Accounting for transmitter noise in system budget

(in support of comments #84, #87, #97)

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Supporters

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Note on PAM-4 and NRZ

- This presentation seems focused on PAM-4; this is mainly because the RX ITT was originally written for clause 94.
- Nevertheless, most of the problems and the proposed solutions are relevant regardless of the number of levels used.

Problem statement

- TX performance is specified by several measurements:
  - Jitter
  - SNDR (minimum across phases) – currently only clause 94, >19 dB
  - Linear fit error (average across sampling phases)
  - Far-end noise
- COM calculation accounts only for jitter – no other TX noise assumed*
  - Possibly too optimistic
- RX tolerance test calibrates TX noise, and then target COM
  - Aligns with channel spec only if TX hits noise limits due to jitter
  - Using a better-than-minimum TX requires adding BBN, which may penalize RX (as demonstrated below).
  - ➔ COM assumption of noises/RX capability is not enough (performance deficit)
- Goal: balanced link budget

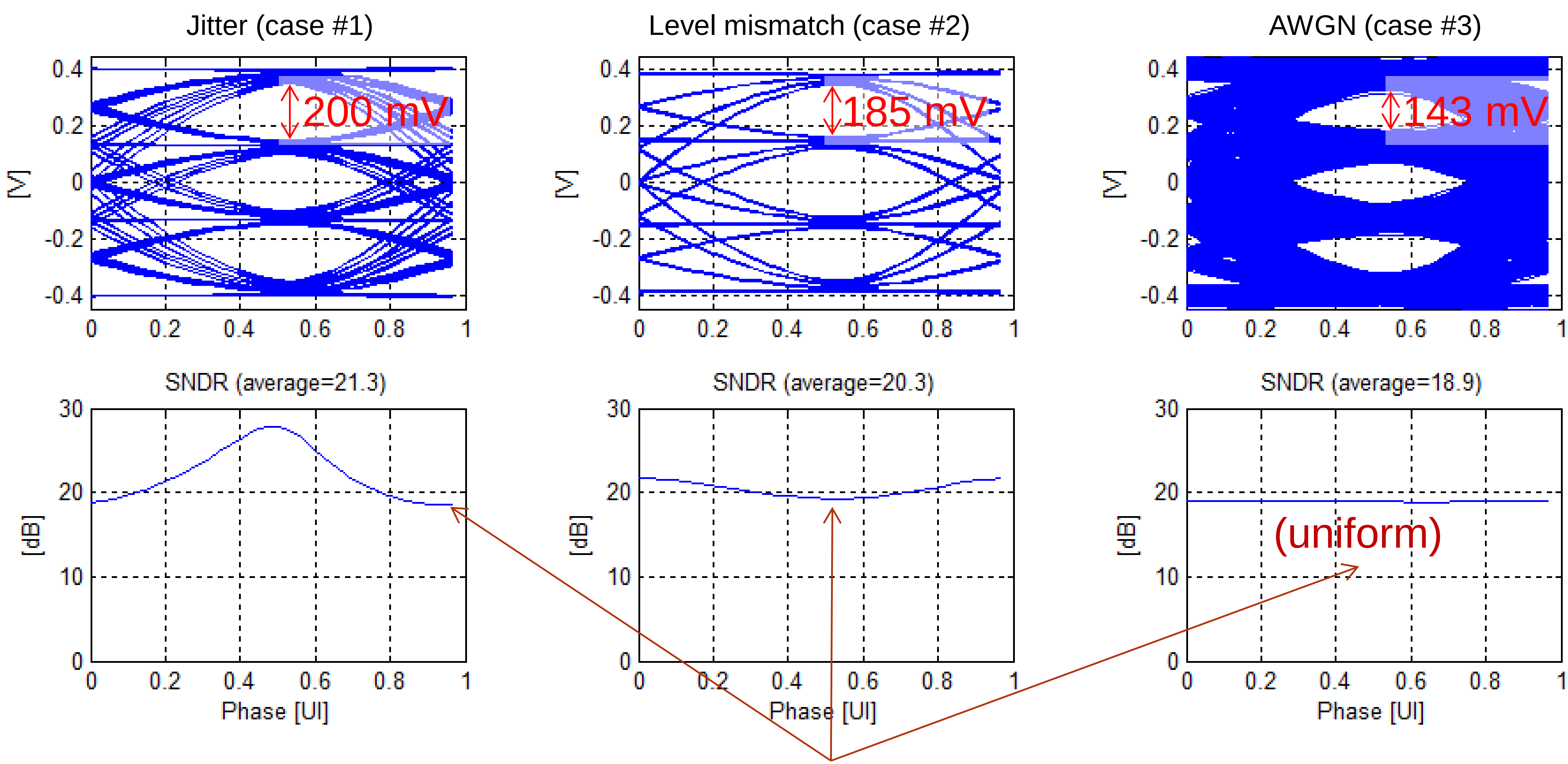
* Previously noted by Arash Farhood (comment #252 on D2.0)

Does “worst case jitter” necessarily mean “worst case TX”?

- Let’s compare some transmitter impairments:
  1. Jitter
  2. Static level mismatch (only relevant for PAM-4)
  3. AWGN (at TX)
- Impairments tuned to have the same minimum SNDR, ~19 dB

Results

Channel for all 3 cases is 4th order BT at $0.75{*}f_{Baud}$; ideal EH is ~212 mV



Note that minimum SNDR occurs at different phases

Observations

- **Jittered TX is least stressful of the three**
  - Worst SNDR is away from sampling phase; better around sampling phase
  - We can discount the transition area
- **TX static nonlinearity (level mismatch) has a large effect on SNDR**
  - Worst SNDR near sampling phase; better elsewhere
  - Receiver may equalize it, so we can discount it
- **Additive noise has the worst impact**
  - SNDR is not phase dependent
  - Other uncorrelated phenomena such as amplitude modulation may have similar characteristics and impact
  - We don’t want to have this eye!

Can we account for additional TX noise?

- **Static level mismatch:**
  - Very likely to occur – requiring very small mismatch would significantly burden TX
  - Appears as distortion – but if TX levels are known, it's only signal reduction
  - Currently not measured and not modeled in COM
- **Can we assume TX has AWGN with SNR=19 dB?**
  - Adding a Gaussian PDF 19 dB below A_s in COM will have a huge impact – marginal channels will fail
  - This kind of noise is unlikely to occur in a real TX
  - RX tolerance test adds BBN at TX to calibrate worst case SNDR… probably excessive stress
- We want to balance the budget, but without adding a significant noise source…

Proposed changes

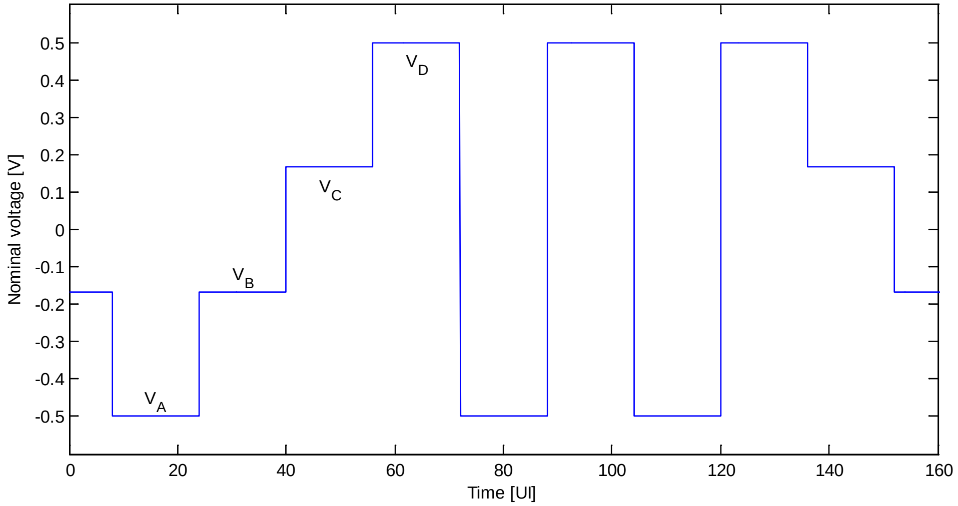
1. In clause 94, increase required SNDR to 22 dB
   - Reduces impact on channel specs and RX tolerance stress
2. Constrain the computation of RMS distortion error to a window spanning no more than [-0.25, 0.25] UI relative to the sampling phase of the peak of the pulse (essentially comment #114 on D1.3)
   - Excludes most of the jitter effect (jitter is limited by its own spec, should not be double counted)
3. In clause 94, measure static levels and use them in linear fit and SNDR calculation (see below)
   - Relaxes TX design, assuming RX can handle some level mismatch
4. In COM, add a Gaussian, signal-dependent noise term σ_{TX} representing TX noise, and, for PAM-4, a signal degradation factor R_{LM}
   - Balances the budget

Proposed changes – details

Item #	Details
2	$k_p = \arg\max_{k=1..M} p(k)$ $SNDR = 20\log_{10} \frac{S_{min}}{\max_{k\in[k_p-\frac{M}{4},k_p+\frac{M}{4}]} \sigma_e(k)}$ (94–14)
3	See next slides
4	$\sigma_{TX} = \sigma_X \cdot A_s/10^{\frac{SNR_{TX}}{20}}$ $FOM = 10\log_{10}\left(\frac{(R_{LM}\cdot A_s)^2}{\sigma_{TX}^2+\sigma_J^2+\sigma_{ISI}^2+\sigma_{XT}^2+\sigma_N^2}\right)$ (93A–33) • Similarly in COM calculation (Eq. 93A–38) • In clause 94, use SNR_TX=22 dB (SNDR); in clause 93, use 29 dB (if SNDR spec is adopted, use SNDR) • In clause 94, use $R_{LM} = 0.91$ (see below); in clause 93, use 1

Measuring static levels
(only for PAM-4)

- Static levels May be difficult to measure from an eye, especially if required at any FFE setting
- Solution: Bring back the test pattern we had in subclause 94.3.11.6 of D1.1
  - Note that period is 80 UI; figure 94-7 of D1.1 shows more than one period
  - Extend each level period to 16 UI to reduce ISI effect
- V_A, V_B, V_C, V_D are the measured (not normalized) voltages at the middle 2 UI (7 to 9) of each level.
- Use the results for the linear fit procedure and SNDR as shown in next slide.



Calculation of S_{min}, R_{LM} and σ_e

(only for PAM-4)

- Define

$$S_{min} = \frac{\min(V_D - V_C, V_C - V_B, V_B - V_A)}{2}$$ (minimal signal across eyes)

$$R_{LM} = \frac{6 \cdot S_{min}}{V_D - V_A}$$ (level mismatch ratio)

$$V_{Avg} = \frac{V_A + V_B + V_C + V_D}{4}$$ (DC offset)

$$V_1 = \frac{V_B - V_{Avg}}{V_A - V_{Avg}}; V_2 = \frac{V_C - V_{Avg}}{V_D - V_{Avg}}$$ (normalized effective mid-levels)

- Add a requirement that $\mathrm{R}_{LM} > 0.92$ [1]
  - COM includes a factor 0.91 to cover for that
  - Effectively a 1.1 dB degradation in COM
- In step 3 of the linear fit procedure (94.3.12.6.1), change "−1, −1/3, 1/3, and 1" to "−1, $-V_1$, V_2, and 1".
  - The resulting σ_e will be independent of level mismatch.

[1] Slide 6 shows TX with R_{LM}=0.84; allowed mismatch is smaller and will create a better eye.

Effect of R_{LM} in RX tolerance test
(only for PAM-4)

- If TX used in the test has R_{LM} higher than the specified minimum, test will be under-stressed.
- To take care of that, after TX noise source is tuned to create the target SNDR, its RMS should be further multiplied by the factor

$$\frac{R_{LM}}{R_{LM(minimum)}} (\geq 1)$$

- This may have a slightly worse impact on RX performance, since all 3 eyes are degraded.

Implications

Proposal divides the toll between TX, channel, and RX:

- TX will need better SNDR, and its level mismatch will be more limited than before
- Channel will have to meet the same COM target but with TX level mismatch and noise included
- RX will have to handle level mismatch, and possibly higher noise in RX tolerance test.

- Hopefully everyone is equally unhappy…

A note on RMS fitting error

- This originates from clause 85, and is used in 93.8.1.6.2 and 92.8.3.7.2 (also in 94.3.12.6.3 but without averaging)
- Clauses 92 and 93 currently refer to the procedure in clause 85, which says “Averaging multiple waveform captures is recommended”. This can result in removal of all uncorrelated noise, leaving only deterministic components such as:
  - ISI beyond the linear fit pulse length
  - Quantization noise (if sampling is coherent)
  - Nonlinearity in the path?
- Waveform averaging seems to remove exactly what we want to measure – and leave things we care less about
  - Is the result meaningful at all?
- Why average (RMS) across all phases? (as noted above)
- Recommendations:
  - Remove the RMS fitting error requirement, and use the SNDR method of clause 94 instead, with limited phases and target as proposed above
  - Remove 94.3.12.6.3

A note on far end transmitter noise

- This measurement has an embedded channel in effect
- It is not integrated with any other specs (no obvious way to do that)
- It can't currently be performed in clause 94 (comment #87)
- It is practically covered by SNDR
- Recommendations:
  - Remove this spec from clause 94
  - If SNDR is adopted in clauses 92 & 93, remove this spec from these clauses as well.

Thank you

Questions?