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
- Latest version on the web today is EFM0_0_2.7.xls, available from http://www.ieee802.org/3/efm/public/tools/index.html
  - 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](http://www.ieee802.org/3/efm/public/tools/EFM0_0_2.7.xls)

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- This presentation to be filed as dawe_1_0104.pdf within http://www.ieee802.org/3/10GMMFSG
- More references listed at http://www.ieee802.org/3/10G_study/email/msg01127.html