

MODEL CORRELATION FOR IBIS-AMI

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Authors:

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AGENDA



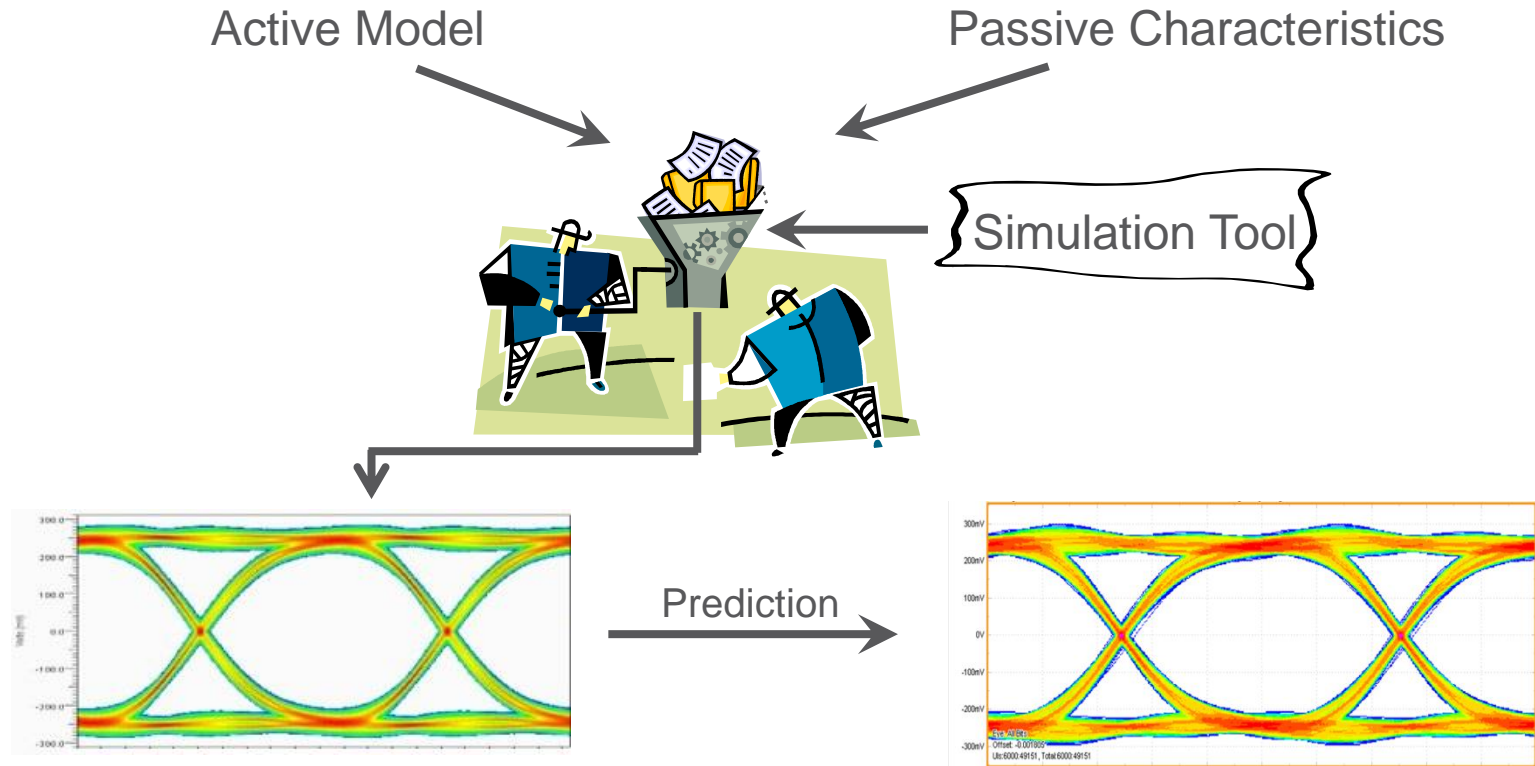
- › Why IBIS-AMI correlation
- › Correlation methodology for TX
- › Correlation methodology for RX
- › Correlation criteria
- › Question and suggestion

AGENDA



- › Why IBIS-AMI correlation
- › Correlation methodology for TX
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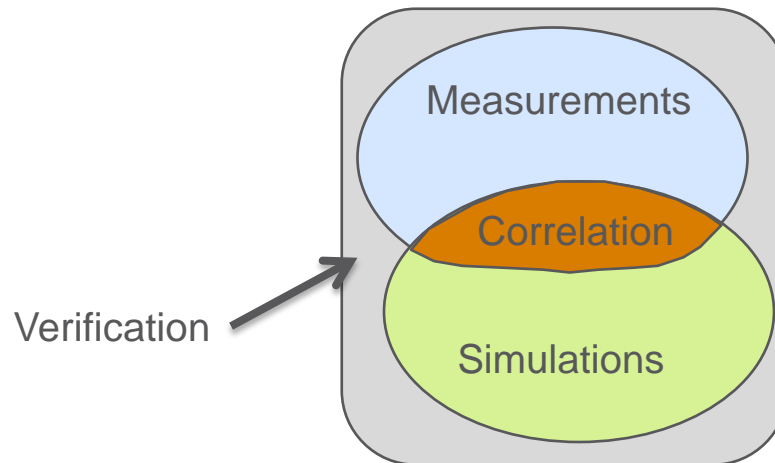
WHY CORRELATION FOR IBIS-AMI



WHY CORRELATION FOR IBIS-AMI



- › Correlation not only can verify simulation model's accuracy, but also can increase the verification coverage once model is matched to real tests. With the correlation, the simulation results can be the part of verification to cover some cases that measurement can not touch.



AGENDA

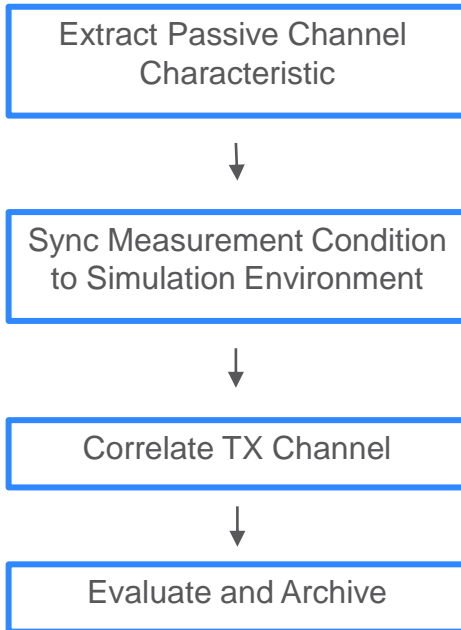


- › Why IBIS-AMI correlation
- › Correlation methodology for TX
- › Correlation methodology for RX
- › Correlation criteria
- › Question and suggestion

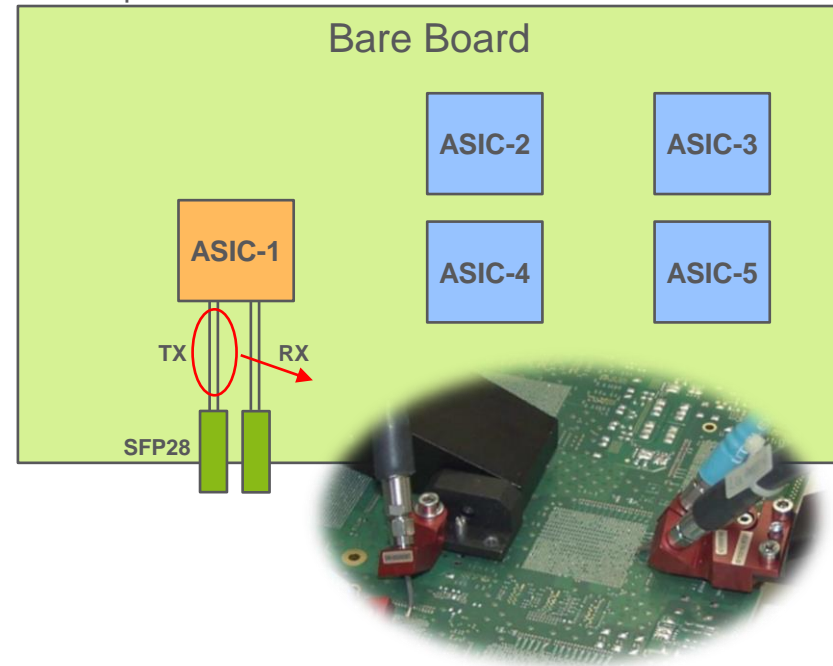
CORRELATION METHODOLOGY FOR TX



› Procedure



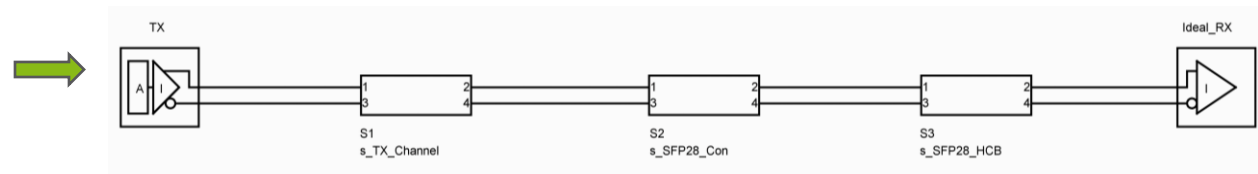
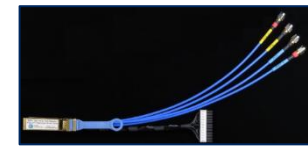
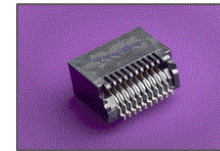
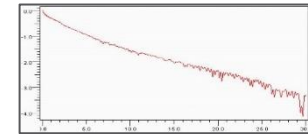
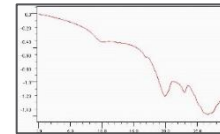
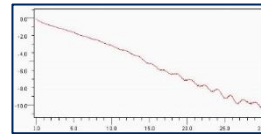
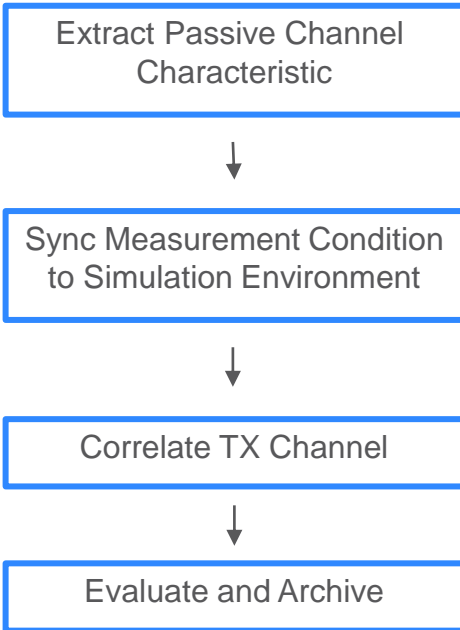
Example



CORRELATION METHODOLOGY FOR TX



› Procedure



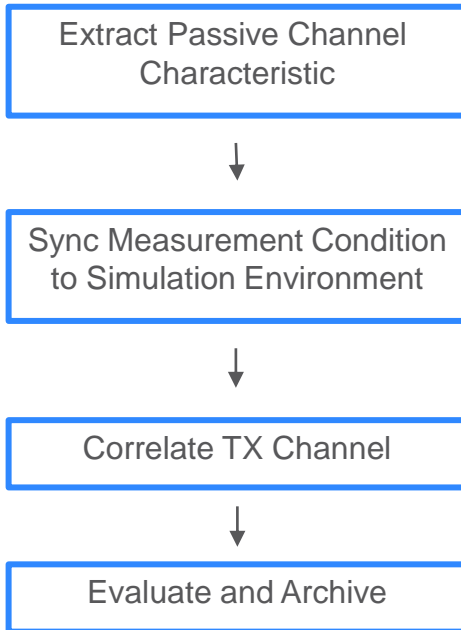
- PVT Settings
- Stimulus patterns
- Running bits
- Samples per bit



CORRELATION METHODOLOGY FOR TX



› Procedure



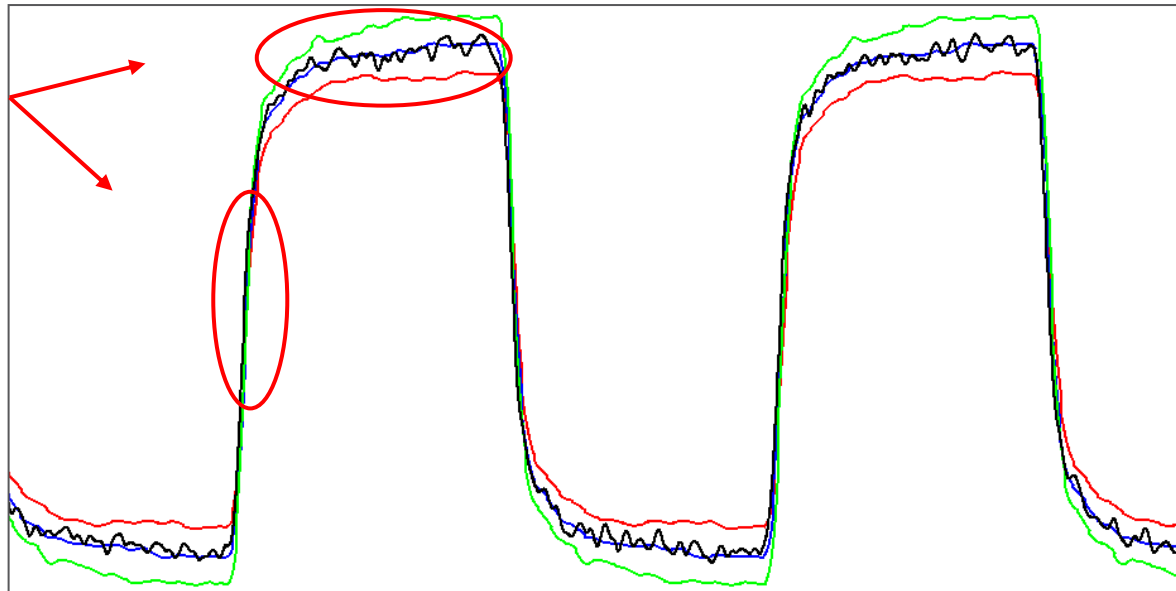
| Item | TXDIFFCTRL[3:0] | TXPRECURSOR[4:0] | TXPOSTCURSOR[4:0] | Pattern | Output | Item | TXDIFFCTRL[3:0] | TXPRECURSOR[4:0] | TXPOSTCURSOR[4:0] | Pattern | Output |
|--------|-----------------|------------------|-------------------|------------|--------------|--------|-----------------|------------------|-------------------|---------|--------------------------|
| Case1 | 0 | 0 | 0 | slow clock | waveform.csv | Case31 | 0 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case2 | 1 | 0 | 0 | slow clock | waveform.csv | Case32 | 1 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case3 | 2 | 0 | 0 | slow clock | waveform.csv | Case33 | 2 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case4 | 3 | 0 | 0 | slow clock | waveform.csv | Case34 | 3 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case5 | 4 | 0 | 0 | slow clock | waveform.csv | Case35 | 4 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case6 | 5 | 0 | 0 | slow clock | waveform.csv | Case36 | 5 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case7 | 6 | 0 | 0 | slow clock | waveform.csv | Case37 | 6 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case8 | 7 | 0 | 0 | slow clock | waveform.csv | Case38 | 7 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case9 | 8 | 0 | 0 | slow clock | waveform.csv | Case39 | 8 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case10 | 9 | 0 | 0 | slow clock | waveform.csv | Case40 | 9 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case11 | 10 | 0 | 0 | slow clock | waveform.csv | Case41 | 10 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case12 | 11 | 0 | 0 | slow clock | waveform.csv | Case42 | 11 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case13 | 12 | 0 | 0 | slow clock | waveform.csv | Case43 | 12 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case14 | 13 | 0 | 0 | slow clock | waveform.csv | Case44 | 13 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case15 | 14 | 0 | 0 | slow clock | waveform.csv | Case45 | 14 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case16 | 15 | 0 | 0 | slow clock | waveform.csv | Case46 | 15 | 0 | 0 | prbs7 | waveform.csv&eye diagram |
| Case17 | 8 | 5 | 0 | slow clock | waveform.csv | Case47 | 8 | 5 | 0 | prbs7 | waveform.csv&eye diagram |
| Case18 | 8 | 10 | 0 | slow clock | waveform.csv | Case48 | 8 | 10 | 0 | prbs7 | waveform.csv&eye diagram |
| Case19 | 8 | 15 | 0 | slow clock | waveform.csv | Case49 | 8 | 15 | 0 | prbs7 | waveform.csv&eye diagram |
| Case20 | 8 | 20 | 0 | slow clock | waveform.csv | Case50 | 8 | 20 | 0 | prbs7 | waveform.csv&eye diagram |
| Case21 | 8 | 0 | 5 | slow clock | waveform.csv | Case51 | 8 | 0 | 5 | prbs7 | waveform.csv&eye diagram |
| Case22 | 8 | 0 | 10 | slow clock | waveform.csv | Case52 | 8 | 0 | 10 | prbs7 | waveform.csv&eye diagram |
| Case23 | 8 | 0 | 15 | slow clock | waveform.csv | Case53 | 8 | 0 | 15 | prbs7 | waveform.csv&eye diagram |
| Case24 | 8 | 0 | 20 | slow clock | waveform.csv | Case54 | 8 | 0 | 20 | prbs7 | waveform.csv&eye diagram |
| Case25 | 8 | 0 | 25 | slow clock | waveform.csv | Case55 | 8 | 0 | 25 | prbs7 | waveform.csv&eye diagram |
| Case26 | 8 | 0 | 31 | slow clock | waveform.csv | Case56 | 8 | 0 | 31 | prbs7 | waveform.csv&eye diagram |
| Case27 | 8 | 5 | 5 | slow clock | waveform.csv | Case57 | 8 | 5 | 5 | prbs7 | waveform.csv&eye diagram |
| Case28 | 8 | 5 | 10 | slow clock | waveform.csv | Case58 | 8 | 5 | 10 | prbs7 | waveform.csv&eye diagram |
| Case29 | 8 | 10 | 5 | slow clock | waveform.csv | Case59 | 8 | 10 | 5 | prbs7 | waveform.csv&eye diagram |
| Case30 | 8 | 10 | 10 | slow clock | waveform.csv | Case60 | 8 | 10 | 10 | prbs7 | waveform.csv&eye diagram |

CORRELATION RESULTS FOR TX



› Slow Clock Pattern – Edge and Amplitude Voltage

Well matched

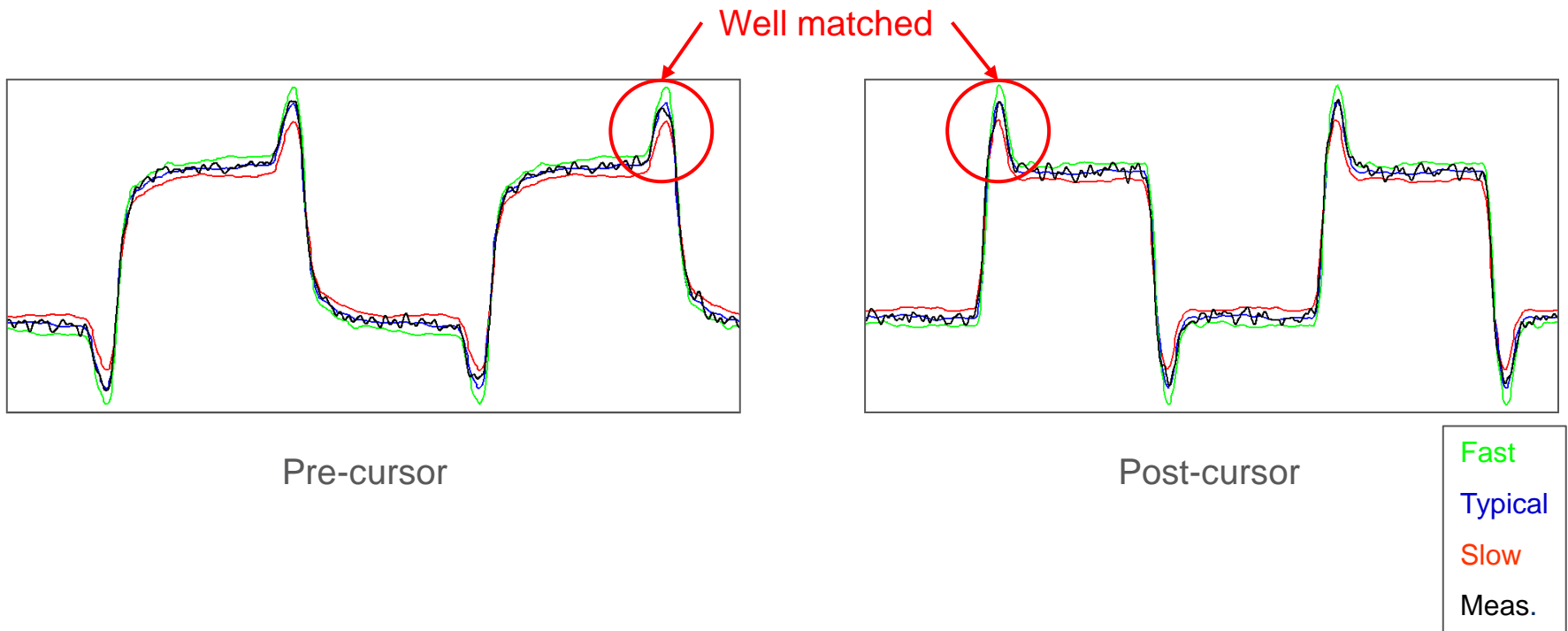


Fast
Typical
Slow
Meas.

CORRELATION RESULTS FOR TX



› Slow Clock Pattern – FFE Taps

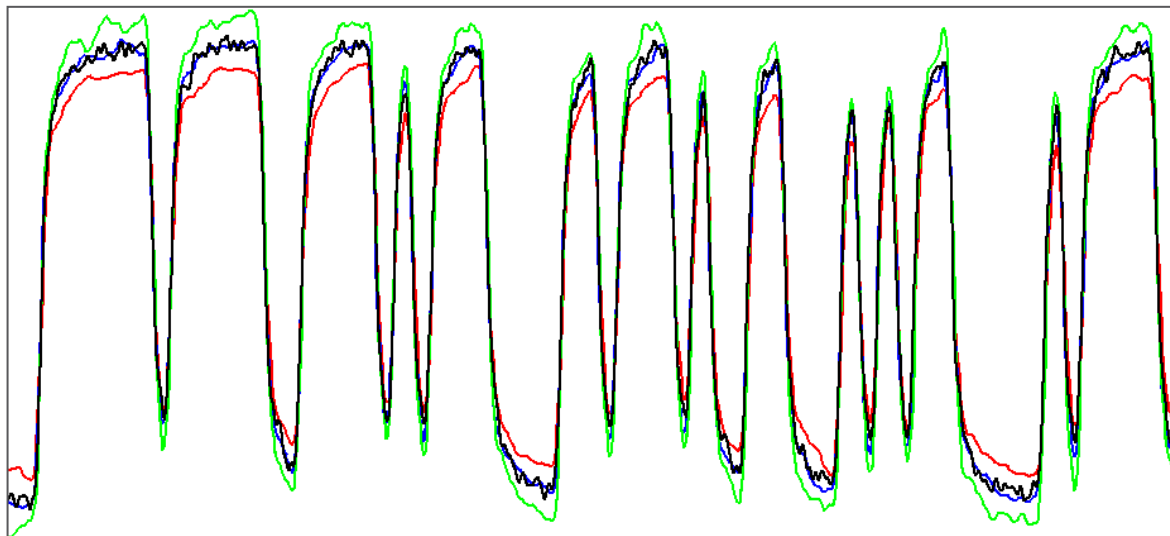


CORRELATION RESULTS FOR TX



› PRBS7 Pattern – Fast Response

Well matched

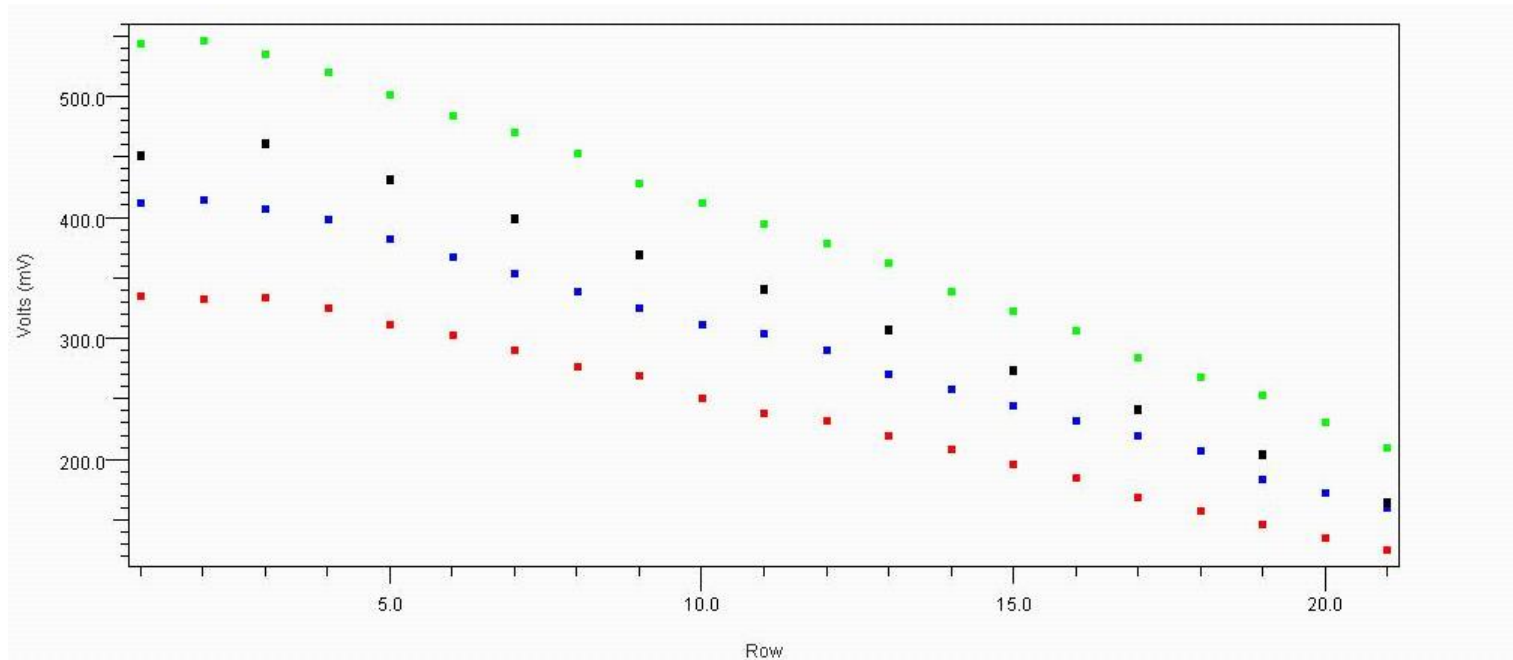


Fast
Typical
Slow
Meas.

TREND CORRELATION FOR TAP



› Time Domain Eye Height – Precursor Sweep

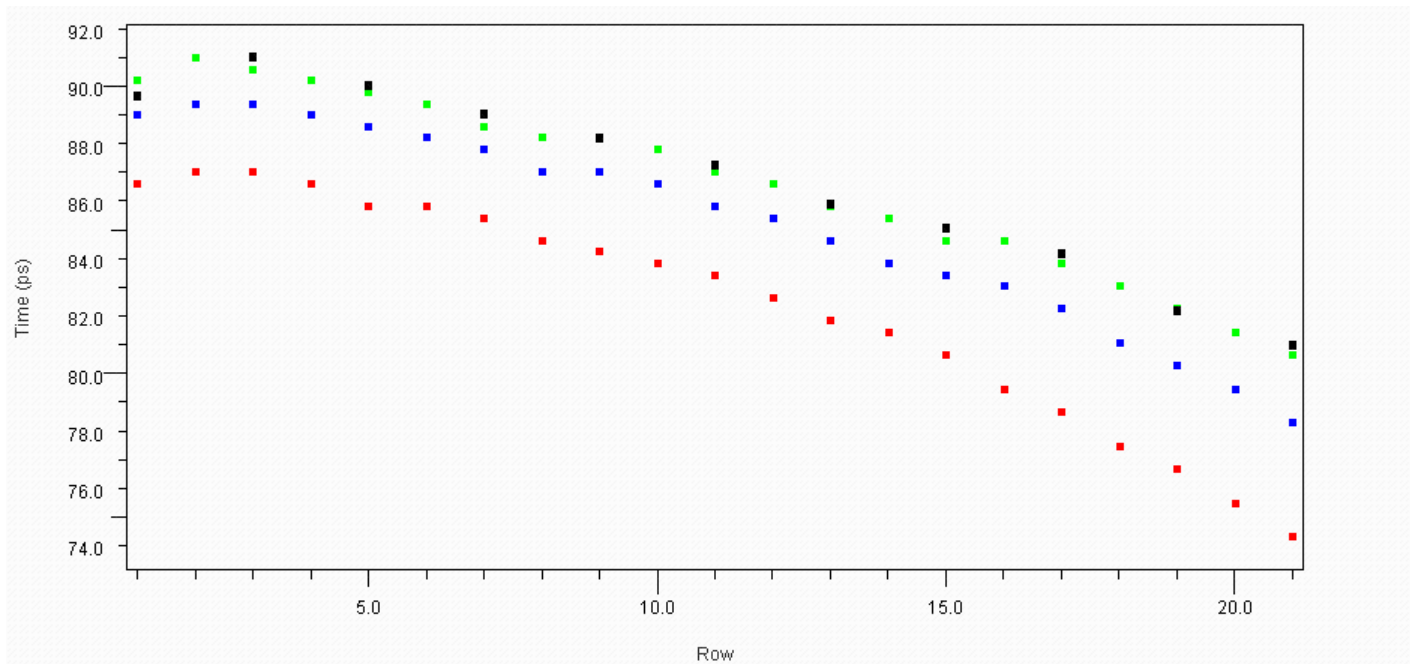


Fast
Typical
Slow
Meas.

TREND CORRELATION FOR TAP



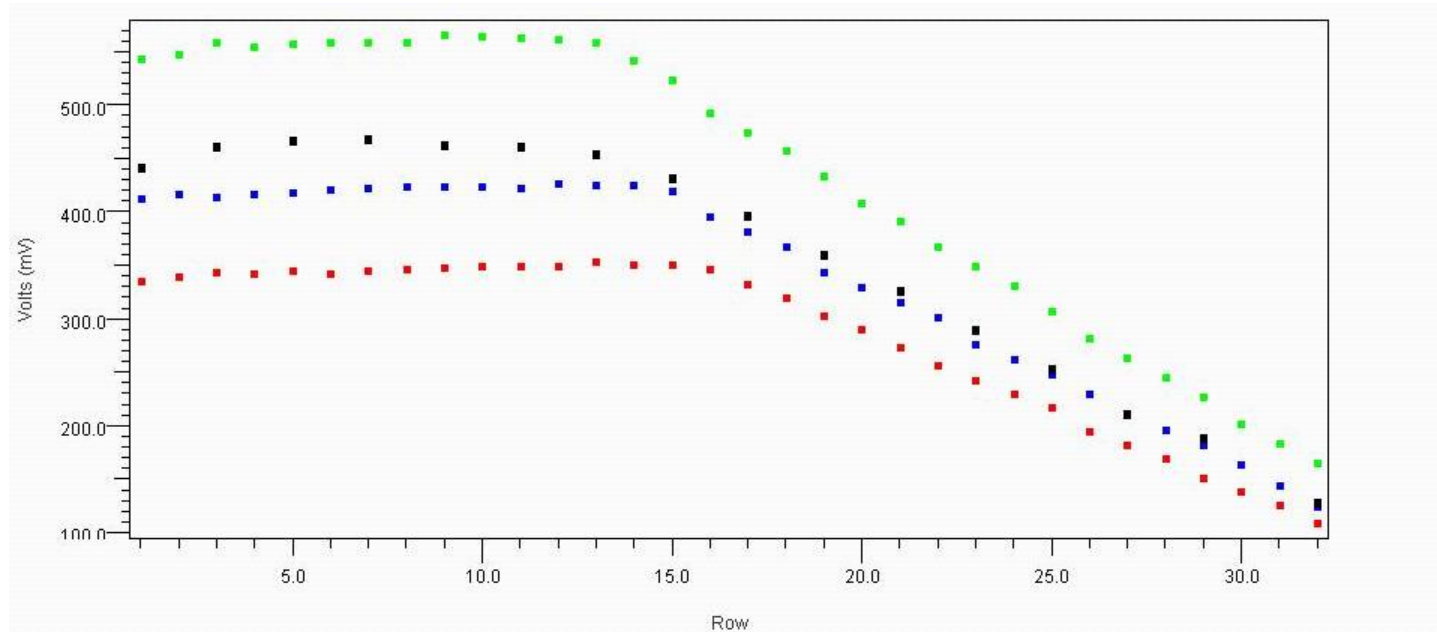
› Time Domain Eye Width – Precursor Sweep



TREND CORRELATION FOR TAP



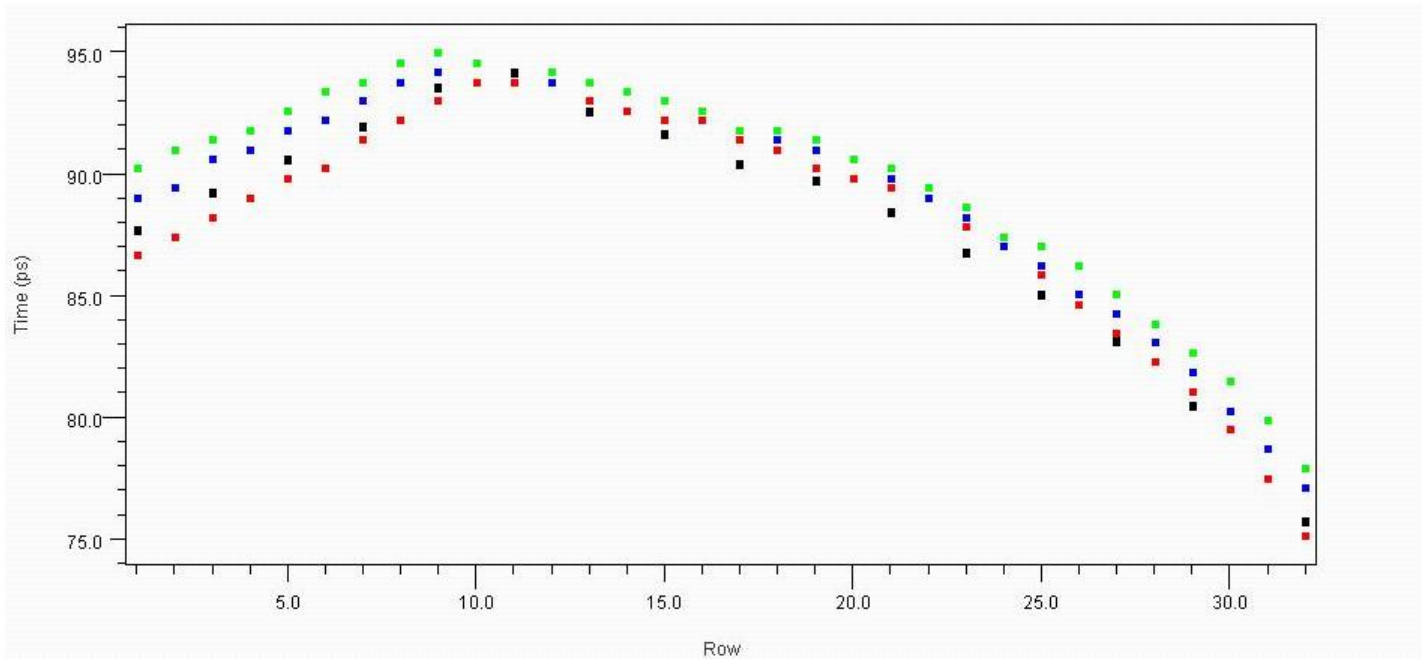
› Time Domain Eye Height – Postcursor Sweep



TREND CORRELATION FOR TAP



› Time Domain Eye Width – Postcursor Sweep



AGENDA

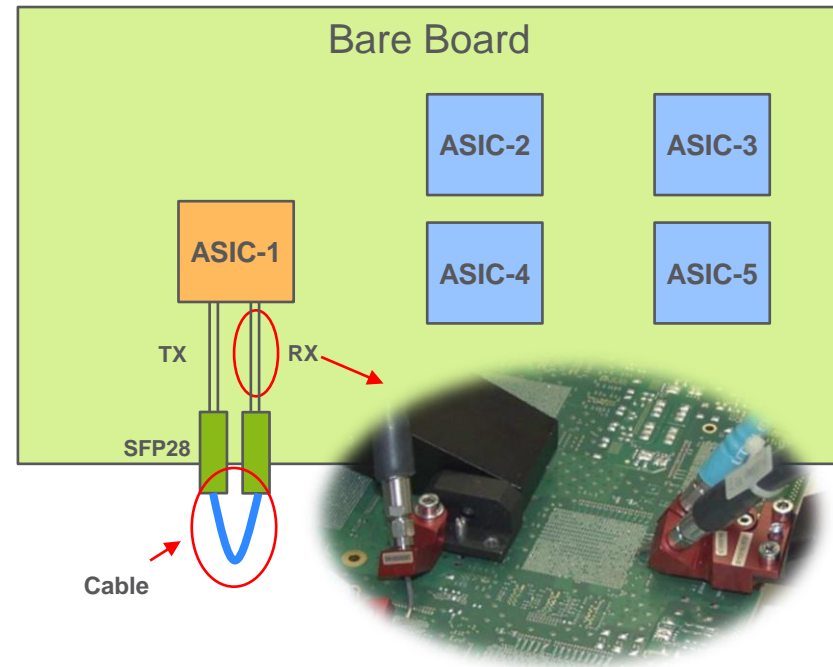
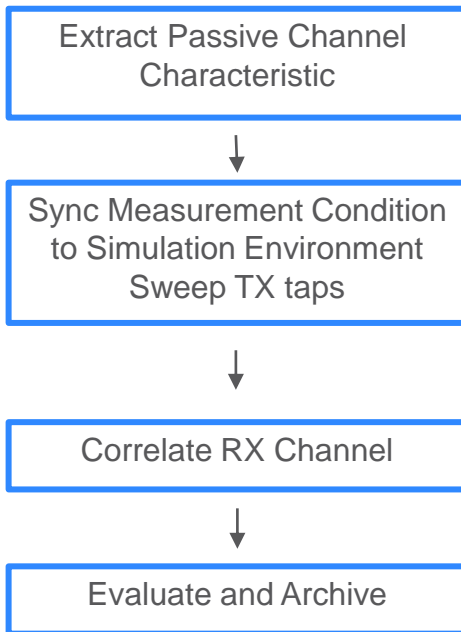


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CORRELATION METHODOLOGY FOR RX



› Procedure



CORRELATION METHODOLOGY FOR RX



› Procedure

Extract Passive Channel Characteristic



Sync Measurement Condition to Simulation Environment
Sweep TX taps



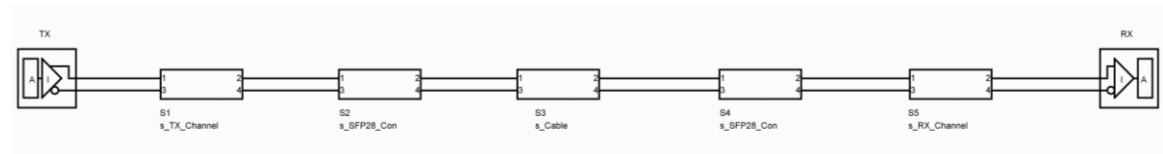
Correlate RX Channel



Evaluate and Archive



- Cable Length:
 - 0.6m
 - 1.0m
 - 1.8m
 - 3.0m
 - 5.0m



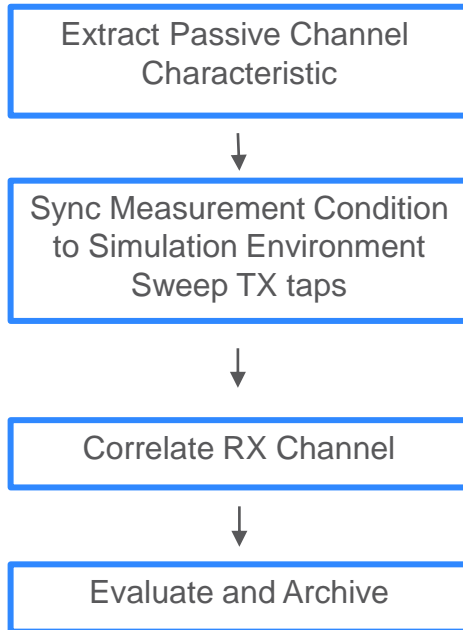
- PVT Settings
- Stimulus patterns
- Running bits
- Samples per bit
- Taps sweep

- RX CTLE adapt
- RX CTLE and DFE adapt

CORRELATION METHODOLOGY FOR RX



› Procedure



| Item | TXDIFFCTRL[3:0] | TXPRECURSOR[4:0] | TXPOSTCURSOR[4:0] | RX Equalization | Pattern | Output |
|--------|-----------------|------------------|-------------------|-----------------|---------|--------------|
| Case1 | 8 | 0 | 0 | CTLE Adapt Only | prbs7 | Internal eye |
| Case2 | 8 | 5 | 0 | CTLE Adapt Only | prbs7 | Internal eye |
| Case3 | 8 | 10 | 0 | CTLE Adapt Only | prbs7 | Internal eye |
| Case4 | 8 | 15 | 0 | CTLE Adapt Only | prbs7 | Internal eye |
| Case5 | 8 | 20 | 0 | CTLE Adapt Only | prbs7 | Internal eye |
| Case6 | 8 | 0 | 5 | CTLE Adapt Only | prbs7 | Internal eye |
| Case7 | 8 | 0 | 10 | CTLE Adapt Only | prbs7 | Internal eye |
| Case8 | 8 | 0 | 15 | CTLE Adapt Only | prbs7 | Internal eye |
| Case9 | 8 | 0 | 20 | CTLE Adapt Only | prbs7 | Internal eye |
| Case10 | 8 | 0 | 25 | CTLE Adapt Only | prbs7 | Internal eye |
| Case11 | 8 | 0 | 31 | CTLE Adapt Only | prbs7 | Internal eye |
| Case12 | 8 | 5 | 5 | CTLE Adapt Only | prbs7 | Internal eye |
| Case13 | 8 | 5 | 10 | CTLE Adapt Only | prbs7 | Internal eye |
| Case14 | 8 | 10 | 5 | CTLE Adapt Only | prbs7 | Internal eye |
| Case15 | 8 | 10 | 10 | CTLE Adapt Only | prbs7 | Internal eye |
| Case16 | 8 | 0 | 0 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case17 | 8 | 5 | 0 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case18 | 8 | 10 | 0 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case19 | 8 | 15 | 0 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case20 | 8 | 20 | 0 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case21 | 8 | 0 | 5 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case22 | 8 | 0 | 10 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case23 | 8 | 0 | 15 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case24 | 8 | 0 | 20 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case25 | 8 | 0 | 25 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case26 | 8 | 0 | 31 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case27 | 8 | 5 | 5 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case28 | 8 | 5 | 10 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case29 | 8 | 10 | 5 | DFE&CTLE Adapt | prbs7 | Internal eye |
| Case30 | 8 | 10 | 10 | DFE&CTLE Adapt | prbs7 | Internal eye |

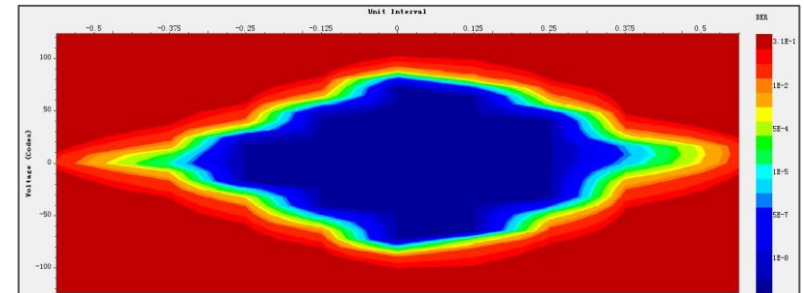
- Sweep Cable Length:
 - 0.6m
 - 1.0m
 - 1.8m
 - 3.0m
 - 5.0m

CORRELATION WITH INTERNAL EYE



› Now scanning RX internal eye with different TX tap settings

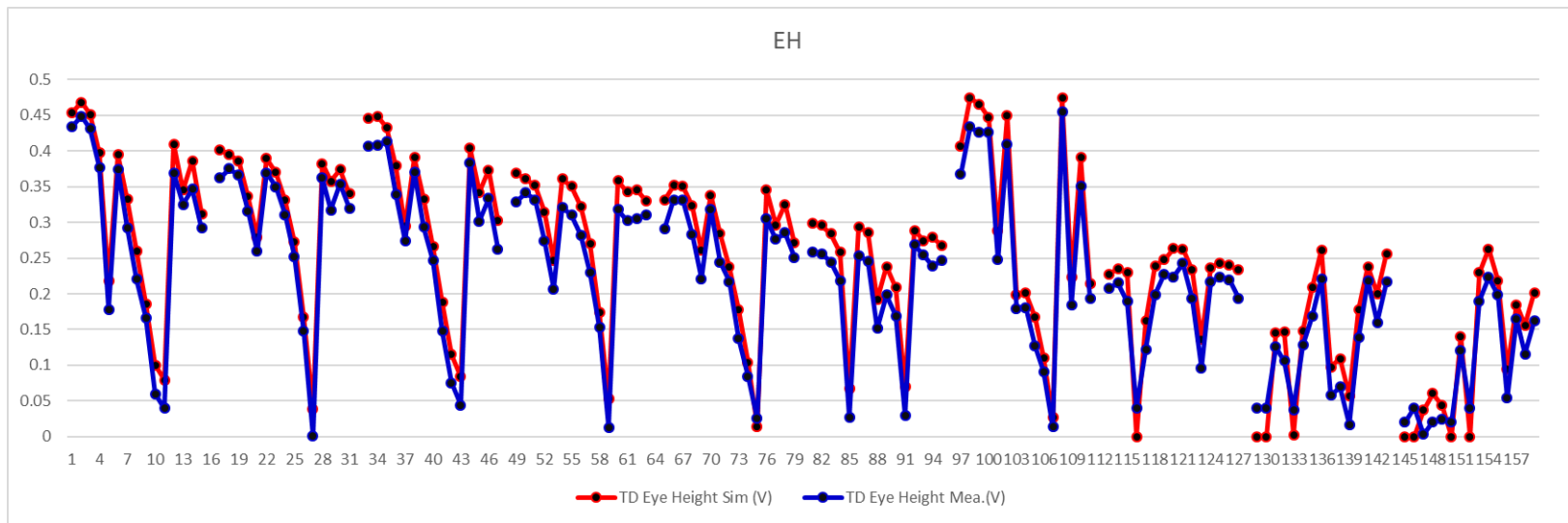
| Run | Link | Link Settings | Scan Type | Status | Progress | Open Area | Hor. Insn | Max Range | Vert Insn | Vert Range | Swath | Swath BEZ | Swath Time | Start Time | End Time |
|---------|---------|---------------|-----------|--------|----------|-----------|-----------|-----------------------|-----------|------------|-------|-----------|------------|-----------------------|---------------------|
| Scan 3 | Link 3 | 24_Full_eye | Done | | | 1008 3584 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:53:11 | 2016-04-27 08:53:38 |
| Scan 4 | Link 4 | 24_Full_eye | Done | | | 1008 3594 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:54:09 | 2016-04-27 08:54:37 |
| Scan 5 | Link 5 | 24_Full_eye | Done | | | 1008 3580 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:54:40 | 2016-04-27 08:55:11 |
| Scan 6 | Link 6 | 24_Full_eye | Done | | | 1008 3136 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:55:14 | 2016-04-27 08:55:41 |
| Scan 7 | Link 7 | 24_Full_eye | Done | | | 1008 3200 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:55:44 | 2016-04-27 08:56:10 |
| Scan 8 | Link 8 | 24_Full_eye | Done | | | 1008 3520 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:56:13 | 2016-04-27 08:56:40 |
| Scan 9 | Link 9 | 24_Full_eye | Done | | | 1008 3264 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:56:42 | 2016-04-27 08:57:09 |
| Scan 10 | Link 10 | 24_Full_eye | Done | | | 1008 3264 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:57:10 | 2016-04-27 08:57:37 |
| Scan 11 | Link 11 | 24_Full_eye | Done | | | 1008 2916 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:57:35 | 2016-04-27 08:57:59 |
| Scan 12 | Link 12 | 24_Full_eye | Done | | | 1008 3776 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:58:01 | 2016-04-27 08:58:26 |
| Scan 13 | Link 13 | 24_Full_eye | Done | | | 1008 3660 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:58:29 | 2016-04-27 08:58:54 |
| Scan 14 | Link 14 | 24_Full_eye | Done | | | 1008 3094 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:59:14 | 2016-04-27 08:59:40 |
| Scan 15 | Link 15 | 24_Full_eye | Done | | | 1008 4188 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 08:59:49 | 2016-04-27 09:00:23 |
| Scan 16 | Link 16 | 24_Full_eye | Done | | | 1008 2432 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 09:00:27 | 2016-04-27 09:01:01 |
| Scan 17 | Link 17 | 24_Full_eye | Done | | | 1008 4056 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 09:00:50 | 2016-04-27 09:01:25 |
| Scan 18 | Link 18 | 24_Full_eye | Done | | | 1008 3840 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 09:01:28 | 2016-04-27 09:02:00 |
| Scan 19 | Link 19 | 24_Full_eye | Done | | | 1008 3980 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 09:01:54 | 2016-04-27 09:02:28 |
| Scan 20 | Link 20 | 24_Full_eye | Done | | | 1008 3100 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 09:02:32 | 2016-04-27 09:03:00 |
| Scan 21 | Link 21 | 24_Full_eye | Done | | | 1008 3084 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 09:03:02 | 2016-04-27 09:03:31 |
| Scan 22 | Link 22 | 24_Full_eye | Done | | | 1008 3908 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 09:03:32 | 2016-04-27 09:04:02 |
| Scan 23 | Link 23 | 24_Full_eye | Done | | | 1008 3120 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 09:04:10 | 2016-04-27 09:04:54 |
| Scan 24 | Link 24 | 24_Full_eye | Done | | | 1008 4100 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 09:04:50 | 2016-04-27 09:05:31 |
| Scan 25 | Link 1 | 24_Full_eye | Done | | | 1008 0 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 09:08:00 | 2016-04-27 09:08:09 |
| Scan 26 | Link 2 | 24_Full_eye | Done | | | 1008 4872 | 8 | -0.500 Hz to 0.500 Hz | 8 | + 1008 | - BEZ | + 1+9 | - | 0.2016-04-27 09:09:57 | 2016-04-27 09:09:32 |



CORRELATION RESULTS FOR RX



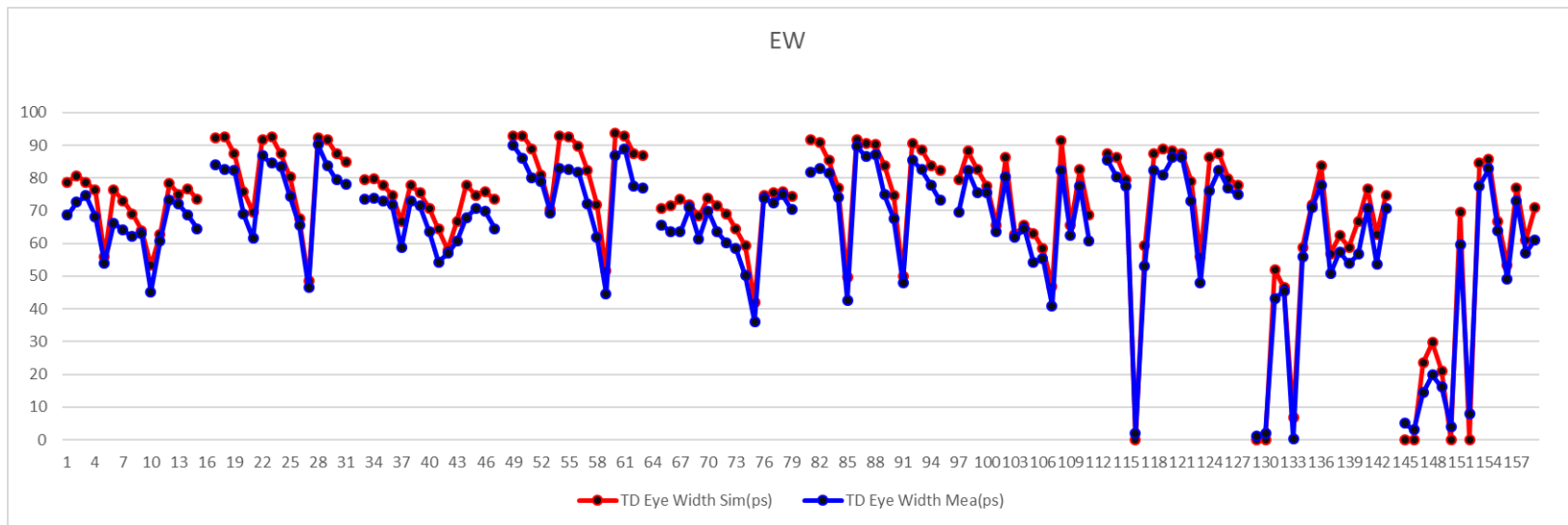
› Trend Correlation – Time Domain Eye Height



CORRELATION RESULTS FOR RX



› Trend Correlation – Time Domain Eye Width



AGENDA



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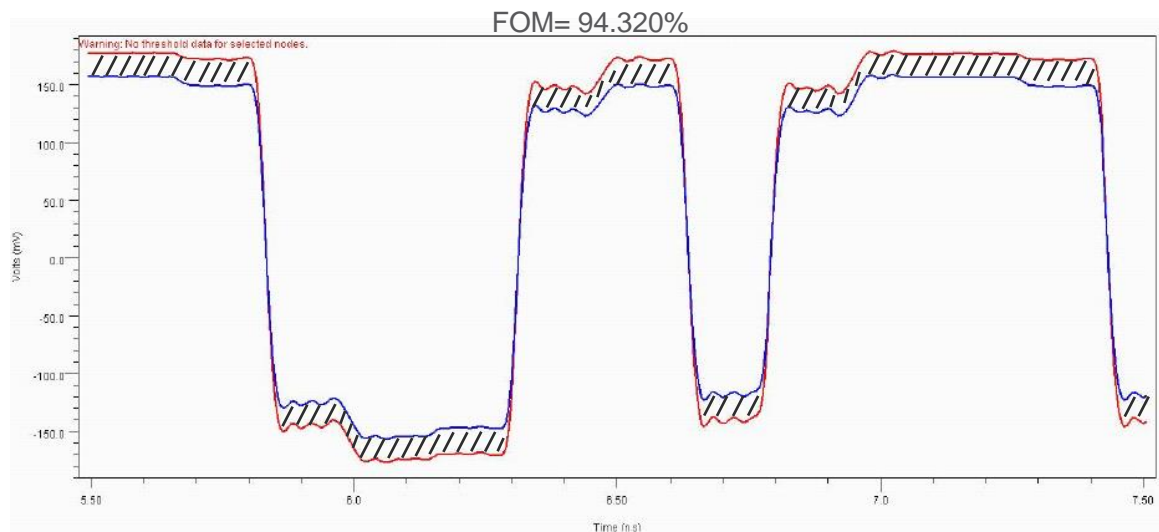
CORRELATION CRITERIA



› Figure of Merit (FOM)

$$FOM = 100 \cdot \left[1 - \frac{\sum_{i=1}^N |X_i(\text{golden}) - X_i(\text{DUT})|}{\Delta X \cdot N} \right]$$

| FOM Value | Qualitative Metric |
|-----------|--------------------|
| > 99% | Excellent |
| > 95% | Very Good |
| > 90% | Good |
| < 90% | Poor |



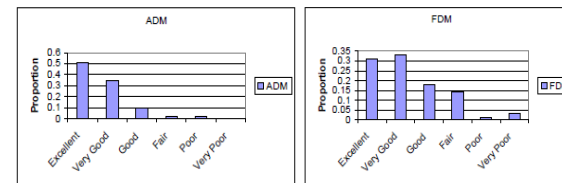
CORRELATION CRITERIA



› Feature Selective Validation (FSV)

The Feature Selective Validation (FSV) method is one of the candidate techniques for the **quantitative validation** of computational electromagnetics (CEM), particularly within electromagnetic compatibility (EMC) and Signal Integrity (SI).

It is based on the decomposition of the original data into two parts: **amplitude (ADM) data** and **feature data(FDM)**. The former will account for the slowly varying data across the data set and the latter will account for the sharp peaks and troughs.



| FSV value (quantitative) | FSV interpretation (qualitative) |
|--------------------------|----------------------------------|
| Less than 0.1 | Excellent |
| Between 0.1 and 0.2 | Very good |
| Between 0.2 and 0.4 | Good |
| Between 0.4 and 0.8 | Fair |
| Between 0.8 and 1.6 | Poor |
| Greater than 1.6 | Very poor |

Reference

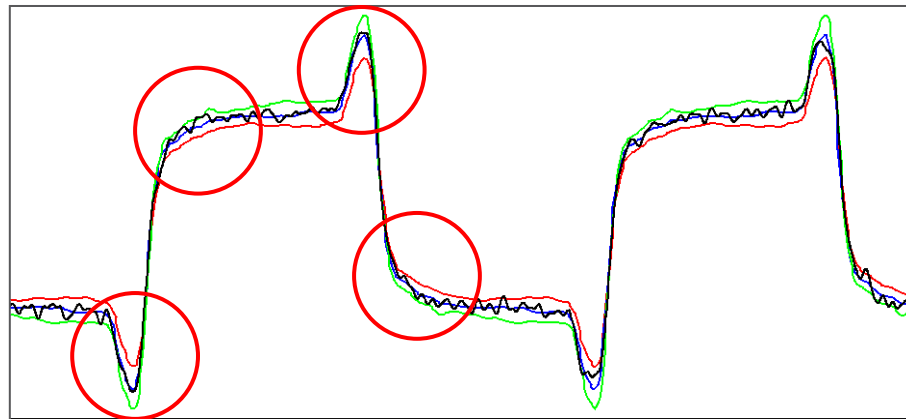
1. Roy Leventhal, "Correlation of Model Simulations and Measurements", Leventhal Design & Communications Presented June 5, 2007 IBIS Summit Meeting, San Diego, California
2. D.Di Febo, F.de Paulis, A.Orlandi "Feature Selective Validation- A new approach for new Engineers" European IBIS Summit Naples, May11, 2011

CORRELATION CRITERIA



› More metrics to correlate

- Besides 5 metrics “high level, low level, rise time, fall time, and duty cycle”, more metrics are necessary: slew rate, cursor pillars..and the metrics should have different weight in final score calculation.



Reference

1. David Banas, “IBIS-to-Spice Correlation a story of 5 metrics”, Presented June 5, 2007 IBIS Summit San Diego, California

AGENDA



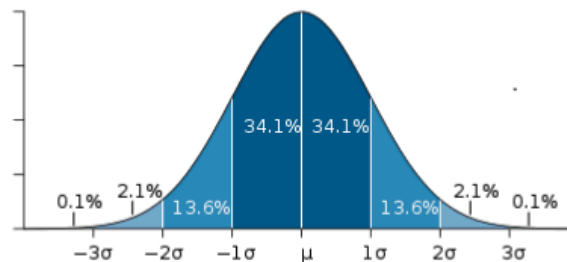
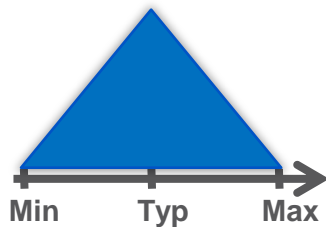
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- › Correlation criteria
- › Question and suggestion

QUESTION AND SUGGESTION



- › In the paper, Measurement is on Typical corner. No Fast and Slow corners measurement data. So, Can we trust the Fast and Slow corners simulation data, even though Typical correlates very well?
How much do the corners of AMI model match the real silicon's behavior? 99.99%...? It is a statistical problem.

- › We need to introduce the statistical distribution for Fast/Typical/Slow corners of IBIS.



- › We need more metrics for correlation evaluation. Some are proposed in this paper.



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