Selecting optimal pre-emphasis value for 10G 4-Lanes Ethernet

November 2004 IEEE 802.3 Plenary meeting

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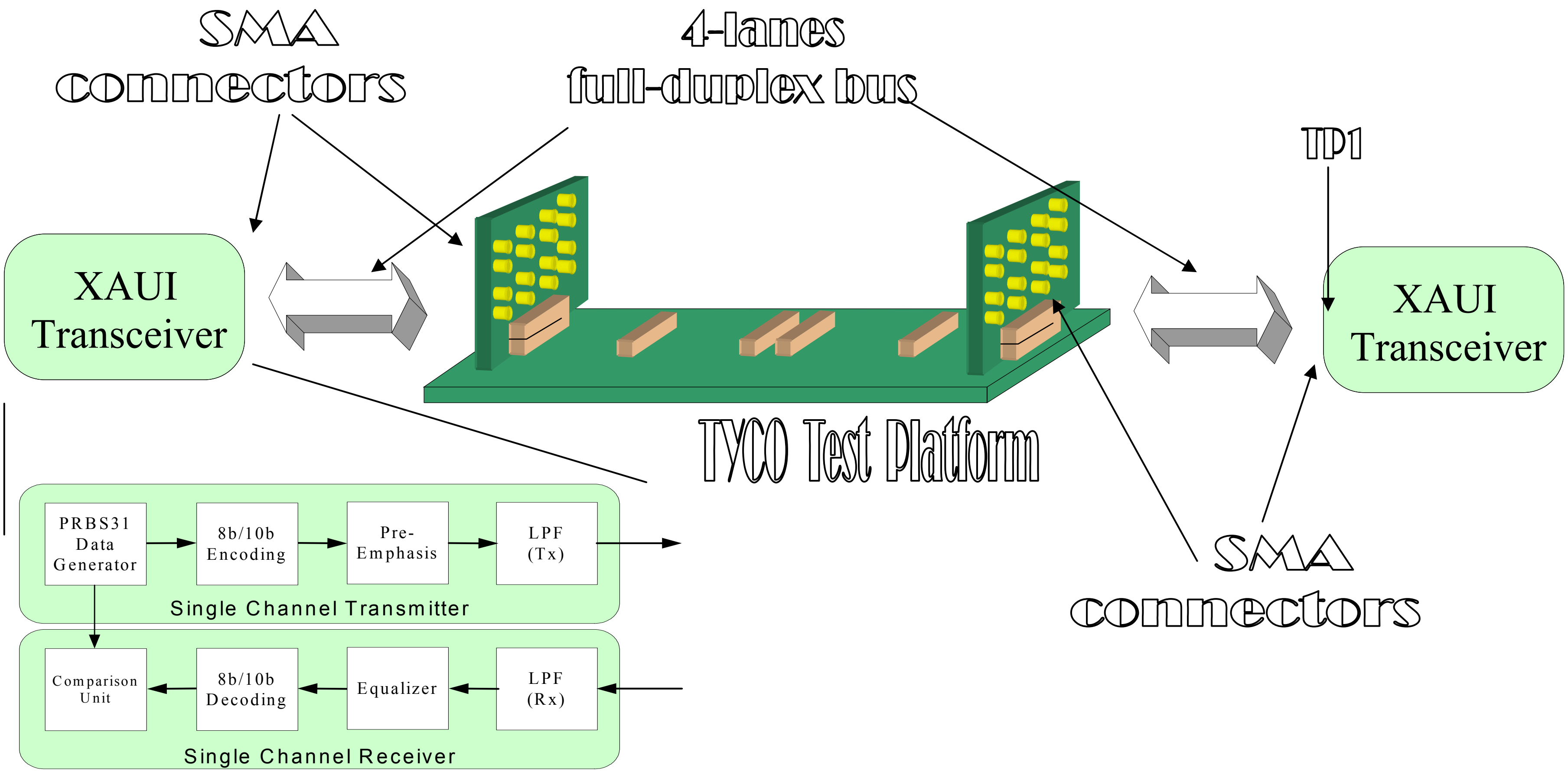
Objectives and Motivation

- Objective 1: define a pre-emphasis level that supports as many backplane interconnect links as possible
- Objective 2: reduce overall system power, improve interoperability, and simplify transceiver design by balancing between Tx and Rx equalization
- Motivation: theoretical and simulation results presented at September interim by gaither_03_0904 and taich_01_0904 showed that moderate amount of pre-emphasis (~3dB) is beneficial to achieve error free operation over long FR-4 traces.

Approach

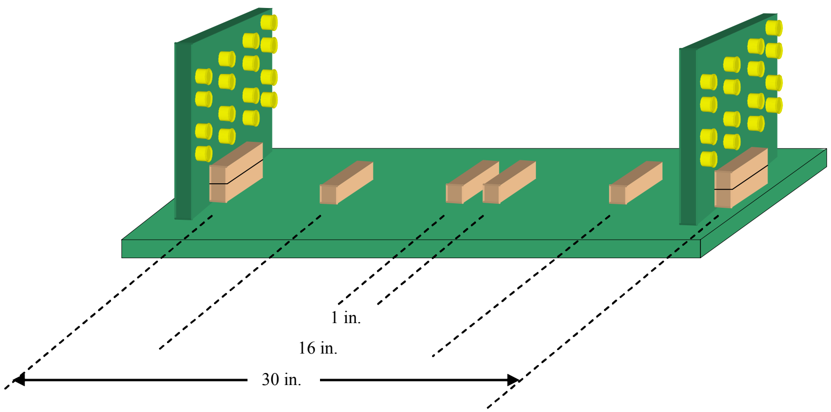
- *BER testing over variety of legacy and new backplanes* is performed using enhanced XAUI-type transceiver with rich set of programmable pre-emphasis and received-side equalization levels.
- While some minimum amount of equalization required to ensure error-free operation over long/low quality legacy traces, short/good quality traces are expected to restrict maximum amount of equalization that can be applied. *Therefore, in real-world system optimal amount of equalization can be found* (sum of the Tx- and Rx-based equalization gains).
- For the sake of selecting proper equalization level, the end-to-end communication link will be treated as approximately linear system
  - RL and Jitter do affect the overall system performance – but have limited affect on the optimal equalization level required for specific type of media

System Description – overview



Data path consists of 2x2" of the FR4 backplane on the Evaluation boards, 4 sets of SMA connectors + ~1m coax cable, 2 SMA-to-HM-Zd line cards (variable lengths) and trace on the backplane.

System setup description: Tyco test platform (Z-PACK HM-Zd)



- *SMA Line Cards 1*
  - Nelco 4000-6
  - 2.5”, 6”, and 10” trace
  - 6 mil trace width, 100 Ω Differential
  - 0.092” thickness
  - 4 Signal layers throughout board

- ***No design optimization.***
- ***No counterboring at any of Z-PACK HM-Zd connector holes***

- ***Platform #1 – HM-Zd XAUI Backplane***
  - Nelco 4000-2
  - 1”, 16”, and 30” traces
  - 10 mil trace width
  - 0.200” thickness, 100 Ω Differential
  - 4 Signal layers throughout board
- ***Platform #2 – HM-Zd QuadRoute Backplane***
  - Nelco 4000-13
  - 2”, 16”, and 30” traces
  - 4.75 mil trace width
  - 0.125” thickness, 100 Ω Differential
  - 8 Signal layers throughout board
    - Same routing capacity as 16 signal layers
- ***Platform #3 – HM-Zd QuadRoute Backplane***
  - Nelco 4000-6
  - 2”, 16”, and 30” traces
  - 4 mil trace width
  - 0.125” thickness, 100Ω Differential
  - 8 Signal layers throughout board
    - Same routing capacity as 16 signal layers

System setup description: testing details

- Full-duplex 4lanes x 3.125G communication link
- Transmit amplitude 800-1200mV p2p dif.
- PRBS of 2^{31}-1 was used as data source for all tests
- Set of TYCO test platforms
- Pass criteria – 5 minutes of the error-free operation – equivalent to ensuring BER<10^{-12} with 95% probability (according UNH IOL calculations)
- Sanity check: few selected configuration were tested for overnight and time frames – which increases results accuracy to 99.(9)
- Pre-emphasis gain values presented as can be measured at TP1.

System setup description: transceivers under test

- 8b/10b coding scheme
- NRZ signaling
- Pre-emphasis levels are programmable in range of 0 – 5dB
  - Pre-emphasis = $20\log_{10}(V_H/V_L)$
- 3 equalization levels were used - with 0, 4 and 5.5dB gain at Nyquist rate vs DC
- Transmitter & Tx package can be modeled as a 2nd order LPF @

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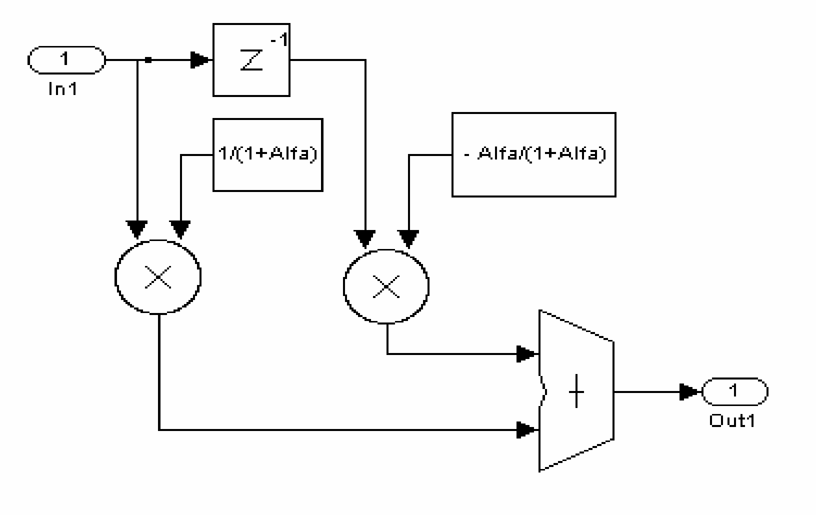
Pre-emphasis & Equalizer



Pre-emphasis filter

$$Hpre(z) = \frac{1}{1+\alpha} - \frac{\alpha}{1+\alpha} z^{-1}$$

Frequency response

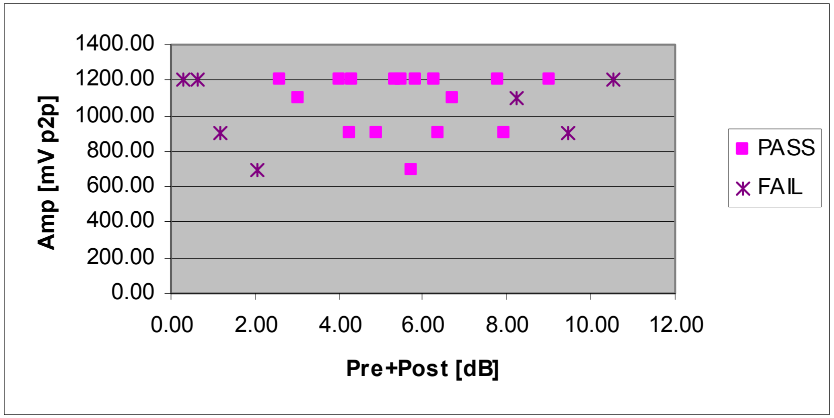
$$|H_{pre}(\theta)|^2 = \frac{1}{(1+\alpha)^2}\left(1 - 2\alpha\cos\theta + \alpha^2\right)$$

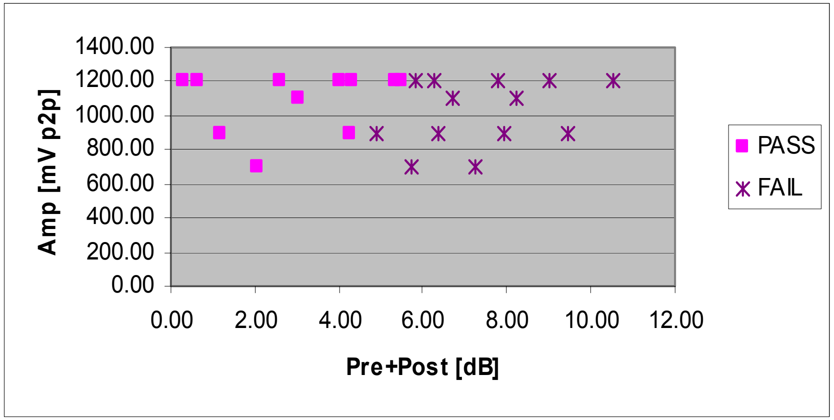
- K - defines the ratio between gain at half the baud rate and the gain at DC (in dB)
- Actually this is a Pre-Emphasis filter that has gain

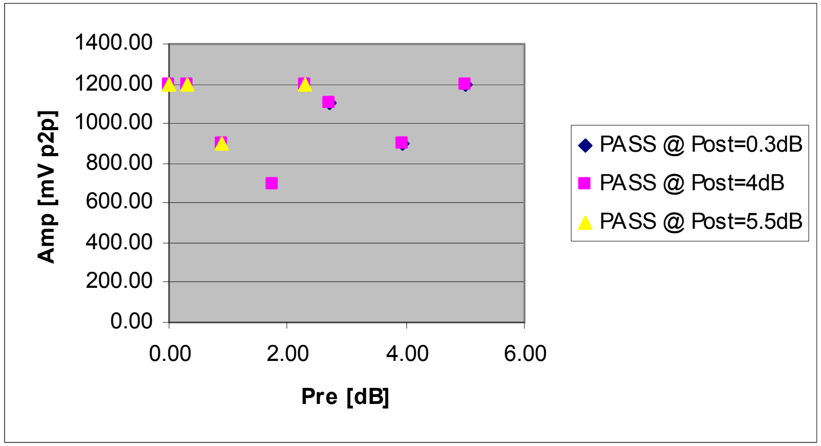
$$Heq(z) = \left(\frac{1}{1+\alpha} - \frac{\alpha}{1+\alpha} z^{-1}\right) * 10^{Gain/20}$$

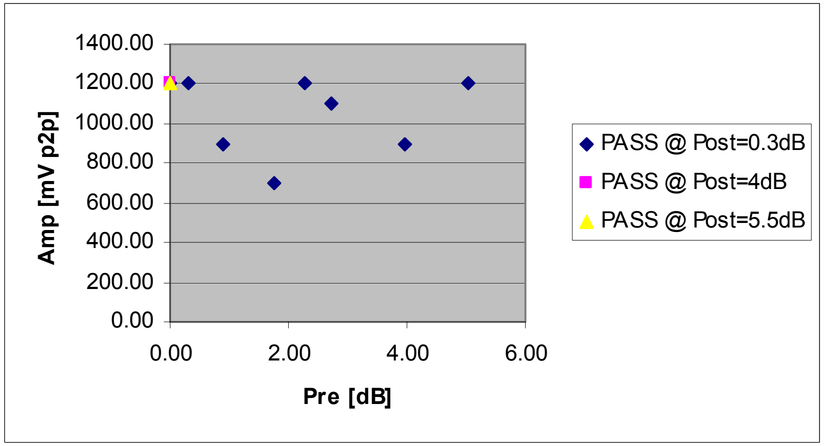
$$\alpha = \frac{10^{K/20} - 1}{10^{K/20} + 1}$$

Test Results – *HM-Zd QuadRoute Backplan* (**Nelco 4000-6)**









10x30x10 configuration

2x2x2 configuration

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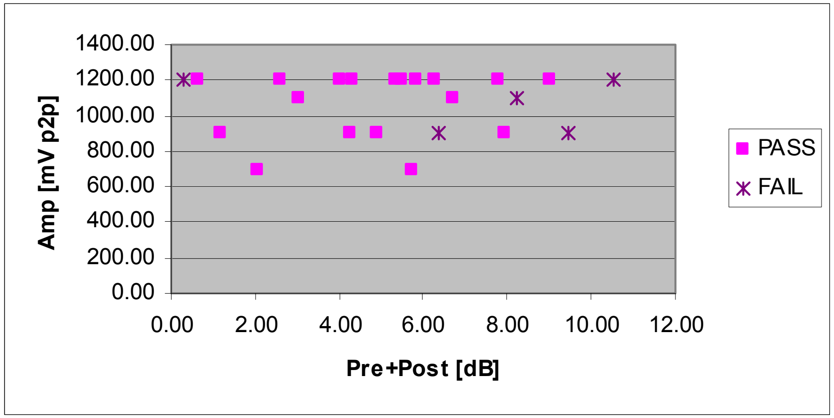
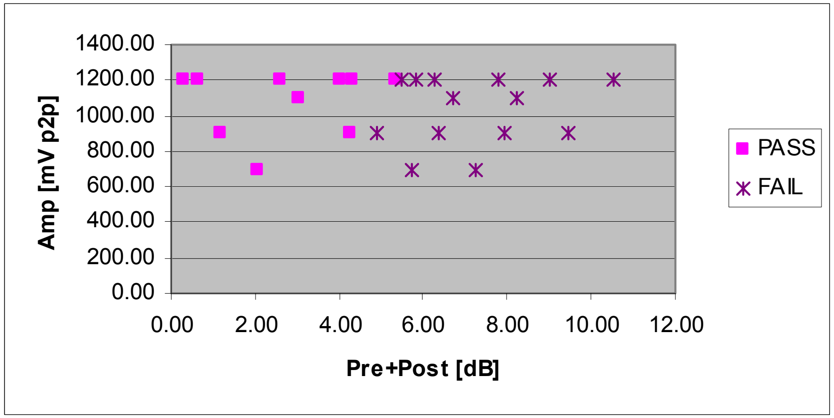
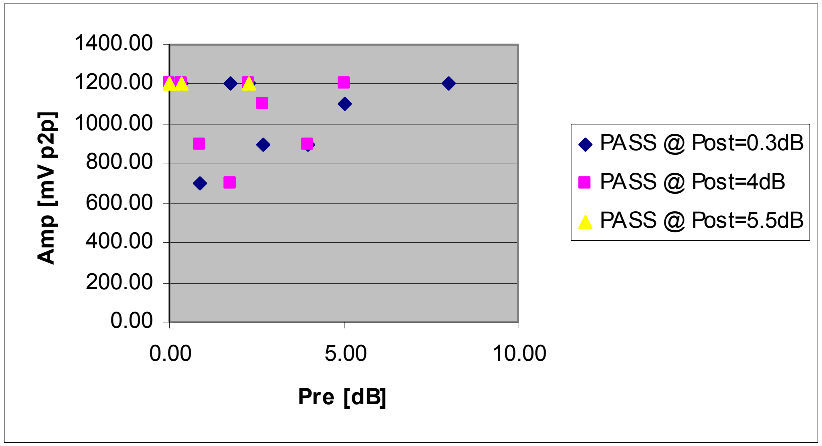
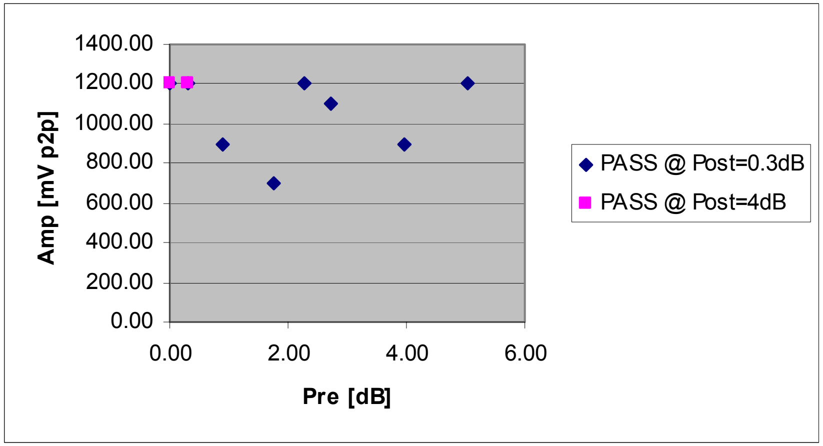
Test Results – *HM-Zd QuadRoute Backplan* (**Nelco 4000-13)**





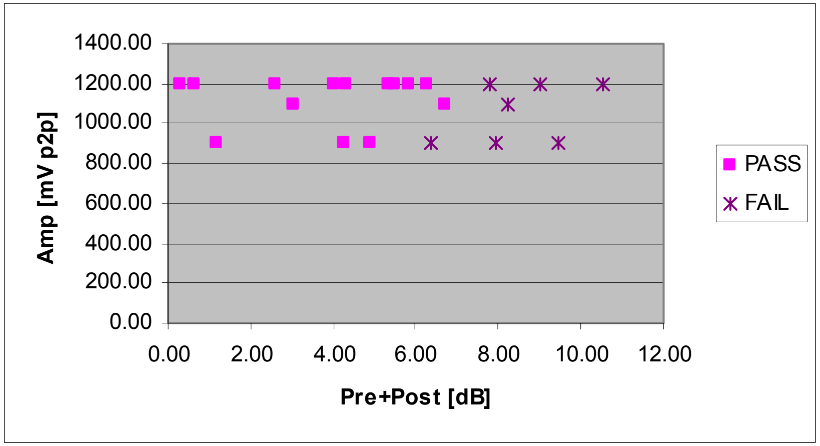


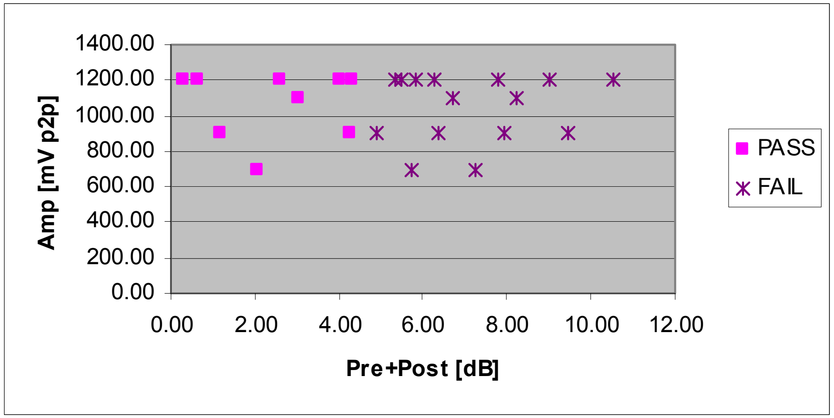


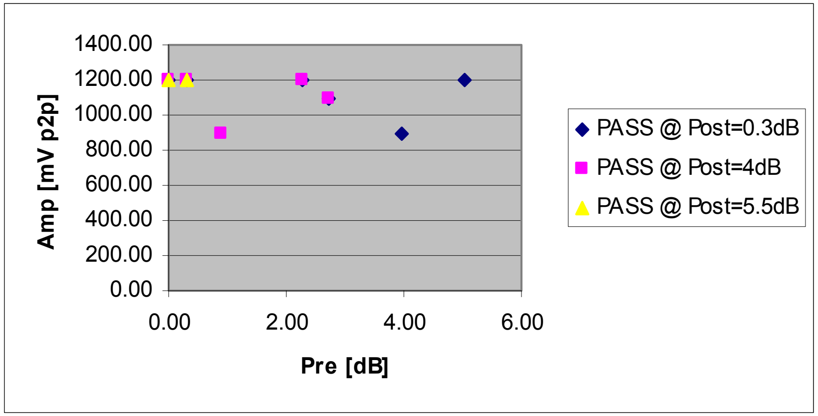
10x30x10 configuration

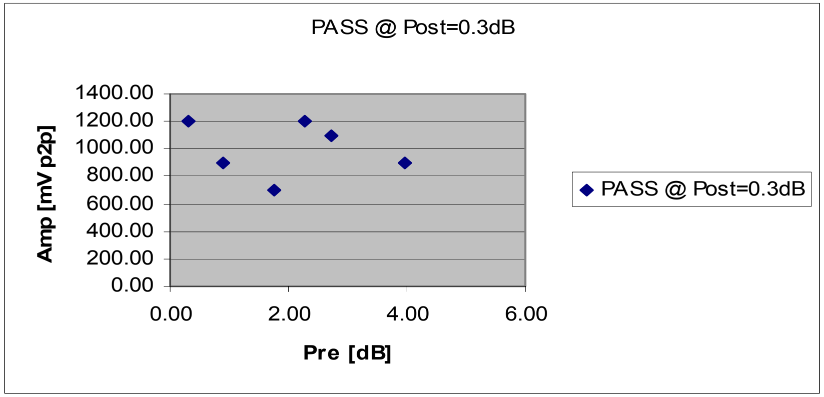
2x2x2 configuration

Test Results – *HM-Zd XAUI Backplane* (**Nelco 4000-2**)







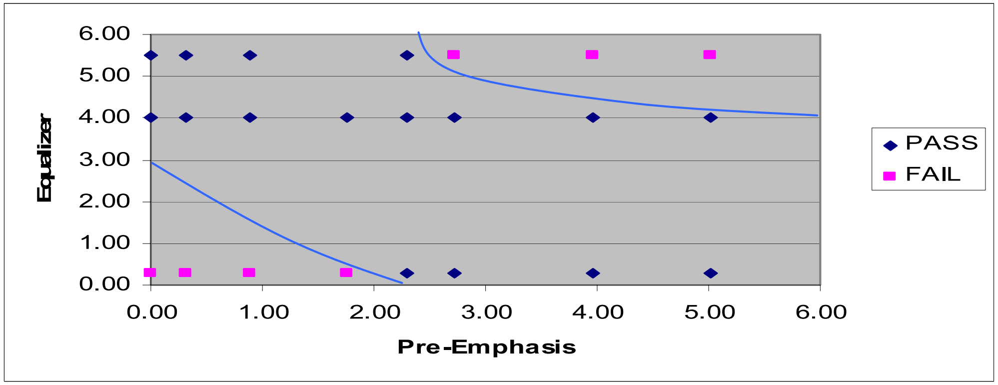


10x30x10 configuration

2x2x1 configuration

Test results – overview

- **6 different configurations have been tested**
- **Due to time constraints, most links were tested for 5 minutes error-free operation**
- **Overnight tests – all resulted in 15 hours error-free operation (BER < 10^{-15})**
  - 10x30x10, Nelco 4000-6 with 3dB equalization gain
  - 10x30x10, Nelco 4000-6 with 6dB equalization gain
  - 10x30x30, Nelco 4000-13 with 1dB equalization gain
  - 2x2x2, Nelco 4000-6 with 4dB equalization gain
  - 2x2x1, Nelco 4000-2 with 2dB equalization gain
- **Although Tx and Rx equalization circuits are not fully interchangeable, it can be seen that overall gain can be used as a good approximation of the min system requirement**



Nelco-4000-6, 10x30x10 conf.

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Test results – summary

	QuadRoute 4000-6		*QuadRoute 4000-13*		XAUI	
Data path Configurations	10x10x30	2x2x2	10x10x30	2x2x2	10x10x30	2x2x1
Min required equalization level	3dB	0dB	0.5dB	0dB	0dB	0dB
Max allowed equalization level	8dB	4dB	6dB	4dB	6dB	4dB

- It has been shown that for legacy backplanes support, moderate level of equalization (up to 3dB) is required
- It has been demonstrated that over-equalized (> 4dB) short channels can fail to meet target BER
- Above results are well correlated with previously reported theoretical calculations and simulation results (taich_01_0904 and geither_03_0904, September interim).

Conclusions

- Fixed amount of pre-emphasis can address whole span of traces and backplanes.
  - Pre-defined Tx side equalization is a well-known parameter – easy to define, easy to test
- Amplitude value has very limited affect on the final results – regardless of chosen pre-emphasis value
- Optional Rx equalizer can be beneficial to ensure good margins numbers and aggressive BER figures.

802.3ak-54.7.3.6 like pre-emphasis proposal

- We recommend to adopt 802.3ak-based procedure (as described in 54.7.3.6) for Tx template testing – with nominal pre-emphasis value of 2.5dB -
  (25% in CX4 terminology → Pre = **1 – V_L/V_H**).
  - Meet equalization requirements for both long and short channels on variety of backplanes – Rx side equalization is optional
  - Well-known, fully defined concept developed for CX4 standard

1) Align the output waveform under test, to achieve the best fit along the horizontal time axis.

2) Calculate the +1 low frequency level as Vlowp = average of any 2 successive unit intervals (2UI) between 2.5UIs and 5.5UI.

3) Calculate the 0 low frequency level as Vlowm = average of any 2 successive unit intervals (2UI) between 7.5UI and 10.5UI.

4) Calculate the vertical offset to be subtracted from the waveform as Voff = (Vlowp + Vlowm)/2.

5) Calculate the vertical normalization factor for the waveform as Vnorm = (Vlowp - Vlowm)/2.

6) Calculate the normalized waveform as: Normalized Waveform = (Original Waveform - Voff) *(**0.75**/Vnorm).

7) Align the normalized output waveform under test, to achieve the best fit along the horizontal time axis.

The only adjustment to be made to CX4 template creation procedure