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Standard Compliant IBIS-AMI Model for System Sign-off with USB4 Gen2 As an Example

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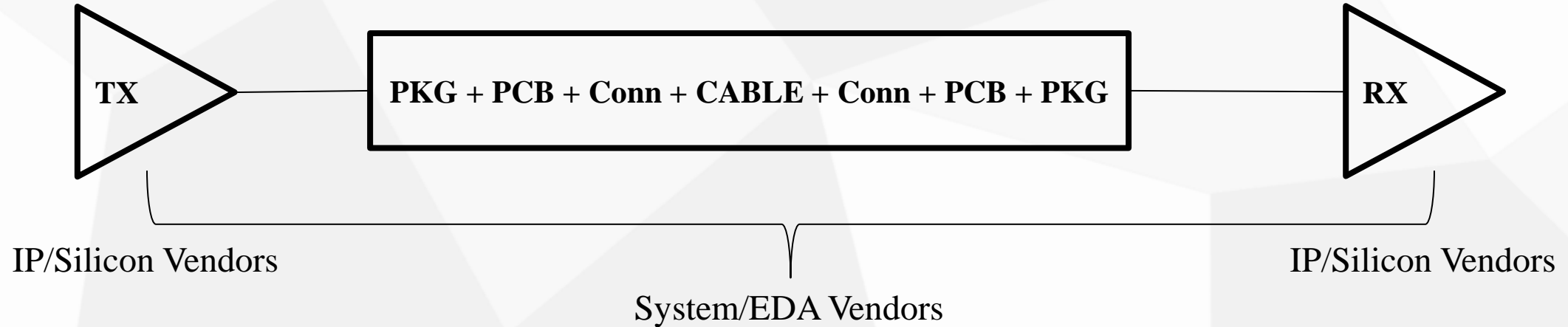
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Missouri S&T EMC lab & JAY Plus Inc



- Background
- Build Standard TX Compliant IBIS-AMI Model Approach
- Build Standard RX Compliant IBIS-AMI Model Approach
- IBIS-AMI Auto Verification



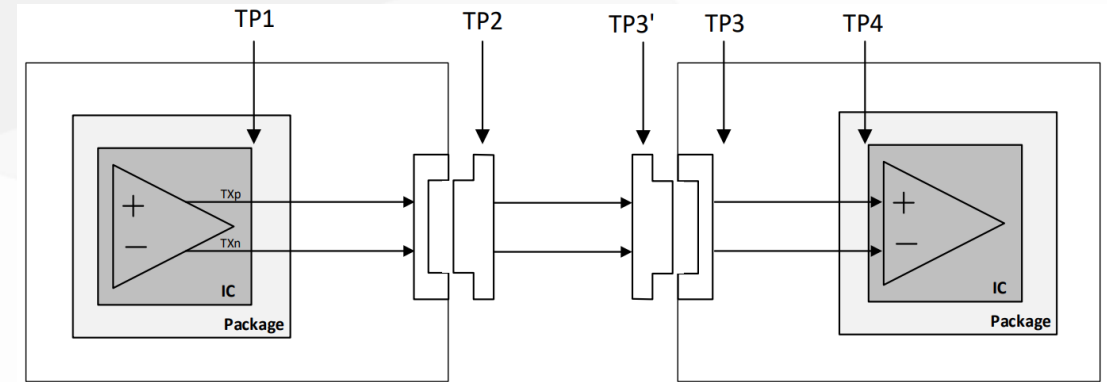
Who needs Standard IBIS – AMI model?



- **System vendors** would like to use the IBIS-AMI model of the IP vendors to verify whether their system meets the compliance test requirements.
- We propose a standard IBIS-AMI model that meets the **minimum protocol standards for system vendors** to test whether the system design meets the compliance test of the corresponding protocols when lack of IP models.

What is Compliance Test?

To deliver a good product for the system supplier, the IP vendors have to pass the correlated protocols, such as USB, PCIe, etc. Here we use USB4 GEN2 as an example.



Compliance Points Definition

Test Point	Description	Comments
TP1	Transmitter IC output	Not used for electrical testing.
TP2	Transmitter port connector output	Measured at the plug side of the connector.
TP3	Receiver port connector output	Measured at the receptacle side of the connector. All the measurements at this point shall be done while applying reference equalization function.
TP3'	Receiver port connector input	Measured at the plug side of the connector.
TP4	Receiver IC input	Not used for electrical testing.

Table1. Electrical Compliance Test Points

Compliance Test: When the product is measured by standard equipment and all test items meet the specification requirements, the product passes the compliance test and can be compatible with other manufacturers' products.

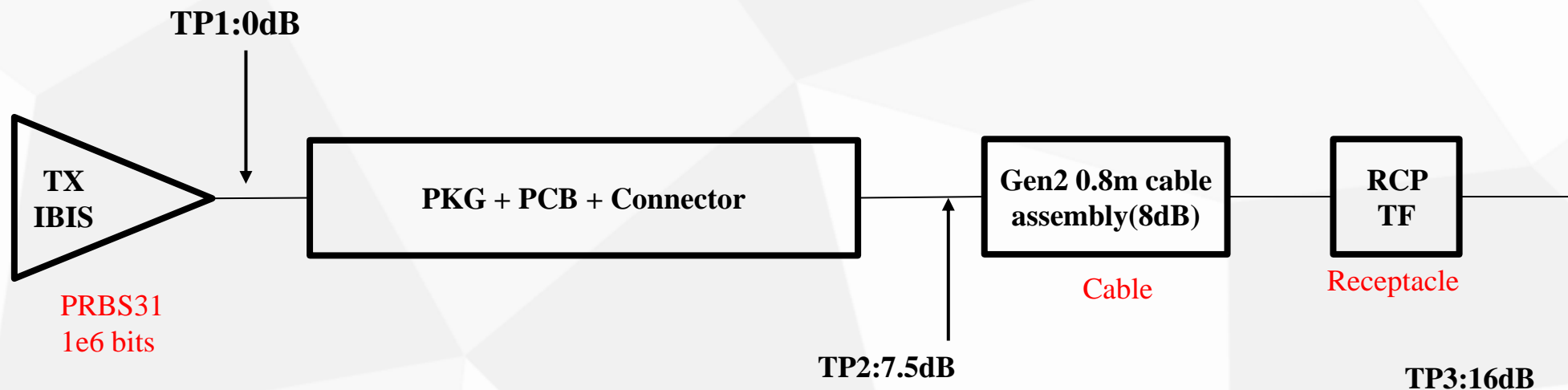


**Build Standard TX Compliant
IBIS-AMI Model Approach**



Standard TX IBIS-AMI Model Construction

➤ Step 1: Build TX Compliance Test Structure



From USB4 Gen2 protocol, it specified the TP1, TP2 and TP3 test point.

- The bit pattern needs to be PRBS31 and 1M bits.
- From TP1 to TP2, the channel loss is specified to be lower than 7.5dB, since we are going to build a model which can marginally pass the TP2/TP3 requirement, we choose a PCB with **7.5dB**.
- From TP1 to TP3, the channel loss needs to be lower than 17dB, therefore USB4 GEN2 standard cable model with 8dB loss from USB website is used for the model construction.

TX Compliance Test Requirement

➤ Step 2: TP2/TP3 Requirement

Item	Description	TP2		TP3	
		Minimum	Maximum	Minimum	Maximum
Y1(mV)	TX eye inner height	140	-	53	-
Y2(mV)	TX eye outer height	-	650	-	650
TJ(UI)	Total Jitter	-	0.38	-	0.6
UJ(UI)	Sum of uncorrelated DJ and RJ components (all jitter components except for DDJ)	-	0.31	-	0.31
DDJ(UI)	Data-Dependent Jitter	-	0.15	-	-
UDJ(UI)	Deterministic jitter that is uncorrelated to the transmitted data	-	0.17	-	0.17
DCD(UI)	Even-odd jitter associated with Duty-Cycle-Distortion	-	0.03	-	-

Table2. USB4 Gen2 Transmitter Specifications

Item	Description	Min	Max	Units
RL_DIFF	Differential Return Loss, 0.05–12 GHz	-	$SDD22(f) = \begin{cases} -8.5 & 0.05 < f_{GHz} \leq 3 \\ -3.5 + 8.3 \cdot \log_{10}\left(\frac{f_{GHz}}{12}\right) & 3 < f_{GHz} \leq 12 \end{cases}$	dB
RL_COM M	Common Mode Return Loss, 0.05–12 GHz	-	$SCC22(f) = \begin{cases} -6 & 0.05 < f_{GHz} \leq 2.5 \\ -3 & 2.5 < f_{GHz} \leq 12 \end{cases}$	dB
TX_EQ	Transmitter Equalization Setting	-	Refer to Table 3-4	-
LANE_TO_LANE_SKE W	Skew between dual transmit signals of the same USB4 Port	-	26	ns
RISE_FALL_TIME	TX rise/fall time measured between 20-80% levels	10	-	ps
V_ELEC_IDLE	Peak voltage during transmit electrical idle	-	20	mV
V_TX_DC_AC_CONN	Instantaneous DC+AC voltages at the connector side of the AC coupling capacitors	-0.5 (min1) -0.3 (min2)	1.0	V

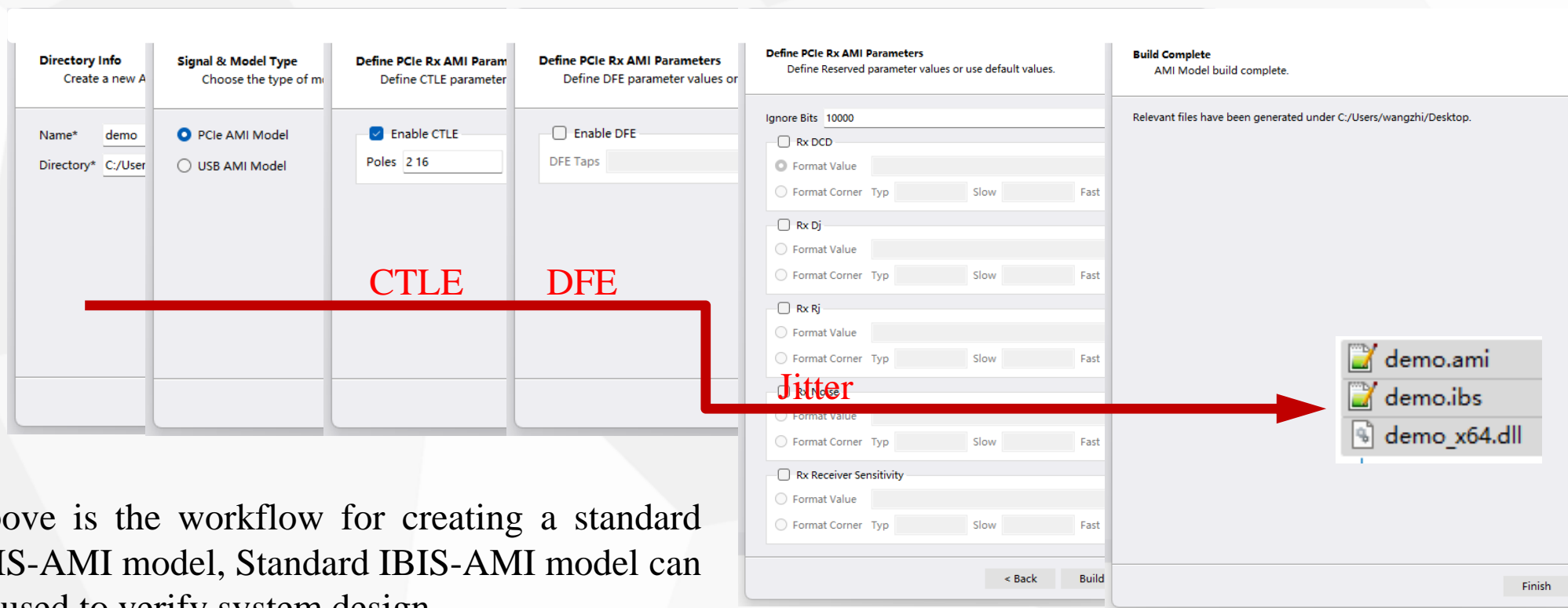
Table3. Transmitter Specifications for USB4 Gen2(at TP2)



Standard TX IBIS-AMI Model Construction

➤ Step 3: Generate the Standard TX Compliant IBIS-AMI Model

Tune the minimum standard IBIS model by adjusting the parameters in the AMI model. The following is the IBIS-AMI model generated according to the official protocols of USB and PCIE, and the AMI parameters in it can be adjusted to obtain the IBIS-AMI model required for system compliance testing.



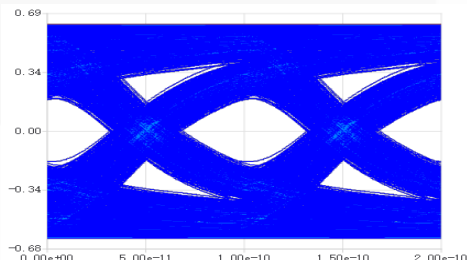
Above is the workflow for creating a standard IBIS-AMI model, Standard IBIS-AMI model can be used to verify system design.

Tuning of IBIS file parameters will be added later...

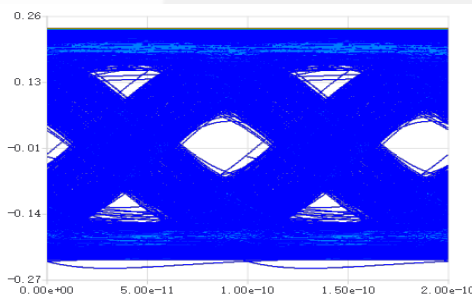


Model Validation

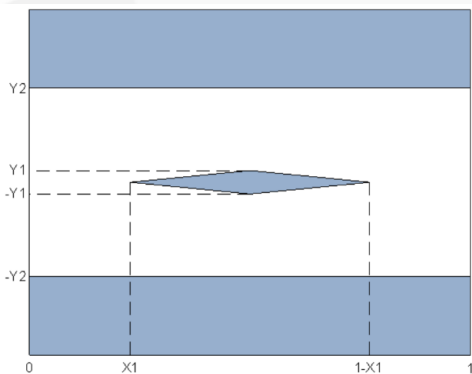
➤ Step 4: Validate the Standard TX Compliant IBIS-AMI Model (TP2:8.3dB, TP3:17dB)



@TP2(eye diagram)



@TP3(eye diagram)



@TX Mask Notations

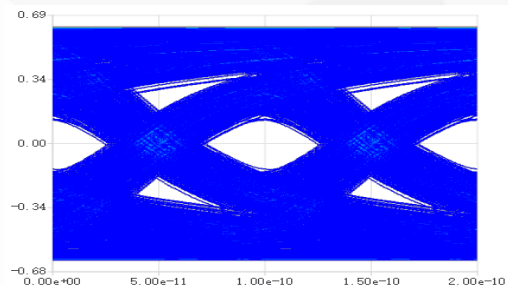
Item	Description	TP2		Standard Channel Simulate Result	Pass/Fail	TP3		Standard Channel Simulate Result	Pass/Fail
		Minimum	Maximum			Minimum	Maximum		
X1(UI)	TX eye horizontal deviation	-	-	-	-	-	0.23	0.2	Pass
Y1(mV)	TX eye inner height	140	-	180	Pass	53	-	60	Pass
Y2(mV)	TX eye outer height	-	650	640	Pass	-	650	640	Pass
TJ(UI)	Total Jitter	-	0.38	0.38	Pass	-	0.6	0.60	Pass
UJ(UI)	Sum of uncorrelated DJ and RJ components (all jitter components except for DDJ)	-	0.31	×		-	0.31	×	
DDJ(UI)	Data-Dependent Jitter	-	0.15	×		-	-	×	-
UDJ(UI)	Deterministic jitter that is uncorrelated to the transmitted data	-	0.17	×		-	0.17	×	

×: Not supported

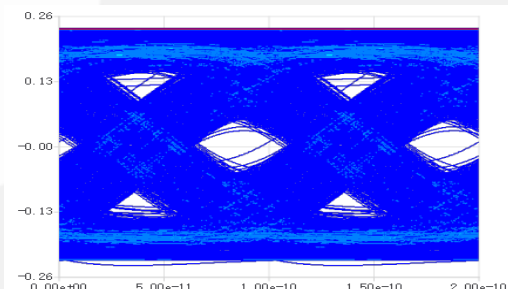


Model Validation

➤ Step 5: Validate the Standard TX Compliant IBIS-AMI Model (TP2:9.6dB, TP3:18dB)



@TP2(eye diagram)



@TP3(eye diagram)

Item	Description	TP2		Channel Simulate Result	Pass/Fail	TP3		Channel Simulate Result	Pass/Fail
		Minimum	Maximum			Minimum	Maximum		
X1(UI)	TX eye horizontal deviation	-	-	-	-	-	0.23	0.2	Pass
Y1(mV)	TX eye inner height	140	-	120	Fail	53	-	50	Fail
Y2(mV)	TX eye outer height	-	650	630	Pass	-	650	230	Fail
TJ(UI)	Total Jitter	-	0.38	0.49	Fail	-	0.6	0.60	Pass
UJ(UI)	Sum of uncorrelated DJ and RJ components (all jitter components except for DDJ)	-	0.31	×		-	0.31	×	
DDJ(UI)	Data-Dependent Jitter	-	0.15	×		-	-	×	-
UDJ(UI)	Deterministic jitter that is uncorrelated to the transmitted data	-	0.17	×		-	0.17	×	

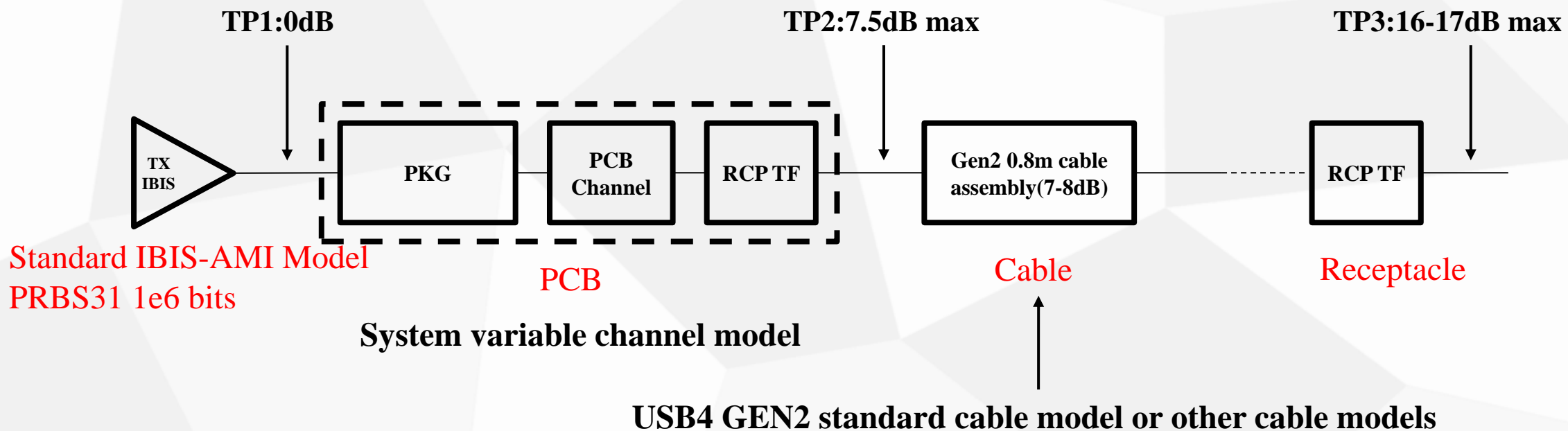
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System TX Compliance Test Workflow

How system vendors use the standard IBIS-AMI model ?

The constructed standard compliant TX IBIS – AMI model is used for the system compliance test. System vendors can use their designed PKG, PCB, Connector, and Cable to verify if the system pass the compliance test





System TX Compliance Test Results



Compliance Report

Person: NANO
Enterprise: DeToolLIC
Date: 2023/07/19 11:12:49

Useful Links

Detool website: <http://www.detooltech.com>

Compliance Test Simulation Setup

Item	Property
Protocol	Universal Serial Bus 4 (USB4) Router Assembly Electrical Compliance Test Specification
IBIS Path	C:/Users/wangzhi/Desktop/ibis-ami/demo.ibs
Bit Rate	1e+10 Hz

Compliance Test Results

Item	Protocol Spec	Simulation Results	Pass/Fail
[TP2: 8.3dB]TP2 Minimum Eye Inner Height(mV)	140	180	Pass
[TP2: 8.3dB]TP2 Maximum Eye Outer Height(mV)	650	640	Pass
[TP2: 8.3dB]TP2 Maximum Total Jitter(UI)	0.38	0.38	Pass
[TP3: 17dB]TP3 Maximum Eye Width(UI)	0.23	0.2	Pass
[TP3: 17dB]TP3 Minimum Eye Inner Height(mV)	53	60	Pass
[TP3: 17dB]TP3 Maximum Eye Outer Height(mV)	650	640	Pass
[TP3: 17dB]TP3 Maximum Total Jitter(UI)	0.6	0.6	Pass

Compliance test report with constructed IBIS-AMI model and protocol defined channel loss

Compliance Report

Person: NANO
Enterprise: DeToolLIC
Date: 2023/07/19 11:12:49

Useful Links

Detool website: <http://www.detooltech.com>

Compliance Test Simulation Setup

Item	Property
Protocol	Universal Serial Bus 4 (USB4) Router Assembly Electrical Compliance Test Specification
IBIS Path	C:/Users/wangzhi/Desktop/ibis-ami/demo.ibs
Bit Rate	1e+10 Hz

Compliance Test Results

Item	Protocol Spec	Simulation Results	Pass/Fail
[TP2: 9.6dB]TP2 Minimum Eye Inner Height(mV)	140	120	Fail
[TP2: 9.6dB]TP2 Maximum Eye Outer Height(mV)	650	630	Pass
[TP2: 9.6dB]TP2 Maximum Total Jitter(UI)	0.38	0.49	Fail
[TP3: 18dB]TP3 Maximum Eye Width(UI)	0.23	0.2	Pass
[TP3: 18dB]TP3 Minimum Eye Inner Height(mV)	53	50	Fail
[TP3: 18dB]TP3 Maximum Eye Outer Height(mV)	650	230	Fail
[TP3: 18dB]TP3 Maximum Total Jitter(UI)	0.6	0.6	Pass

Compliance test report with constructed IBIS-AMI model and channel loss higher than protocol defined

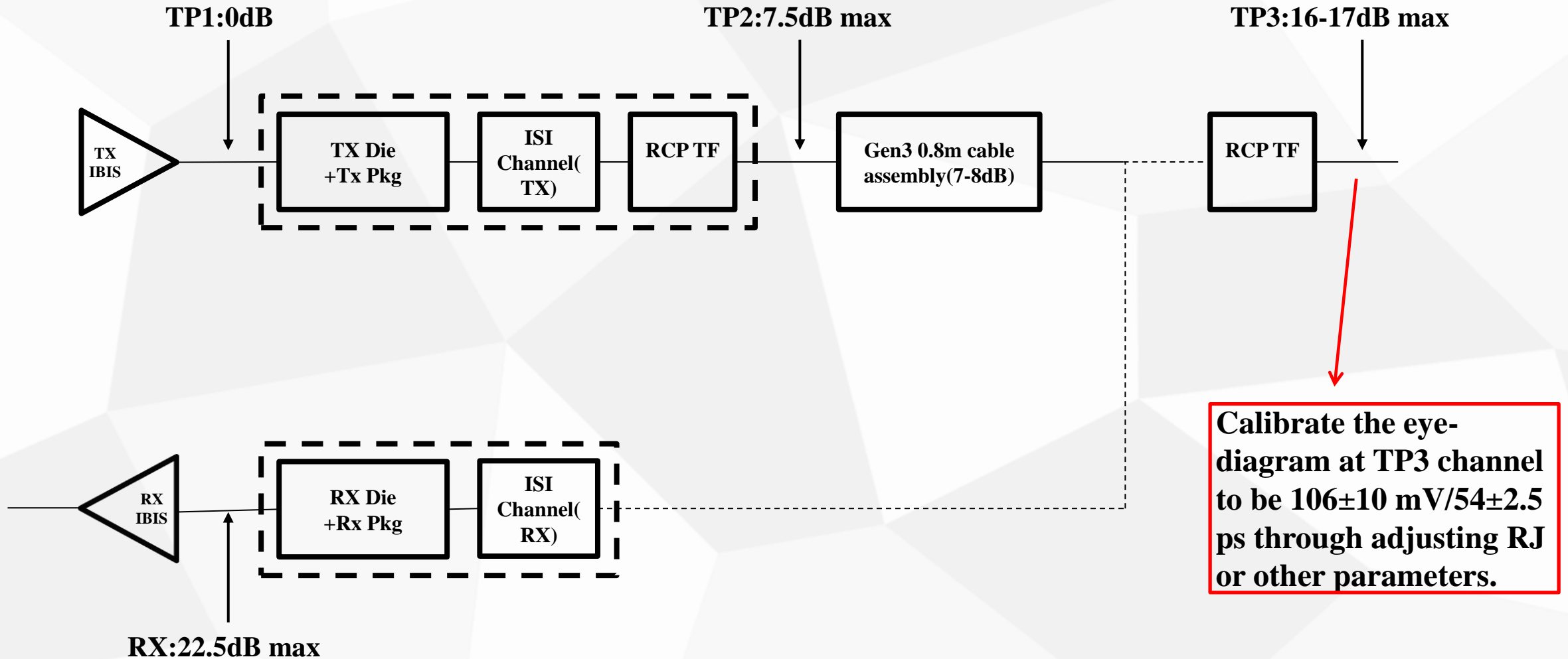
A faint, light gray world map is centered in the background of the slide, showing the continents of North America, South America, Europe, Africa, and Asia.

Build Standard RX Compliant IBIS-AMI Model Approach



Standard RX IBIS-AMI Model Construction

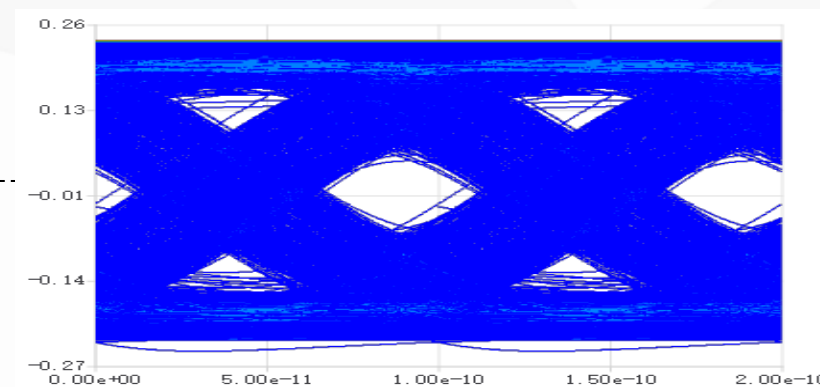
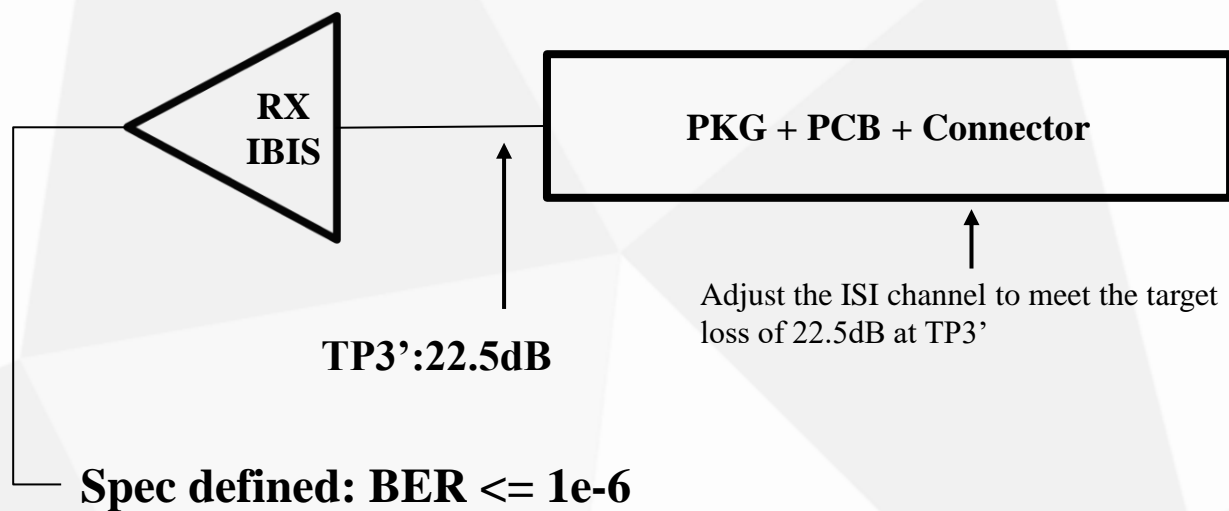
➤ Step 1: Build RX Compliance Test Structure





Standard RX IBIS-AMI Model Construction

- Step 2: Calibrate the eye-diagram at TP3 channel to be 106 ± 10 mV/ 54 ± 2.5 ps through adjusting RJ.

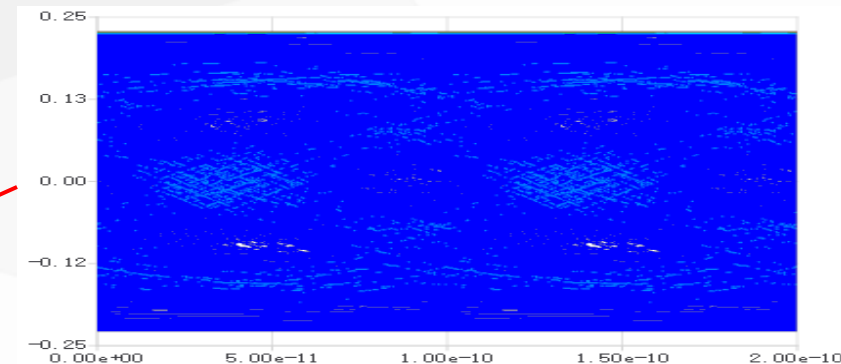


@TP3 Eye Diagram with 106 ± 10 mV/ 54 ± 2.5 ps

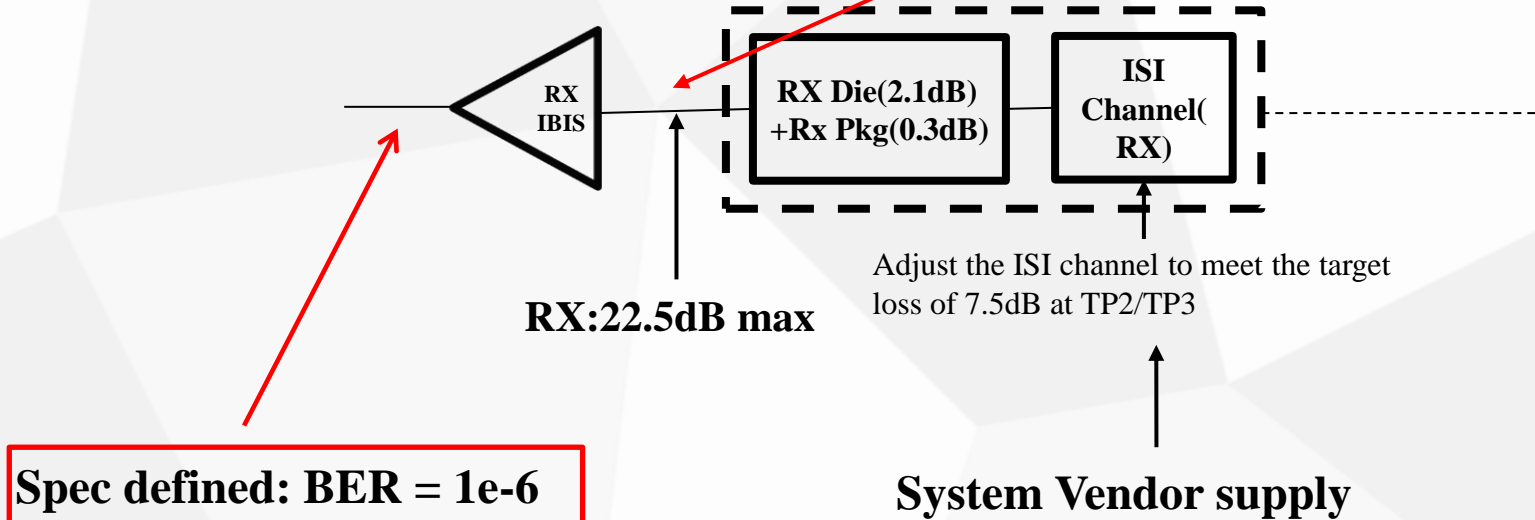


Model Validation

- **Step 4: Tune the channel at RX side to make the total loss of the system meet 22.5dB, and then tune the RX IBIS-AMI model to make the BER barely pass 1e-6.**

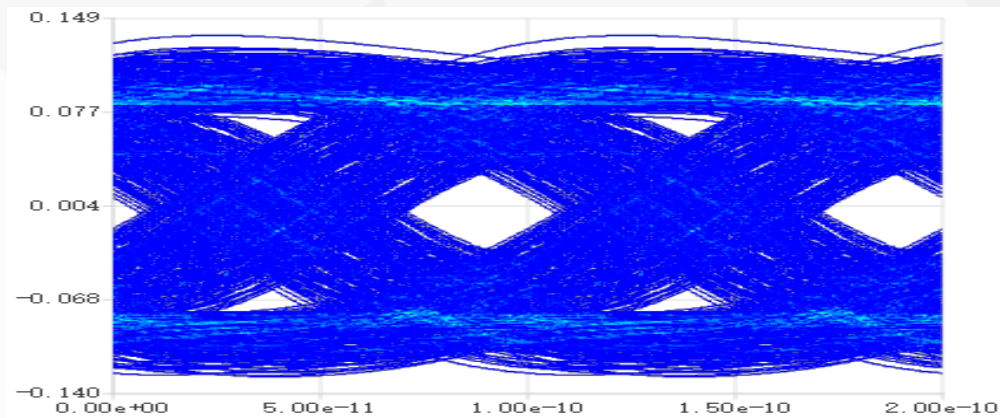


@before RX(eye diagram)





System RX Compliance Test Results(Channel Insertion loss: 22.5 dB)



With adaptive 1-tap DFE and CTLE

@RX(eye diagram)

Compliance Report

Person: NANO
Enterprise: DeToolIC
Date: 2023/07/19 11:12:49

Useful Links

Detool website: <http://www.detooltech.com>

Compliance Test Simulation Setup

Item	Property
Protocol	Universal Serial Bus 4 (USB4) Router Assembly Electrical Compliance Test Specification
IBIS Path	C:/Users/wangzhi/Desktop/ibis-ami/demo.ibs
Bit Rate	1e+10 Hz

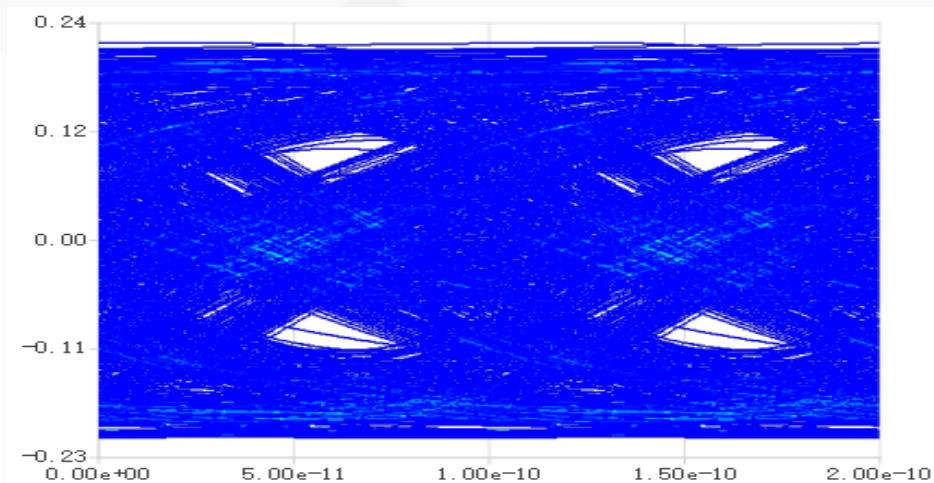
Compliance Test Results

Item	Protocol Spec	Simulation Results	Pass/Fail
[TP2: 22.5dB]Error Bit Number	0	0	Pass

@RX(compliance test report)



System RX Compliance Test Results(Channel Insertion loss: 23.2 dB)



With adaptive 1-tap DFE and CTLE

@RX(eye diagram)

Compliance Report

Person: NANO
Enterprise: DeToolIC
Date: 2023/07/19 11:12:49

Useful Links

Detool website: <http://www.detooltech.com>

Compliance Test Simulation Setup

Item	Property
Protocol	Universal Serial Bus 4 (USB4) Router Assembly Electrical Compliance Test Specification
IBIS Path	C:/Users/wangzhi/Desktop/ibis-ami/demo.ibs
Bit Rate	1e+10 Hz

Compliance Test Results

Item	Protocol Spec	Simulation Results	Pass/Fail
[TP2: 23.2dB]Error Bit Number	0	131	Fail

@RX(compliance test report)



IBIS – AMI Auto Verification



Auto Verification

Multi-rate, multi-channel validation of IBIS-AMI models, generation of validation test results, and viewing of eye diagram information.

The screenshot displays the DeToolIC software interface. On the left, a 'Test Report' window shows simulation results for a USB4 Gen2 signal. The report includes parameters such as RJ Amplitude (1.4e-11), PJ Frequency (1e+06Hz), and PJ Amplitude (1.7e-11CTLE: USB4 Gen2[0 dB], DFE: LMS). The results indicate a 'Fail' status with a 'Bit Error Number: 1032'. The main window shows a 'Multiple Channel' dialog box with fields for Bit Rate (5Gbps) and Unit (Gbps). Below the dialog, a 'Signal' section shows 'Select Component' set to 'pciex_tx' and 'Select Model' set to 'pciex_tx'. At the bottom, an eye diagram plot shows the signal waveform over time, with a blue background and a white signal trace.

- ◆ Multi-rate, multi-channel IBIS-AMI simulation, Generate compliance test report.
- ◆ Check whether the protocol compliance test requirements are met and generate a conformance test report.



Thank you

Any Questions?