SerDesDesign.com Example Tx Circuit Black Box Model 2020/02/13

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About SerDesDesign.com

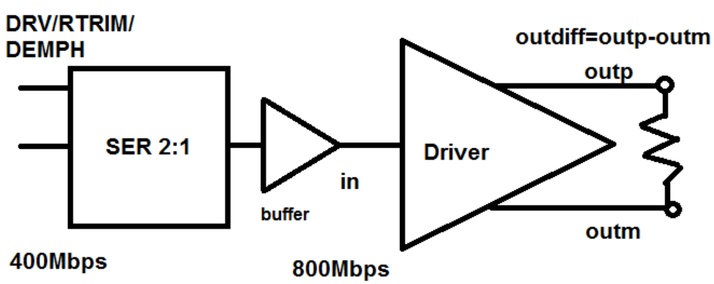
- Focused on Cloud based behavioral modeling and simulation of multi-gigabit high speed digital (HSD) integrated circuits (ICs) used in serializer/deserializer (SerDes) channels/systems.
- Features: Details at IntroductionToSerDesDesign.com
  - Free and subscription-use of on-line tools.
  - Tools for creating custom SerDes system IBIS-AMI models and SystemVue models.
    - IBIS-AMI models are portable for use in any standards compliant SerDes system channel simulator.
  - Consulting and training for custom IBIS-AMI modeling.
- SerDesDesign.com provides quick, efficient, accurate and cost effective modeling for SerDes systems.

What this training is and is not:

- First what this training is not:
  - Not focused on understanding SerDes systems in general.
  - Not for understanding details in SerDes system modeling.
  - Not an introduction to Channel Simulation or the IBIS-AMI standard.
  - Not an introduction to SerDesDesign.com
- What this training is:
  - The training is focused on modeling and testing SerDes system applications using tools on SerDesDesign.com.
  - The Tx circuit is presumed to be an FFE for use with NRZ data
  - The Tx circuit black box model is based on input/output waveforms.
  - The objective is to give SerDesDesign.com users an understanding on how to model a SerDes Tx circuit using SerDesDesign.com tools, generate an IBIS-AMI model for their Tx circuit, and use the generated IBIS-AMI model in the SerDesDesign.com Channel Simulator.

Modeling a Tx Circuit as a Black Box

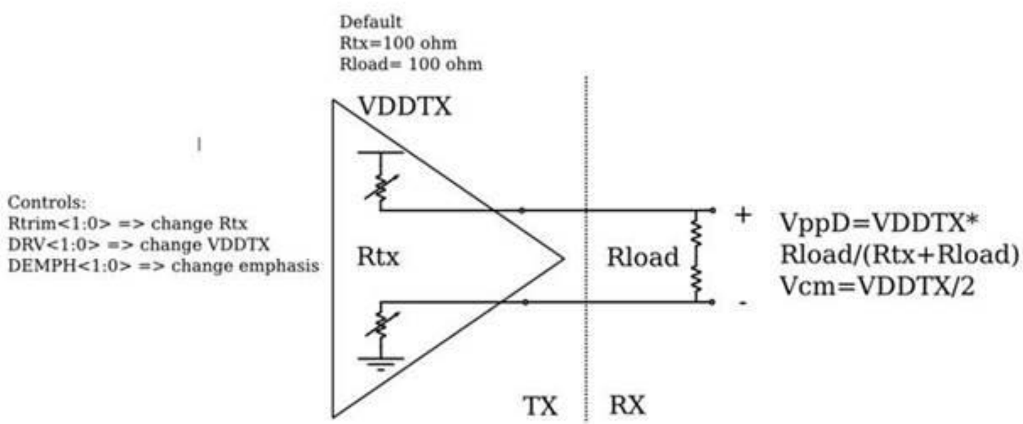
- The Tx circuit of interest is used for low voltage differential signalling (LVDS), contains a 2-tap feed forward equalizer (FFE) and is to be modeled as a black box.
- A 2 tap FFE Tx circuit is defined as shown in this figure.



- The bit rate can range from 0.8 Gbps to 6.4 Gbps for NRZ signals.
- The driver is defined for three corner cases: Typical, Slow, Fast.
- The driver is defined from points marked ‘in’ to ‘outdiff=outp-outm’.
- The driver is modelled as a block box by collecting waveforms from ‘in’ to the differential output ‘outdiff’ with load Rload = 100 Ohms.

Example Tx: Black Box Driver

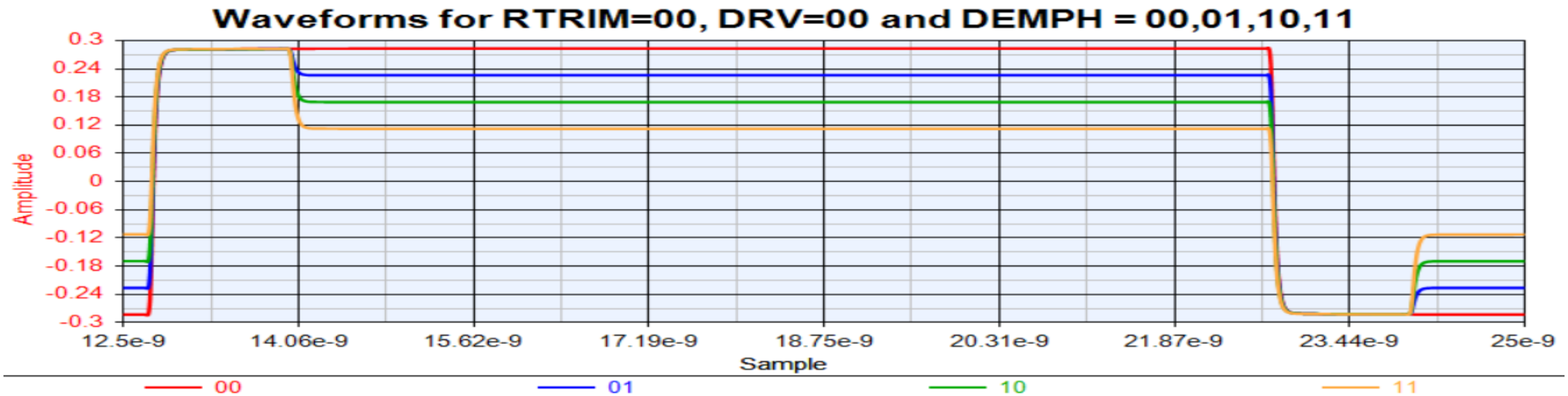
- This driver circuit is defined in the following figure.



- The driver has these controls:
  - RTRIM <1:0> two bits that define the nominal output resistance Rtx/2 for each pin.
  - DRV <1:0> two bits that define the driver swing voltage level VDDTX.
    - '00'=0.4V; '01'=0.48V; '10'=0.56V; '11'=0.64V
  - DEMPH <1:0> two bits that define the emphasis level.
    - Emphasis ranges 0 dB to approx 9 dB dependent on values for RTRIM, DRV and DEMPH.
- The actual Rtx is dependent on RTRIM and the data provided (4 states per corner case).

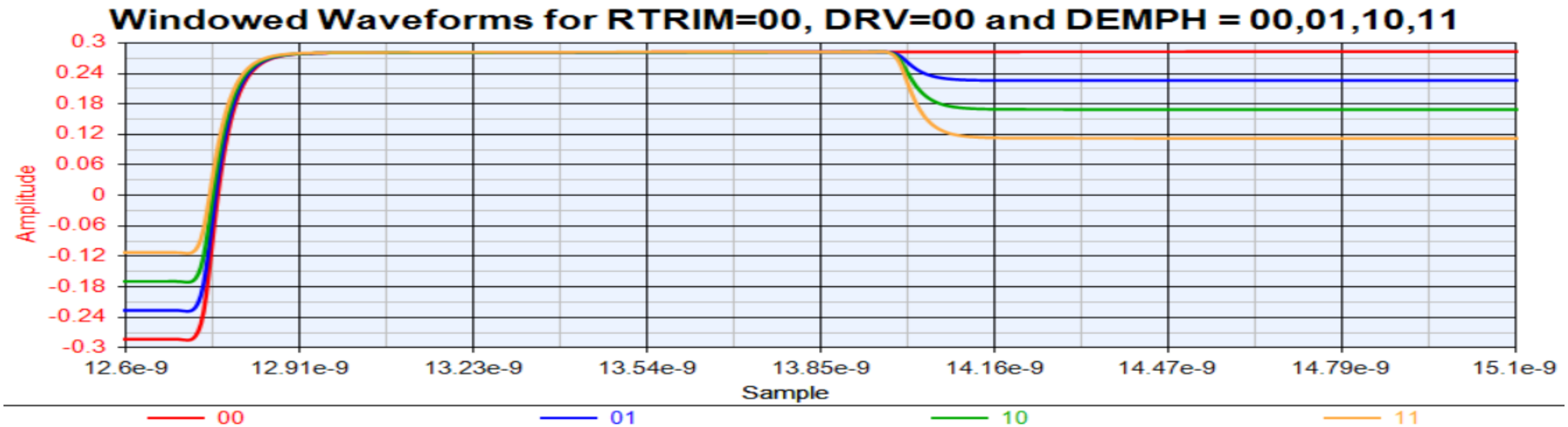
Example Tx: Black Box Waveforms

- The output response waveforms can be captured over the full set of driver states:
  - 4 RTRIM * 4 DRV * 4 DEMPH = 64 waveforms for each corner case.
- Waveform capturing requirement:
  - Use the lowest bit rate: BR = 0.8 Gbps in this case
  - Set constant time step: Tstep = 1/(highest bit rate)/32 = 4.8828125e-12 in this case
  - Require an integer value for: (1/BR)/(1/Tstep) = 256 in this case
  - Use repeating NRZ waveform with N 0's and N 1's; in this case N = 8
- Waveforms are displayed for RTRIM=11, DRV=11 and all 4 DEMPH states.



Example Tx: Black Box Waveforms

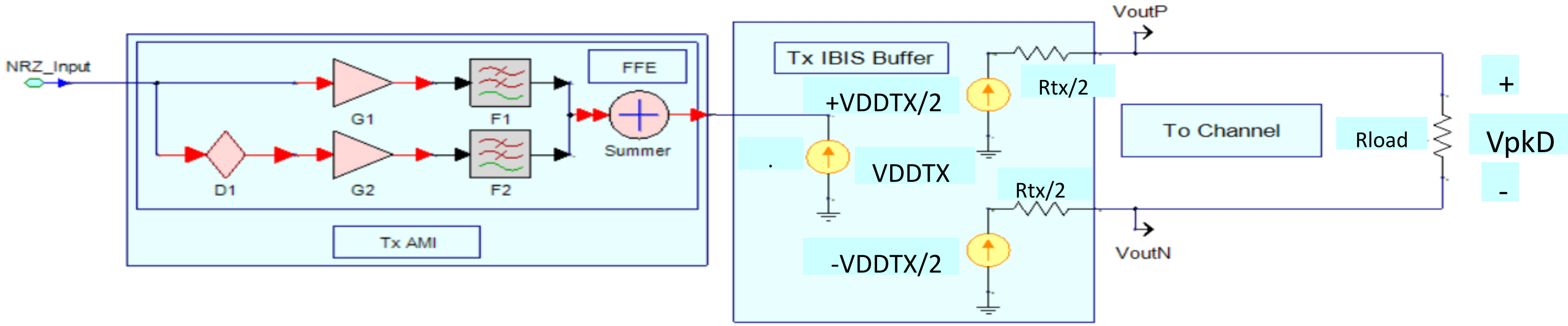
- Data from the waveforms are collected from a Tstart to Tstop = Tstart+2 UI.
  - Tstart is set to just when the rising edge starts.
  - In this case, Tstart was set to 12.6e-9.
  - In this case, Tstop = Tstart + 2 UI = 15.1e-9 where 2 UI = 2.5e9



- Group data into one file for each RTRIM setting (4 files for each corner case) with 17 columns with this ordering:
  - Time, (DRV 00, DEMPH 00), (DRV 00, DEMPH 01), (DRV 00, DEMPH 10), (DRV 00, DEMPH 11), …, , (DRV 10, DEMPH 11), (DRV 11, DEMPH 00), (DRV 11, DEMPH 01), (DRV 11, DEMPH 10), (DRV 11, DEMPH 11)

Example Tx: Black Box Model

- The collected data has named files: RTRIM_<r>_Tx_Data_<c>.csv
  - Where <r> = 0, 1, 2, 3 and <c> = Typ, Slow, Fast; use CSV format
- This data is used to create the Tx IBIS-AMI model per this figure.



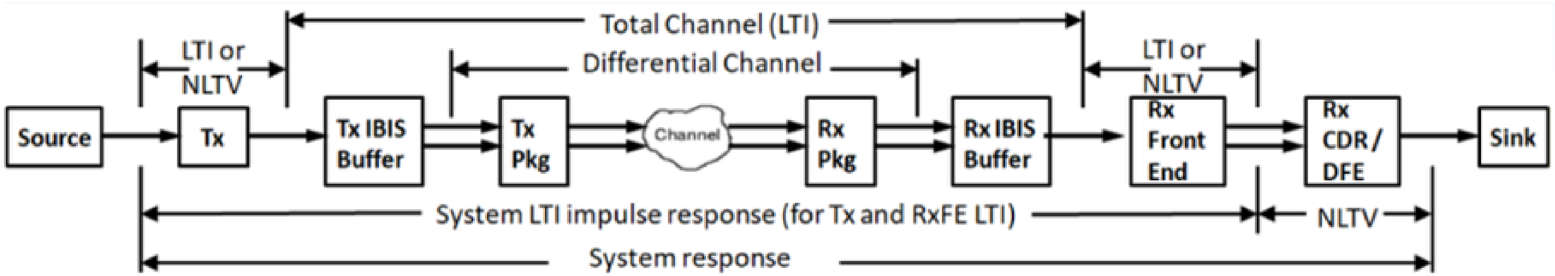
- The data represents the transfer function: NRZ input to Rload output.
- Tx IBIS buffer: derived from the data
  - Source resistance; Rtx/2 Ohms per output differential pin.
- Tx AMI: derived from the data with the IBIS buffer de-embedded.
  - G1, G1 are FFE gain blocks.
  - F1, F2 are filter blocks.
  - D1 is a 1 UI delay

Example Tx: Black Box IBIS Buffer

- From the collected data, the Rtx values are derived from the given relationships:
  - DRV -> VDDTX : ‘00’=0.4V ; ’01’=0.48V; ‘10’=0.56V; ‘11’=0.64V
  - Rload = 100 Ohms
  - VpkD = peak step response value; 1 UI (for 0.8 Gbps) after start.
  - VpkD = VDDTX * (Rload)/(Rload + Rtx)
- Tx IBIS Buffer uses VI tables [Pullup]/[Pulldown] to represent output resistance per pin (Rtx/2) for the differential output pair.
- The 4 states for Rtx/2 for each corner case are derived.
  - Rtx = Rload * (VDDTX/VpkD – 1)

Use the SerDes.com Channel Simulator

- **Single channel SerDes system:** serdes-system-single-channel-tool



- Source: NRZ or PAM4 data source
- Tx: Transmiter equalization; typically an FFE; see **Note** below.
- Tx/Rx IBIS Buffers: IBIS buffer to the differential channel; defines the on-die impedance; see **Note** below.
- Tx/Rx Pkg: Package characteristic defined in SnP files.
- Channel: SerDes channel defined in a SnP file.
- Rx Front End: Receiver equalization; typically a CTLE; see **Note** below.
- Rx CDR/DFE: Receiver timing/eq; typically a CDR and DFE; see **Note** below.
- **Note**: Can be a built-in model or a user defined IBIS-AMI model.

Tx Example: Setting the Model

- The Tx data can be used in the SerDesDesign.com Tx model.
- Set TransmitterType = 4; open the dialog box; set EnableFFEBlackBox = 1.
- Set the other Transmitter parameters as shown here:

Name	Description	Entry Value(s)
AdaptForChannel	Auto adapt to equalize the channel	0
NumStepResp	Number of step responses in data	16
EnableCorners	Enable corner cases	1
CornerCase	Corner case	0
DataColumnType	Data column type for file	1
StepRespDataFile	Step response data file (typical corner). Alpha-numeric or underbar; start with alpha	RTRIM_3_Tx_Data_Typ.csv Choose File No…n
StepRespDataFile_Slow	Step response data file (slow corner). Alpha-numeric or underbar; start with alpha	RTRIM_3_Tx_Data_Slow.csv Choose File No…n
StepRespDataFile_Fast	Step response data file (fast corner). Alpha-numeric or underbar; start with alpha	RTRIM_3_Tx_Data_Fast.csv Choose File No…n
EnableFFEBlackBox	Enable FFE step response data as a black box	1
Drive	Drive index value	3
PostCursor1	Post cursor 1 index value	3
NumPreCursor1	Number of pre cursor 1 values	0
NumPostCursor1	Number of post cursor 1 values	4
DataBitRate	Black box data symbol rate	0.8e9

Use the 'Choose File' button to upload the data files.

Tx Example: Set the rest of the system

- The initial tests are for the Tx only without a channel or receiver.
- Set ChannelType = 0:

ChannelType	Channel specification type	0

- Set ReceiverFrontEndType = 0

ReceiverFEType	Receiver front end type	0

- Set ReceiverCDRDFEType = 0:

ReceiverCDRDFEType	Receiver CDR/DFE type	0

- Set the BitRate and SamplesPerBit:

SymbolRate	Symbol rate (same as bit rate for NRZ)	0.8e9
SamplesPerSymbol	Samples per symbol (same as samples per bit for NRZ)	256

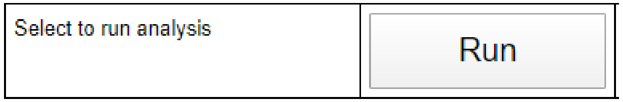
- Use the SetupOptions to use a NRZ stream with 8 repeating 1's and 0's collecting 100 symbols with zero ignore symbols.

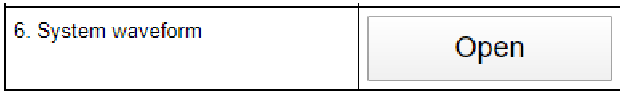
DisplaySourceType	Source type	1
DisplaySourceN	Source N value	8

DisplayIgnoreSymbols	Ignore initial output symbols (same as bits for NRZ)	0
DisplaySymbols	Symbols (same as bits for NRZ) to display after DisplayIgnoreSymbols	100

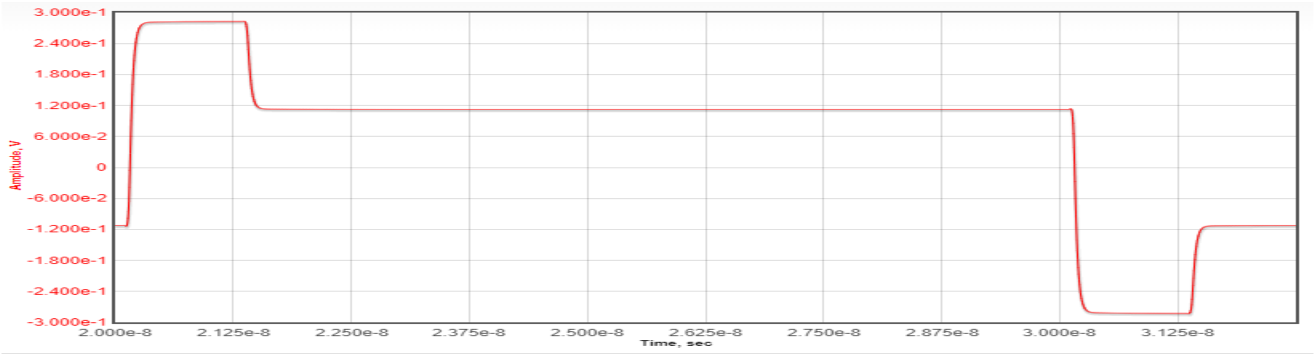
Tx Example: Observe the Model Data

- Run the Channel Simulation by selecting the ‘Run’ button.



- Open the System waveform: 

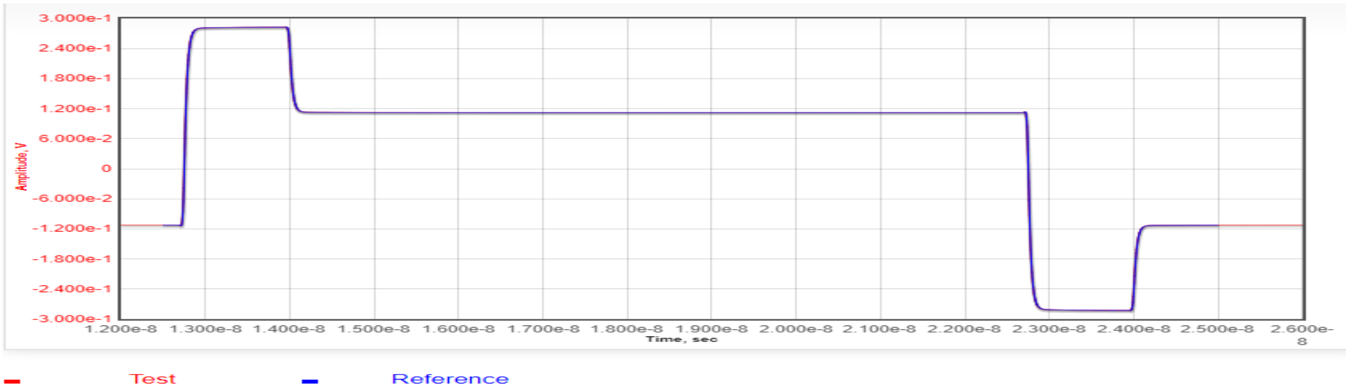
- Observe the that graph displays a waveform that agrees with the original data on slide 6 for DEMPH=‘11’, the yellow curve:



- This Tx model is usable at any BitRate in the range 0.8 Gbps to 6.4 Gbps at other SamplesPerBit for any of the three corner cases.

Tx Example: Validate the Waveform

- Compare the waveform against a reference waveform which might be generated from a Spice circuit simulation for example.
- A Spice based waveform file is available named:
  - outdiff_cr_tt_DR_0.8e9_drv_11_rtrim_11_demph_11.csv
- Use ‘Compare Waveform to Reference Waveform’, upload this file as WaveformReferenceFile.
- With proper setting of WaveformTimeOffset and WaveformVoltageOffset, the following display results after Run:



- As can be seen there is an exact match between Test and Reference

Tx Example: Use with a Channel

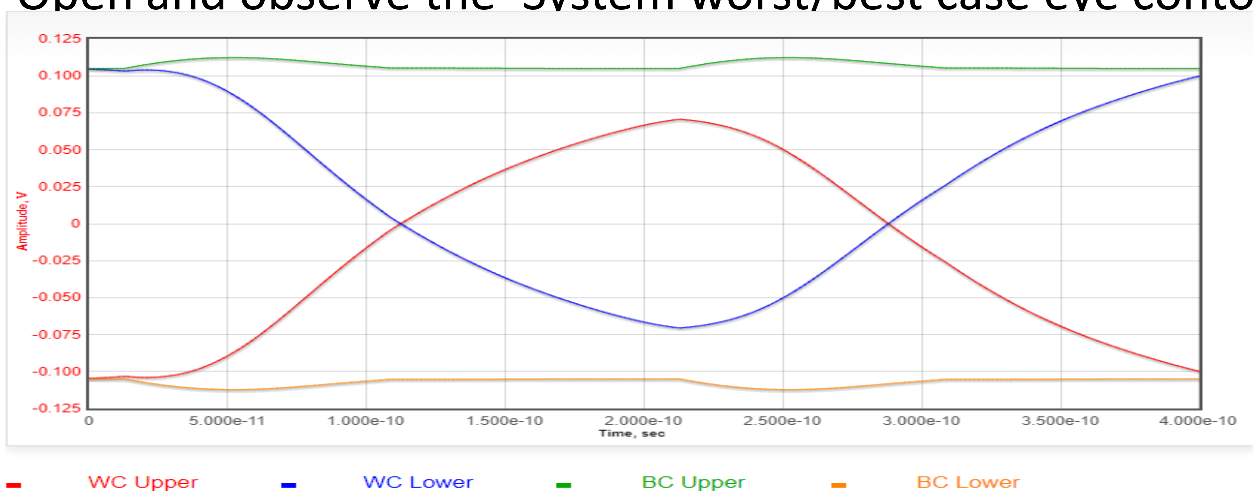
- Use default built-in channel; set ChannelType = 2; 7.6 dB loss at Nyquist.
- Set the Tx AdaptForChannel = 1.

AdaptForChannel	Auto adapt to equalize the channel	1

- Set BitRate = 5.0e9, SamplesPerBit = 32 and Run the Channel Simulator.
- Observe the message output from the Tx model:

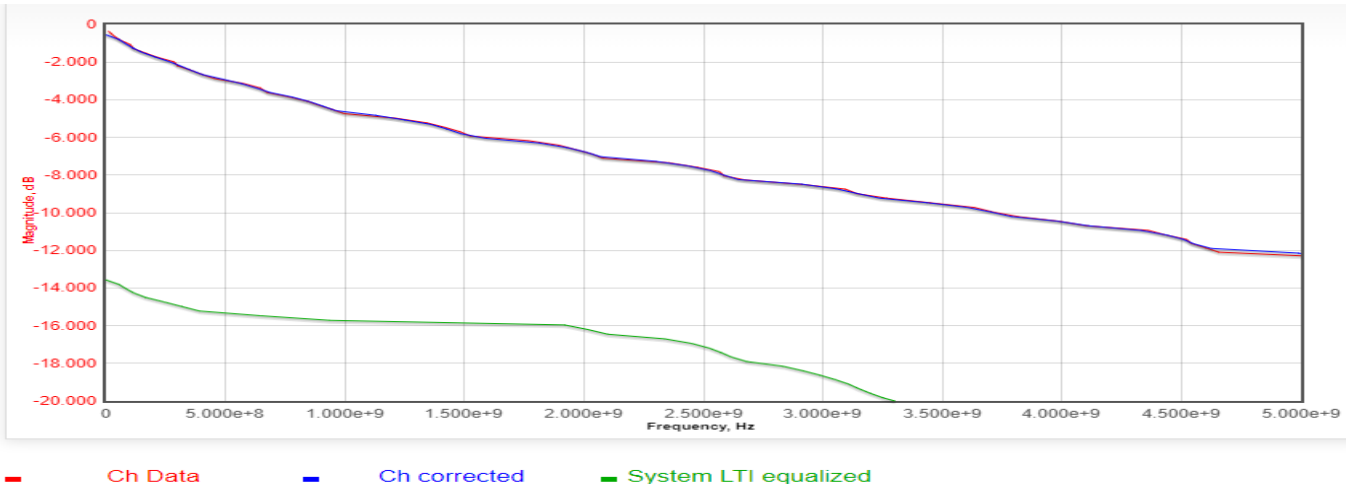
Generating Transmitter FIR based on step response data.
Adaptation of the channel+equalizer for best eye opening results in Tx_Drive = 0 and Tx_PostCursor1 = 2 with eye opening ratio = 0.62.

- This shows the DRV and DEMPH values selected for the optimal eye at the channel output.
- Open and observe the ‘System worst/best case eye contours’:



Tx Example: Observe the Spectrum

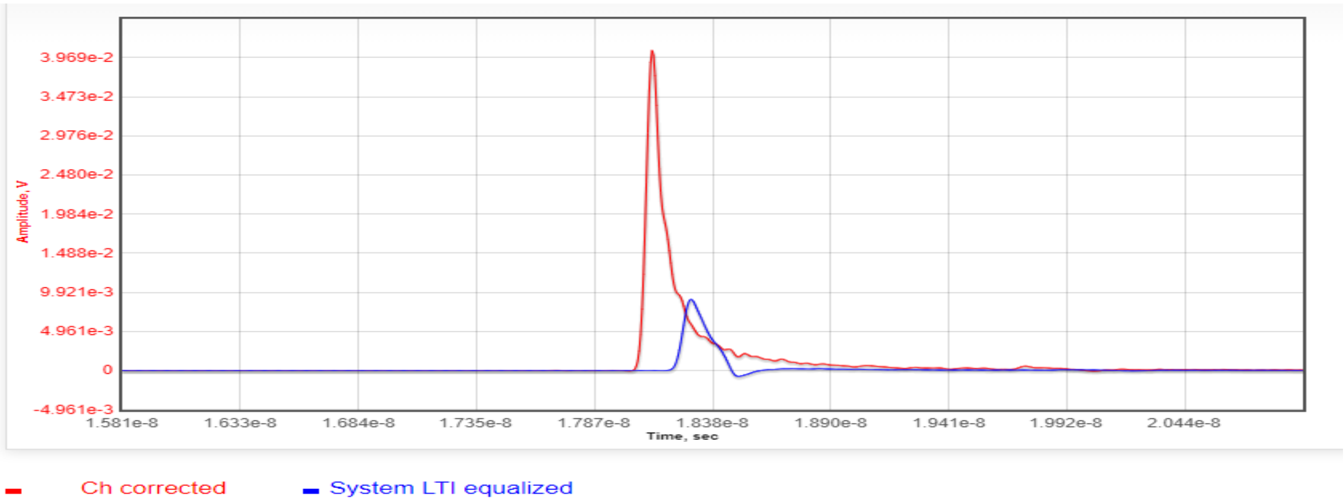
- Open the display for ‘Channel and System LTI spectrum magnitude’ and set the X-axis for display up to the bit rate.



- ‘Ch Data’ is the s21dd characteristic for the channel S-parameter data.
- ‘Ch corrected’ is the s21dd characteristic for the channel impulse model and tracks the S-parameter data.
- ‘System LTI equalized’ is for the Tx+channel and shows the effects of the Tx equalization.

Tx Example: Observe the Impulse

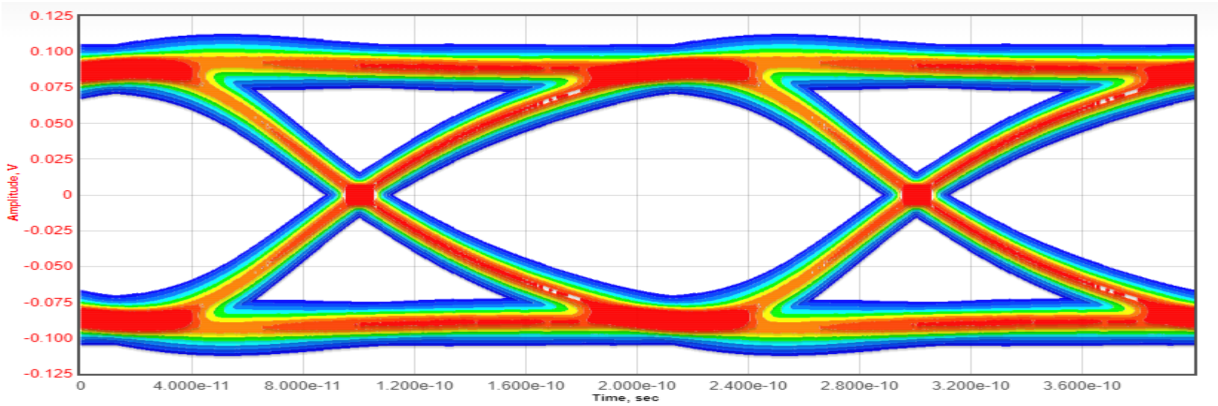
- Open the display for 'System LTI impulse magnitude'.



- 'Ch corrected' is for the channel h21dd impulse model.
- 'System LTI equalized' is for the Tx+channel and shows the effects of the Tx equalization.

Tx Example: Observe the Detail Eye

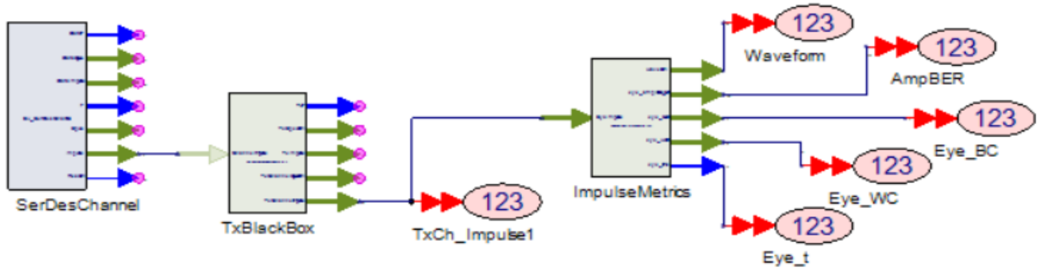
- Since the Channel Simulation saved a statistical data set from its analysis, that statistical data can be further post processed in the Eye Analysis tool to observe the detail eye analysis.
- Open the Eye Analysis Tool: eye-analysis-tool
- Set the ChAnalysisName to the AnalysisName used with the Channel Simulator and select Run.
- Open the Eye Analysis plot.



- The eye contours from prior page overlap this detail Eye plot.
- Additional metrics are available: eye width/height, BER and more

Define and use as a SystemVue model

- The Tx model in the prior slides can also be defined/used in SystemVue.
  - Use the SerDesDesign.com SystemVue add-on library (SerDesDesign).
- The SystemVue model SerDesDesign_TxBlackBox is used in this example.



- SerDesChannel: SV model that converts an SNP file
  - Impulse h21dd and s21dd response.
  - S-parameter data h21dd and s21dd response.
- TxBlackBox: SV model that converts input impulse.
  - Tx and Tx+Ch impulse and spectrum response.
- ImpulseMetrics: SV model that converts impulse to eye metrics:
  - Eye best and worst contours vs time (for 2 UI)
  - Waveform for defined bit source; Eye amplitude waterfall BER.

Define and use as a SystemVue model

- Same results in SystemVue as shown on SerDesDesign.com.
- SerDesEyeMetricsNRZ/PAM4: SV models that convert eye histogram data to eye metrics.
  - Ability to change the eye amplitude and timing slicing levels for BER analysis.
  - BER extrapolation for Bit-by-Bit analysis.
  - Outputs eye metrics: eye width, jitter rms, jitter p2p, more.
- Use of SystemVue models in SystemVue provides more flexible SerDes system topologies, Channel Simulations, displays, and pre- and post-processing.

Tx Example: Iterate Analyses

- The Channel Simulator and the Eye Analysis tools can be used to test various Tx Model and Channel configurations and observe eyes, BER results and more.
- When one is comfortable with the results obtained, one can then generate the Tx IBIS-AMI model – as discussed next.

Tx Example: Generate IBIS-AMI Model

- When one is ready, a Tx IBIS-AMI model can be generated.
- Use the Channel Simulator with 'Setup Analysis' GenerateModels = 1 to generate the Tx IBIS-AMI model for the defined analysis set up.
- When Run is selected, the analysis is run and the files needed to generate the Tx IBIS-AMI model are saved.
- The Analysis log file displays this message:

```
====================================================================================

You have requested that a Tx IBIS-AMI model be generated.

The files associated with this successful analysis have been saved with reference number:
user-37_1581871383

The saved files will be used to generate the IBIS-AMI models and for validation testing.

Use this log file as your IBIS-AMI model ordering form.
Copy, paste and complete this form into your email (same email used to register for SerDesDesign.com) and email to: admin@serdesdesign.com
  ...
Pricing for delivery of this generated Tx IBIS-AMI model is: $3000 USD for 1 OS or $4000 USD for 2 OSs.

Include any additional custom requirements for creation and delivery of your model. List it into your email:

_ _ _< list additional requirements > _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Your additional requirments may be included at no extra charge or you will be informed of any incremental additional cost if any.
====================================================================================
```

Tx Example: Order the IBIS-AMI Model

- The form on the prior page can be sent to admin@serdesdesign.com to order you IBIS-AMI model.
- The '…' lines can be filled-in as shown here in **bold**.

Order Windows 64 bit models: ____**Yes**______ (Yes or No)
Order Linux 64 bit models: ____**Yes**______ (Yes or No)

The settable LTI Tx model parameters (fill in the user defined names):
Tx_AdaptForChannel; ___**AutoInit**__________; Auto **init DRV and DEMPH** to equalize the channel; 1 = Yes.
Tx_CornerCase; ___**CornerCase**_________; Corner case; 0 = Typical; 1 = Slow; 2 = Fast.
RTRIM; RTRIM integer in the range [0, 3]; DO NOT CHANGE; set by the IBIS Model_Selector
Drive; _____**DRV**___________; Drive index value in the range [0, 3]; used when **AutoInit** = 0.
PostCursor1; ____**DEMPH**__________; **De-emphasis** value in the range [0, 3]; used when **AutoInit** = 0.
Tx_OutputGain; ___**OutputGain**_______; Output scalar gain.

The above parameters are customized based on the discussion below.

Default 'tx_model_name' = Serdes_TxLVDS_Test_Tx; User defined 'tx_model_name' = __**TxLVDS**___________

Optional deliverable: Include SystemVue model: ___**No**_______ (Yes or No)

Tx Example: Finalize the Model Order

- <list additional requirements> can be defined as:

```
The Tx model files simulated were:  RTRIM_3_Tx_Data_Typ.csv, RTRIM_3_Tx_Data_Slow.csv, RTRIM_3_Tx_Data_Fast.csv
There are a total of 12 files in the full set included with this orfer with names:  RTRIM_<r>_Tx_Data_<c>.csv
where r = 0, 1, 2, 3;  c = Typ, Slow, Fast
Derive the 4 Tx IBIS buffer output resistances, Rtx, for the 4 (RTRIM) values for each corner case.
* VpkD = VDDTX * Rload / ( Rload + Rtx) where
* VpkD = the single sided peak voltage across the differential load, Rload, at the Tx IBIS buffer output.
* Rload = 100 Phms
* VDDTX - the built-in DRV level associated with the DRV value:  '0'=0.4V; '1'=0.48V; '2'=0.56V; '3' = 0.64V.
* Set up the Tx *.ibs files with a [Model Selector] to enable selection of the specific RTRIM value.
* The derived Rtx value is used as Rtx/2 to define the [Pullup] and [Pulldown] IV tables in the *.ibs file.
```

- Email your order to admin@serdesdesign.com
- You will receive an email response confirming your order and pricing.
- The listed price may be increased based on any additional requirements.
- If you agree to the price quote, then deposit your funds using PayPal from the [Store](#) web site.
- In this case select: 5. E. Single Tx or Rx IBIS-AMI model with 2 OS, 3 corners: $4,000.00 Add to Cart
- For additional requirement costs select with quantity: 1. A. HSD IBIS-AMI Consulting Hourly Rate: $250.00 Add to Cart

Tx Example: Include Order Options

- Besides ordering the IBIS-AMI model, Web based Training can be ordered
  - Includes the model source code and instructions on how the model can be further modified on Windows and/or Linux.
  - Training is required for source code delivery.
  - Web based training is for 4 remote hours plus up to 2 hours post training support.
  - This training is available from SerDesDesign.com for $8000 USD with up to 12 attendees.
  - The price can be reduced if post training support in not required, typically because the new training is with a customer that had prior training.
- Additionally, a custom Linux build machine can be ordered
  - The machine plugs into a PC and is fully loaded with all software required including the model software and build environment.
  - Pricing is $2000 USD

Tx Example: IBIS-AMI Model Delivery

- The purchased model ordered will be provided via DropBox link within 1-2 business.
- Each IBIS-AMI model delivered includes these deliverable files:
  - <name>.ibs (IBIS buffer specification file)
    - In this case, the *.ibs file includes a [Model Selector].
  - <name>.ami (Model definition based on the IBIS standard)
    - In this case, there are 16 *.ami files, one for each (RTRIM, DRV) combination.
  - <name>_x64.dll (64 bit Windows dynamic linked library file)
  - <name>.so (64 bit Linux shared object file)
  - <name>.pdf (custom model documentation)
  - where <name> is the customer specified name for the model.

Tx Example: Using this IBIS-AMI Model

- This Tx IBIS-AMI model can be used in any Channel Simulator based on the IBIS standard.
- Discussed here is the use in the SerDesDesign.com Channel Simulator at: serdes-system-single-channel-tool
- We will use the Tx_LVDS_RTRIM_0_DRV_0 model for Typical corner case.
- Edit the tex file Tx_LVDS_RTRIM_0_DRV_0.ami in a text editor and set AutoInit default to 1 so the optimal DRV/DEMPH values will be selected.
- Set the TransmitterType = 5, open the dialog box and set UseIBS_File = 1.

UseIBS_File	Use Tx *.ibs file for IBIS-AMI model	1

- Upload the TxLVDS.ibs file:

Tx_IBS_FileName	Tx IBIS-AMI model *.ibs file. Alpha-numeric or underbar; start with alpha	TxLVDS.ibs Choose File No f…sen

- Set the Tx_IBS_ModelName:

Tx_IBS_ModelName	Tx IBIS model name. Alpha-numeric or underbar; start with alpha	TXLVDS_RTRIM_0

- We will use the default channel S-parameter file with ChannelType = 3 which has 7.6 dB loss at Nyquist.

ChannelType	Channel specification type	3

Tx Example: Run Channel Simulation

- Set BitRate = 5.0e9 Gbps and SamplesPerBit = 32.

SymbolRate	Symbol rate (same as bit rate for NRZ)	5e9
SamplesPerSymbol	Samples per symbol (same as samples per bit for NRZ)	32

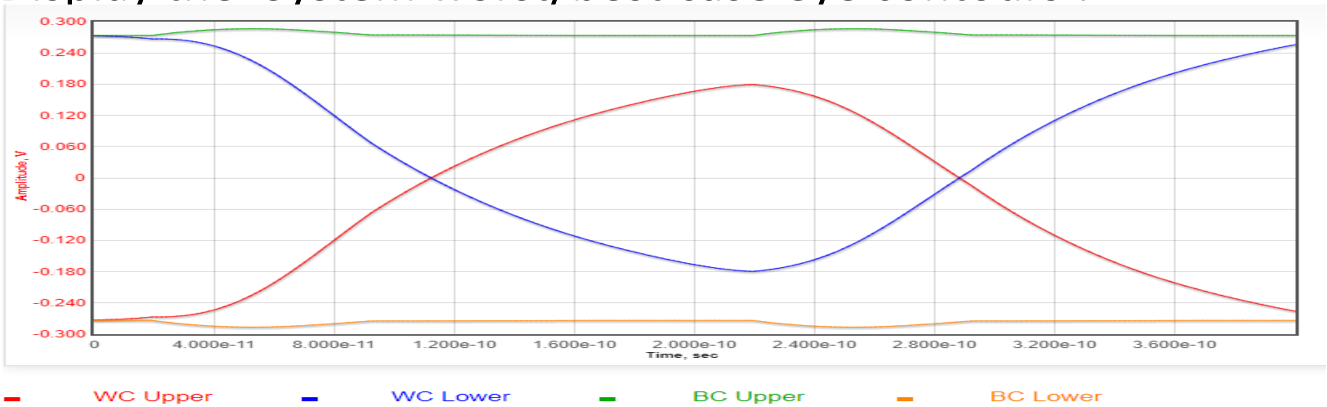
- Run the analysis and observe the resulting log file message displayed for the Tx IBIS-AMI model:

```
Begin Message returned by AMI_Init()
CornerCase = 0; RTRIM = 0;
Generating Transmitter DIR based on step response data.
Adaptation of the channel + equalizer for best eye opening results in DRV = 0 and DEMPH = 3 with eye opening ratio = 0.6.
End Message returned by AMI_Init()
```

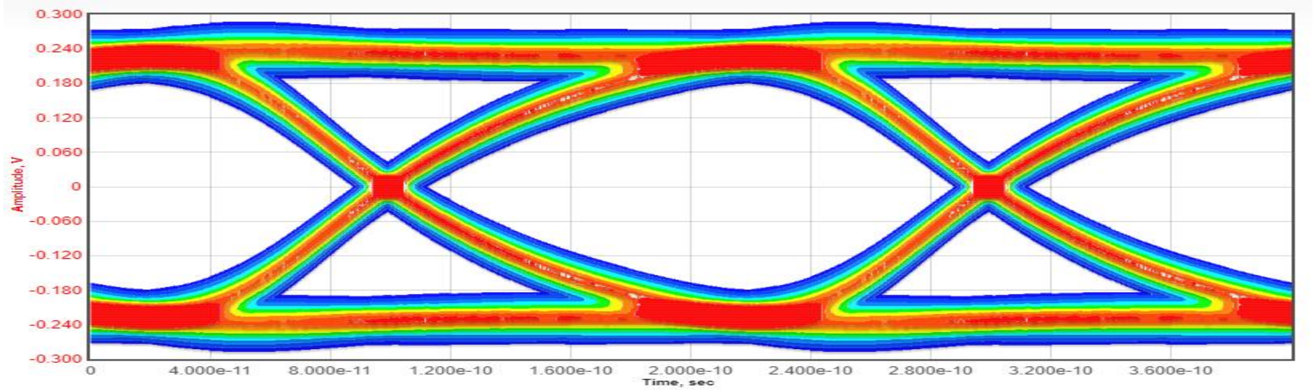
- This shows that DRV = 0 and DEMPH = 3 for the optimal eye at the channel output into a 100 ohm load at the channel output.

Tx Example: Observe Output Eye

- Display the ‘System worst/best case eye contours’:



- Open the Eye Analysis tool, Run the analysis and observe the ‘System eye density plot’:



- The system eye contours fit within and outside this detail eye.

Tx Example: Conclusion

- This presentation provided details on creating a Tx IBIS-AMI model by treating the Tx circuit as a black-box and recording Tx circuit simulation data for response waveforms into a Tx load.
  - The Tx circuit was discussed.
  - The Tx circuit waveforms were defined.
  - The Tx modeling approach was discussed.
  - The Tx circuit data was used in the Tx model.
  - The Tx model was simulated in a channel simulator.
  - The Tx model was exported as a Tx IBIS-AMI model.
  - The Tx IBIS-AMI models was used in a channel simulator.
- The presentation demonstrated just one of the many types of SerDes system Tx or Rx models that can be created using SerDesDesign.com.

Appendix

IBIS-AMI Modeling Flow – Model Development

- Use SerDesDesign.com for IBIS-AMI model development
- Construct the IBIS-AMI models in the SerDes Systems Tool
  - https://www.serdesdesign.com/home/serdes-system-single-channel-tool
  - Iterate as needed to achieve desired performance.
- Generate the Tx or Rx IBIS-AMI model from the web site.
  - Typical cost is as low as $2K per model.
- There is no need for the IBIS-AMI model developer to be an expert on the IBIS standard, C/C++ coding, or in setting up the compile and linking rules in the Microsoft Visual Studio or Linux tools.
- IBIS-AMI Tx and Rx models can be created by users in this SerDes System Tool.