## Subject: SerDesDesign.com RxCTLE_Modeling_Tool

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For the past 10+ years, John Baprawski has provided cost-efficient high-quality IBIS-AMI models to 40+ high speed digital (HSD) integrated circuit (IC) companies using his IBIS-AMI Model Development Environment for use in any standards compliant SerDes system channel simulator. That work has relied on his free web-based tools including his SerDes Channel Simulator (**https://www.serdesdesign.com/home/**). That work has also focused on collecting correct circuit data and automating the process for converting that data into IBIS-AMI models.

This paper highlights the process for creating a perfect Rx CTLE IBIS-AMI model from circuit data. **Perfect = IBIS-AMI model exactly agrees with Spice simulations**.

## Overview

Be sure to read these two documents first:

READ_ME_FIRST_-_License_Agreement.pdf

READ_ME_SECOND_-_Instructions.pdf

This Rx Tool has this directory structure:

C:/AMI_CTLE/RxAMI_Solution_SerDes_CTLE - SerDesDesign.com IBIS-AMI build directory.
C:/AMI_CTLE/RxCTLE_SS_Modeling_Tool - Rx CTLE Modeling Tool.
C:/AMI_CTLE/RxWaveformSmallSignalData – directory for the circuit data files.

## Circuit Data Collection

The circuit is assumed to be for a SerDes receiver (Rx) continuous time linear equalizer (CTLE) with differential inputs that interface with a differential SerDes channel.

The data to be collected is:

- The Rx circuit input differential impedance versus frequency.
- The Rx circuit input waveform.
- The Rx circuit CTLE output waveform for each CTLE state.

For detail instruction on this required circuit data see the report:
**Modeling_an_LTI_RxSerDes_CTLE_wih_TimeData.pdf**

Place this circuit data into the directory C:\AMI_CTLE\RxWaveformSmallSignalData.

Within that directory create the file InputFileNameList.txt which is to contain a list of all the CTLE waveform files in the desired order.

## Setting up the RxCTLE Modeling Tool

The RxCTLE Modeling tool is in the directory C:\AMI_CTLE\RxCTLE_SS_Modeling_Tool.

Within that directory, the file DataFiles\RxCTLE_SS_Modeling.txt needs to be set up by the user.

This file contains two lines. In the following, the user entered values are within angle braces <…>.

**Line 1:** SetupAnalysis BitRate <bit_rate> SamplesPerBit <samples_per_bit> NumStepResp <num_step_resp>

<bit_rate>: this is the maximum bit rate for an NRZ data pattern.

<samples_per_bit>: can remain at 32.

<num_step_resp>: number of CTLE states.

**Line 2:** RxCTLE_Modeling DirName <small_signal_dir_name> IBIS_SParamFile <s2p_filename> SkipLines <skip_lines> ExtractionTStart <extraction_tstart> ExtractionTLength <extraction_tlength>

<small_signal_dir_name>: can remain at C:\AMI_CTLE\RxWaveformSmallSignalData.

<s2p_filename>: Name of the s2p data file.

<skip_lines>: Number of lines at the top of the waveform files to skip.

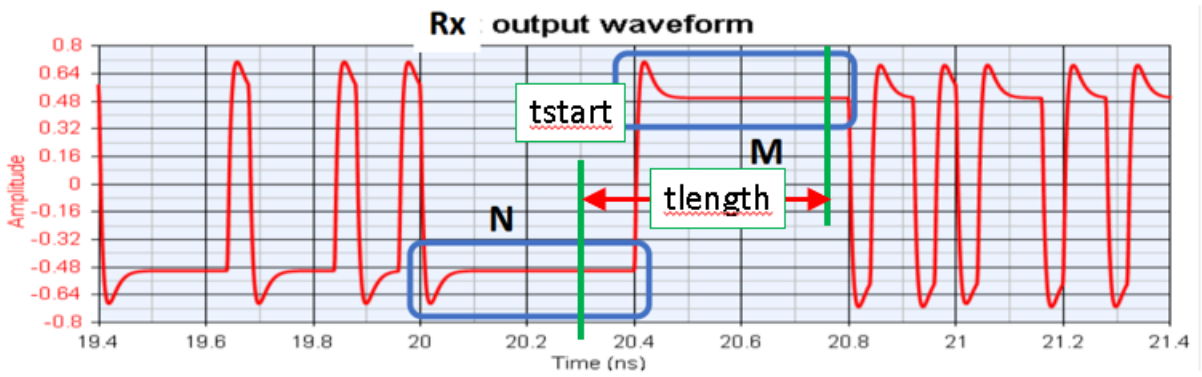
<extraction_tstart>: the time stamp in the waveform file use to start waveform extraction.

<extraction_tlength>: the time length after the tstart for the end of the waveform extraction.

Discussion:

It is assumed that all CTLE waveform files use the same NRZ data pattern and the same time samples. As such, all files have the same NRZ segment with N zeros and M ones. Set tstart to a reference time before the zero-to-one transition. Set tlength to the point after this transition and before the next transition.

This figure shows this concept.




## Running the RxCTLE Modeling Tool

The RxCTLE Modeling tool is run by selectin the batch file C:\AMI_CTLE\\RxCTLE_SS_Modeling_Tool\RxCTLE_SS_Modeling.bat

When this is done, a Windows Command window pops up and displays the running simulation status. The following screen captures show the starting and ending screen captures.

```
C:\AMI_CTLE\RxCTLE_SS_Modeling_Tool>RxCTLE_SS_Modeling_Tool.exe

*** Starting RxCTLE_Modeling_Tool
BitRate = 2.57812e+10
SamplesPerBit = 32
NumStepResp = 32
*** Completed Analysis Setup.
DirName = C:\AMI_CTLE\RxWaveformSmallSignalData
IBIS_SParamFile = RxSerDes_CTLE.s2p
SkipLines = 4
ExtractionTStart = 5.05e-08
ExtractionTLength = 1.4e-09
*** Completed RxCTLE_Modeling_Tool Setup.
```

```
Exiting RxCTLE_Modeling_Tool with success.

Hit any key to continue and exit this program.
```

The process produces its log files in the RxWaveformSmallSignalData directory: Log_RxCTLE_Modeling_Tool.log.

This process takes several steps along the way. Each step produces a log file and other output files into the RxWaveformSmallSignalData directory.

Step 1: Combine the circuit waveform files.

```
*** Starting RxCTLE_ResampleWaveform
    Running RxCTLE_ResampleWaveform Sweep
    Running RxCTLE_ResampleWaveform CreateOutFile
    For detail log, see file:  C:\AMI_Test\WaveformSmallSignalData\Log_ResampleWaveformData.log
    Generated file:  C:\AMI_Test\WaveformSmallSignalData\Combined.csv
*** Completed RxCTLE_ResampleWaveform
```

Step 2: Generate the IBIS S4P file and IBIS impulse response.

```
*** Starting RxCTLE_GenerateIBIS_Impulse
    Running RxCTLE_GenerateIBIS_Impulse Convert IBIS S2P to impulse response; this may take several minutes.
    For detail log, see file:  C:\AMI_Test\WaveformSmallSignalData\Log_GenerateIBIS_Impulse.log
    Generated files:
              C:\AMI_Test\WaveformSmallSignalData\RxCTLE.s2p.s4p
              C:\AMI_Test\WaveformSmallSignalData\RxCTLE.s2p.ImpulseResponse.csv
*** Completed RxCTLE_GenerateIBIS_Impulse
```

Step 3: Extract the desired waveform segment from the combined waveform file.

```
*** Starting RxCTLE_ExtractStepResponseData
    Running RxCTLE_ExtractStepResponseData output step response extracted waveform.
    Running RxCTLE_ExtractStepResponseData input step response extracted waveform.
    For detail log, see file:  C:\AMI_Test\WaveformSmallSignalData\Log_ExtractStepResponseData.log
    Generated files:
              C:\AMI_Test\WaveformSmallSignalData\Combined.OutputStepExtracted.csv
              C:\AMI_Test\WaveformSmallSignalData\Combined.InputStepExtracted.csv
*** Completed RxCTLE_ExtractStepResponseData
```

Step 4: Deembed the input waveform segment with IBIS impulse applied from the output waveform segment to achieve the step response data for the AMI model.

```
*** Starting RxCTLE_DeembedInputResp
    Running Get OutputStepData.
    Running Write Final and Peak Output Step Values.
    Running Get InputStepData.
    Running Write Input Step Gain Levels.
    Running Get IBIS_ImpulseData.
    Running Derive Output Gain and Peaking Ratios; this may take several minutes.
    Running Convolve Input Step with IBIS Impulse.
    Running Deembed Input with IBIS from Output.
    Running Write Input Step with IBIS.
    Running Validate Deembedded Output Steps
    For detail log, see file:  C:\AMI_Test\WaveformSmallSignalData\Log_DeembedInputResp.log
    Generated files:
              C:\AMI_Test\WaveformSmallSignalData\Combined.InputStepExtracted.InputStepLevels.csv
              C:\AMI_Test\WaveformSmallSignalData\Combined.OutputStepExtracted.InputDeembeded.GainAndPeakingValues.csv
              C:\AMI_Test\WaveformSmallSignalData\Combined.OutputStepExtracted.InputDeembedded.csv
              C:\AMI_Test\WaveformSmallSignalData\Combined.OutputStepExtracted.InputWithIBISDeembedded.csv
              C:\AMI_Test\WaveformSmallSignalData\Combined.InputStepExtracted.WithIBIS_Impulse.csv
*** Completed RxCTLE_DeembedInputResp
```

The log file, Log_DeembedInputResp.log, shows the internal test results comparing the resultant IBIS-AMI model responses with the original data output responses.

```
*** Begin validation process by convolving deembedded step responses with input with IBIS impulse responses
and comparing to the original step responses.
*** During validation the maximum final step value % error = 0.000483397 %.
*** During validation the maximum peak step value % error = 0.3205 %.
*** Completed validation process.
```

This verification step shows excellent agreement.

One file contains all the combined waveform data:  Combined.csv

Two files are used in creating the Rx CTLE IBIS-AMI model:

- RxSerDes_CTLE.s2p.s4p (rename your *.s2p.s4p file to this name).
- Combined.OutputStepExtracted.InputWithIBISDeembedded.csv

## Generating the RxCTLE IBIS-AMI Model

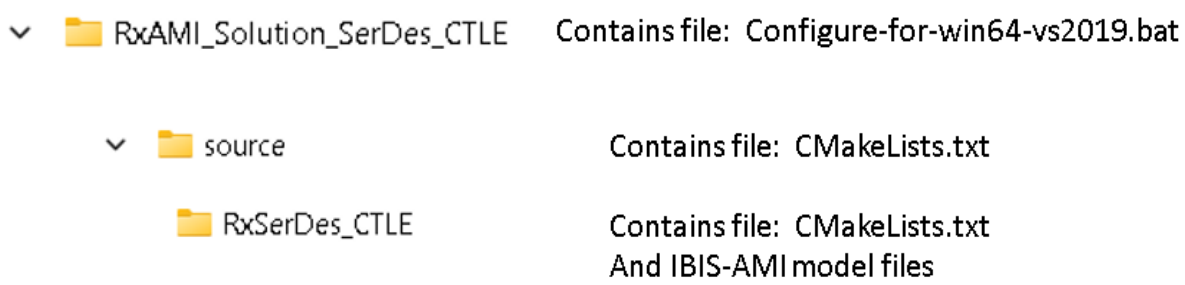
This section provides instructions on building the IBIS-AMI models – only with the instructions needed to be successful.  This section does not include detail discussion of these steps, the reasons for these steps, the structure of the files generated, or other such detail.  That detail is available in the separate SerDesDesign.com product called the 'SerDesDesign.com IBIS-AMI Model Development Environment'.  The content included with this RxCTLE tool is a subset of that full model development environment.

The full product, IBIS-AMI Model Development Environment for Windows/Linux, is available at the SerDesDesign.com store ( https://www.serdesdesign.com/home/store/products/products ).

Creating IBIS-AMI models on a Windows 64-bit PC requires installing the free Microsoft Visual Studio 2019 tool.

See this link for instruction on installing Visual Studio 2019:
http://www.serdesdesign.com/home/web_documents/models/Installing_Visual_Studio_2019.pdf

The RxAMI_Solution_SerDes_CTLE directory is used for building the IBIS-AMI model.  It has this structure:



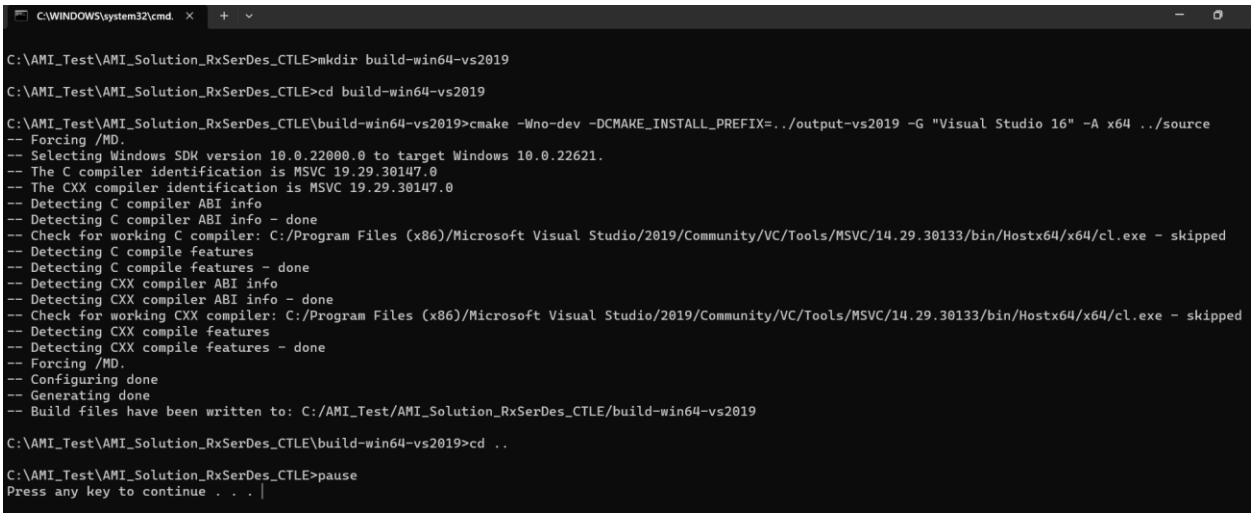
As identified in the prior section, two files from the prior section are used in creating the Rx CTLE IBIS-AMI model:

- RxSerDes_CTLE.s2p.s4p (rename your *.s2p.s4p file to this name).
- Combined.OutputStepExtracted.InputWithIBISDeembedded.csv

Copy these files to the RxSerDes_CTLE directory.

With Visual Studio 2019 installed and operable, build this AMI_Solution by running the batch file Configure-for-win64-vs2019.bat. When this batch file is run, a Windows Command window opens and runs the process to build the Visual Studio solution.

A screen captures for a successful running of this build process is shown here.

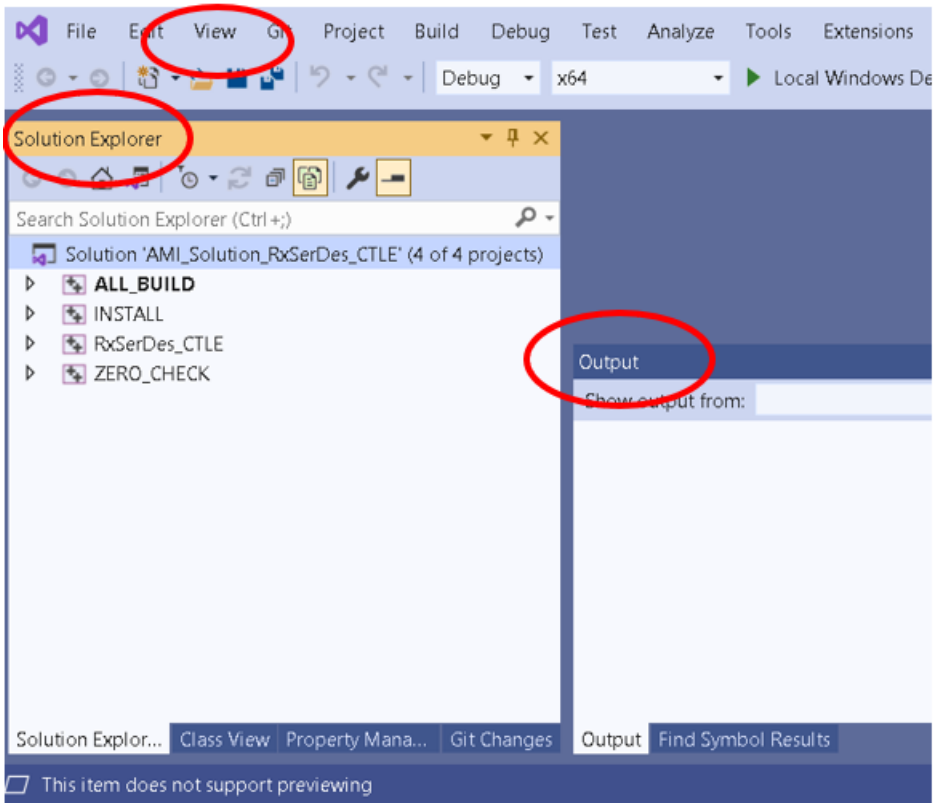



Press any key to continue. You will see the directory build-win64-vs2019 within RxAMI_Solution_SerDes_CTLE.

Though many files were generated, only one file is used for our purpose.

See the file RxAMI_Solution_SerDes_CTLE.sln within the build-win64-vs2019 directory.

Double click on this *.sln file and Visual Studio 2019 will open with this view:

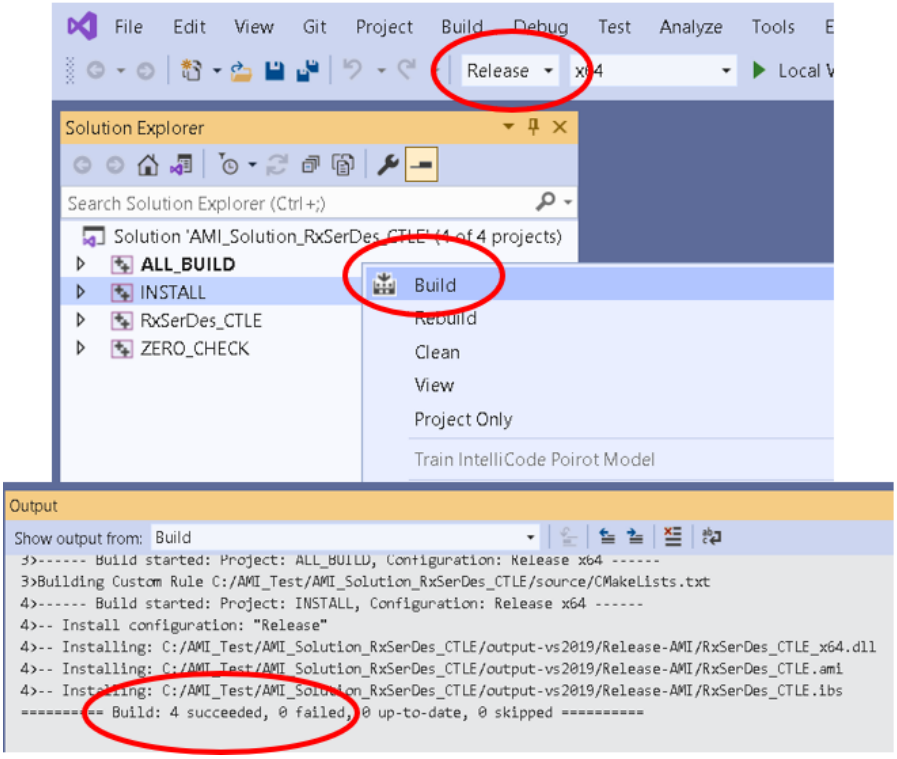



Observe the display for the '**Solution Explorer**' and '**Output**' windows.

You may have to use the '**View'** menu on the top toolbar to display these windows.

The IBIS/AMI/Source code is in the RxSerDes_CTLE sub folder.

To build the IBIS-AMI model, Set the Solution Configuration to '**Release'**. Select INSTALL, right mouse click; select '**Build'**.




The Output displays build success message. The IBIS-AMI files are placed into '**output-vs2019\Release-AMI**'. **We are DONE!!!**

Files RxSerDes_CTLE.ibs/.ami/_x64.dll along with the s4p file can be used in any Channel Simulator on your Windows PC.

**An unlimited number of IBIS-AMI models can be generated with this Tool and used with any Channel Simulator on this Windows PC.**

## How to Remove IBIS-AMI Model Licensing Restrictions

The IBIS-AMI models generated by this Tool have the same time-based node-locked licensing restrictions as the Tool.

Use of the IBIS-AMI model on any Windows or Linux machine requires that the built-in licensing restrictions must be removed. To do this, zip up and send your RxAMI_Solution_SerDes_CTLE project, with any additional instructions, to **admin@serdesdesign.com**.

An IBIS-AMI model with licensing restrictions removed will be sent to you after your payment in the SerDesDesign.com store ( **https://www.serdesdesign.com/home/store** ) for an amount that is 50% of standard model pricing as defined in the response you receive from **admin@serdesdesign.com**.

Example: Standard pricing for an Rx IBIS-AMI model on Windows or Linux is $2,000. So, the 50% pricing results in a price of $1,000.

## Example Tool Process with the Included Circuit Data Files

The example circuit data files are in the RxWaveformSmallSignalData directory.

These files are:

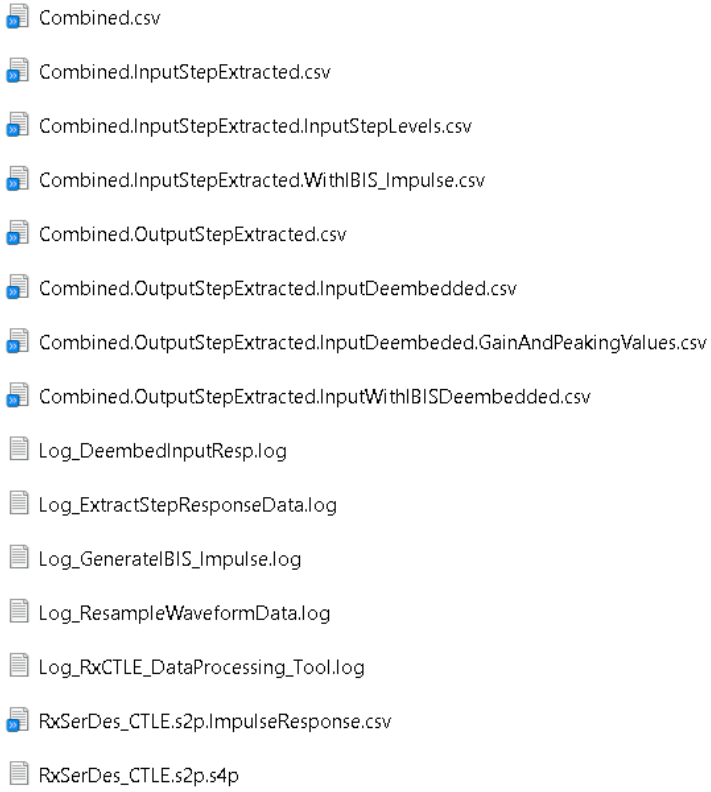
- RxSerDes_CTLE.s2p - the Rx circuit differential input S-parameters.
- CTLE_<n>.tim – the 32 waveform files (n=1 to 32) for the 32 CTLE states. These files were generated using the Keysight ADS Spice circuit simulator and use the ADS text file *.tim format. The top four lines contain header information and are to be skipped.
    - Any circuit simulator text output file can be used provided it follows the required format.
- InputFileNameList.txt – the text file with 32 lines listing the 32 CTLE waveform file names.

The example setup for the RxCTLE Modeling Tool is defined in the file RxCTLE_Modeling.txt in the RxCTLE_SS_Modeling_Tool\DataFiles directory. This file has these two lines:

- SetupAnalysis BitRate 25.78125e9 SamplesPerBit 32 NumStepResp 32
- RxCTLE_SS_Modeling DirName C:\AMI_CTLE\RxWaveformSmallSignalData IBIS_SParamFile RxSerDes_CTLE.s2p SkipLines 4 ExtractionTStart 5.0500e-08 ExtractionTLength 1.4000e-09

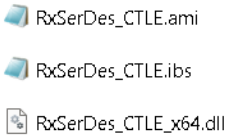
Notice the value provided in these two lines that are specific for this set of example circuit data files.

The RxCTLE Modeling Tool is run by double clicking on the batch file RxCTLE_Modeling.bat in the RxCTLE_SS_Modeling_Tool directory and results in these generated files in the RxWaveformSmallSignalData directory.




The two files RxSerDes_CTLE.s2p.s4p and Combined.OutputStepExtracted.InputWithIBISDeembedded.csv are to be copied manually to the RxAMI_Solution_SerDes_CTLE\source\RxSerDes_CTLE directory.

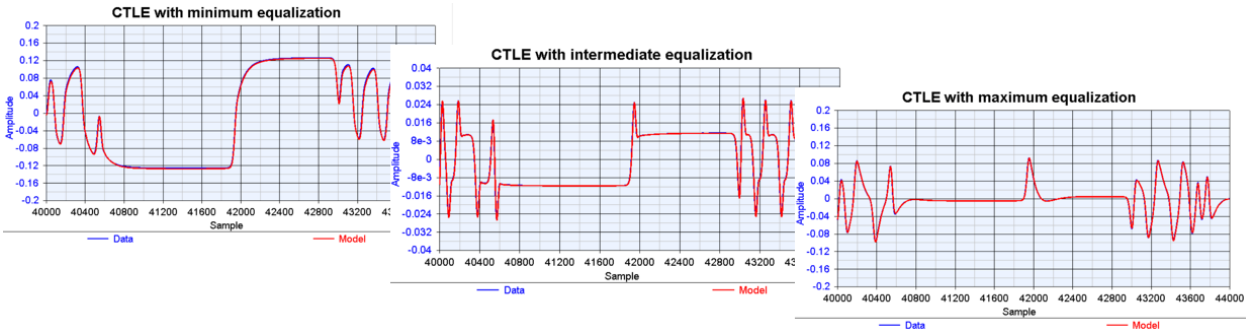
When the Visual Studio solution is generated and the Visual Studio build process is run, these files are generated in the RxAMI_Solution_SerDes_CTLE\output-vs2019\Release-AMI directory.




These three files along with the RxSerDes_CTLE.s2p.s4p files can be used in any Channel Simulator on the Windows PC that supports the IBIS 7.0 specification or later.

This example RxSerDes_CTLE IBIS-AMI model will provide perfect agreement with the circuit waveform output data when used with the same circuit input waveform data.

Here is a display for the CTLE with min, intermediate and max equalization.




## Using the Example IBIS-AMI Model in a Channel Simulator

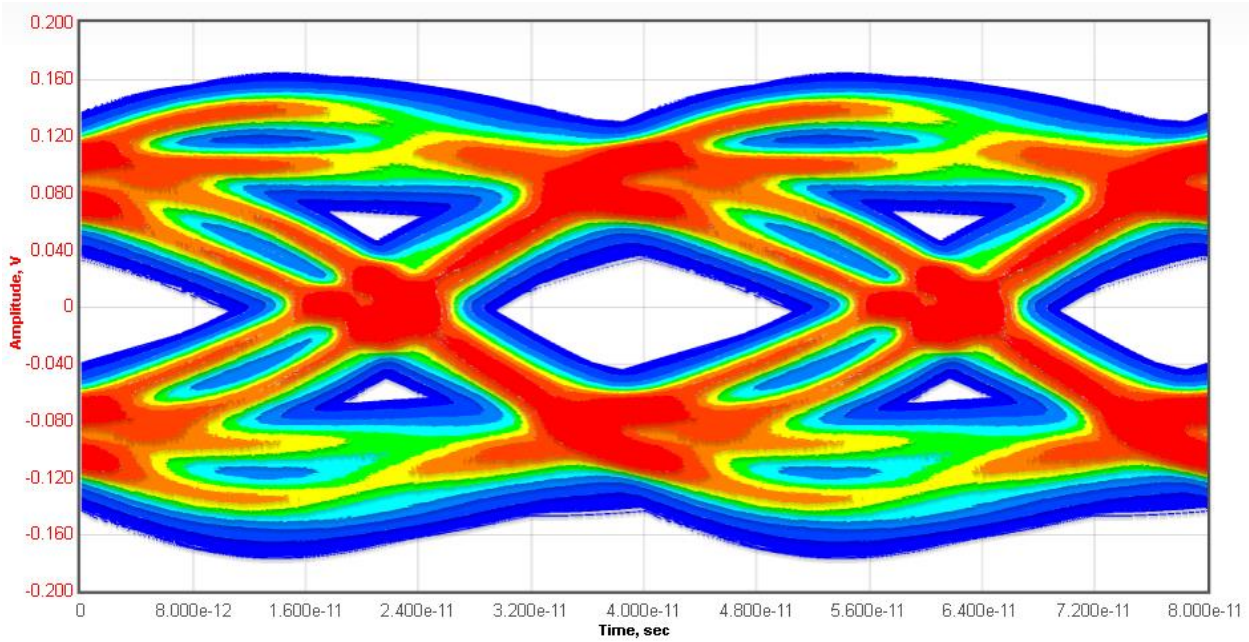
The example RxSerDes_CTLE IBIS-AMI model can be used in any Channel Simulator on the Windows PC that supports the IBIS 7.0 specification or later.

For discussion in this report the SerDesDesign.com channel simulator will be used with the version that can be downloaded and installed onto a Windows 64-bit PC. The Windows PC copy is available for a fee with a time-based node-locked license. The free copy available on the web (http://www.serdesdesign.com/home/serdes-system-tool ) requires Linux based IBIS-AMI models.

The SerDes system discussed here uses NRZ signaling with these constituent parts:

- Bit rate = 25 Gbps; simulated with 32 samples per bit.
- No Tx IBIS-AMI model
- No TxPkg.
- Channel defined with S4P file with 30 dB loss at Nyquist (12.5 GHz) for the differential transmission path.
- No RxPkg.
- Rx IBIS-AMI model
    - RxSerDes_CTLE IBIS-AMI model.

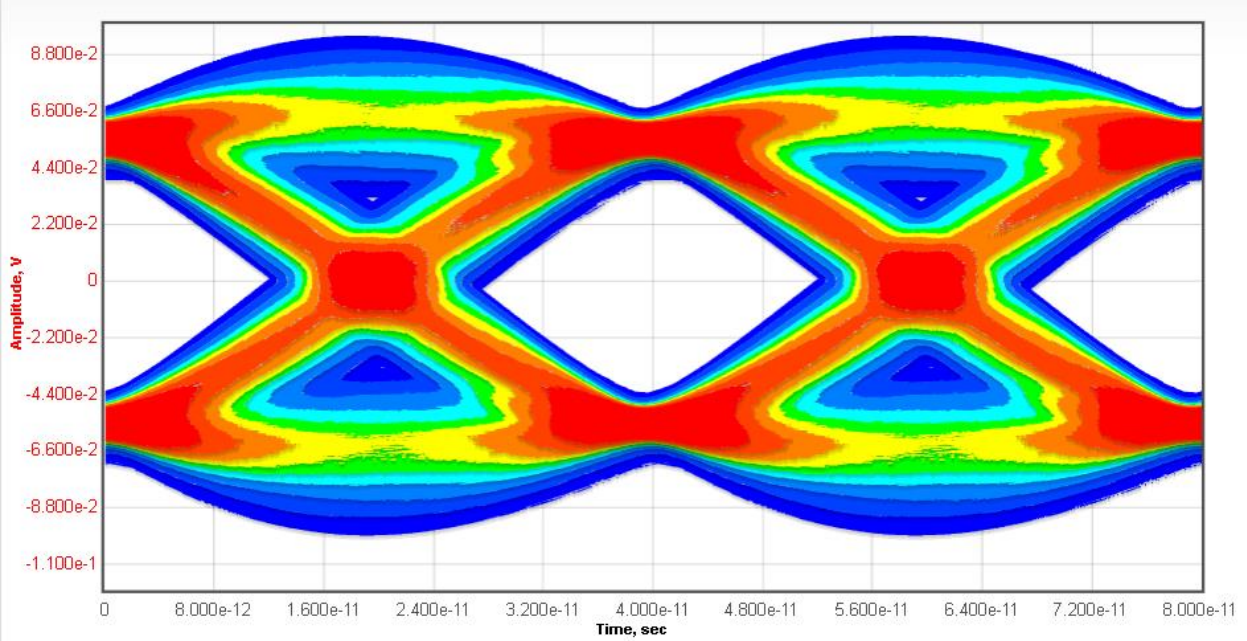
With Bit-by-Bit mode simulating 1,000,000 UIs, the resultant eye density plot is shown here. Observe that this eye has marginal NRZ performance at 25 Gbps.




The SerDes system discussed here uses NRZ signaling with these constituent parts:

- Bit rate = 25 Gbps; simulated with 32 samples per bit.
- Tx IBIS-AMI model
  - Tx FFE with 3 pre-cursor and 3 post-cursor taps.
- No TxPkg.
- Channel defined with S4P file with 30 dB loss at Nyquist (12.5 GHz) for the differential transmission path.
- No RxPkg.
- Rx IBIS-AMI model
  - RxSerDes_CTLE IBIS-AMI model.
  - Using SerDesDesign.com built-in Back Channel Training with the Tx model.

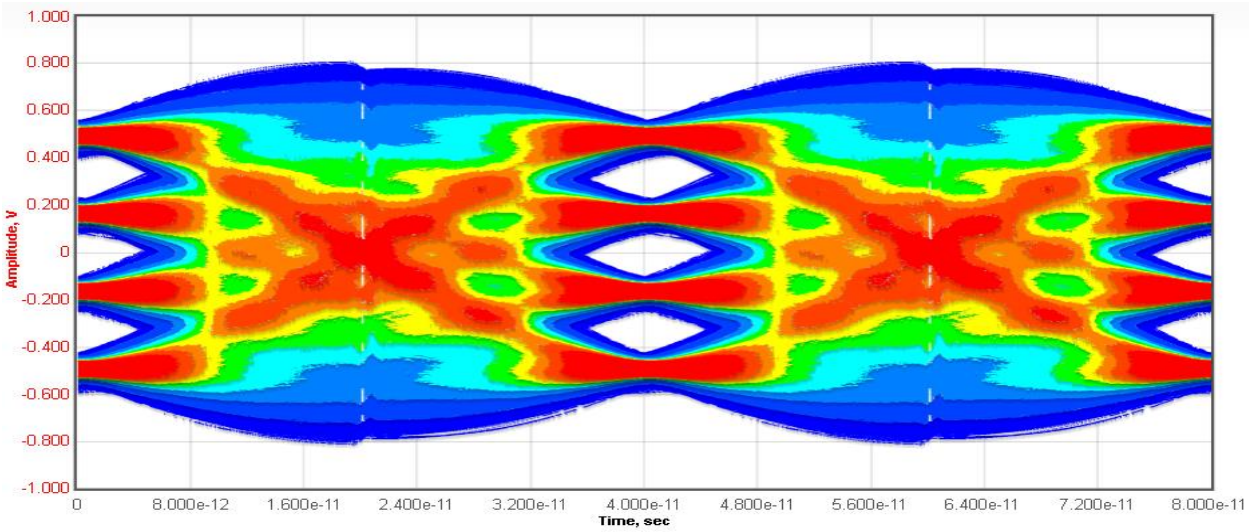
With Bit-by-Bit mode simulating 1,000,000 UIs, the resultant eye density plot is shown here. Observe the improved eye performance with the use of the SerDesDesign.com built in Back Channel Training with 25 Gbps.



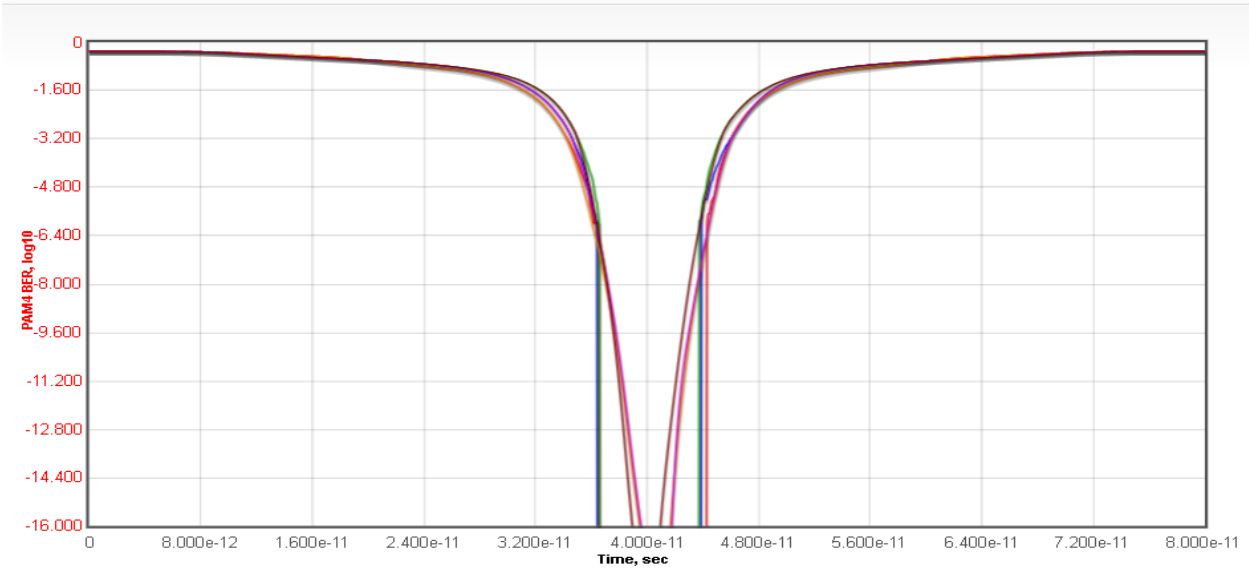

The SerDes system discussed here uses PAM4 signaling with these constituent parts:

- PAM4 Baud rate = 25 Gbps (50 Gbps); simulated with 64 samples per symbol.
- Tx IBIS-AMI model
  - Tx FFE with 3 pre-cursor and 3 post-cursor taps.
- No TxPkg.
- Channel defined with S4P file with 30 dB loss at Nyquist (12.5 GHz) for the differential transmission path.
- No RxPkg.
- Rx IBIS-AMI model
  - RxSerDes_CTLE IBIS-AMI model.
  - Using SerDesDesign.com Rx AGC applied.
  - Using SerDesDesign.com Rx Nonlinearity applied.
  - Using SerDesDesign.com Rx CDR applied.
  - Using SerDesDesign.com Rx DFE applied.
  - Using SerDesDesign.com built-in Back Channel Training with the Tx model.

With Bit-by-Bit mode simulating 1,000,000 UIs, the resultant eye density plot is shown here. Observe that the RxCTLE model with the additional Tx FFE using Back Channel Training and the Rx AGC, nonlinearity, CDR and DFE results in excellent PAM4 performance for the same channel but with 50 Gbps.




**PAM4 Eye timing bathtub BER for system vs time**




Thus, an RxCTLE that gives marginal NRZ performance gives excellent performance at double the bit rate using PAM4 and additional Tx/Rx features.

## Topics for Further Consideration

Additional SerDesDesin.com Premium Tools are available with local download and installation on a user's Windows 64-bit PC.

For details see the links:

https://www.serdesdesign.com/home/web_documents/SerDes_Design_Premium_Tool.pdf

https://www.serdesdesign.com/home/store/

See these store options:

- **Description; Guarantee; Webinar;** Premium Tool – SerDes_System_Tool

- **Guarantee**; Premium Tool – SerDes_IBIS-AMI_Model_Generation_Tool
- This an add-on to the SerDes System Tool and includes the SerDesDesign.com IBIS-AMI Model Development Environment for Windows/Linux.

- **Guarantee**; Premium Tool – SerDes IBIS-AMI TxFFE Modeling Tool

- **Description**; **Guarantee**; **Webinar**; Premium Tool – SerDes IBIS-AMI Rx/Tx CTLE Modeling Tool

- **Guarantee;** Premium Tool – SerDes IBIS-AMI Rx CTLE with Nonlinearity Modeling Tool; includes the SerDes IBIS-AMI Rx/Tx CTLE Modeling Tool.

## Terms and Conditions

See terms and conditions for IBIS-AMI Modeling are at this link: **Terms & Conditions | Privacy Policy**