What Channels Should be Considered by the IEEE 802.3ap Signaling Ad Hoc?

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Tyco Electronics

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To Date

- Informative model (See Slide #13 goergen_03_0904) based on "improved FR-4" and 0.030" stub has been proposed
  - Looks reasonable in loss dominated channels
- Channel data with longer stubs or resonant behavior (nulls, ripple) have been shown to fail proposed informative channel model
- Debate over whether channels that have longer stubs and resonant behavior should be considered by Signaling Ad Hoc
  - Signaling methodology implications
  - Cost implications – how much counterboring would be required?
  - Extent of Broad Market Potential debate
- Debate over amount of frequency content – Nyquist? 3rd harmonic?

Observations

- Actual performance measurements on channels -
  - Nulls in 6 to 7 GHz region
  - Similar loss characteristics to proposed model
- Simulations have shown various implementations can solve loss dominated systems
- Simulations have shown implementation sensitivity to being able to deal with channels that have nulls in 5 to 7 GHz region
- Simulations have shown that channels above the model with ripple can be challenging

Loss Dominated Channels

Scenario	Channel Description	Modulation Scheme	Analysis & Results Description	Reference Presentation	Reference Backup Slide
1	Tyco Case #3 – Margin Case Loss dominated – below proposed informative channel model	NRZ	Simulation with xtalk 10^-17 BER Results for some implementations Packaging had impacts Data pattern – random (Analysis with PAM-4, see lui_01_0904, Analysis with duobinary not available)	abler_01_0904.pdf	12 13, 14
2	Tyco Case #3 – Margin Case Loss dominated – below proposed informative model	NRZ / PAM-4	Simulation with xtalk 10^-15 BER Results for some implementations for both Data pattern - ? (Analysis with duobinary not available)	lui_01_0904.pdf	12, 15
3	Tyco Case #2 Loss dominated < 6 GHz Ripple at informative model > 6 GHz below informative model	Duobinary	Testing, no xtalk, hand-built implementation 10^-14 BER demonstrated Data pattern – PRBS 2^31-1 (Analysis with NRZ – see abler_01_0904, lui_01_0904, Analysis with PAM-4 – see lui_01_0904)	sinsky_01_0904..pdf	16, 17
4	Tyco QuadRoute Backplane (13SI) – Synopsys Line Cards Mixture of channels - Loss dominated, stub, ripple effects Above and below proposed model depending on configuration	PAM-4	Testing 5G part overdriven , with xtalk 10^-12 BER demonstrated across all channels for multiple configurations Data pattern – PRBS 2^31-1 (Analysis with NRZ and duobinary not available)	hoppin_01_0304..pdf	25, 26, 27

Stub Dominated Channels

Scenario	Channel Description	Modulation Scheme	Analysis & Results Description	Reference Presentation	Reference Backup Slide
1	Tyco Case #6 - Modification < 6.5 GHz – above proposed model 6.5 GHz – 11 GHz – null dominated, below channel model	Duobinary	Testing, no xtalk, hand built implementation 10^-14 BER demonstrated Data pattern – PRBS 2^31 -1 (Analysis with NRZ and PAM-4 not available)	sinsky_01_0904.pdf	16, 18
2	Tyco XAUI Backplane, 34" channel (4000-2 material) < 5 GHz – similar loss to proposed model > 5 GHZ null dominated, below channel model	Duobinary	Simulation, with xtalk Open Eye, No BER stated Data pattern – PRBS 2^31-1 (Analysis with NRZ and PAM-4 not available)	koziuk_01_0904.pdf	19, 20
3	Tyco Case #6 – < 6.5 GHz – above proposed model 6.5 GHz – 11 GHz – null dominated, below channel model	NRZ	Simulation with xtalk 10^-12 OR 10^-17 BER - limited # of implementations could pass Packaging had impacts Data pattern – random (Analysis with PAM-4, see lui_01_0904, analysis with duobinary not available)	abler_01_0904.pdf	21 22, 23
4	Tyco Case #6 < 6.5 GHz – above proposed model 6.5 GHz – 11 GHz – null dominated, below channel model	NRZ / PAM-4	Simulation with xtalk 10^-15 BER Results for some implementations Data pattern - ? NRZ - 1 more tap than Scenario #2 loss dominated necessary PAM-4 – more margin than loss dominated results shown in Scenario #2 (Analysis with duobinary not available)	lui_01_0904.pdf	21, 24
5	Tyco QuadRoute Backplane (13SI) – Synopsys Line Cards Mixture of channels - Loss dominated, stub, ripple effects Above and below proposed model depending on configuration	PAM-4	Testing 5G part overdriven, with xtalk 10^-12 BER demonstrated across all channels for multiple configurations Data pattern – PRBS 2^31-1 (Analysis with NRZ and duobinary not available)	hoppin_01_0304..pdf	25, 26, 27

Ripple Dominated Channels

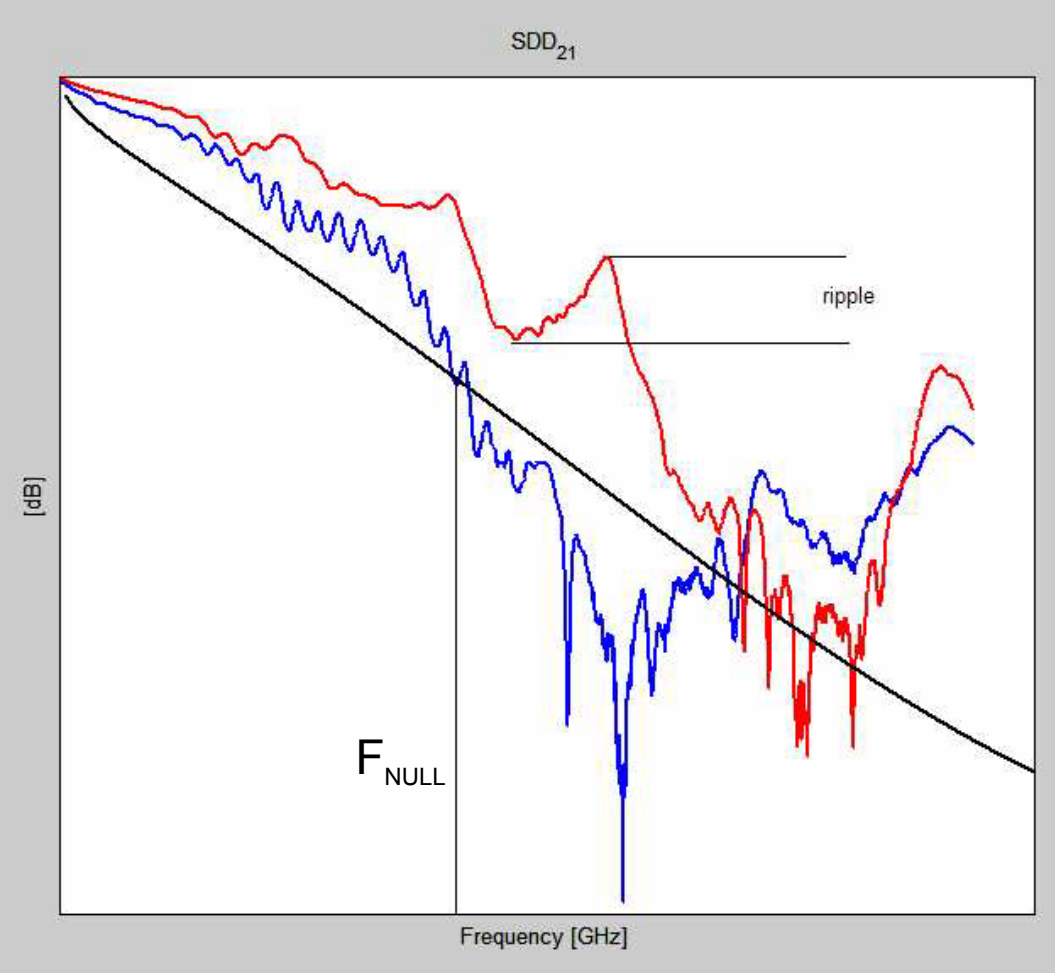
Scenario	Channel Description	Modulation Scheme	Analysis & Results Description	Reference Presentation	Reference Backup Slide
1	Tyco QuadRoute Backplane (13SI) – Synopsys Line Cards Mixture of channels - Loss dominated, stub, null efects Above and below proposed model depending on configuration	PAM-4	Testing 5G part overdriven, with xtalk 10^-12 BER demonstrated across all channels for multiple configurations Data pattern – PRBS 2^31-1 (Analysis with NRZ and duobinary not available)	hoppin_01_0304..pdf	25, 26, 27
2	Tyco Case #7 Above proposed model with increased ripple	NRZ	Simulation with xtalk 10^-12 BER demonstrated for some implementations 10^-17 BER demonstrated (packaging had impact) for some implementations Data pattern – Random (Analysis with PAM-4, see lui_01_0904, analysis with duobinary not available)	abler_01_0904.pdf	28, 29, 30
3	Tyco Case #7 Above proposed model with increased ripple	NRZ / PAM-4	Simulation, with xtalk 10^-15 BER demonstrated for some implementations for both Data pattern – ? (Analysis with duobinary not available)	lui_01_0904.pdf	28, 31

Channel Challenges

- Loss
- Deep Nulls and ripples that go below the loss curve
- Ripple on channels above the loss curve

- Premature to use proposed informative channel model as a filter for deciding what test cases should be considered

Aspects of Channel



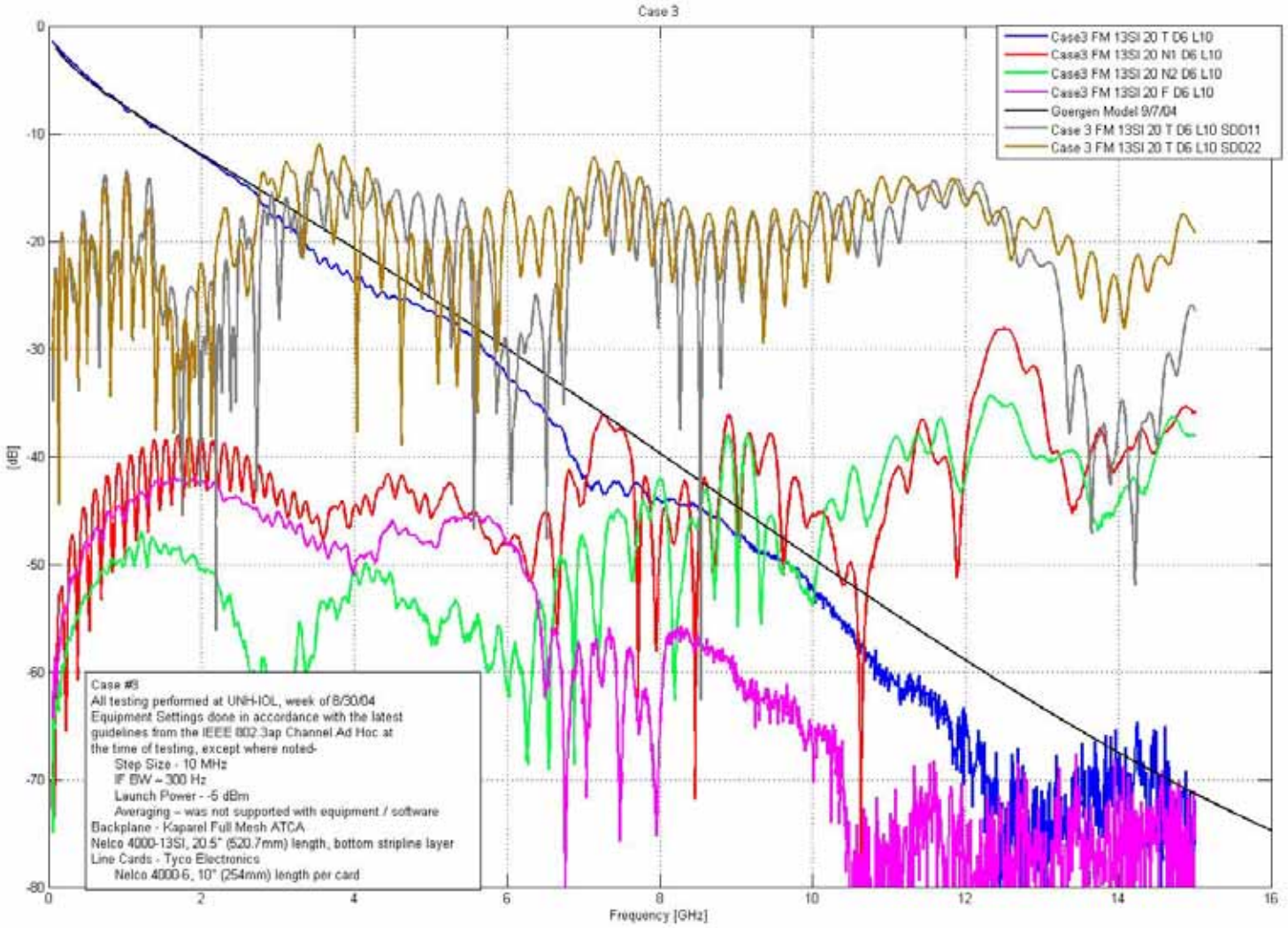
- Informative model loss seems reasonable
- F_{Null}, the frequency of the 1st crossing of the proposed informative channel model caused by one or more nulls, needs to be considered
- Ripple needs to be considered
  - Above the model
  - Partial channel response below the model
- Current Informative mask set limited
- Subsequent analysis of channel data by Signaling Ad Hoc -
  - Determine F_{Null}
  - Deterimine ripple characteristics

Conclusions

- Need to consider channel data regardless of whether it meets current proposed informative model
  - Informative model drove loss, but signaling methodology will impact F_{Null} and Ripple limits
  - Future modifications of informative model will be possible based on analytical work on channel data
  - Use of time domain information for channel model?
- To allow a fair trade-off, Signaling Ad Hoc needs to standardize all parameters outside of the consideration of the Channel Ad Hoc, i.e. TP1 to TP5
- More than channel pass / failure criteria necessary and needs to be evaluated
  - Power
  - Implementation issues

BACKUP SLIDES

Case #3



See dambrosia_01_0904.pdf

Case 3 with Organic Package

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

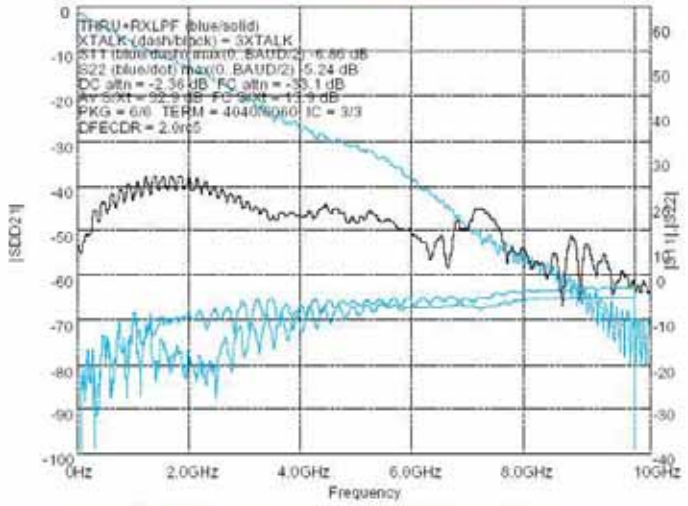
	FFE2	FFE3	FFE4
DFE0	e-2	e-2	e-2
DFE1	e-4	e-9	5.5%
DFE2	e-5	5.2%	8.1%
DFE3	e-9	5.6%	15.5%
DFE4	4.4%	9.6%	16.2%
DFE5	9.0%	17.6%	15.4%

Summary

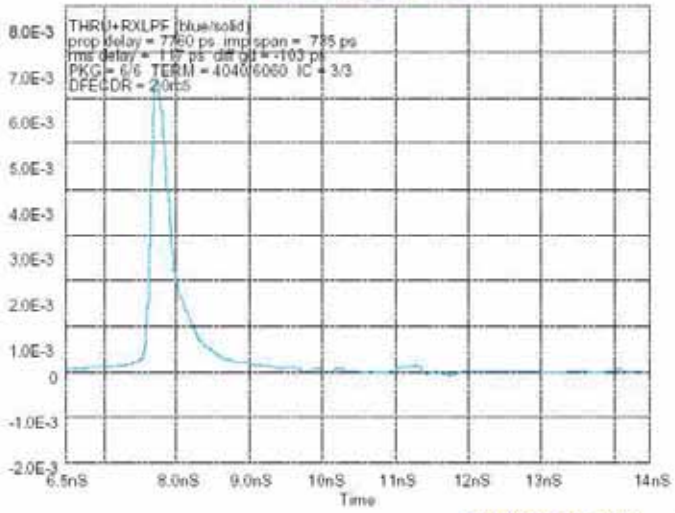
- Channel response -33.1dB
  - Severe attenuation
- Impulse response is clean
- Min solution FFE3DFE2

* 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



See abler_01_0904.pdf

Case 3 with Plastic Package

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

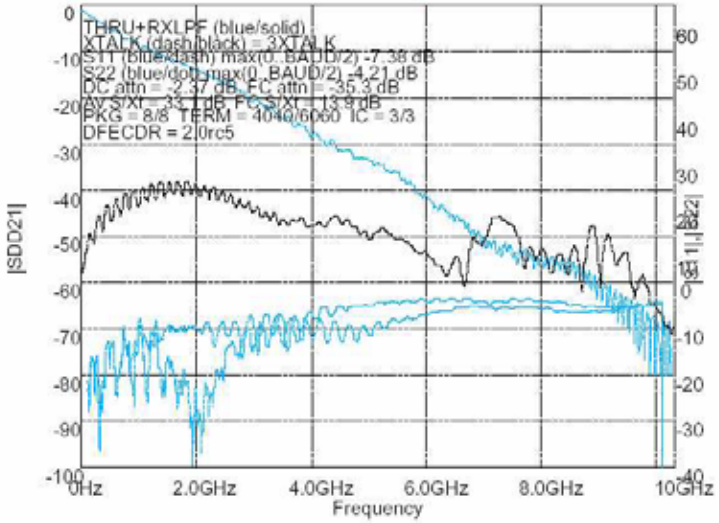
	FFE2	FFE3	FFE4
DFE0	e-2	e-2	e-2
DFE1	e-3	e-8	7.0%
DFE2	e-3	0%	10.9%
DFE3	e-7	0.1%	13.5%
DFE4	e-9	11.0%	12.1%
DFE5	0.1%	14.3%	14.5%

Summary

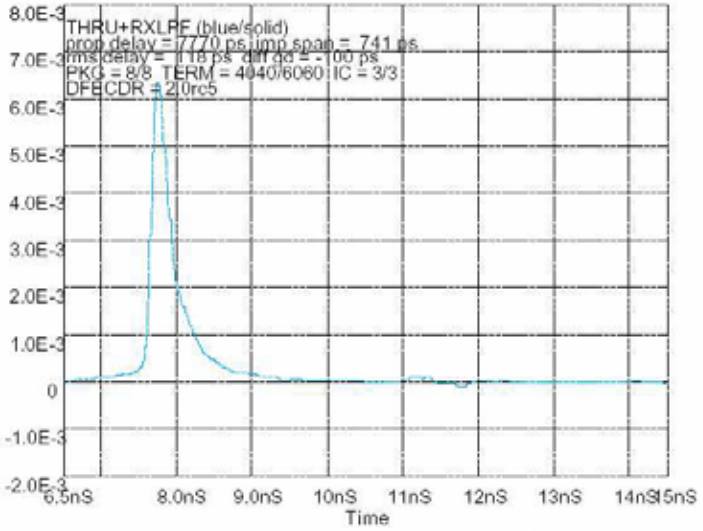
- Channel response -35.3dB
  - Severe attenuation
- Impulse response is clean
- Min solution FFE3DFE3

* 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

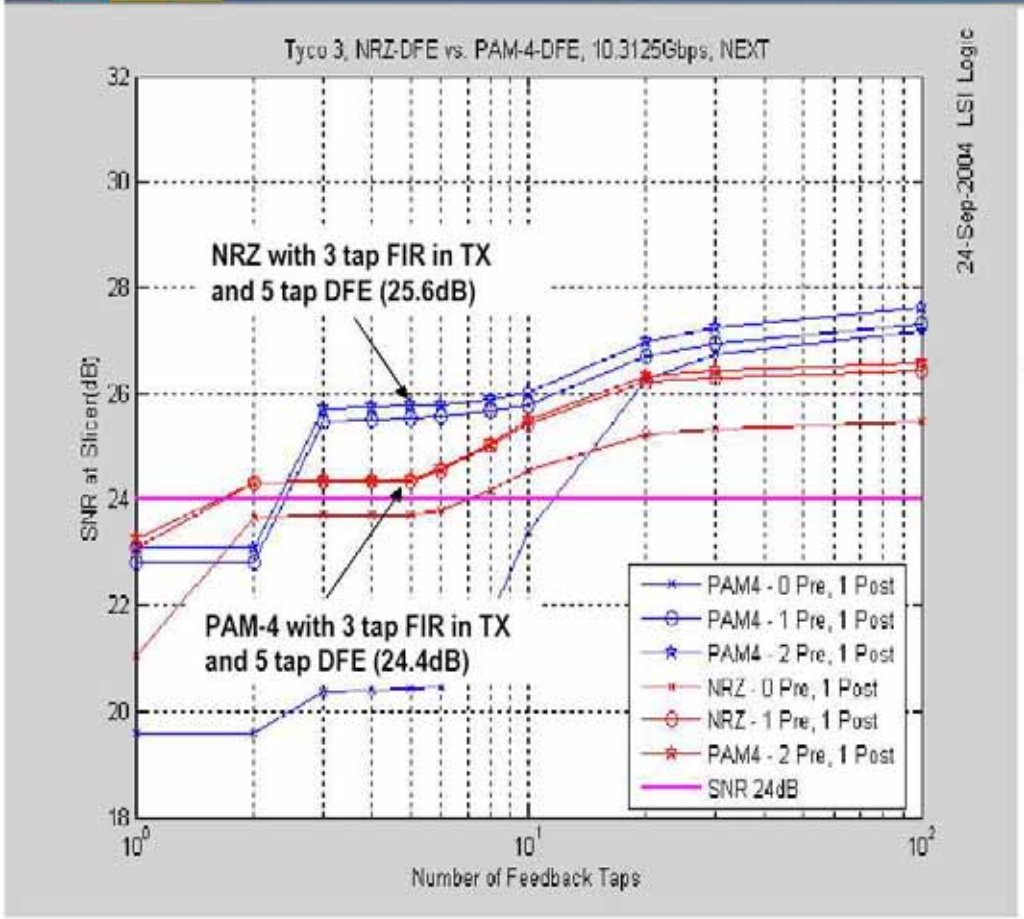


See abler_01_0904.pdf

LSI LOGIC

NRZ vs PAM-4

Tyco Channel 3; 10.3125Gbps; NEXT;

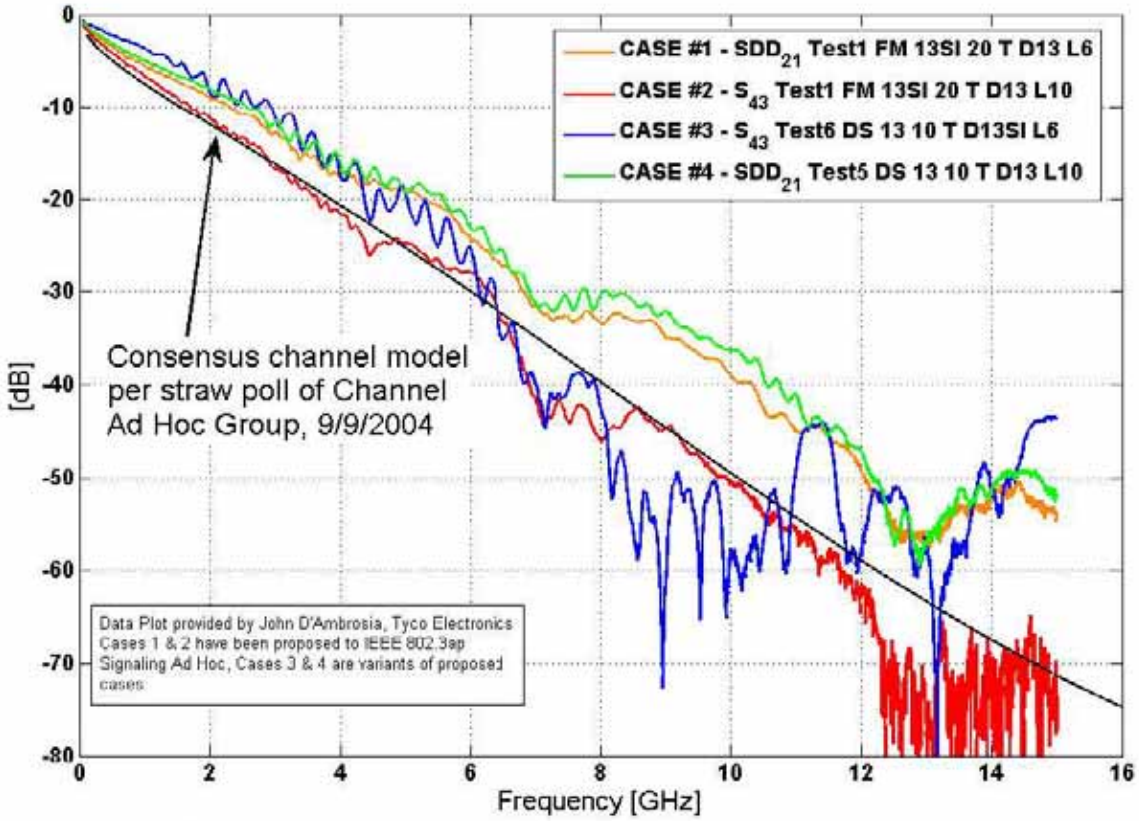


- This channel exhibited 11.9dB loss between the Nyquist frequency for PAM-4 (2.5GHz) and that for NRZ (5.0GHz).
- With NEXT and three tap FIR, NRZ meets SNR goal with three DFE taps and PAM-4 requires two.
- With NEXT, performance of three tap FIR and 5 DFE taps, NRZ shows 1.2dB margin over PAM-4.

10

See lui_01_0904.pdf

ATCA Backplane Channels



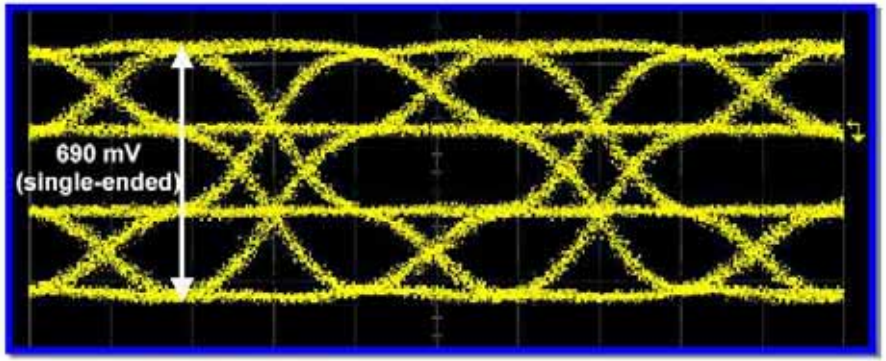
VITESSE
Lucent Technologies
Bell Labs Innovations

See sinsky_01_0904.pdf

Case #2

Duobinary over ATCA Test1 FM 13SI 20 T D13 L10

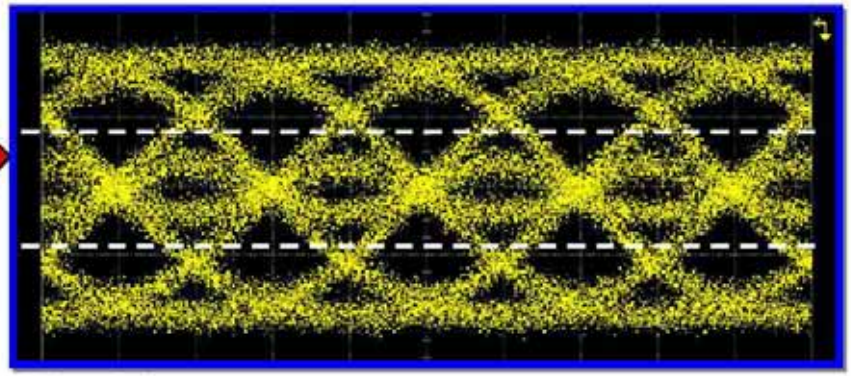
Kaparel – 40" Trace – 10" Line Card



- FIR Settings
  - 6 dB Attenuation
  - 150 ps delay
- Performance at 10 Gb/s
  - BER $<10^{-14}$ (time limited measurement)

Pre-emphasized data

25 ps/div



Backplane Output

50 ps/div

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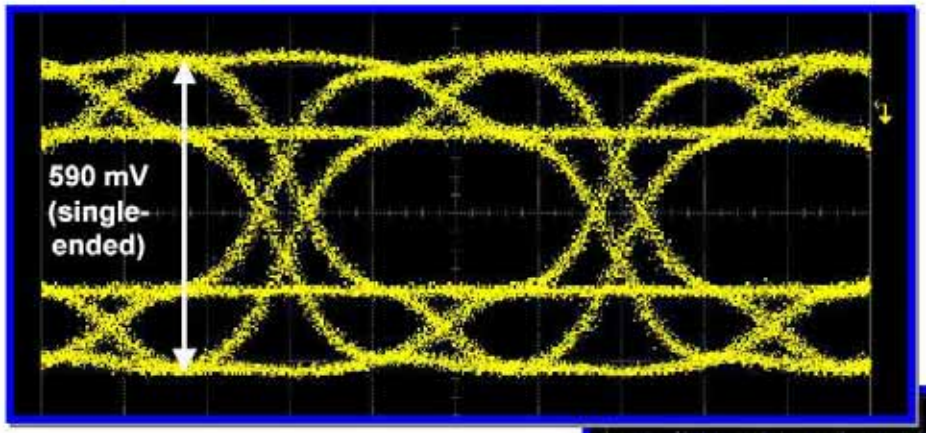
See sinsky_01_0904.pdf

Case #3

Duobinary over ATCA Test6 DS 13 10 T D13 L6

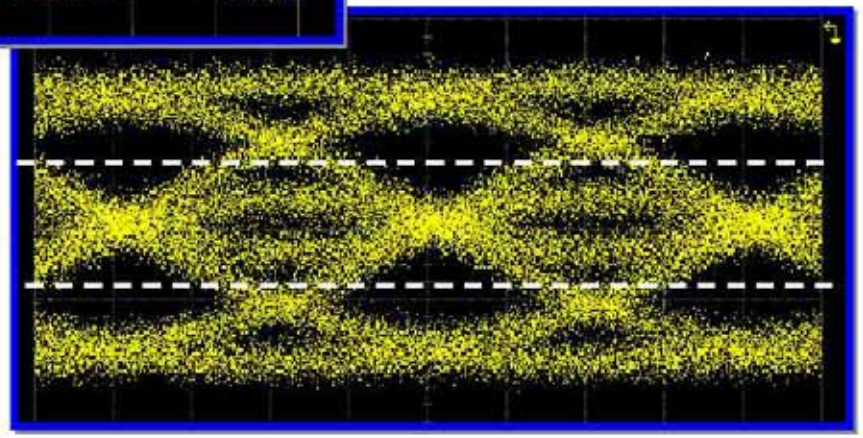
Tyco – 32" Trace – 6" Line Card



- FIR Settings
  - 10 dB Attenuation
  - 145 ps delay
- Performance at 10 Gb/s
  - BER $<10^{-14}$ (time limited measurement)

25 ps/div

Pre-emphasized data



Backplane Output

25 ps/div

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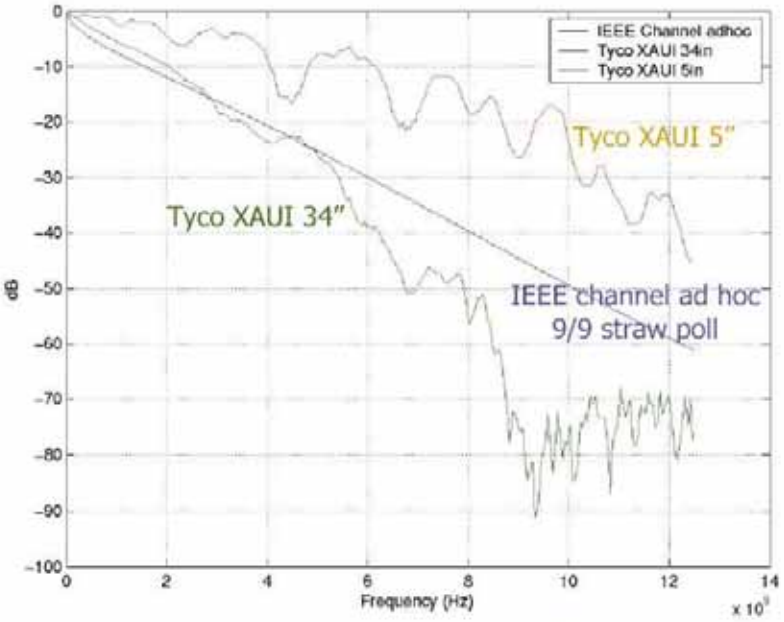
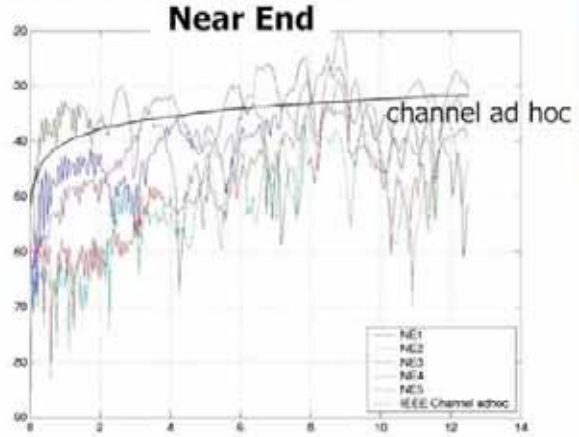
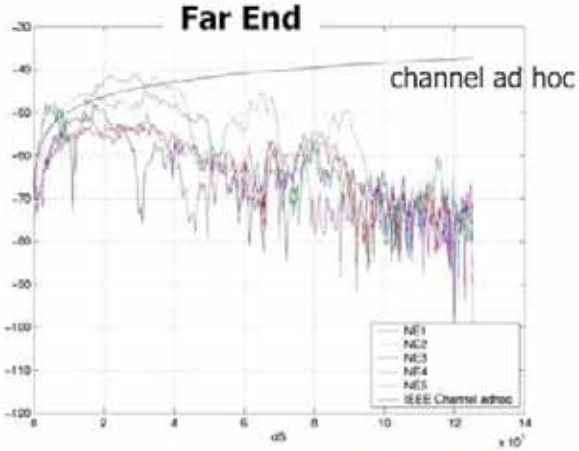
See sinsky_01_0904.pdf

S-parameters and Crosstalk



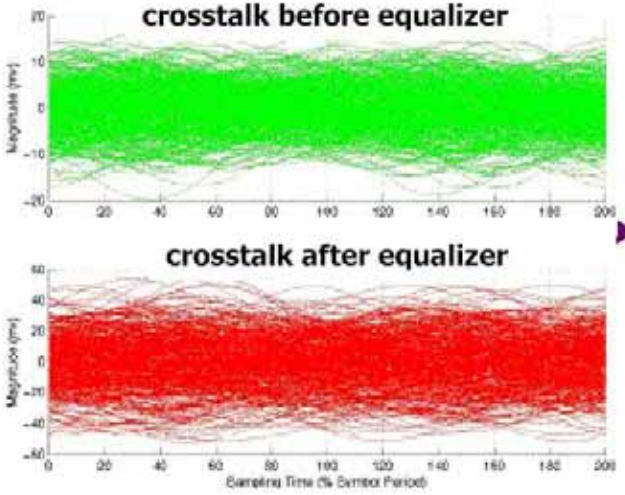




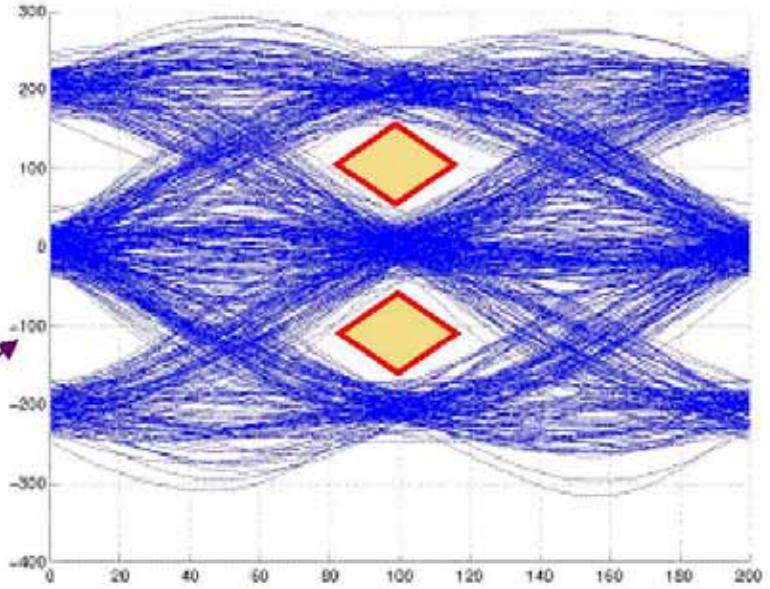
Total of 10 aggressors, 5 near/5 far, each synchronous with random delay w/ respect to measured signal, near end is more dominate

See koziuk_01_0904.pdf

Duobinary crosstalk @ slicer – 34”



Crosstalk after equalizer is approximately 2.8x greater than before equalizer

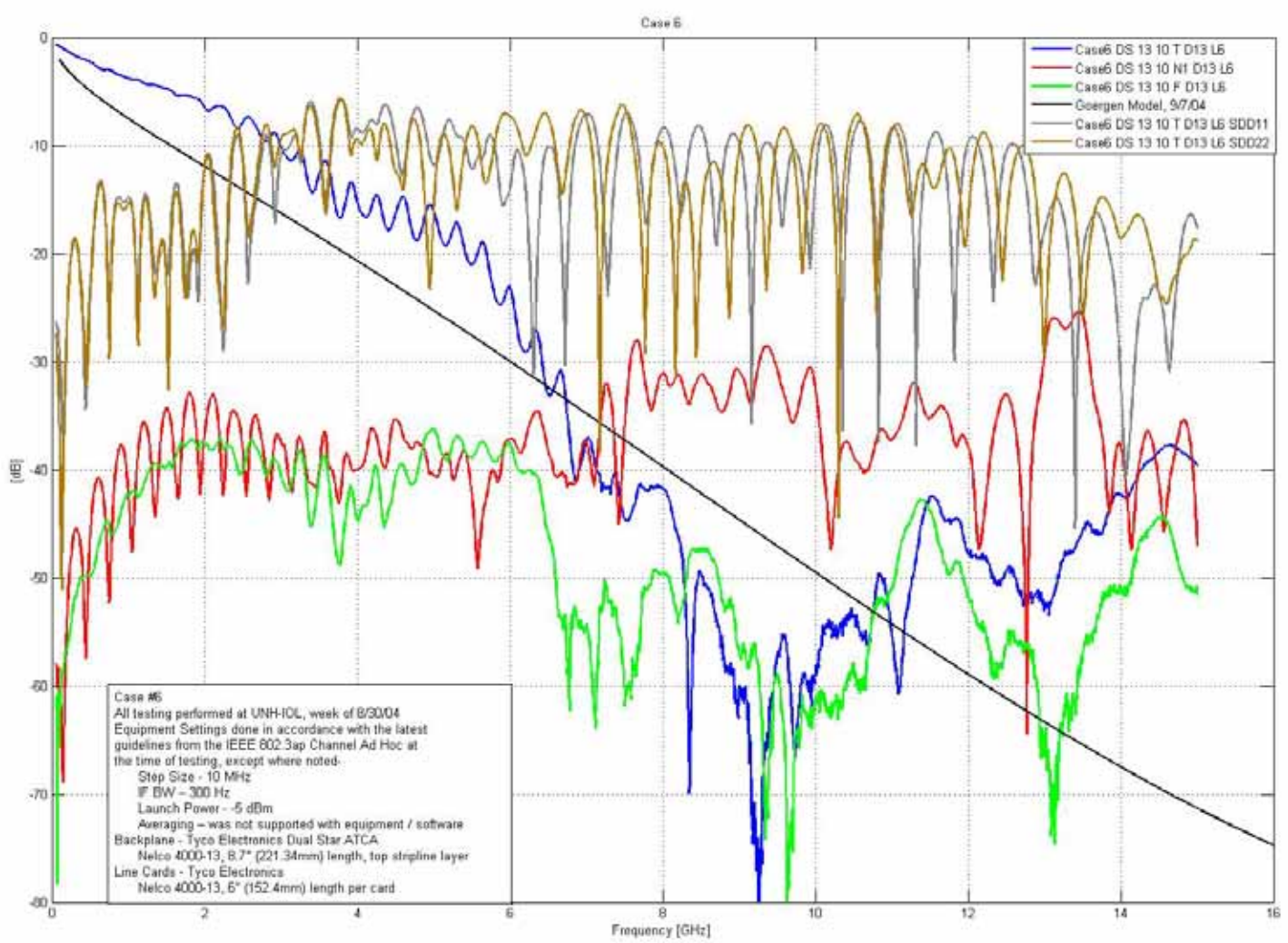


Recoverable data within Duobinary data eye, aiding 10Gb/s operation in systems

Note: FSE results only, DFE not used

See koziuk_01_0904.pdf

Case #6



See dambrosia_01_0904.pdf

Case 6 with Organic Package

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

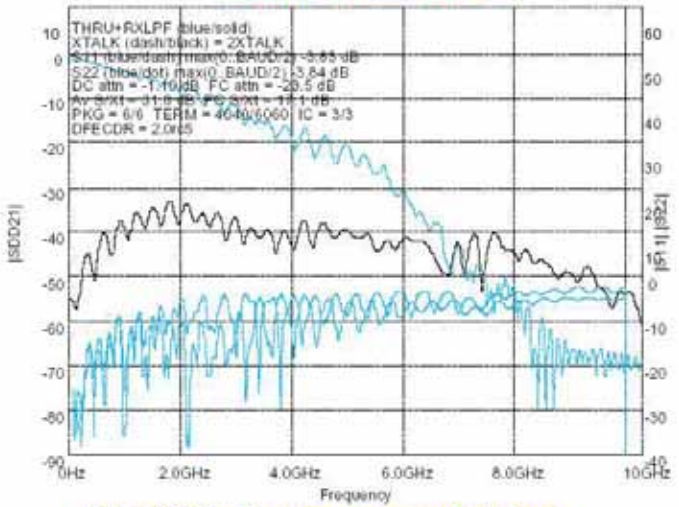
	FFE2	FFE3	FFE4
DFE0	e-3	e-4	e-6
DFE1	e-8	0%	e-11
DFE2	e-8	0%	0%
DFE3	e-8	0%	2.8%
DFE4	e-9	4.6%	3.4%
DFE5	e-11	5.5%	8.4%

Summary

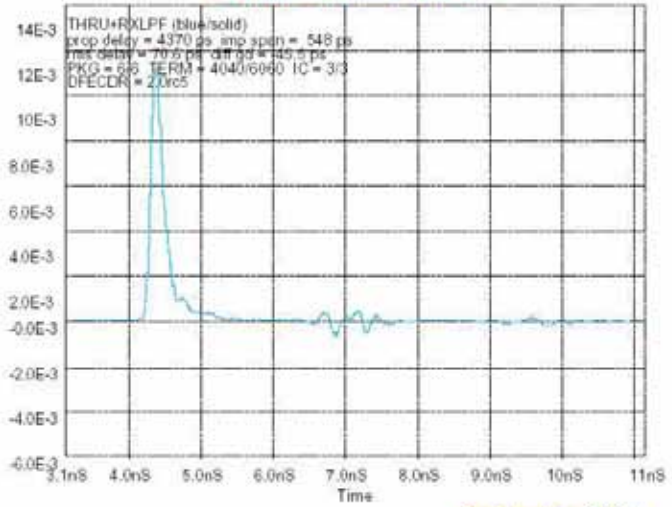
- Channel response -23.5dB
  - Moderate attenuation
- Impulse response shows moderate reflections
- Min solution FFE3DFE4

* 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



See abler_01_0904.pdf

Case 6 with Plastic Package

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

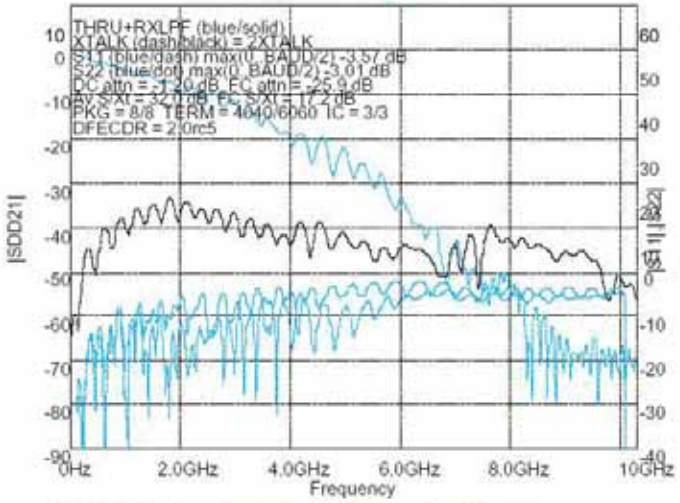
	FFE2	FFE3	FFE4
DFE0	e-3	e-3	e-4
DFE1	e-7	0%	e-9
DFE2	e-8	0%	e-11
DFE3	e-8	4.1%	0.1%
DFE4	e-10	4.4%	0%
DFE5	0%	4.6%	3.9%

Summary

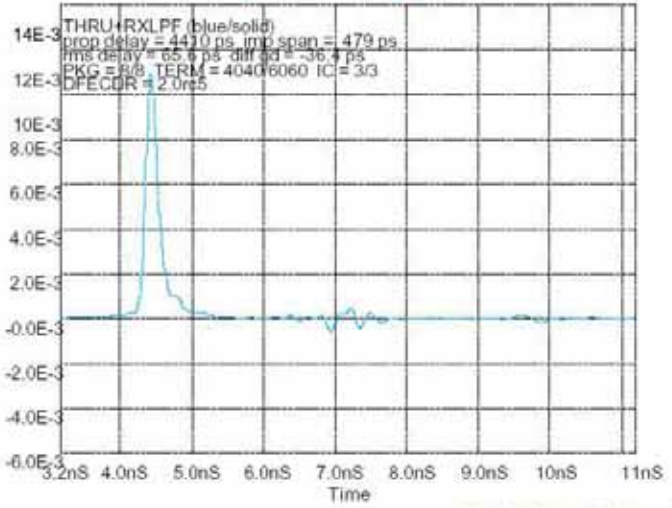
- Channel response -25.9dB
  - Moderate attenuation
- Impulse response shows moderate reflections
- Min solution FFE3DFE3

* 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

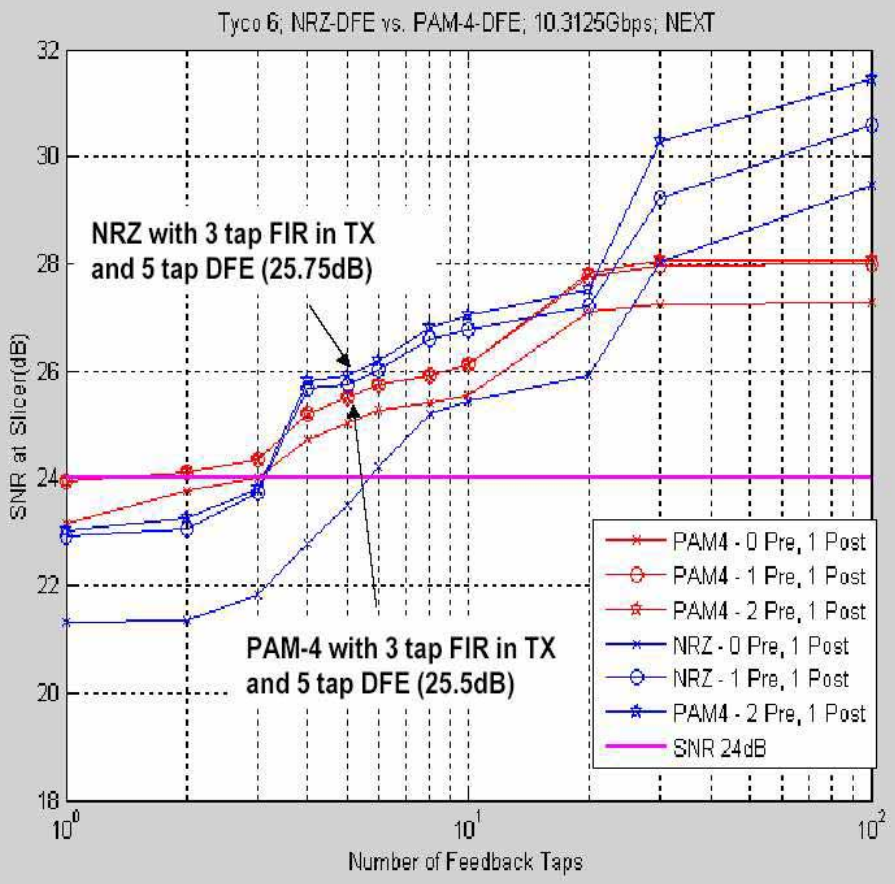


See abler_01_0904.pdf

LSI LOGIC

NRZ vs PAM-4

Tyco Channel 6; 10.3125Gbps; NEXT;



- This channel exhibited 8.0dB loss between the Nyquist frequency for PAM-4 (2.5GHz) and that for NRZ (5.0GHz). (Difficult to estimate due to ringing.)
- With NEXT and three tap FIR, NRZ meets SNR goal with four DFE taps and PAM-4 requires two taps.
- With NEXT, performance of three tap FIR and 5 DFE taps, NRZ shows 0.25dB margin over PAM-4.

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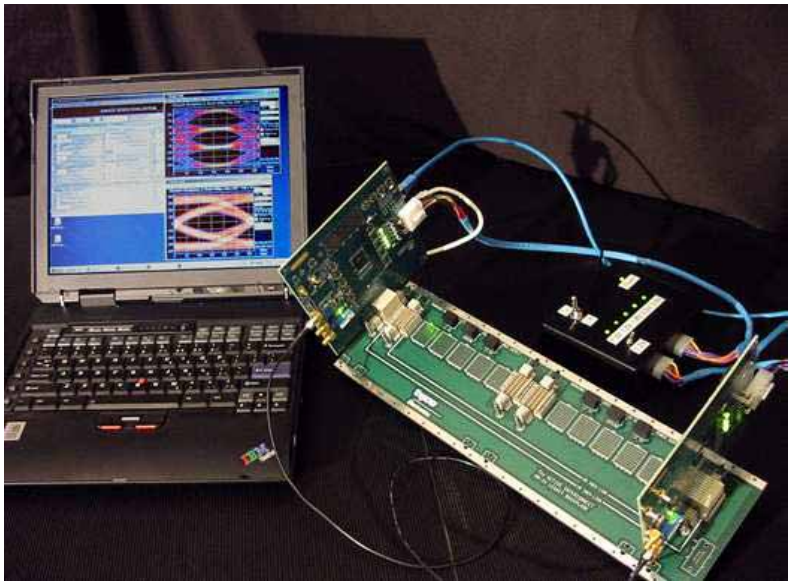
See lui_01_0904.pdf

10G Payload Measured Feasibility Data

- 6 backplane configurations
  - 4000-6, 4000-13, 4000-13SI, 6000, 6000SI, and ISOLA 620
  - 4.75 mil wide traces (4 mil on 4000-6 variants)
- 3 Lengths
  - 8”, 22” and 36” lengths
- 3 types of HM-Zd signal routing (4 FEXT, 4 NEXT)
  - QuadRoute Tx to Tx, Rx to Rx
  - QuadRoute Tx to Rx, Rx to Tx
  - Non QuadRoute

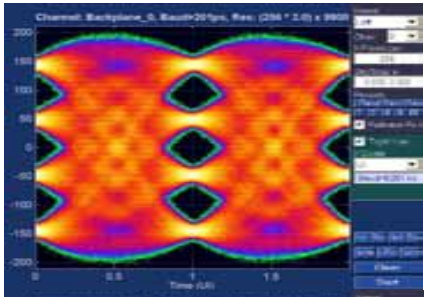


	Pair A/B	Pair C/D	Pair E/F	Pair G/H
Column 5	Tx_0	Tx_1	Tx_2	Tx_3
Column 6	Rx_0	Rx_1	Rx_2	Rx_3

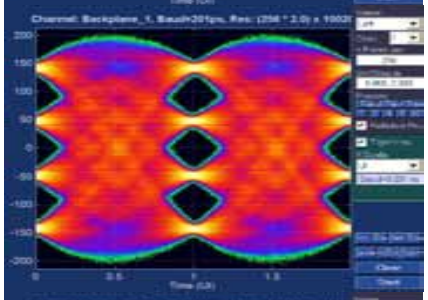
See hoppin_01_0304.pdf

Accelerant Networks / Synopsys Measured 10G Payload Data

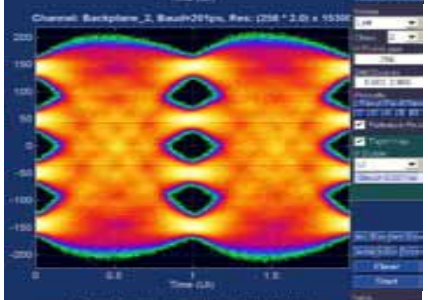
1 C0



1 C1



1 C2



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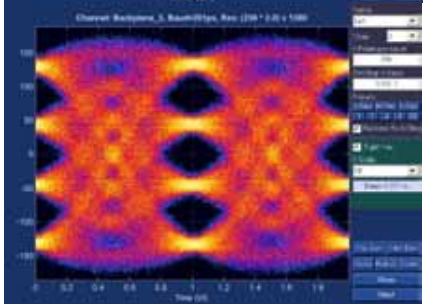


5G PAM4 .13u device running at 10G. Gray Encoding, 0% Overhead

All 8 pairs active on QuadRoute FR4 4000-13SI, full crosstalk conditions (4 FEXT, 4 NEXT)

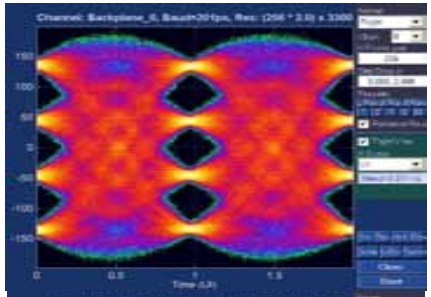
All devices tested to BER 10^-12 using 2^31 PRBS Pattern over 36 inches

8” and 22” link conditions across all 6 materials passed BER 10^-12 using 2^31 PRBS Pattern

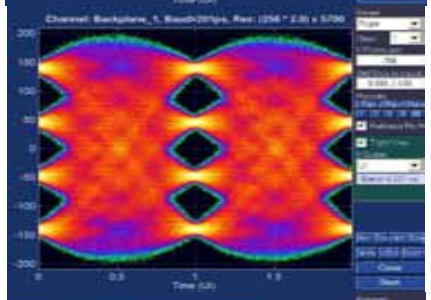
Out of 336 links tested, 34 36” link configurations did not pass and will be the subject of future simulation work on a mutually agreed to channel model with purpose built 10G designs

See hoppin_01_0304.pdf

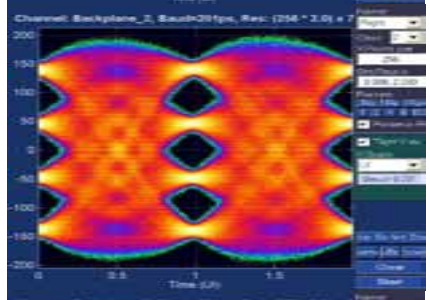
2 C0



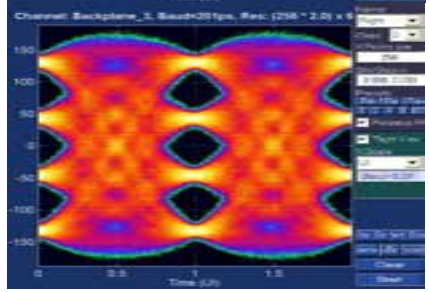
2 C1



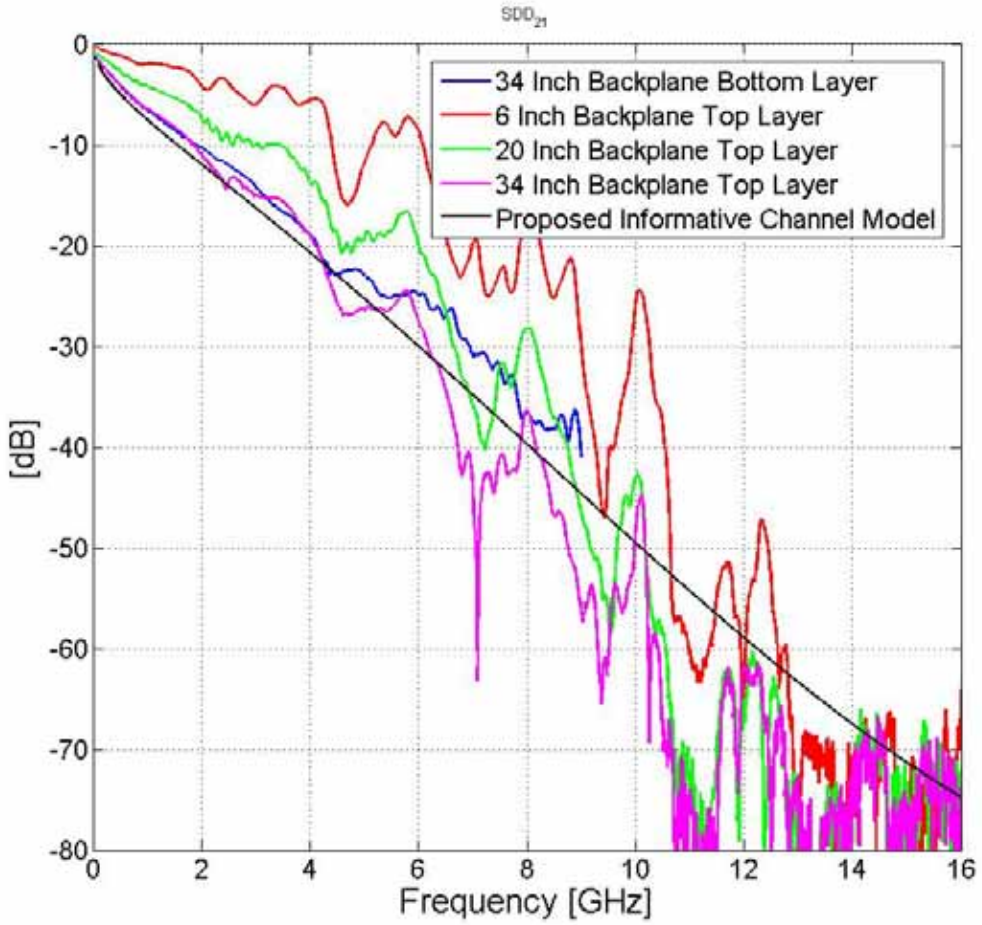
2 C2



2 C3



10Gb/s with PAM-4 to 10^-12 BER with Crosstalk Across These Channels**

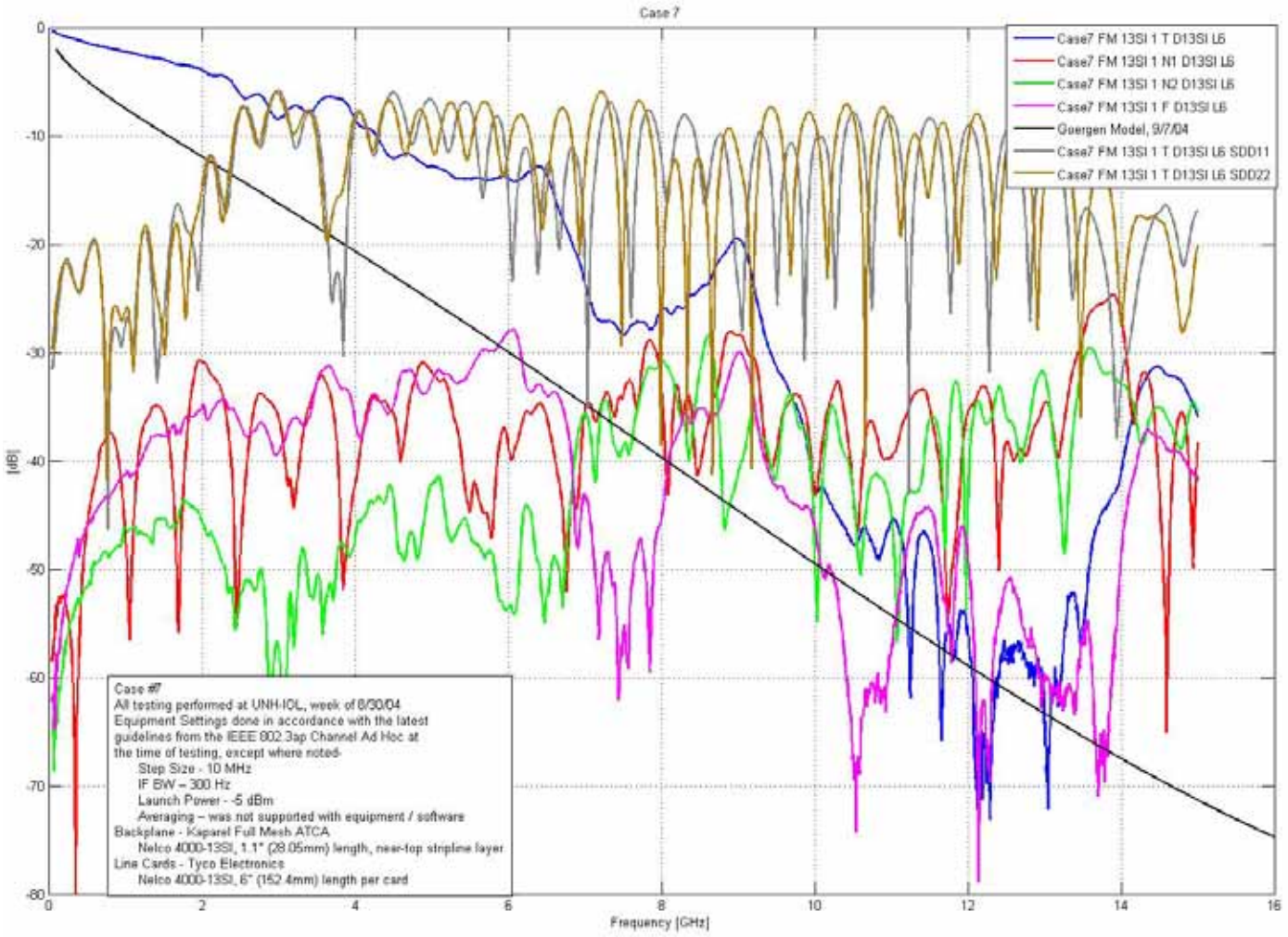


** Note – Measurements are channel approximations. Actual line cards had active devices on them. Channel measurements made with passive SMA line cards

Active cards – 3”

Passive line cards – 2”

Case #7



See dambrosia_01_0904.pdf

Case 7 with Organic Package

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

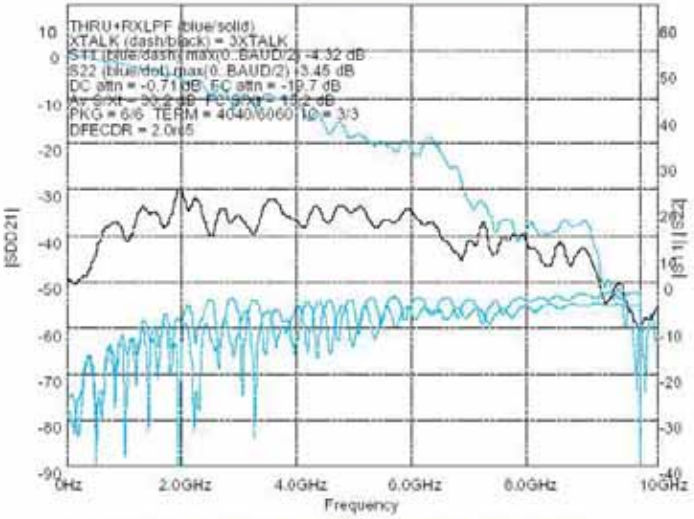
	FFE2	FFE3	FFE4
DFE0	e-5	e-5	e-6
DFE1	e-9	0.1%	0%
DFE2	e-11	4.6%	3.8%
DFE3	0.1%	4.4%	4.8%
DFE4	6.2%	6.2%	12.1%
DFE5	10.9%	9.7%	9.7%

Summary

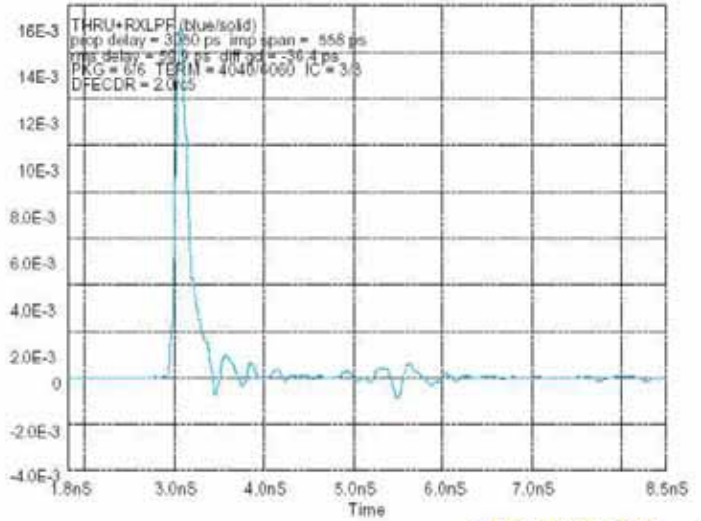
- Channel response -19.7dB
  - Relatively low attenuation
- Impulse response shows multiple reflections
- Min solution FFE3DFE1

* 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



See abler_01_0904.pdf

Case 7 with Plastic Package

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

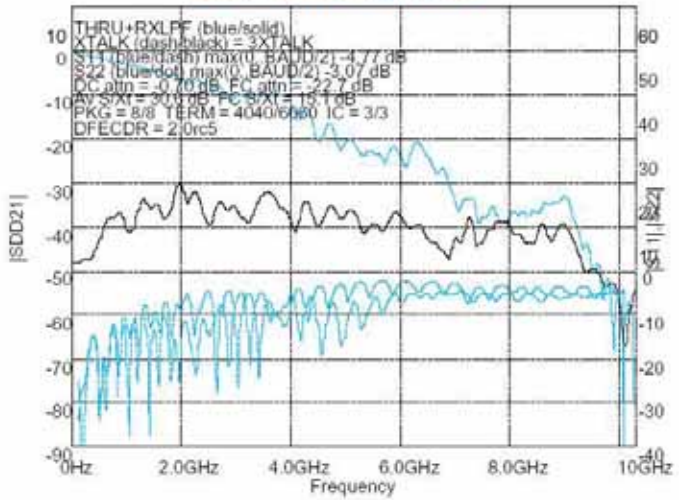
	FFE2	FFE3	FFE4
DFE0	e-4	e-4	e-5
DFE1	e-11	e-9	0.4%
DFE2	e-9	0.4%	5.4%
DFE3	4.1%	1.7%	3.9%
DFE4	1.5%	4.7%	5.8%
DFE5	5.9%	3.8%	4.2%

Summary

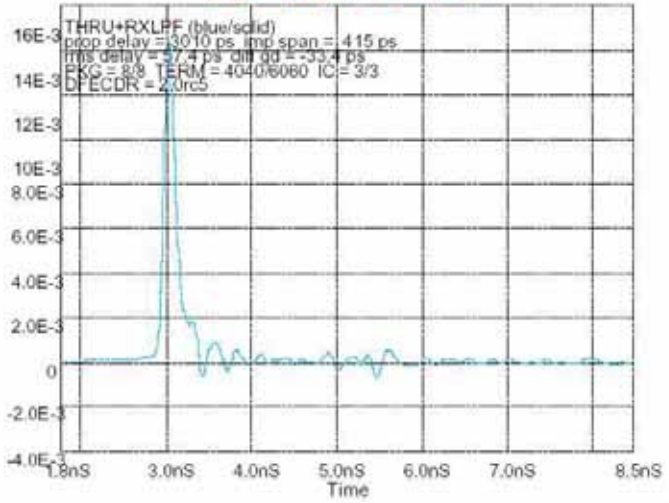
- Channel response -22.7dB
  - Relatively low attenuation
- Impulse response shows multiple reflections
- Min solution FFE3DFE2

* 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



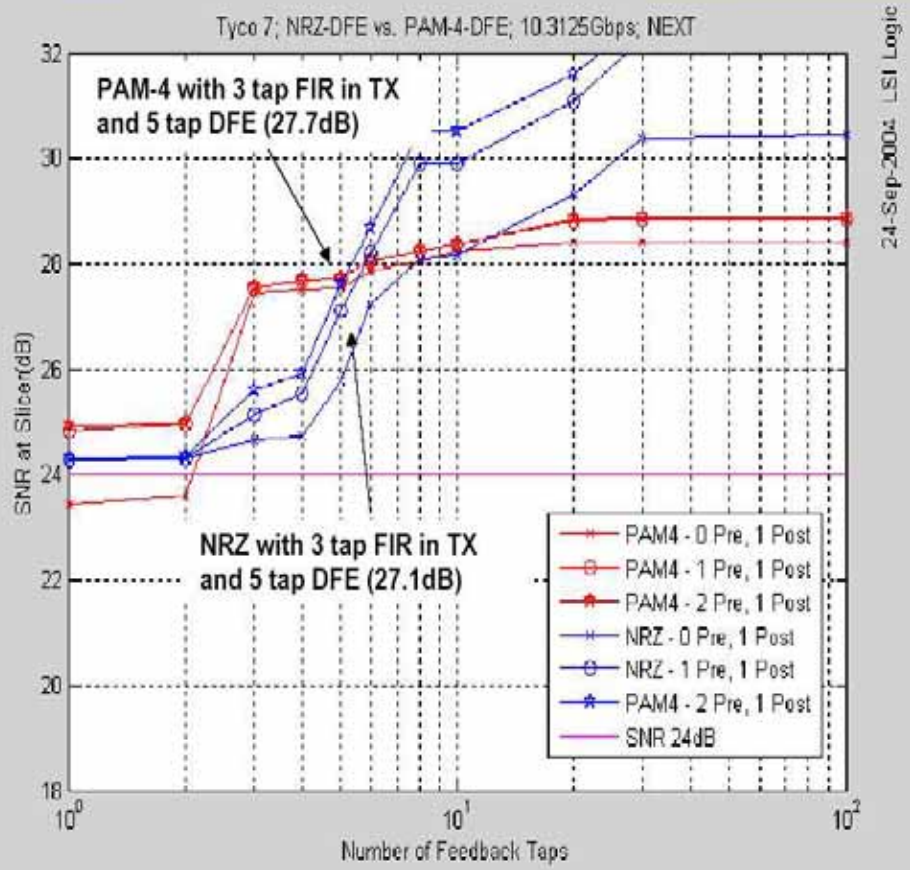
Impulse Response



See abler_01_0904.pdf

NRZ vs PAM-4

Tyco Channel 7; 10.3125Gbps; NEXT;



- This channel exhibited 6.5dB loss between the Nyquist frequency for PAM-4 (2.5GHz) and that for NRZ (5.0GHz).
- With NEXT and three tap FIR, both NRZ and PAM-4 meet SNR goal with one DFE tap.
- With NEXT, performance of three tap FIR and 5 DFE taps, NRZ shows 0.6dB loss relative to PAM-4.

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See lui_01_0904.pdf

Vendor Quote - Nortel

"Nortel supports a channel model that addresses legacy backplanes (2.5G/3.125G) with significant via stubs (no back drilling). ATCA full mesh and dual star backplanes should be used as a reference legacy backplane example for the standard."

Bryan Parlor

Nortel Networks