Enhancements to Gigabit Ethernet Link Budget Spreadsheet 2

Piers Dawe and David Dolfi
Agilent Technologies

piers_dawe@agilent.com   dave_dolfi@agilent.com

Motivation

As in March

- Striving for accuracy and correctness
  - New fibre types
  - Tough decisions at 10G: can't afford to over- or under-engineer
- Extending GbE spreadsheet to cover scrambled as well as block codes

Side Benefit

- More consistent treatment of interactions between power penalties

As in March

New features 1 of 2

- v2 substantive
  - New boxes for baseline wander (BLW)
  - New "Pcross" column

  - v2 presentational
    - "Back-to-back" row in spreadsheet
    - Attenuation at wavelength clarified
    - Graphing of penalties
    - Marker to show target length, readout of margin at target
    - New pages for new fibre/wavelength combinations

Continued...

New

New features 2 of 2

- 0.4.6 substantive
  - Change to self-consistent, Gaussian ISI calculation
  - Receiver risetime.bandwidth factor slightly revised to textbook value
  - TP4 penalty revised to Gaussian ISI formula
  - 62 MMF dispersion S0 at worst lambda0 corrected from 0.11 to 0.093

  - 0.4.6 presentational
    - “P-C” column replaced by single box to simplify layout
    - Pages populated with 10G examples not GBE examples

What's not changed

- The methodology
- How to use it
- The layout (hardly) and symbols
- Most equations
- The results - hardly (at 1.25 GBd)

Mainly as in March

Issues outstanding

- Needs more experimental verification
- Attenuation formula at 1550 nm not very accurate (but you see what you are using)

Issues not covered or not changed

- Duty Cycle Distortion (DCD)
- Mode partition noise (but groundwork prepared) *New*
- Optical Modulation Amplitude specification
- Jitter
- Multilevel coding
- Chirp

As in March

Methodology 1

As before,

min. transmitted power - max. receiver sensitivity = power budget

budget - (worst losses & impairments) = margin

Spreadsheet is a tool to aid specification of link length and optical interfaces facing the link, not primarily for transceiver design

As in March

Baseline Wander (BLW)

Diagrams deleted for easier viewing/printing: see March presentation

Low frequency cut (high pass filter, "zeros") causes baseline wander

BLW penalty is part of measured receiver sensitivity. There must be some there, if very little, even in 8B10B systems. See T11.2 Fibre Channel "Methodologies for Jitter Specification" by Dennis Petrich (see references for URL). It comes into this spreadsheet ONLY because it interacts with ISI, which involves the link (fibre) not just the transceiver.

BLW could occur in transmitter or receiver.

One extension vs. March

Interacting Impairments

GbE spreadsheet has eight losses and impairments (penalties). Of these, we believe five or six interact (within the methodology of the spreadsheet)

	ISI	TP4	RIN	MPN	BLW	MN
ISI		*New* Yes	*Already included* Yes	? *	Yes	? #
TP4			No?	? *	?	? #
RIN				Yes	Yes	? #
MPN					Yes	? #
BLW						? #

* Petar Pepeljugoski and Dave Dolfi looking at this

\# any interaction not addressed here

Analogy (if it helps): a matrix with diagonal terms present and some off-diagonal terms

As in March

Methodology 2 (Going deeper…)

1. Calculate BLW penalty in absence of ISI but with TP4 eye closure. This effect is already included in the receiver sensitivity, hence in the power budget. Fill entries in spreadsheet header.
2. Work out each loss and impairment separately, for each length, fill entries in spreadsheet table.
3. Work out total impairment of interacting things, subtract relevant separate impairments including any (BLW) hidden in the receiver. Result goes in box "Pcross".
4. Add across table to get total penalties.
5. Graph out each penalty and total penalties against length, record margin at target reach.

As in March

BLW Equations

For scrambled binary (PAM-2) codes, BLW is Gaussian and can be treated as noise:

sigma_BLW = sqrt(pi*f_Low/B)

where

B = line rate = Baud rate,

f_Low = high pass filter frequency if single zero,

sigma_BLW = (one standard deviation of BLW) / (half eye height before ISI)

So it's like a signal-to-noise ratio.

(Extreme case) if sigma_BLW > 1/Qmin = 1/7.04 = 0.142, penalty for BER = 10^-12 is infinite.

For sigma_BLW = 0.025 (i.e. 1.25% of whole eye), f_Low/B = 0.0002 (for B = 10Gbit/s that's 2 MHz)

Diagram deleted for easier viewing/printing: see March presentation

As in March

Equations continued

sigma_BLW does NOT decrease in line with the eye in the face of ISI (while RIN does) - but the eye closes anyway.

Hence penalty

P_BLW = -5 log10[1 - (Qmin*sigma_BLW/H_ISI)^2] dB

where H_ISI is the ratio of the eye height after and before ISI

e.g. for sigma_BLW = 0.025, no ISI, P_BLW = 0.07 dB
for sigma_BLW = 0.025, 3 dB ISI, P_BLW = 0.29 dB

Compare this with the RIN penalty,

P_RIN = -5 log10[1 - (Qmin*sigma_RIN)^2] dB

And mode partition noise penalty,

P_MPN = -5 log10[1 - (Qmin*sigma_MPN)^2] dB

As in March

Combined penalty 1

P = -5 log10 [1 - { (Qmin*sigma_BLW/H_ISI)^2 +
(Qmin*sigma_RIN)^2 +
(Qmin*sigma_MPN)^2 }] dB

which is not quite the same as

P_BLW + P_RIN + P_MPN .

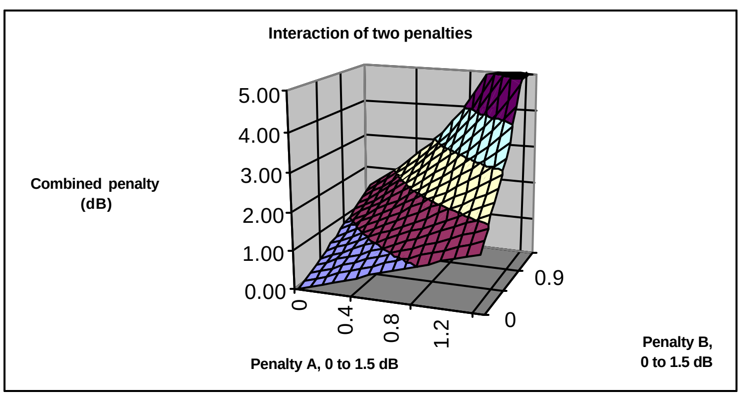
The difference is tiny in most healthy systems.

Eye closure caused by TP4 timing error/uncertainty is treated like bandwidth-induced ISI - actual equations are in the spreadsheet.

As in March

Combined penalty 2

How bad ISI exacerbates BLW penalty (or vice versa, or RIN and MPN penalties, or...)



Revised ISI formula *New*

Was (GBE and v2, blue line)

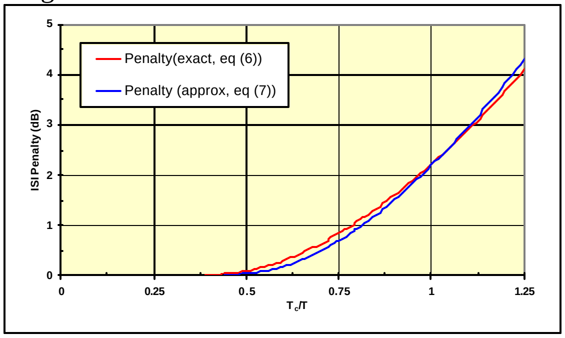
$$P_{ISI} = -10 \log_{10}[\ 1- 1.425\exp\{-1.28(T/Tc)\hat{}2\}\ ]$$

Now (0.4.6, red) $P_{ISI} = -10 \log_{10}[\ 2h_e(0)-1\ ]$

where $h_e(0) = \mathrm{erf}[\ b_g{*}Tb/(\mathrm{sqrt}(8){*}Tc)\ ]$,

Tb = "effective" bit period,
Tc as column G

- "New" is more consistent with rest of model, solid foundation for any future extensions



Revised receiver eye (TP4) penalty formula 1 *New*

Was (GBE and v2)

$$P_{R.eye} = -10 \log_{10}[\ \{2{*}\sin(pi{*}T_{TP4}/Tb)/ \{pi{*}(T_{TP4}/Tb){*}(1-(T_{TP4}/Tb)^2)\} - 1\ ]$$

Now (0.4.6) $P_{R.eye} = 10 \log_{10}[\ P_{ISI}/\{h_{e1}+h_{e2}-1\}\ ]$

where

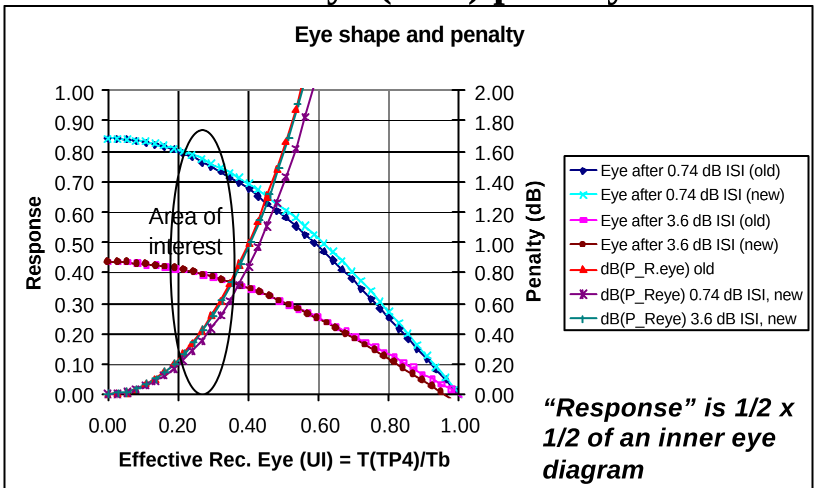
$h_{e1} = \mathrm{erf}[\ b1{*}Tb{*}\{1+(T_{TP4}/Tb)\}/\{\mathrm{sqrt}(8){*}Tc\}\ ]$,
$h_{e2} = \mathrm{erf}[\ b1{*}Tb{*}\{1-(T_{TP4}/Tb)\}/\{\mathrm{sqrt}(8){*}Tc\}\ ]$,
b1 = 2.563, Tb ="effective" bit period, Tc as column G

"New" formula

- accounts for variable pulse shape
- is more consistent with rest of spreadsheet, solid foundation for any future model extensions

New

Revised receiver eye (TP4) penalty formula 2



"New" formula is slightly more optimistic for low ISI, same for high ISI. Compare [Cunningham & Lane p318]

Newly changed value

Revised receiver risetime.bandwidth constant 1

Was (GBE and v2)

Tc_Rx*BW_Rx = **0.35** (hidden in spreadsheet)

Now (0.4.6)

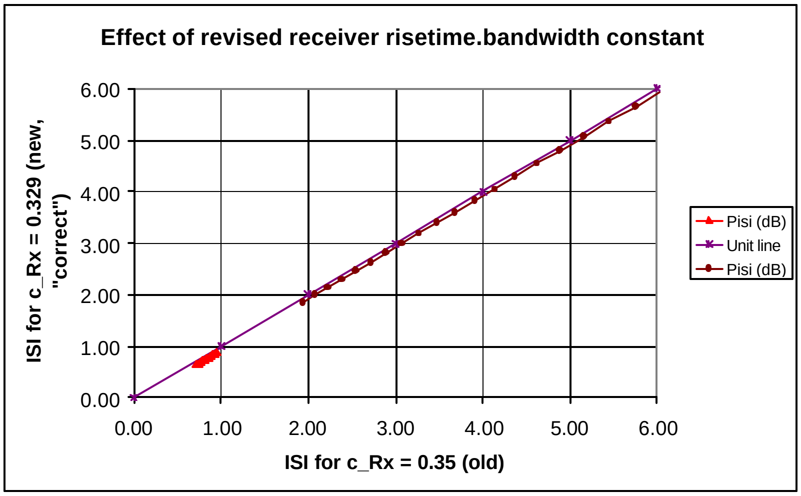
Tc_Rx*BW_Rx = **0.329** = c_Rx (box T9 of spreadsheet)

"New" formula

- Is in line with literature [Brown]
- Takes 0.1 dB "undue pessimism" away

Newly changed value

Revised receiver risetime.bandwidth constant 2



Agilent Technologies

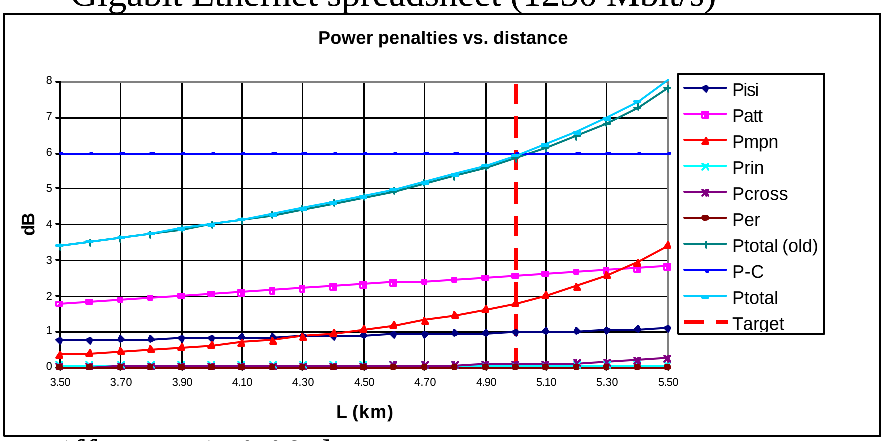
Enhancements to Gigabit Ethernet Link Budget Spreadsheet 2

IEEE 802.3ae San Diego 10-13 July 2000 slide 19

As in March: refers to v2

Example 1

This is the greatest effect to any sheet of the current Gigabit Ethernet spreadsheet (1250 Mbit/s)



Difference is 0.08 dB at worst case.

Agilent Technologies

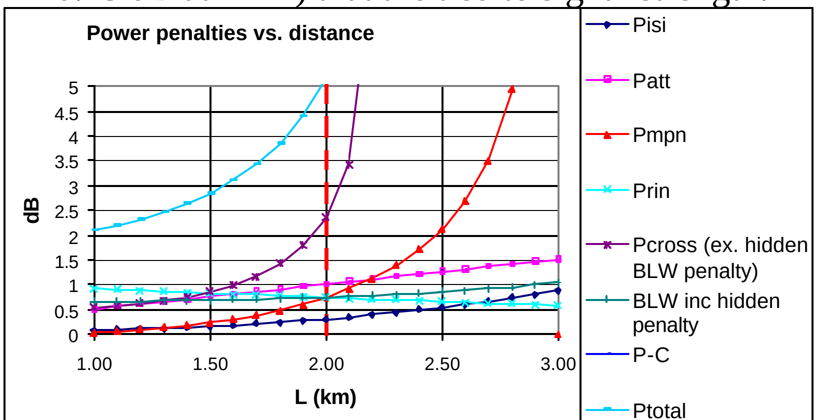
Enhancements to Gigabit Ethernet Link Budget Spreadsheet 2

IEEE 802.3ae San Diego 10-13 July 2000 slide 20

As in March: refers to v2

Example 2 (fictitious)

Almost no ISI, three equal terms (RIN, MPN, BLW ~0.75 dB at 2 km) that are tied to signal strength.



Interaction of noise terms costs an extra ~2 dB at 2km

As in March

More detail on Baseline Wander

We think that if there are multiple low-pass filters:

- In the non-limited case (small signal theory), the appropriate f_Low is roughly the -3dB point that you measure
- If there is BLW before and after a clipping (limiting) function, much of the BLW from before may be clipped out **** Warning; we haven't proved this statement, either by simulation or experiment.*

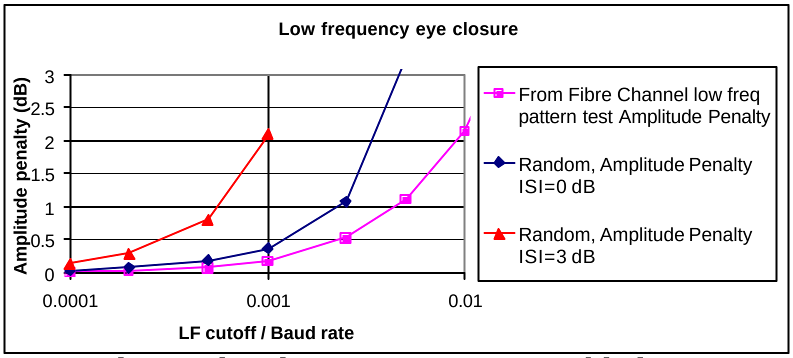
Spreadsheet not designed as a transceiver design tool, but if you have a receiver and consider changing the BLW (by changing a coupling capacitor, say), if you change box E9 (Budget) from e.g. “8” to “=8-T11” (T11 being P_BLW) we think you will see the effect explicitly.

As in March

Baseline Wander and line code

Graph shows power penalty for LF cut:

8B10B case, data from Petrich, Fibre Channel document
Scrambled case, calculated using formulae shown



Apparently, need 2x lower LF cut in scrambled to get same penalty as for 8B10B, if no ISI, 10x with 3 dB ISI

Conclusions

1. As in March

– Modified spreadsheet does more, no harder to use
– Needs experimental verification
– Baseline Wander is a manageable item
– Keep LF cut low or your stressed eye will suffer!
– Be wary of any signal-borne noise

2. New

- We must adopt the March model extensions (or similar) to manage proposed line codes
- We should adopt the July model revisions for enhanced accuracy, flexibility and foundation for any future revisions

Acknowledgements

- Russ Patterson for identifying and quantifying one of the interactions
- Rick Walker, Charles Moore for the mathematics of baseline wander
- Del Hanson, David Cunningham and Mark Nowell for a great start point
- Mike Dudek, Petar Pepeljugoski for valuable discussions

List revised and extended, shorter URLs

References

Hanson and Cunningham,
http://www.ieee802.org/3/10G_study/public/email_attach/All_1250.xls

Petrich, "Methodologies for Jitter Specification" Rev 10.0,
ftp://ftp.t11.org/t11/pub/fc/jitter_meth/99-151v2.pdf

Hanson, Cunningham, Dawe,
http://www.ieee802.org/3/10G_study/public/email_attach/All_1250v2.xls

Hanson, Cunningham, Dawe, Dolfi,
http://www.ieee802.org/3/10G_study/public/email_attach/3pmd046.xls

Dolfi, http://www.ieee802.org/3/10G_study/public/email_attach/new_isi.pdf

Cunningham and Lane, "Gigabit Ethernet Networking", Macmillan Technical Publishing, ISBN 1-57870-062-0

Pepeljugoski, Marsland, Williamson,
http://www.ieee802.org/3/ae/public/mar00/pepeljugoski_1_0300.pdf

Dawe, http://www.ieee802.org/3/ae/public/mar00/dawe_1_0300.pdf

Cunningham, Nowell, Hanson, "Proposed Worst Case Link Model for Optical Physical Media Dependent Specification Development",
http://www.ieee802.org/3/z/public/presentations/jan1997/dc_model.pdf

Nowell, Cunningham, Hanson, Kazovsky, "Evaluation of Gb/s laser based fibre LAN links: Review of the Gigabit Ethernet model", Optical and Quantum Electronics, 32, pp 169-192, 2000.

Gair D. Brown, "Bandwidth and Rise Time Calculations for Digital Multimode Fiber-Optic Data Links", JLT, vol. 10, no. 5, May 1992, pp. 672-678.

This presentation to be: http://www.ieee802.org/3/ae/public/jul00/dawe_1_0700.pdf

More references listed at http://www.ieee802.org/3/10G_study/email/msg01127.html