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

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## 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?

Background

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.

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.
ТРЗ	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**







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

		T	P2		TP3	Item	Description	Min	Max	Units
Item	Description	Minimu m	Maximu m	Minim um	Maximum	RL_DIFF	Differential Return	-	$SDD22(f) = \begin{cases} -8.5 & 0.05 < f_{cHz} \le 3\\ -3.5 + 8.3 \cdot \log 10 \left(\frac{f_{CHz}}{12}\right) & 3 < f_{CHz} \le 12 \end{cases}$	dB
Y1(mV)	TX eye inner height	140	-	53	-	PL COM	Common Mode Paturn			uD
Y2(mV)	TX eye outer height	-	650	-	650	M	Loss, 0.05–12 GHz	-	$SCC22(f) = \begin{cases} -6 & 0.05 < f_{GHz} \le 2.5 \\ -3 & 2.5 < f_{GHz} \le 12 \end{cases}$	dB
TJ(UI)	Total Jitter	-	0.38	-	0.6	TX_EQ	Transmitter Equalization Setting	-	Refer to Table 3-4	-
UJ(UI)	Sum of uncorrelated DJ and RJ components (all jitter components except for DDJ)	-	0.31	-	0.31	LANE_TO_ LANE_SKE W	Skew between dual transmit signals of the same USB4 Port	-	26	ns
DDJ(UI)	Data-Dependent Jitter	-	0.15	-	-	RISE_FAL L_TIME	TX rise/fall time measured between 20- 80% levels	10	-	ps
UDJ(UI)	Deterministic jitter that is uncorrelated to the	-	0.17	-	0.17	V_ELEC_I DLE	Peak voltage during transmit electrical idle	-	20	mV
DCD(UI)	Even-odd jitter associated with Duty- Cycle-Distortion	-	0.03	-	-	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

 Table2. USB4 Gen2 Transmitter Specifications

Table3. Transmitter Specifications for USB4 Gen2(at TP2)

# **Standard TX IBIS-AMI Model Construction**



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

be used to verify system design.

**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.

Directory Info Create a new A	Signal & Model Type Choose the type of me	Define PCIe Rx AMI Param Define CTLE parameter	Define PCIe Rx AMI Parameters Define DFE parameter values or	Define PCIe Rx AMI Parameters Define Reserved parameter values or use default	values.	Build Complete AMI Model build complete.
				Ignore Bits 10000		Relevant files have been generated under C:/Users/wangzhi/Desktop.
Name* demo	PCIe AMI Model	Enable CTLE	Enable DFE	Rx DCD		
Directory* C:/User	O USB AMI Model	Poles 216	DFE Taps	O Format Value		
				O Format Corner Typ Slow	Fast	
				🗌 Rx Dj		
				O Format Value		
		CTLE	DFE	O Format Corner Typ Slow	Fast	
		CILL		- Rx Rj		
				O Format Value		
				Format Corner Typ     Slow	Fast	🔛 demo.ami
				Jitter		
				Format Value	-	
				O Format Corner Typ Slow	Fast	🕒 demo_x64.dll
				Rx Receiver Sensitivity		
•	1.01	<b>c</b>		Format Value		
ve is the	workflow	tor creating	a standard	O Format Corner Typ Slow	Fast	
	110, 1		<b>T 1 1</b>			

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

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8

Finish

## Model Validation



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



Item	Description	TP	2	Standard Channel Simulate Result	Pass/ Fail	TP	3	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	×	

**@TX Mask Notations** 

1-X1

**×: Not supported** 9

## Model Validation



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



 $1.00 e^{-10}$ 

@TP3(eye diagram)

2.00e-10

-0.26 0.00e+00

5.00e-11

Item	Description	TP	2	Channel Simulate Result	Pass/ Fail	TP	3	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** 10

# **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



**USB4 GEN2 standard cable model or other cable models** 

## **System TX Compliance Test Results**



## **Compliance Report**

0.6

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

#### **Useful Links**

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

[TP3: 17dB]TP3 Maximum Total Jitter(UI)

#### 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		

0.6

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

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

#### **Useful Links**

Pass

#### Detool website: http://www.detooltech.com

#### **Compliance Test Simulation Setup**

Item	Property
Bratasal	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 Report** 

#### **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.



## 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. 0.25 0.13 0.00 -0.12 -0.25 0.00e+00 5.00e-11 1.00e - 101.50e-10 2.00e-10 @before RX(eye diagram) ISI RX Die(2.1dB) RX **Channel**( IBIS +Rx Pkg(0.3dB) RX) Adjust the ISI channel to meet the target loss of 7.5dB at TP2/TP3 RX:22.5dB max Spec defined: BER = 1e-6 System Vendor supply

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





## With adaptive 1-tap DFE and CTLE

## @RX(eye diagram)

	<b>Compliance Report</b>
erson: NANO	
nterprise: DeTooLIC	
ate: 2023/07/19 11:12:49	
Jseful Links	
etool website: http://www.detooltech.com	
Compliance Test Simulation Setup	
em	Property

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
a 11 - i a 11	

**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)

## 18

# **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.

IBIS C:/Users/wangzhi/AppData/Local/Programs/DeTooLIC/SonicHS/example	/ibis_ami/DDR5y32a_ibis_ar	mi/y32a_ami.ibs			
	RX				
5Gbps	e Compare	bns	тря	3' TP3	
	HS AM	Al tinle RitPate		Multiple Channel	
Test Report		Bit Rate	Unit	Snp files	
Start Simulate	1	8	Gbps	1 C:/Users/wangzhi/AppData/Local/Programs/DeTo example/snpFiles/111_050523_110113_25380555.5	ooLIC/SonicHS/ 8P
**************************************	*****				
protocol TP3 Spec					
High Voltage Level Threshold: 0.675 V, Low Voltage Level Threshold: 0.325 V, B	it errors are not allowe			RX	
	1815	file path C:/Users/wangzhi/Des	ktop/pcie20230710/pcie5_tx.ibs	IBIS file path C:/Users/wangzhi/Desktop/pcie202307	10/pcie5_nx.ibs
(RJ Amplitude: 1.4e-11	AMI	dll path C:/Users/wangzhi/Der	ktop/pcie20230710/pcie5_tx_x64.dll	AMI dll path C:/Users/wangzhi/Desktop/pcie202307	10/pcie5_rx_x64.dll
PJ Frequency: 1e+06Hz	AMI	file path C:/Users/wangzhi/Des	ktop/pcie20230710/pcie5_tx.ami	AMI file path C:/Users/wangzhi/Desktop/pcie2023071	10/pcie5_rx.ami
PJ Amplitude: 1.7e-11CTLE: USB4 Gen2(0 dB1, DFE: LMS):					
Fail ************************Bit Error Number: 1032	Stim	nulus			
	- 91	RBS		Signal	
(RI Amplitude: 1 4e-11	M	ode	PRBS Generator •		
PI Frequency: 1e+06Hz	Nu	um	15 •	Select Component pcie5	tx 💌
PLAmplitude: 1.7e-11CTLF: USB4 Gen2[1.dB]_DEF: LMS):	N	umber	1000		
Fail ************************************	Ini	itial Sequnce		Select Model pcie5	tx 💌
	En	coder	None 💌		
(PLAmplitude: 1.4e-11	Us	ser Defined Sequence		Select Data Type Type	*
	Bit	t File Path	-		
PLAmplitude: 1.7e-11CTLE: USB4 Gen2(2.dB)_DEE: LMS):					
Enil ************************************					OK Cancel
	525 1+4	Appla			Data Revvet: (Dye Wettings, Dye Height V)
(DLAmplitude: 1.4o.11		11 020023 110113 25200225.589			
RI Fraguency: 1a+06Hz	A fitpe	(12:63, 11076)			
PJ Frequency, re-tooniz PJ Amplitude: 1.76, 11CTLE: USR4 Con012 dP1, DEE: LMC):					
F) Ampinude. 1.7e-TICTLE. USb4 Gen2[5 db], DFE. LWIS).			and the second se		
Fall Dit Effor Number, 1032		675			1 and the second
(K) Amplitude. 1.4e-11					
PJ Frequency, re+uonz					
PJ Amplitude. 1./e-TICILE. USB4 Gen2[4 db], DFE. LIVIS).		2+0			
Fail and Bit Error Number: 1032					
(D) Amerikansk de de					and the state of the
(K) Amplitude: 1.4e-11		824			
PJ Frequency: Te+06HZ					
PJ Amplitude: 1.7e-11CTLE: USB4 Gen2[5 dB], DFE: LMS):					
		60	e -00 6.25c 11	1.25-10 1.28-10	2.55c 10

- 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 2you

# Any Questions?