The Ethernet Link Model

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What is it?

• A spreadsheet with equations
  – Runs quickly, in Excel
• Can be populated with parameter values to represent different fibre-optic links
  – One sheet per scenario
  – Equations on each sheet are identical
• Available to all on www
Why does the committee need models?

• Define a common starting area
  – Document agreed physical effects
  – Define common terminology

• Provide a “theory check” for new proposals
  – Saves much time debating whether provably good or bad scenarios are good, or bad
  – Quick “what-if” calculations
  – Allows for peer review

• Some parameters may map directly onto spec items in standard
  – Reduces human error
  – Provides some level of audit trail: why is the spec what it is?
Purpose of the Link Model

• 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, some documentation
  – Earlier, Gigabit Ethernet model was validated by experiments in multiple labs
  – Tries to be abstract enough to avoid detailed implementation assumptions

• Generally used for worst case analysis
This project may need multiple models

• Could model propagation in MMF
  – e.g. refractive index profile -> impulse response
• May wish to relate impulse response, bandwidth, unequalised and equalised penalty
• May wish to relate mode selective loss and delay to modal noise
• This model does none of these
  – It assumes all frequency responses (Tx, fiber, Rx) have the same filter shape
History

- Late 90’s  Model was developed for Gigabit Ethernet
- 2000-2001  Extensions to meet needs of 802.3ae, 10 Gigabit Ethernet
- 2001-3  Extensions for EFM
  - Each file has detailed change notes for those used to earlier revisions
Physical effects in model 1/3

• For short block codes or unbounded codes
  – e.g. 8B10B, SONET, 64B66B

• Multimode fibre (MMF), single-mode fibre (SMF)
  – Fibre modal bandwidth (for MMF), polarisation mode dispersion (PMD) (for 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)
Physical effects in model 3/3
Noise effects

• Receiver sensitivity
  – “thermal noise”
• Laser relative intensity noise \( RIN \)
• Laser mode partition noise \( MPN \)
• Modal noise (for MMF) \( MN \)
• 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 plotted 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
What it doesn’t do

• Not a time-domain simulator
• Not well suited to iterative calculations or large numbers of scenarios
• Doesn’t deal with Tx or Rx CDR “random” jitter
  – Assumes that this is less important than receiver random noise – I think that’s true in most usable links
• Doesn’t really model the fiber
  – Doesn’t do waveguide calculations
  – Doesn’t understand laser chirp for chromatic dispersion (CD)
  – Treats all CD, PMD and DMD as Gaussian filters
• Doesn’t do modal noise theory
• Doesn’t yet know about equalisation
Advantages of Ethernet link model

- Trusted and familiar
  - Mostly
- Seen as Official
- Source code can be inspected
- Clean, not over complicated
  - but growing
- “Fit for purpose” (1/10 Ethernets)
- Each physical effect can be turned on or off independently
Disadvantages of Ethernet link model for 10G MMF project

• All bandwidth, risetime, DMD effects modelled as Gaussian risetimes
  – Too simple for the variety of impulse responses we see with MMF
  – Does not consider the variety of equalised response shapes

• Assumes fixed input-referred receiver noise
  – Set by basic receiver sensitivity and BER limits
  – Equalising receiver noise can vary

• Bandwidth penalty Pisi goes to infinity in area of interest

• Spurious accuracy

• Some areas need experimental verification
Can Ethernet link model be extended 10G MMF project?

• Address variety of pulse shapes
  – Variety is not good for a quick, portable model
  – If we knew what the few “worst” case(s) were, we could revisit the Gaussian pulse-shape assumption

• Address variable input-referred receiver noise
  – Seems feasible – when we know how it varies!

• Can work on an alternative Pisi definition if necessary

• New understanding
  – e.g. may wish to refine the Modal Noise calculation if it becomes significant

• Some areas need experimental verification
Relation of link model to other items

- Channel (fiber)
  - Measured results
  - Model (e.g. waveguide)
  - Spec limit
- Signal at input to receiver
  - Stressed eye generator
- Test procedures
- New info or theory
  - Noises, equalisation, …
- Terminology and definitions
  - ISI penalty with an equalising receiver?
  - What is a good metric of channel response?
References 1 of 2

Latest model file http://www.ieee802.org/3/efm/public/tools/ EFM0_0_2.7.xls

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