Subject: SerDesDesign.com TxFFE_BB_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 Tx FFE Black Box 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 See this file for instructions on installing this tool and its directory structure.

This Tx Tool has this directory structure:

C:/AMI/FFE/TxAMI_Solution_SerDes_FFE_BB - SerDesDesign.com IBIS-AMI build directory.
C:/AMI/FFE/TxFFE_BB_Modeling_Tool - Tx FFE Modeling Tool.
C:/AMI/FFE/TxWaveformData – directory for the circuit data files.

Circuit Data Collection

The circuit is assumed to be for a SerDes receiver (Tx) feed forward equalizer (FFE) with differential outputs that interface with a differential SerDes channel.

The data to be collected is:

- The Tx circuit output differential impedance versus frequency.
- The Tx circuit FFE output waveform for each FFE state.

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

Place this circuit data into the directory C:\AMI/FFE\TxWaveformData.

Within that directory create the file InputFileNameList.txt which is to contain a list of all the FFE waveform files in the proper order. Start with zero pre and post cursor. For each post cursor, list the sequence of pre-cursor files. Ending with the file with the maximum post and re-cursor.

Within that directory create the file InputFileDiveNameList.txt which is to contain a list of all the FFE drive waveform files in the proper order. Start with the largest drive level; ending with the lowest drive level.

Setting up the TxFFE Modeling Tool

The TxFFE Modeling tool is in the directory C:\AMI\FFE\TxFFE_BB_Modeling_Tool.

Within that directory, the file DataFiles\TxFFE_BB_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 <…>.

SetupAnalysis MaxBitRate 28.0625e9 SamplesPerBit 32 MinBitRate 1.0e9 NumPostCusors 17 NumPreCursors 13 NumDriveLevels 14

TxFFE_BB_Modeling DirName C:\AMI\Tools\FFE\TxWaveformData IBIS_SParamFile TX_IBIS.s2p SkipLines 1

Line 1: SetupAnalysis MaxBitRate <max_bit_rate> SamplesPerBit <samples_per_bit> MinBitRate <min_bit_rate> NumPostCursors <num_post_cursors> NumPreCursors <num_pre_cursors> NumDriveLevels <num_drive_levels>

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

<samples_per_bit>: for the max_bit_rate, can remain at 32.

<min_bit_rate>: this is the minimum bit rate; at least 10X smaller than max_bit_rate; where 32*MaxBR/MinBR is an integer.

<num_post_cursors>: number of FFE post cursor states in the listed files.

<num_pre_cursors>: number of FFE pre-cursor states in the listed files.

<num_drive_levels>: number of FFE drive levels in the listed files.

Line 2: TxFFE_BB_Modeling DirName <waveform_dir_name> IBIS_SParamFile <s2p_filename> SkipLines <skip_lines>

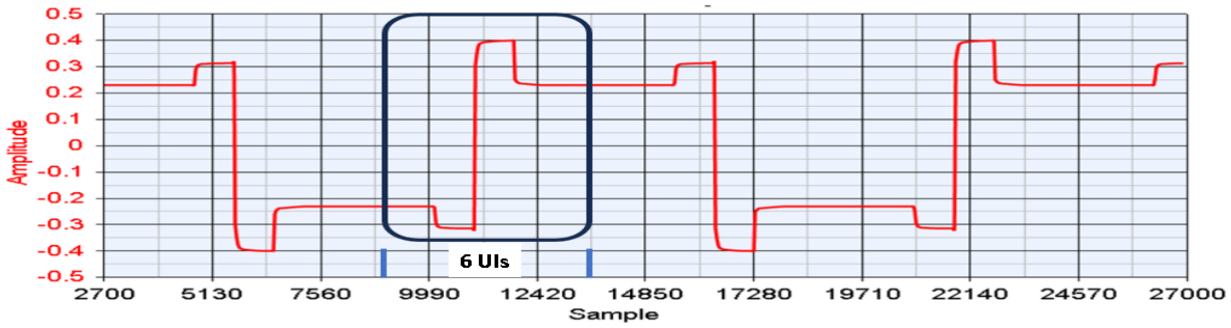
<waveform_dir_name>: can remain at C:\AMIFFE\TxWaveformData.

<s2p_filename>: Name of the s2p data file.

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

Discussion:

It is assumed that all FFE waveform files use the same NRZ data pattern and the same time samples. As such, all files have the same NRZ segment with the output waveform collected using MinBR with an NRZ repeating pattern of 6 1's and 6 0' as shown in this figure. A waveform segment 6 UI's long is captured to file; with 1 UI before the precursor and 2 UI after the post cursor.



With one FFE precursor and postcursor, these assumptions are made:

- The precursor/postcursor has K/L values that can be positive or negative (default).
- The FFE has M drive levels.
- Set 1: Collect waveforms for each drive level with the pre/post-cursors set to zero. If M = 14, then 14 waveforms are collected.
- Set 2: With max drive level, collect waveforms with the negative pre/post-cursor values; it is assumed the positive pre/post-cursor waveforms are inverted from that for the negative pre/post-cursors. If K=13 and L=17, then 221 waveforms are collected.

There is one file for each Tx SerDes state. The output file is a text file with these columns.

- Column 1: time
- Column 2: Tx SerDes output into properly terminated load resistance (S2P sdd11 at 0 Hz).

Use a filename that includes the Tx SerDes name, the corner case name, and the names of any control parameters.

Running the TxFFE BB Modeling Tool

The TxFFE BB Modeling tool is run by selectin the batch file
C:\AMI\FFE\TxFFE_BB_Modeling_Tool\TxFFE_BB_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\FFE\TxFFE_BB_Modeling_Tool>TxFFE_BB_Modeling_Tool.exe  TxFFE_BB_Modeling.txt

*** Starting TxFFE_BB_Modeling_Tool
NumPostCursors * NumPreCursors = 221
MaxBitRate = 2.80625e+10
SamplesPerBit = 32
MinBitRate = 1e+09
NumPostCusors = 17
NumPreCursors = 13
NumDriveLevels = 14
MinBitRate SamplesPerBit = 898 for the given MaxBitRate, SamplesPerBit, and MinBitRate.
*** Completed Analysis Setup.
DirName = C:\AMI\FFE\TxWaveformData
IBIS_SParamFile = TxSerDes_IBIS.s2p
SkipLines = 1
*** Completed TxFFE_BB_Modeling_Tool Setup.
```

```
Exiting TxFFE_BB_Modeling_Tool with success.

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

The process produces its log files in the TxWaveformData directory: Log_TxFFE_Modeling_Tool.log.

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

Step 1: Combine the circuit waveform files.

```
*** Starting TxFFE_BB_ResampleWaveform
    Running TxFFE_BB_ResampleWaveform Sweep
    Running TxFFE_BB_ResampleWaveform Sweep_Drive
    For detail log, see file:  C:\AMI\FFE\TxWaveformData\Log_ResampleWaveformData.log
    Generated file:  C:\AMI\FFE\TxWaveformData\Combined.csv
    Generated file:  C:\AMI\FFE\TxWaveformData\Combined_Drive.csv
*** Completed TxFFE_BB_ResampleWaveform
```

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

```
*** Starting TxFFE_BB_GenerateIBIS_Impulse
    Running TxFFE_BB_GenerateIBIS_Impulse Convert IBIS S2P to impulse response; this may take several minutes.
    For detail log, see file:  C:\AMI\FFE\TxWaveformData\Log_GenerateIBIS_Impulse.log
    Generated files:
              C:\AMI\FFE\TxWaveformData\TxSerDes_IBIS.s2p.s4p
              C:\AMI\FFE\TxWaveformData\TxSerDes_IBIS.s2p.ImpulseResponse.csv
*** Completed TxFFE_BB_GenerateIBIS_Impulse
```

Step 3: Deembed the IBIS impulse from the output waveform segment to achieve the step response data for the AMI model.

```
*** Starting TxFFE_BB_DeembedIBISResp
    Running Get OutputStepData.
    Running Get OutputDriveStepData.
    Running Get IBIS_ImpulseData.
    Running Deembed Output with IBIS_ImpulseData.
    Running Deembed Drive with IBIS_ImpulseData.
    For detail log, see file:  C:\AMI\FFE\TxWaveformData\Log_DeembedIBISResp.log
    Generated files:
              C:\AMI\FFE\TxWaveformData\Combined.WithIBISDeembedded.csv
              C:\AMI\FFE\TxWaveformData\Combined_Drive.WithIBISDeembedded.csv
*** Completed TxFFE_BB_DeembedIBISResp
```

The log file, Log_DeembedIBISResp.log, shows the test results.

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

Three files are used in creating the Tx FFE IBIS-AMI model:

- TxSerDes_IBIS.s2p.s4p (rename your *.s2p.s4p file to this name).
- Combined.WithIBISDeembedded.csv
- Combined_Drive.WithIBISDeembedded.csv

Generating the TxFFE BB IBIS-AMI Model

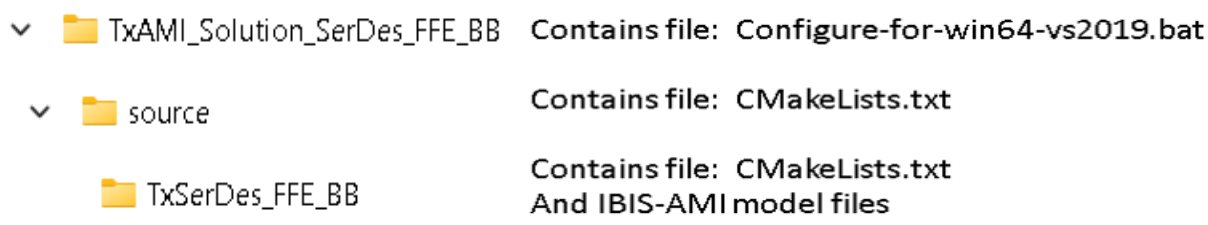
This section provides instructions on building the IBIS-AMI models – only with the instructions needed to be successful. This section does not include detail discussion of these steps, the reasons for these steps, the structure of the files generated, or other such detail. That detail is available in the separate SerDesDesign.com product called the 'SerDesDesign.com IBIS-AMI Model Development Environment'. The content included with this TxFFE 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 TxAMI_Solution_SerDes_FFE_BB directory is used for building the IBIS-AMI model. It has this structure:



As identified in the prior section, three files from the prior section are used in creating the Tx FFE BB IBIS-AMI model:

- TxSerDes_IBIS.s2p.s4p (rename your *.s2p.s4p file to this name).
- Combined.WithIBISDeembedded.csv
- Combined_Drive.WithIBISDeembedded.csv

Copy these files to the TxSerDes_FFE_BB 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.

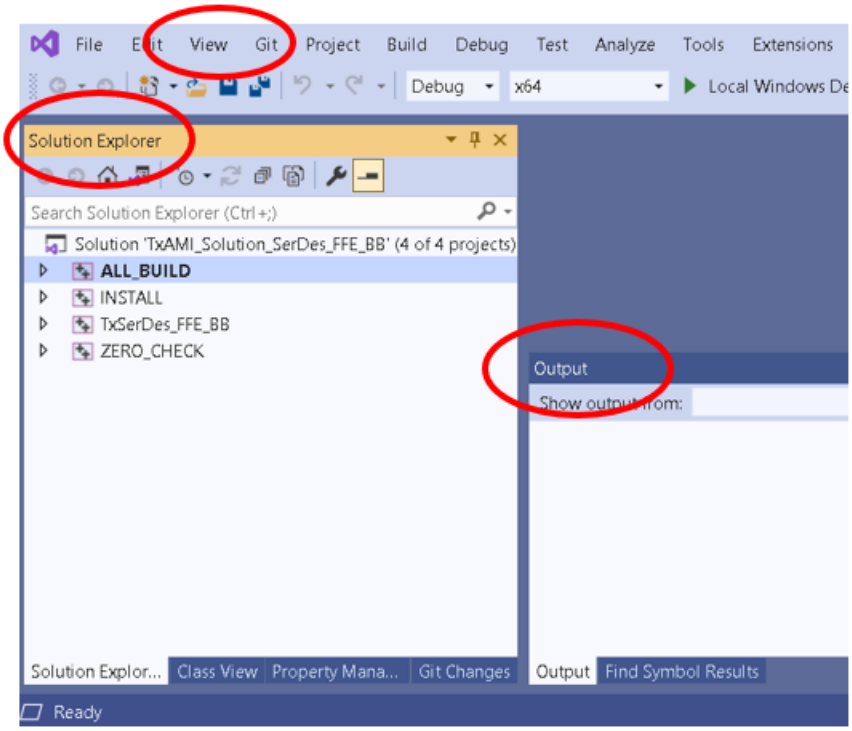
```
C:\AMI\FFE\TxAMI_Solution_SerDes_FFE_BB>cd build-win64-vs2019

C:\AMI\FFE\TxAMI_Solution_SerDes_FFE_BB\build-win64-vs2019>cmake -Wno-dev -DCMAKE_INSTALL_PREFIX=.
./output-vs2019 -G "Visual Studio 16" -A x64 ../source
-- Forcing /MD.
-- Selecting Windows SDK version 10.0.22000.0 to target Windows 10.0.22621.
-- The C compiler identification is MSVC 19.29.30147.0
-- The CXX compiler identification is MSVC 19.29.30147.0
-- Detecting C compiler ABI info
-- Detecting C compiler ABI info - done
-- Check for working C compiler: C:/Program Files (x86)/Microsoft Visual Studio/2019/Community/VC/
Tools/MSVC/14.29.30133/bin/Hostx64/x64/cl.exe - skipped
-- Detecting C compile features
-- Detecting C compile features - done
-- Detecting CXX compiler ABI info
-- Detecting CXX compiler ABI info - done
-- Check for working CXX compiler: C:/Program Files (x86)/Microsoft Visual Studio/2019/Community/V
C/Tools/MSVC/14.29.30133/bin/Hostx64/x64/cl.exe - skipped
-- Detecting CXX compile features
-- Detecting CXX compile features - done
-- Forcing /MD.
-- Configuring done
-- Generating done
-- Build files have been written to: C:/AMI/FFE/TxAMI_Solution_SerDes_FFE_BB/build-win64-vs2019

C:\AMI\FFE\TxAMI_Solution_SerDes_FFE_BB\build-win64-vs2019>cd ..

C:\AMI\FFE\TxAMI_Solution_SerDes_FFE_BB>pause
Press any key to continue . . .
```

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

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

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

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

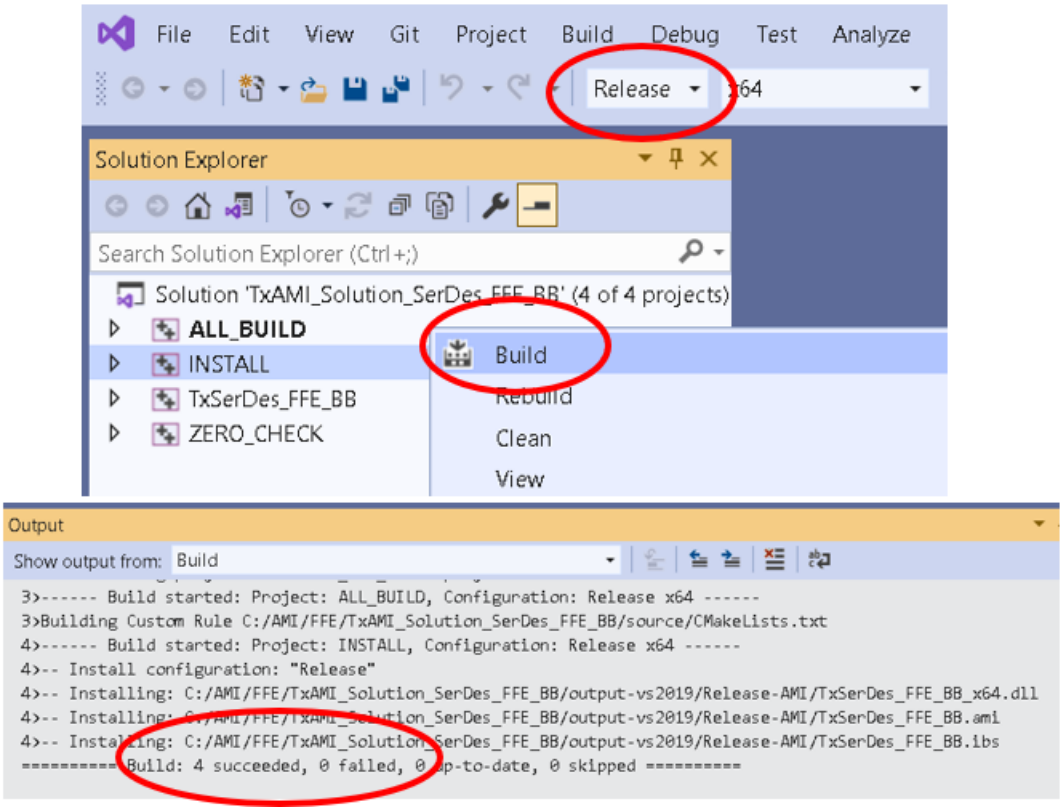


Observe the display for the '**Solution Explorer**' and '**Output**' windows.

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

The IBIS/AMI/Source code is in the TxSerDes_FFE_BB 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 TxSerDes_FFE_BB.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 TxAMI_Solution_SerDes_FFE_BB 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 Tx 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 TxWaveformData directory.

These files are:

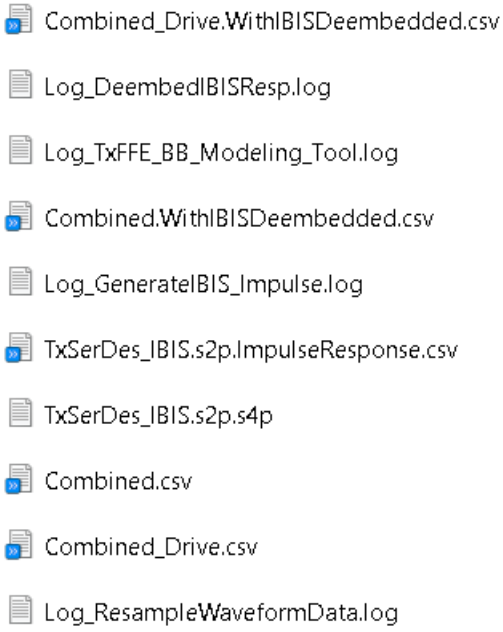
- TxSerDes_IBIS.s2p - the Tx circuit differential input S-parameters.
- Drive_<n>.csv – the 14 waveform files (n=0 to 13) for the 14 Drve states.
- InputFileDriveNameList.txt – the text file with 14 lines listing the 14 Drive waveform file names.
- Post_<n>_Pre_<m>.csv – the 221 waveform files; (n=0 to 16) for the 17 post cursor states; (m=0 to 12) for the 13 pre cursor states;
- InputFileNameList.txt – the text file with 221 lines listing the 221 post/pre cursor waveform file names.

The example setup for the TxFFE BB Modeling Tool is defined in the file TxFFE_BB_Modeling.txt in the TxFFE_BB_Modeling_Tool\DataFiles directory. This file has these two lines:

- SetupAnalysis MaxBitRate 28.0625e9 SamplesPerBit 32 MinBitRate 1.0e9 NumPostCusors 17 NumPreCursors 13 NumDriveLevels 14
- TxFFE_BB_Modeling DirName C:\AMI\FFE\TxWaveformData IBIS_SParamFile TxSerDes_IBIS.s2p SkipLines 1

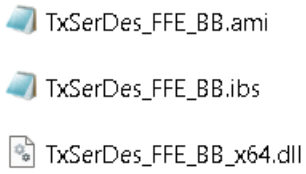
Notice the value provided in these two lines that are specific for this set of example circuit data files.

The TxFFE BB Modeling Tool is run by double clicking on the batch file TxFFE_BB_Modeling.bat in the TxFFE_BB_Modeling_Tool directory and results in these generated files in the TxWaveformData directory.



The three files TxSerDes_IBIS.s2p.s4p, Combined.WithIBISDeembedded.csv, and Combined_Drive.WithIBISDeembedded.csv are copied to the TxAMI_Solution_SerDes_FFE_BB\source\TxSerDes_FFE_BB directory.

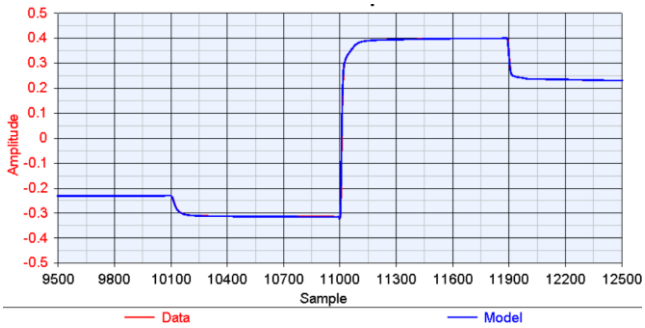
When the Visual Studio solution is generated and the Visual Studio build process is run, these files are generated in the AMI_Solution_TxSerDes_FFE\output-vs2019\Release-AMI directory.



These three files along with the TxSerDes_IBIS.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 TxSerDes_FFE_BB 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 FFE with typical equalization. In all cases, the Model waveform response is equal to the Data waveform response.



Topics for Further Consideration

Additional SerDesDesign.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; add-on to the SerDes System Tool; includes the SerDesDesign.com IBIS-AMI Model Development Environment for Windows/Linux.
- **Description**; **Guarantee**; **Webinar**; 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 Front End 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**