# T10/08-404r1
# SAS-2: Tools for TX characterization (and jitter tolerance setup qualification)

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# Overview

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- 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

# Link to Previous material (1)

- 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

# Guiding Principles (2)

- 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)

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- 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

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

# 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

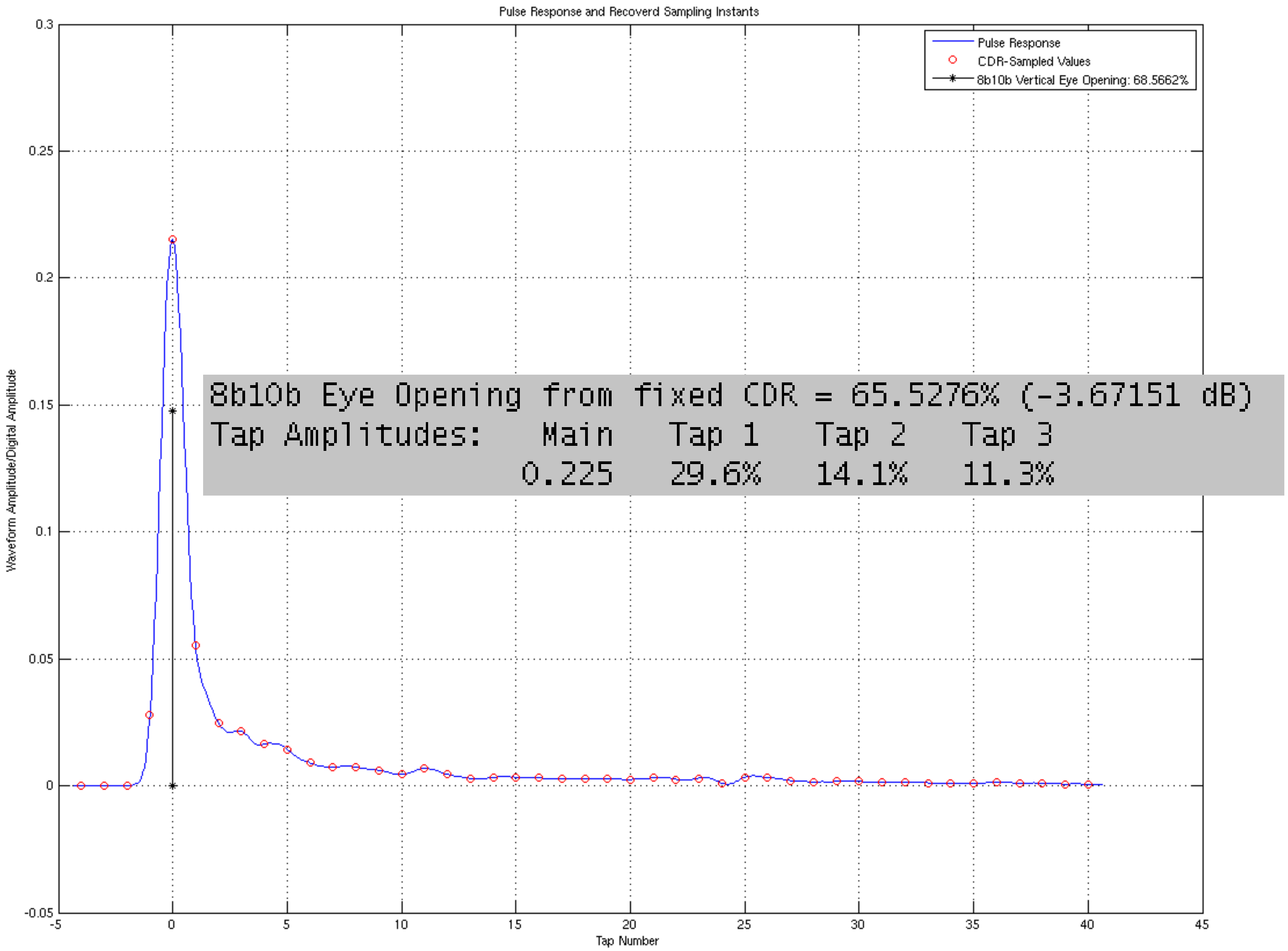
# Issues with SASWDP

| TX | TX de-emphasis | Pattern | Channel | SASWDP (original) | ncDDJ (original) |
|---|---|---|---|---|---|
| Generated 113ps rft 0-100% | 3 | *TxDataFile_6m-cjtpat* | 10m SAS | 11.4 | 0.578 |
| Generated 113ps rft 0-100% | 3 | *TxDataFile_10m-prbs10* | 10m SAS | 10.6 | 0.297 |
| Generated 113ps rft 0-100% | 3 | PRBS10, poly x204 | 10m SAS | 11.2 | 0.263 |
| Generated 113ps rft 0-100% | 0 | TxDataFile_6m-cjtpat | 10m SAS | 11.3 | 0.52 |
| Generated 113ps rft 0-100% | 0 | TxDataFile_10m-prbs10 | 10m SAS | 13.2 | 0.325 |
| Generated 113ps rft 0-100% | 0 | PRBS10, poly x204 | 10m SAS | 14 | 0.364 |
| Generated 113ps rft 0-100% | 3 | TxDataFile_6m-cjtpat | HP24 | **15.4** | 0.725 |
| Generated 113ps rft 0-100% | 3 | TxDataFile_10m-prbs10 | HP24 | 10.6 | 0.368 |
| Generated 113ps rft 0-100% | 3 | PRBS10, poly x204 | HP24 | 10.3 | 0.397 |
| Generated 113ps rft 0-100% | 0 | TxDataFile_6m-cjtpat | HP24 | **24.3** | 1 |
| Generated 113ps rft 0-100% | 0 | TxDataFile_10m-prbs10 | HP24 | 12 | 0.284 |
| Generated 113ps rft 0-100% | 0 | PRBS10, poly x204 | HP24 | 11.7 | 0.324 |

# SAS_EYEOPENING.m

- 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

# SAS_EYEOPENING.m

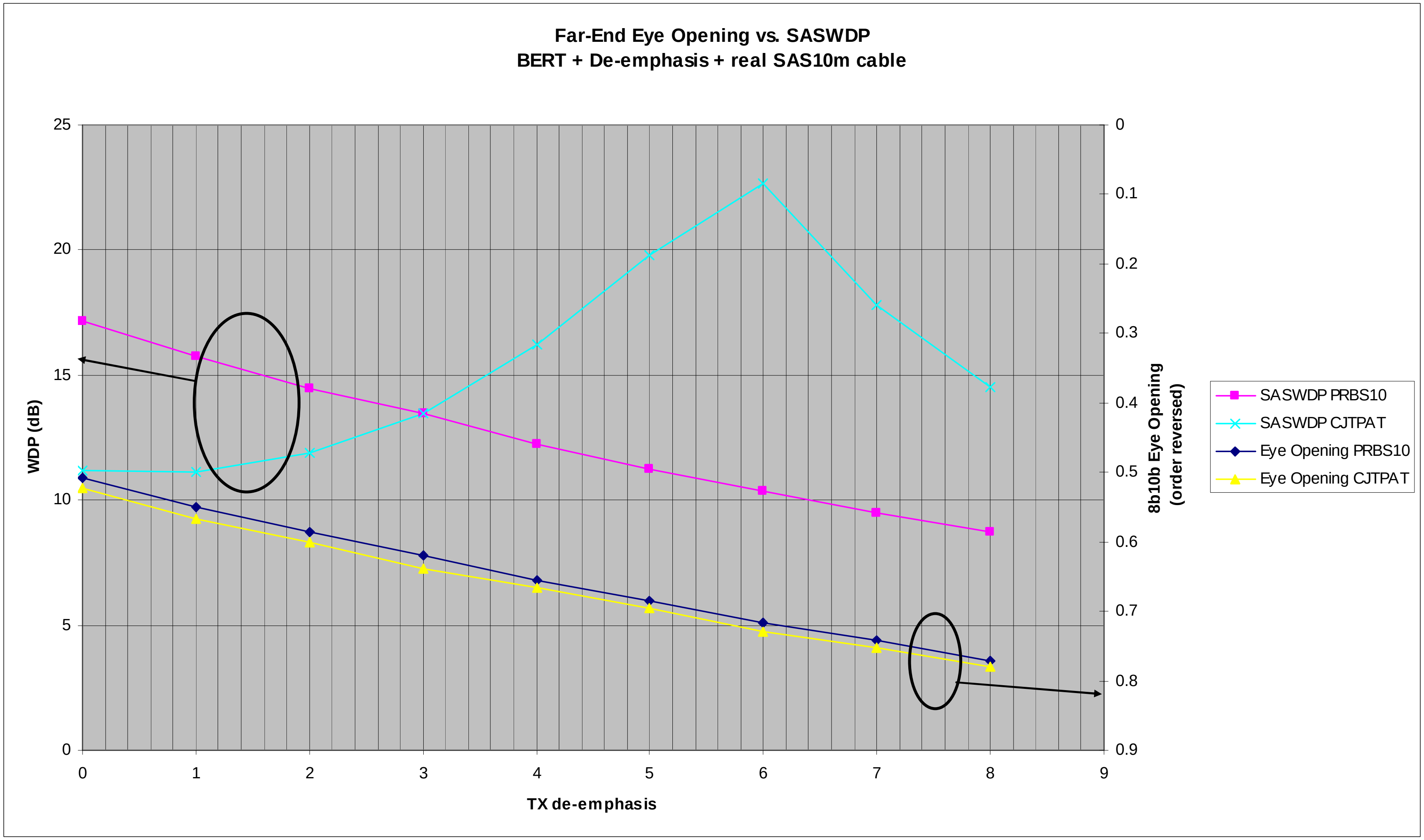


# SAS_EYEOPENING vs. SASWDP

| TX | TX de-emphasis | Pattern | Channel | SASWDP (original) | ncDDJ (original) | "8b10b" eye opening |
|---|---|---|---|---|---|---|
| Generated 113ps rft 0-100% | 3 | *TxDataFile_6m-cjtpat* | 10m SAS | 11.4 | 0.578 | 65.6% |
| Generated 113ps rft 0-100% | 3 | *TxDataFile_10m-prbs10* | 10m SAS | 10.6 | 0.297 | 65.6% |
| Generated 113ps rft 0-100% | 3 | PRBS10, poly x204 | 10m SAS | 11.2 | 0.263 | 65.5% |
| Generated 113ps rft 0-100% | 0 | TxDataFile_6m-cjtpat | 10m SAS | 11.3 | 0.52 | 56.7% |
| Generated 113ps rft 0-100% | 0 | TxDataFile_10m-prbs10 | 10m SAS | 13.2 | 0.325 | 56.6% |
| Generated 113ps rft 0-100% | 0 | PRBS10, poly x204 | 10m SAS | 14 | 0.364 | 56.6% |
| Generated 113ps rft 0-100% | 3 | TxDataFile_6m-cjtpat | HP24 | 15.4 | 0.725 | 65.4% |
| Generated 113ps rft 0-100% | 3 | TxDataFile_10m-prbs10 | HP24 | 10.6 | 0.368 | 64.6% |
| Generated 113ps rft 0-100% | 3 | PRBS10, poly x204 | HP24 | 10.3 | 0.397 | 64.6% |
| Generated 113ps rft 0-100% | 0 | TxDataFile_6m-cjtpat | HP24 | 24.3 | 1 | 61.4% |
| Generated 113ps rft 0-100% | 0 | TxDataFile_10m-prbs10 | HP24 | 12 | 0.284 | 60.7% |
| Generated 113ps rft 0-100% | 0 | PRBS10, poly x204 | HP24 | 11.7 | 0.324 | 60.6% |

# SAS_EYEOPENING vs. SASWDP

- SASWDP vs. SAS_EYEOPENING (PRBS10)



# SAS_EYEOPENING vs. SASWDP

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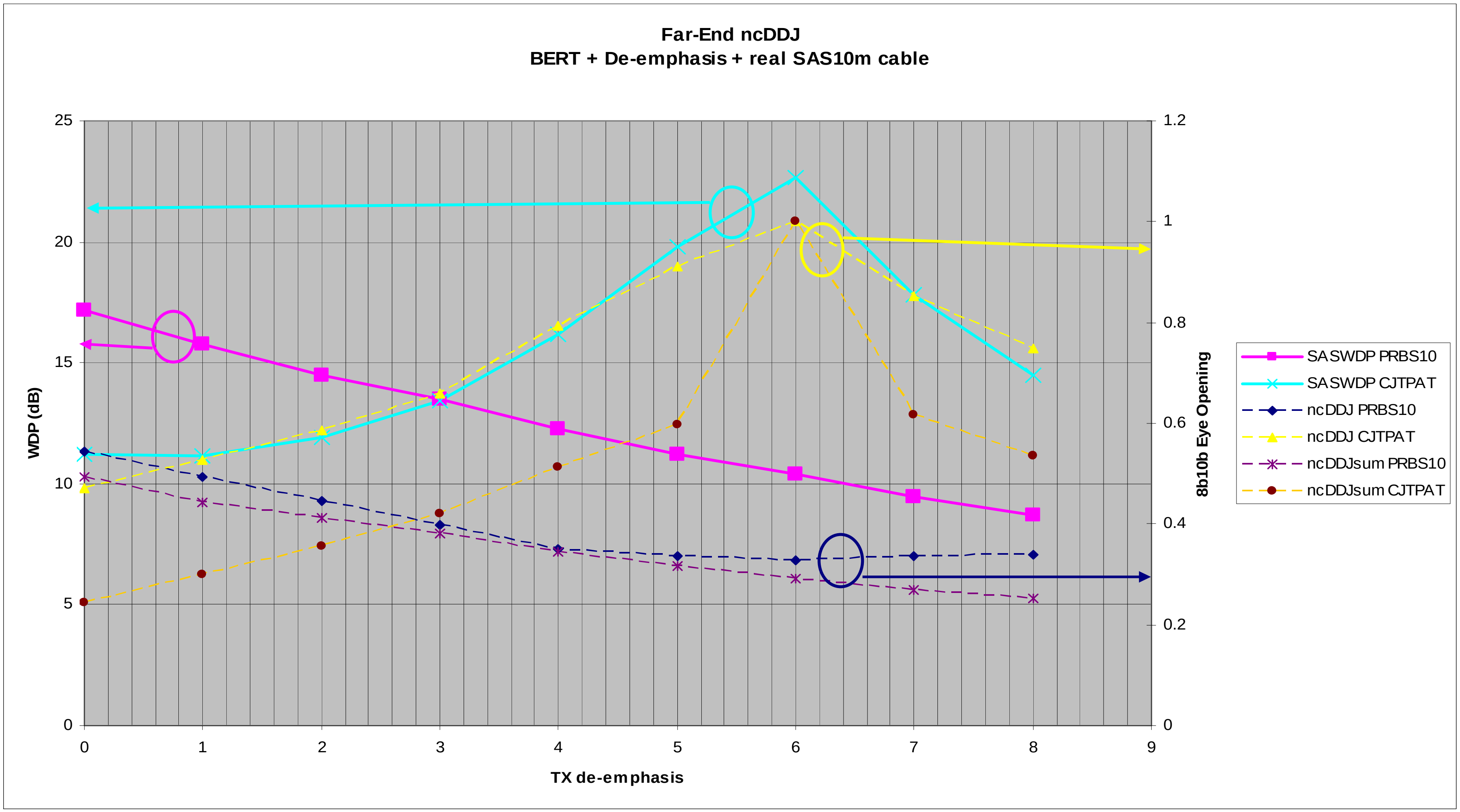
- SASWDP: CJTPAT vs. PRBS10 (results averaged)
  - PRBS10 gives consistent results vs. De-emphasis



# SAS_EYEOPENING vs. SASWDP

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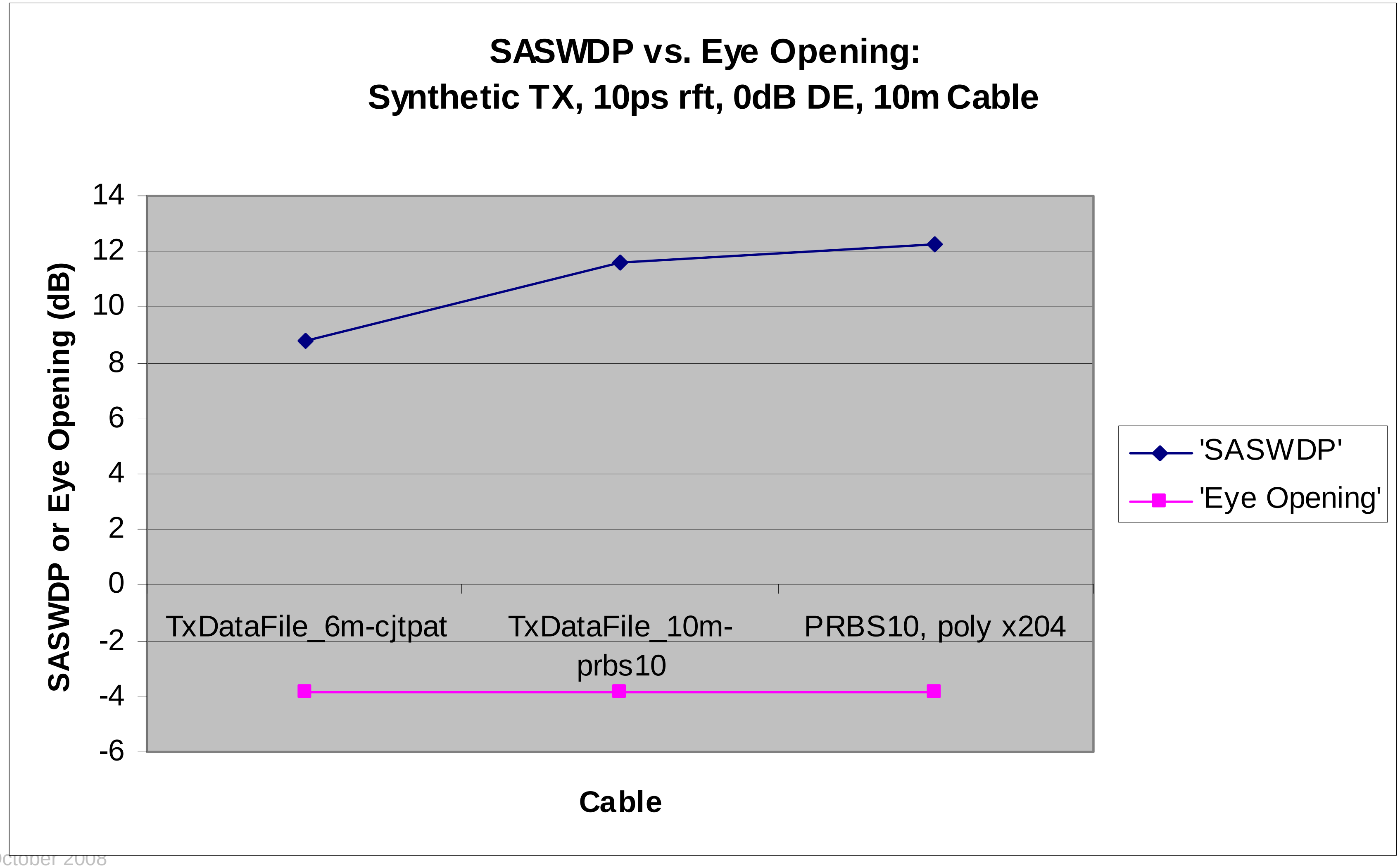
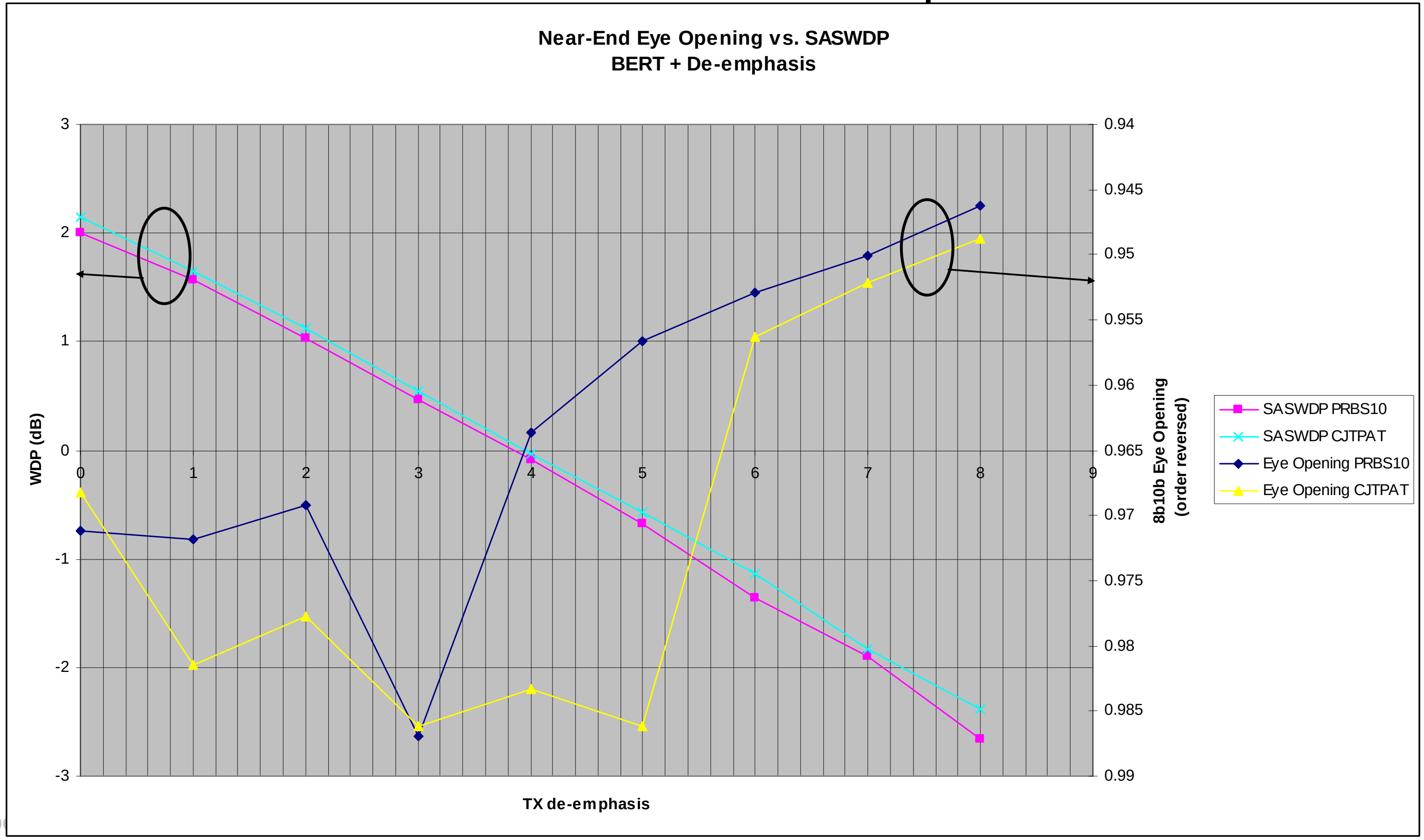
- SASWDP vs. SAS_EYEOPENING (PRBS10)



# SAS_EYEOPENING vs. SASWDP

- SASWDP vs. SAS_EYEOPENING at TX NEAR-END
  - Why is SASWDP WDP dropping? Eye should stay open at near end, or reduce with too much post-cursor.



# SAS_EYEOPENING vs. SASWDP

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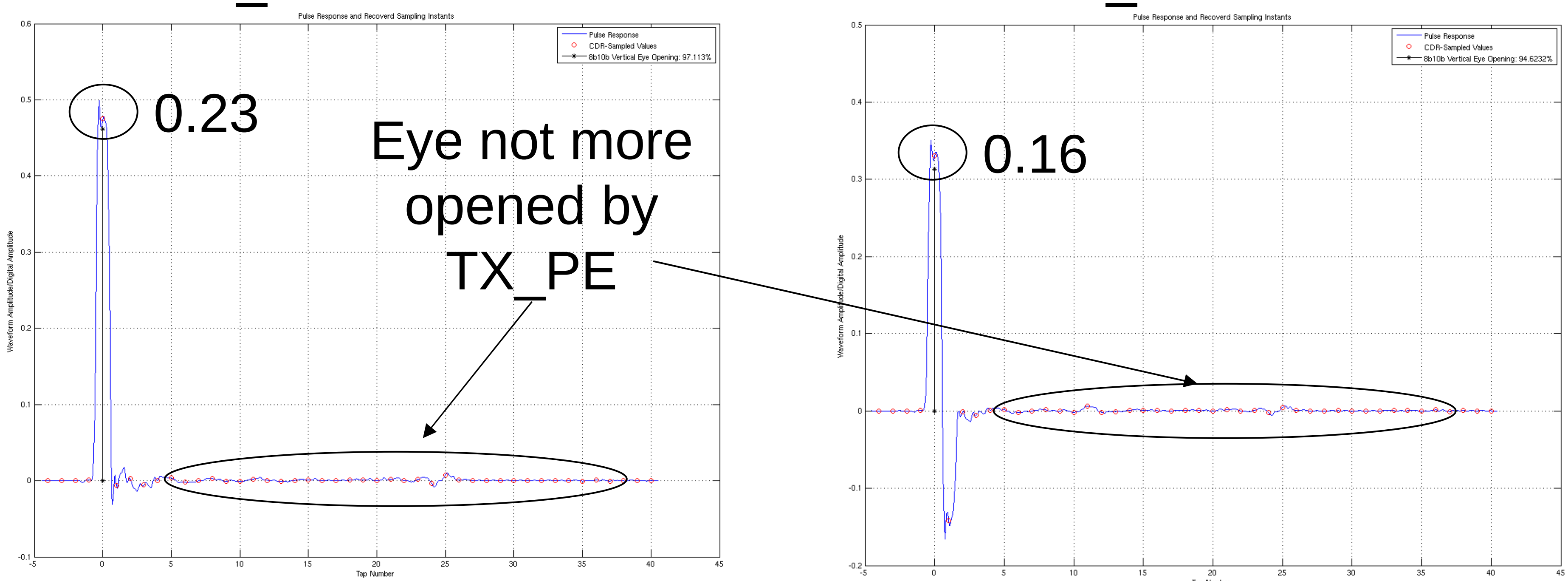
- As DE increases, the main cursor amplitude drops
  - This explains why eye opening slightly degrades: the small energy beyong Tap 3 is scaled by a smaller main cursor

TX_PE=0dB

TX_PE=8dB



# SAS_EYEOPENING vs. SASWDP

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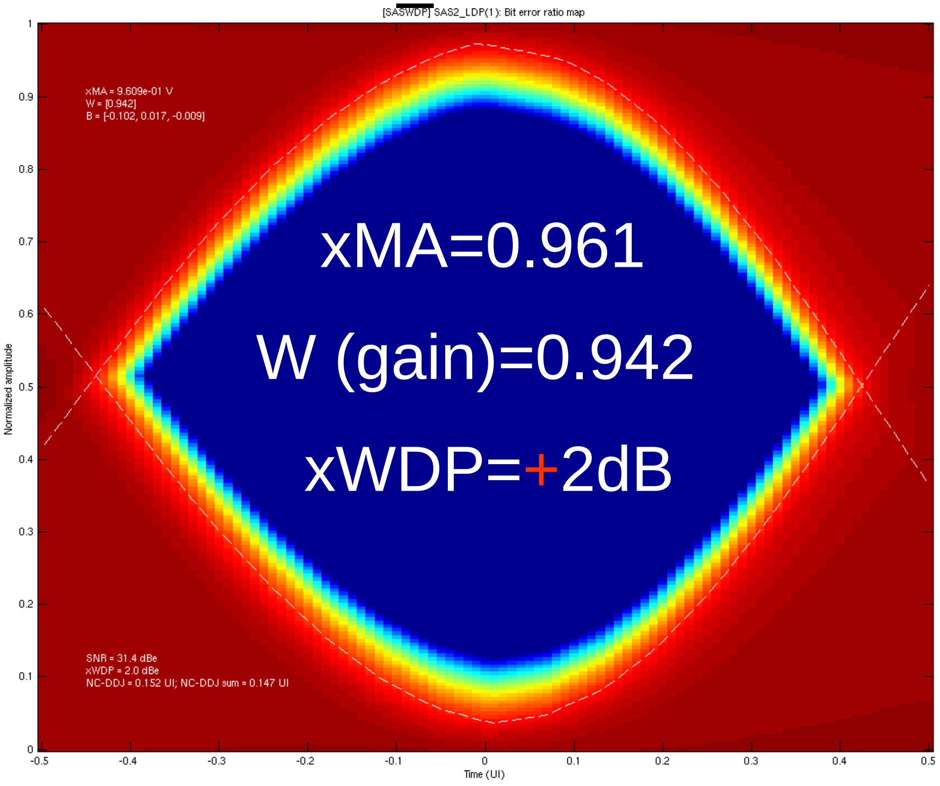
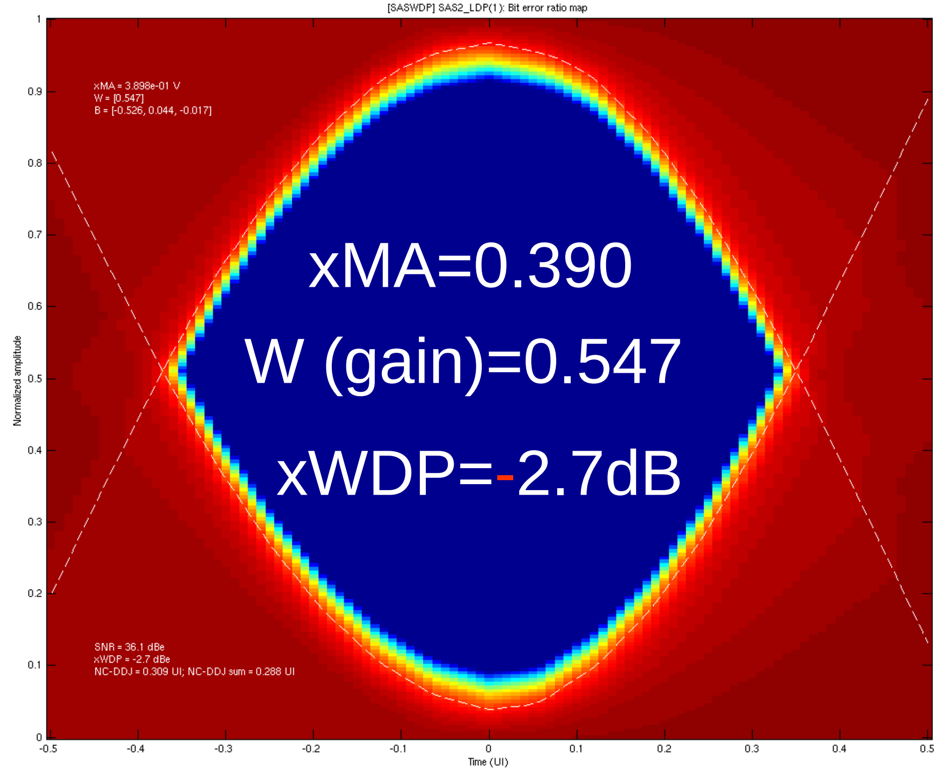
- xWDP gives strange results:
  - The original script reduces WDP (improves) as PE increases
  - Gain/xMA not constant – effect of CR? The amplitude after scaling by Gain/xMA is larger for PE=8dB, explaining the better SNR

TX_PE=0dB



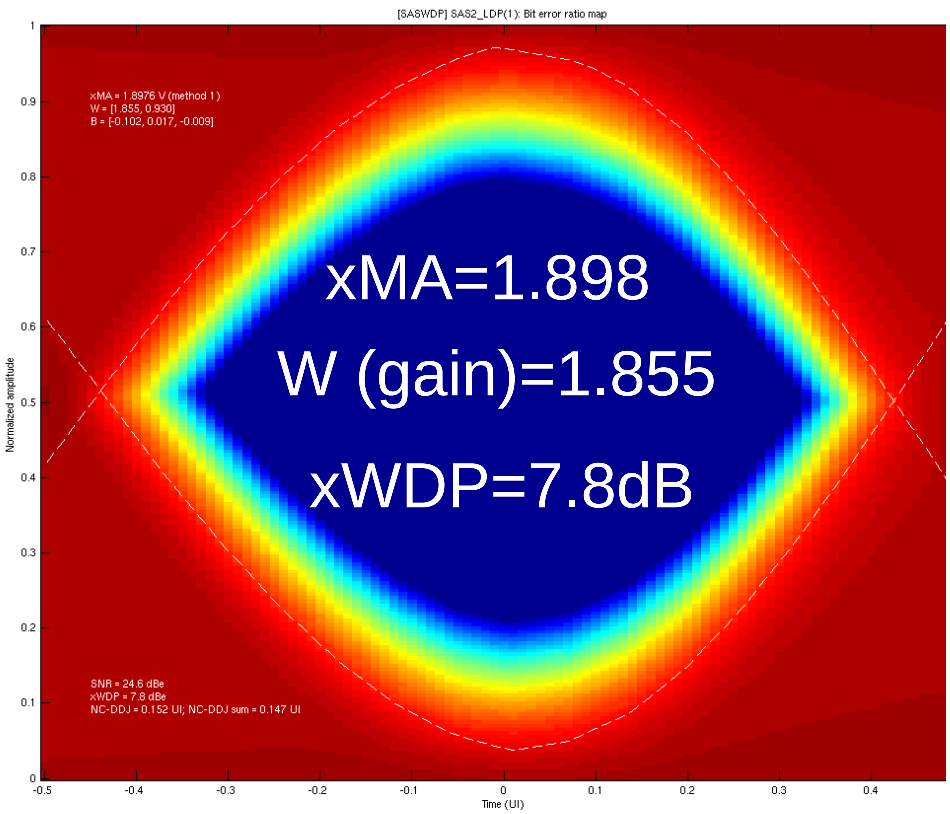

TX_PE=8dB



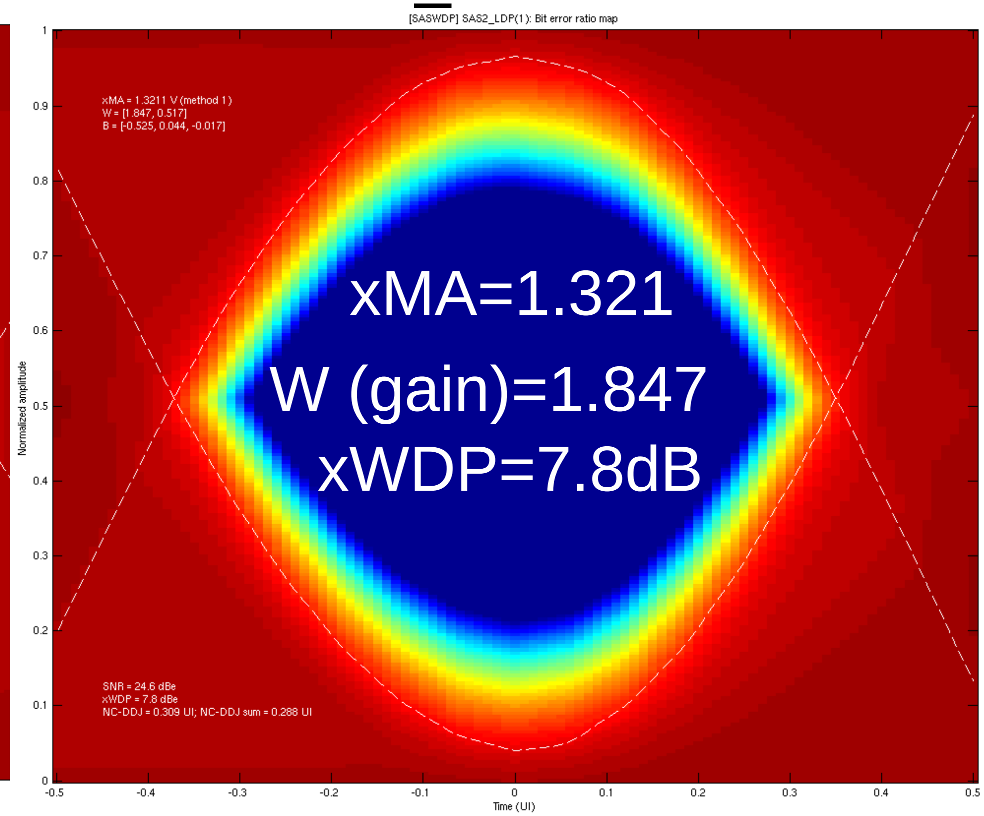
# SAS_EYEOPENING vs. SASWDP

- 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



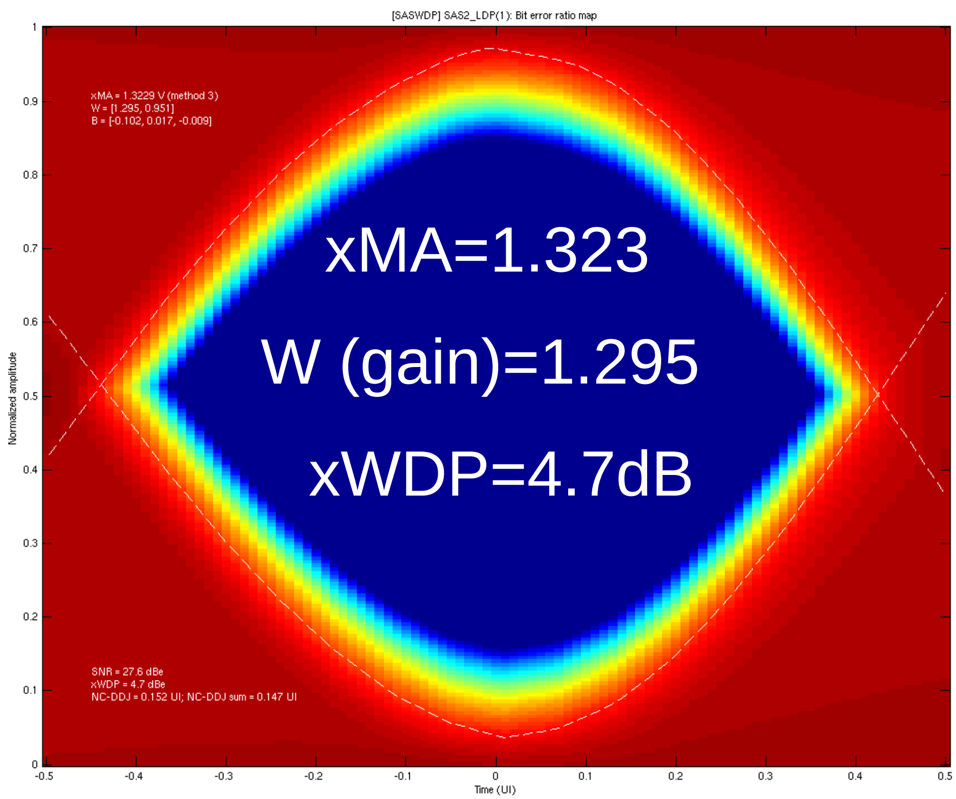

TX_PE=8dB



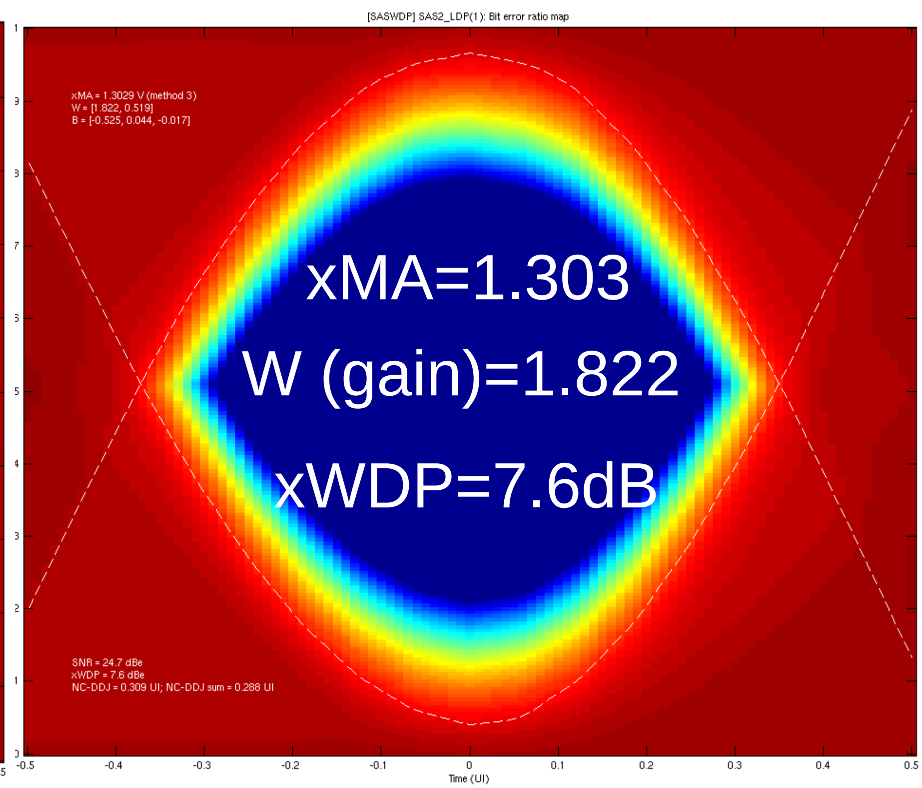
# SAS_EYEOPENING vs. SASWDP

- 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




TX_PE=8dB

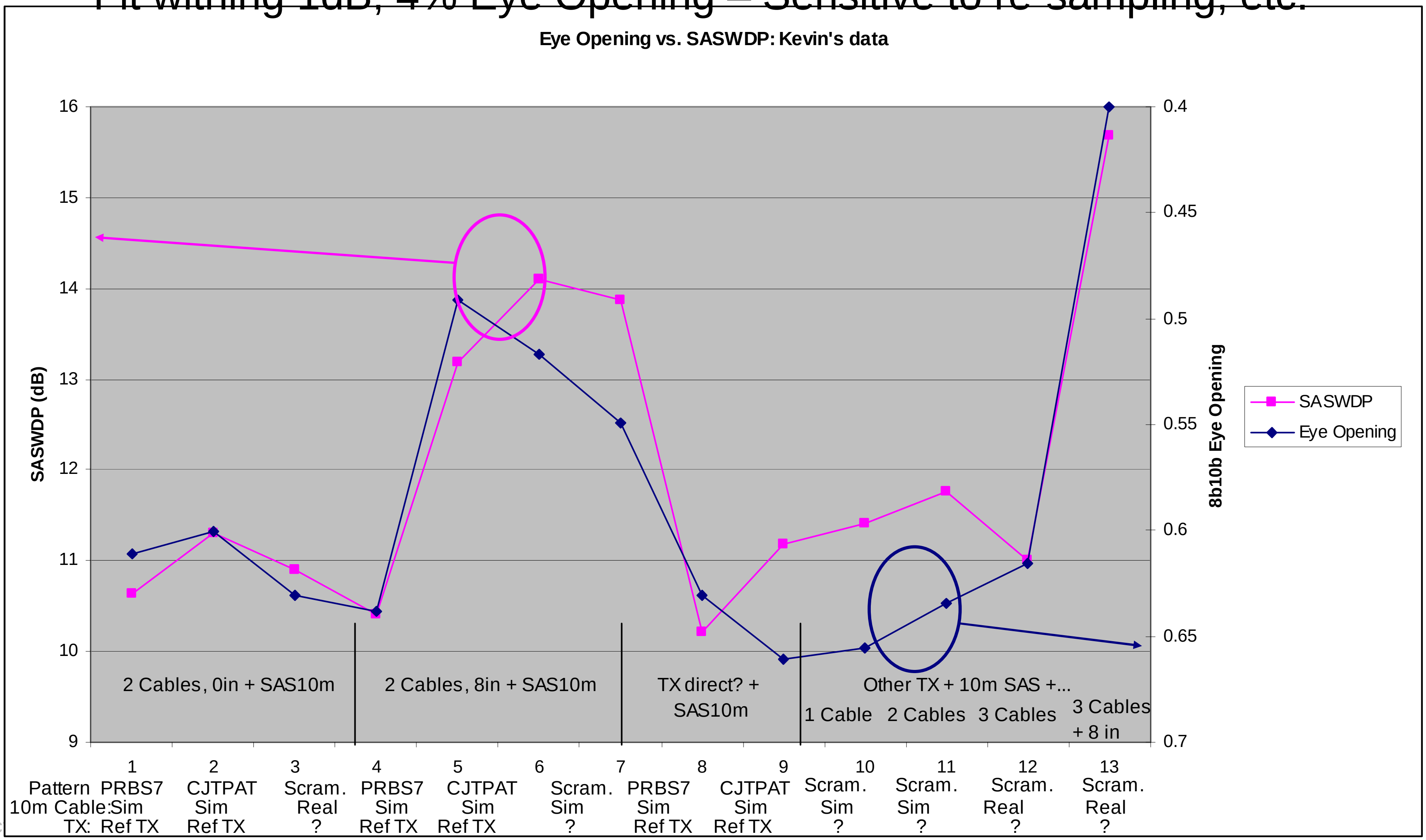


# SAS_EYEOPENING vs. SASWDP

- 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

# SAS_EYEOPENING vs. SASWDP

- Reprocessed some of Kevin`s results
  - Fit withing 1dB, 4% Eye Opening – Sensitive to re-sampling, etc.



# SAS_EYEOPENING vs. SASWDP

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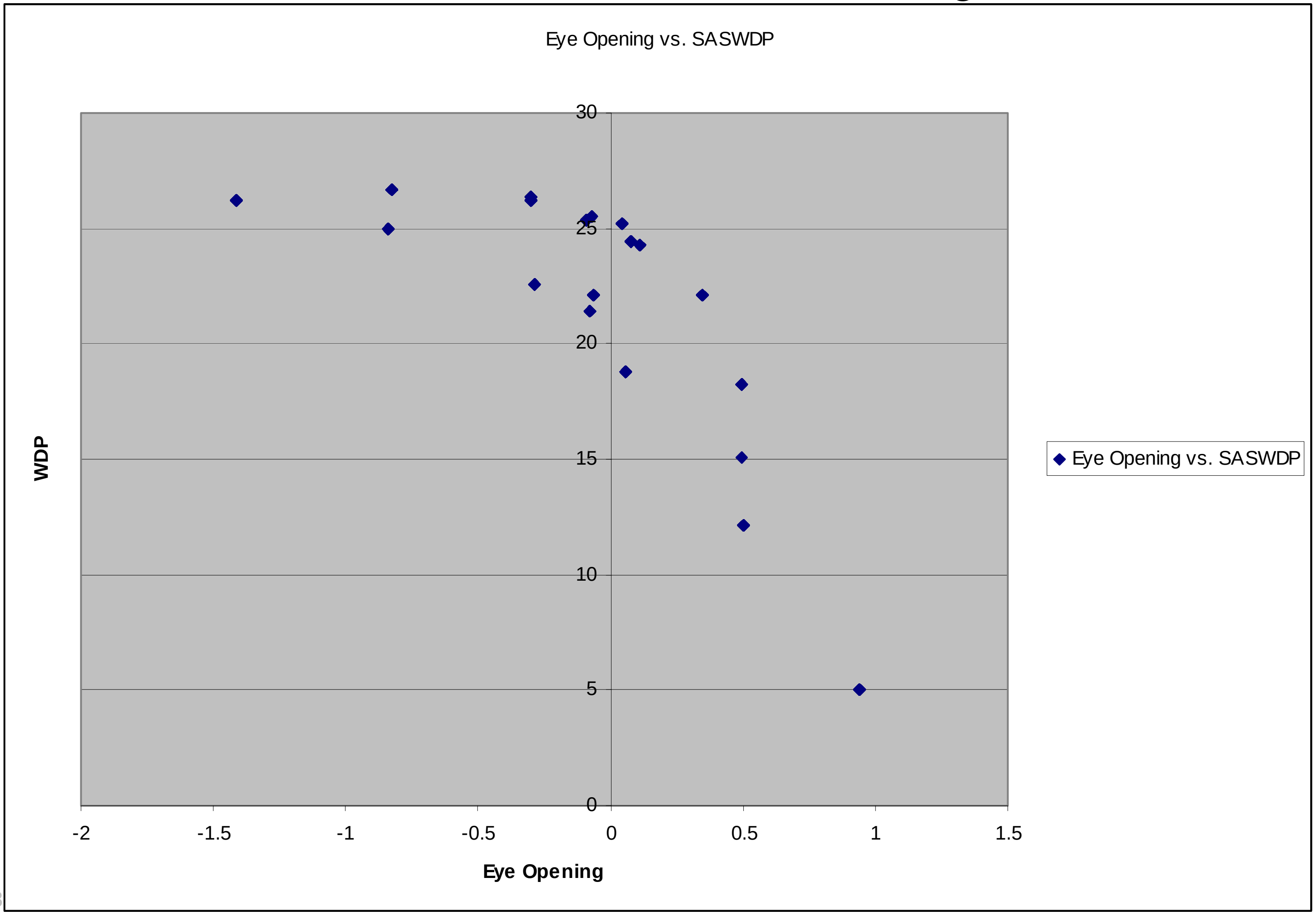
- Comparison of different test cases
  - Need to run more tests. Match « linear » in region of interest?



# Far-end Measurements Orthogonality

| Specification | | Impacts SASWDP result | Impacts SAS_EYE_OPENING result |
|---|---|---|---|
| RJ | | No | No |
| BUJ | PJ | No | No |
| | DCDJ | Yes | No |
| | SSCJ | N/A | N/A |
| DDJ | | Yes, that's the goal | Yes, that's the goal |
| Amplitude | | Yes through W parameter | Yes, that's the goal |
| De-Emphasis | | Yes, that's the goal | Yes, that's the goal |
| Rise/Fall Times | | Yes, that's the goal | Yes, that's the goal |
| Pattern type | | Yes | No |

# 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

# SAS_EYEOPENING.m
# Operational Features

- 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

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- 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

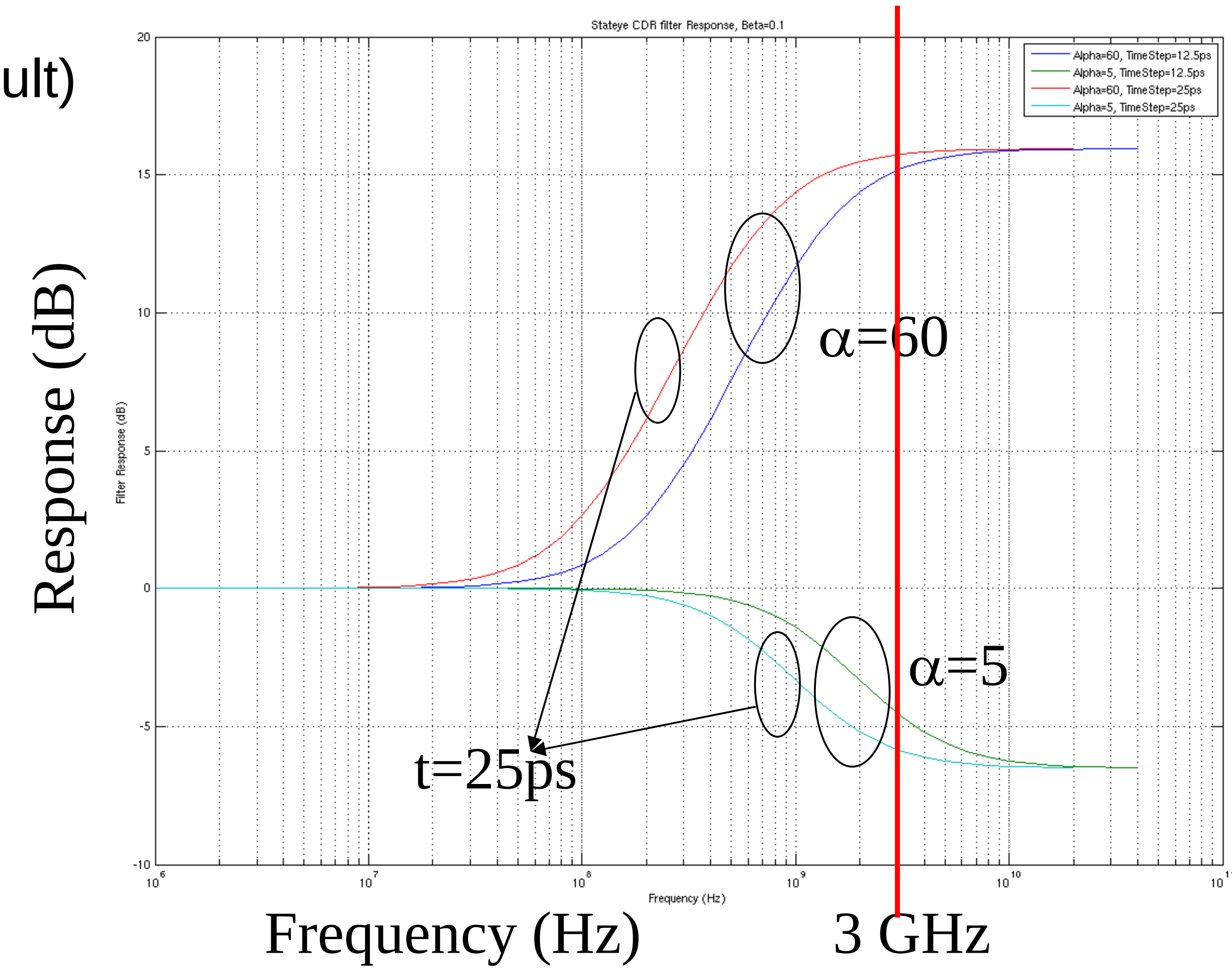
****Very similar to TX procedure****

# StatEye Clock Recovery

- Data is filtered by a digital filter
  - Parameters:
    - Alpha (high-pass)
    - Beta (low-pass)
    - Time Step (overall frequency scaling)
- Serves as noise filter
- Can serve as equalization
- Examples (testall.bat) included Alpha=5 and Default Alpha=60
  - Parameter z in testcase.py
  - Beta always 0.1
- Some examples forced Time Step=12.5ps
  - Parameter x in testcase.py
- Further NOTE from Rob Elliott:
  - This is for the extraction from the waveform (extractsignal.py)
  - The part of the code we are interested in for correlation with previous result does not contain this routine

# StatEye Clock Recovery

- Example Responses:
  - $\alpha$=5 or 60
  - $\beta$=0.1 (default)
  - t=12.5ps or 25ps



# StatEye Clock Recovery

- CDR then works on the edges of the « emphasized » input
  - Emphasis based on user-defined parameters & time-step
  - It seems to then filter the transitions further
    - Parameters m and k in cdr.py
      - period += [period[-1] + phaseError[-1] * k]
      - phase += [phase[-1] + phaseError[-1] * m + nperiod[-1]*period[-1]]
- Conclusion:
  - StatEye allows the user to specify input filtering
    - It does have an hard-coded jitter filtering
  - Default is a high-pass filter
  - Parameters should be scaled vs. time step
- What should we do?
  - Specify a filter for clock recovery?
  - Work on unequalized eye?
- To do: look more at StatEye to see what it does when no measured input is provided

# 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 (in process)
- Try to make output WDP-like
- Look at StatEye's CDR (partly done).
- Compare StatEye to Eye Opening for Synthetic TX cases
- 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