MPN Penalty Considerations

Petar Pepeljugoski

IBM T.J. Watson Research Center

Yorktown Heights, NY 10598

(914)-945-3761, petarp@us.ibm.com

Rob Marsland, Rob Williamson

Focused Research

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Introduction

- mode partition noise (MPN) penalty limiting factor in several PMD solutions
- original MPN penalty theory developed (and checked) for SMF transmission
- application to systems with ISI needs different formula

Outline

- examine Ogawa’s formula
- check validity of approximations
- do simulatons to check assumptions
- propose a correction to spreadsheet model

Ogawa's MPN Penalty Formula

- MPN standard deviation (also used by spreadsheet model) given by:

$$\sigma_{mpn} = k\left[\sum_i f_i^2\overline{A_i} - \left(\sum_i f_i\overline{A_i}\right)^2\right]^{1/2} \approx \frac{k}{\sqrt{2}}\{1 - \exp[-(\pi BLD\sigma_\lambda)^2]\}$$

- Assumptions:

  1. signal at RX output is a raised cosine signal given by:

$$r(t) = \sum_i A_i \cos[\pi B\Delta t_k] = \sum_i A_i \cos[\pi BDL(\lambda_k - \lambda_0)] = \sum_i f_i A_i \quad \text{where} \quad \Delta t_k = DL(\lambda_k - \lambda_0)$$

  2. laser spectrum is a continuum of modes

l_k - wavelengths of individual laser modes	A_i - relative intensities of laser modes
B - bit rate	L - fiber length

Quick Check for Formula Validity

- assume ideal square signal (very fast TX and RX, SMF)
- the MPN penalty is flat (and low) for long distance (until relative mode delays exceed bit time), since no SNR degradation occurs
  - critical length L_c is (until which no MPN penalty):

$$L_c = \frac{T}{D\Delta\lambda}$$

where $\Delta\lambda = \max(\lambda_i - \lambda_j)$ Ex: $\Delta\lambda$=1nm, D=120 ps/km/nm, **Lc ~ 800m** for SX

  - **but the model predicts gradual increase and a floor!!**
- pulse spreading in bandwidth limited systems flattens the top of the pulse, situation analogous to the ideal case regarding MPN

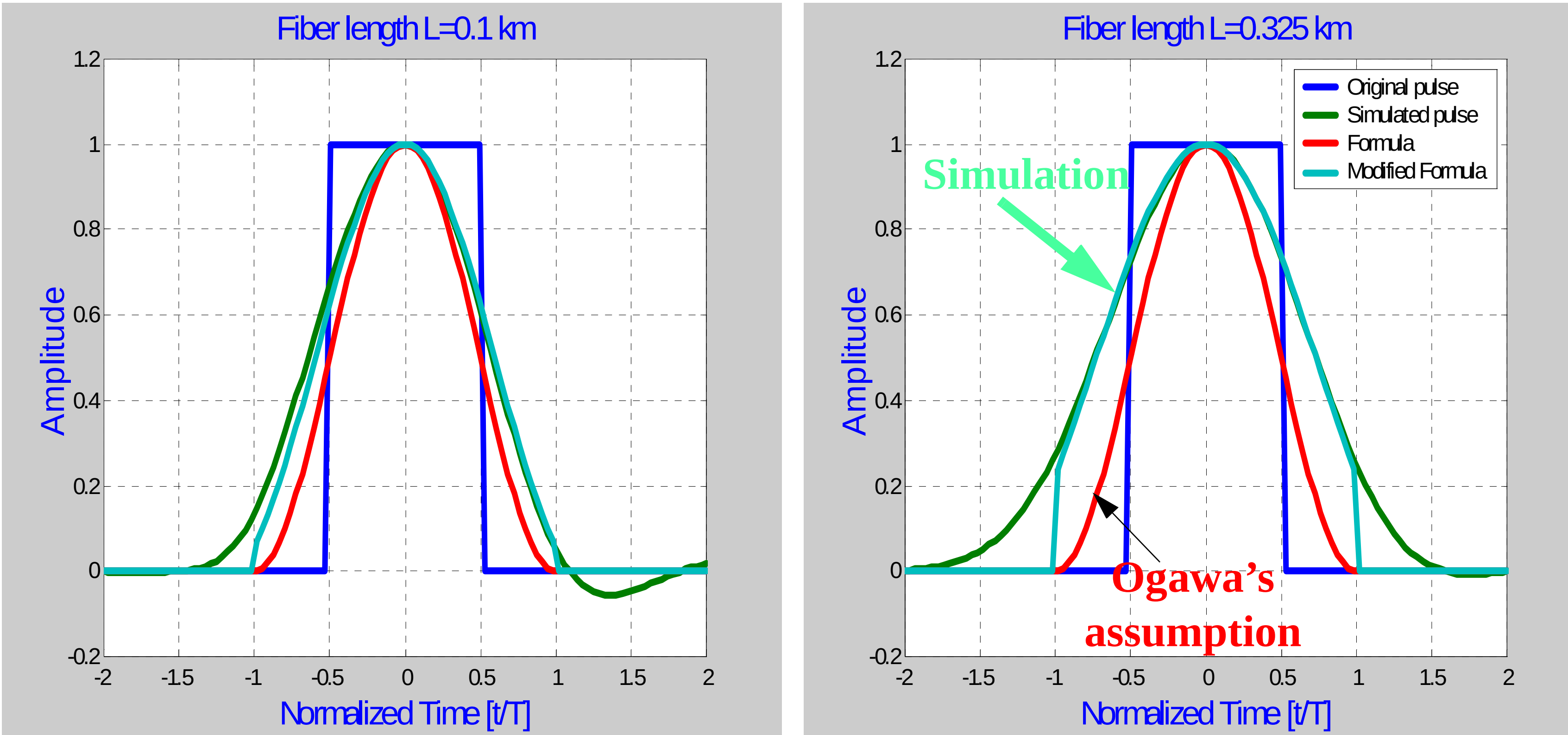
Are the assumptions valid?

- raised cosine shape MAY be valid
- width of raised cosine shape is NOT accurately described by the bit rate only, correction necessary
- continuum of modes may not be valid for lasers with few modes

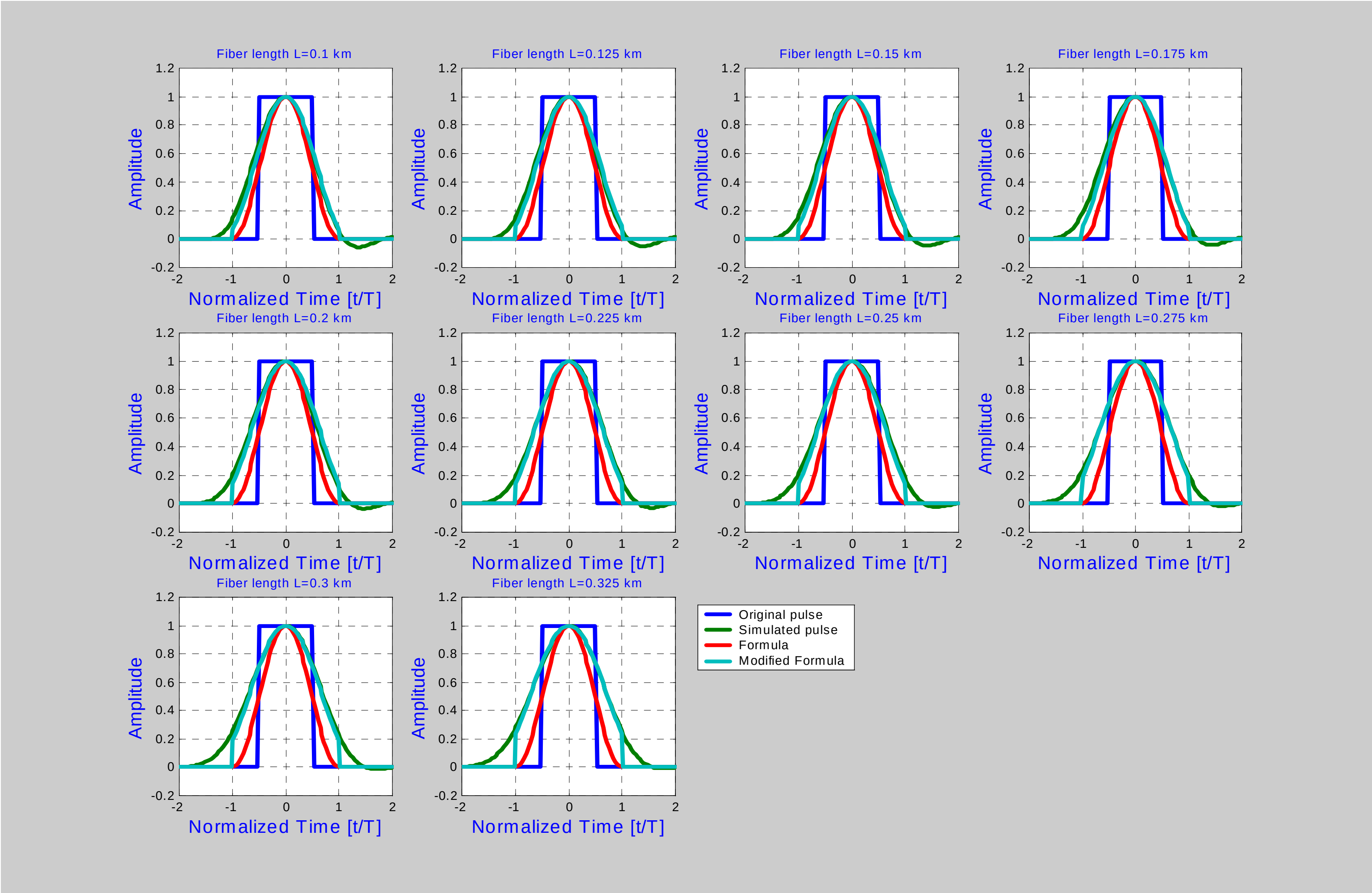
Simulations to Check Validity of Raised Cosine Assumption

- pattern of isolated one preceeded and followed by large number of zeros
- short wavelength system for various lengths simulated
  - worst case parameters assumed
- output signal compared to raised cosine
- correction factor (ratio of FWHM values) used to compare system impulse response with corrected raised cosine
- rise time of output signal correlated to correction factor

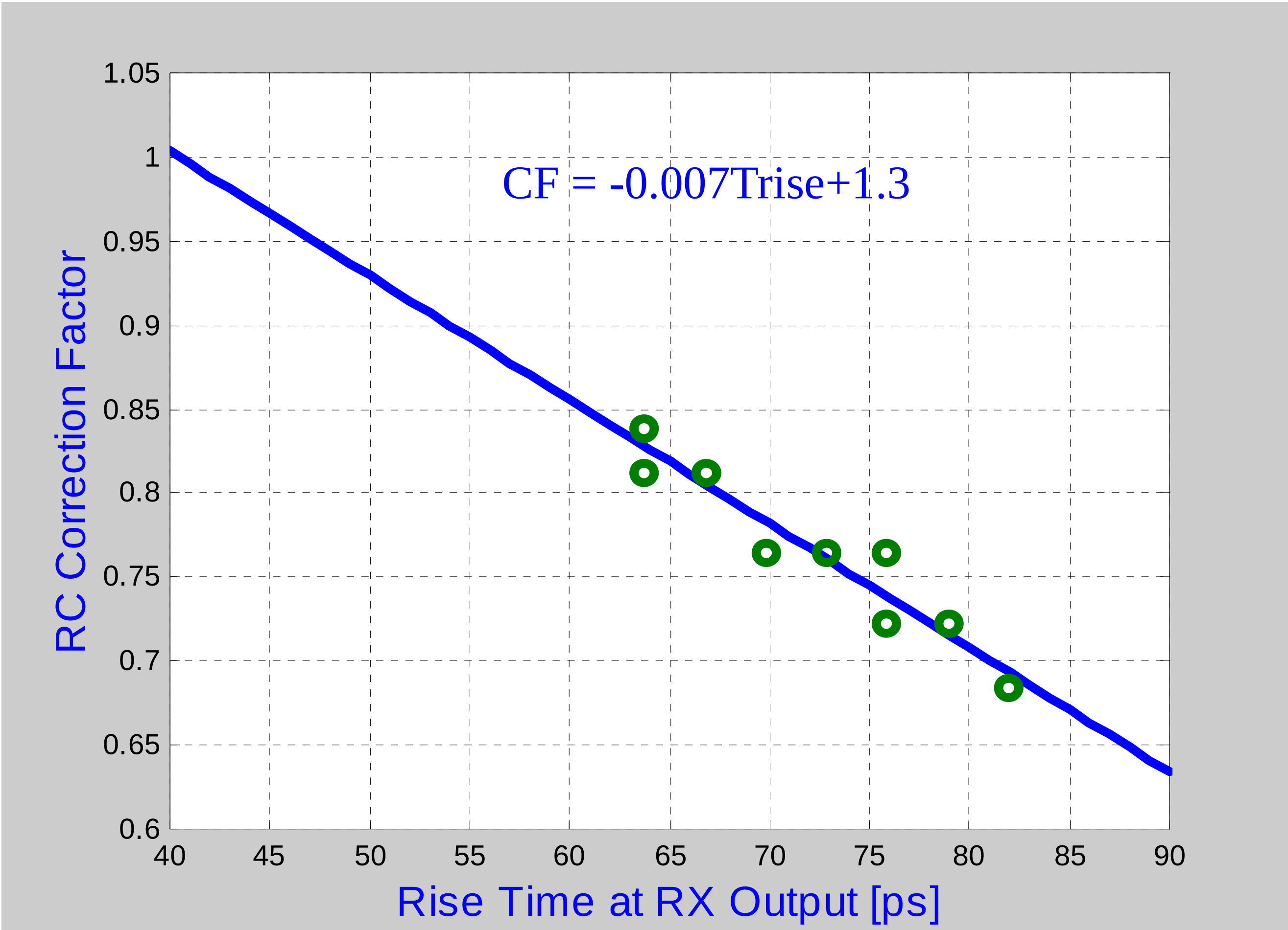
Simulation Results



Signal Shapes Comparison for Different Lengths



Correlation of Correction Factor and Rise Time



Impact and Plan of Action?

- analysis most beneficial to MMF with high ISI values
- use of corrected formula gives lower MPN penalty:
  - assume k=0.5, rms linewidth 0.5 nm, 840nm:
  - old model: 2.11, new model 0.17 dB;
- correct the MPN penalty formula to use the BASE baud rate
- introduce a correction factor to take into account pulse spreading
- recalculate penalties and relax some parameters
- why do we need to keep the RIN low?

What About The Continuum of Modes Approximation?

- the use of continuum of modes approximation may underestimate the MPN penalty for some lasers
- analytic results can be incorporated in the model for two mode devices

$$\sigma_{mpn} = k(1 - f_1)\sqrt{A_1(1 - A_1)}$$

- some lasers may need further specifications, in addition to line-width