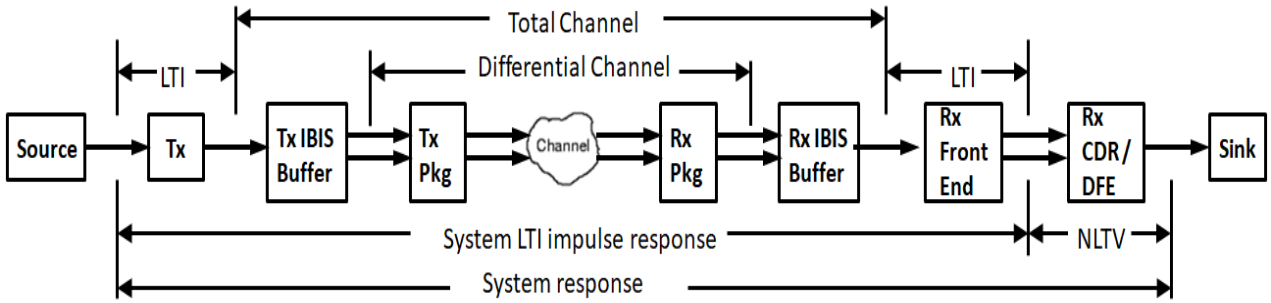
Subject: Example NRZ SerDes System Using IBIS-AMI Models

Author: John Baprawski; John Baprawski Inc. (JB)

Date: Jun. 27, 2022 (Updated March 10, 2023)

This paper discusses features on the web site: **https://www.serdesdesign.com**

A SerDes system for a single channel has the typical structure shown in this figure.



See details in **About the SerDes System Single Channel Tool...**

Many of the features available in the SerDesDesign.com tools are free; others are available for a fee. This document is on the modeling and simulation of a SerDes system using NRZ signaling, Tx/Rx IBIS-AMI models, S4P data for the channel, and using the SerDesDesign.com channel simulator.

Discussion on the IBIS-AMI Models

Every IBIS-AMI model is based on the IBIS standard with these files (as a minimum):

- *.ibs: the IBIS file that defines the IBIS buffer.
- *.ami: the AMI file that defines the Algorithmic model and possibly an alternate for the IBIS buffer.
- *_x64.dll: the 64 bit Windows dynamic linked library.
- *_x64.so: the 64 bit Linux shared object file.

In this example, the Tx IBIS-AMI model has these files:

- SerDes_TxFFE.ibs, .ami, _x64.dll, _x64.so
- This model is for a linear and time invariant (LTI) Tx feed forward equalizer (FFE) that allows one to set up to two pre-cursors and two post-cursors.
- For your use, the Tx IBIS-AMI is made available here:
  - **SerDes_TxFFE.zip**
  - In the AMI file, set the default values to the desired values and upload the AMI file with these desired values into the SerDesDesign tool.

In this example, the Rx IBIS-AMI model has these files:

- SerDes_RxCTLE_CDRDFE.ibs, .ami, _x64.dll, _x64.so
- This model is a nonlinear and time variant (NLTV) model with an LTI continuous time linear equalizer (CTLE), clock and data recovery circuit (CDR) and a decision feedback equalizer (DFE). The CDR is Bang-Bang type of CDR. The DFE has 5 taps.

- For your use, the Rx IBIS-AMI is made available here:
  - **SerDes_RxCTLE_CDRDFE.zip**
  - In the AMI file, set the default values to the desired values and upload the AMI file with these desired values into the SerDesDesign tool.

Top Level Web Page Overview

The top-level channel simulator used is at this web page:
https://www.serdesdesign.com/home/serdes-system-tool/

Registration is required to use. Registration is free and available on the home page.

For this example, this top-level page is changed from the default values to these settings:

- Define Transmitter section: TransmitterType = 5
- Define Channel section: ChannelType = 3
- Define Receiver section:
  - ReceiverFEType = 0
  - ReceiverNLType = 0
  - ReceiverNLTVType = 3
- Setup Analysis section:
  - SymbolRate = 25e9
  - SetupBitByBitMode = 1

The resultant top-level web page will appear as shown here:

1. Define Analysis Name

Description and Name Prefix	Name	Status	Comment	Action	Action
Analysis name: Serdes_	SystemTest		Alpha-numeric characters or underbar - case sensitive - start with alpha character	Recall	Info...

2. Define Transmitter - nonlinear and/or time variant (NL/NLTV) model forces Bit-by-Bit Analysis mode.

Name	Description	Entry Value(s)	Status	Type	Limits	Comment	Action
TransmitterType	Transmitter type	5		Integer	[0, 5]	0 = None 1 = FFE 2 = FFE Black Box 3 = FFE with Registers 4 = CTLE 5 = Tx LTI AMI model 6 = Tx NLTV AMI model	Open...

3. Define Channel - model is linear and time invariant (LTI).

Name	Description	Entry Value(s)	Status	Type	Limits	Comment	Action
ChannelType	Channel specification type	3		Integer	[0, 3]	0 = None 1 = Channel implulse data 2 = Channel S-parameter data 3 = Channel + Tx/Rx IBIS/pkg	Open...
EnableChAntiAliasing	Enable channel impulse anti-alising	0		Integer	[0, 1]	0 = No; 1 = Yes Used only when ChannelType=1	
ChAntiAliasingFc	Channel anti-alising filter corner frequency	0		Real	>= SymbolRate	Value in Hz; Used only when ChannelType=1 and EnableChAntiAliasing=1	

4. Define Receiver - nonlinear and/or time variant (NL/NLTV) model forces Bit-by-Bit Analysis mode.

Name	Description	Entry Value(s)	Status	Type	Limits	Comment	Action
ReceiverFEType	Receiver LTI front end type	0		Integer	[0, 7]	0 = None 1 = 1 section CTLE 2 = 2 section CTLE 3 = 3 section CTLE 4 = 4 section CTLE 5 = Rx FFE 6 = Rx FFE Black Box 7 = Rx LTI IBIS-AMI model	Open...
ReceiverNLType	Receiver NL type	0		Integer	[0, 1]	0 = None 1 = Gain with nonlinearity	Open...
ReceiverNLTVType	Receiver NLTV type	3		Integer	[0, 3]	0 = None 1 = CDR 2 = CDR + DFE 3 = Rx NLTV IBIS-AMI model	Open...

5. Setup Analysis - Analysis uses Statistical or Bit-by-Bit mode based on the selected models.

Name	Description	Entry Value(s)	Status	Type	Limits	Comment	Action
SymbolRate	Symbol rate (same as bit rate for NRZ)	2.50E+10		Real	> 0	Symbols per second (same as bits per second for NRZ)	
SamplesPerSymbol	Samples per symbol (same as samples per bit for NRZ)	32		Integer	[4, 128]		
SetupOptions	Setup analysis options	0		Integer	[0, 1]	0 = No 1 = Yes	Open...
SetupBitByBitMode	Setup bit-by-Bit mode	1		Integer	[0, 1]	0 = No 1 = Yes	Open...
GenerateModels	Generate IBIS-AMI models Generate models after Run with satisfactory results	0		Integer	[0, 1, 2, 3]	0 = No 1 = Yes: Tx only 2 = Yes: Rx only 3 = Yes: Tx and Rx	Info...

Setting Up the Transmit Model

In the ‘Define Transmitter’ section, select the TransmitterType ‘Open…’ button.

The Tx dialog box is displayed. This page is changed from the default values to these

settings:

- EnableChIBIS_AMI = 0;
- AMI_File = upload file SerDes_TxFFE.ami with the default values set to the desired values for simulation.
- ObjectFile = upload file SerDes_TxFFE_x64.so (use SerDes_TxFFE_x64.dll on Windows).
- Change EnableChIBIS_AMI = 1; this states that the IBIS-AMI model will be defined with the Channel model.

Select the HELP button at the bottom of this page for more detail on this Tx model.
Select the APPLY button to verify the settings. If they are good, then each parameter will have a green circle with a check mark will appear in its 'Status' field.
Select the OK button to close this dialog box. If the box was setup properly, then a green circle with a check mark will appear in the TransmitterType 'Status' field.

The resultant Tx dialog box will appear as shown here:

Transmitter - 5. Tx LTI AMI model

Name	Description	Entry Value(s)	Status	Type	Limits	Comment
EnableChIBIS_AMI	Enable AMI from Channel Tx IBIS buffer section	1		Integer	[0,1]	0 = No 1 = Yes
FormatCorner	AMI file format corner case; used when parameter format is Corner	0		Integer	[0,2]	0 = Typ 1 = Slow 2 = Fast

Setting Up the Channel Model

In the 'Define Channel' section, select the ChannelType 'Open…' button.

The Channel dialog box is displayed. This page is changed from the default values to these settings:

- EnableTxBuffer = 2
- IBIS_File = SerDes_TxFFE.ibs; this file is to be uploaded into the dialog box.
- IBIS_ModelName = SerDes_TxFFE; this is specific to this *.ibs file
- This *.ibs file references the AMI and SO (DLL on Windows) files which will be used in the simulation.
- EnableChannel = 1; this enables use of the default S4P file to define the differential channel. Alternatively, another S4P can be uploaded and used.
- EnableRxBuffer = 2
- IBIS_File = SerDes_CTLE_CDRDFE.ibs; this file is to be uploaded into the dialog box.
- IBIS_ModelName = SerDes_CTLE_CDRDFE; this is specific to this *.ibs file
- This *.ibs file references the AMI and SO (DLL on Windows) files which will be used in the simulation.

Select the HELP button at the bottom of this page for more detail on this Tx model.
Select the APPLY button to verify the settings. If they are good, then each parameter will have a green circle with a check mark will appear in its 'Status' field.
Select the OK button to close this dialog box. If the box was setup properly, then a green

circle with a check mark will appear in the ChannelType ‘Status’ field.

The resultant Channel dialog box will appear as shown here:

Channel - 3. Tx Buffer/Pkg + Channel + Rx Pkg/Buffer

Name	Description	Entry Value(s)	Status	Type	Limits	Comment
EnableTxBuffer	Enable transmit IBIS buffer	2	✓	Integer	[0, 3]	0 = No 1 = Yes 2 = Use IBIS 3 = Use Alt IBIS
IBS_File	Tx *.ibs file. Alpha-numeric or underbar; start with alpha	SerDes_TxFFE.ibs Choose File No …en	✓	File		Upload a Tx IBIS file (*.ibs format) or list previously uploaded file
UseIBS_RampOrWaveform	Use Tx *.ibs file [RAMP] or [Rising/Falling Waveform] tables	0	✓	Integer	[0, 1]	0 = Use [Ramp] 1 = Use[Rising / Falling Waveform] tables
IBS_CornerCase	Tx IBIS model corner case;0=Typ;1=Min;2=Max	0	✓	Integer	[0, 2]	0 = Typical 1 = Min 2 = Max
IBS_ModelName	Tx model name. Alpha-numeric or underbar; start with alpha	SerDes_TxFFE	✓	String		
DeembedIBIS	Deembed Tx IBIS response from Tx AMI LTI model	0	✓	Integer	[0, 1]	0 = No 1 = Yes
BufRI	Tx IBIS output load per pin for deembedding	50	✓	Real	>0	Value in Ohms; used when Tx_DeembedIBIS=1
EnableTxPkg	Enable transmit package	0	✓	Integer	[0, 1]	

EnableChannel	Enable channel	1	✓	Integer	[0, 1]	
SParamFile	S-parameter file. Alpha-numeric or underbar; start with alpha	Channel_25Gbps.s4p Choose File No file chosen	✓	File		Upload a file (Touchstone 1.0 format) or list previously uploaded file
NumSPorts	Number of ports	4	✓	Integer	>=4	For S-parameter file
InPortPositive	Input port + (positive side)	1	✓	Integer	[1, Ch_NumSPorts]	Must be different from the other in and out ports. PHP error alert: If the integer entered (ie. 7) fails, put a zero in front of it (ie. 07)
InPortMinus	Input port - (minus side)	3	✓	Integer	[1, Ch_NumSPorts]	Must be different from the other in and out ports. PHP error alert: If the integer entered (ie. 7) fails, put a zero in front of it (ie. 07)
OutPortPositive	Output port + (positive side)	2	✓	Integer	[1, Ch_NumSPorts]	Must be different from the other in and out ports. PHP error alert: If the integer entered (ie. 7) fails, put a zero in front of it (ie. 07)
OutPortMinus	Output port - (minus side)	4	✓	Integer	[1, Ch_NumSPorts]	Must be different from the other in and out ports. PHP error alert: If the integer entered (ie. 7) fails, put a zero in front of it (ie. 07)
ForceReciprocity	Force reciprosity	0	✓	Integer	[0, 1]	Force Sij=Sji
EnableRxPkg	Enable receive package	0	✓	Integer	[0, 1]	
EnableRxBuffer	Enable receive IBIS buffer	0	✓	Integer	[0, 3]	0 = No 1 = Yes 2 = Use IBIS 3 = Use Alt IBIS
EnableRxBuffer	Enable receive IBIS buffer	2	✓	Integer	[0, 3]	0 = No 1 = Yes 2 = Use IBIS 3 = Use Alt IBIS
IBS_File	Rx *.ibs file. Alpha-numeric or underbar; start with alpha	SerDes_RxCTLE_CDRDFE.ibs Choose File No file chosen	✓	File		Upload a Rx IBIS file (*.ibs format) or list previously uploaded file
IBS_CornerCase	Rx IBIS model corner case;0=Typ;1=Min;2=Max	0	✓	Integer	[0, 2]	0 = Typical 1 = Min 2 = Max
IBS_ModelName	Rx model name. Alpha-numeric or underbar; start with alpha	SerDes_RxCTLE_CDRDFE	✓	String		
DeembedIBIS	Deembed Rx IBIS response from Rx AMI LTI model	0	✓	Integer	[0, 1]	0 = No 1 = Yes
BufRI	Rx IBIS input load per pin for deembedding	50	✓	Real	>0	Value in Ohms; used when Rx_DeembedIBIS=1
SetTotalChannelTolerance	Set total channel frequency domain tolerance	0	✓	Real	[0, 1]	0=auto set

Setting Up the Receiver Model

In the ‘Define Receiver’ section, select the ReceiverNLTVType ‘Open…’ button.

The Rx dialog box is displayed. This page is changed from the default values to these settings:

- EnableChIBIS_AMI = 0;

- AMI_File = upload file SerDes_CTLE_CDRDFE.ami with the default values set to the desired values for simulation.
- ObjectFile = upload file SerDes_CTLE_CDRDFE_x64.so (use SerDes_CTLE_CDRDFE_x64.dll on Windows).
- Change EnableChIBIS_AMI = 1; this states that the IBIS-AMI model will be defined with the Channel model.

Select the HELP button at the bottom of this page for more detail on this Rx model.
Select the APPLY button to verify the settings. If they are good, then each parameter will have a green circle with a check mark will appear in its 'Status' field.
Select the OK button to close this dialog box. If the box was setup properly, then a green circle with a check mark will appear in the ReceiverNLTVType 'Status' field.

The resultant Rx dialog box will appear as shown here:

Receiver NLTV - 3. Rx NLTV AMI model

Name	Description	Entry Value(s)	Status	Type	Limits	Comment
EnableChIBIS_AMI	Enable AMI from Channel Rx IBIS buffer section	1	✓	Integer	[0,1]	0 = No 1 = Yes
FormatCorner	AMI file format corner case; used when parameter format is Corner	0	✓	Integer	[0,2]	0 = Typ 1 = Slow 2 = Fast

Setting Up the Analysis Bit-by-Bit Mode

In the 'Setup Analysis section, select the SetupBitByBitMode 'Open…' button.

The setup dialog box is displayed. This page is changed from the default values to these settings:

- AnalysisSymbols = 1000000

Select the HELP button at the bottom of this page for more detail on this setup dialog.
Select the APPLY button to verify the settings. If they are good, then each parameter will have a green circle with a check mark will appear in its 'Status' field.
Select the OK button to close this dialog box. If the box was setup properly, then a green circle with a check mark will appear in the SetupBibByBitMode 'Status' field.

The resultant 'Bit-by-Bit' dialog box with appear as shown here:

Analysis - Bit-by-bit mode

Name	Description	Entry Value(s)	Status	Type	Limits	Comment
AnalysisSymbols	Number of analysis symbols (same as bits for NRZ) after IgnoreSymbols/Bits	1000000		Integer	>= 1000	
HistogramMaxLevel	Eye histogram max level; 0 for auto set	0.0		Real	>= 0	0=AutoSet; must be >0 when any IBIS/AMI model is used
EnablePAM4	Enable PAM4 source	0		Integer	[0,1]	0 = No use NRZ 1 = Yes use PAM4
PRBS_Len	PRBS register length	0		Integer	0 or [0,32]	0 = auto set based on AnalysisSymbols
BlockSizeSymbols	Number of symbols (same as bits for NRZ) used for each AMI_GetWave call	0		Integer	>= 0	0 results in automatic setting
MaxNumProc	Maximum number of processors	0		Integer	[0,4]	Used when AnalysisSymbols >= 100,000

Run the Analysis

In the 'Run Analysis section, select the Run button. If the SerDes design was setup properly, then each top-level web page parameter will have a green circle with a check mark appear in its 'Status' field.

As the simulation is run, the number of run seconds will display to the right of the Run button.

During simulation the following steps will be performed.

- The total channel is analyzed and represented with a single ended impulse response.
- The Tx model will be setup and initialized.
- The Rx model will be setup and initialized.
- The simulator will set the 'IgnoreSymbols' to the value set for the Rx model AMI file. The simulator will run the simulation for the AnaysisSymbols after these IgnoreSymbols.
    - The AnalysisSymbols will be rounded up to a power of 2, 1,048,576 in this case.
- The simulator will run a time domain simulation using a time step = 1/SampleRate = 1/SymbolRate/SamplesPerSymbol = 1/25e9/32 = 1.25e-12 sec.
    - The simulator will create NRZ symbols using bits from a PRBS bit generator. The PRBS generator length will be set to 20 because, the Analysis setup used the default PRBS_Len = 0. The value 20 is used because 2^20 = 1,048,576/2.
- The simulator will collect a histogram database of amplitude vs time values. This database will be post processed after the simulation run to derive all metrics, include eye density and BER plots.

At the end of the simulation run, the 'Analysis log file' will open at the bottom of the web-page.

Observe in the log file:

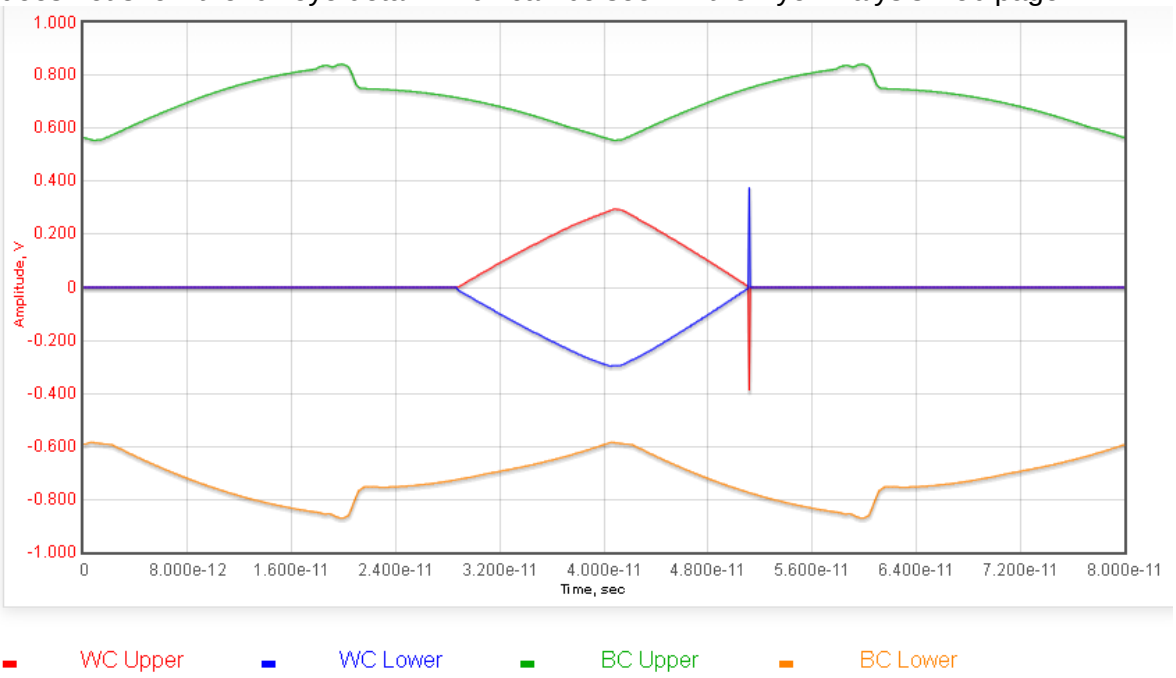
- The Tx AMI model AMI_Init() output message.

- The Rx AMI model AMI_Init() output message.
  - For this Rx AMI model, a message file is written to the user's account directory on the server. If the user purchased FTP access, then the user would have access to their dedicated server directories.
- The simulation of 1,048,576 symbols plus the ignore symbol took 103 sec.
  - This simulation can be reduced by a factor of N (approximately) if the user purchased N multi-processing capability (standard is N=4; upto N=28 is supported). This is important when simulating millions of symbols (or more), especially for PAM4 signaling.

Observe Quick Results

On this top-level web page, the 'Display Results' section provide the ability to see quick results.

For example, here is a quick display of the eye best and worst case contours. Note: This does not show the full eye detail which can be seen in the Eye Analysis web page.



The glitch seen in the plot is an artifact of the contour approximation routine and of no concent.

For detail results for eye density, BER and more, open the Eye Analysis web page: https://www.serdesdesign.com/home/eye-analysis-tool/ (on Windows open the local Eye Analysis Tool).

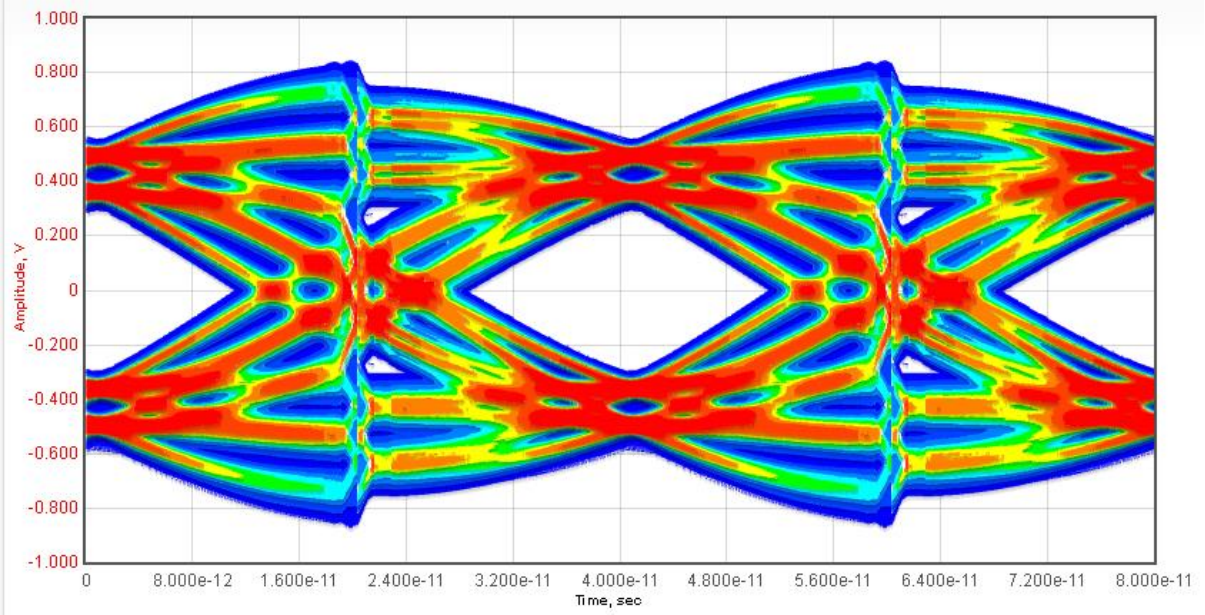
In this web-page, one can set up many ways to post process the channel simulation output data. To do this, as a minimum, set the 'ChAnalysisName' to the same 'Analysis name' used in the prior web-page, 'Serdes_SystemTest' is used in this case.

Set MaxEyeColorSize to 120000 (the default is 40000) for better eye density detail. A larger

value gives the eye density more detail at the cost of more data traffic between the server and user's computer.

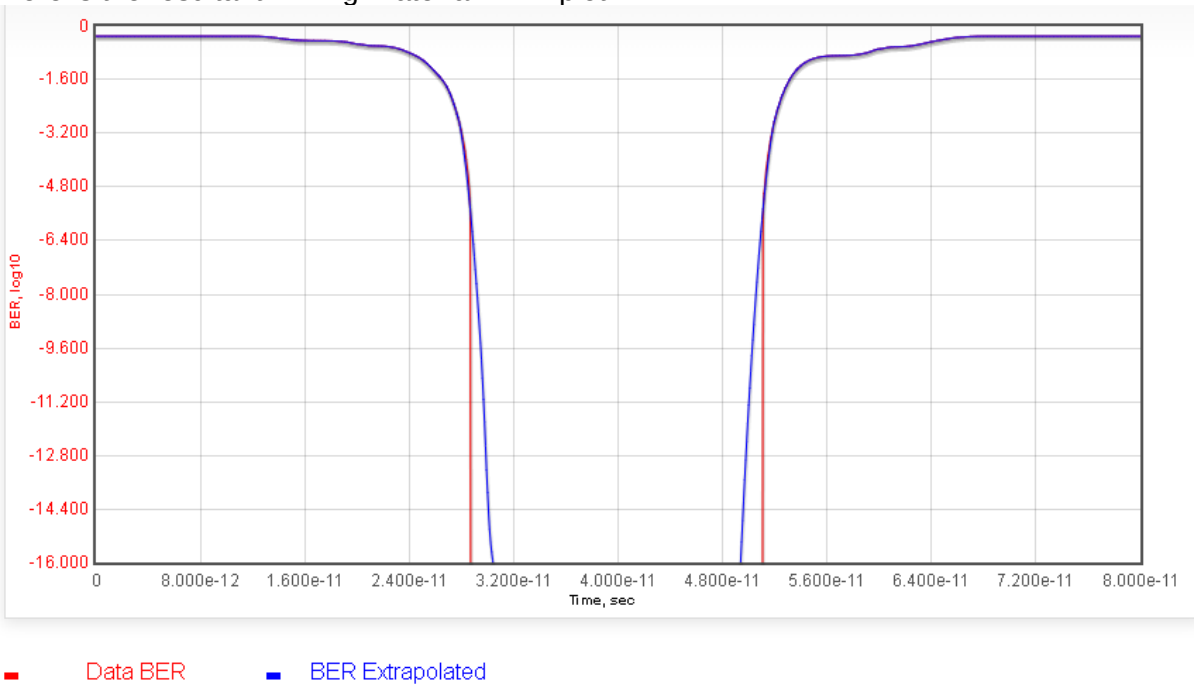
After setup, run the Eye Analysis by selecting the Run button.

Here is the resultant Eye Density plot:



Redish colors are for higher densities. Bluish colors are for lower densities.

Here is the resultant Timing Waterfall BER plot.



The raw (Monte-Carlo based) BER curve is shown along with the extrapolated BER curve. The raw BER goes down to the level (in this case) of 10^(-6). The extrapolated BER goes

down to 10^(-16). The display of both shows that the extrapolated BER curves overlap the raw BER data very well above 10^(-6).

Many ways of displaying the channel simulation data are possible.