Open Source Matlab Simulation Model for EDC based 10GBASE-LRM

Sudeep Bhoja - Big Bear
Jesper Hanberg - Intel
Petre Popescu - Quake
Abhijit Shanbhag - Scintera
Kevin Witt - Vitesse

Supporters

John Ewen – JDS Uniphase
Nick Weiner – PhyWorks
Eric Borisch – JDS Uniphase
Sudeep Bhoja - Big Bear
Jesper Hanberg – Intel
Andre Van Schyndel - Bookham
Petre Popescu - Quake
Abhijit Shanbhag - Scintera
Kevin Witt – Vitesse
Ryan Latchman – Gennum
Stefano Bottacchi - Infineon

Objectives

- **Unified comprehensive simulation platform to assist in and guide EDC-based 10GBASE-LRM standards effort**
  - **Link budget feasibility of at least 220m for FDDI-grade fiber and 300m of selected MMF with different equalization structures and architectures**
  - **Compliant transmitter parameters at TP2 and receiver parameters at TP3; Assist in evaluating different channel metrics at TP2, TP3**
  - **Quantify penalties due to important miscellaneous impairments including jitter, time-varying ISI, etc…**
  - **Study sensitivity of EDC to various parameters such as Tx & Rx Bandwidth, RIN etc…**

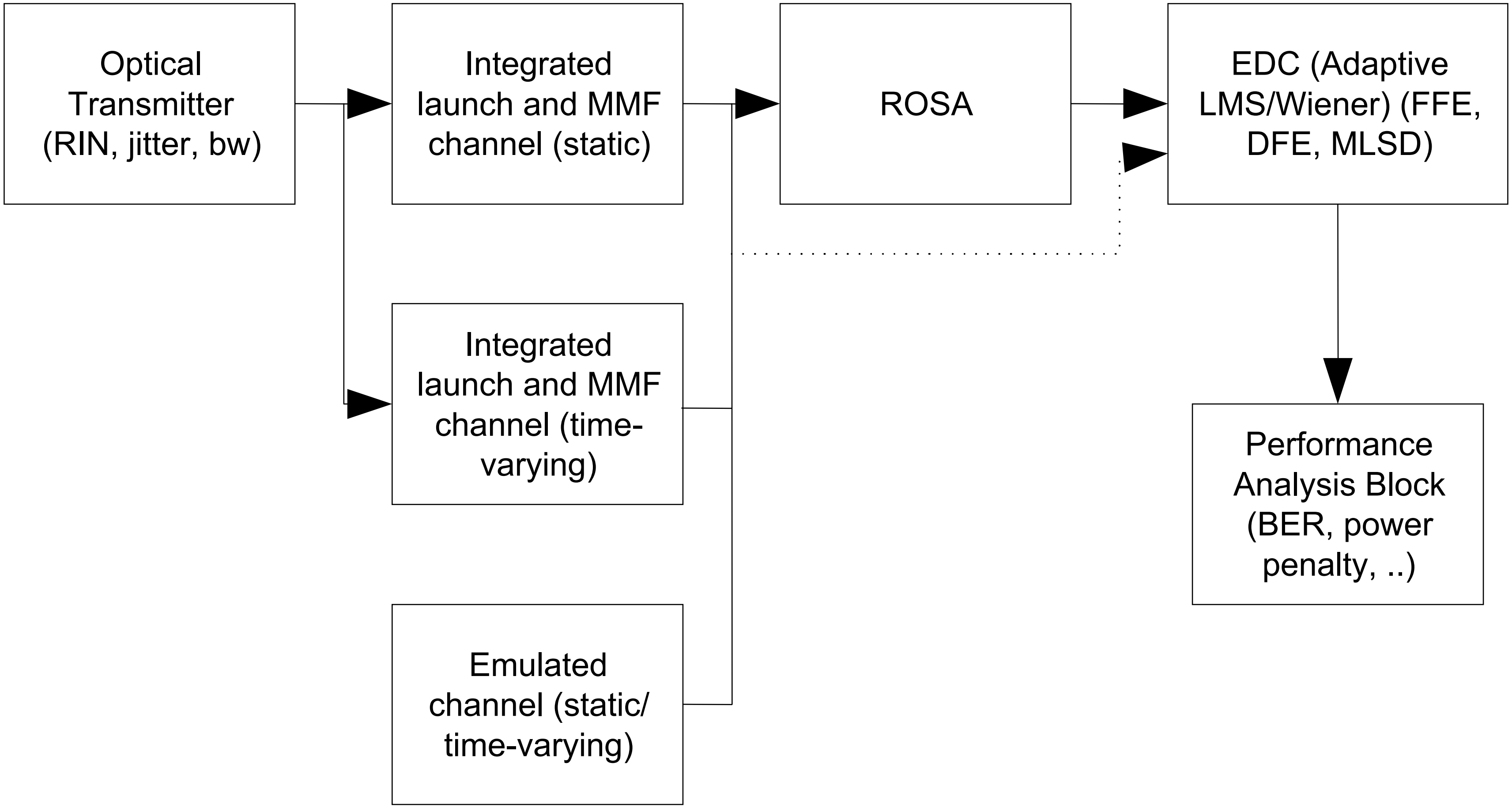
Comprehensive Simulation Platform: Need for Unified Framework

- There have been numerous simulations put forward in the various Study Group presentations
  - Infer a 3-6dB for Equalizer penalty, but currently difficult to come up with a precise number
  - Methodology & details for the various simulations are not transparent
    - Definition of coverage?
    - What is included? Is the reference back-to-back or Rx OMA sensitivity?
    - Various channel models used; 802.3z National Labs, Cambridge, Measured impulse responses
  - Little data provided on time tracking & none on jitter
- These shortfalls need to be addressed for consistency, for comparisons, and for eventual ‘fine tuning’ of the specifications

Comprehensive Simulation Platform: Need for Unified Framework

- Use similar methodology as in 10GBASE-T & 1000BASE-T
- Matlab Open Source model for “textbook” Equalizers
  - Agree on an approach
  - Peer review of the details
  - Results will change as channel model evolves
- Matlab model to minimize/avoid using toolboxes
- Matlab model can assist in developing and confirming the methodologies, performance figures of merit, parameters and feasibility for compliance within D1.0

Top-Level Simulation Block Diagram



Tx & Rx Link Parameters

- Transmitter rise time assume guassian
  - Default: 47.1ps as in IEEE 802.3ae LR link model
- RIN is assumed white and gaussian at the Transmitter, but spectrally shaped by the fiber and the Rx
  - Default: -128 dB/Hz
- TIA Noise PSD S(f) assumed constant and computed from receiver sensitivity according to
  - $S(f) = S_{OMA}^2 / (8\ Q_0^2\ B_n)$, where
    - S_{OMA} = Sensitivity in OMA
    - Q_0 = 7.03 for BER = 10^{-12}
    - B_n = Noise equivalent bandwidth
  - S(f) is referred to optical domain; hence units are mW^2/GHz
- Receiver can be parameterized
  - Default: S_{OMA} = -12.6 dBm. BW = 7.725 GHz, B_n = 1.032*B
- Thus
  - $S(f) = 9.63 \times 10^{-7}\ mW^2/GHz$

EDC Power Penalty – LE & FFE+DFE

- Model takes a collection of impulse responses and sweeps allocated dispersion penalty for yield estimates
- Use well established and documented[1] Minimum Mean Square Error (MMSE) analysis for finite length FFE/DFE based Rx
- MMSE results automatically account for residual ISI and noise
- T/2 spaced Equalizer are simulated
  – Allows the FFE to implement a matched filter followed by a T spaced Equalizer for optimal performance
- Tap Coefficients: (Wiener) $w = R^{-1} \cdot P$ and Adaptive LMS-based
  – R is the channel autocorrelation matrix of the sampled data signal
  – P is the channel cross-correlation vector
- Number of taps can be chosen as a parameter
  – Default Parameters:
    - LE – 12 taps
    - DFE – 9 tap FFE + 3 tap Feedback

Ref 1 - pp521-524 in "Digital Communication" by Edward Lee and David Messerschmitt

EDC Power Penalty – MLSD

- Supported within the simulation platform to obtain the Maximum Likelihood Sequence Detection (MLSD) bound.
  - Complex to implement but equalization structures with performance between DFE and MLSD may be implemented
- MLSD simulated as whitened matched filter followed by trellis-based sequence detection.
- Whitened matched filter implemented as T/2 spaced FIR filter.
- T-spaced channel impulse response (to generate state metric for sequence detection) obtained from FIR-based channel emulator.
- Number of trellis states for MLSD may be selected as a parameter.
- Number of taps for whitened matched filter front-end may be selected as parameter.

EDC Power Penalty - Jitter

- Phase jitter is assumed white and Gaussian, and it is converted into (colored) amplitude noise
  - Oscar Agazzi, Equalization ad hoc
    - http://www.ieee802.org/3/ae/public/adhoc/equal/agazzi_1_0301.pdf
  - First and second derivatives of the pulse response are used to estimate jitter induced amplitude noise

- RMS jitter on the recovered clock is parameterized
  - RMS jitter is composed of
    - Residual VCO phase noise
    - Data dependent Jitter due to phase detection
    - Jitter due to TIA noise
  - Default RMS jitter parameter: 3ps

Power Penalty – Time Varying Channels

- Methodology described in bhoja_1_0304
- Establish benchmark by treating each constituent impulse response as static and compute the MMSE theoretical performance
- Adaptive DFE updated at full rate by a decision directed LMS adaptation algorithm
- The adaptation step size μ determines speed of adaptation
  - For stability with LMS adaptation $\mu \ll 2 / \lambda_{max}$
    - λ_{max} the maximum eigenvalue of the autocorrelation matrix R
    - μ should be small to keep excess MSE small
  - Sub sampled implementations of LMS "effectively" decrease the step size μ
- Adaptation step size is parameterized
  - Default μ – 1E-3

Summary

- Open Source Matlab model is currently under development
  - Goal is to assist in and guide EDC-based 10GBASE-LRM standards effort
    - Link budget feasibility
    - Aid in compliance test methodology and compliance parameters
- Comprehensive Simulation model can study sensitivity of EDC to
  - Jitter
  - Temporal channel variation
  - Receiver Bandwidth
  - Transmitter Bandwidth
  - RIN
- Simulation model under development and a subset will be available shortly