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Technical Feasibility of Serial 25 Gb/s Signaling over Backplanes: Channel and System Analysis

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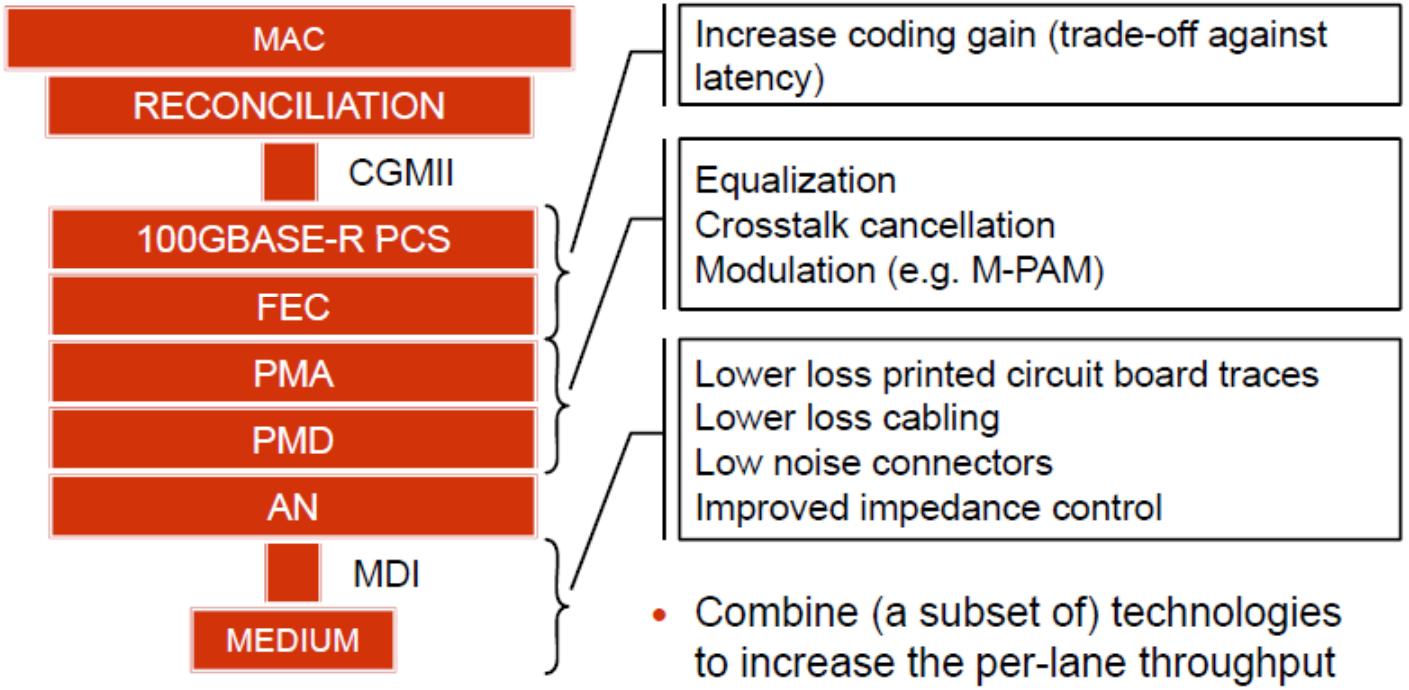
Introduction

- There is a clear demand to develop 25 Gb/s serial over backplane solutions towards higher throughput per lane:
  - Higher port density in servers and data centers.
  - Current trends for chip-chip backplane speeds vary from 19.9 to 25.8 Gb/s/lane.
- Technical & economical feasibility are among major concerns for end users:
  - Signal integrity through 25 Gb/s backplane is hard to achieve with higher insertion losses, distortions, and impairments.
  - Various well-understood technologies such as equalization, multi-level coding schemes, and FEC can be combined to achieve 25 Gb/s.
  - New and higher-cost channel materials and connectors with improved signal integrity are in development by industry.
  - Technical solutions, while feasible, should make economic sense (power/complexity/cost/latency).

Considering Technology Enablers

Potential enablers for more Gb/s/lane

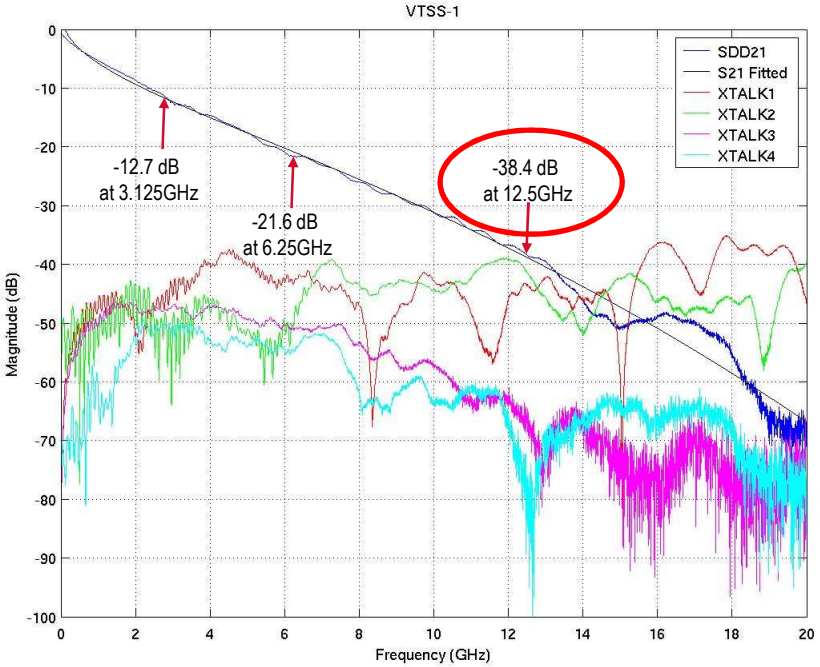


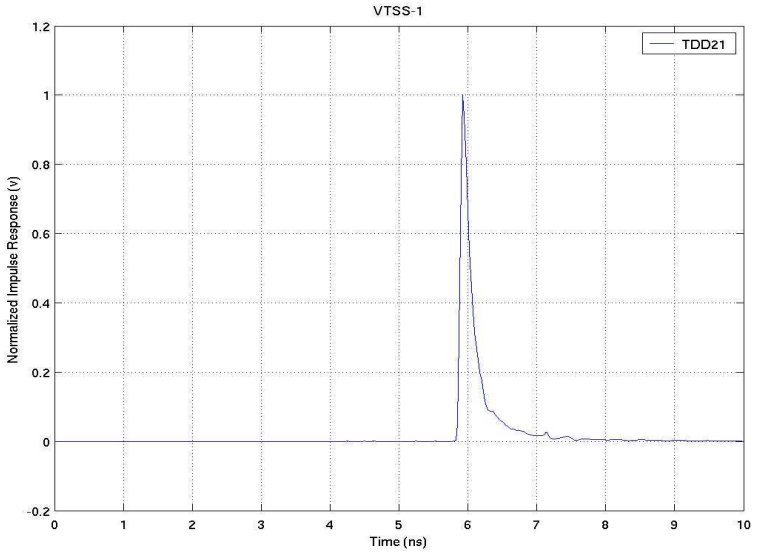
- Combine (a subset of) technologies to increase the per-lane throughput

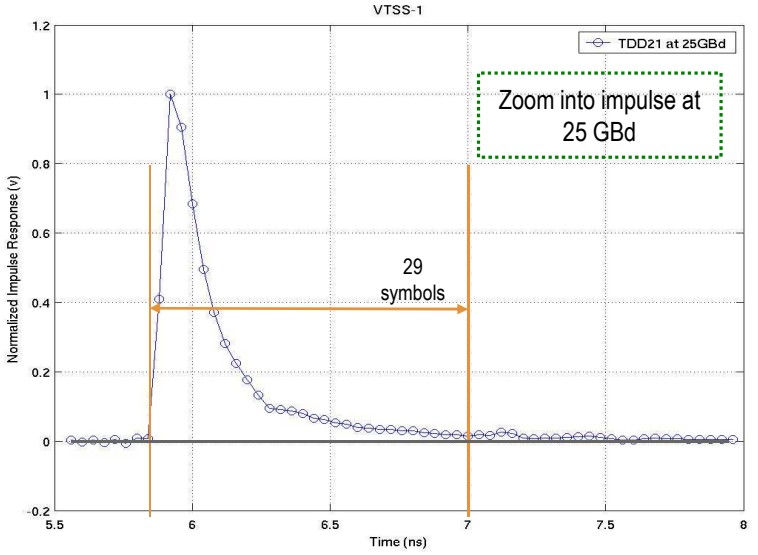
25 Gb/s Backplane Channels: Initial Insight

- The Study Group should first reach consensus on clear objectives regarding the reference channel models based on end users' input.
- Early visibility into 25 Gb/s backplane channels reveals 2 categories:
  - Legacy 10 Gb/s designs
    - Long lengths (≈ 30")
    - 10G-generation trace material
    - 10G-generation connectors
    - Example case study: VTSS-1
  - New/Upgraded designs
    - Intermediate and short lengths (≈ 20" and 10")
    - Backwards compatible
    - 10G-generation trace material
    - Improved connectors
    - Example case study: VTSS-2 and VTSS-3

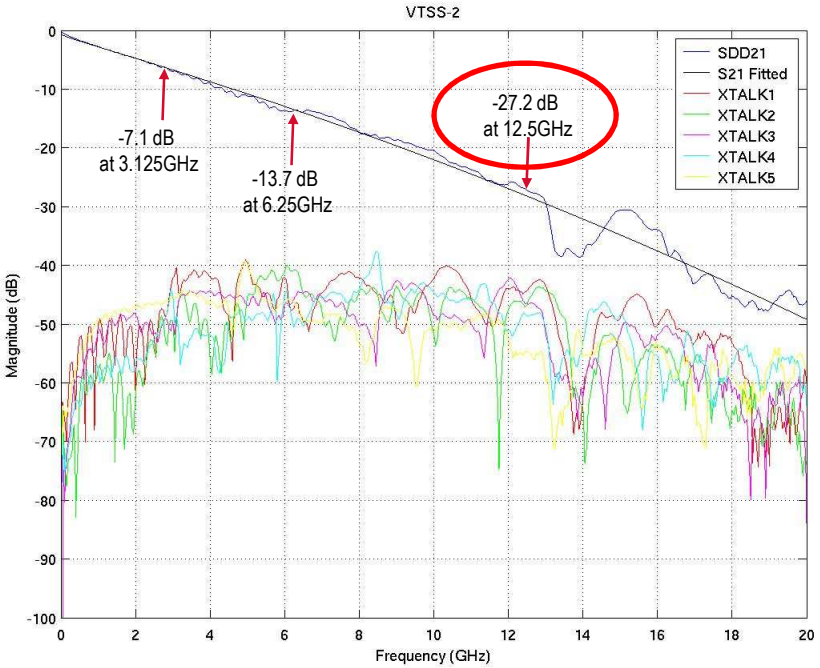
Backplane Channel: VTSS-1 (LR Traces)

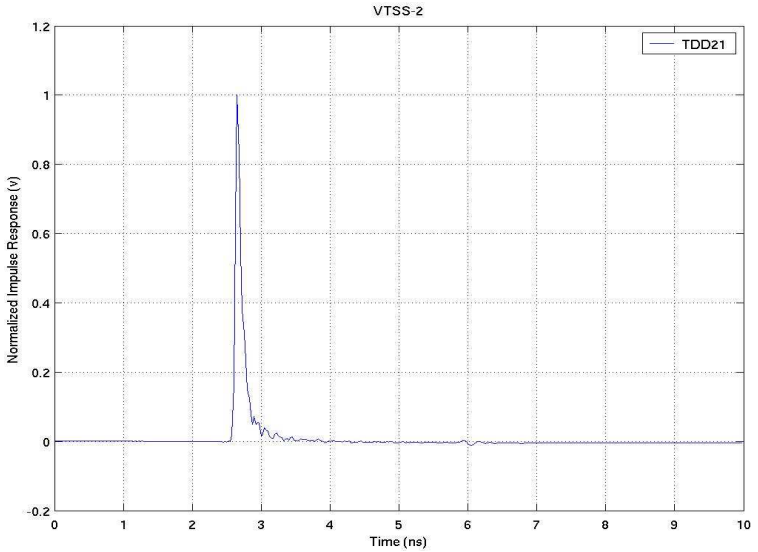


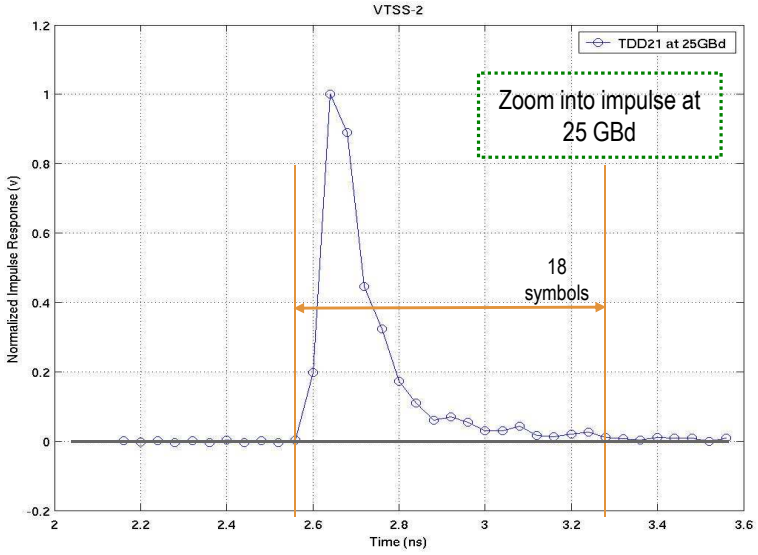




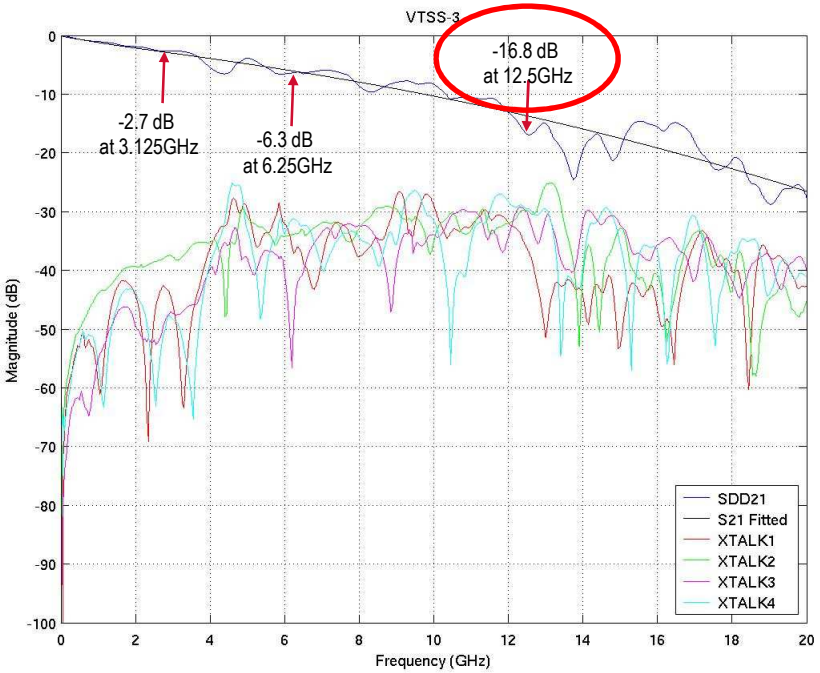
Backplane Channel: VTSS-2 (IR Traces)

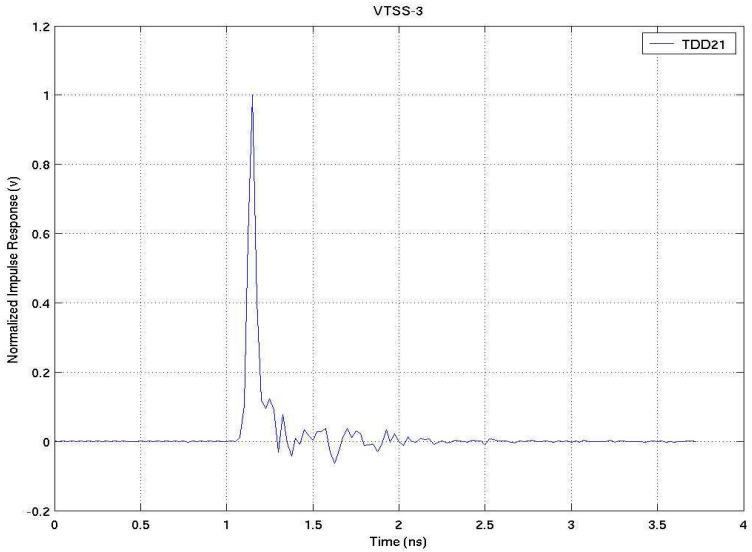


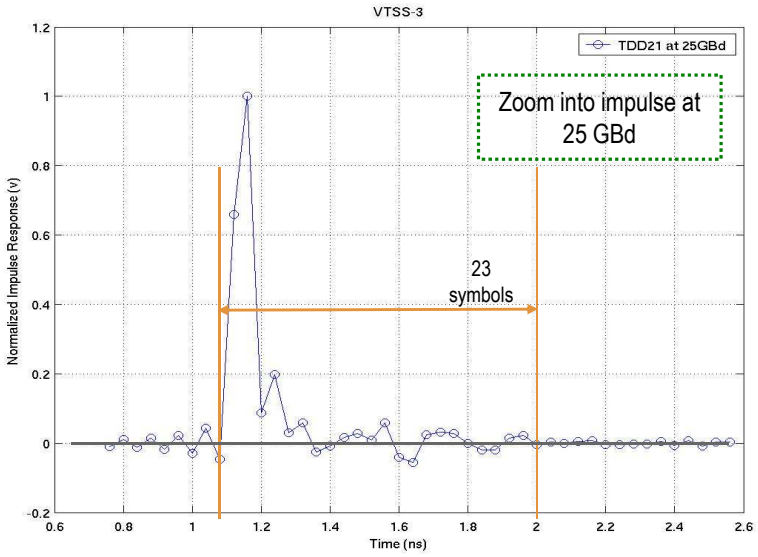




Backplane Channel: VTSS-3 (SR Traces)







Equalization and Modulation

- Equalization Requirements:
  - Approximate equalizer size derived from impulse responses sampled at 25GHz:
    - Legacy designs: ≈ 25 equalizer taps
    - Upgraded designs: ≈ 20 equalizer taps
  - Rx equalizer only.
  - Combination of Tx equalizer and Rx equalizer.
- Potential Line Codes to Consider and Compare:
  - NRZ:
    - Viable with next-generation trace materials and connectors.
  - Duobinary:
    - Potentially outperform NRZ coding at high data rates with similar complexities.
  - PAM-4:
    - More complex coding scheme at half the baud rate.
- Ultimately, time-domain simulations are required to determine best equalization and to compare line codes.

Criteria for Line Code Comparisons

- When comparing multi-level and NRZ codes using time-domain simulations, pay attention to:
  - Transmit Power:
    - Same V_{pp} : NRZ at a launch power advantage.
    - Same V_{RMS} : all line codes should have similar TX launch power.
  - Equalizer Convergence: Different modulation schemes tend to have different adaptive (LMS) equalizer convergence rates. Use ideal (LS/MMSE) equalizer results in conjunction with LMS equalizer results, especially on difficult channels requiring long simulation time for convergence.
  - Signal to Noise ratio (SNR): absolute SNRs are irrelevant, compare SNR margins at given BER:

    $SNR_{margin} = SNR_{actual} - SNR_{required}$

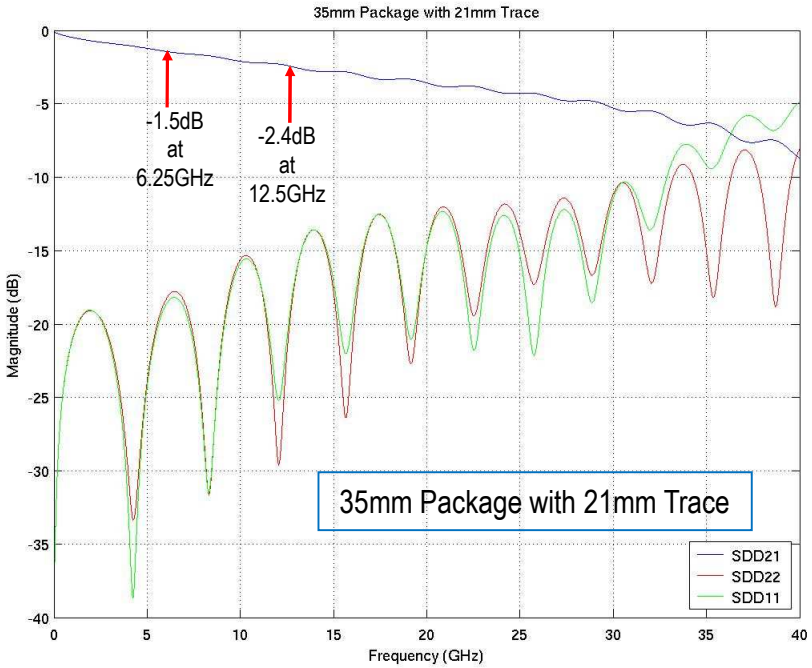
Line Code Summary

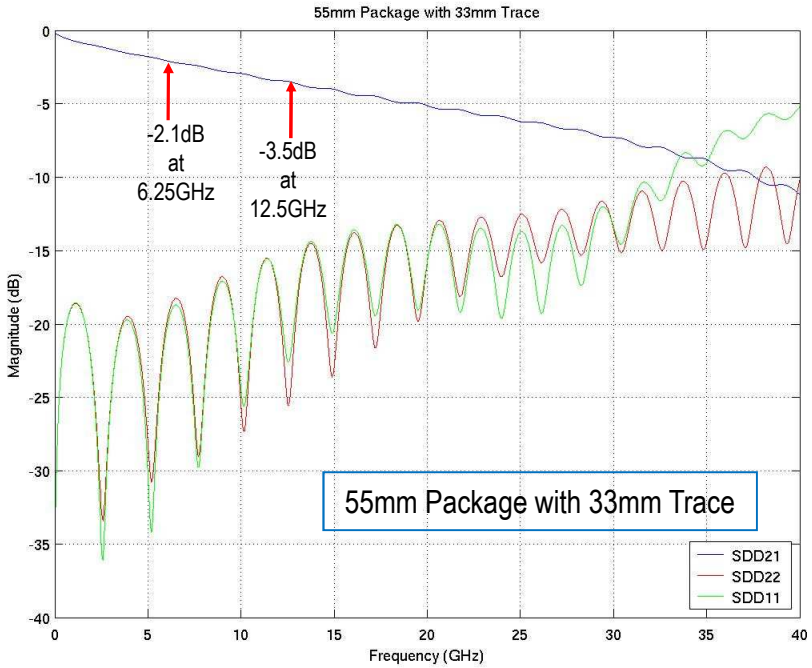
Line Code	Bit Rate (Gb/s)	Symbol Alphabet (a_K)	Tx V_{PP} (v)	Tx V_{RMS} (v)	Baud Rate (GHz)	Nyquist freq. (GHz)	Approx. VTSS-1 channel loss at Nyquist (dB)	Rx Slicers
NRZ	25	{±1}	2	1	25	12.5	-38.4	1
Duobinary	25	{±1,0}	2	0.5	25	12.5	-38.4	2
PAM-4	25	{±1,±1/3}	2	0.56	12.5	6.25	-21.6	3

FEC and Crosstalk Cancellation

- Forward Error Correction (FEC)
  - Burst-Error-Correcting codes provide 2-3 dB of net electrical coding gain (NECG):
    - Low-latency and low-power (Fire/cyclic codes).
    - Common implementation handles single bursts.
    - Example: 10GBASE-KR FEC
  - Burst-and-Random-Error-Correcting codes provide 5-7 dB NECG:
    - Higher latency and higher power/complexity (Reed-Solomon codes, BCH codes, concatenated codes, etc.)
    - Example: RS(255,239) FEC
  - Enhanced Burst-and-Random-Error-Correcting codes provide >7 dB NECG:
    - LDPC, Turbo Codes, Interleaved codes, etc.
    - Example: G.975 codes such as Vitesse CI-BCH FEC
- Crosstalk Cancellation
  - Crosstalk canceller block requires access to aggressor waveforms:
    - Better suited for near-end crosstalk cancellation.
    - For some applications, NEXT is no longer an issue because of physical separation at pin-out level.
    - Of concern at these rates is package crosstalk.

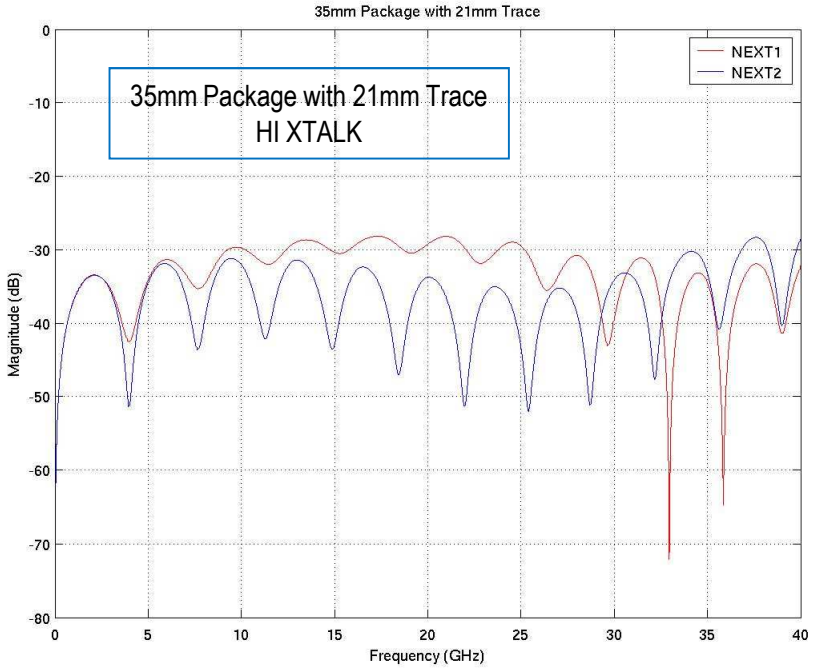
Package Models: Insertion Loss and Return Loss

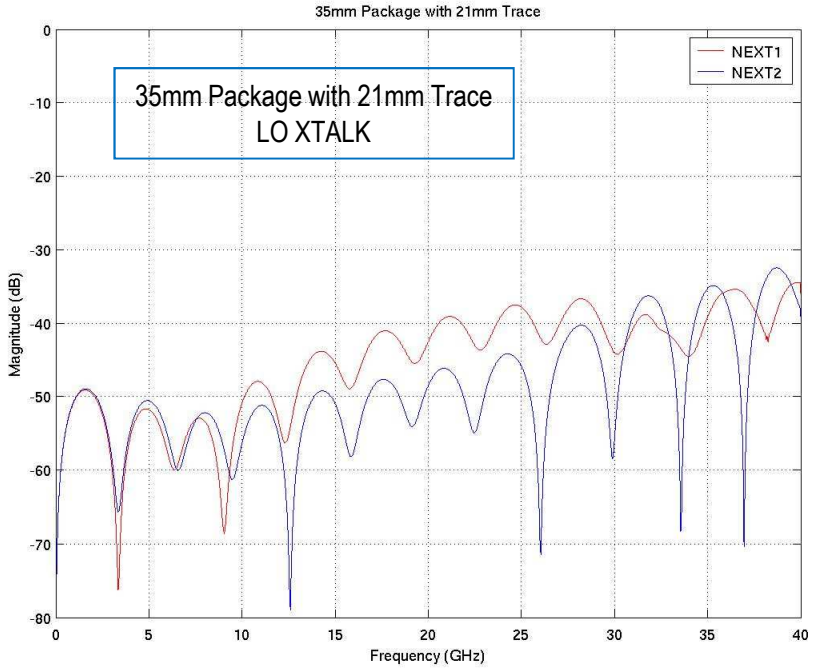


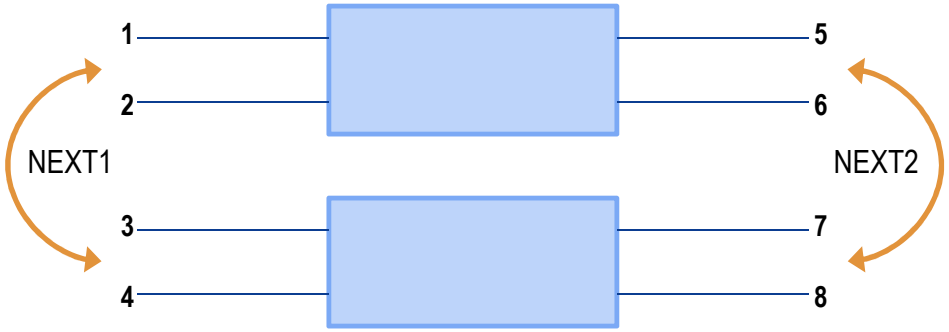


- At 25 Gb/s serial over backplanes, packaging insertion loss, return loss, and possibly crosstalk become important factors:
  - Package IL favors multi-level line codes.
  - Package RL not as deterministic and has large variations.
  - Package models above provided courtesy of IBM:
    - www.ieee802.org/3/ba/public/tools/PkgModels40GHz.zip

Package Models: Crosstalk







Conclusions

- Strong market demand for 25 Gb/s serial over backplanes.
- The Study Group should first reach consensus on clear objectives regarding the reference channel models based on end users' input:
  - Current Vitesse backplane channels limited to 30'' in length with mostly 10G-era components.
- It is technically feasible to transmit 25Gb/s serial over backplanes:
  - Multi-level coding techniques need to be considered in addition to NRZ:
    - The pro and cons of various line coding schemes need to be carefully taken into account.
    - When comparing NRZ and multi-level coding schemes, keep playing field as leveled as possible.
  - Consider economic feasibility.
- Need to specify package models for specific process node:
  - At 25 Gb/s serial over backplanes, packaging insertion loss, return loss, and possibly crosstalk become important factors.
- FEC will most likely be needed:
  - Mandatory or optional depending on line code and channel reach.
  - Investigate codes with "mid-range" NECGs (3-5 dB) while keeping latency low.