The 10G Ethernet Link Model

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What is it?

- A spreadsheet with equations
  - Runs in Excel
- Can be populated with parameter values to represent different fibre-optic links
  - One sheet per scenario
  - Equations on each sheet are identical
  - For “conventional” optical links (not using equalization)
- Available to all on world wide web
  - See references for URLs

Purpose

- For developing optical spec numbers
  - Portable, runs quickly
  - Not intended as a transceiver design tool
- An agreed framework for comparing options
  - Uses standard engineering theory, mostly available in textbooks
  - Open source, open to peer review, documentation available
  - Earlier, Gigabit Ethernet, model was validated by experiments in multiple labs
- Generally used for "worst case" analysis

History

- Model was developed in late 90s for Gigabit Ethernet
- Extensions to meet needs of 802.3ae (10 Gigabit Ethernet) and EFM
- Last version accepted by P802.3ae was 3.1.16a (aligned to D3.2/3)
- Last version accepted by EFM was EFM0_0_2.7 (aligned to D2.1)
  - Each file has detailed change notes

Physical effects in model 1/3

- For short block codes or unbounded (scrambled) codes
  - e.g. 8B10B, SONET, 64B66B
- Multimode fibre (MMF), single mode fibre (SMF)
  - Fibre modal bandwidth (MMF), polarisation mode dispersion (PMD) (SMF)
- “1st, 2nd, 3rd windows”
  - 850, 1310, 1550 nm bands
- Fibre attenuation, connector attenuation

Physical effects in model 2/3

- Optical Modulation Amplitude OMA
- Mean power
- Extinction ratio ExR

- Duty cycle distortion DCD
- Deterministic Jitter DJ
  - Controversial
- Receiver eye opening requirement (timing)
  - Not used in 802.3ae

Physical effects in model 3/3
Noise effects

- Receiver sensitivity
  - "thermal noise"
- Laser relative intensity noise RIN
- Laser mode partition noise MPN
- Interferometric or reflection noise RN
- Baseline wander BLW
- Modal noise (for multimode fibre) MN

Methodology: How does it work? What you see

- Each loss or penalty is calculated separately
  - Results displayed
  - Losses and penalties plotted against link length
- Overall losses and penalties calculated together
  - Margin displayed against link length
- Example eye diagram drawn

What it does 1/2
Deterministic

- Fibre attenuation and dispersion calculated according to standard formulae
- All risetime, bandwidth, chromatic distortion calculated as Gaussian impulse responses
- DCD, DJ and receiver eye opening requirement determine timing pulse edges and/or “decision point”
- Eye closure is calculated
- Result: effective signal strength

What it does 2/2
Noise, margin

- Almost all noises combined as variances
- Effective signal/noise ratio related to target
  - Determines margin
  - Interactions of impairments (cause of error floors) are predicted
- Exceptions
  - Mode partition noise calculated by textbook formula
  - Reflection noise is more like a bounded noise or “deterministic” effect - like crosstalk

Advantages of 10 Gigabit model

- Trusted and familiar
- “Official”
- Portable
- Documented
- “Keeps proposals honest”
  - Not completely, but it helps
- Source code can be inspected
- Clean, not too over complicated
- Suitable for a “corners” analysis where there are just one or two “near worst cases”
- “Fit for purpose” (optical 10 Gigabit Ethernet except 10GBASE-LRM)
- Each physical effect can be turned on or off independently

Disadvantages of 10 Gigabit model

- Not at all accurate (but can be used) for chromatic dispersion penalty of single mode lasers (“chirp”)
    - There is no simple generally accepted model for this
- Does not cover crosstalk - coherent or incoherent
- Not accurate for laser mode partition noise
- Spurious accuracy
- Encourages over pessimistic “corners” analysis
- Not suitable for multidimensional problems e.g. MMF at 10G
- Some areas need experimental verification
- Equations are hidden in the spreadsheet cells (but documented)
- Some definitions differ between Ethernet and SONET

Model vs. reality

- Model has been pessimistic by maybe 1 to 2 dB (optical)
  - Result is conservative specifications
  - One issue during P802.3ae was noise and jitter in test equipment
    - More modern test equipment is better
    - Or it could be that receivers are better than we thought (always some transmitter penalty even with test equipment)
  - A zero or slightly negative penalty output from the model may be acceptable
- Jitter measurements are inaccurate and not easily corrected by calibration
  - Best to avoid reliance on jitter specs
- The parameters populate the model; they are not part of the model itself
  - Need to input reasonable parameters
- The model doesn’t know everything
  - New scenarios still have to be validated

What is stressed sensitivity?

- Two sensitivities in Gigabit and 10 Gigabit Ethernet
- “Nominal” sensitivity
  - Measured with a very good transmitter
- Stressed sensitivity
  - Measured with a transmitter as slow and with as much deterministic jitter as allowed
  - Intent is to prove interoperability by measurement
- Don’t have to use stressed sensitivity to use model

What are TDP, VECP, TWDP?

- TDP Transmitter and dispersion penalty
  - The difference in sensitivity for a reference receiver when comparing an ideal transmitter with a very short fibre against the transmitter under test with the rated fibre dispersion
- VECP Vertical eye closure penalty
  - An amount of eye closure to be applied in stressed receiver testing
- TWDP Transmitter and waveform dispersion penalty
  - A metric of transmitted eye quality appropriate to a low-bandwidth MMF link and an equalising receiver. Used in 10GBASE-LRM
- TDP and VECP limits can in principle be derived from the model but in practice, such limits are very excessive and more lenient limits have been chosen with engineering judgement

Compatibility with HSSG goals

- Chromatic dispersion with DFBs or modulators
  – Use a false linewidth to give the desired dispersion penalty
- Forward error correction
  – Set target signal/noise ratio in model appropriately
- Splitters and WDMs
  – We can consider using the "connector loss" input for any loss
- Crosstalk
  – May be able to use or modify reflection noise term
- Optical duobinary
  – Not addressed

Other issues?

References 1 of 3

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