DeTooLIC

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

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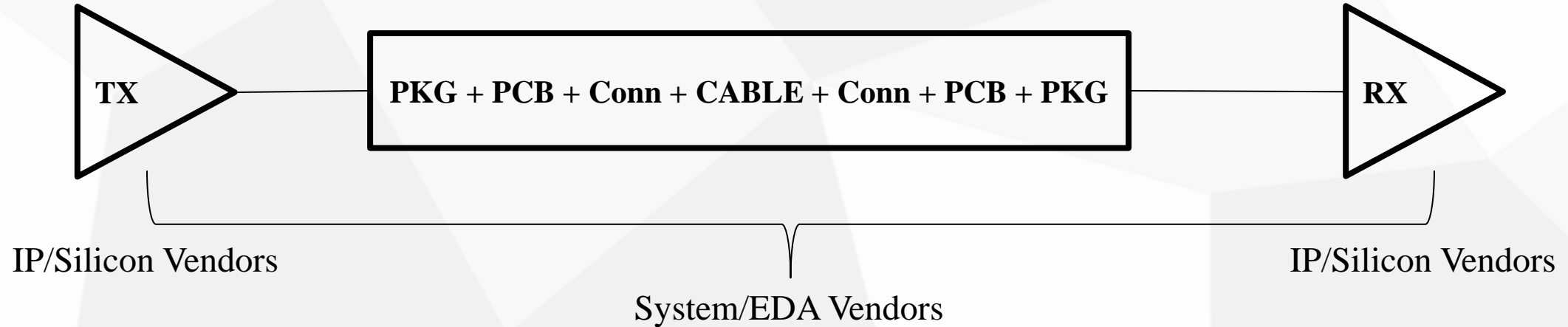Co-Author: Dr. Zhiping Yang
Missouri S&T EMC lab & JAY Plus Inc

Outline

➢ 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.

Background

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.
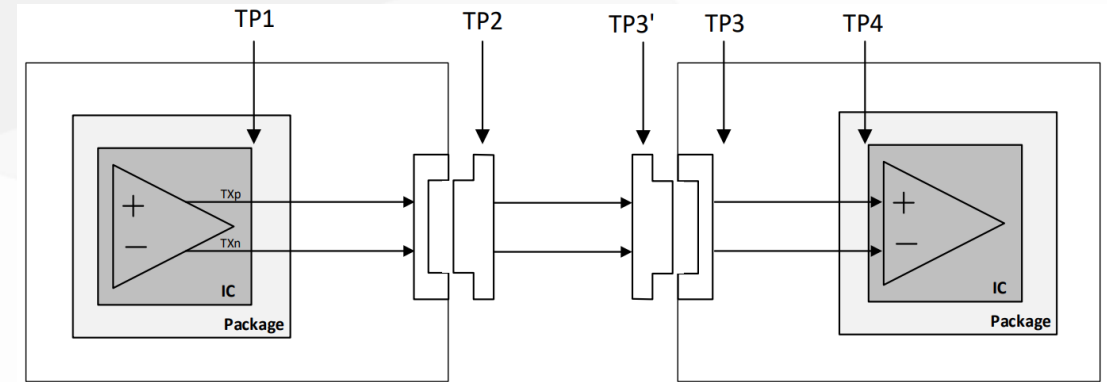
Compliance Points Definition

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.
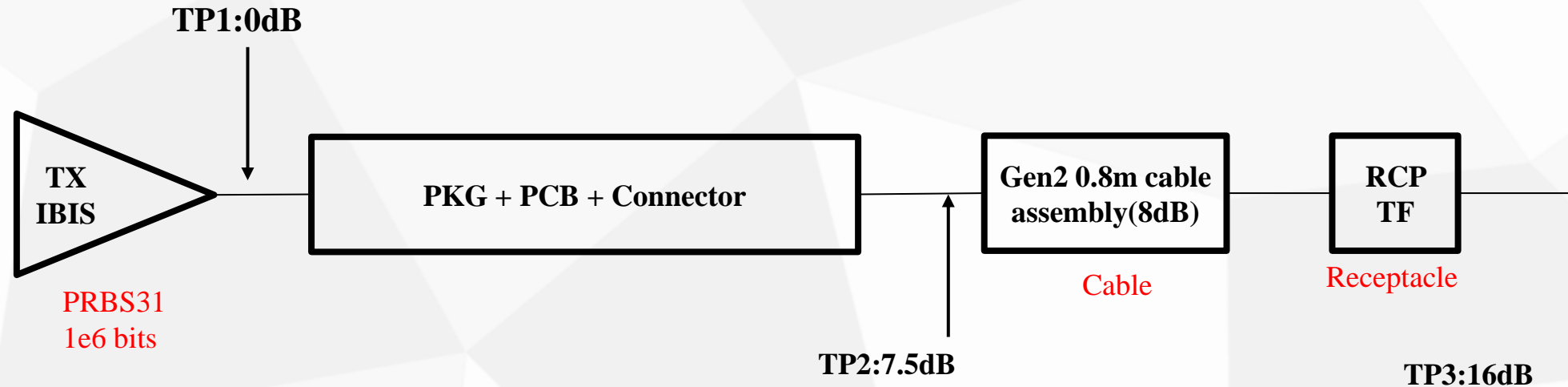
All the open sources in this presentation are from: Universal Serial Bus 4 (USB4®)Specification

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 Minimum	TP2 Maximum	TP3 Minimum	TP3 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_COMM	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_SKEW	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)

➢ **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.
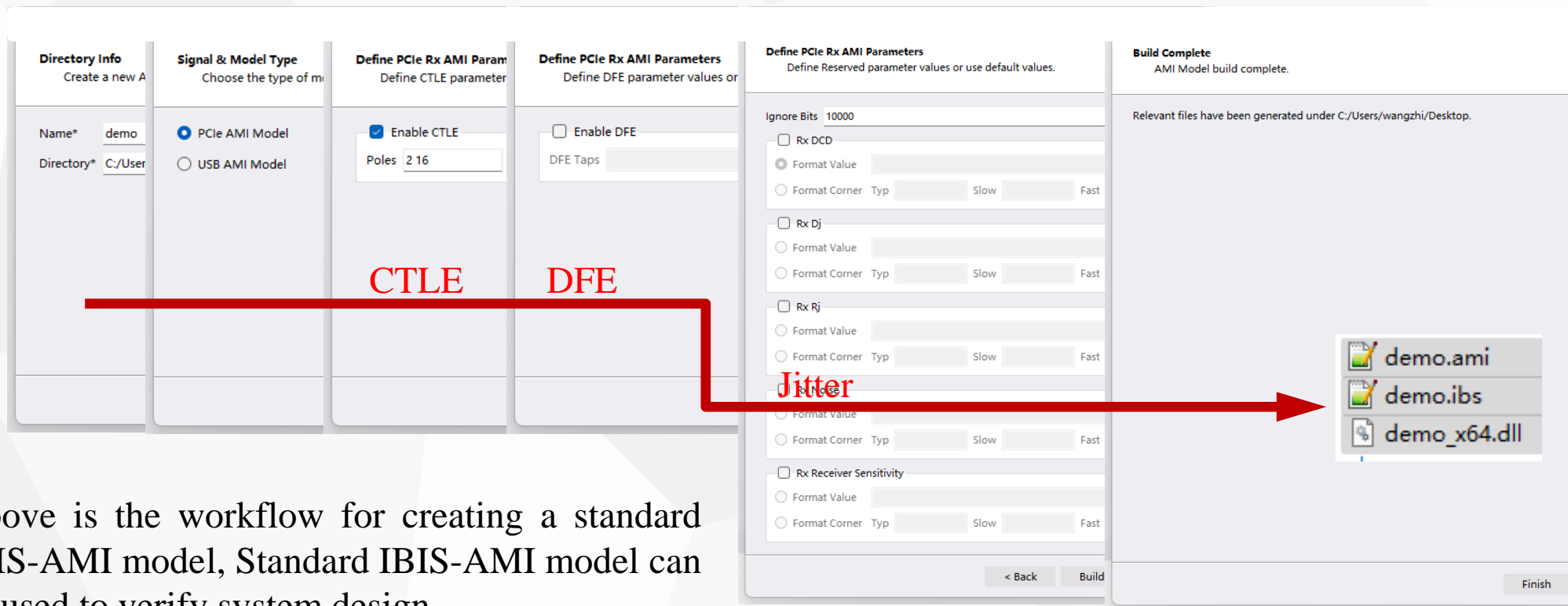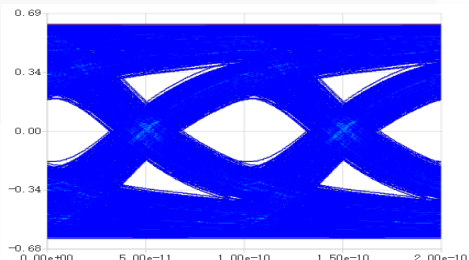

Above is the workflow for creating a standard IBIS-AMI model, Standard IBIS-AMI model can be used to verify system design.

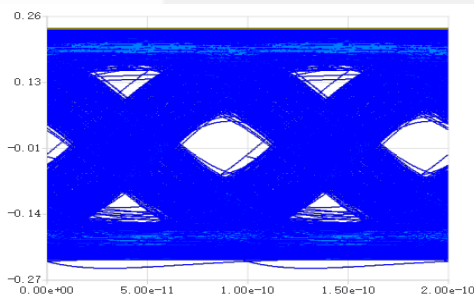*Tuning of IBIS file parameters will be added later...*
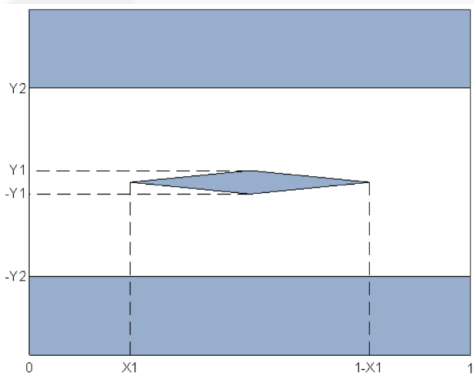
Model Validation

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

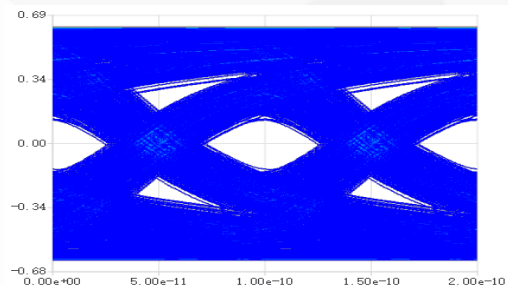@TP2(eye diagram)

@TP3(eye diagram)

@TX Mask Notations

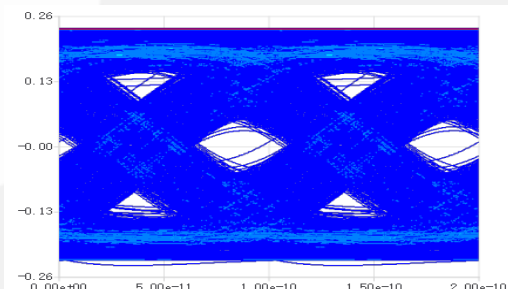| Item	Description	TP2		Standard Channel Simulate Result	Pass/Fail	TP3		Standard Channel Simulate Result	Pass/Fail
		Minimum	Maximum			Minimum	Maximum		
X1(UI)	TX eye horizontal deviation	-	-	-	-	-	0.23	0.2	Pass
Y1(mV)	TX eye inner height	140	-	180	Pass	53	-	60	Pass
Y2(mV)	TX eye outer height	-	650	640	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**

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Model Validation

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

@TP2(eye diagram)

@TP3(eye diagram)

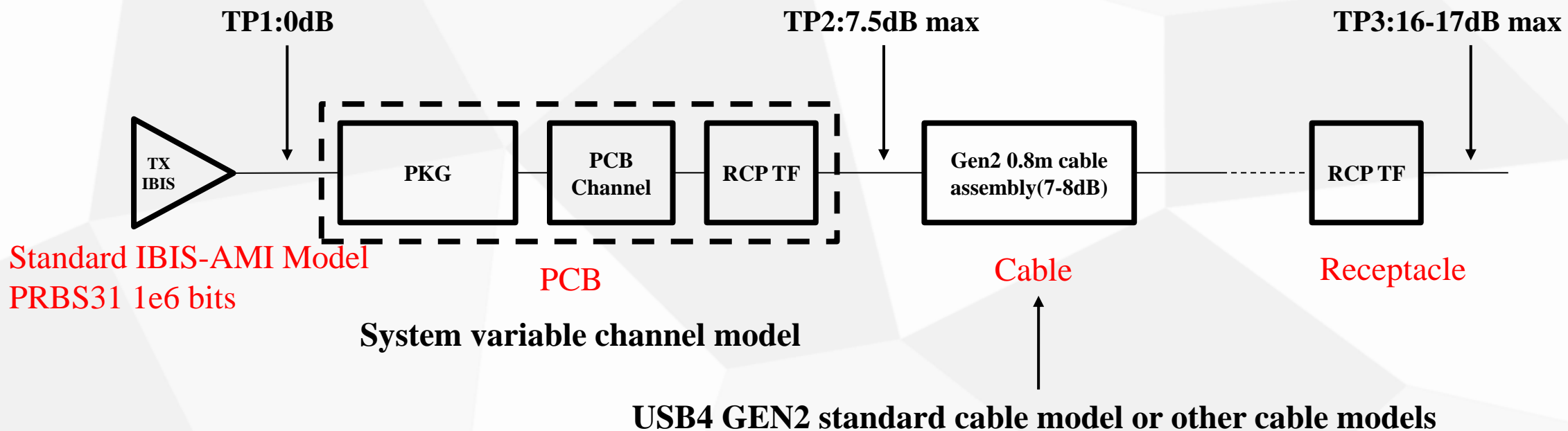| Item	Description	TP2		Channel Simulate Result	Pass/ Fail	TP3		Channel Simulate Result	Pass/ Fail
		Minimum	Maximum			Minimum	Maximum		
X1(UI)	TX eye horizontal deviation	-	-	-	-	-	0.23	0.2	Pass
Y1(mV)	TX eye inner height	140	-	120	Fail	53	-	50	Fail
Y2(mV)	TX eye outer height	-	650	630	Pass	-	650	230	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	×	

×: Not supported

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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

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: 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: 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: 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

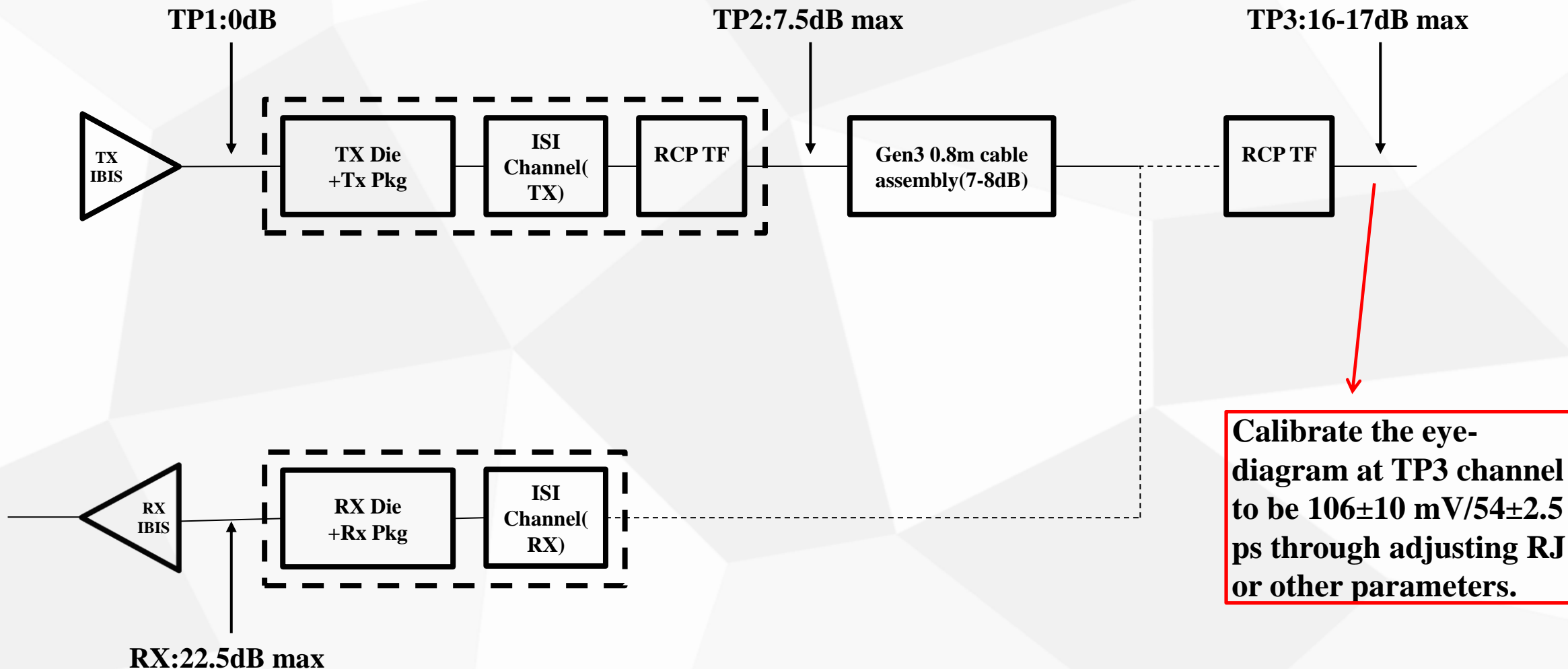Compliance test report with constructed IBIS-AMI model and channel loss higher than protocol defined

Build Standard RX Compliant IBIS-AMI Model Approach

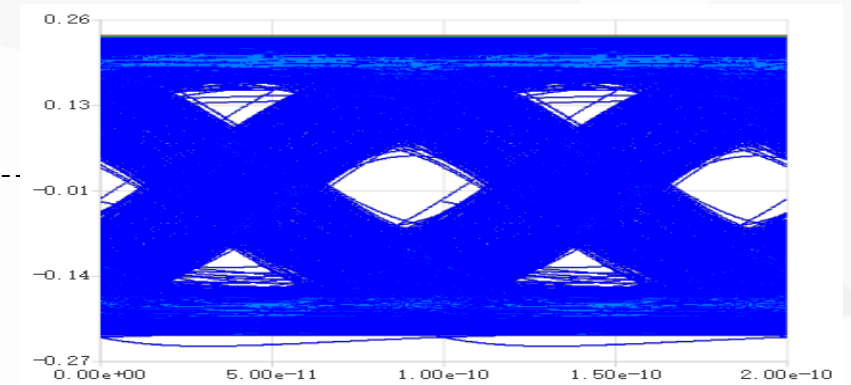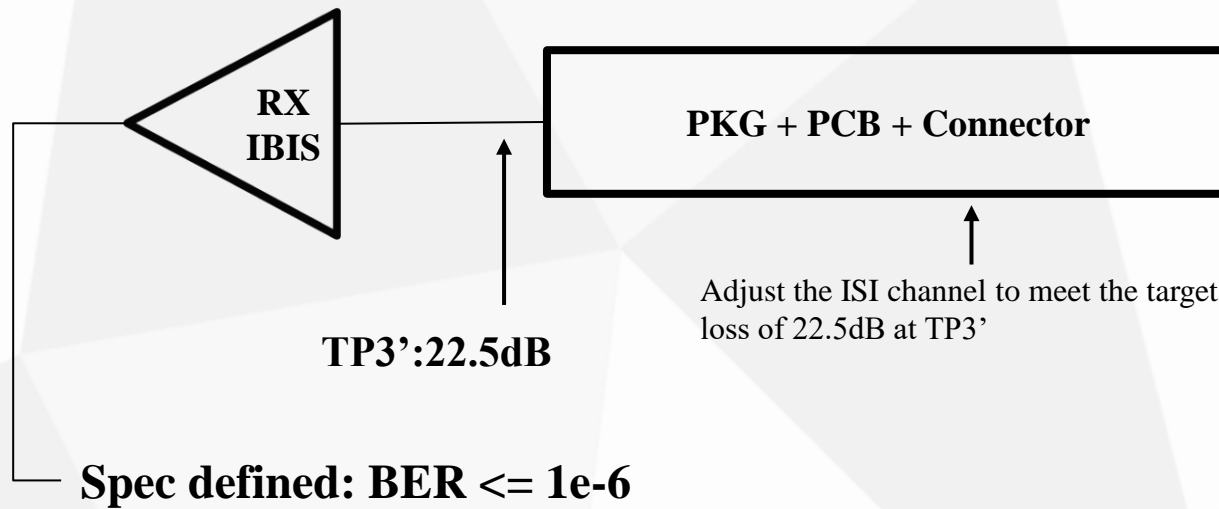# Standard RX IBIS-AMI Model Construction

➢ **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.**
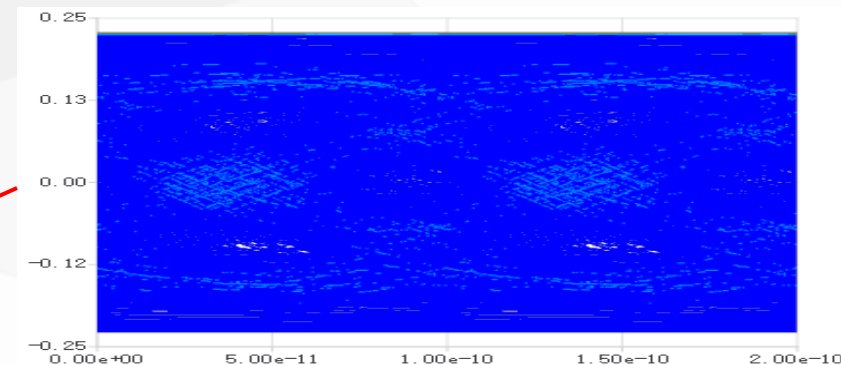

TP3':22.5dB

Spec defined: BER <= 1e-6

PKG + PCB + Connector

Adjust the ISI channel to meet the target
loss of 22.5dB at TP3'

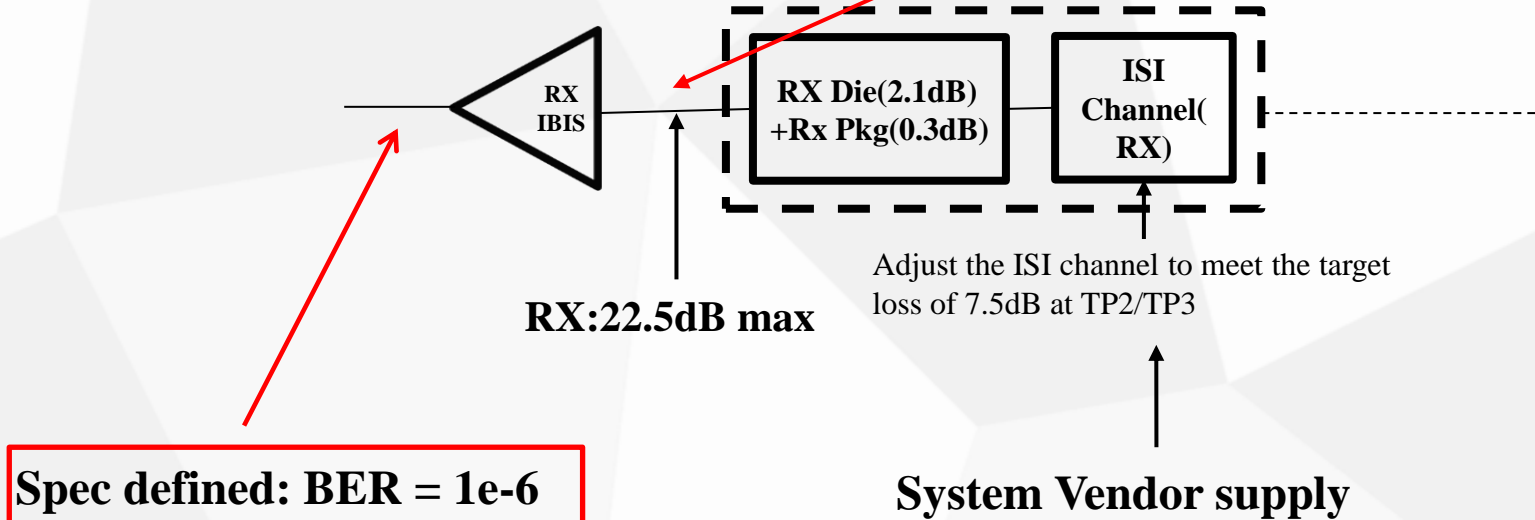@TP3 Eye Diagram with
106±10 mV/54±2.5 ps

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.**
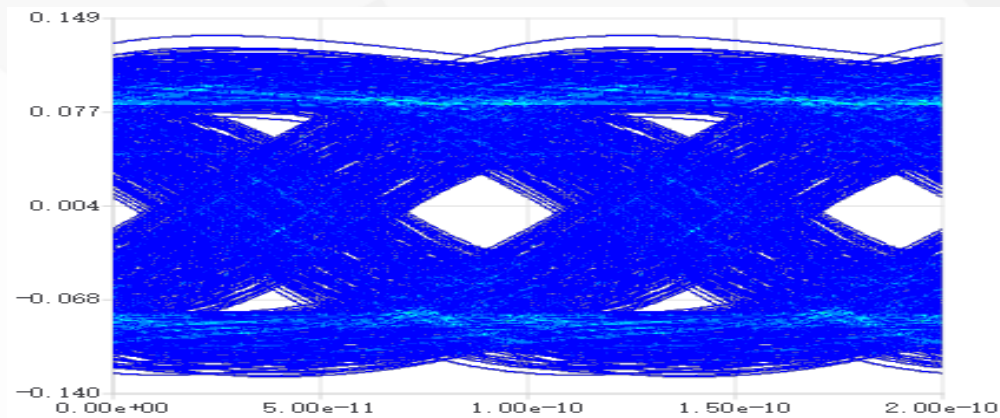

@before RX(eye diagram)

RX IBIS — **RX Die(2.1dB) +Rx Pkg(0.3dB)** — **ISI Channel(RX)**

RX:22.5dB max

Adjust the ISI channel to meet the target loss of 7.5dB at TP2/TP3

Spec defined: BER = 1e-6

System Vendor supply

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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

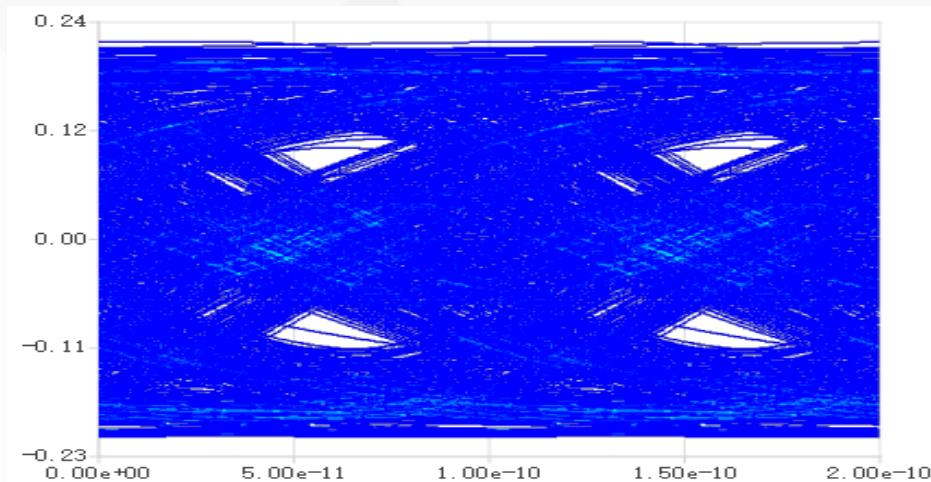| Item	Property
Protocol	Universal Serial Bus 4 (USB4) Router Assembly Electrical Compliance Test Specification
IBIS Path	C:/Users/wangzhi/Desktop/ibis-ami/demo.ibs
Bit Rate	1e+10 Hz

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.

◆ 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

2023

Any Questions?