T10/08-404r0
SAS-2: Tools for TX characterization (and jitter tolerance setup qualification)

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Overview

- Link to Previous Material
- Guiding Principles
- Transmitter Specifications
- Far-end Measurements Orthogonality
- Issues with SASWDP
- SAS_EYEOPENING
  - Presentation
  - Features
  - Operational Features
- SASWDP vs. SAS_EYEOPENING
- Summary
- To do
In 08-330r0 and 08-345r1 Kevin Witt presented results showing how the SASWDP program could be used to characterize transmitters at the far end, after the compliance channel.

- The idea is to replace traditional near-end measurements with a single far-end metric
  - Makes the process more flexible to different TX features
  - Makes the process pattern-independent
  - Same point as for RX characterization - consistent

The measurement is taken at the TX – as close as possible to the chip pin and convolved with the reference channel.
Guiding Principles (1)

- 2 ways to view the TX compliance:
  1. Generate a waveform that an RX can recover
  2. Meet specific TX criterions that will ensure an RX can recover its output
- The WDP approach is of the first kind – verify if the RX can recover without checking the specific parameters directly
- To verify specific TX criterions is restrictive on the type of equalization that can be provided by a TX
Spec. contains only few mandatory patterns to be generated by the TX
- CJTPAT (Table 61, note g)
- D10.2 or D21.5 (Table 61, note f)
- PHY_TEST_PATTERN is not mandatory

Specification measurements are usually done at the near end
- Easier to setup
- At 6 Gbs, de-embedding results at compliance points is an issue
- Measurement at the chip removes uncertainty: Treats board as part of the channel
  - Minimal impact of testing probe – likely no de-embedding
Guiding Principles (3)

- Most TX specifications can be tested easily at the near end
  - Mostly DDJ remains, which is mostly orthogonal to other specifications

- Next slides review the standard TX specs:
  - Whether they are orthogonal to DDJ from TX and channel
  - How they relate to system performance
  - Whether they are covered easily by near-end measurements
## Transmitter Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Best Pattern</th>
<th>Near-End Measurement</th>
<th>Simulated Far-End Measurement</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>RJ</td>
<td>D10.2 or D24.3</td>
<td>Easy</td>
<td>Difficult Requires long capture</td>
<td></td>
</tr>
<tr>
<td>BUJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PJ</td>
<td>CJTPAT</td>
<td>Easy</td>
<td>Difficult Requires long capture</td>
<td></td>
</tr>
<tr>
<td>DCDJ</td>
<td>CJTPAT or D10.2</td>
<td>Easy</td>
<td>Possible</td>
<td></td>
</tr>
<tr>
<td>SSCJ</td>
<td>CJTPAT or D24.3</td>
<td>Easiest (but not easy)</td>
<td>Difficult Requires long capture</td>
<td></td>
</tr>
<tr>
<td>DDJ</td>
<td>CJTPAT</td>
<td>Constrains de-emphasis type</td>
<td>Eye opening after DFE</td>
<td>Zero-Length Test Load must be de-embedded if used to capture tx signal</td>
</tr>
<tr>
<td>Amplitude</td>
<td>CJTPAT</td>
<td>Possible</td>
<td>Tap0 magnitude in CPR</td>
<td></td>
</tr>
<tr>
<td>De-Emphasis</td>
<td>CJTPAT</td>
<td>Constrains de-emphasis type</td>
<td>Eye opening after DFE</td>
<td></td>
</tr>
<tr>
<td>Rise/Fall Times</td>
<td>CJTPAT</td>
<td>Easy Relevant for EMI</td>
<td>Eye opening after DFE</td>
<td></td>
</tr>
</tbody>
</table>
Far-end measurements orthogonality

- Specs affected by channel are best measured at far-end
  - TX amplitude
  - TX De-emphasis
  - TX DDJ
  - TX Rise-Fall time
- RX eye opening is really a combination of all the specs.
  - Need a tool for far-end measurements that can ignore the effects of specs measured at the near-end.
    - I.e., the far-end specs must be measured orthogonally to the near-end ones.
- Can we use SASWDP?
Issues with SASWDP

- Requires a PRBS pattern (new to spec)
  - Data must be properly captured to be periodic
- Requires the digital pattern
  - Data and pattern must be aligned
- Has large variations vs. pattern
  - Up to 0.8 dB between two PRBS10
- Sometimes the Clock Recovery does not converge
- Its CDR creates a new « hidden » spec.
- ncDDJ incorrectly measured?
  - Large variations anyway

See next slide
## Issues with SASWDP

<table>
<thead>
<tr>
<th>TX</th>
<th>TX de-emphasis</th>
<th>Pattern</th>
<th>Channel</th>
<th>SASWDP (original)</th>
<th>ncDDJ (original)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generated 113ps rft 0-100%</td>
<td>3</td>
<td>TxDataFile_6m-ctjpat</td>
<td>10m SAS</td>
<td>11.4</td>
<td>0.578</td>
</tr>
<tr>
<td>Generated 113ps rft 0-100%</td>
<td>3</td>
<td>TxDataFile_10m-prbs10</td>
<td>10m SAS</td>
<td>10.6</td>
<td>0.297</td>
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<tr>
<td>Generated 113ps rft 0-100%</td>
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<td>PRBS10, poly x204</td>
<td>10m SAS</td>
<td>11.2</td>
<td>0.263</td>
</tr>
<tr>
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<td>10m SAS</td>
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<td>0.52</td>
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<td>TxDataFile_10m-prbs10</td>
<td>10m SAS</td>
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<td>0.325</td>
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<td>PRBS10, poly x204</td>
<td>10m SAS</td>
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<td>0.364</td>
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<tr>
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<td>TxDataFile_6m-ctjpat</td>
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<td>15.4</td>
<td>0.725</td>
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<tr>
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<td>Generated 113ps rft 0-100%</td>
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<td>PRBS10, poly x204</td>
<td>HP24</td>
<td>11.7</td>
<td>0.324</td>
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</table>
- SAS_EYEOPENING.m script developed
- Evaluates pulse response from the channel (-4 pre-cursors to +40 post-cursors – inspired by SASWDP)
- Extracts sampling instant assuming a random input
  - Insensitive to input pattern
  - Could be improved to consider 8b10b?
- Re-computes the pulse response at this point
- Computes a simple « worst-case » 8b10b sequence
- Computes the eye opening due to DDJ, after a perfect 3-taps DFE
- Outputs information about each of the DFE's 3-taps compensation
8b10b Eye Opening from fixed CDR = 65.5276% (-3.67151 dB)
Tap Amplitudes: Main Tap 1 Tap 2 Tap 3
0.225 29.6% 14.1% 11.3%
## SAS_EYEOPENING vs. SASWDP

<table>
<thead>
<tr>
<th>TX</th>
<th>TX de-emphasis</th>
<th>Pattern</th>
<th>Channel</th>
<th>SASWD P (original)</th>
<th>ncDDJ (original)</th>
<th>&quot;8b10b&quot; eye opening</th>
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<td>0</td>
<td>TxDataFile_6m-cjtpat</td>
<td>HP24</td>
<td>24.3</td>
<td>1</td>
<td>61.4%</td>
</tr>
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SAS_EYEOPENING vs. SASWDP

- SASWDP vs. SAS_EYEOPENING (PRBS10)

![Graph showing Far-End Eye Opening vs. SASWDP with BERT + De-emphasis + real SAS10m cable]
SAS_EYEOPENING vs. SASWDP

- SASWDP: CJTPAT vs. PRBS10 (results averaged)
  - PRBS10 gives consistent results vs. De-emphasis
SASWDP vs. SAS_EYEOPENING (PRBS10)

SASWDP vs. Eye Opening:
Synthetic TX, 10ps rft, 0dB DE, 10m Cable
SAS_EYEOPENING vs. SASWDP

- SASWDP vs. SAS_EYEOPENING (PRBS10 & CJTPAT)
  - Why is SASWDP WDP dropping? Eye should stay open at near end, or reduce with too much post-cursor.
SAS_EYEOPENING vs. SASWDP

- As DE increases, the main cursor amplitude drops
  - This explains why eye opening slightly degrades: the small energy beyond Tap 3 is scaled by a smaller main cursor

TX_PE=0dB

0.23

Eye not more opened by TX_PE

TX_PE=8dB

0.16
xWDP gives strange results:
- The original script reduces WDP (improves) as PE increases
- Gain/xMA not constant – effect of CR? The amplitude after scaling by Gain/xMA is larger for PE=8dB, explaining the better SNR

**TX_PE=0dB**

xMA=0.961
W (gain)=0.942
xWDP=+2dB

**TX_PE=8dB**

xMA=0.390
W (gain)=0.547
xWDP=-2.7dB
SAS_EYEOPENING vs. SASWDP

- If we fix the amplitude extraction (xMA) to use the main cursor’s
  - Results are now more constant (only verified for one case)
  - This is what we should expect

TX_PE=0dB

- xMA=1.898
- W (gain)=1.855
- xWDP=7.8dB

TX_PE=8dB

- xMA=1.321
- W (gain)=1.847
- xWDP=7.8dB
If we fix the amplitude extraction to use the main cursor, but using SASWDP Clock recovery to set it’s location
- Now xWDP increases with increased TX_PE
- Due to optimization loop of DFE?

**TX_PE=0dB**

- xMA=1.323
- W (gain)=1.295
- xWDP=4.7dB

**TX_PE=8dB**

- xMA=1.303
- W (gain)=1.822
- xWDP=7.6dB
Thus using EYE_OPENING's main tap makes SASWDP results more consistent for processing near-end data.

Near-end data is not what we want to process:
- but that raises questions as whether SASWDP could be useful to process anything but results from a very well-defined environment.
- In theory, we should be able to qualify the TX at the near-end with the same tool.
<table>
<thead>
<tr>
<th>Specification</th>
<th>Impacts SASWDP result</th>
<th>Impacts SAS_EYE_OPENING result</th>
</tr>
</thead>
<tbody>
<tr>
<td>RJ</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>BUJ</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>PJ</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>DCDJ</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>SSCJ</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>DDJ</td>
<td>Yes, that's the goal</td>
<td>Yes, that's the goal</td>
</tr>
<tr>
<td>Amplitude</td>
<td>Yes through W parameter</td>
<td>Yes, that's the goal</td>
</tr>
<tr>
<td>De-Emphasis</td>
<td>Yes, that's the goal</td>
<td>Yes, that's the goal</td>
</tr>
<tr>
<td>Rise/Fall Times</td>
<td>Yes, that's the goal</td>
<td>Yes, that's the goal</td>
</tr>
<tr>
<td>Pattern type</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
SAS_EYEOPENING Features

- Independent to pattern. CJTPAT can be used.
- Little dependence to rise/fall times
  - This is somewhat part of the DDJ
- Low sensitivity to DCD
- Likely some sensitivity to TX impedance (?)
  - This is also somewhat part of the DDJ
- Does not support SSC
  - Same as SASWDP
- Can be used both at near and far ends
  - Will cover cables from 0 to 10m
SAS_EYEOPENING
Operational Features

- Can self-correct digital errors
  - Can use data recovered from a closed eye
  - Can thus be used directly from simple time/value scope captures
  - Can re-align data
- Does not require a periodic capture
- Fast & simple to use
  - Long sequences can be used:
    - 120 kBits in ~3 minutes, including correcting > 6k digital errors in 7 passes
  - Insensitive to RJ without pre-averaging
Example run output (from closed-eye recovered data)

Iteration 1...
  Number of digital errors: 1038
Iteration 2...
  Number of digital errors: 83
Iteration 3...
  Number of digital errors: 49
Iteration 4...
  Number of digital errors: 25
Iteration 5...
  Number of digital errors: 15
Iteration 6...
  Number of digital errors: 5
Iteration 7...
  Number of digital errors: 2
Iteration 8...
  Number of digital errors: 0

8b10b Eye Opening from fixed CDR = 65.5276% (-3.67151 dB)
Tap Amplitudes:  Main  Tap 1  Tap 2  Tap 3  
  0.225  29.6%  14.1%  11.3%
SAS_EYEOPENING Procedure: 
**TX characterization**

- Measure Time/Values at TX near end
- Extract Exact Clock frequency from transitions
  - Or use a synchronous setup
- Extract data from opened-eye
  - Or provide exact sequence if known and align to get the best correlation
- Re-sample values at an integer multiple of the bit rate
  - 16 works fine
- Convolve with Channel
- Send Values and Digital Data to SAS_EYEOPENING
- Compare EyeClosure8b10b with spec.
  - Maybe also DFE 3 taps
SAS_EYEOPENING Procedure: RX characterization

- Measure Time/Values at RX near end
- Extract Exact Clock frequency from transitions
  - Or use a synchronous setup
- Extract approximative data from closed-eye
  - Or provide exact sequence if known and align to get the best correlation
- Re-sample values at an integer multiple of the bit rate
  - 16 works fine
- Send Values and Digital Data to SAS_EYEOPENING
- Compare EyeClosure8b10b with spec.
  - Maybe also DFE’s 3 taps

**Very similar to TX procedure**
Summary

- Keep the same methodology as for SASWDP
  - Near-end measurement convolved for TX
  - Far-end measurement for RX
- Change the script from SASWDP to SAS_EYEOPENING
  - Change the spec from WDP & ncDDJ to 8b10b eye opening
  - Add Taps 0 to 3 amplitudes?
- More flexibility (use time/value captures, corrects errors)
- No question about CDR, ncDDJ, SASWDP variability
To do

- Test orthogonality to more effects
  - BUJ, DCD
  - TX impedance
- Test with more TX and channels
- Try to make output WDP-like
- Look at StatEye’s CDR
- Define a min. eye opening spec. for the TX
- Define a max. eye opening spec. for the RX
- Evaluate if a spec. on DFE coefficients is required
  - There is no such limit in the spec.
  - However, this is a direct indication of how hard a 3-tap DFE has to work
- Evaluate near-end results convolved with channel