Channel specifications for 802.3ck – challenges and possible paths

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Outline

- Past (some history)
- Present (COM)
- Future (challenges and paths forward)

Channel specifications – why?

1. Enable vendors of “channels” (backplanes, cables, fibers…) to design products that are expected to work
2. Enable integrators and network designers to use certified channels without testing each one
3. Enable device designers to create good enough receivers
   - Receiver design requires some knowledge about expected channels, e.g. to decide what kind of equalization is needed
4. As a physical layer specification we are expected to “guarantee” that compliant components will create a working system
   - We always specify Tx and Rx normatively; usually channels too
   - Preferably, component specs are linked to create the expected system performance
   - Preferably, minimize false pass and false fail probabilities

Brief history of channel electrical specifications in 802.3

- Early days – 10 Megabit variations
  - Mostly based on external cabling specifications (RG 58 , ISO/IEC 11801 Class D aka Category 5e)
  - Main specifications are impedance, insertion loss (specific frequencies - 5 / 10 MHz), velocity of propagation, edge jitter, DC loop resistance; for twisted-pair, also crosstalk
  - Receiver is essentially a burst CDR; equalization not required or assumed; no stress test specified
- BASE-T higher rates (100M to 40G)
  - Based on external cabling specifications (ISO/IEC 11801 class D, E, F… aka category 5e/6/6A…) with up to 100 meter reach (later 30 m)
  - Detailed equations of frequency-domain masks for IL, RL, NEXT, FEXT, MDNEXT, PSELFEXT…
  - No time-domain specifications
    - Tight RL specs protect against reflections in reasonable installations
  - Receivers assumed to have strong adaptive equalization and cancellation (at least from 1000BASE-T and on)
    - Receiver expectations are not specified explicitly
    - Receiver BER specified with compliant cables, including noise stress tests

Channel specs history – continued

- Early copper cable 10GBASE-CX4
  - Uses BASE-T specification methods (frequency-domain masks, no time-domain specifications)
  - No receiver stress test specified
- 10G/40G backplane and copper cable (802.3ap, 802.3ba)
  - Annex 69B: fitted attenuation, IL, ILD, RL, ICR
  - Frequency domain masks, informative
  - Receiver stress test specified but had poor correlation with operation on real channels
- 25G/100G backplane and copper cable (802.3bj, 802.3by)
  - Introduced COM (detailed below)
  - RL still as frequency domain mask
- 50G backplane and copper cable (802.3cd)
  - Introduced ERL

What's COM

- COM is a method to generate one figure of merit for a channel, using
  1. Time-domain analysis (pulse responses) of input channels
  2. Reference noise sources (SNR_{TX}, η_0, jitter)
  3. Reference model for Rx equalization capabilities (with standard-specified Tx equalization)
  4. Reference models for packages and PCB traces
  5. Figure of merit and search algorithm to maximize it using equalization
  6. Statistical analysis to calculate the margin for a target detector error ratio (DER)
- COM provides a common language between signal integrity and SERDES designers – design guidance and a single figure of merit

What’s in COM

- Until now we have used a long zero-forcing DFE as part of the reference Rx
  - Very simple to analyze
  - Close to something that can be implemented
  - Implementations may be different from the reference
- The famous 3 dB minimum was an allowance for implementation “penalties”
  - Non-ideal slicers, internal noise, CDR jitter, DFE quantization, etc.
  - Receivers can be “better than the reference” and operate well over lower-COM channels
- Some inaccuracies are still included
  - Mainly related to nonlinear effects, but also actual packages, terminations, and boards
  - Assumed to be covered by the 3 dB margin
- In practice, not everything is worst-case at the same time, so there is an apparent pessimism
- COM has been widely adopted by the industry

The COM tool

- Contributed as Matlab source code during 802.3bj
  - Mostly by Rich Mellitz and Adee Ran
- It is an example of implementation of annex 93A – not an official tool
  - However, it is widely used
- Work in minor maintenance mode continued in 802.3bm, 802.3by, 802.3bs, 802.3cd
  - Including extensions to ERL
  - Thank you, Rich!
- The existence of a tool significantly accelerated the standards completion and helped adoption
  - I assumed we want to continue this

Challenges for 100GEL - #1

- Reference receiver model
  - Long analog DFE seems impractical (for expected modulations in this project)
  - Digital Rx architecture should be considered
    - Long DFE still impractical, but long FFE is possible (with perhaps 1-tap DFE)
    - Digital implementation brings in quantization/dynamic range considerations which are not negligible
  - What is the reference analog equalizer?
    - In the ~25 GBd standards we had a 1st-order CTLE with pole at ½ Nyquist and tunable zero (+ similar low-frequency 1st-order CTLE)
    - Digital/analog equalization tradeoffs may result in analog implementations quite different from this
    - Can we standardize a complex analog circuit?
- Should the reference receiver be close to an actual implementation? Or should it be simple?
  - Simplicity will reduce correlation with actual implementations
  - Accuracy will require lots of details that require consensus and editing, will make the standard complex, and may match a single implementation
  - Something in between?

Challenges for 100GEL - #2

- If equalization includes a long FFE, what is the optimization method?
  - Currently COM uses exhaustive search for short FFE choice (in the Tx)
  - Impractical for long FFE
  - There are analytic methods, not as simple as zero forcing the ISI
    - For a given TX+CTLE setting, zero forcing the ISI (as a DFE would) may be a reasonable approximation
  - In practice, Rx equalization settings will be implementation dependent
    - Especially with digital receivers – which may have various analog pre-equalizers
- 100GEL will likely have new challenges and new solutions
  - Example: far ISI from package reflections
  - Will the method predict how a channel will "work" across receiver implementations?
  - If not – it's not too useful…

Challenges for 100GEL - #3

- Run time considerations
  - The original COM tool in 802.3bj, with 3-tap Tx equalizer and 1 degree of freedom for CTLE, took a few minutes to run on a single dataset
  - With 4^{th} tap and 2 degrees of freedom (802.3cd) – ~15 minutes
  - More Tx taps? ➔ problem
- Is there a faster optimization?
  - Either a mathematical method or some heuristic…
  - Can we implement something in a tool without defining it?

Summary of open questions

- Reference Rx: accuracy / simplicity tradeoff
- Optimization method: detailed math, exhaustive search, approximation, other?
- More Tx taps: can we optimize them in COM calculation?
- Should we incorporate complex solutions (if adopted) into COM?
- Assuming we continue providing a tool – should the standard specify search heuristics?

We should start working…

- Option A:
  - Keep using the current COM reference receiver
  - Play with parameters to find “what would it take”, build consensus, decide
  - Let chip designers cope with the details
- Option B:
  - Look for new reference receiver proposals (including detailed optimization methods)
  - Implement into the current tool or build a new tool, test contributed channels
    - For each proposal? or after choosing?
  - Build consensus, choose one proposal
  - Let chip designers cope with the result

- OR -

- Start with option A, shift to B if/when needed (and depending on proposals)

DISCUSSION…