Proposed Tx Jitter methodology and limit values

(comments #204, #236 against D1.0)

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Introduction

- Jitter specification (parameters and values) for all electrical interfaces are currently missing
  - Table 179–7, 179.9.4.7, Table 178–6, Table 176D–1, 176D.3.3.6 have TBDs
  - Annex 176E (C2M) output specs are written based on the EH/VEC methodology which has no separate jitter specification.
- The term “jitter” has different meaning to different people
- The importance of measuring and limiting jitter is sometimes debated
- The feasibility and accuracy of jitter measurement is sometimes challenged
- This presentation intends to bring some order to chaos, and enable moving forward.

What jitter are we talking about

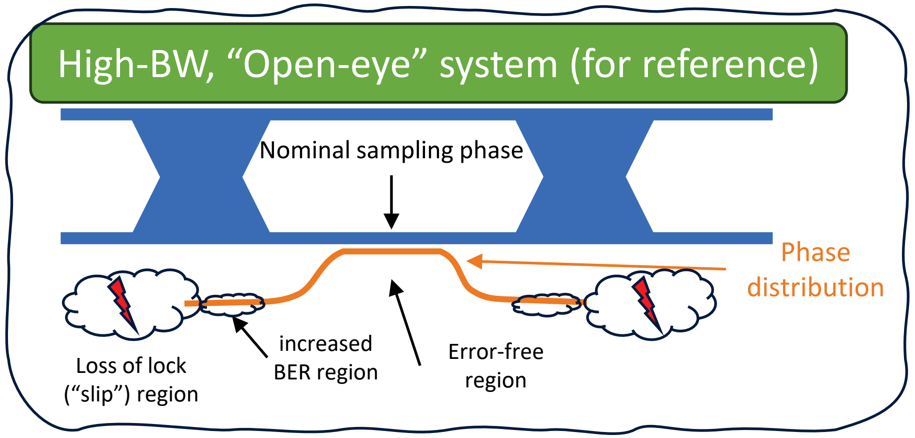
- Jitter measurement using simple “edge timing distribution” after a dispersive channel includes the effect of ISI, which receivers are capable of mitigating
  - a.k.a. data-dependent jitter (DDJ)
  - ISI should not be counted as jitter (it is measured in other ways)
  - The jitter we should look at is the uncorrelated components
- Uncorrelated jitter can be further separated into bounded (sometimes called “deterministic”) and unbounded (often called “random”) jitter
- The reasoning for this separation comes both from typical implementations and from the effect of jitter on receiver performance
- This topic has been explored in 802.3 and other standards, see for example li_01_0109 (802.3ba, 2009)

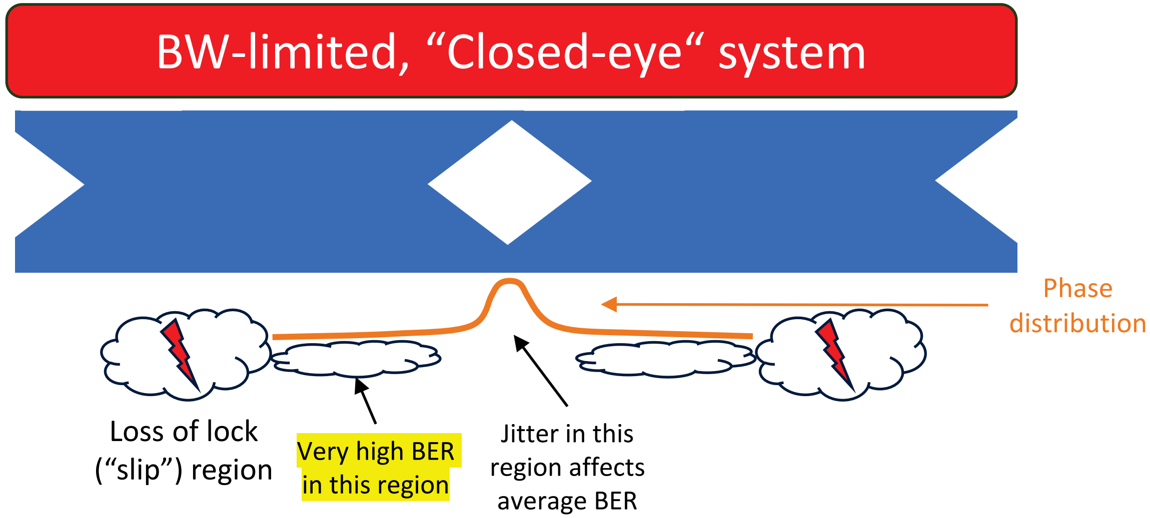
The effect of uncorrelated jitter

- Jitter is measured after the effect of a clock recovery unit (CRU) that represents the expected receiver phase tracking
- The measured jitter parameters represent the distribution of the signal’s phase relative to the receiver’s clock
  - The receiver’s clock can have its own phase noise – and it can only make things worse
- Jitter has different effects on high-bandwidth (“open-eye”) and limited-bandwidth (“closed-eye”) systems
  - This presentation focuses on the case of high-dispersion channel and assumes T-spaced equalization, which is associated with a non-rectangular “statistical eye”
  - A high-bandwidth system is shown in the next slide for comparison

Jitter in systems with strong equalization and FEC

- The diagrams on the right are simplified illustrations of the “statistical eye” or “BER eye” of the receiver after equalization and without Tx jitter
  - Not the eye diagram associated with transmitter measurements
- In a bandwidth-limited system, even small values of phase error affect the BER
- Bounded uncorrelated jitter makes the phase distribution wider
  - Increasing the average BER
  - High frequency jitter can cause additional degradations, not addressed here
- Low-frequency jitter causes variations in the BER
  - When coupled with FEC, the FEC performance is governed by the BER in (relatively rare) codewords that suffer from high jitter, rather than the average BER
- **In bandwidth-limited systems with FEC it is more important to limit the jitter**





Jitter specification

- Early specifications ignored the DDJ components (which can be neglected if measurement is after a channel with low enough dispersion)
- For measurement after a dispersive channel, it was important to specify jitter without the DDJ component
  - For example, for 40GBASE-CR4, Table 85–5 specifies “Total jitter excluding data dependent jitter”
  - However, DDJ is not a deterministic value that can be subtracted from a measurement result (rather, a random variable with some distribution)
  - Subtracting distributions is not well-defined
- The jitter measurement method introduced in clause 92 (802.3bj) measures the timing of two specific transitions in a PRBS9 pattern
  - This measures only the uncorrelated component – which is what we want

Jitter specification (2)

- The method for PAM4 was introduced in Annex 120D as an extension of the Clause 92 method
- It includes the following concepts:
  - Spectrally-rich PAM4 test pattern (PRBS13Q)
  - Measurement of the RMS value of the phase distribution (J_{RMS}), the “all-but-10^{-4}” peak-to-peak (J4u), and the highest-frequency component (even-odd jitter)
  - Measurement using all 12 possible transitions in a PAM4 signal
- This method has been successfully used in all 50 Gb/s per lane interfaces (clauses 136 and 137 in addition to annex 120D)
  - In 120D it was assumed that jitter values at probabilities below 10^{-4} can be ignored (compared to the specified 10^{-4} FEC symbol error ratio of the AUI-C2C interface)
  - For PMDs, the maximum allowed FEC symbol error ratio is ~10^{-3}, so the specification became J3u instead.
  - For the CR PMD, limit are slightly relaxed to account for possible degradation when measuring after a lossy channel.
- The limits for J_{RMS} and J4u/J3u are all based on a dual-Dirac BUJ with amplitude of 0.02 UI, convolved with a Gaussian RJ with RMS of 0.01 UI
  - Same values as COM’s A_{DD} and σ_{RJ}.

Jitter specification (3)

- During the standardization of 100 Gb/s electrical interfaces (802.3ck) some issues were identified
  - EOJ results were unexpectedly high
    - This was explained by the relatively long period of PRBS13Q compared to the CRU bandwidth (calvin_3ck_01_1020)
    - As a result, PRBS9Q was added as an optional pattern for EOJ measurement (ran_3ck_02a_1020)
    - In fact, all measurements can be performed with this pattern and should yield similar results
  - Measurement after a host loss showed degraded J3u results
    - This was explained by increased sensitivity to noise (AM-PM conversion) in the smaller PAM4 transitions. It was suggested that the two largest transitions, R03/F30, are what we should focus on (rysin_3ck_01b_0122)
    - As a result, another specification was added: $J3u_{03}$ in Clause 162 and 163, and $J4u_{03}$ in Annex 120F (ran_3ck_05b_0122)
    - J3u and J4u remain as specifications but with significantly larger limits

- In P802.dj, calvin_3dj_elec_01a_240104 reported that jitter on the R03/F30 transitions can be measured with good accuracy after a 30 dB channel (much higher loss than the 802.3ck host channel)
  - J3u and J_{RMS} using all transitions are much higher (as could be expected)
  - **This suggests that all jitter measurements should only consider R03/F30**
  - This method can be used for AUI-C2M output specifications – where jitter specs are as important as in all other interfaces (especially with host loss >30 dB).

New issue

- The combination of J3u and J_{RMS} is expected to protect against both wide-distribution BUJ and large-RMS RJ
  - As shown earlier, both can affect BER and FEC performance
- However, it is possible to meet both specs with higher-than-expected RJ, if the BUJ component is small
- Is that acceptable?
  - High RJ causes large excursions from the average phase to become more frequent
  - This is a source of correlated errors
  - It can cause FEC performance to be worse than what is expected by the average BER
- Example
  - **Case A**: Tx jitter equivalent to the COM parameter values A_{DD}=0.02 UI and σ_{RJ}=0.01 UI, creating J3u=0.106 UI and J_{RMS}=0.022 UI, barely meeting the existing specs
  - **Case B**: Tx jitter equivalent to A_{DD}=0 and σ_{RJ}=0.0173 UI – it will have the same J3u and lower J_{RMS} (0.016 UI) – apparently a better transmitter?
  - Assume Rx jitter is the same as case A
  - In case A, the probability of a 0.164 UI phase excursion due to the combined Tx+Rx jitter is 4.1e-19 – which at 106.25 GBd would be a once-per-year event
  - In case B, with the same Rx, the probability of the same 0.164 UI phase excursion becomes 2.2e-17 – which at 106.25 GBd would happen once a week
  - An excursion of 0.15 UI will happen every 1.5 hours in case A, but every 10 minutes in case B!

Proposed additional spec to limit RJ

- Purpose: **rule out transmitters that meet J3u but can cause correlated errors**
- Add a new spec parameter **J6u**, with similar definition to J3u but at a probability of 10^{-6}.
- Use a maximum value of 0.138 UI (which corresponds to the COM transmitter model) for measurement after a low loss (e.g., module output).

Summary

- Proposal for all electrical interfaces: CR, KR, C2C, C2M host and module
- Use the jitter measurement methodology based on Annex 120D, with the following exceptions:
  - All parameters are measured only on the R03/F30 edges.
  - All measurements can be performed with either PRBS13Q or PRBS9Q.
  - For uniformity, use J3u for all interfaces, with the same limits, regardless of the error budget.
  - Add a new specification, J6u, similar to J3u but at a probability of 10^{-6}.
- Limit values:
  - For C2M (host output and module output) specific limits are proposed in a separate presentation.
  - For C2C and for KR classes A and B (measured at TP0v), and for CR host classes (measured at TP2), use values interpolated between the C2M module output (lowest loss) and C2M host output (highest loss) based on the assumed loss from the transmitter to the measurement test point.
  - Summarized in the next slide.

Proposed limit values (all values in UI)

Interface	Max J_{RMS}	Max J3u	Max J6u	Max EOJ
AUI-C2M module output	0.022	0.106	0.138	0.024
C2C and KR transmitter class A	0.022	0.108	0.140	0.024
C2C and KR transmitter class B	0.023	0.109	0.142	0.025
CR transmitter, host-low	0.022	0.108	0.140	0.024
CR transmitter, host-nom	0.023	0.110	0.144	0.025
CR transmitter, host-high	0.024	0.113	0.147	0.025
AUI-C2M host output	0.026	0.122	0.159	0.027

That’s all

Questions?