Adaptive Transmit Equalization Proposal for 40GBASE-CR4 and 100GBASE-CR10

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Supporters

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Agenda

- Background
- Simulation results
- Proposal
- Summary

Background

- The Cu channel is characterized by frequency dependent loss
  - Loss strongly depends on channel length
  - Requires equalization in order to operate at the required BER
- Possible equalization options
  - TX equalization (fixed or adaptive)
  - Simple RX equalization
  - Complex RX equalization
- We will demonstrate the dependence of performance upon equalizer optimality

Background (contd.)

	Pros	Cons
Fixed TX equalization	•Very simple implementation •Low power	•Suboptimal equalization in virtually all cases
Adaptive TX equalization	•Simple implementation •Low power •Efficient equalization	•Adaptation requires control channel –but… control channel already defined in the KR standard
Simple RX equalization (e.g. CTLE)	•Simple implementation •Low power	•Inefficient adaptation – suboptimal equalization
Complex RX equalization (e.g. with A/D & DSP)	•Efficient equalization	•Highly complex implementation •High power

Proposal Abstract

- Adopt the adaptive TX equalization scheme
- Use the control channel, startup protocol and electrical specifications as defined in 10GBASE-KR
- Enjoy the benefits:
  - Simple implementation
  - Low power
  - Enhanced performance
  - Leverage proven KR technology
  - Low standardization effort

Simulation Conditions

- Common parameters:
  - TX jitter as defined in 802.3ap Clause 72.7.1.8
    - RJ: 0.0107 UI RMS → 0.15 UI PtP @10^{12}
    - DJ: 0.115 UI (156 MHz, square wave) + 0.035 UI DCD
    - PtP of total jitter @10^{12} – 0.28 UI
  - Receiver with adaptive 5-tap DFE
  - Suboptimal receiver with impairments: detailed analog models, clock recovery and adaptation logic
  - IEEE 802.3ap package model for both TX and RX
  - No crosstalk or noise (data wasn't available for all cases)

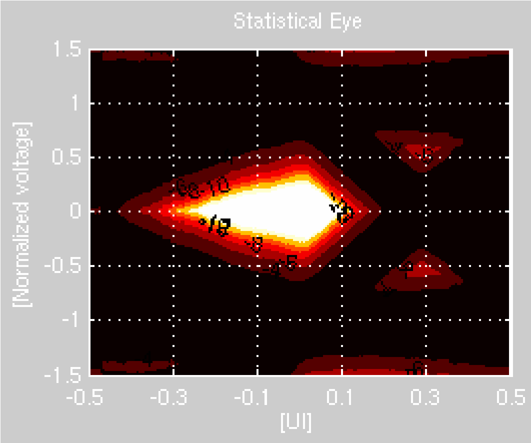
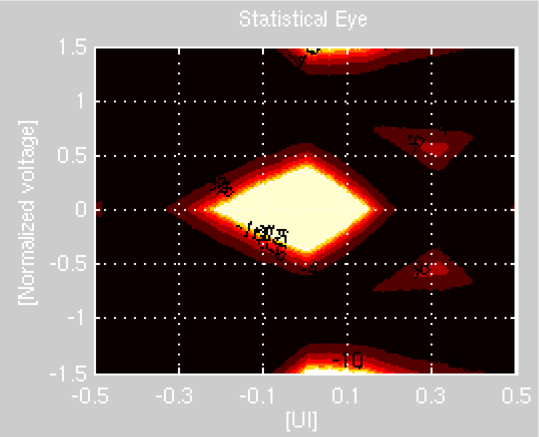
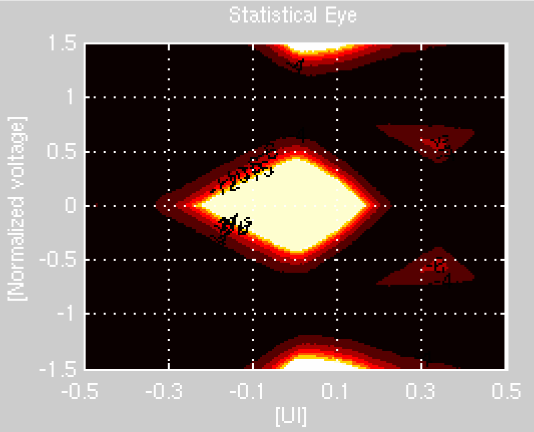
Simulation Conditions

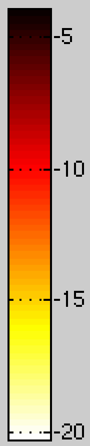
- Simulated test cases:
  - Channels:
    - 1m “Direct Attach” SFP+ Twinax assembly with 2* 2” PCB (measurement by Intel)
    - 6 m 26AWG Twinax cable assembly with enhanced CX4 connector and 2*2.5” PCB (source: **Meritec**)
    - 10 m 24AWG Twinax assembly with QSFP connector and 2*3” PCB (source: **Leoni High Speed cables + Molex**)
  - TXFFE options:
    - Fixed, optimized to meet SFI mask at point B
      (see SFF-8431)
    - Fixed at 10GBASE-KR “INIT” condition
    - Adaptive, using 10GBASE-KR spec and adaptation protocol
- Different cable length used to cover real-life scenarios; we do not attempt to compare performance across cable types
- Performance across TXFFE alternatives is compared

Performance Metrics

- Based on statistical eye analysis
  - Eye width (to probability 1e-12)
  - Eye height (at mean sampling phase, relative to DFE reference voltage)
  - BER with specified jitter
    - Eye symmetry taken into account
    - Finite slicer sensitivity assumed

Simulation Results (1) – 1m SFP+ assy

SFI mask	10GBASE-KR INIT	Adaptive
		
EW=0.39 UI EH=±0.335 V_{REF} BER=4e-13	EW=0.38 UI EH=±0.41 V_{REF} BER=3e-26	EW=0.4 UI EH=±0.44 V_{REF} BER<1e-30



BER Exponent Color map

Simulation Results (2) – 6m CX4 assy

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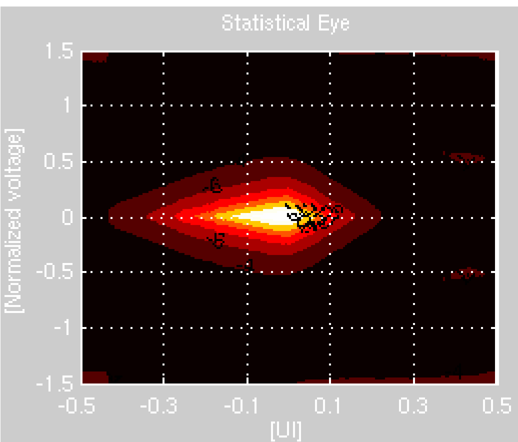
<tr><th>SFI mask</th><th>10GBASE-KR INIT</th><th>Adaptive</th></tr>
<tr>
<td>
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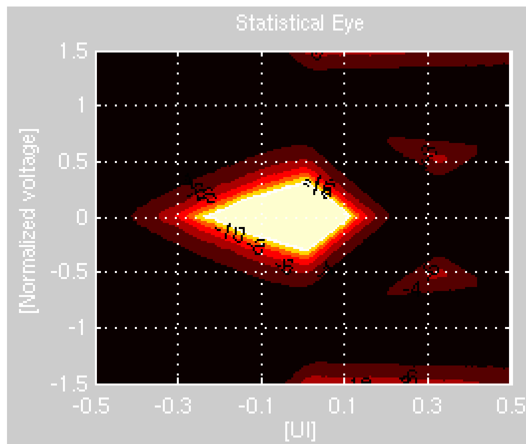
<td>
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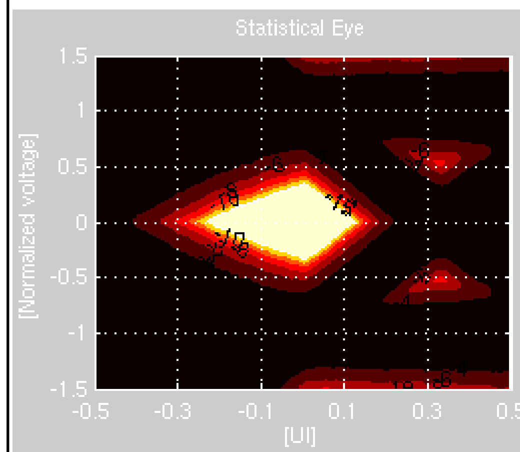
<td>
</td>
</tr>
<tr>
<td>EW=0.24 UI
EH=±0.14 V_{REF}
BER=5e-10</td>
<td>EW=0.38 UI
EH=±0.35 V_{REF}
BER=2e-17</td>
<td>EW=0.39 UI
EH=±0.38 V_{REF}
BER=2e-20</td>
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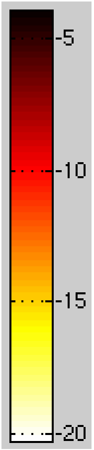
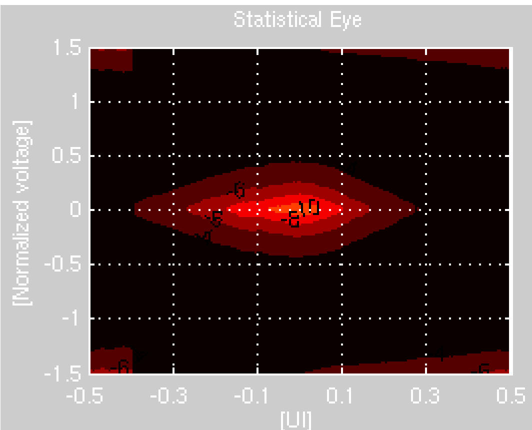
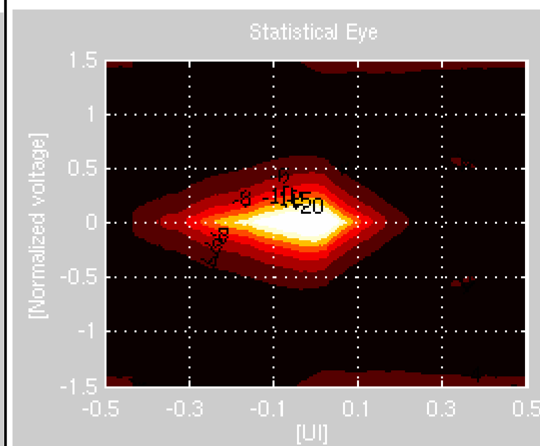
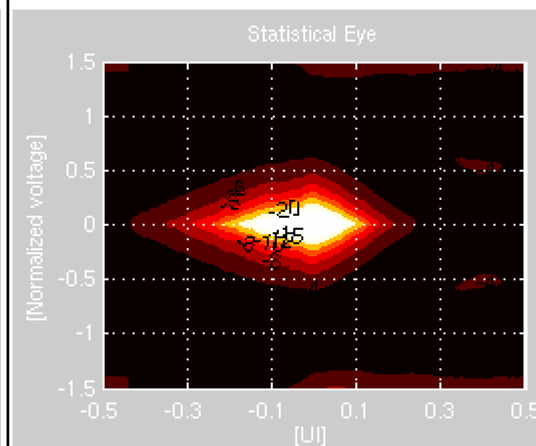
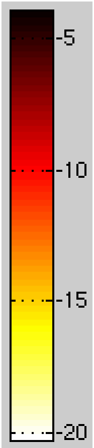


BER Exponent Color map

Simulation Results (3) – 10m QSFP assy

SFI mask	10GBASE-KR INIT	Adaptive
		
EW=0 EH=0 BER=2e-8	EW= 0.32 UI EH=±0.23 V_{REF} BER=9e-11	EW=0.33 UI EH=±0.24 V_{REF} BER=3e-13



BER Exponent Color map

* Longer DFE was used to mitigate higher ISI duration

Simulation Results – Summary

- Adaptive TX equalization enables enhanced performance compared to fixed equalization
  - Better margins for noise (including crosstalk) and jitter
  - Broader range of cable lengths and tolerances can be supported
  - Overall, a more robust communication system
- SFI equalization creates an open eye at the transmitter test point, but performs poorly at the receiver
  - Additional linear equalization in the receiver is required for long cables

Proposal for 40GBASE-CR4 and 100GBASE-CR10

- Adopt the 10GBASE-KR PMD control function as defined in IEEE Std 802.3ap Clause 72.6.10
- Use the TX FFE structure based on IEEE Std 802.3ap Clauses 72.7.1.10 and 72.7.1.11
- Electrical TX specifications to be based on 72.7.1, modified appropriately to accommodate CR4/CR10 test points

Summary

- Several equalization schemes were compared
- Adaptive TX equalization capabilities were simulated, displaying enhanced performance over copper cable assemblies
  - Higher cable reach compared to fixed TX equalization
  - Higher noise/jitter margins
- Additional benefits
  - Lower power consumption compared to RX-based equalization
  - Leverage existing, proven and standardized technology
- Proposal – adopt the KR startup protocol and electrical specifications for 40G and 100G operation over copper cable assembly

BACKUP

Transmit Equalizer Structure

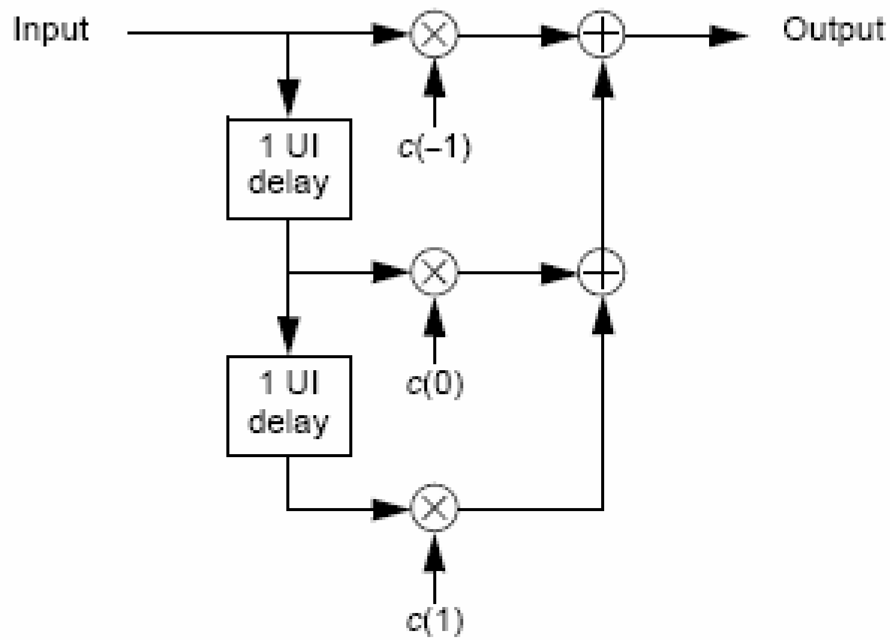


Figure 72–11—Transmit equalizer example

Source: **IEEE Std 802.3ap™-2007**

Insertion and Return Loss Of Tested Channels