

Presentation to IEEE P802.3ap Backplane Ethernet Task Force September 2004 Working Session

Title: **Simulation Results on Proposed Signaling Ad-hoc Test Channels**

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Abstract: This contribution provides simulation results of performance analysis across the set of test channels proposed for use by the signaling ad-hoc. Simulations are performed using a full function simulator which constructs a complete end to end transceiver-package-channel-package-transceiver model.

Simulation Approach

Use internally available IBM simulator for analysis of Tyco channels

- ▶ Tool models advanced equalization approaches including NRZ/DFE & PAM4 architectures
- ▶ Tool and associated models have gone through extensive hardware to model correlation
 - NRZ/DFE designs operating up to 6.25Gbps
 - Hardware to model correlation across process, temperature, & voltage

Appropriately configure simulator for analysis at 10.3Gbps

- ▶ Configure simulator for worst case parameters proposed to 10G EoBP standard

Include analysis of 2 representative package types

- ▶ Organic & flip chip plastic

Perform analysis across full set of test channels proposed to signaling ad-hoc

- ▶ Include all cross-talk channels in analysis
- ▶ Evaluate range of FFE/DFE architectures which would support the various channels

Summary

Validation of Existing DFECDR Simulator

Feature rich simulator developed over several years

- ▶ Developed for 6.25Gbps serdes architecture validation
 - Required for analysis of advanced equalization techniques & CDR architectures
- ▶ Continually updated with additional features and improved coverage of secondary performance effects
 - Used for development of multiple link types within IBM Research & Development community
- ▶ Distributed as customer tool for system level verification
 - Today used by dozens of customers evaluating a variety of applications

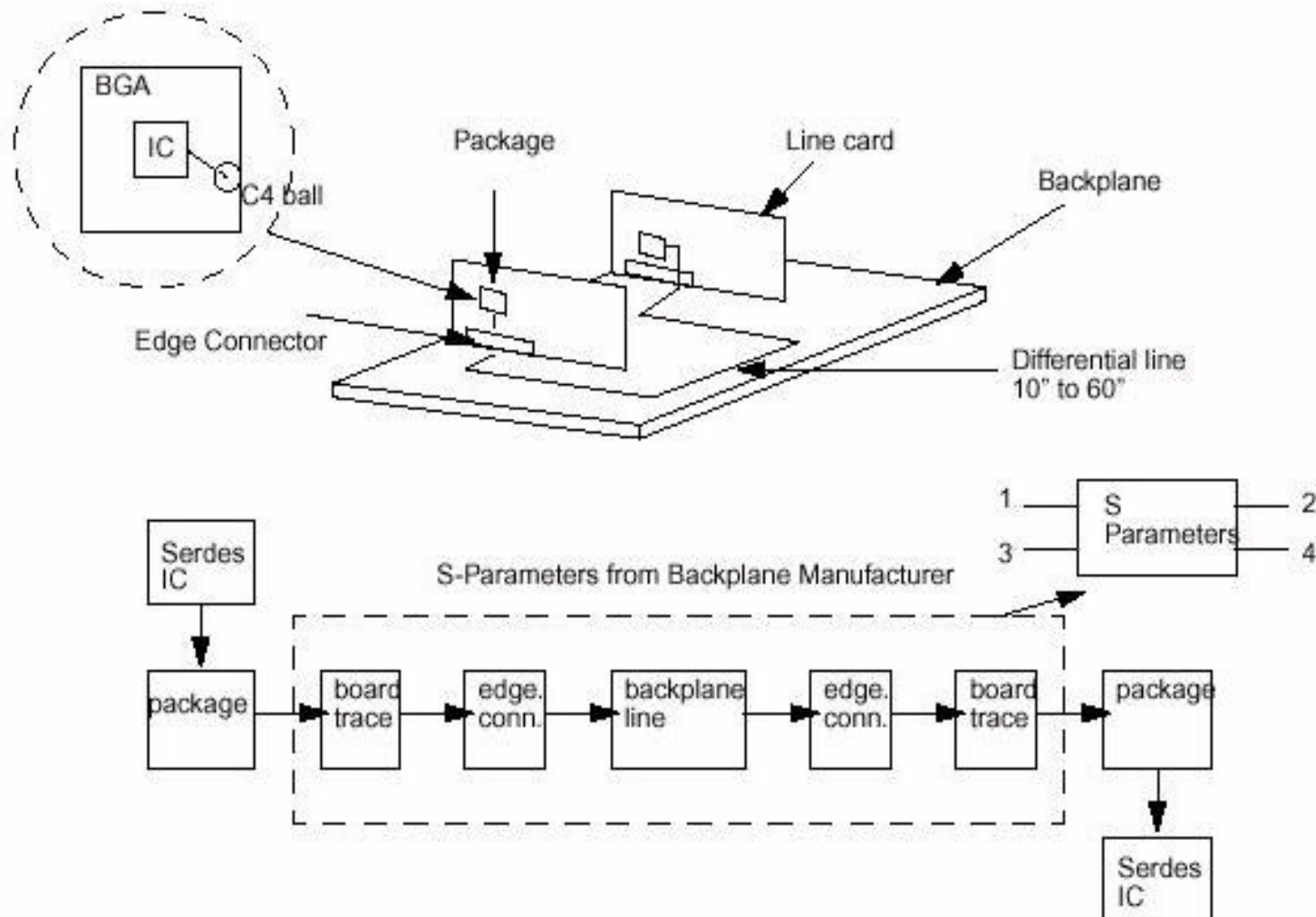
NRZ/DFE architecture fully validated in hardware

- ▶ 6.25 Gbps 4-tap FFE, 5-tap DFE based serdes in IBM 0.13um technology available since last year
- ▶ System level performance ($BER < 10^{-15}$) demonstrated on a multitude of channel types
 - Severely attenuated channels in the range of 30dB to 35dB loss
 - Channels in the range of 25dB to 30dB loss along with severe discontinuities or high crosstalk

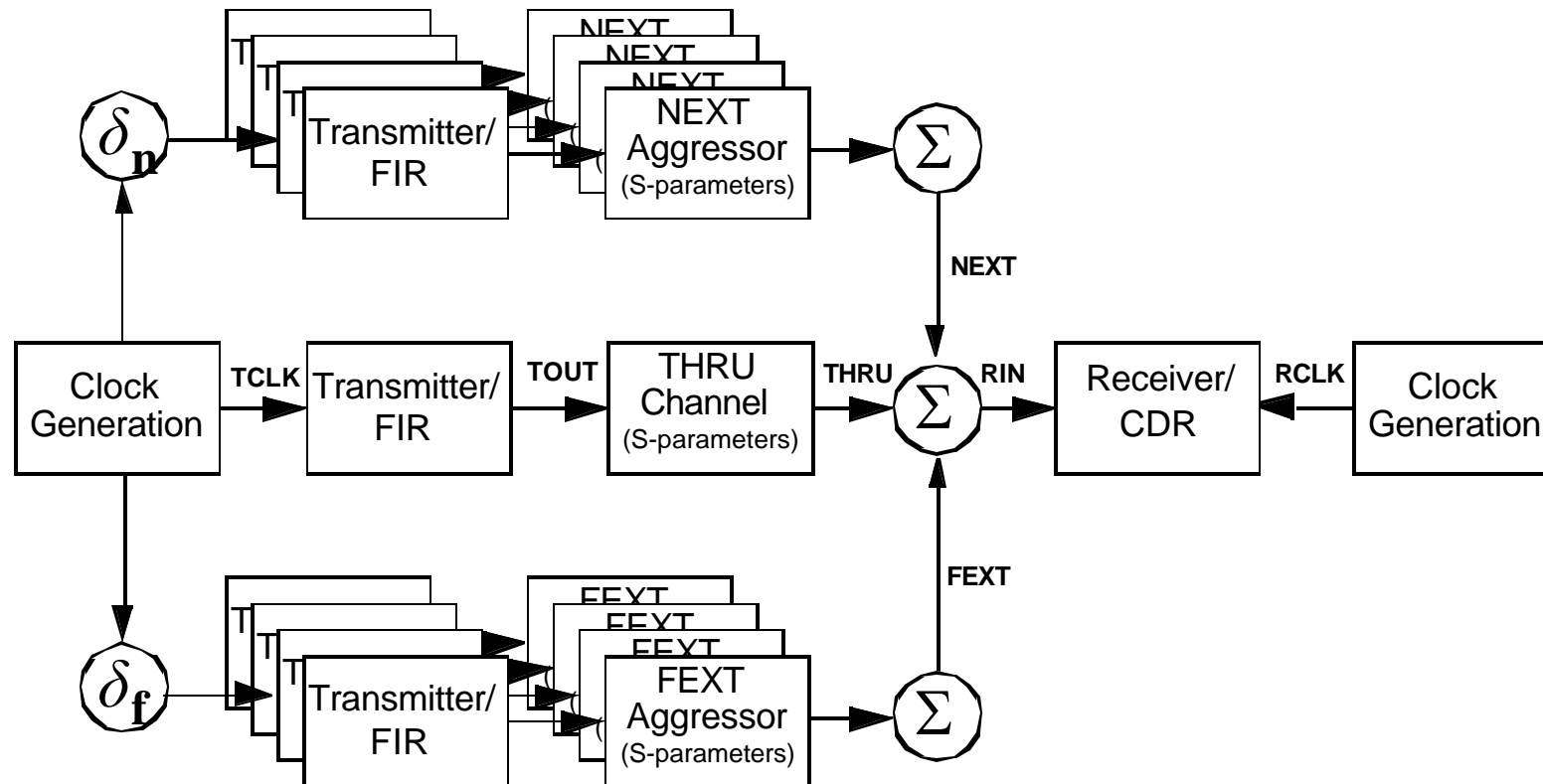
Simulator fully correlated to hardware across corner conditions

- ▶ Simulator includes extracted parasitics from design base
 - Extractions across nominal, worst case, and best case process variation
 - Extractions across range of equalizer & launch voltage settings
- ▶ All serdes designs are built & characterized with split lot process corners
 - 3-way threshold voltage (V_t) & 5-way delta-L (poly length) splits
 - Full characterization performed across process, temperature, & voltage
- ▶ Simulator successfully correlated to hardware characterization
 - Across best case, worst case, and nominal conditions
 - Done for multiple design points and serdes architectures

DFECDR High Level Simulation Structure:



High Level Simulation Structure:



Simulator Feature Summary

A complete end to end system model is constructed

- ▶ Transmitter model and termination network
 - including extracted parasitics for bc, nc, wc options
- ▶ Package + C4 + module ball parasitics
- ▶ Channel model S-parameter representation
 - Optional crosstalk aggressor S-parameter models
- ▶ Package + C4 + module ball parasitics
- ▶ Full receiver model
 - Receiver model and termination network, including extracted bc, nc, wc parasitics
 - AGC Amplifier
 - DFE summing amplifiers
 - Complete model of CDR algorithm

The tool includes simulation of the following performance detractors:

- ▶ Channel Impairments (DJ/ISI)
 - Derived directly from channel S-parameters
- ▶ Circuit Impairments
 - Sinusoidal Jitter (SJ): accounts for external SJ modulation as well as Tx DCD and system DJ
 - Random Jitter (RJ): one sigma RJ term representing the RMS of Tx and Rx RJ.
 - Amplitude Noise: one sigma RMS voltage noise referred to receiver input
 - Minimum Latch Overdrive: loss in eye opening due to latch overdrive (level resolution concern)

Simulator Feature Summary...

The tool incorporates an algorithm to compute optimal FFE & DFE coefficients

- ▶ Based on channel characteristics
- ▶ Optimizes system performance in presence of crosstalk

Configuration of key system parameters to evaluate varied performance scenarios

- ▶ Data coding
 - PRBS7, CJTPAT, JTPAT, CRPAT, RPAT, CSPAT, SPAT, ALT10 (1010..), Random 8B/10B, User specified...
- ▶ Transceiver configuration
 - Baud rate
 - Driver level amplitude
 - FFE/DFE configuration
 - Optional coefficient override
- ▶ Jitter controls
 - RJ, SJ, amplitude noise, latch min overdrive, etc.
- ▶ Runtime options
 - Runlength, settle length, etc.

Numerous output plot options

- ▶ Frequency Response, Impulse Response, Eye diagram, NRZ eye,
- ▶ Horizontal and Vertical CDF, Phase rotator tracking, text performance summary

Configuration for NRZ Simulations

Configure for worst case (expected) standard definition

- ▶ Launch amplitude set to minimum 800 mVpp
- ▶ Transmitter DJ set to maximum 0.15 UIpp
- ▶ Transmitter RJ set to maximum 0.0107 UIrms (0.15UIpp @ 10^{-12} BER)
- ▶ Tx/Rx termination skewed to maximum tolerance 4040/6060 ohms

Conservatively model receiver implementation

- ▶ Receiver DJ in addition to termination parasitics 0.05 UIpp
- ▶ Receiver RJ set to maximum 0.0107 UIrms (0.15UIpp @ 10^{-12} BER)

Approximate parasitics for worst case 12Gbps implementation

- ▶ Use nominal case parasitics from 6Gbps design in 0.13um technology
 - Extracted parasitics for 12Gbps implementation are not available
 - These parasitics considered highly conservative relative to WC parasitics of 90nm 12Gbps design

Configure system parameters

- ▶ Data rate: 10.3 Gbps
- ▶ Receiver offset: 200 ppm
- ▶ Data pattern: Random
- ▶ Use all cross talk channels for each test case
- ▶ Vary FFE/DFE configuration across runs
 - FFE2 as single post-cursor
 - FFE3 & FFE4 includes a single pre-cursor
- ▶ Run test suite across 2 package types (organic & flip chip plastic)
- ▶ 10M bit simulation time per testcase

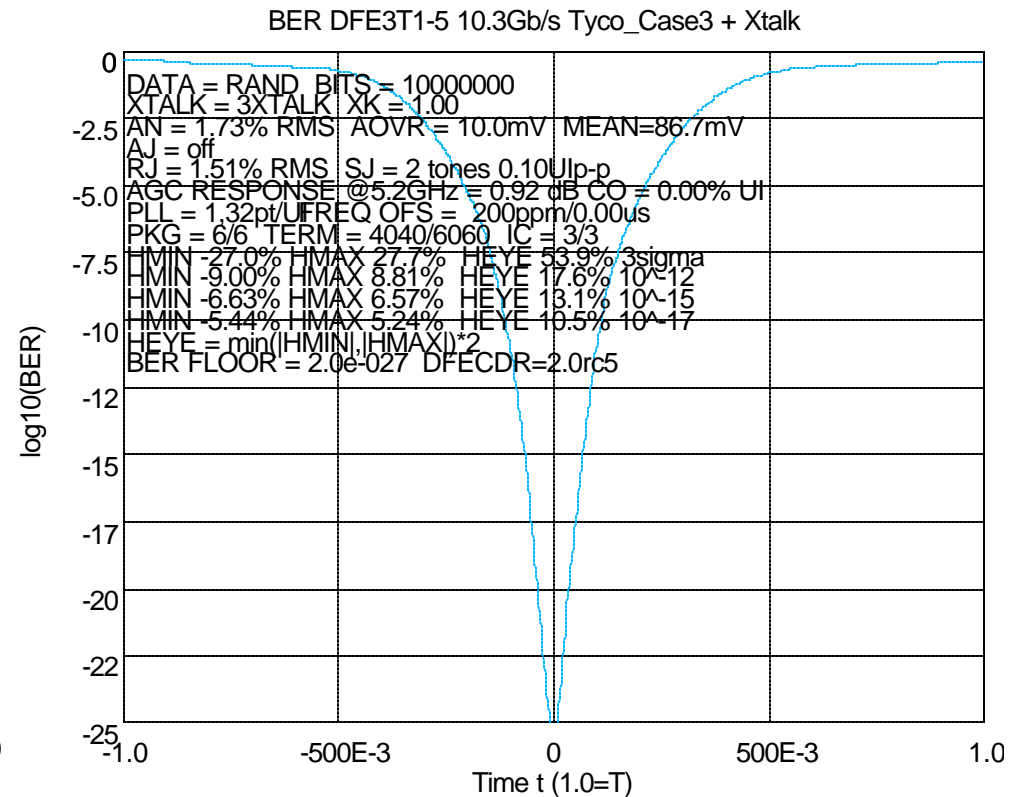
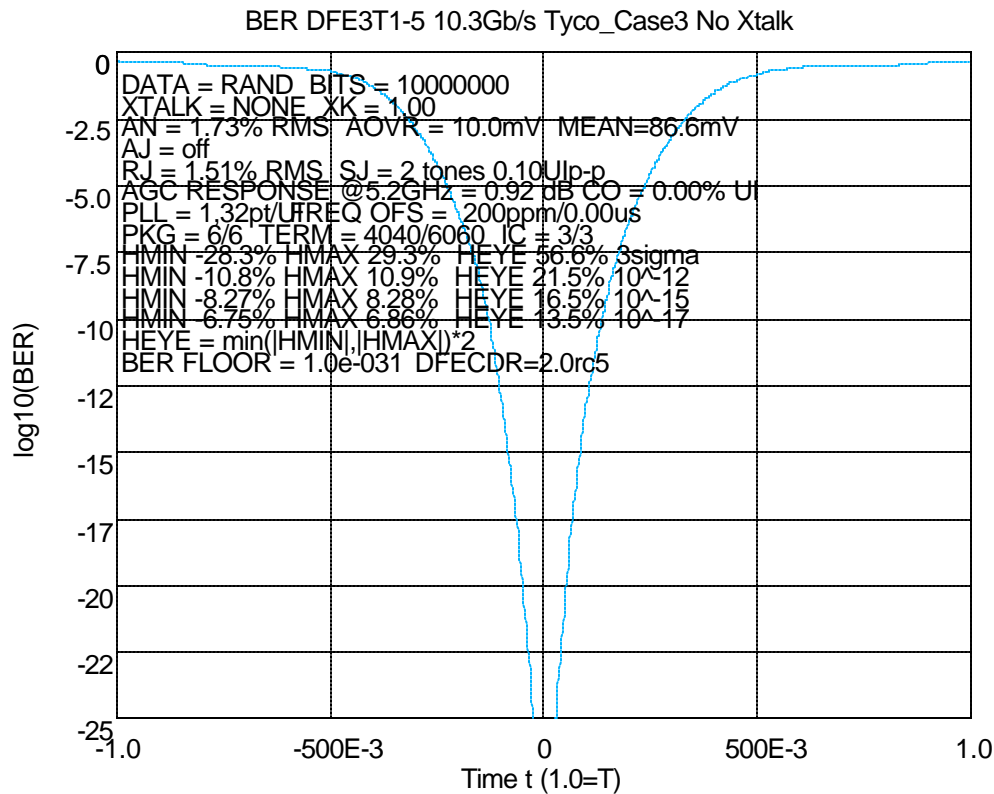
Example Output

Tyco Channel Case #3

- Organic package
- FFE3/DFE5 Configuration

Without Crosstalk
21.5% open @ BER 10⁻¹²

With Crosstalk
17.6% open @ BER 10⁻¹²

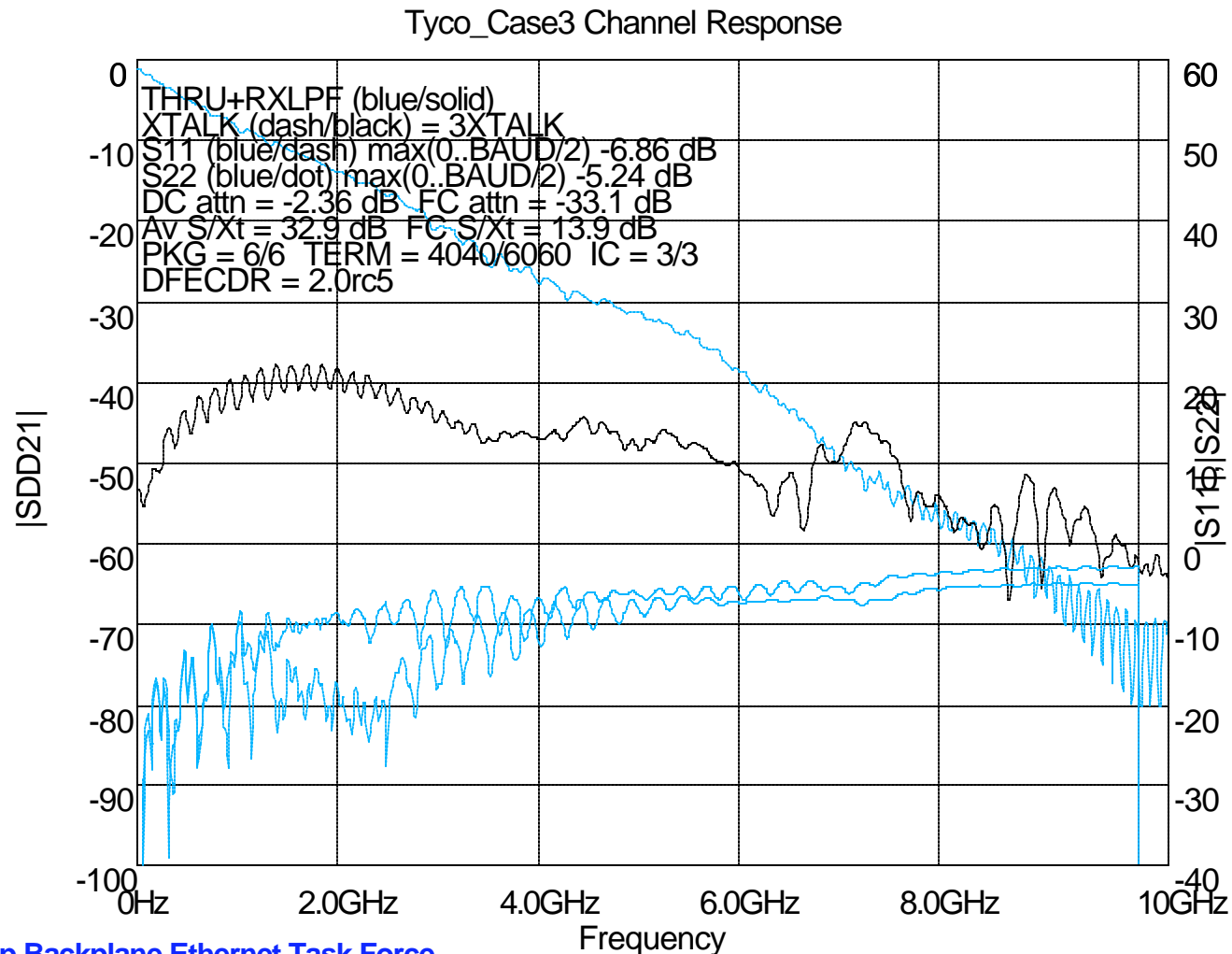


Organic Package



Effects of package on overall channel model

- ▶ Shown for Testcase #3 (Margin case somewhat below the proposed model from channel ad-hoc)
- ▶ Attenuation drops significantly
 - Raw channel down 27dB at fundamental frequency
 - Package and module parasitics drops this to -33.1dB at fundamental frequency!



Case 1 with Organic Package

Simulation Results* (opening at 10^{-12} BER)

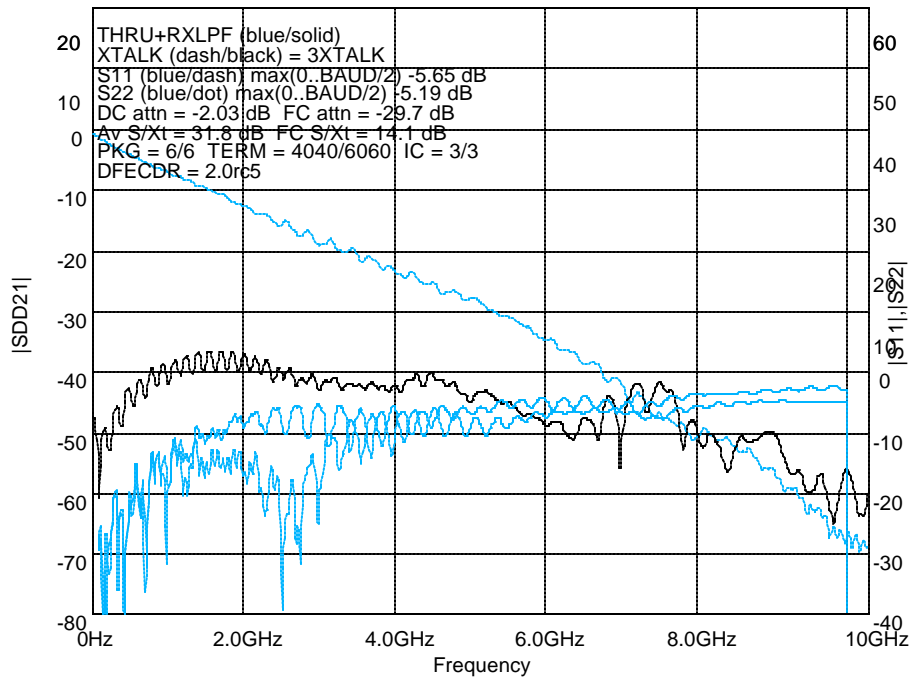
	FFE2	FFE3	FFE4
DFE0	e-4	e-5	e-4
DFE1	e-6	16.2%	10.4%
DFE2	e-8	23.4%	15.1%
DFE3	14.9%	21.8%	16.2%
DFE4	13.0%	21.8%	21.0%
DFE5	18.7%	22.0%	20.9%

Summary

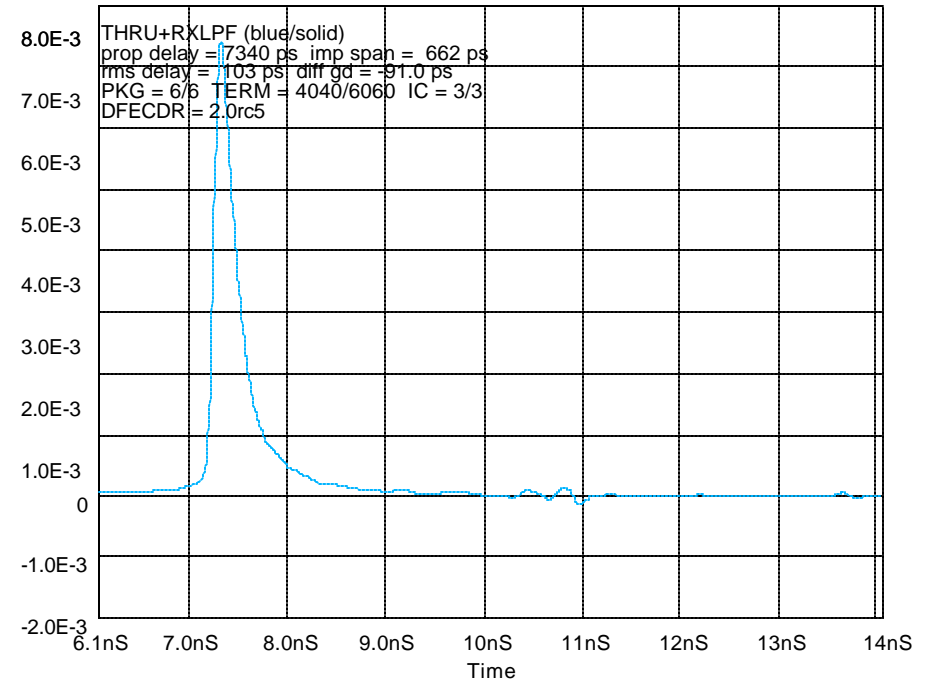
- ▶ Channel response -29.7dB
- ▶ Impulse response is clean
- ▶ Min solution FFE3DFE1

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Case 2 with Organic Package

Simulation Results* (opening at 10^{-12} BER)

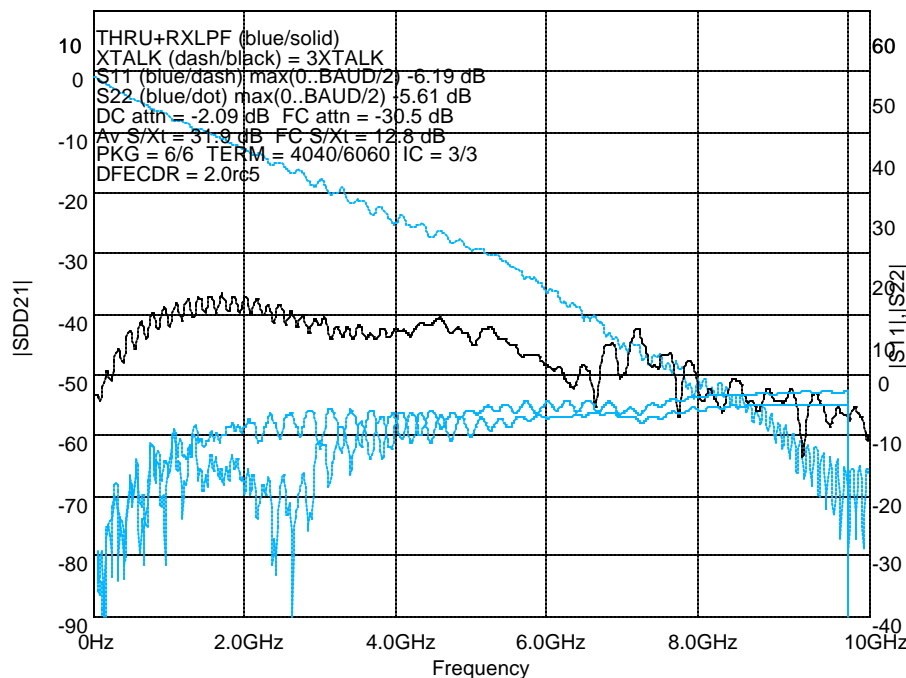
	FFE2	FFE3	FFE4
DFE0	e-3	e-4	e-4
DFE1	e-5	10.6%	15.1%
DFE2	e-7	12.8%	18.8%
DFE3	0.4%	12.8%	16.2%
DFE4	0.1%	17.8%	17.2%
DFE5	11.2%	21.0%	17.7%

Summary

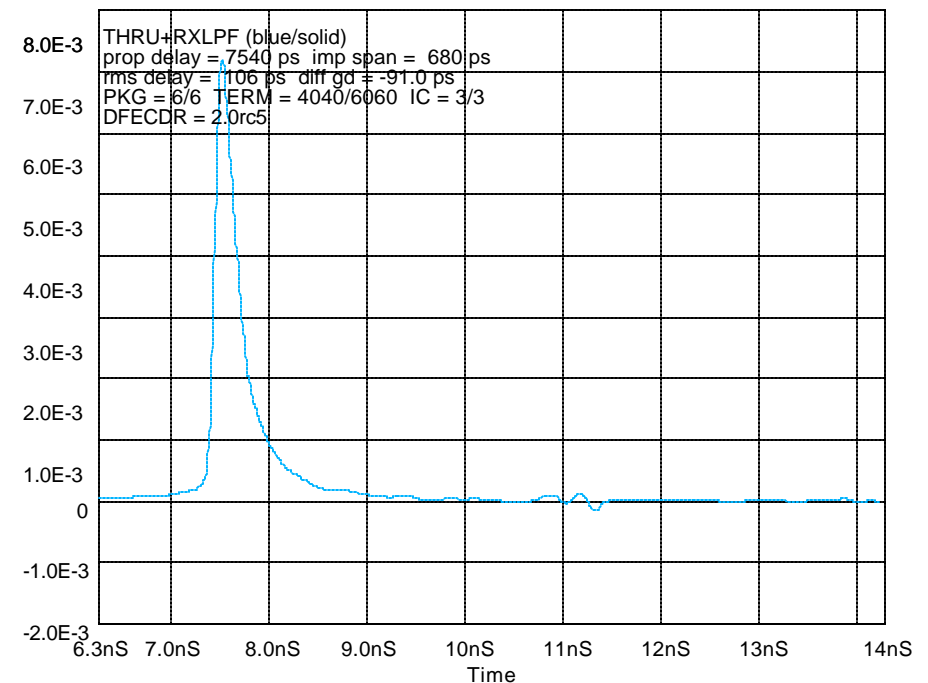
- ▶ Channel response -30.5dB
 - Severe attenuation
 - Relatively high crosstalk at fundamental
- ▶ Impulse response is clean
- ▶ Min solution FFE3DFE1

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Case 3 with Organic Package

Simulation Results* (opening at 10^{-12} BER)

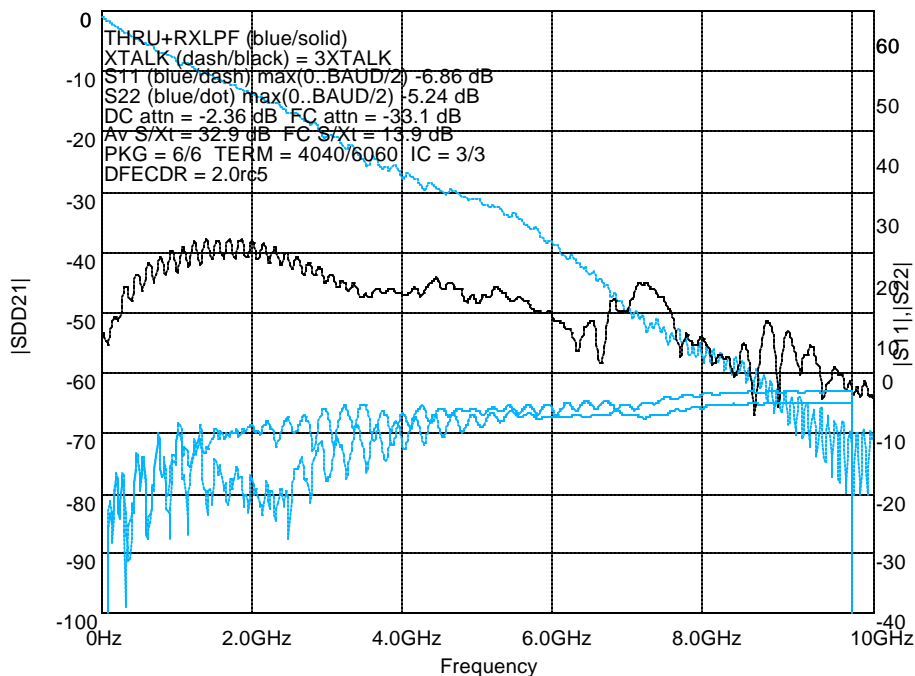
	FFE2	FFE3	FFE4
DFE0	e-2	e-2	e-2
DFE1	e-4	e-9	5.5%
DFE2	e-5	5.2%	8.1%
DFE3	e-9	5.6%	15.5%
DFE4	4.4%	9.6%	16.2%
DFE5	9.0%	17.6%	15.4%

Summary

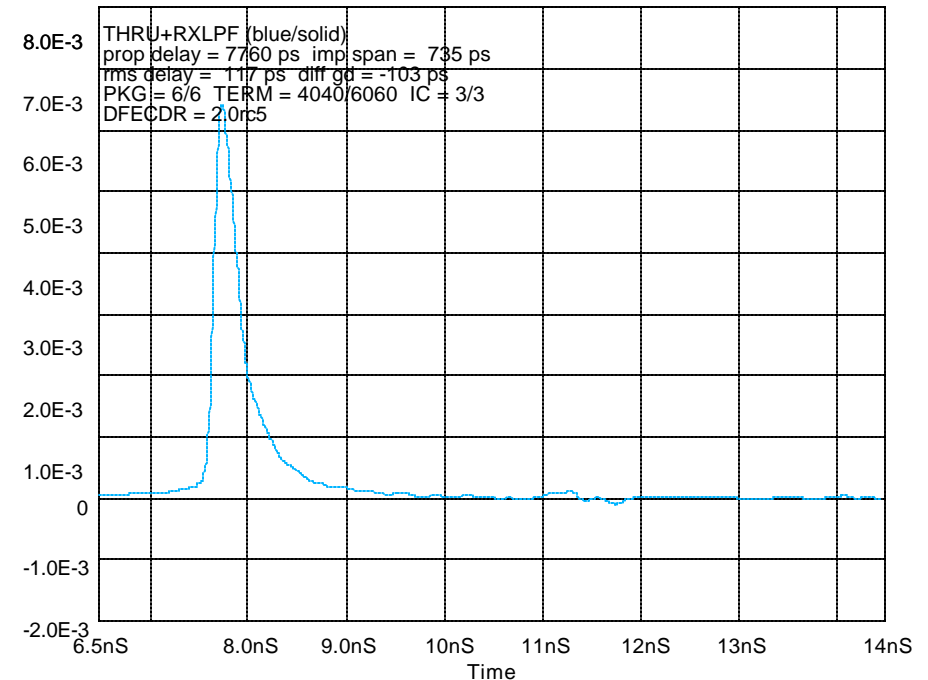
- ▶ Channel response -33.1dB
 - Severe attenuation
- ▶ Impulse response is clean
- ▶ Min solution FFE3DFE2

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Case 4 with Organic Package

Simulation Results* (opening at 10^{-12} BER)

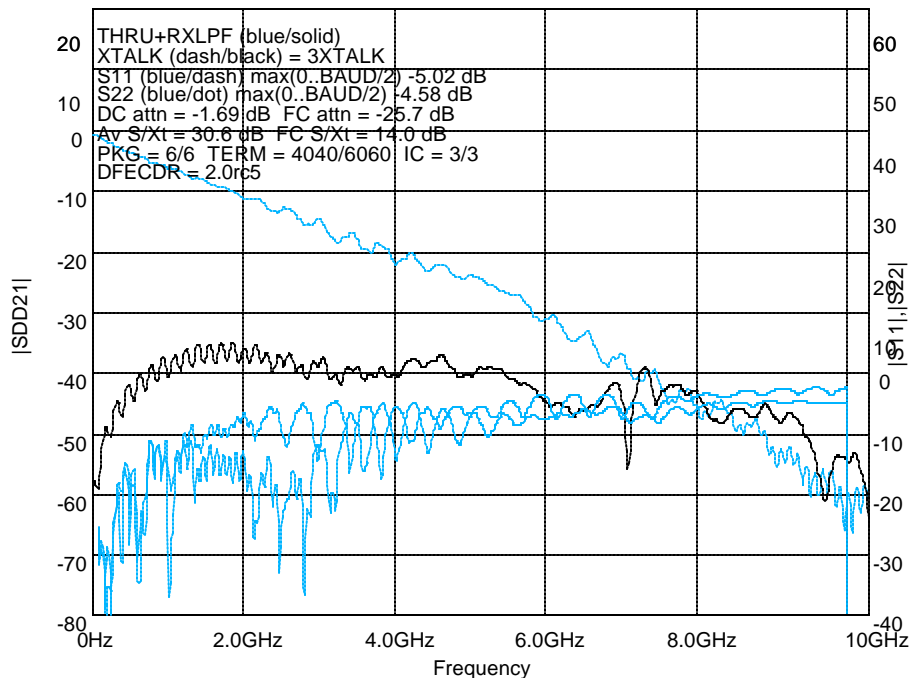
	FFE2	FFE3	FFE4
DFE0	e-5	e-8	5.6%
DFE1	e-11	18.3%	13.9%
DFE2	0%	17.3%	16.3%
DFE3	11.5%	19.5%	20.7%
DFE4	15.5%	20.6%	20.7%
DFE5	17.1%	21.9%	20.9%

Summary

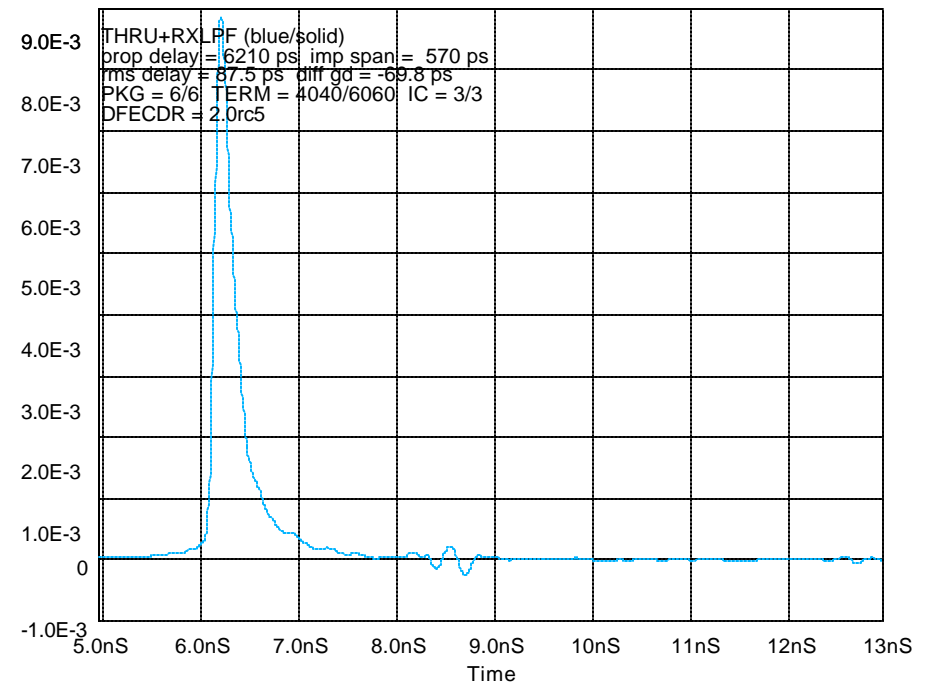
- ▶ Channel response -25.7dB
 - Heavy attenuation
- ▶ Impulse response is relatively clean
- ▶ Min solution FFE3DFE1

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Case 5 with Organic Package

Simulation Results* (opening at 10^{-12} BER)

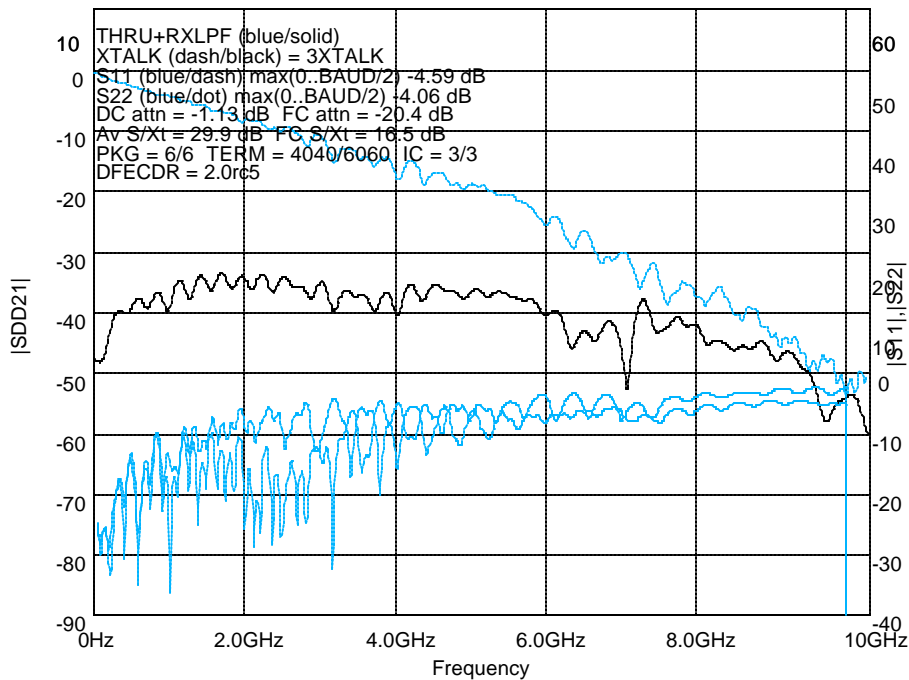
	FFE2	FFE3	FFE4
DFE0	5.7%	9.5%	20.2%
DFE1	9.8%	21.1%	9.8%
DFE2	12.2%	17.4%	9.7%
DFE3	16.0%	18.9%	15.4%
DFE4	18.8%	23.1%	12.2%
DFE5	21.3%	22.2%	10.4%

Summary

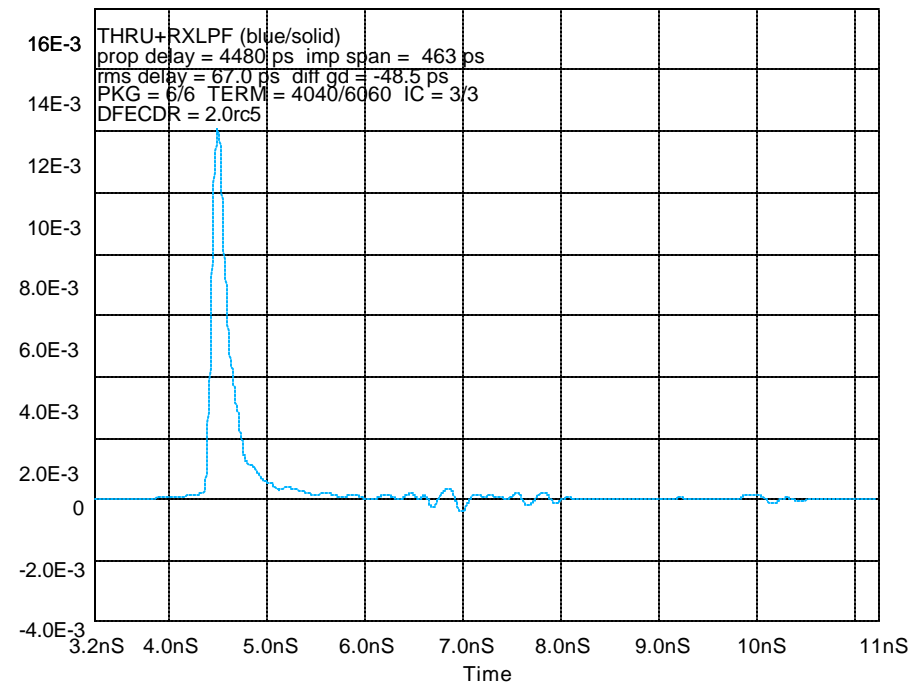
- ▶ Channel response -20.4dB
 - Relatively high ave crosstalk
- ▶ Impulse response is relatively clean
- ▶ Min solution FFE3
 - No DFE required

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Case 6 with Organic Package

Simulation Results* (opening at 10^{-12} BER)

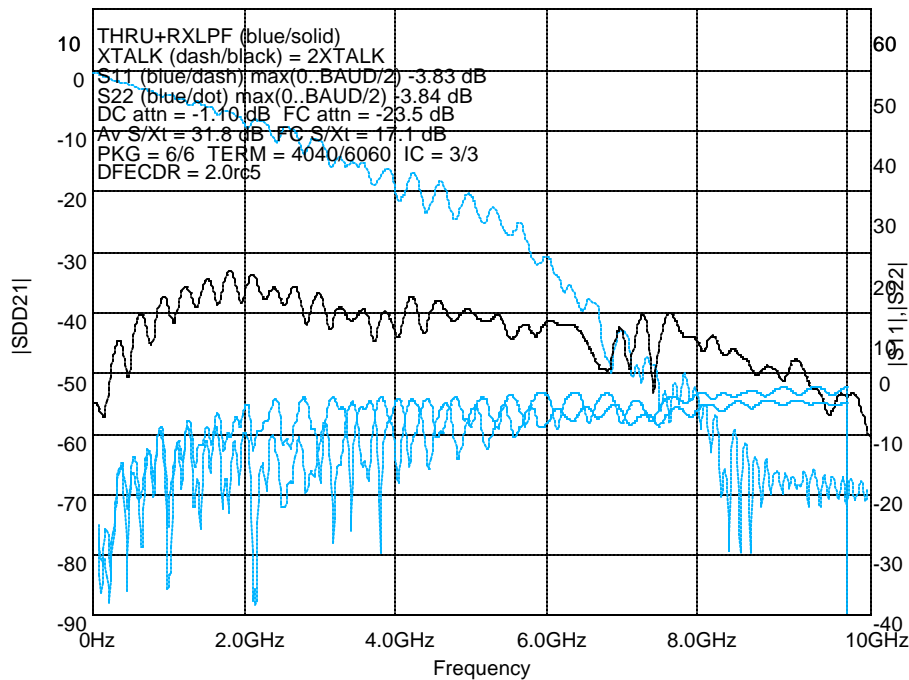
	FFE2	FFE3	FFE4
DFE0	e-3	e-4	e-6
DFE1	e-8	0%	e-11
DFE2	e-8	0%	0%
DFE3	e-8	0%	2.8%
DFE4	e-9	4.6%	3.4%
DFE5	e-11	5.5%	8.4%

Summary

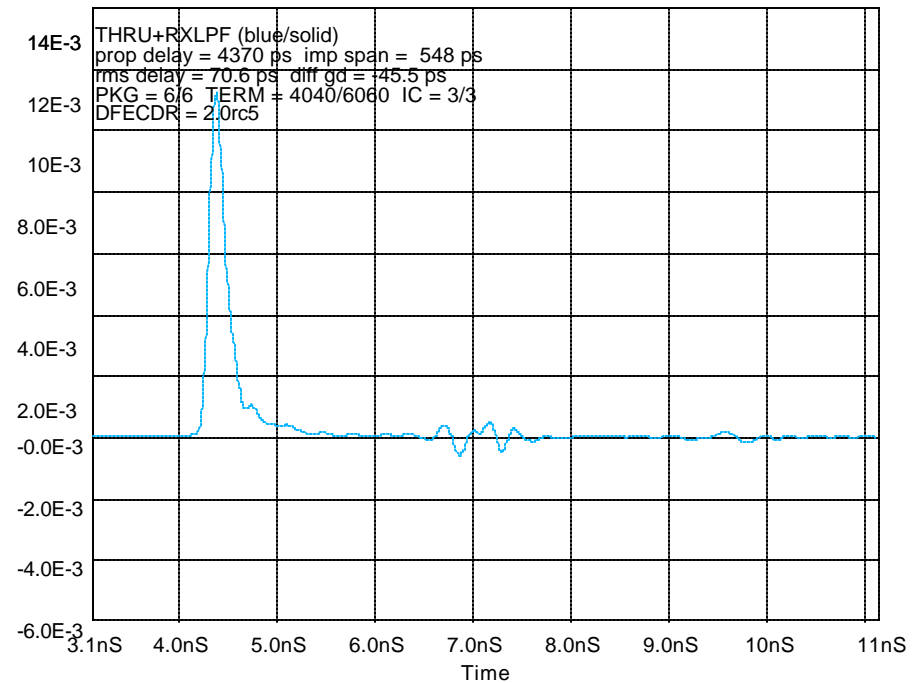
- ▶ Channel response -23.5dB
 - Moderate attenuation
- ▶ Impulse response shows moderate reflections
- ▶ Min solution FFE3DFE4

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Case 7 with Organic Package

Simulation Results* (opening at 10^{-12} BER)

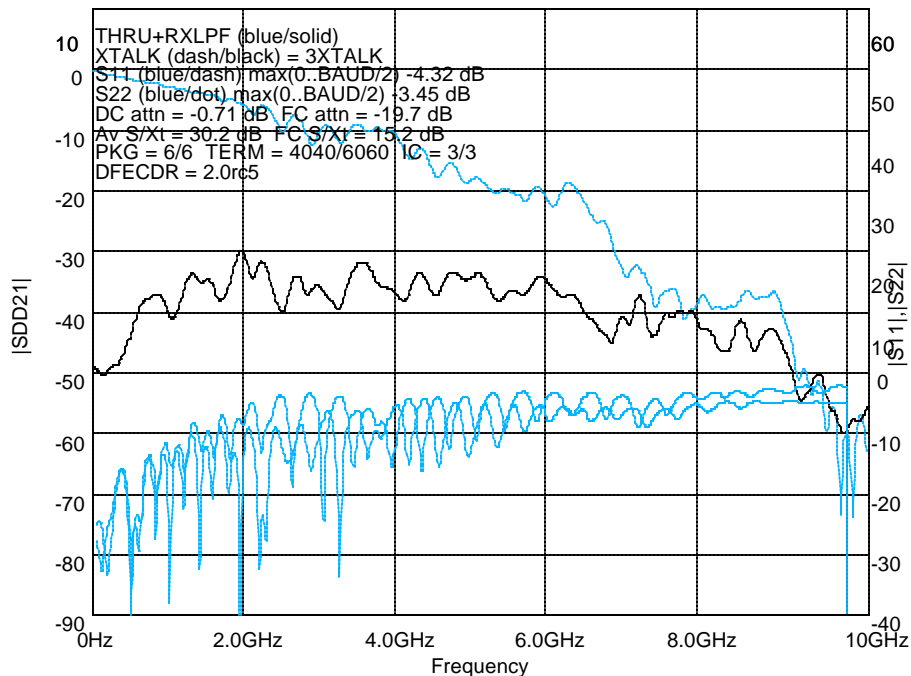
	FFE2	FFE3	FFE4
DFE0	e-5	e-5	e-6
DFE1	e-9	0.1%	0%
DFE2	e-11	4.6%	3.8%
DFE3	0.1%	4.4%	4.8%
DFE4	6.2%	6.2%	12.1%
DFE5	10.9%	9.7%	9.7%

Summary

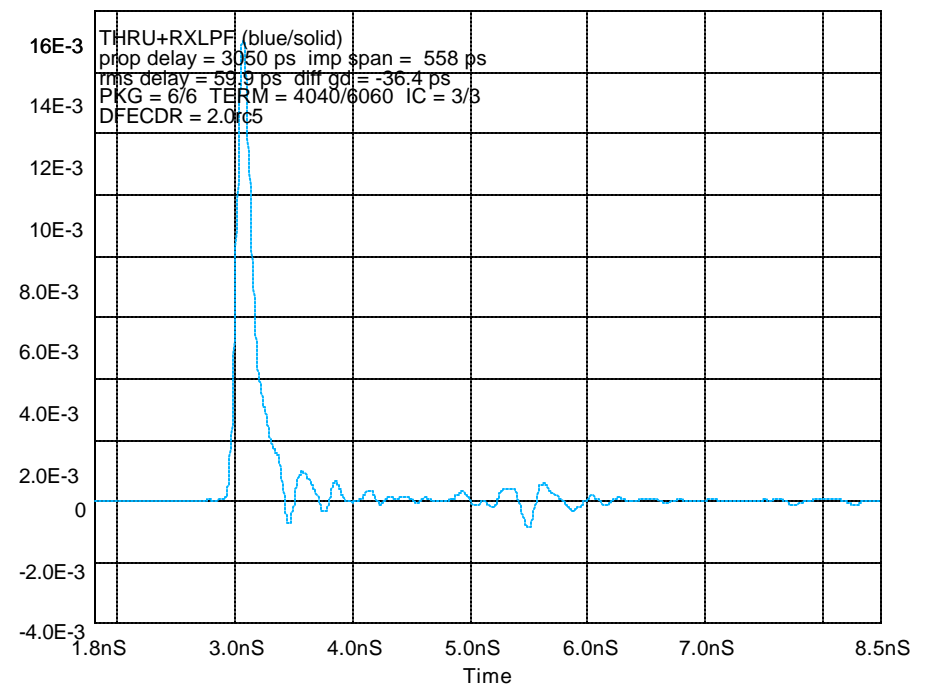
- ▶ Channel response -19.7dB
 - Relatively low attenuation
- ▶ Impulse response shows multiple reflections
- ▶ Min solution FFE3DFE1

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response

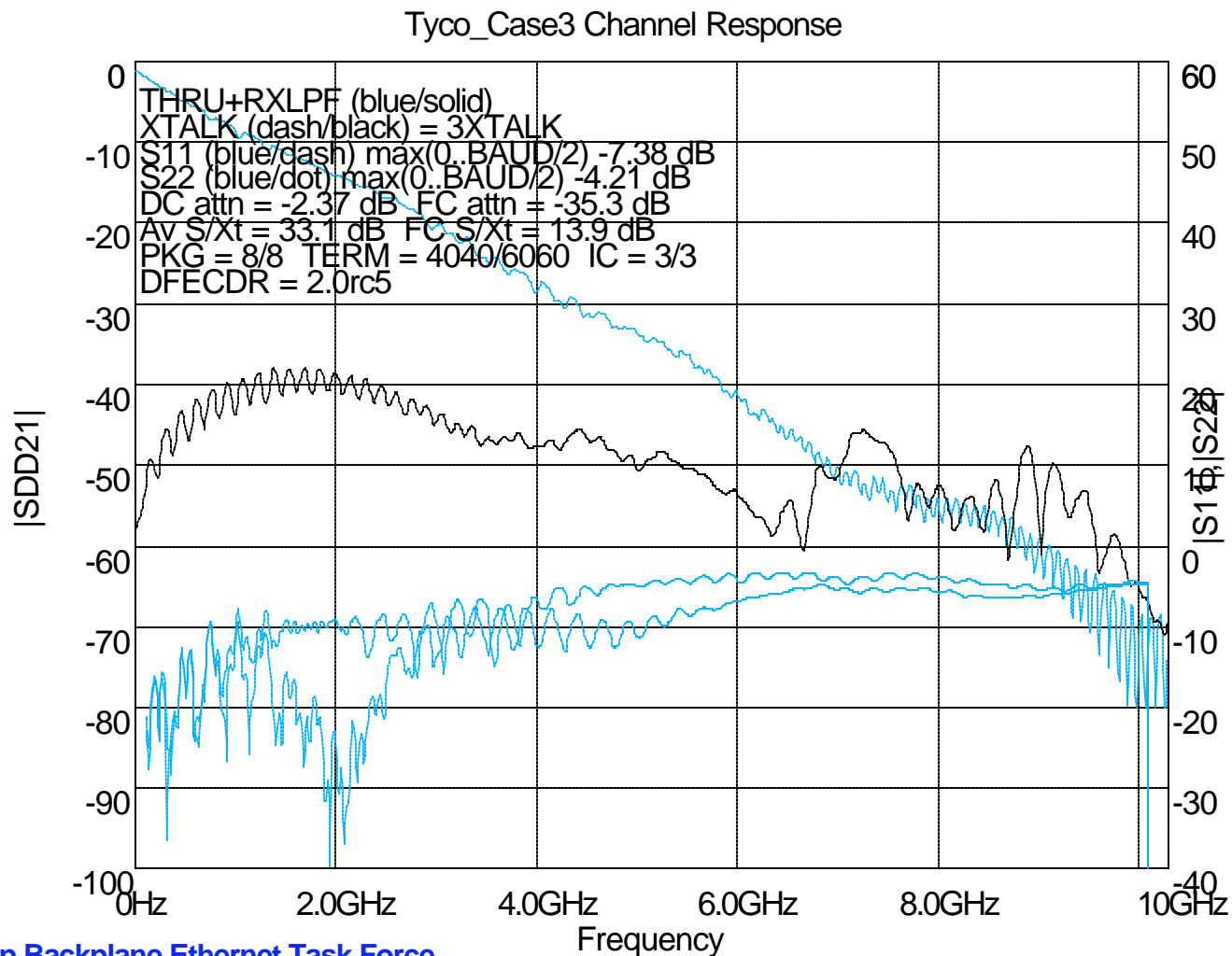


Flip Chip Plastic Package



Effects of package on overall channel model

- ▶ Shown for Testcase #3 (Margin case somewhat below the proposed model from channel ad-hoc)
- ▶ Attenuation drops significantly
 - Raw channel down 27dB at fundamental frequency
 - Package and module parasitics drops this to -35.3 dB at fundamental frequency!



Case 1 with Plastic Package

Simulation Results* (opening at 10^{-12} BER)

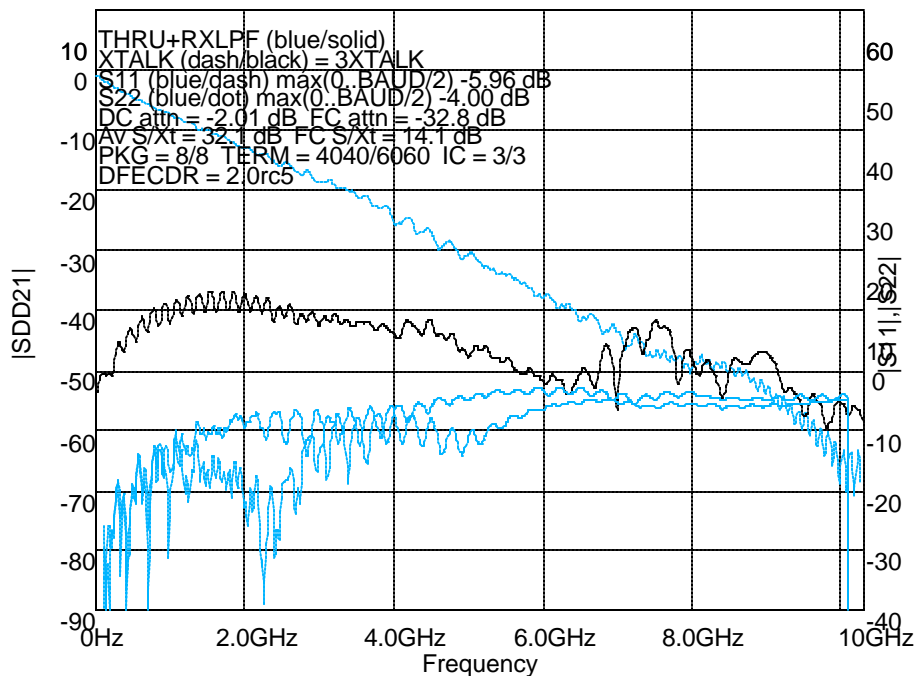
	FFE2	FFE3	FFE4
DFE0	e-2	e-4	e-3
DFE1	e-5	10.8%	10.9%
DFE2	e-6	14.7%	13.8%
DFE3	e-10	14.7%	16.6%
DFE4	5.0%	16.0%	16.1%
DFE5	5.7%	16.7%	20.4%

Summary

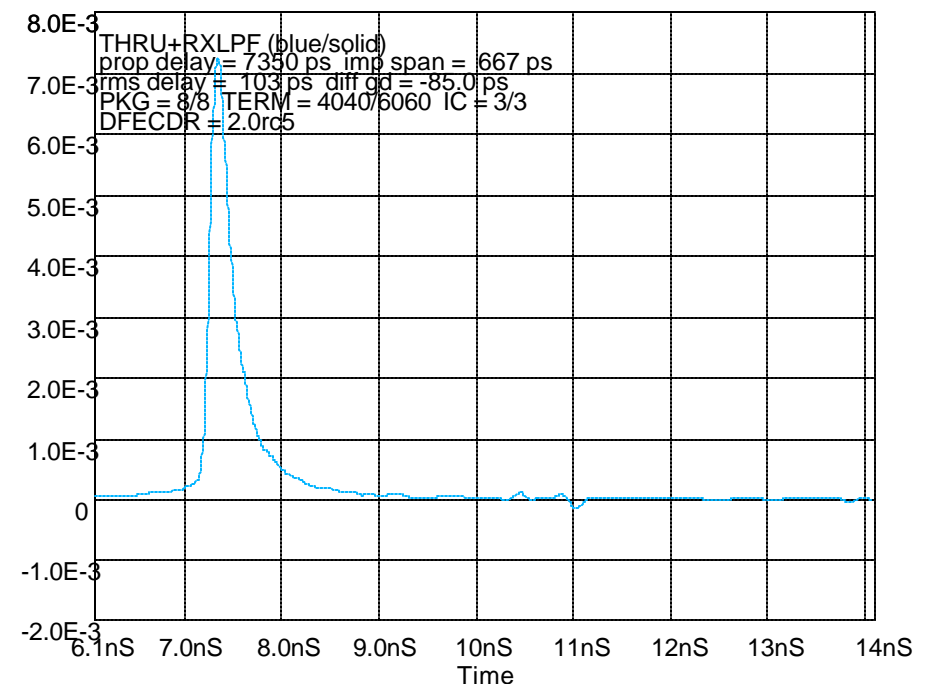
- ▶ Channel response -32.8dB
- ▶ Impulse response is clean
- ▶ Min solution FFE3DFE1

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Case 2 with Plastic Package

Simulation Results* (opening at 10^{-12} BER)

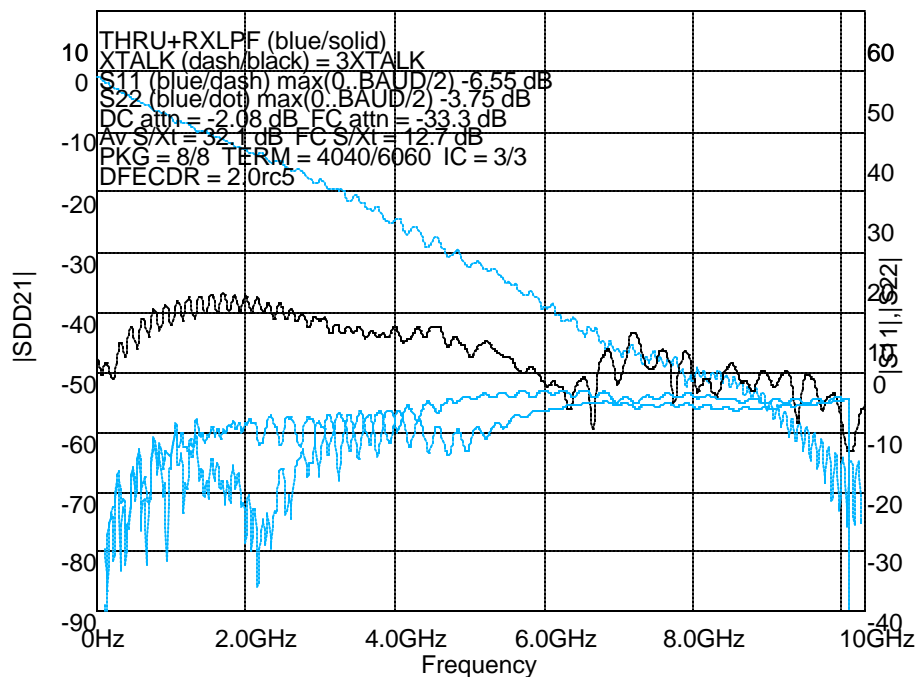
	FFE2	FFE3	FFE4
DFE0	e-2	e-3	e-3
DFE1	e-4	4.8%	11.6%
DFE2	e-5	8.3%	10.9%
DFE3	e-8	5.2%	16.6%
DFE4	0.1%	15.1%	16.0%
DFE5	4.3%	17.3%	15.5%

Summary

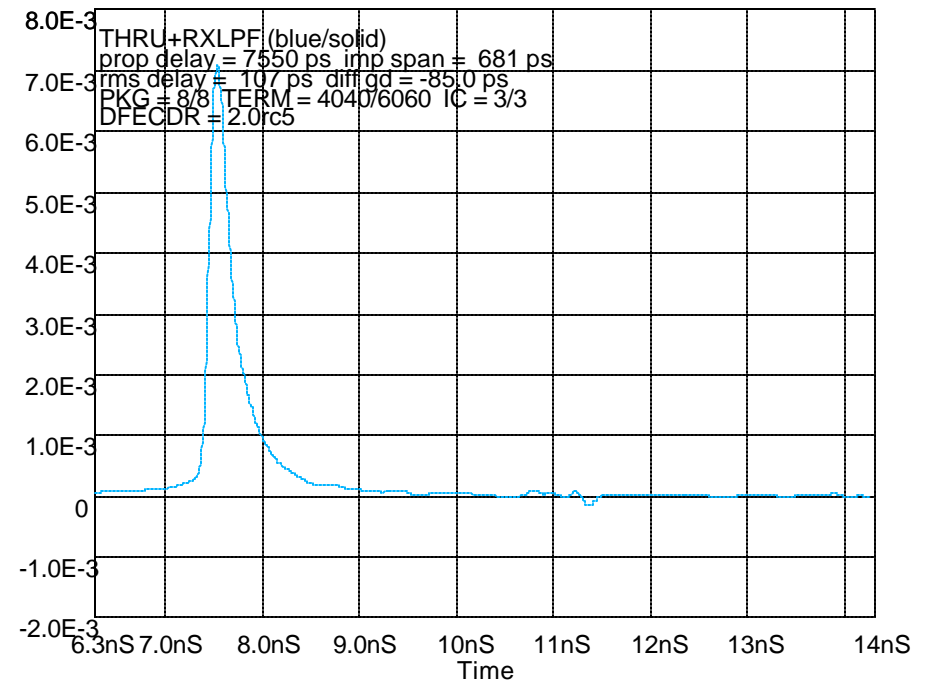
- ▶ Channel response -33.3dB
 - Severe attenuation
 - Relatively high crosstalk at fundamental
- ▶ Impulse response is clean
- ▶ Min solution FFE3DFE1

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Case 3 with Plastic Package

Simulation Results* (opening at 10^{-12} BER)

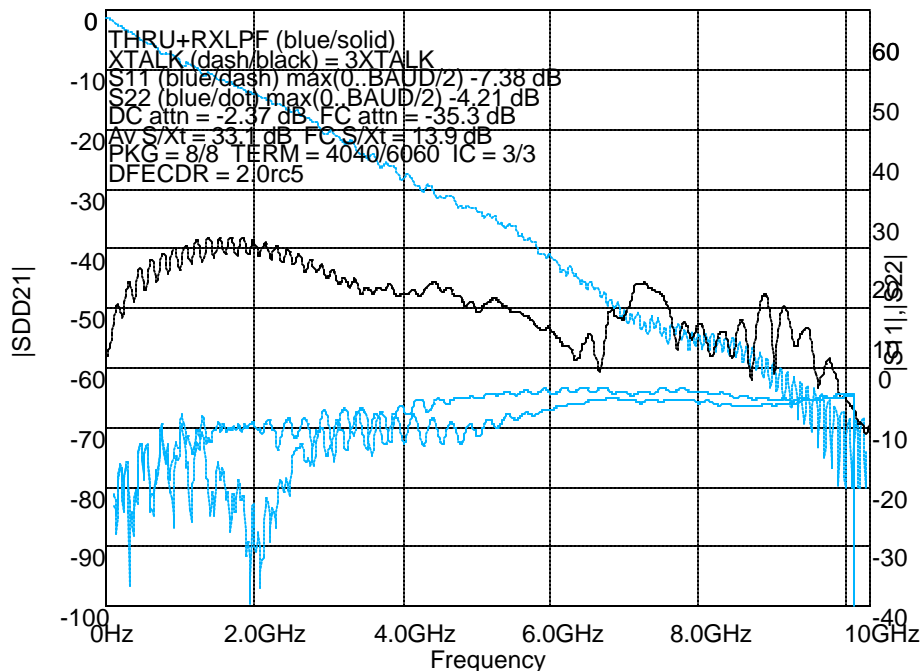
	FFE2	FFE3	FFE4
DFE0	e-2	e-2	e-2
DFE1	e-3	e-8	7.0%
DFE2	e-3	0%	10.9%
DFE3	e-7	0.1%	13.5%
DFE4	e-9	11.0%	12.1%
DFE5	0.1%	14.3%	14.5%

Summary

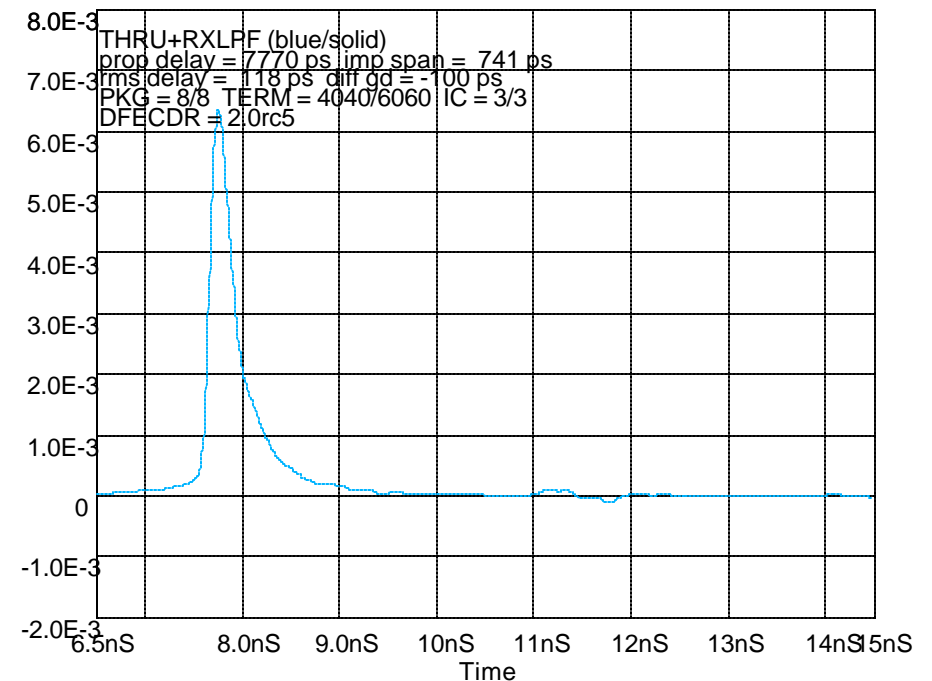
- ▶ Channel response -35.3dB
 - Severe attenuation
- ▶ Impulse response is clean
- ▶ Min solution FFE3DFE3

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Case 4 with Plastic Package

Simulation Results* (opening at 10^{-12} BER)

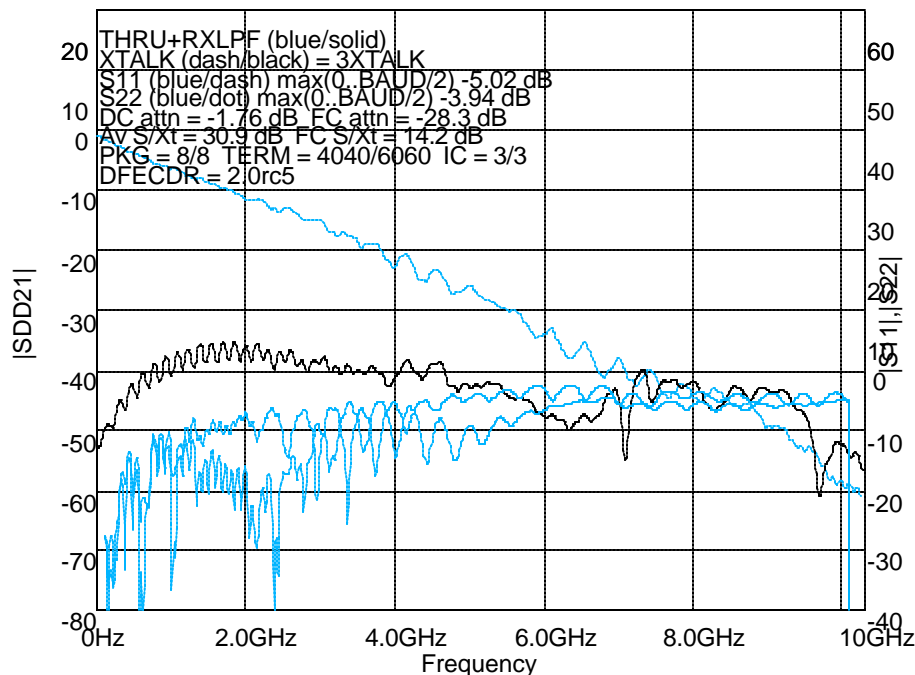
	FFE2	FFE3	FFE4
DFE0	e-4	e-5	e-6
DFE1	e-7	18.8%	18.5%
DFE2	e-8	16.6%	16.4%
DFE3	11.1%	20.4%	16.6%
DFE4	20.7%	23.2%	18.0%
DFE5	17.3%	23.5%	21.0%

Summary

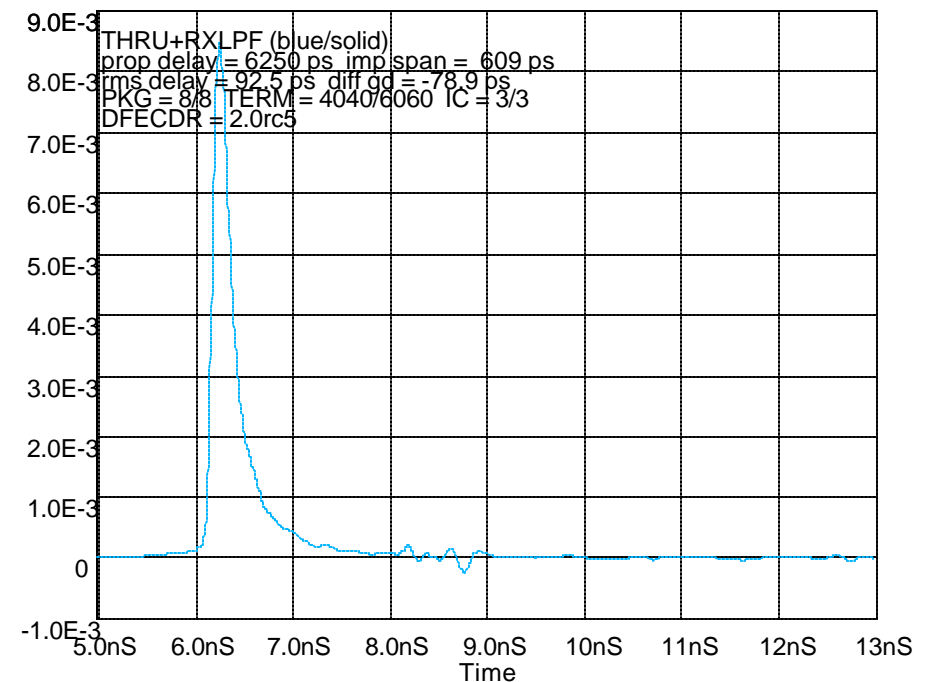
- ▶ Channel response -28.3dB
 - Heavy attenuation
- ▶ Impulse response is relatively clean
- ▶ Min solution FFE3DFE1

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Case 5 with Plastic Package

Simulation Results* (opening at 10^{-12} BER)

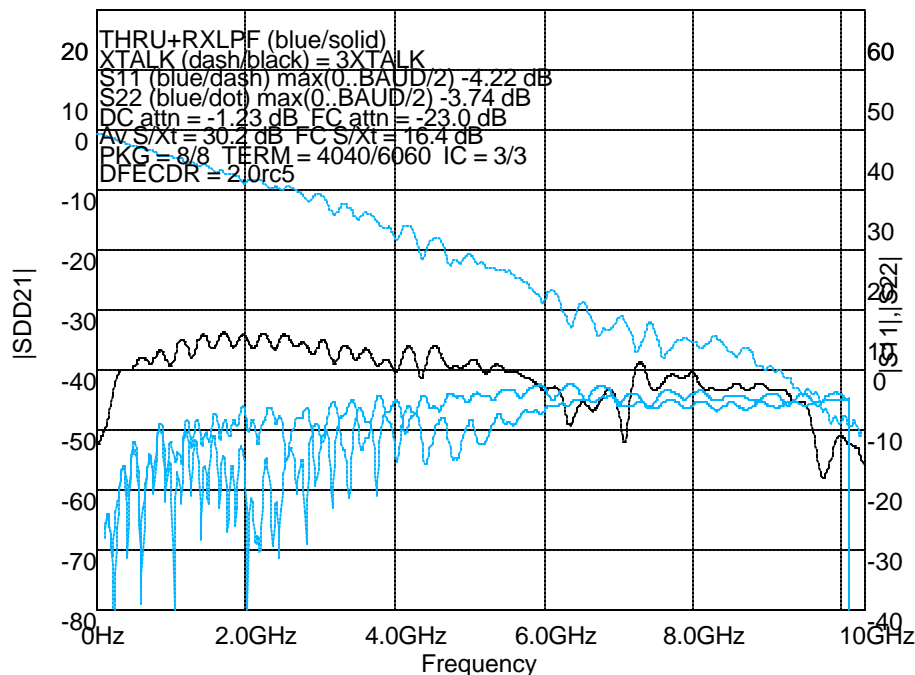
	FFE2	FFE3	FFE4
DFE0	e-6	e-7	11.2%
DFE1	9.7%	15.7%	17.1%
DFE2	9.7%	15.0%	17.1%
DFE3	14.6%	16.7%	15.2%
DFE4	16.5%	15.8%	20.9%
DFE5	20.8%	15.5%	21.1%

Summary

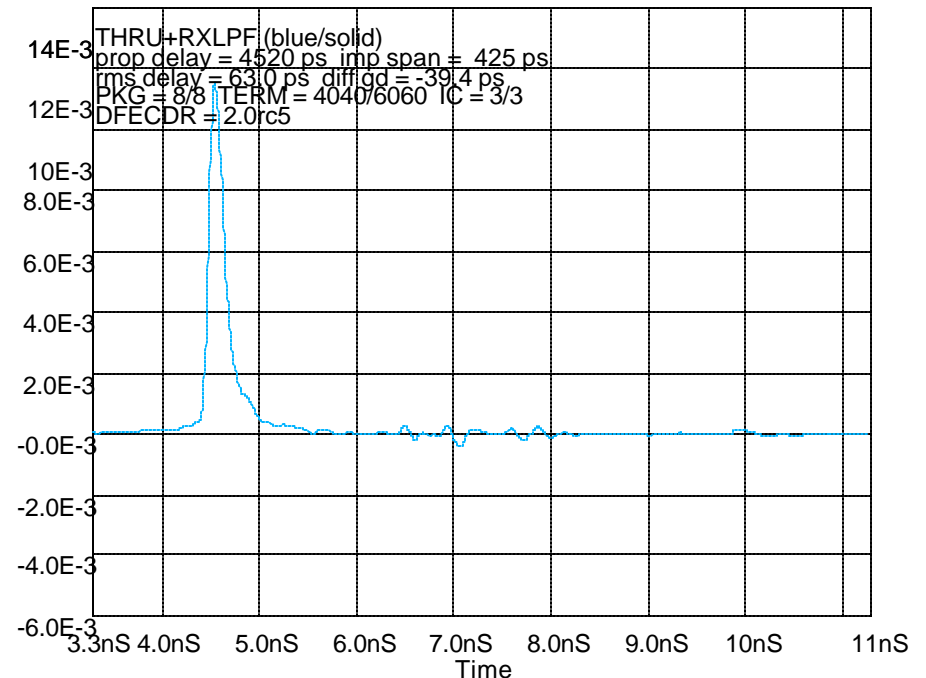
- ▶ Channel response -23.0dB
 - Relatively high ave crosstalk
- ▶ Impulse response is relatively clean
- ▶ Min solution FFE4
 - No DFE required

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Case 6 with Plastic Package

Simulation Results* (opening at 10^{-12} BER)

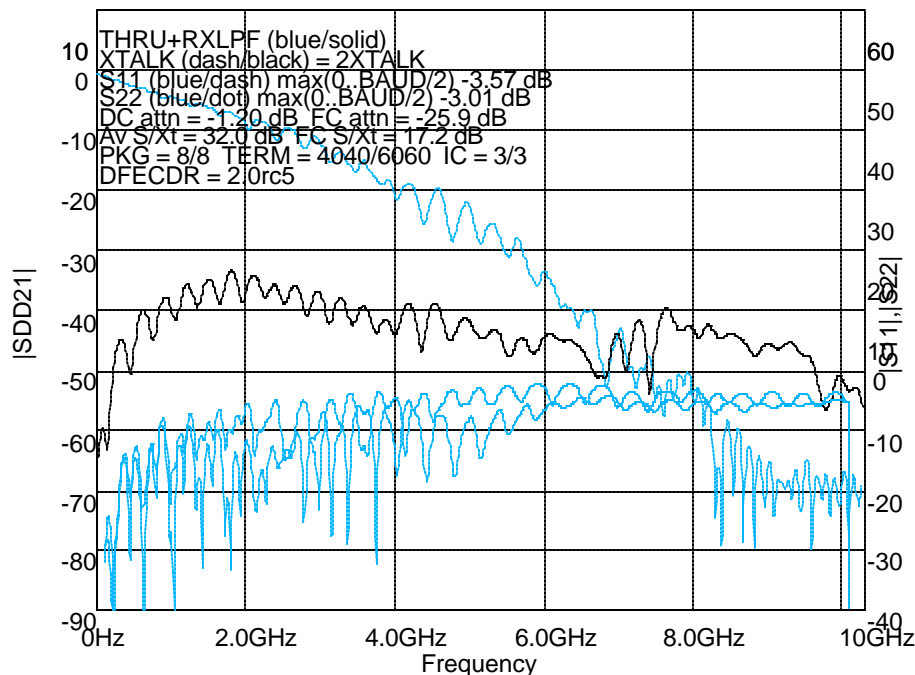
	FFE2	FFE3	FFE4
DFE0	e-3	e-3	e-4
DFE1	e-7	0%	e-9
DFE2	e-8	0%	e-11
DFE3	e-8	4.1%	0.1%
DFE4	e-10	4.4%	0%
DFE5	0%	4.6%	3.9%

Summary

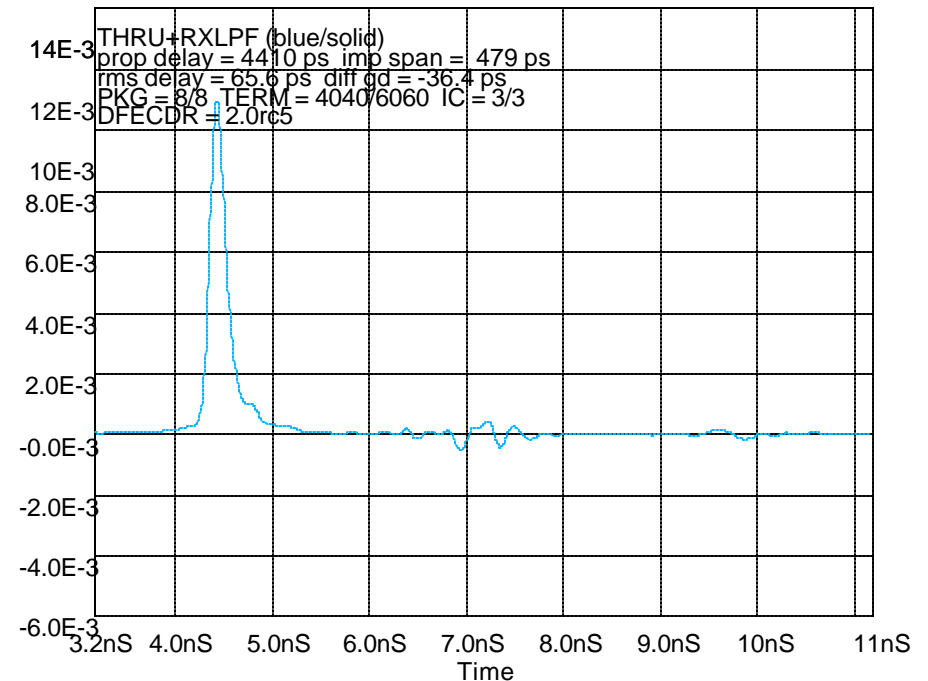
- ▶ Channel response -25.9dB
 - Moderate attenuation
- ▶ Impulse response shows moderate reflections
- ▶ Min solution FFE3DFE3

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Case 7 with Plastic Package

Simulation Results* (opening at 10^{-12} BER)

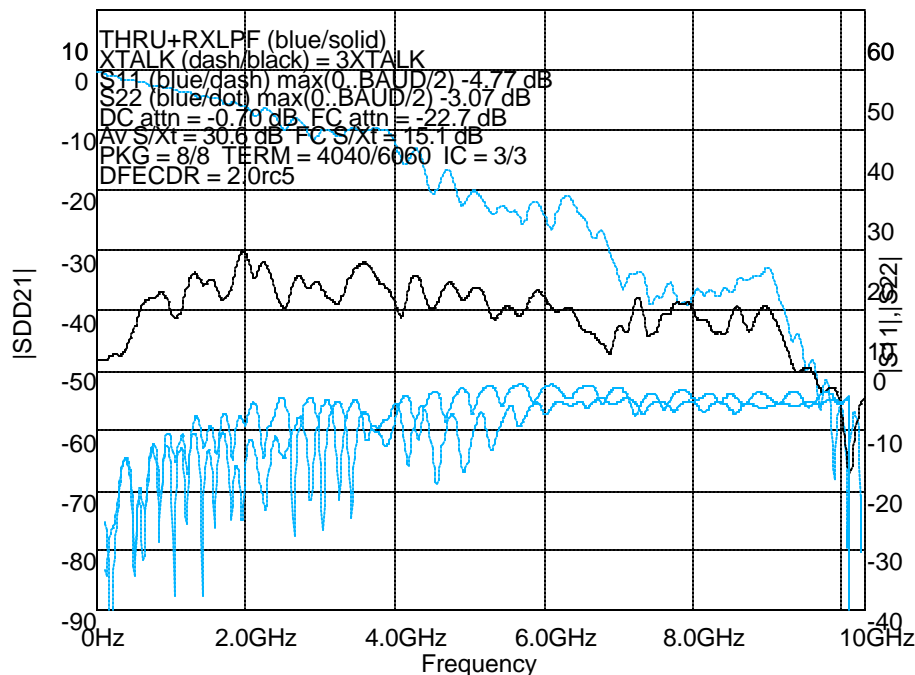
	FFE2	FFE3	FFE4
DFE0	e-4	e-4	e-5
DFE1	e-11	e-9	0.4%
DFE2	e-9	0.4%	5.4%
DFE3	4.1%	1.7%	3.9%
DFE4	1.5%	4.7%	5.8%
DFE5	5.9%	3.8%	4.2%

Summary

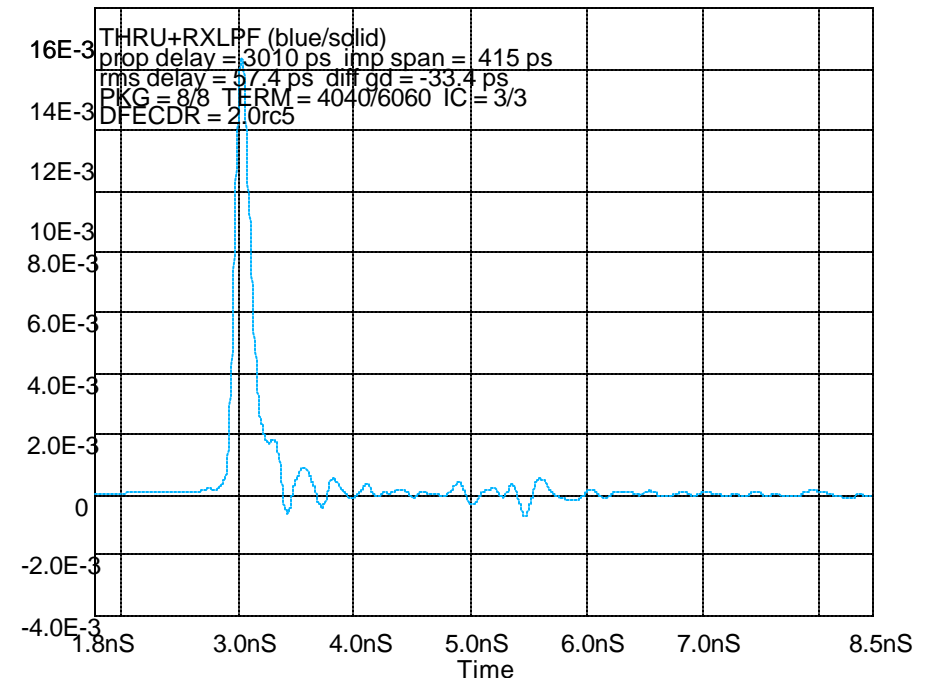
- ▶ Channel response -22.7dB
 - Relatively low attenuation
- ▶ Impulse response shows multiple reflections
- ▶ Min solution FFE3DFE2

* Percentage eye opening at e-12 BER, else BER floor is indicated in red if less. Configurations that support e-17 BER or better are shaded in green.

Channel Response



Impulse Response



Summary

NO, We Don't Need 10+ Tap DFEs!

- ▶ All channels shown to be solvable with nominal DFE designs - summary of minimum configurations:

	Case1	Case2	Case3	Case4	Case5	Case6	Case7
Organic	FFE3DFE1	FFE3DFE1	FFE3DFE2	FFE3DFE1	FFE3	FFE3DFE4	FFE3DFE1
Plastic	FFE3DFE1	FFE3DFE1	FFE3DFE2	FFE3DFE1	FFE4	FFE3DFE3	FFE3DFE2

Significant room exists for vendors to add robustness

- ▶ e.g. 4-tap FFE, 5-tap DFE

Room exists for vendors to optimize for power

- ▶ e.g. 3-tap FFE, 1-tap DFE solved channels above proposed ad-hoc line
- ▶ e.g. Duobinary receiver with common NRZ 3-tap FFE transmitter

Feasibility shown with a proven simulator, with full modeling of serdes & channel

- ▶ Thoroughly correlated to hardware characterized across process, voltage, & temperature

Evaluation conservatively performed for worst case conditions

- ▶ Worst case DJ, RJ, Termination tolerance, etc as expected to be defined by standard
- ▶ Conservative 10G parasitic extraction estimates

NRZ/DFE architecture validated in existing designs

- ▶ Significant experience with 6.25Gbps FFE4/DFE5 hardware
- ▶ Operates across channels of comparable and even worse quality than those proposed to signaling ad-hoc