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USB 3.0 IBIS-AMI Model Construction based on Measurement and Neural Network

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Outline

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II. IBIS-AMI Model at USB 3.0 Tx

III. Neural Network Training

IV. IBIS-AMI Model Construction and Validation

I. Conclusion

Motivation

- Ensuring signal integrity in high-speed data transfer is critical for the USB 3.0 standard.

- Normally, signal analysis depends on the transmitter (Tx) model provided by the manufacturer.

  - ➢ But what if the model of USB 3.0 Tx is not provided by the manufacturer?
  - ❖ It can be reconstructed from carefully measured output waveforms.

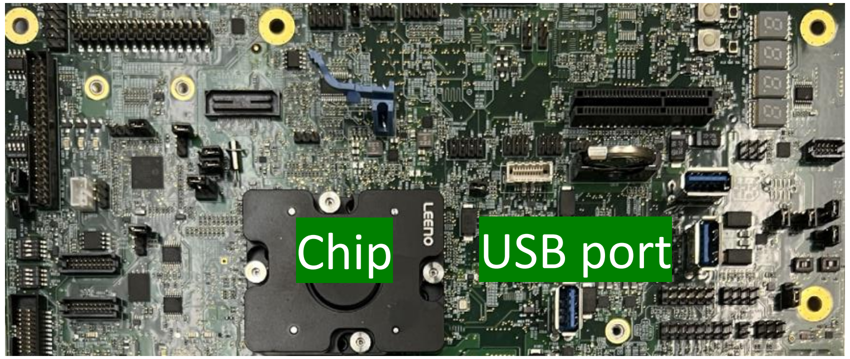
  - ➢ And what if measurement points and conditions are limited, such as when the chip is already on the motherboard?
  - ❖ Even then, the USB output waveforms still contain valuable information about the model.

Motivation (cont.)

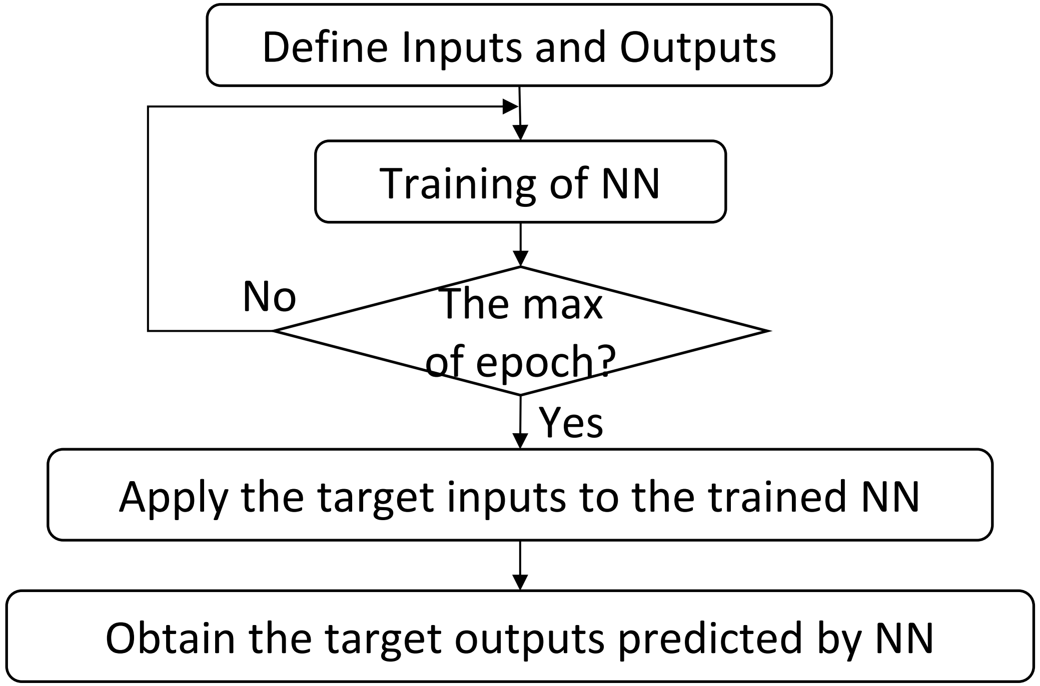
- In this work, we proposed a method to construct a digital output model for the USB 3.0 Tx based on the measurement.

➢ Device under test (DUT)

- The digital output from the chip assembled on motherboard
- The output signal through a PCB channel and a USB port
- The output signal is measured using a USB-SMA fixture



➢ Neural Network (NN)



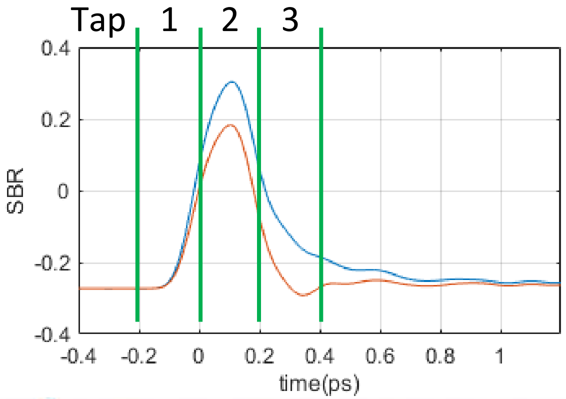
IBIS-AMI Model on USB 3.0 Tx

- IBIS-AMI model is commonly used in superspeed USB instead of IBIS model. In this work, an IBIS-AMI model is constructed for the USB 3.0 transmitter.

AMI Parameters:
FFE

AMI Parameters:
DFE / CTLE / CDR

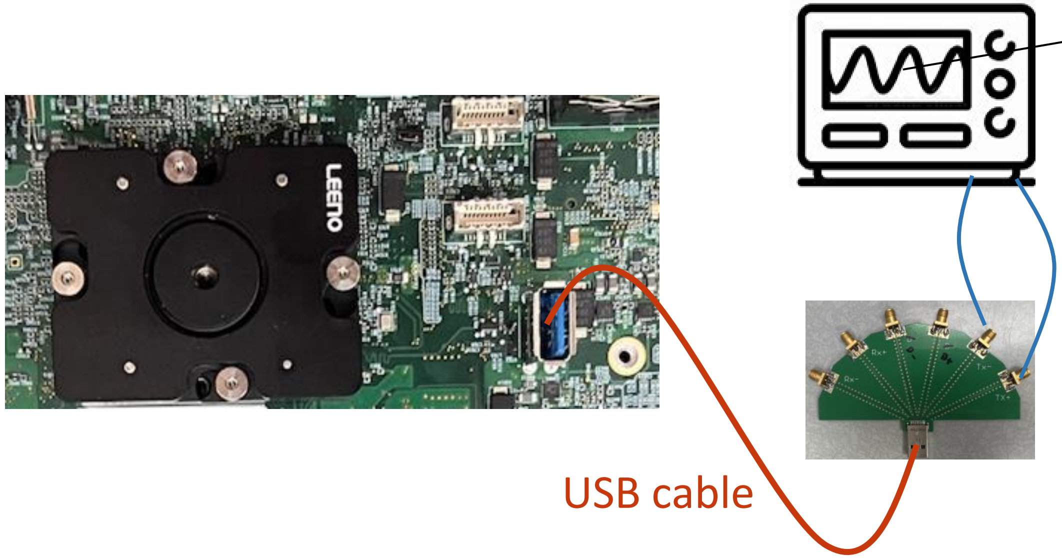
- The IBIS-AMI model construction focused on FFE taps values in AMI models and voltage level in IBIS models.
  - For example:
  - In IBIS file: [Voltage Range] 1.0 0.8 1.5
  - In AMI file: FFE defined in Model_Specific, [tap1 tap2 tap3]

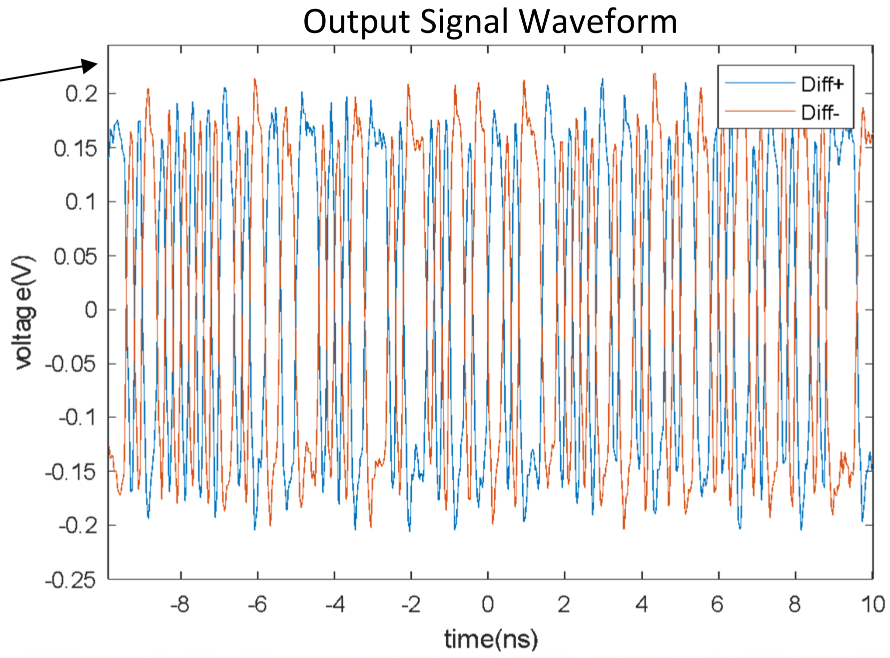


Single-bit-response waveform with different FFE tap values.

Measurement on USB 3.0 Tx

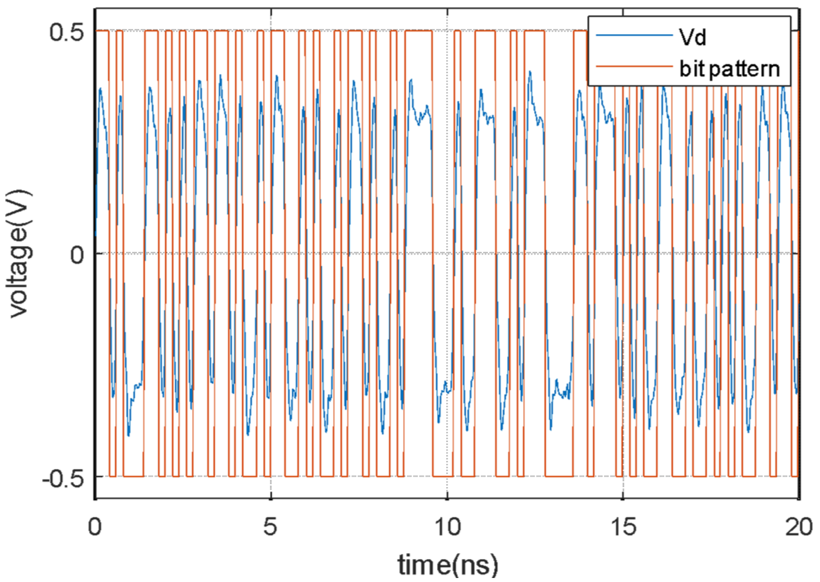
- The 5Gbps PRBS signal from USB 3.0 port is measured by the oscilloscope.

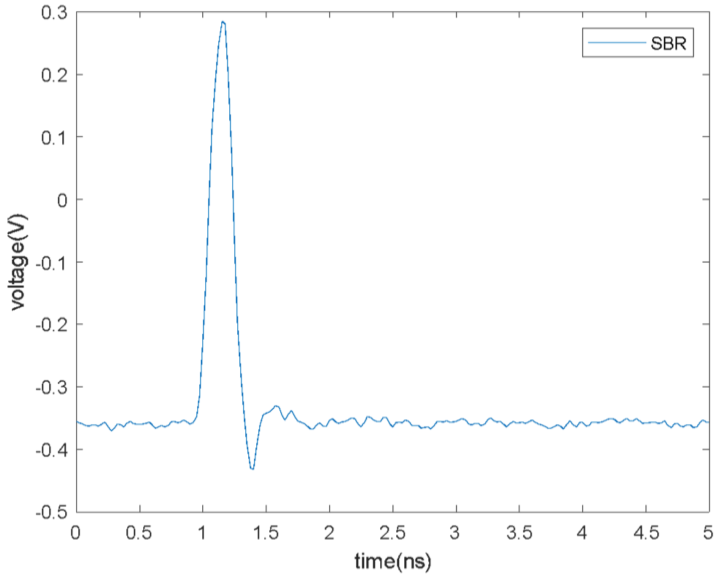




Measurement on USB 3.0 Tx (cont.)

- The differential single bit response is extracted from the measured waveform.



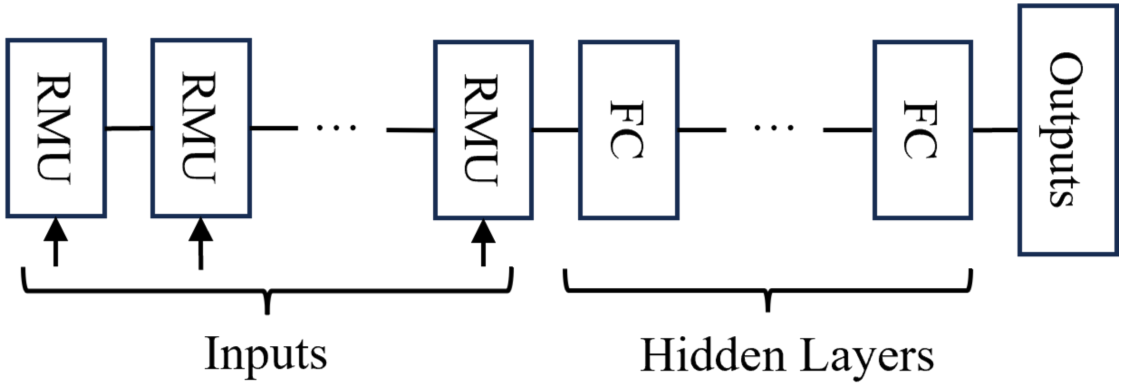


Neural Network Training

- Hybrid fully connected and gated recurrent units (GRU) neural network (NN) is used in this work. NN was trained with single bit response (SBR) waveforms as inputs and IBIS-AMI model parameters as outputs.

Inputs:

SBR voltage waveforms



Outputs:

IBIS_AMI models

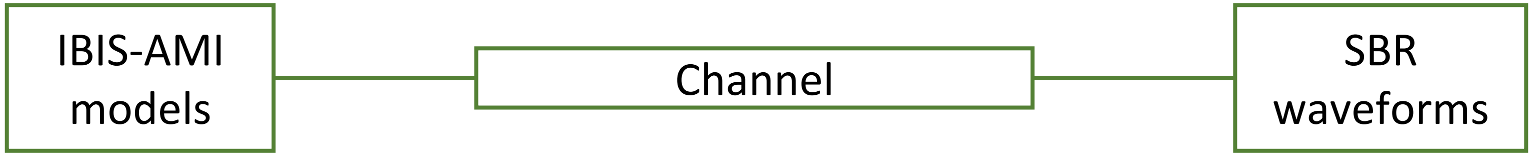
IBIS: Voltage level
AMI Parameters: FFE taps

Dataset for NN training

- The dataset contains around 1000 sets of IBIS-AMI models and SBR waveforms.
  - IBIS-AMI models:

    Generated a group of IBIS-AMI models by sweeping voltage level and 2 FFE tap values (*tap1* and *tap3*) in a reasonable range.
  - SBR waveforms:

    SBR waveforms are simulated with difference IBIS-AMI models in the EDA tool.



Measured channel S-parameters including
PCB channel, USB fixture, SMA cable

Neural Network Training Performance

- Training Accuracy
  - 90% datasets used as NN training
  - 10% datasets used as NN testing

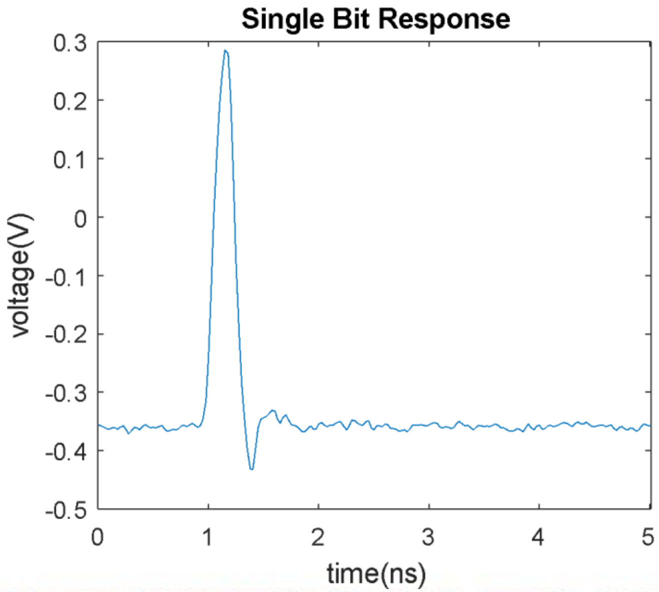
- Neural Network training results show a good correlation between SBR waveforms and IBIS-AMI models parameters

- Training efficiency:

  For an epoch of 500, the training takes around 1 hour.

IBIS-AMI model construction

- With a well-trained NN, the NN is recalled with inputs ⍰ the SBR extracted from measured waveform.
- The NN gives the outputs ⍰ IBIS-AMI models parameters



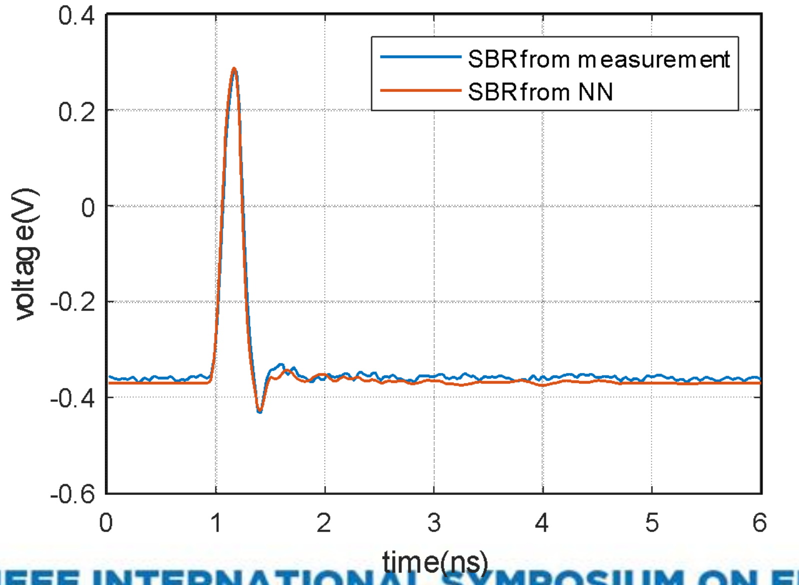
Prediction:

- Voltage level: 1.3V
- FFE:
  - Tap1: 0
  - Tap2: 0.8
  - Tap3: -0.2

The IBIS-AMI model for the USB Tx digital outputs is constructed with predicted parameters. (Attached in appendix)

Constructed IBIS-AMI model validation

- The constructed IBIS-AMI model is simulated in the EDA tool for validation. The SBR waveforms from measurement and IBIS-AMI model constructed by NN are compared.

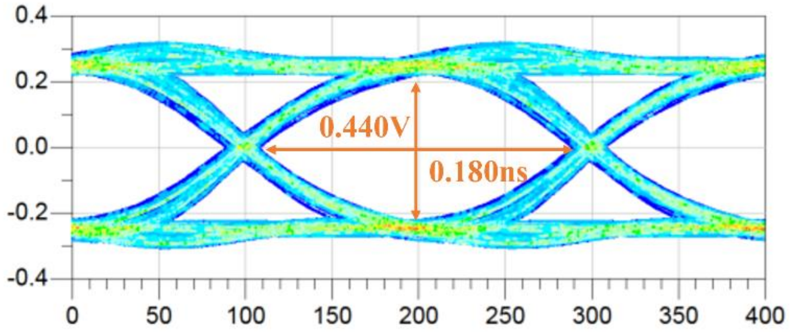


The waveform from the constructed model matches well with measurement.

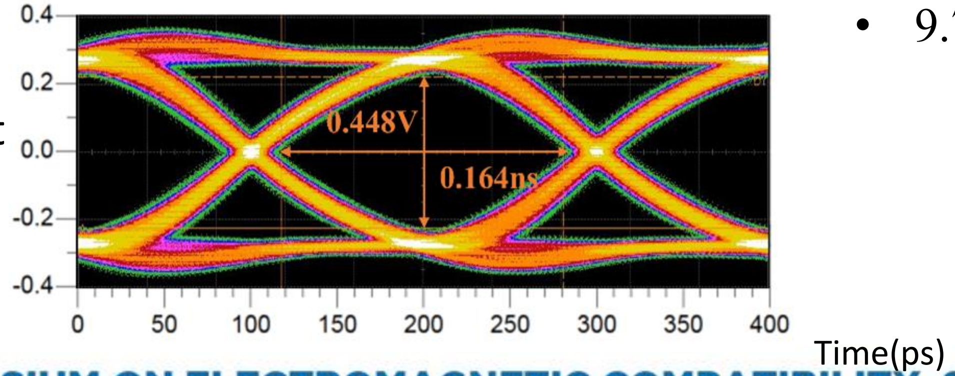
Constructed IBIS-AMI model validation (cont.)

- The eye-diagrams are also compared.

Eye-diagram from simulation with Constructed IBIS-AMI model



Eye-diagram from Measurement on Oscilloscope

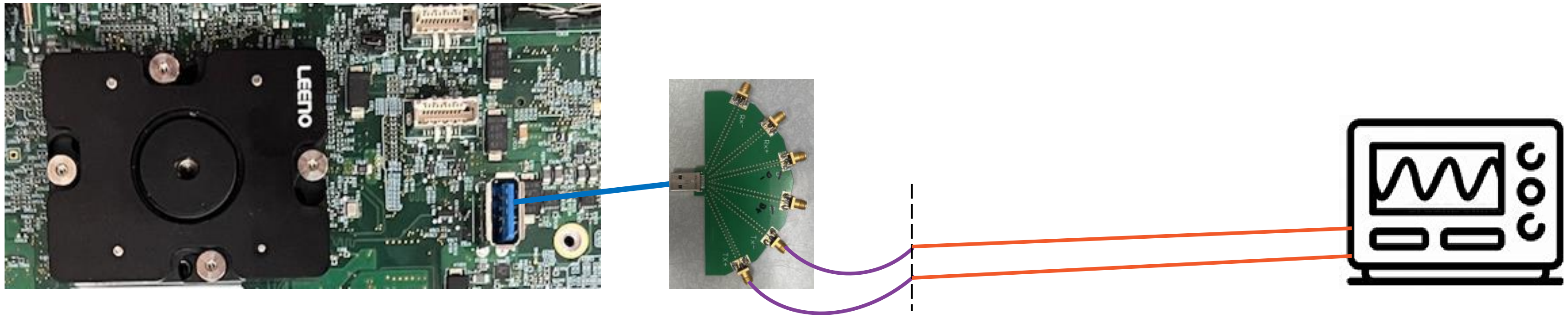


The eye-diagrams have limited difference.

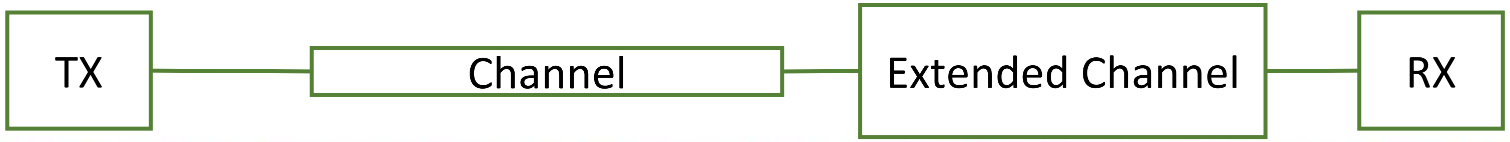
- 1.78% difference in eye height
- 9.75% difference in eye width

Validation with different channels

- The IBIS-AMI model is validated with extended channels.
  - Two SMA cables are added at the end of the signal path.
  - Two pairs of cables are used. (2 validations)

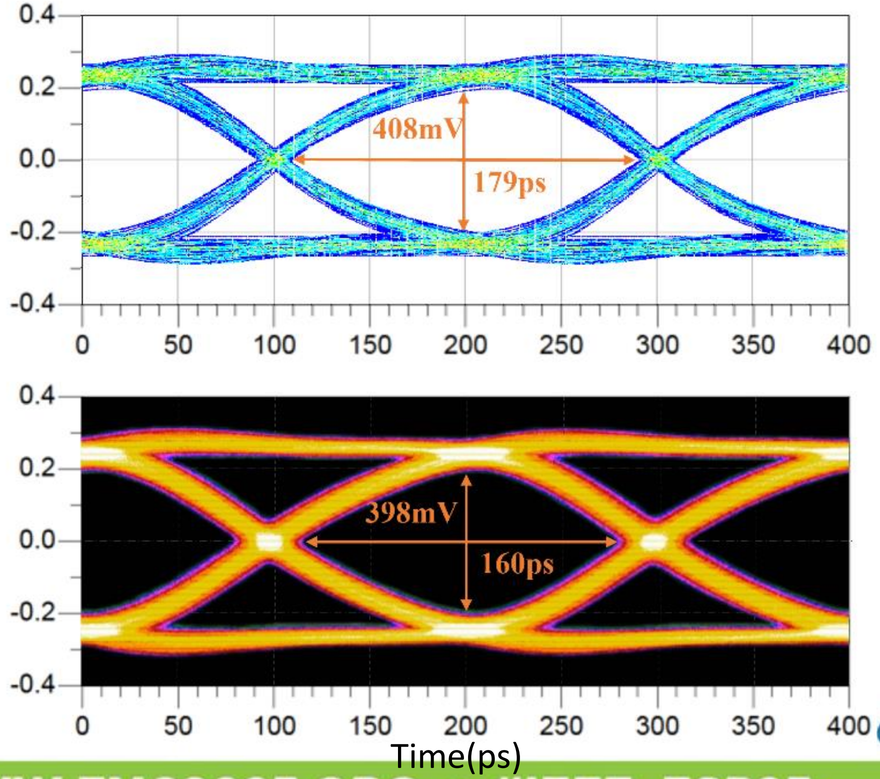


  - Simulation validation and eye-diagram comparison

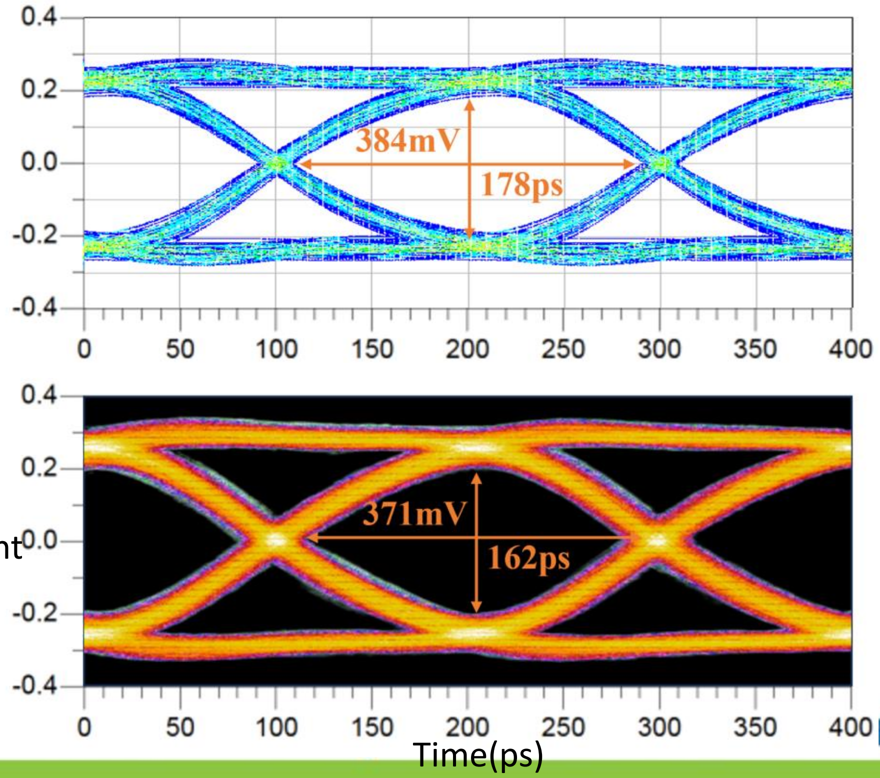


Validation with different channels (cont.)

- Validation 1
  - Channel-1 : A pair of 49 inches cables



- Validation 2
  - Channel-2 : A pair of 60 inches cables



From Constructed IBIS-AMI model

From measurement

Conclusion

- Using a neural network is an efficient method for the IBIS-AMI model construction for USB 3.0 based on the measurement.
- The predicted output model from Neural Network shows a good correlation with the measurement.
- The method can be applied to the other digital outputs with higher speed and propagating in different channels.

End of presentation

T&Q

Appendix 1

- IBIS file

```
[IBIS Ver]     5.1
[File Name]    tx.ibs
[File Rev]     1.0
[Component]    tx
[Manufacturer] My Company

[Package]
R_pkg  0.0    NA      NA
L_pkg  0.0    NA      NA
C_pkg  0.0    NA      NA

[Pin]    signal_name           model_name       R_pin L_pin  C_pin
1p       tx_p         tx
1n       tx_n         tx

[Diff_Pin] inv_pin vdiff tdelay_typ tdelay_min tdelay_max
1p       1n          NA    NA    NA    NA

[Model] tx
Model_type Output

C_comp 0p 0p 0p
Cref = 0
Vref = 0.5
Rref = 50
Vmeas = 0.5

[Temperature_Range] 25 125 0

[Voltage Range] 1.3 0.8 1.5

[Algorithmic Model]
Executable Windows_cl19.35.32215_64 tx_x64.dll tx.ami
[End Algorithmic Model]

[Pulldown]
-6.6        -0.132       -0.132       -0.132
 0.0         0.0          0.0          0.0
 6.6         0.132        0.132        0.132

[Pullup]
-6.6         0.132        0.132        0.132
 0.0         0.0          0.0          0.0
 6.6        -0.132       -0.132       -0.132

[GND Clamp]
-6.6         0.0          0.0          0.0
 0.0         0.0          0.0          0.0
 6.6         0.0          0.0          0.0

[Power Clamp]
-6.6         0.0          0.0          0.0
 0.0         0.0          0.0          0.0
 6.6         0.0          0.0          0.0

[Ramp]
dV/dt_r 0.3/1.5p 0.3/1.5p 0.3/1.5p
dV/dt_f 0.3/1.5p 0.3/1.5p 0.3/1.5p

[END]
```

Appendix 2

- AMI file

```
(tx
   (Reserved_Parameters
      (AMI_Version (Usage Info) (Type String) (Default "5.1") (Description "Valid for AMI Version 5.1 and above"))
      (Init_Returns_Impulse (Usage Info) (Type Boolean) (Default True) (Description "Init_Returns_Impulse True"))
      (GetWave_Exists (Usage Info) (Type Boolean) (Default False) (Description "GetWave_Exists False"))
      (Max_Init_Aggressors (Usage Info) (Type Integer) (Default 2147483646) (Description "Max_Init_Aggressors 2147483646"))
   )
   (Model_Specific
      (FFE
         (0 (Usage In) (Type Tap) (Format Value 0) (Description "FFE 0"))
         (1 (Usage In) (Type Tap) (Format Value 0.8) (Description "FFE 1"))
         (2 (Usage In) (Type Tap) (Format Value -0.2) (Description "FFE 2"))       )    ))
```