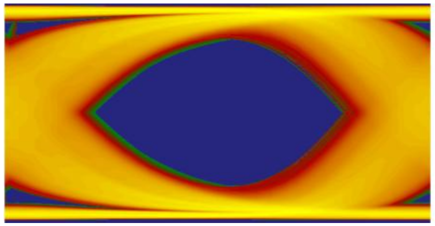
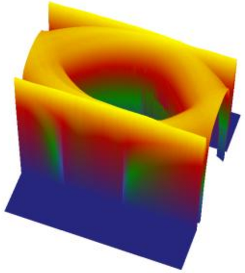
Responses of entire channel

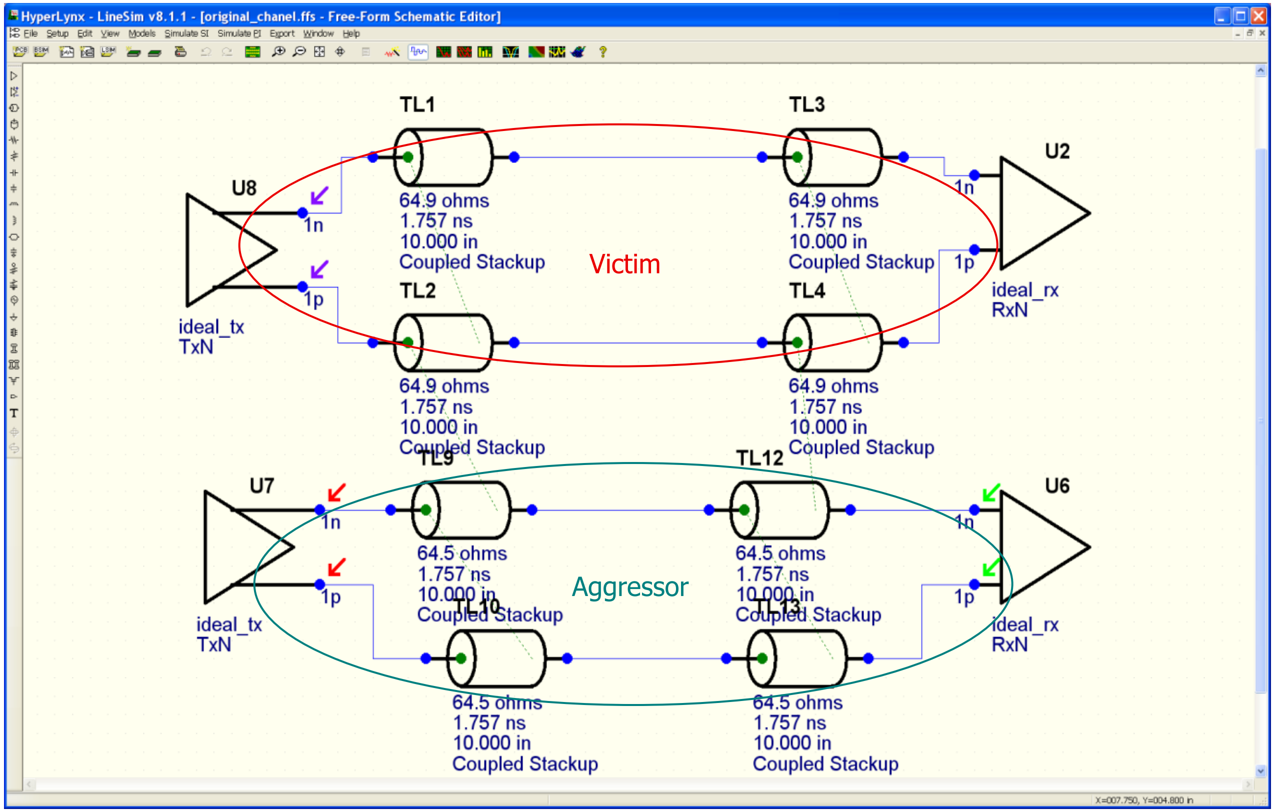




Channel coupling

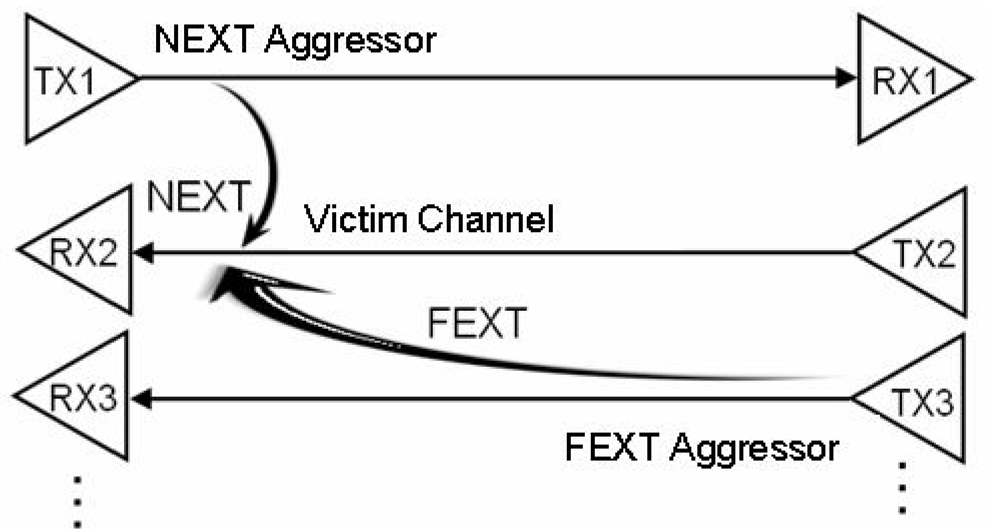
Multi-channel examples

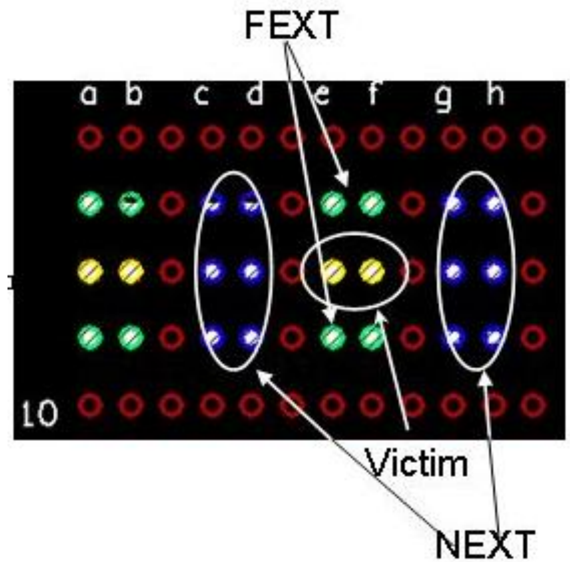
- Sample



General user requirements

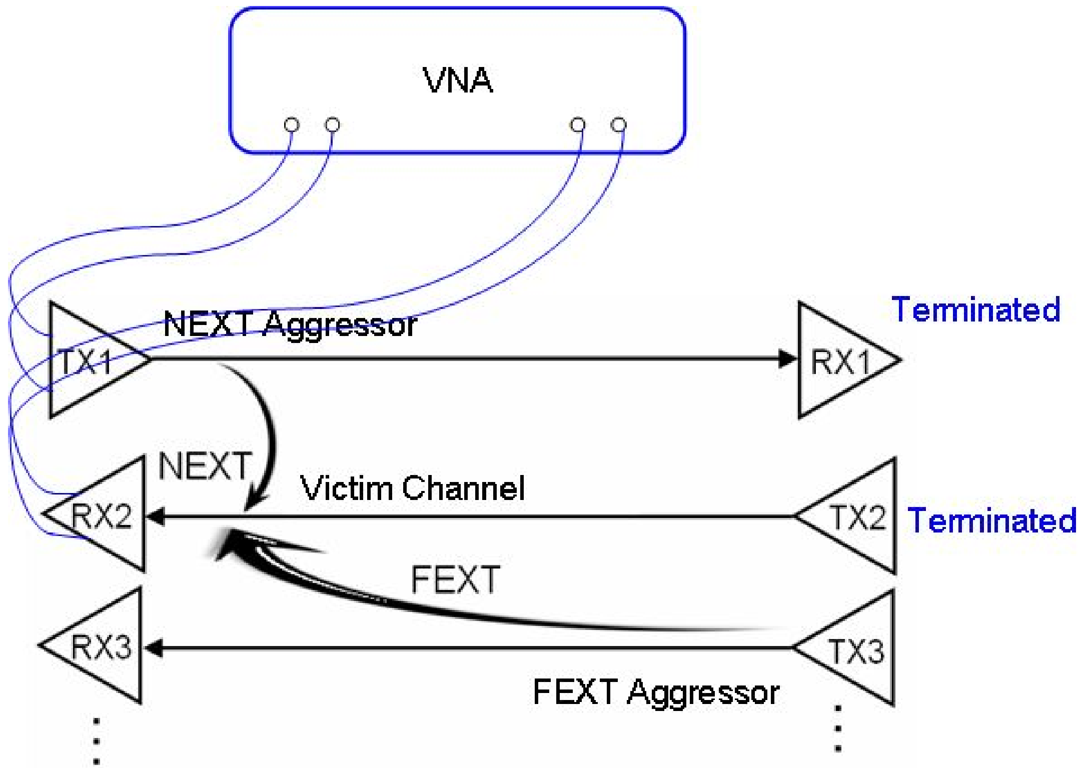
- Coupling effects from multiple channels (aggressors)
  — With signals being transferred in both directions
- Tx and Rx of all the channels are represented by IBIS-AMI models





Practice of channel crosstalk measurements

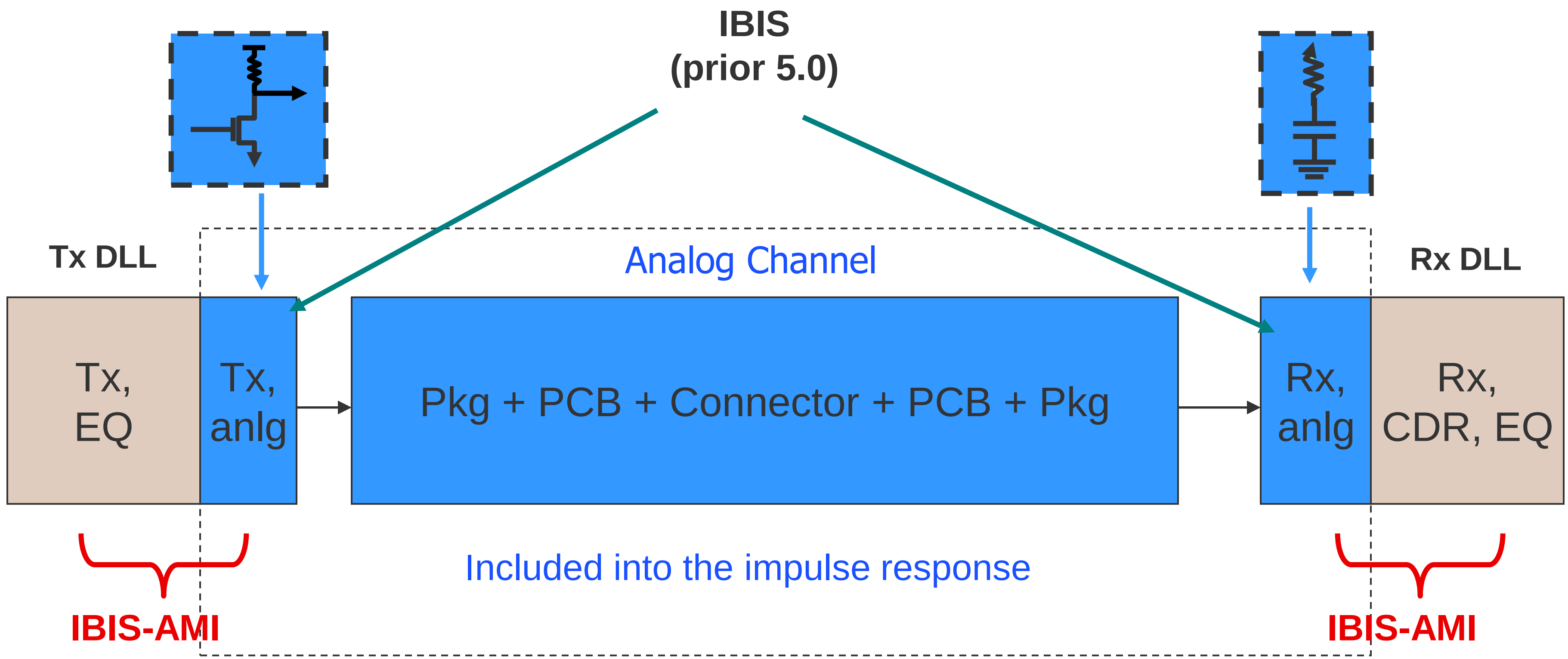
- Channel models for both victim and aggressors are measured s-parameters in .s4p files
  - In general, there are N + 1 .s4p files with one as victim model and rest as crosstalk models
- The channel simulation tool should perform simulation on the victim channel with aggressors' effects included



Characterizing coupled channels

Channel responses

- Same methodologies used for victim channels and aggressors



Generating crosstalk responses

- Two approaches to generate the crosstalk responses in time domain
  - The first approach
    - Assumes linearity of the output (or input) characteristic of a driver (or receiver) to be linear
      - With known corresponding impedance
    - Produce the transfer function of crosstalk in frequency domain from one channel input to another probing point
    - This transfer function is later converted into time domain response through iFFT
  - The second approach
    - Considers the non-linearity of a driver (or receiver)
      - Channel termination conditions may be unknown
    - Conduct characterization with time domain simulation

Simulation methods of channel crosstalk: synchronous and asynchronous

Possible choices of crosstalk simulation methods

- Synchronous time-domain crosstalk
- Synchronous statistical crosstalk
- Asynchronous time-domain crosstalk
- Asynchronous statistical crosstalk

Synchronous method

- Assumptions
  - Constant phase of transitions
    - between different crosstalk channels
    - between every crosstalk and signal channel
- BER description

$$P_{xtalk\_i} = P(V,t), i = 1,2,\ldots$$

- Advantage
  - Able to consider the effects from many fine causes
    - Such as mutual delays between rising/falling edges in different channels
- Limitations
  - Requires many parameters to be specified
    - Including the input pattern and encoding, and possible jitter distribution

Asynchronous method

- Assumptions
  - Phases in different channels are statistically independent
    - May have arbitrary relationship with respect to each other and to the clock of the signal channel
- BER description

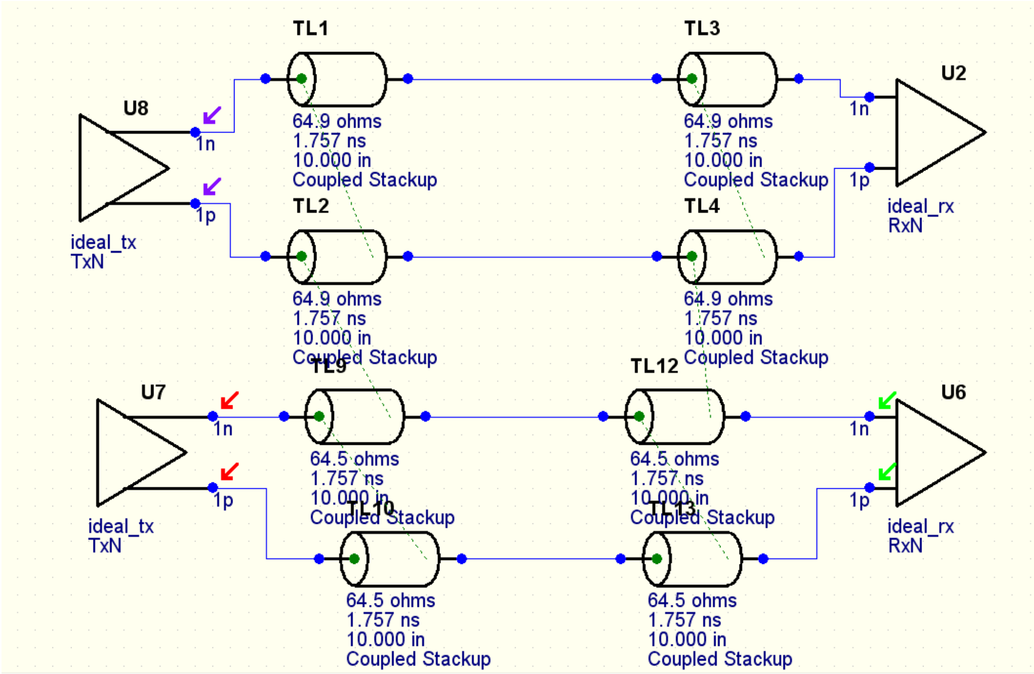
$$P_{xtalk\_i}(V) = \frac{1}{T}\int_0^T P(V,t)dt, i = 1,2,\ldots$$

- Advantages
  - Phases in different channels are statistically independent
- Limitations
  - Crosstalk effect on the final eye diagram becomes averaged out along the unit UI

Analysis examples and discussions

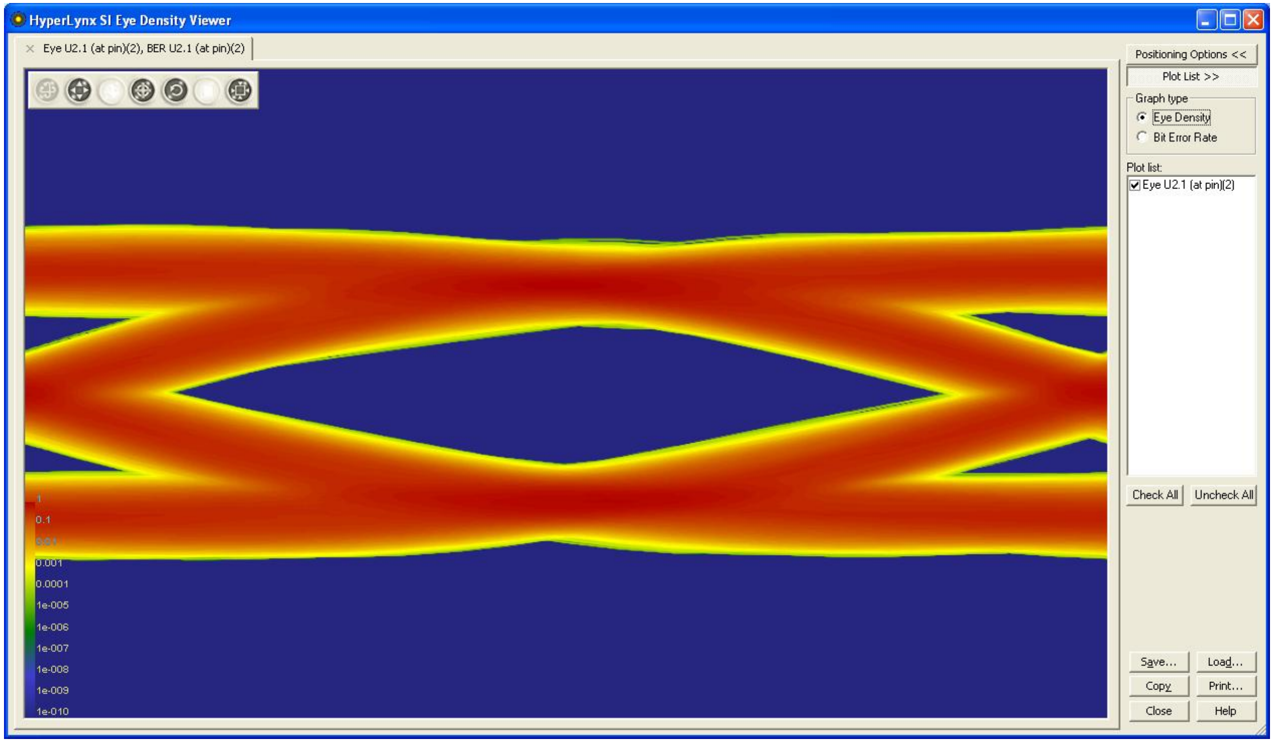
Coupled channels

- Sample topology



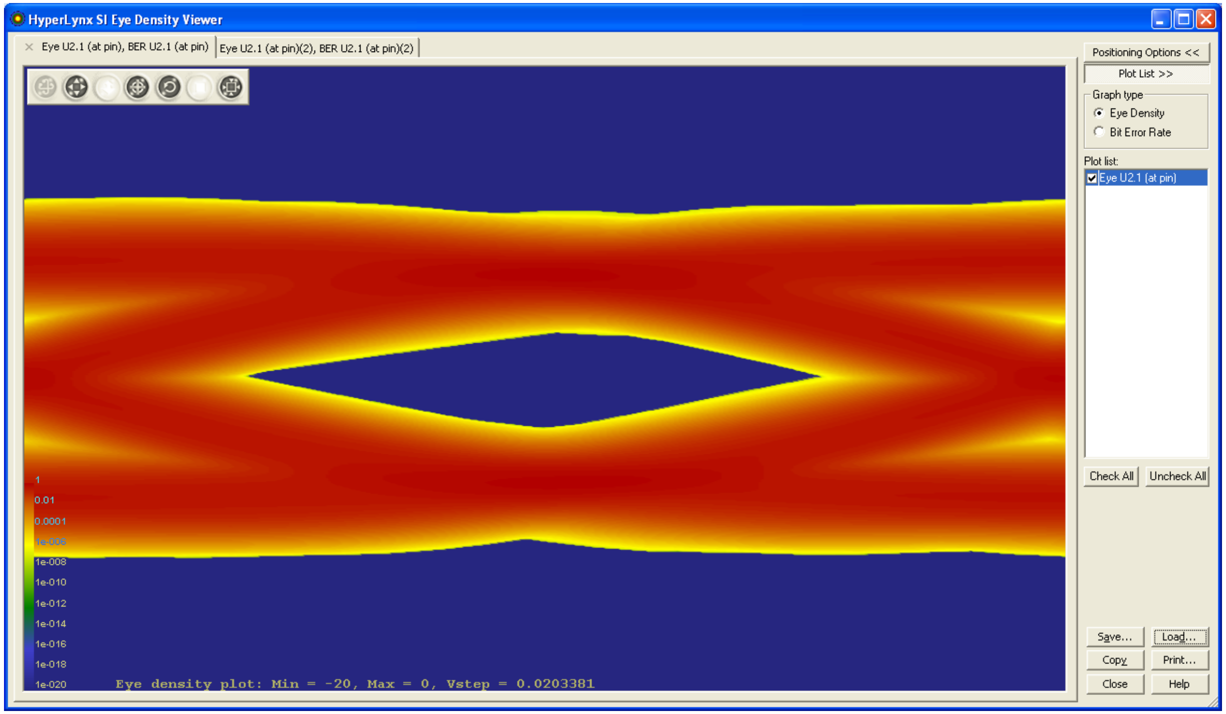
Crosstalk effects simulated with different approaches

- No crosstalk effect included in simulation



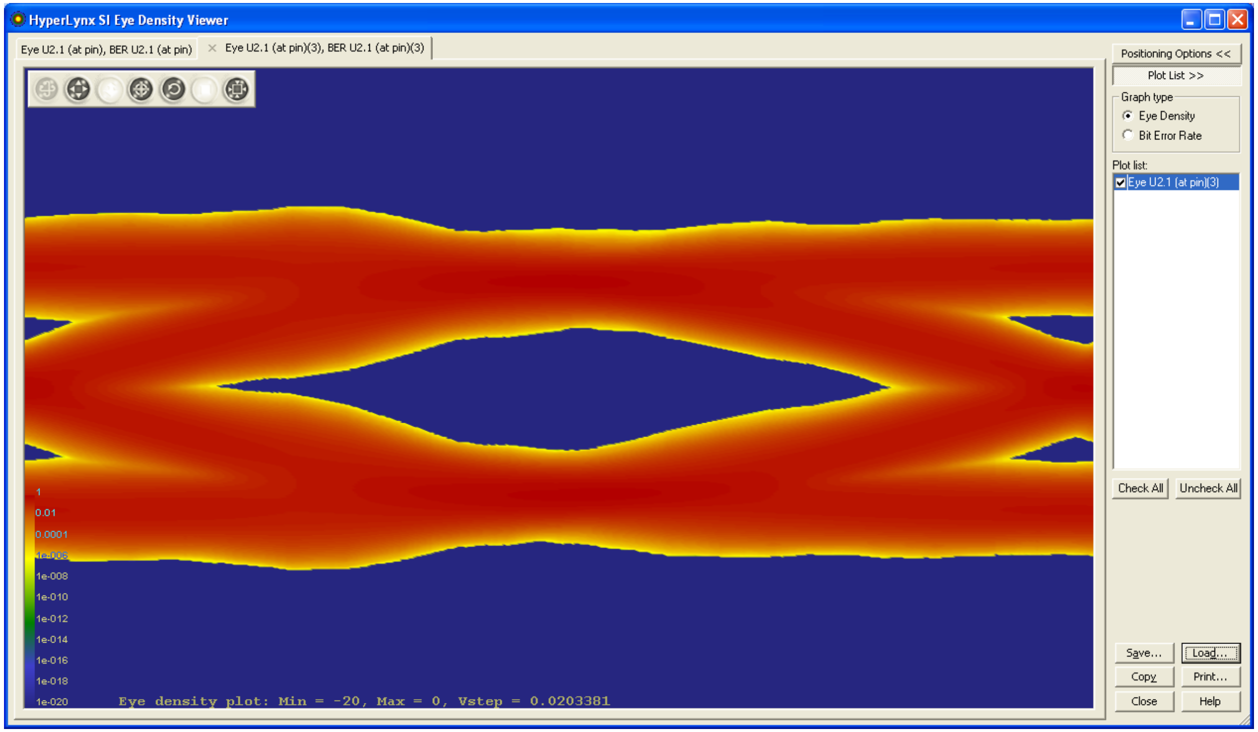
Crosstalk effects simulated with different approaches (cont')

- Using statistical asynchronous approach



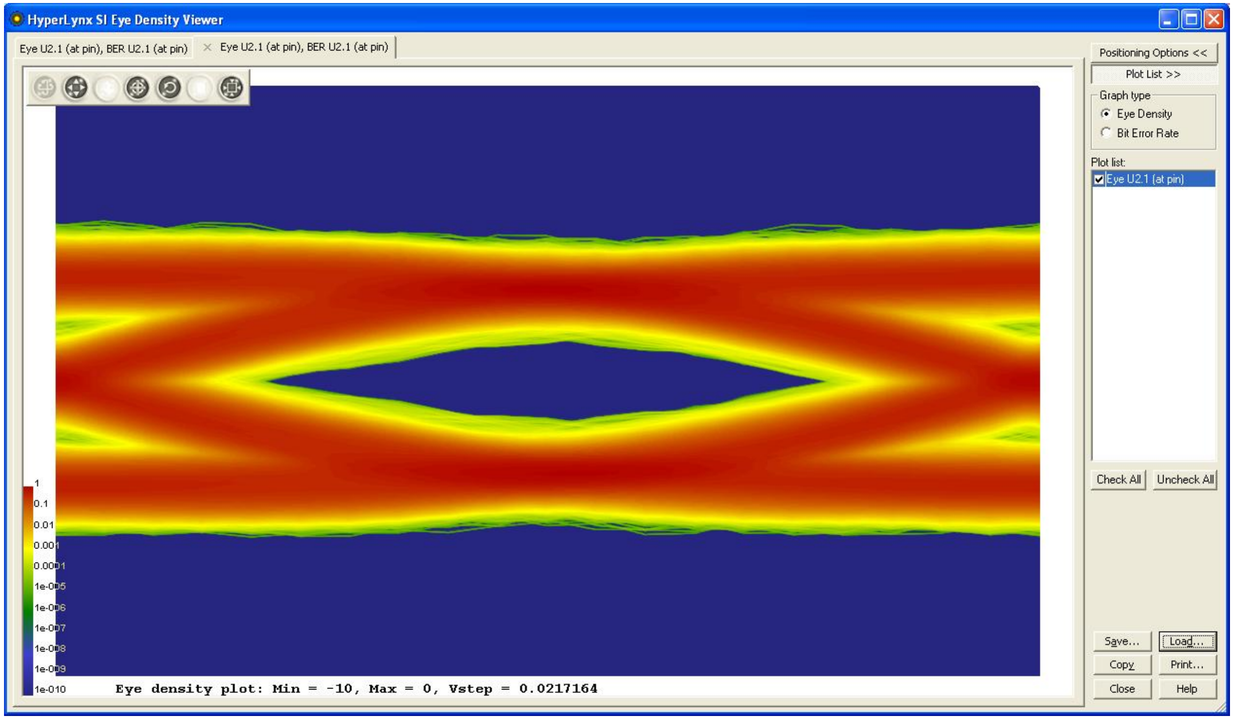
Crosstalk effects simulated with different approaches (cont')

- Using statistical synchronous approach



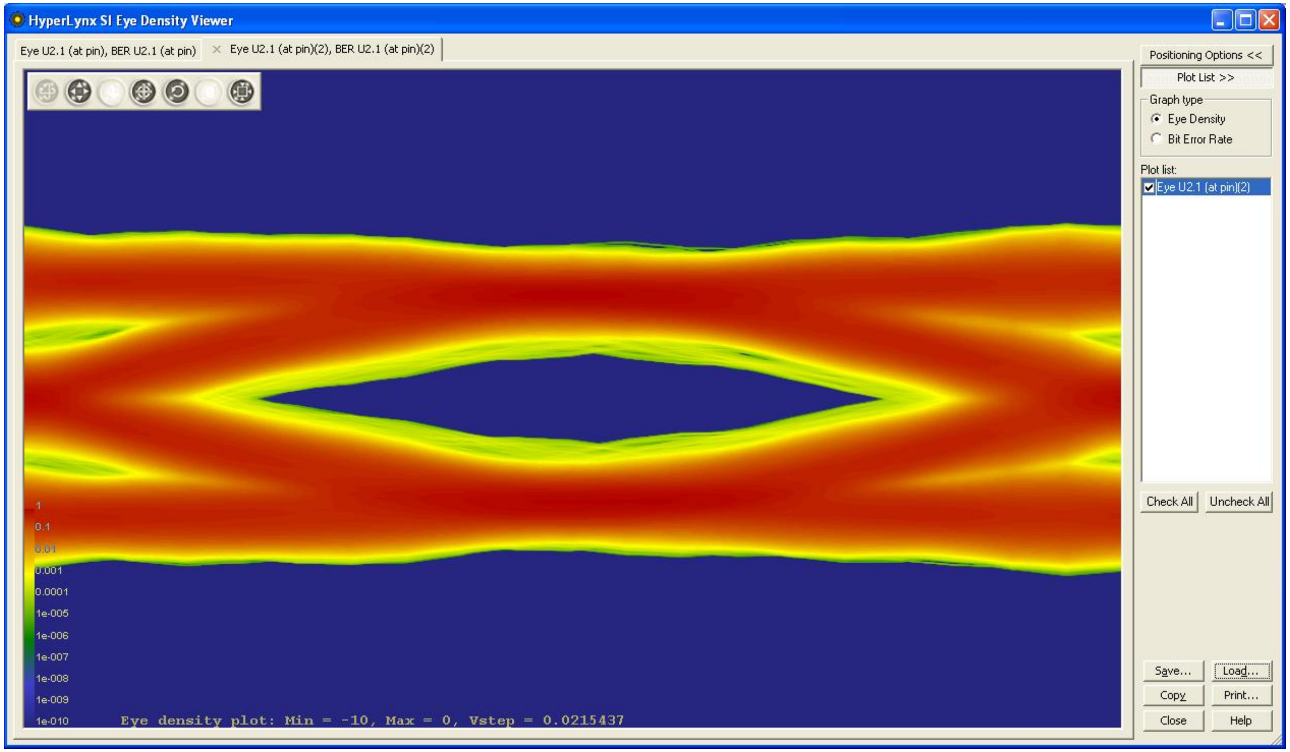
Crosstalk effects simulated with different approaches (cont')

- Using time domain asynchronous approach



Crosstalk effects simulated with different approaches (cont')

- Using time domain synchronous approach



Summary

Conclusions

- It is important to understand the advantages and limitations of using multiple 4-port S-parameter models in channel study
- For the two simulation approaches on channel crosstalk, either of the synchronous nor asynchronous method is perfect
  - The decision of using one of the methods can be design-dependent
- The information provided by each method helps designers understand the behavior of coupled serial links
  - Guide designers in high-data rate channel designs

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