The 10G Ethernet Link Model

Piers Dawe
Avago Technologies

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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 90’s 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
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
- Source code can be inspected
- Clean, not 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

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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 10GEPON goals

• Chromatic dispersion with DFBs
  – 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

• Single fibre operation
  – May be able to use reflection noise term for coherent crosstalk
    • Use Tx, Rx reflection coefficients?

• Burst mode issues
  – Not addressed

Other issues?
References are in roughly chronological order

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  http://webstore.iec.ch/webstore/webstore.nsf/artnum/030446
• D G Cunningham, "10 Gigabit Ethernet: from standards to applications", ECOC 2002, Tutorial 1
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  – Best starting point for a new project?
• This presentation to be filed at
  http://iee802.org/3/10GEPON_study/public/may06/dawe_1_0506.pdf
• More references listed at
  http://iee802.org/3/10G_study/email/msg01127.html