Proposed Worst Case Link Model for Optical Physical Media Dependent Specification Development.

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Outline

- Objectives
- Multimode Fiber Bandwidth Model
- Link and Channel Rise Times
- Extinction Ratio & RIN
- Mode Partition Noise (MPN)
- Inter-symbol Interference (ISI)
- Experimental Results
- Conclusions

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Goals

- Develop an accurate analytical model for laser based multimode fiber links.
  - ➡ *Use original Del Hanson model for LED based links as the starting point,*
  - ➡ *Insert additional terms specific to laser based links,*
  - ➡ *Investigate accuracy of model by comparison with experiment.*
- Develop worst case spread sheet model as basis for the development of the physical media dependent specifications.

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MMF Chromatic Bandwidth Model

Chromatic Dispersion Coefficients:

$$D1 = \frac{S0}{4} \cdot \left(\lambda c - \frac{\lambda 0^4}{\lambda c^3} \right) \quad \text{and} \quad D2 = 0.3 \cdot S0 \cdot \sigma\lambda$$

where,

S0 = Dispersion Slope Parameter at λo in (ps/nm^2km),

λo = Zero Dispersion Wavelength in nm,

λc = Source Center Wavelength in nm,

σλo = Source rms Wavelength in nm.

Chromatic Bandwidth, BWch, in MHz:

$$BWch = \frac{0.187}{L \cdot \sigma\lambda} \cdot \frac{1}{\sqrt{D1^2 + D2^2}}$$

where L is the link length in km.

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Link and Channel Response Time

Let the 10-90% fiber exit rise and fall time be Te(ns). It is given by:

$$Te^2 = (C1/BWm)^2 + (C1/BWch)^2 + Ts^2$$

where,

BWm = Modal Bandwidtrh (MHz);
BWch = Chromatic Bandwidth (MHz);
Ts = Source 10-90% response time;
L = Link length in km;
C1 = conversion factor; 480 for gaussian impulse response.

The channel exit rise and fall time, Tc(ns), is reduced by receiver bandwidth, BWr(MHz). For single pole receiver Tc is:

$$Tc^2 = Te^2 + (350/BWr)^2$$

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Extinction Ratio & RIN

The extiction ratio penalty in dB is: $P\varepsilon := 10 \cdot \log\left[\dfrac{1 + 10^{-\frac{\varepsilon}{10}}}{1 - 10^{-\frac{\varepsilon}{10}}}\right]$

where ε is the extinction ratio of the laser source in dB.

The penalty in dB due to laser relative intensity noise,
RIN (dB/Hz) is:

$$Prin = 5 \cdot \log\left[\frac{1}{1 - \left(Q^2 \cdot \sigma r^2\right)}\right]$$ and $$\sigma r^2 = 4 \cdot BWr \cdot 10^{\frac{RIN}{10}}$$

where BWr is the receiver bandwidth in Hz, and Q is 7.03 for BER of 1 in 10^{12}

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Two basic effects of chromatic dispersion

Chromatic dispersion: *different propagation velocities of light components having different colours.*

It leads to two different effects:

- pulse spread, resulting in ISI;
- Mode Partition Noise (MPN)

Pulse broadening and ISI

The ISI-caused chromatic dispersion penalty (in dB) can be estimated as follows[4]:

$$P_{ISI} = 5 \log [1 + 2 \pi (B D L \sigma\lambda)^2]$$

where B is Baud rate, D is fiber chromatic dispersion coefficient, L is link length and $\sigma\lambda$ is the RMS spectral width of laser.

However, this is a poor estimate of P_{ISI}. We will improve it later.

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Mode partition noise (MPN)

Partitioning of laser power between laser modes does not change the total transmitted power and does not cause additional noise at the laser output.

However, different laser modes travel at different velocities in the fiber.

As a result, power fluctuations between modes lead to MPN at the fiber output.

Mode partition noise penalty

The power penalty in dB due to MPN can be estimated as [4]:

$$P_{mpn} = 5 \log [1 / (1 - Q_a^2 \sigma_{mpn}^2)]$$

where Q_a is the desired argument of:

$$BER(Q) = [Q (2 \pi)^{1/2}]^{-1} \exp(- Q^2 / 2)$$

and

$$\sigma_{mpn} = (k / 1.414)[1 - \exp\{ - (\pi B D L \sigma\lambda)^2 \}]$$

σ_{mpn}^2 is the MPN variance.

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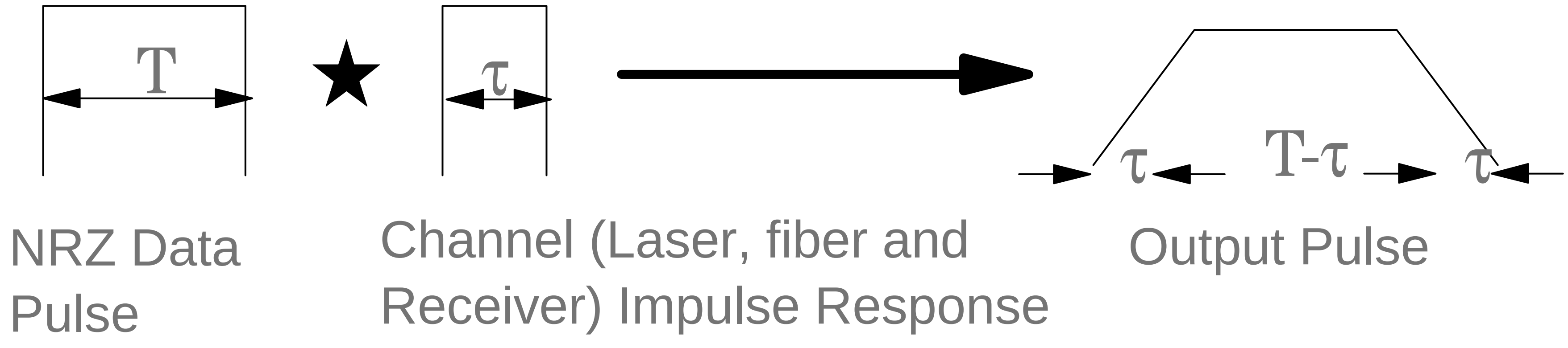
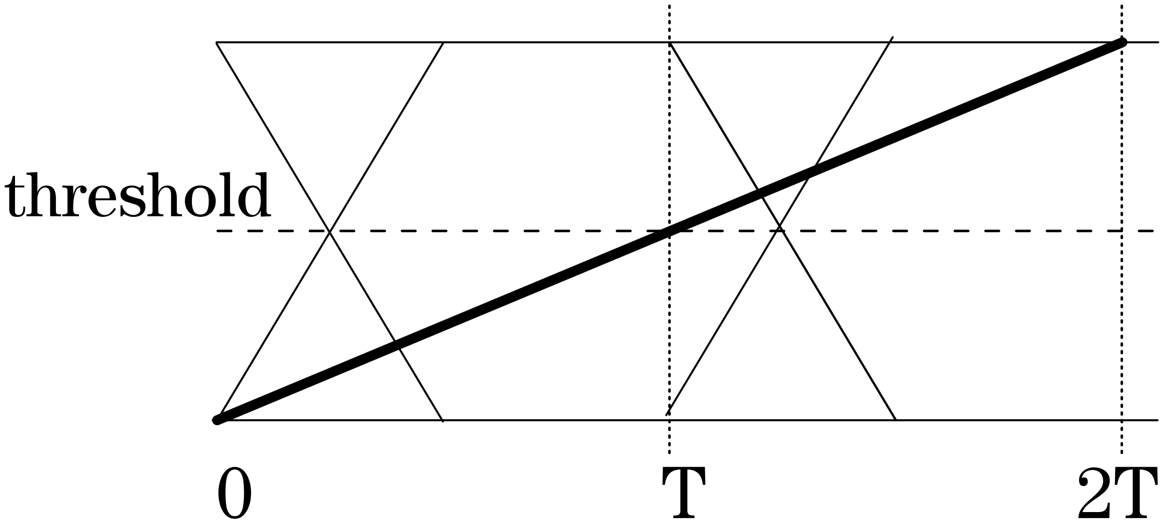
ISI in a Unequalized Optical Receiver: *Trapezoidal Output*

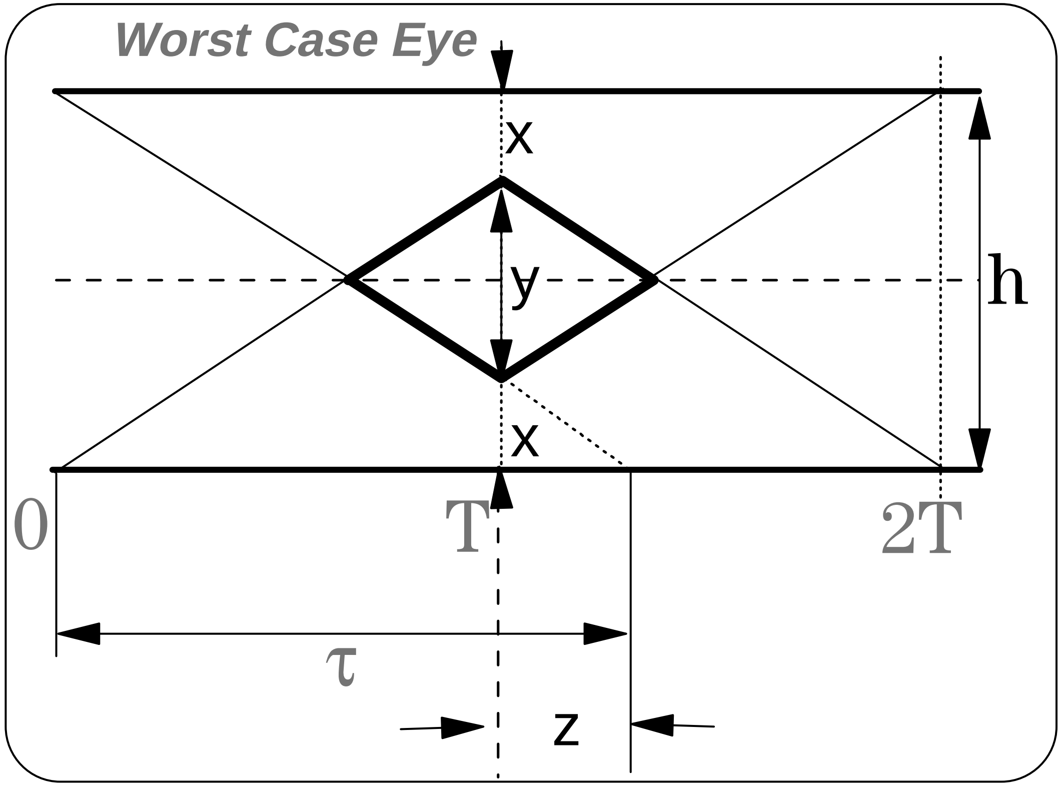




- Eye Fully Open for Tc < 0.8 T
- Eye Closed for Tc = 1.6 T
- Tc is 10% -90% risetime

⋆ *See reference 3 for more details*

ISI in an Unequalized Optical Receiver: *Trapeziodal Output for Tc > 0.8 T*



The ISI penalty, Pisi, is:

$$Pisi = h/y$$

$$= \tau/(2T - \tau)$$

But $Tc = 0.8\tau$

so that for $Tc > 0.8T$:

Pisi = Tc/(1.6 -Tc)

Pisi = zero otherwise

ISI in an Unequalized Optical Receiver: *Arbitary Output Pulse Shapes*

The ISI penalty is given by[3]: $Pd = 10 \cdot \log\left(\frac{1}{1 - Em}\right)$

where $Em = 2\left(1 - \int_{-\infty}^{\infty} Hp(f) \cdot Hf(f) \cdot Hr(f) \cdot e^{-i \cdot 2 \cdot \pi \cdot f \cdot to}\, df\right)$

Hp(f) is spectrum of the data pulse, Hf(f) is the transfer function of the laser and fiber, Hr(f) is the transfer function of the receiver and to is the sampling time.

Multimode Fiber Links

Multimode fiber systems are usually approximated by an overall gaussian impulse response.

For NRZ data pulses and the gaussian product H(f)Hr(f), Em is given by:

$$Em = \left[2 - 4 \cdot \int_{-\infty}^{0} \frac{\sin\left(\pi \cdot \frac{f}{B}\right)}{\pi \cdot f} \cdot \exp\left[-\frac{(2 \cdot \pi \cdot f \cdot \sigma t)^2}{2}\right] \cdot \exp(i \cdot 2 \cdot \pi \cdot f \cdot t0)\, df\right]$$

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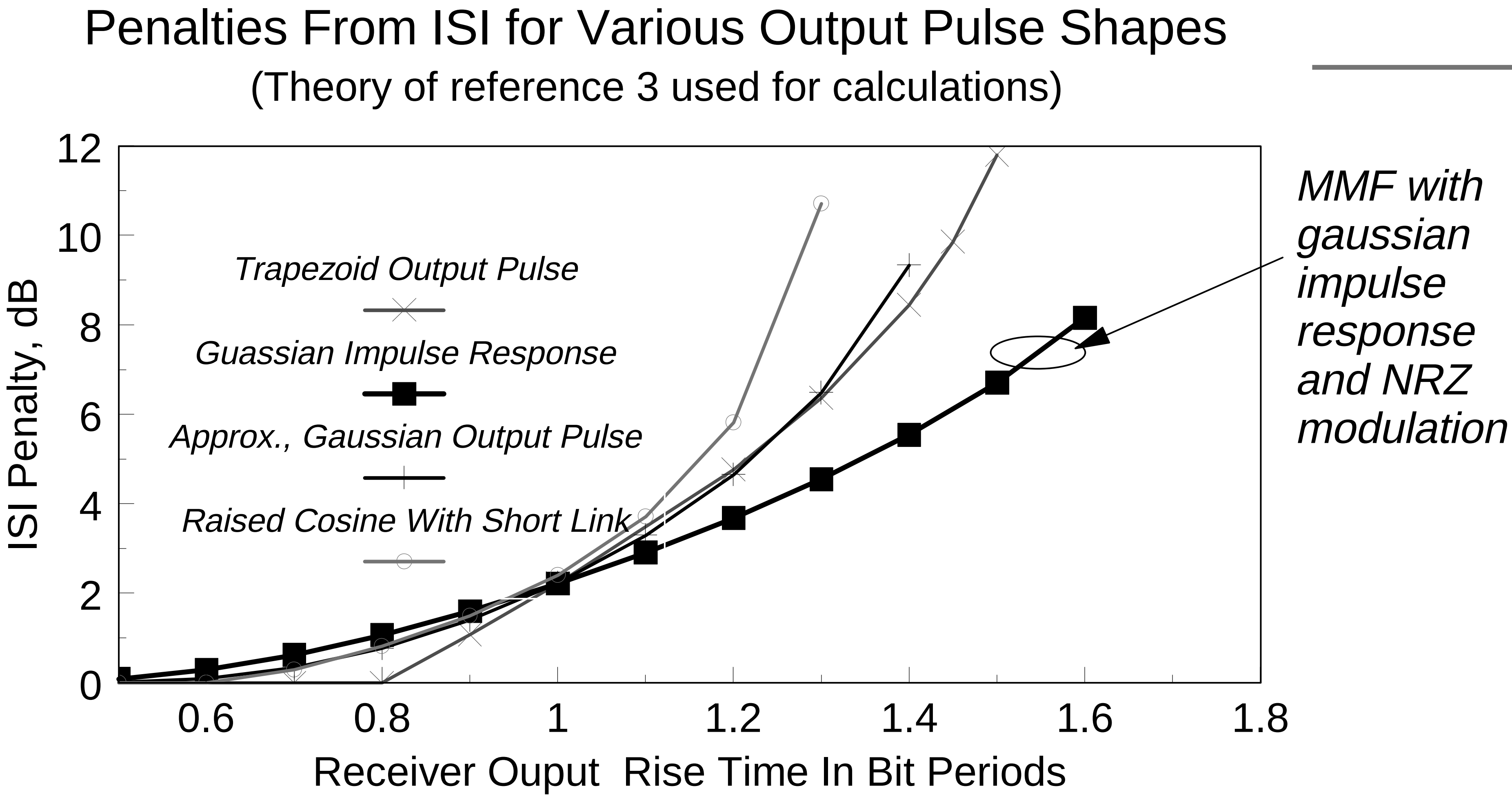
ISI in an Unequalized Optical Receiver: *Link with Gaussian Impulse Response*

$$Em = \left[2 - 4 \cdot \int_{-\infty}^{0} \frac{\sin\left(\pi \cdot \frac{f}{B}\right)}{\pi \cdot f} \cdot \exp\left[- \frac{(2 \cdot \pi \cdot f \cdot \sigma t)^2}{2} \right] \cdot \exp(i \cdot 2 \cdot \pi \cdot f \cdot t0) \, df \right]$$

The power penalty (Pisi) for the MMF link, with an assumed gaussian impulse response, was estimated by calculating Em numerically. The numerically calculated curve was found to be well approximated by:

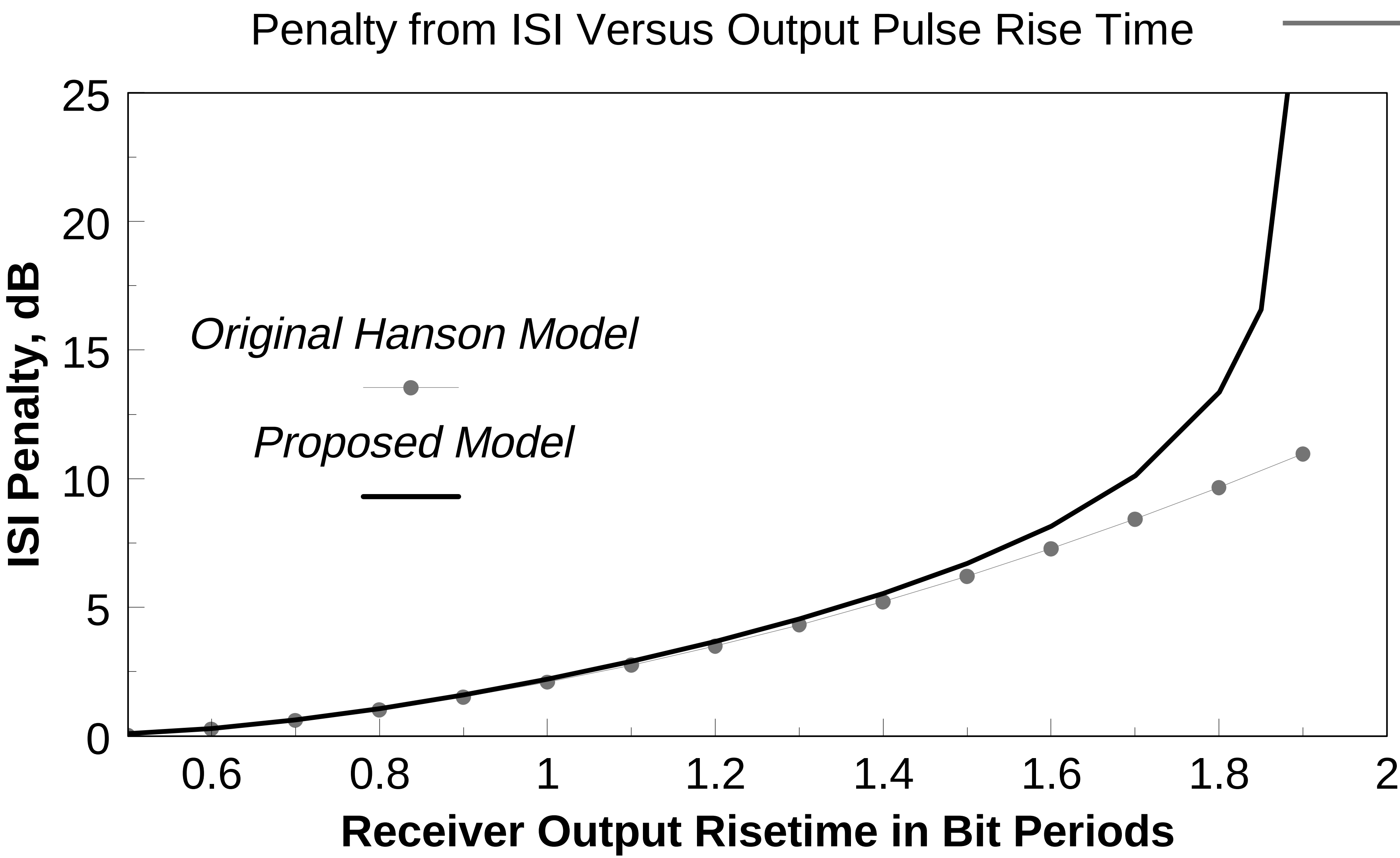
$$Pisi = 10 \cdot \log \left[\frac{1}{1 - 1.425 \cdot \exp\left[-1.28 \cdot \left(\frac{Tb}{Tc} \right)^2 \right]} \right]$$

Penalties from ISI: *Theory*



- *If the output pulse rise time is greater than the bit period then the worst case ISI penalty depends on receiver output pulse shape.*

Comparison of ISI Models: *Theory*



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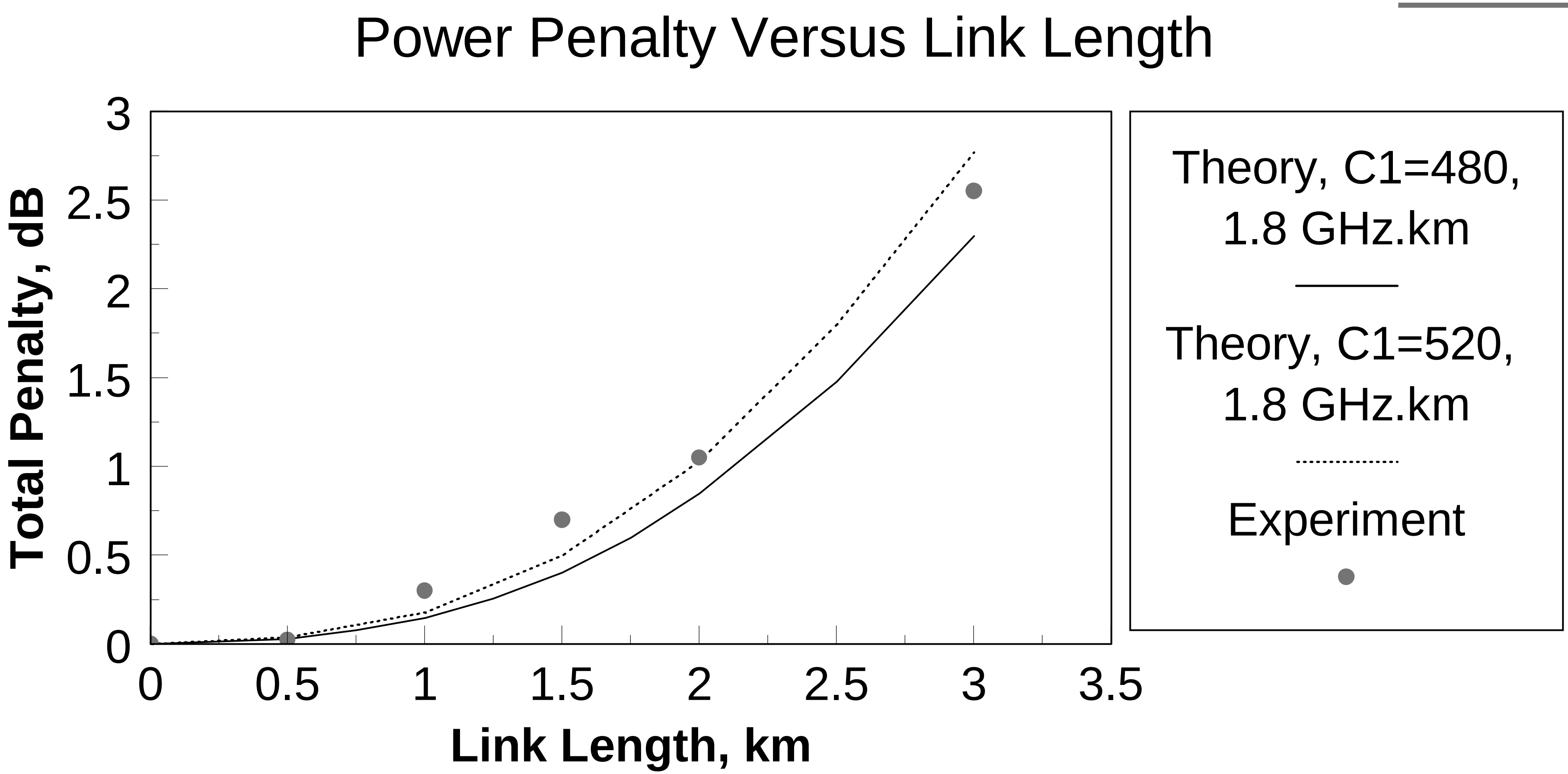
Comparison of Theory & Experiment:

Long Wavelength Link With Typical Components



HP coaxial laser, 1318 nm, 1.5 nm rms width, k=0.5, Ts=350 ps, RIN = -137 dB/Hz

62MMF, 2 GHz.km modal bandwidth, Zero Dispersion=1377nm, So=0.084 ps/(nm^2.km),

ALL ABOVE TRANSCEIVER AND FIBER PARAMETERS WERE MEASURED BY HPLB

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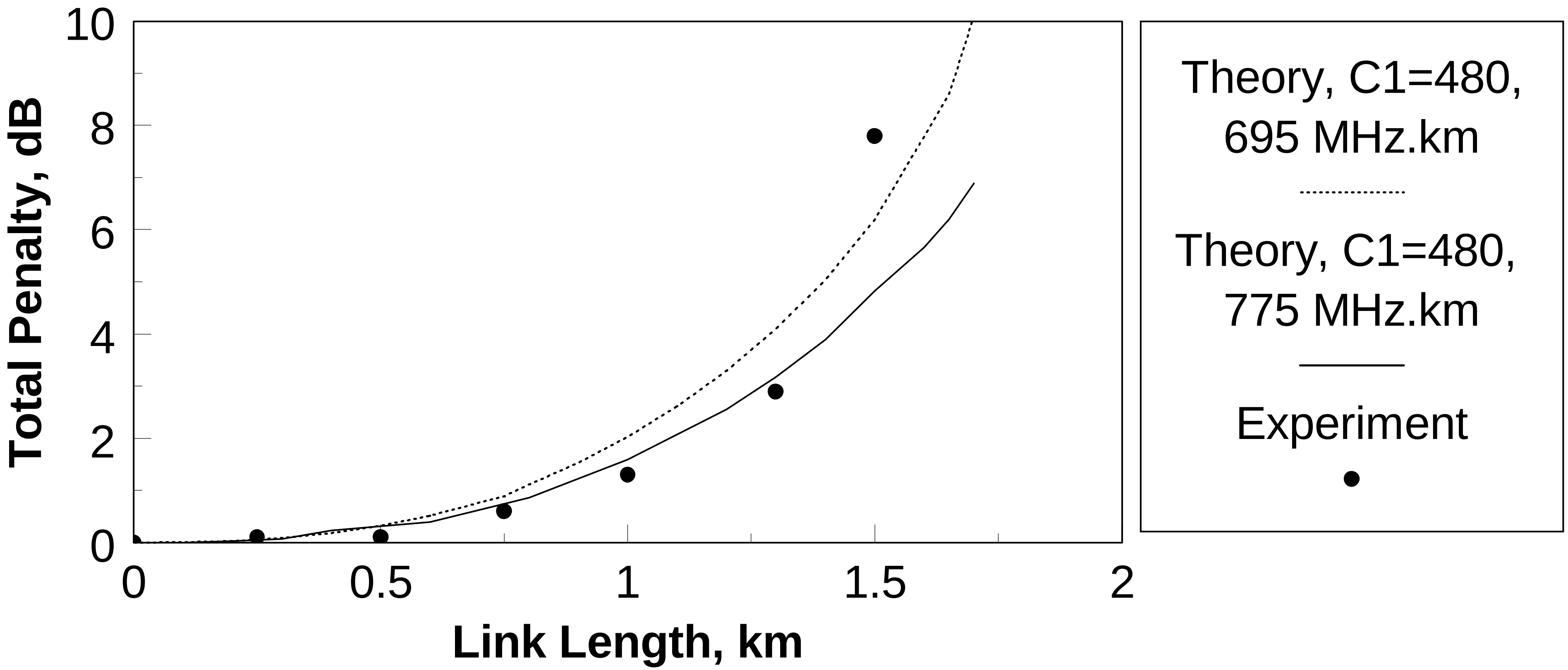
Comparison of Theory & Experiment:

Short Wavelength (857 nm) Link With Typical Components

Power Penalty Versus Link Length



SW (FP) laser, 857 nm, 0.85 nm rms width, k=0.85, Ts=300 ps, RIN=-125 dB/Hz

62MMF, 775 MHz.km modal bandwidth, Zero Dispersion=1377nm, So=0.084 ps/(nm^2.km)

ALL ABOVE TRANSCEIVER AND FIBER PARAMETERS WERE MEASURED BY HPLB

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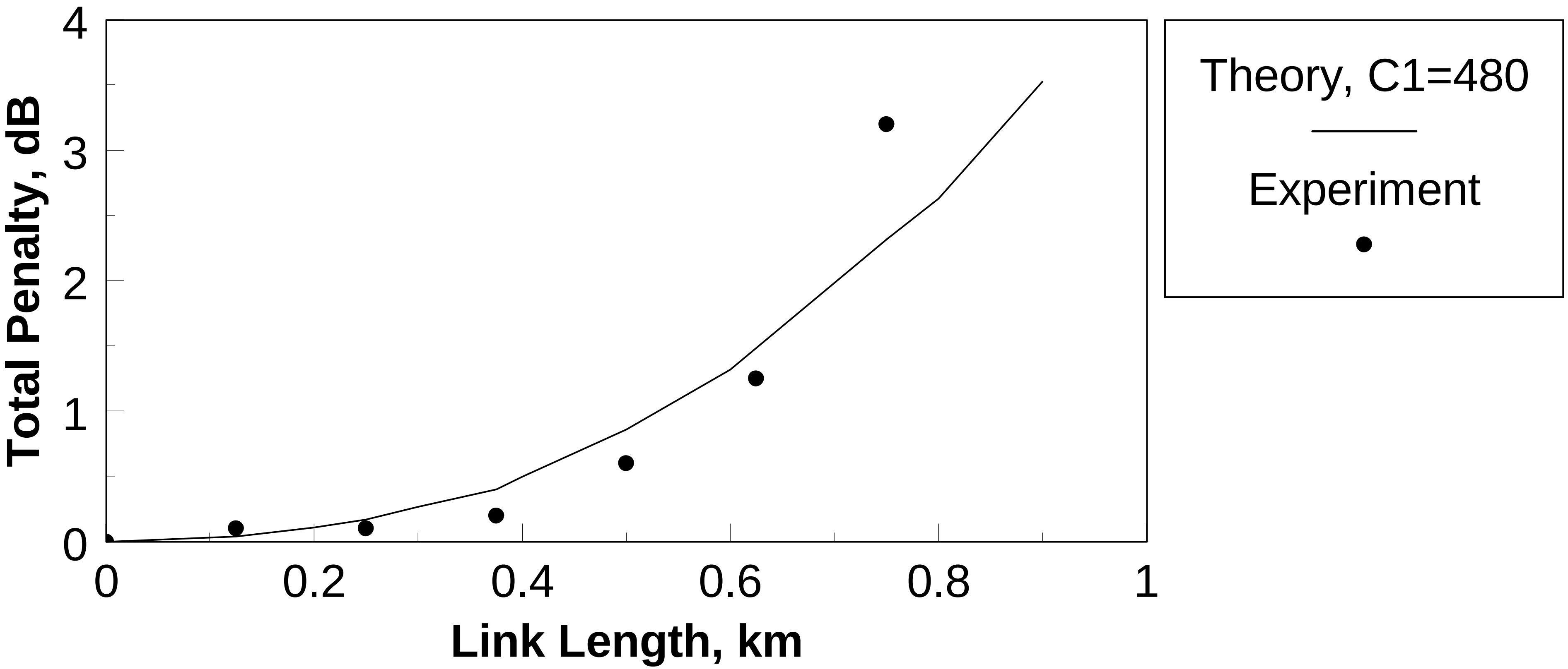
Comparison of Theory & Experiment:

Short Wavelength (770 nm) Link With Typical Components

Power Penalty Versus Link Length



SW (FP) laser, 794 nm, 0.8 nm rms width, k=0.85, Ts=300 ps, RIN=-120 dB/Hz

62MMF, 525 MHz.km modal bandwidth, Zero Dispersion=1377nm, So=0.084 ps/(nm.km^2)

ALL ABOVE TRANSCEIVER AND FIBER PARAMETERS WERE MEASURED BY HPLB

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Conclusions

- We have developed an analytical model for laser based multimode fiber links;

  ➡ *Using the original Del Hanson model for LED based links as the starting point,*

  ➡ *Inserting additional terms specific to laser based links.*

- We have shown that the model accurately predicts the link penalties for laser based links operating at wavelengths of 770 nm, 850 nm and 1300 nm.

- A spread sheet model has been developed which will be the basis of "Link Lengths For 850 nm & 1300 nm Optical PMDs With All Link Penalties" to be presented by Del Hanson.

References

1. ANSI T1.646-1995, Broadband ISDN-Physical Layer Specification For User-Network Interfaces, Appendix B.

2. Gair D. Brown, "Bandwidth and Rise Time Calculations for Digital Multimode Fiber-Optic Data Links", Journal of Ligthwave Technology, VOL. 10, No. 5, May 1992, pp 672-678.

3. James L. Gimlett and Nim K. Cheung, "Dispersion Penalty Analysis for LED/Single-Mode Fiber Transmission Systems", Journal of Ligthwave Technology, VOL., LT-4, No. 9, Sept.,1986, pp 1381-1392.

4. 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.