Gigabit Ethernet Fiber Optic Link Model & Refinements Needed For Projected 10 Gigabit Ethernet Link Cases

Del Hanson & David Cunningham
Hewlett-Packard Company
Fiber Optic Communications Division
350 W. Trimble Road
San Jose, CA 95131
Phone: 408-435-6246
email: del_hanson@hp.com

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Ethernet Standard Perspective

- Ethernet is a very successful networking technology. A major reason for this has been IEEE 802.3's use of a *worst-case design philosophy,* which states the following:

  ▸ *"When all specified link parameters are at their worst-case values, the link should operate normally."*

- This is a very restrictive design philosophy but, over the years, it has proven its worth to customers (and suppliers) in this marketplace.

- The Ethernet committee may allow a statistical specification of parameters if full multi-vendor statistics of parameter behavior are made available to all.

GbE Spread Sheet Model

- The Gigabit Ethernet (GbE) spreadsheet link model was developed and used by the (GbE) optical task force to understand potential trade-offs in the Optical PMD specification.
- The model provided a common baseline for discussion of the optical link specifications.
- Given that the entire 802.3z committee was to use the model, it had to be:

  - Simple to understand,
  - Easy to use,
  - Reasonably accurate.

Power Penalties & Link Margin

- The Gigabit Ethernet optical link model is a worst-case, power-budget-based model utilizing power conservation, i.e.,
- **Ave. receive power (min), (dBm) = Ave. launch power (min), (dBm)**
-   **– Losses (dB) – Margin (dB)**

  ▸ *Ave. launch power (min) is the minimum optical power launched into the fiber,*
  ▸ *Ave. receive power (min) is the worst-case optical receiver sensitivity.*
- There are two types of **losses** that must be accounted for:
  ▸ The loss of **average optical power,** as measured with an optical power meter,
  ▸ The loss of the **modulated signal,** due to system impairments.
    – The loss of modulated signal strength can be compensated for by increased optical power. This type of loss is called an **optical power penalty**.
- *Margin is an amount of power set aside for design margin.*

Link Model Assumptions

- The Gigabit Ethernet optical link model assumes that the laser and multimode fiber impulse responses are Gaussian in shape. It also assumes that the optical receiver is non-equalized and has a raised cosine response.

- Expressions that convert the root-mean-square (rms) impulse response widths of the laser, fiber, and optical receiver to risetimes, fall times, and bandwidths are included in the model.

- The calculated risetimes, fall times, and bandwidths are then used to determine the fiber exit response time and composite channel exit response time.

- The composite channel exit response time is used to calculate the inter-symbol interference (ISI) penalty that is required for the link power budget analysis.

Link Power Penalty Contributions

- In the link model, **power penalties** are **calculated** to account for the following effects:
  - *Finite laser extinction ratio (ER)*
  - *Inter-symbol interference (ISI)*
  - *Minimum eye opening requirement at the receiver output*
  - *Mode partition noise (MPN)*
  - *Laser relative intensity noise (RIN)*

- In addition, **power loss** or **power penalty allocations** are made for the following items:
  - *Fiber attenuation*
  - *Connectors and splices*
  - *Modal noise (MN)*
  - *Duty cycle distortion (DCD)*

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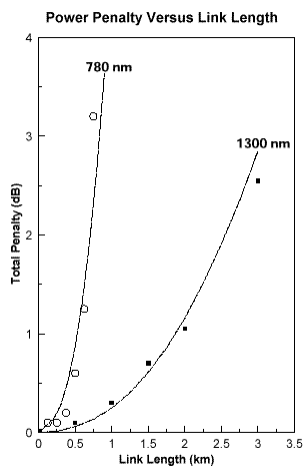IEEE 802.3 HSSG Interim Meeting, York, U.K., September 27-29, 1999   Monday, September 20, 1999
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Penalties Not Explicitly Included

- *Return Loss:* The Gigabit Ethernet model does not explicitly include penalties due to the reflection of laser light from the receiver or connectors back into the laser. Rather, the maximum loss experienced by the reflected laser light (the return loss) from the link components is specified to allow the worst-case link to operate normally.

- *Note:* The Gigabit Ethernet link model is only worst case when all its input parameters are set to their worst-case values—if typical values are used, the typical link performance will be modeled.

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Experimental Verification of GbE Link Model

Power Penalty Versus Link Length

•Power Penalty Versus Link Length in 62.5 µm Multimode Fiber for 780 nm and 1,300 nm operation.

•Typical link components were measured at specific link lengths, instead of using worst-case component parameters.

•No fitting was used—the experimentally measured input parameters were just fed into the Gigabit Ethernet link model and the results plotted, along with the experimental power penalties.

•Clearly there is very good agreement.

ISI Penalty: DMD issues

•During the Gigabit Ethernet standardization, it was discovered that there is an installed population of multimode fibers which, in conjunction with certain laser launch conditions, exhibit differential modal delay (DMD) characteristics that can cause the overall channel impulse response to be non-Gaussian.

•For 1000BASE-LX operating with such fibers, the impulse response is returned to near Gaussian with a mode conditioning patch cord. Thus, the GbE Link model is a reasonable model for worst-case 1000BASE-LX links.
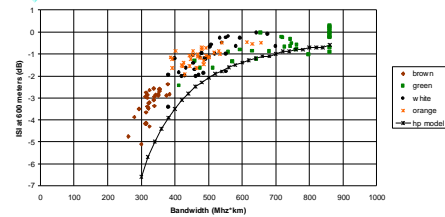
•For 1000BASE-SX links, specification of the receiver upper bandwidth range is believed to control the overall impulse response sufficiently for the Gigabit Ethernet link model to be used as a worst-case model.
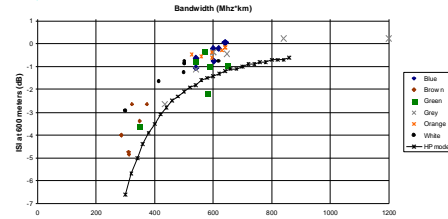
Non-HP Measurements of ISI Penalty vs. Link Model

Measured ISI versus Effective Modal Bandwidth (source Corning)

Measured ISI versus Effective Modal Bandwidth (source Cielo)

TIA FO-2.2 Task Force Group on Modal Dependence of Bandwidth, Michael Hackert, Chairman, 5/11/99 Status Update

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GbE Jitter Budget & DCD Allocation

Table 38-10, specifying pk-pk Total Jitter (TJ) & showing related pk-pk Deterministic Jitter (DJ), is from IEEE 802.3z Clause 38. This also shows the allocation of DCD.

	Line Rate (MBd)=	1250							
	Baud Period (ps)=	800							
			Table 38-10						
		Total		DJ		DCD		RJ	
		TJ(UI)	TJ(ps)	DJ(UI)	DJ(ps)	rms, (ps)	% of DJ	RJ(UI)	RJ(ps)
SerDes Tx, TP1		0.240	192	**0.100**	80			**0.140**	112
FO Tx Added		0.284	227	**0.100**	80			**0.184**	147
FO Tx Out, TP2		0.431	345	0.200	160	46	29	0.231	185
Fiber Added		0.170	136	**0.050**	40			**0.120**	96
Fiber Out, TP3		0.510	408	0.250	200	65	33	0.260	208
FO Rx Added		0.332	266	**0.212**	170			**0.120**	96
FO Rx Out, TP4 **		0.749	599	0.462	370	80	22	0.287	229
SerDes Rx Window		0.251	201						
** Note: Measured With A TP3 Conformance Test Signal (sub-clause 38.6.11) Set To An Average Optical Power 0.5 dB									
Greater Than The Stressed Receive Sensitivity From Table 38-4 for 1000BASE-SX &Table 38-8 For 1000BASE-LX									

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Upgrading GbE model for 10GbE

<u>**Case 1:**</u> PMDs using encoded or scrambled NRZ streams,
e.g., for WWDM, Parallel or Serial proposals.

For these cases, relatively minor changes are required.

<u>**Case 2:**</u> PMDs using multilevel modulation schemes,
e.g., PAM 5 or 10000BASE-T proposals.

For these cases, the GbE link model methodology can be used. However, major modifications would be required.

<u>Case 1</u>: PMDs using encoded or scrambled NRZ

- **MPN penalty:** *For low cost DFB lasers, use discrete sum of modes (Reference Agrawal, et.al.) and start with k = 0.8.*

- **RIN penalty:** *Reset **a** parameter to 1.*

- **MN penalty:** *Recalculate worst-case allocations using worst case model from Reference Bates, et. al.*

- **DCD allocation:** *Determine the DCD contributions for the various PMD interfaces.*

<u>Case 1</u>: PMDs using encoded or scrambled NRZ

- **ISI Penalty:**
  - *IEEE 802.3 requires a <u>worst-case</u> analysis,*

  - *It is difficult (impossible?) to envision a statistical worst-case analysis. How would we get full statistics for transmitters, fiber and receivers which relate to manufactured products from all vendors?*
  - *The Gaussian impulse response assumption is near worst-case.*

- **The 10GbE link model should use the ISI equation from the GbE link model for most cases of interest to 10GbE.**
- **Investigate modifications for 10GbE links having high chromatic dispersion that use single frequency lasers.**

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<u>Case 2:</u> Proposed modifications for PMDs using multilevel modulation

- **Multilevel Power Penalty**: *Add new equation.*

- **Non-linearity Power Penalty:** *Add new equation.*

- **RIN Power Penalty:** *Modify GbE equation.*

- **MN Power Penalty:** *Determine how to use Bates, et. al., worst-case model to allocate worst-case penalty.*

- **ISI Power Penalty:** *Use Gaussian impulse response methodology from GbE; modified for multilevel operation.*

- **Coding Gain:** *If present, allocate worst-case value for particular modulation scheme.*

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Proposed 10GbE Jitter Budget Methodology

- Define the appropriate interface test points for the various PMD alternatives.
- Explore the bundling of interfaces to minimize the compounding of jitter specifications at tandem test points.
- Further explore the coupling between the link model analysis and the jitter budget.
- Determine whether we continue to use an increase in the line rate in the link model proportional to the DCD component of DJ eye closure or use another mechanism.

Conclusions

- The GbE Fiber Optic Link Model Has Been Shown To Provide Accurate Link Analysis.
- Proposed Refinements To The Link Model For 10GbE PMD Operation Are Described.
- A More Detailed Paper Will Be Presented At The November Plenary Showing The Modified Power Penalty Equations.
- Calculations Will Be Presented For The Proposed 10GbE Modal Noise Penalties.

References

- **Agrawal, et. al., 1988:** Govind P. Agrawal, P. J. Anthony, and T. M. Shen, "Dispersion Penalty for 1.3-μm Lightwave Systems with Multimode Semiconductor Lasers," *Journal of Lightwave Technology*, Vol. 6, No. 5, May 1988, pp. 620-625.

- **Bates, et. al., 1995:** Richard J. S. Bates, Daniel M. Kuchta, and Kenneth P. Jackson, "Improved Multimode Fiber Link BER Calculations due to Modal Noise and Non Self-Pulsating Laser Diodes," *Optical and Quantum Electronics*, No. 27, 1995, pp. 203-224.

- "Gigabit Ethernet Networking" by David G. Cunningham and William G. Lane, published May 1999 by: Macmillan Technical Publishing, 201 West 103rd Street, Indianapolis, IN 46290 USA. ISBN: 1-57870-062-0