IBM Research

Line Signaling Performance Comparison on Emerson Channel

Troy Beukema
Mounir Meghelli
John Ewen

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Contributors/Supporters

Mike Peng Li, Altera

Pravin Patel, IBM

Mike Dudek, Qlogic

Scott Kipp, Brocade

Tom Palkert, Luxtera

Mark Bugg, Molex

Peerouz Amleshi, Molex

Scott Sommers, Molex

Myles Kimmit, Emulex

Jitendra Mohan,TI

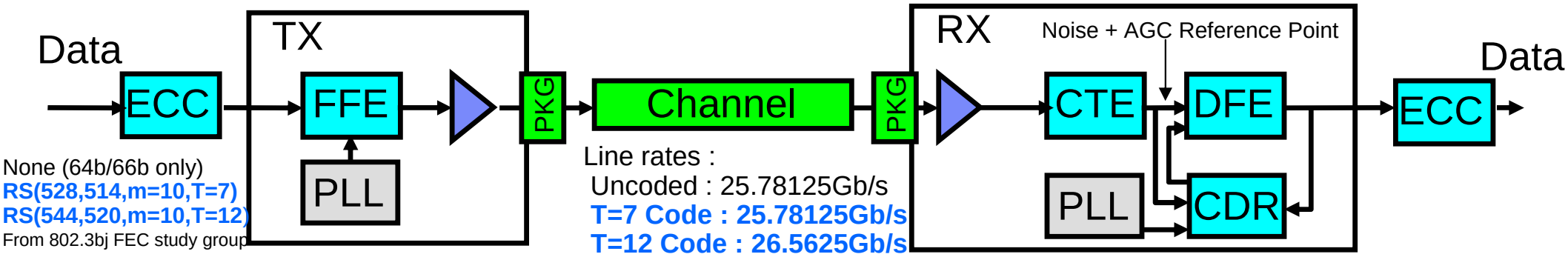
Ziad Hatab, Vitesse

Frank Chang, Vitesse

George Noh, Vitesse

Piers Dawe, IPtronics

Update/Review of Reference Model I/O Parameters



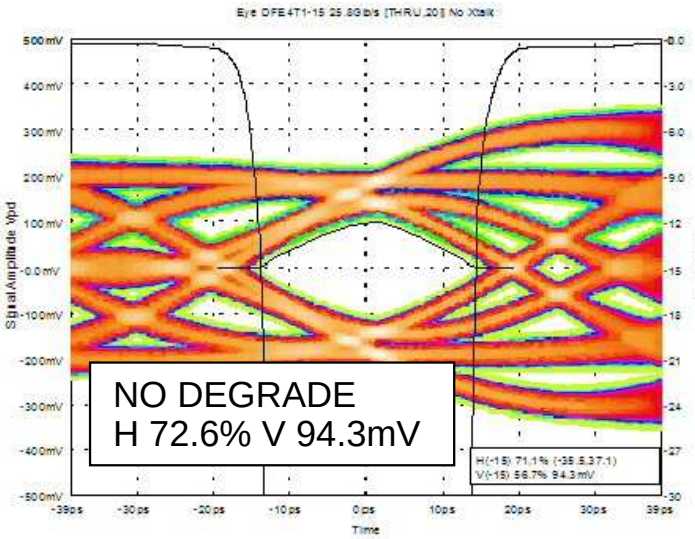
PARAMETER	VALUE NRZ	VALUE PAM4
PEAK SWING	1000mVppd	1000mVppd
RJ	350fs RMS	350fs RMS
DCD	1.6% (49.2:50.8)	0
SJ	5% UI	5%
BW	-1.5dB@13GHz 2 pole Bessel	-1.5dB @13GHz 2 pole Bessel
PKG	-2.6dB@13GHz	-2.6dB @13GHz
FFE	4 tap 2 precursor	4 tap 2 precursor

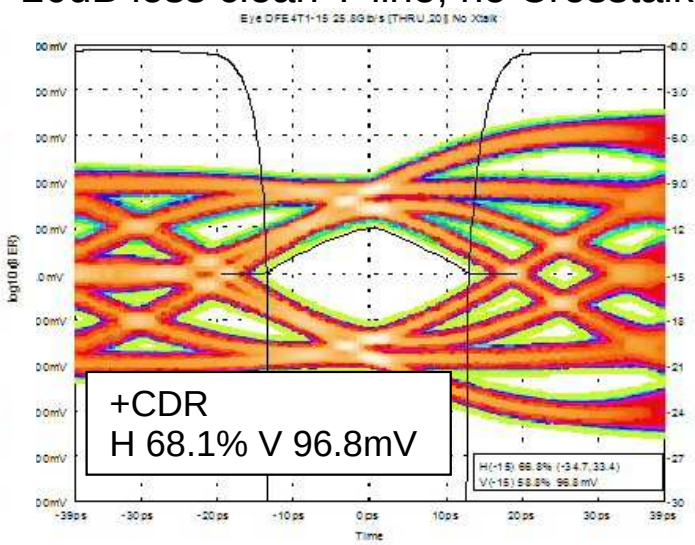
PARAMETER	VALUE NRZ	VALUE PAM4
NOISE@ SLICER AN	2.75mV RMS	2mV RMS
Minimum Latch Overdrive AM	20mVpd	20mVpd
AGC LEVEL	280mVpd	280mVpd
AGC GAIN MAX	3	3
RJ	350fs RMS	350fs RMS
SJ	5% UI	0%
BW	-1.5dB @13GHz 4 pole Bessel	-1.5dB @13GHz 4 pole Bessel
PKG	-2.7dB @ 13GHz	-2.7dB @ 13GHz
CTE	12dB max peak @ 13GHz 3 pole 2 zero, adapted	12dB max peak @ 13GHz 3 pole 2 zero, adapted
DFE	15 tap	15 tap (2X NRZ)

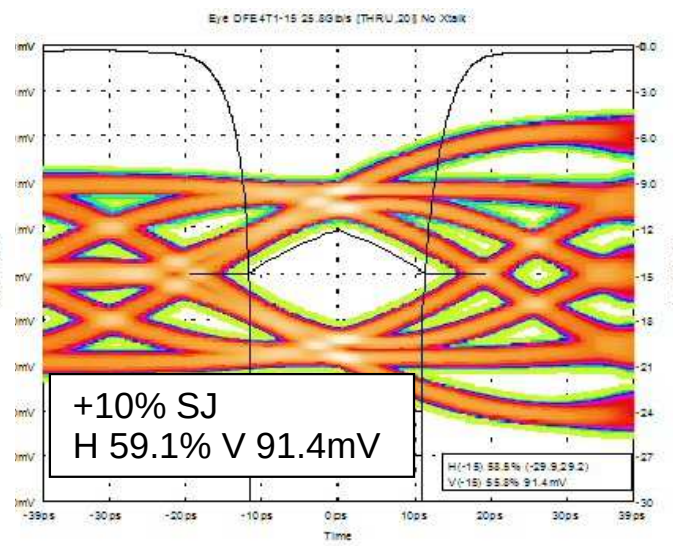
Simplified T & R model
Parameters selected to approximate
"real" hardware realization performance
Set up to "favor" PAM4 : 2x complex DFE,
no Rx SJ, No Tx DCD
Target BER = 1E-15
CDR active for NRZ & PAM4

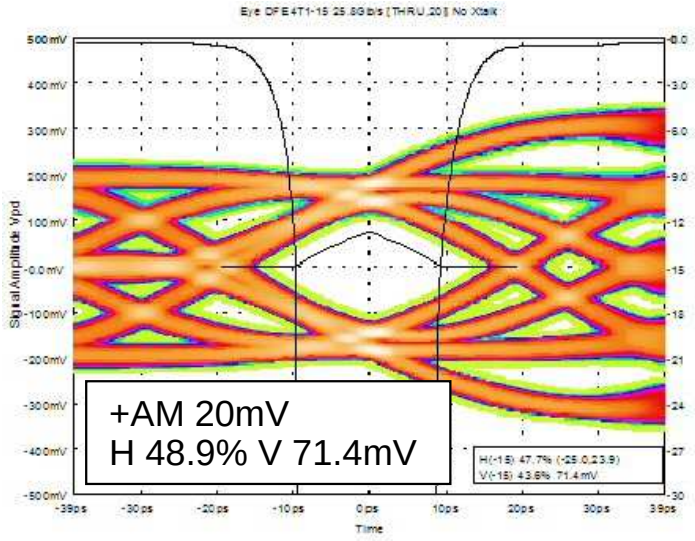
NRZ Eye Vs. I/O Core Degradations

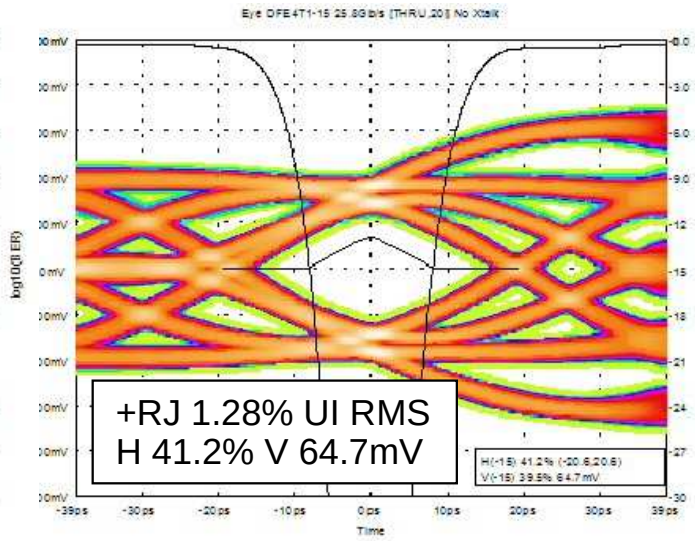
~20dB loss clean T-line, no Crosstalk

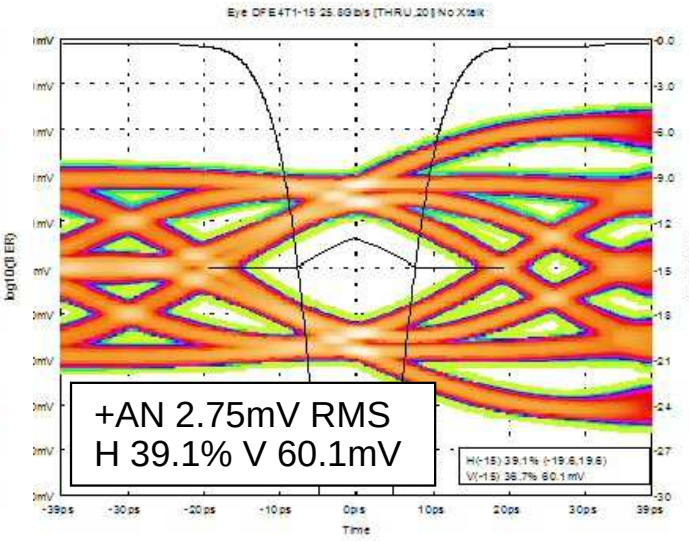










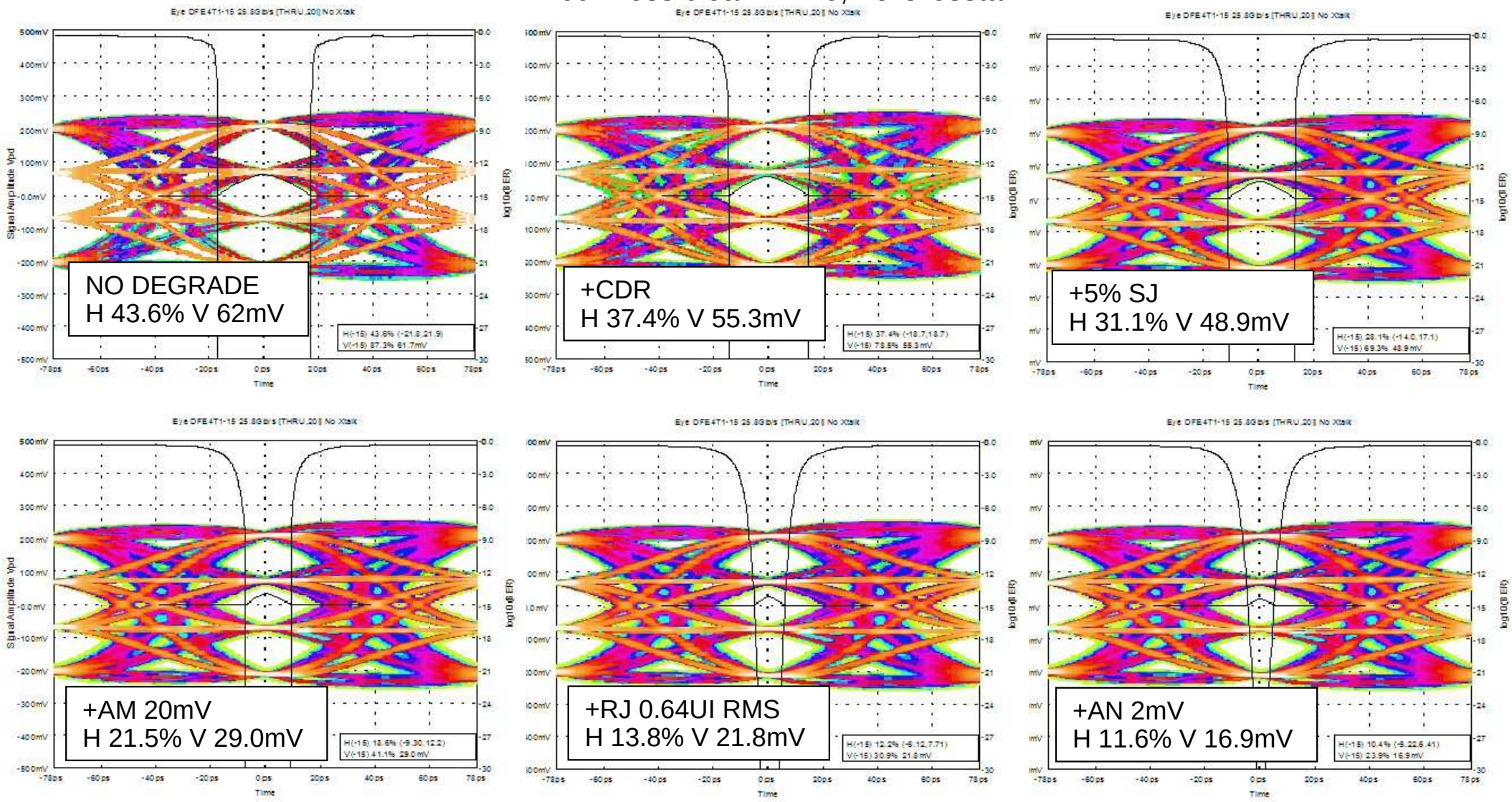


NRZ HAS GOOD MARGIN WITH I/O CORE DEGRADATIONS

ALL DEGRADATIONS ARE SIGNIFICANT AND MUST BE MODELED

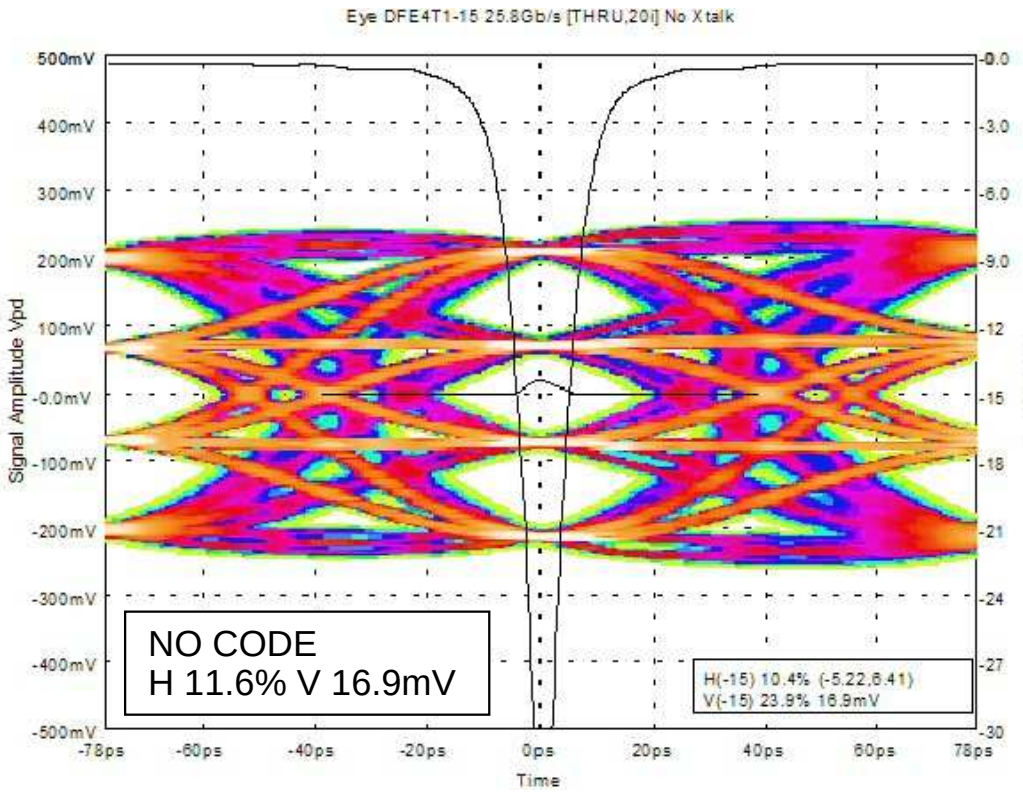
PAM4 Eye Vs. I/O Core Degradations

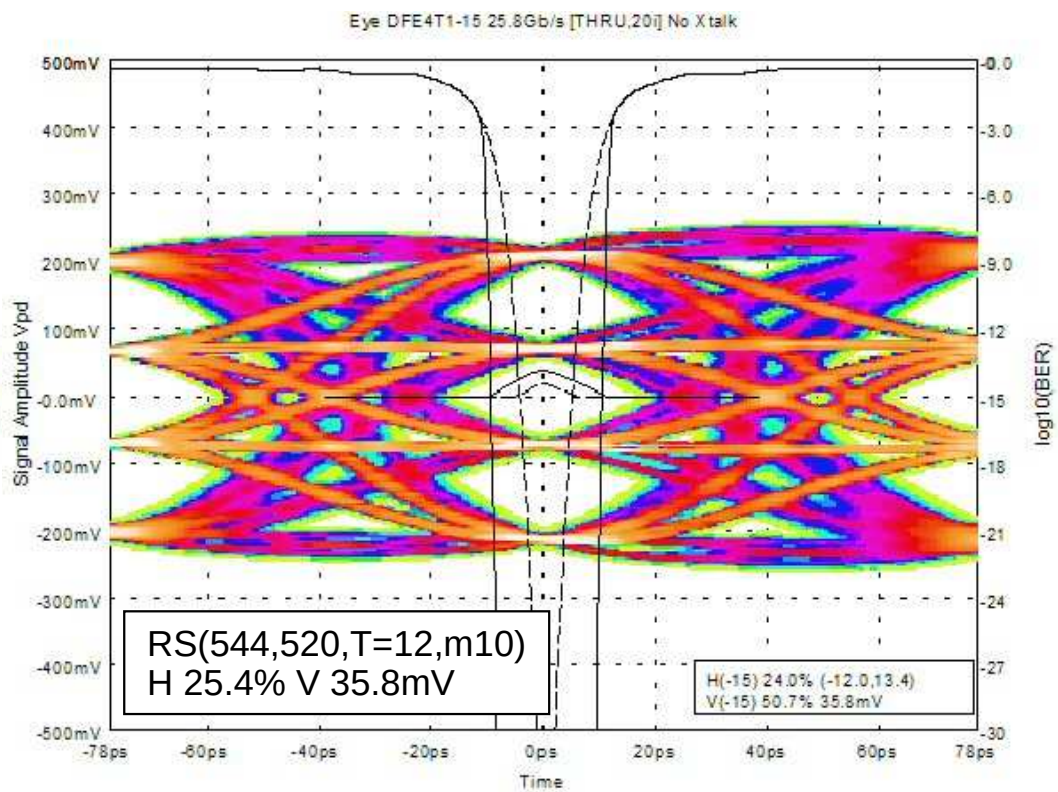
~20dB loss clean T-line, no Crosstalk



PAM4 HAS LOW MARGIN WITH I/O CORE DEGRADATIONS DUE TO 3x SMALLER VERTICAL EYE

ECC Mitigates I/O Core Degradations

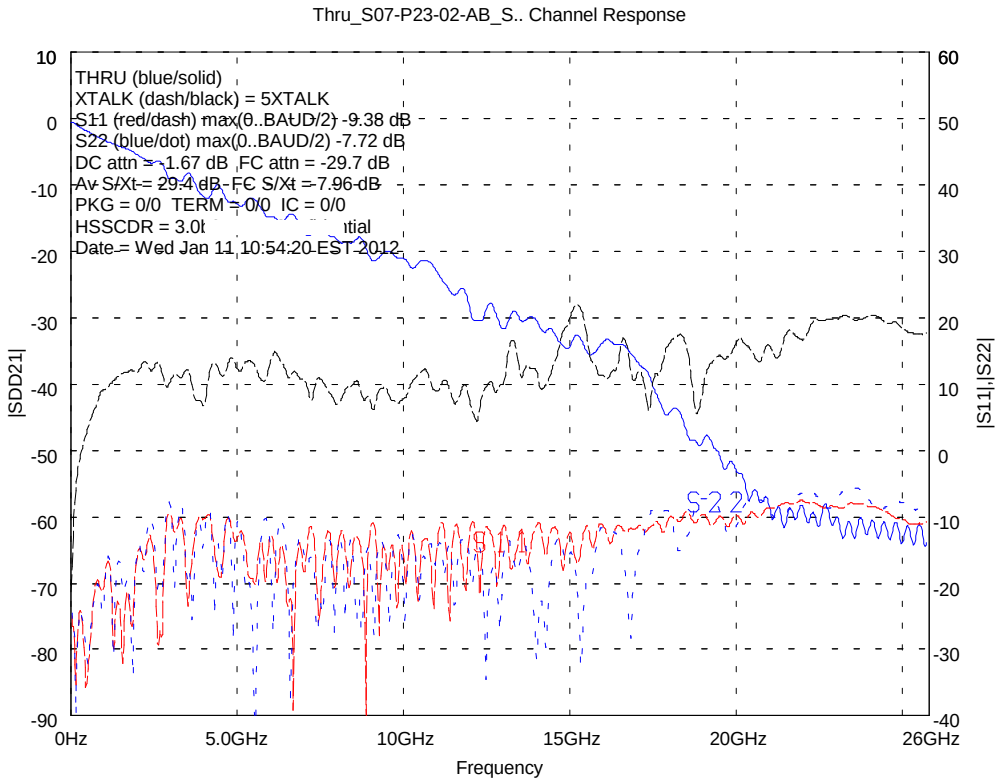


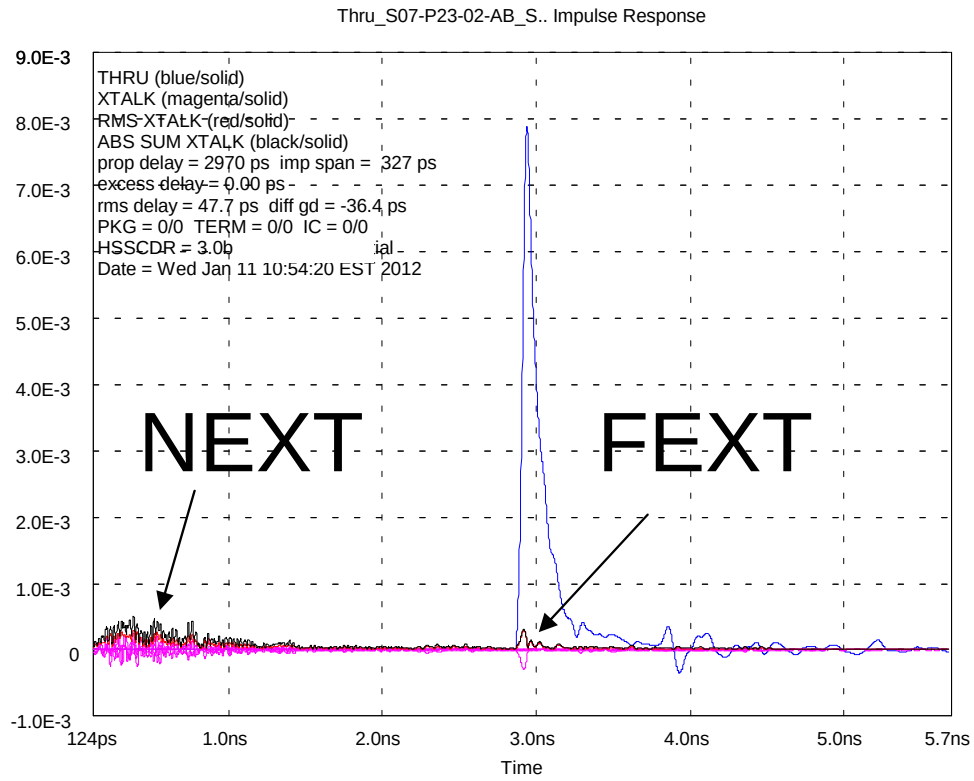


But is it enough on a tough channel?

Emerson Short Channel Response

SHORT: Thru_S07-P23-02-AB_S09-P23-02-CD_NNN.s4p

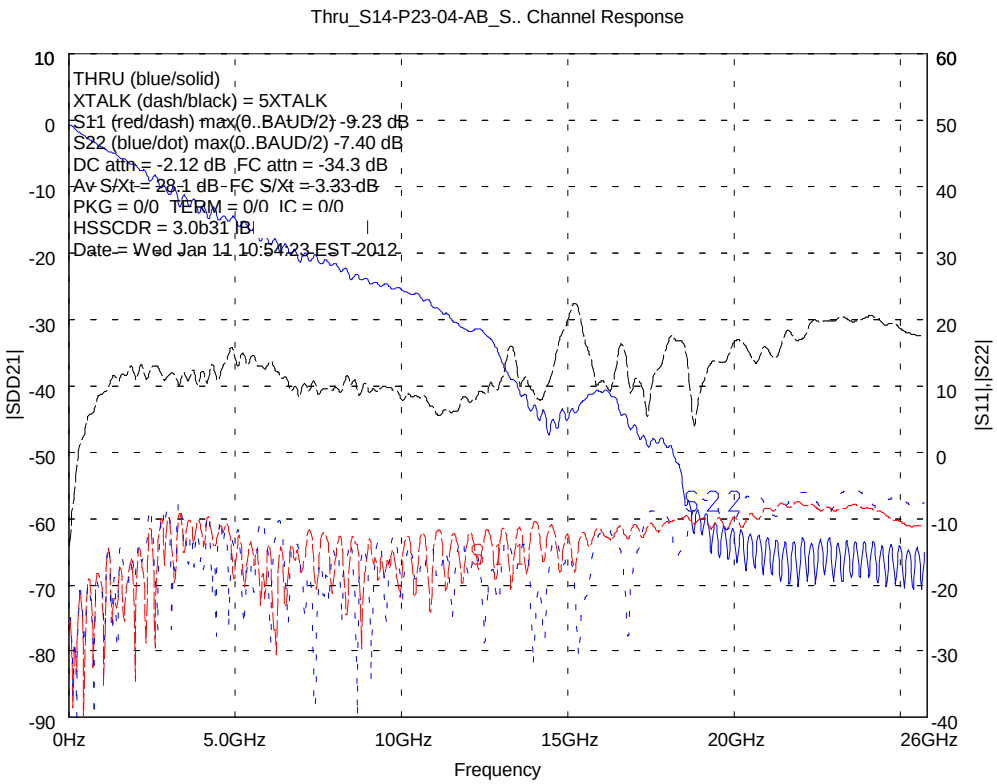


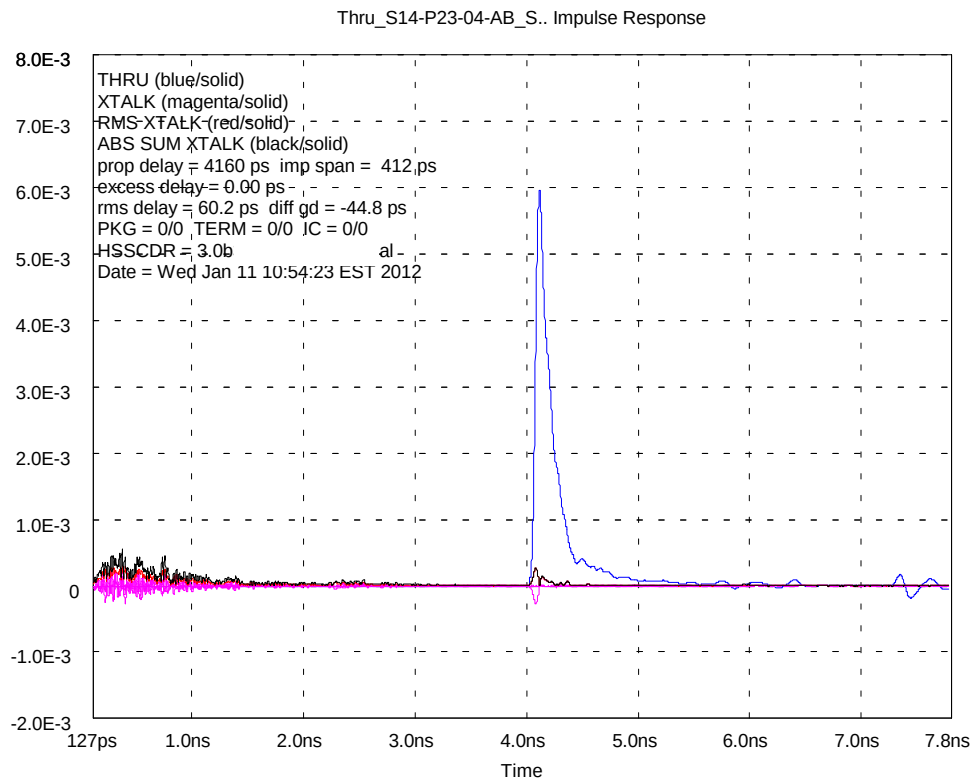


1 FEXT+4NEXT
BAUD/2 LOSS 29.7dB
BAUD/2 S/Xt 8dB

Emerson Long Channel Response #1

LONG1 : Thru_S14-P23-04-AB_S06-P20-10-CD_NNN.s4p

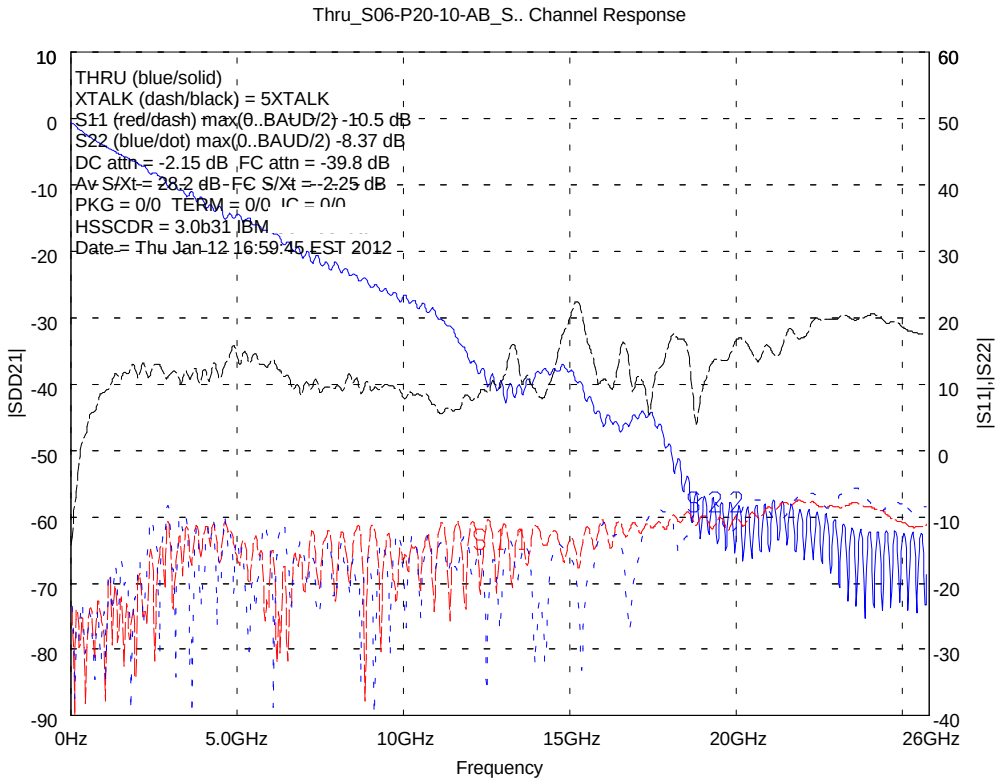


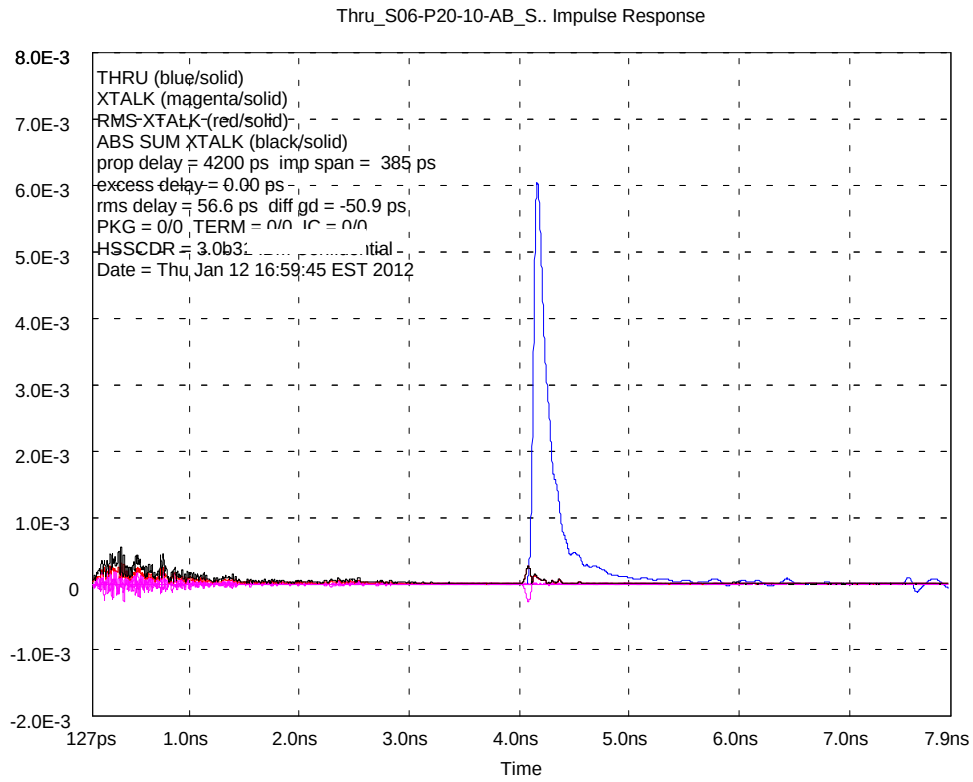


1 FEXT+4NEXT
BAUD/2 LOSS 34.3dB
BAUD/2 S/Xt 3.3dB

Emerson Long Channel Response #2

LONG2 : Thru_S06-P20-10-AB_S14-P23-04-CD_NNN.s4p





1 FEXT+4NEXT
BAUD/2 LOSS 39.8dB
BAUD/2 S/Xt 2.25dB

Emerson Channel HEYE/VEYE Ideal I/O[1] Results Summary

1E-15 confidence on all results
DFE1 Error prop. for NRZ ECC
No Error prop. for PAM4 ECC

NRZ
T=12

	HEYE	VEYE
LONG1	49.20%	40.4mV
LONG2	47.90%	43.1mV
SHORT	51.30%	48.0mV

NRZ
T=7

	HEYE	VEYE
LONG1	43.60%	35.8mV
LONG2	44.2%	41.5mV
SHORT	39.4%	34.2mV

NRZ
T=0

	HEYE	VEYE
LONG1	0%	0mV
LONG2	0%	0.1mV
SHORT	0%	0.4mV

PAM4 T=12

	HEYE	VEYE
LONG1	17.90%	17.0mV
LONG2	31.80%	24.9V
SHORT	27.3%	33.0mV

PAM4 T=7

	HEYE	VEYE
LONG1	16.0%	15.3mV
LONG2	21.60%	26.8mV
SHORT	24.80%	29.0mV

PAM4 T=0

	HEYE	VEYE
LONG1	0%	0mV
LONG2	2.4%	2.5mV
SHORT	5%	4.2mV

NRZ Ideal I/O model supports channels with T=7 or T=12 RS code.
PAM4 Ideal I/O model supports channels with T=7 or T=12 RS code
Uncoded PAM4 has more margin than uncoded NRZ on 2 channels

[1]All I/O core degradations set to 0, including no CDR, IC Frequency responses remain in I/O core models

Emerson Channel HEYE/VEYE AM=10mV[1] Results Summary

1E-15 confidence on all results
DFE1 Error prop. for NRZ ECC
No Error prop. for PAM4 ECC

NRZ
T=12

	HEYE	VEYE
LONG1	34.50%	28.2mV
LONG2	34.30%	30.3mV
SHORT	37.80%	35.0mV

NRZ
T=7

	HEYE	VEYE
LONG1	28.10%	20.3mV
LONG2	28.3%	25.0mV
SHORT	30.0%	26.4mV

NRZ
T=0

	HEYE	VEYE
LONG1	0%	0mV
LONG2	0%	0mV
SHORT	0%	0mV

PAM4 T=12

	HEYE	VEYE
LONG1	6.80%	5.2mV
LONG2	11.80%	12.4mV
SHORT	17.1%	19.2mV

PAM4 T=7

	HEYE	VEYE
LONG1	3.4%	2.8mV
LONG2	10.50%	12.4mV
SHORT	14.20%	16.3mV

PAM4 T=0

	HEYE	VEYE
LONG1	0%	0mV
LONG2	0%	0mV
SHORT	0%	0mV

NRZ model supports channels with T=7 or T=12 RS code.

PAM4 model does not support all channels with either T=7 or T=12 RS code

[1]All I/O core degradations turned on, including CDR, with AM reduced to 10mV

Emerson Channel HEYE/VEYE AM=20mV[1] Results Summary

1E-15 confidence on all results
DFE1 Error prop. for NRZ ECC
No Error prop. for PAM4 ECC

NRZ
T=12

	HEYE	VEYE
LONG1	25.50%	18.4mV
LONG2	25.90%	20.3mV
SHORT	29.90%	25.2mV

NRZ
T=7

	HEYE	VEYE
LONG1	18.20%	12.2mV
LONG2	19.90%	15.2mV
SHORT	21.40%	16.3mV

NRZ
T=0

	HEYE	VEYE
LONG1	0%	0mV
LONG2	0%	0mV
SHORT	0%	0mV

PAM4 T=12

	HEYE	VEYE
LONG1	0%	0.0mV
LONG2	3.50%	3.4mV
SHORT	10.70%	9.6mV

PAM4 T=7

	HEYE	VEYE
LONG1	0%	0.0mV
LONG2	3.20%	3.2mV
SHORT	6.90%	6.2mV

PAM4 T=0

	HEYE	VEYE
LONG1	0%	0mV
LONG2	0%	0mV
SHORT	0%	0mV

NRZ model supports channels with T=7 or T=12 RS code and realistic I/O model.

PAM4 model does not support any channel with either T=7 or T=12 RS code

[1]All I/O core degradations turned on, including CDR, with AM set at nominal value to approximate a worst-case core

More Realistic PAM4 I/O Model

Add 5% Rx SJ and 1.6% Tx DCD Back in
Set Rx CTE bandwidth ½ of NRZ bandwidth to align frequency peak to BAUD/2
Add a stronger ECC[1] : RS(448,416,T=16,m=10) RS(560,514,T=23,m=10) (6% OC)

Rx AM = 20mV

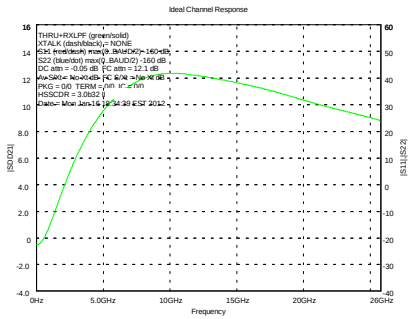
PAM4 T=23

	HEYE	VEYE
LONG1	0%	0.0mV
LONG2	0%	0.0mV
SHORT	3.90%	3.4mV

PAM4 T=16

	HEYE	VEYE
LONG1	0%	0mV
LONG2	0%	0mV
SHORT	0%	0mV

Rx CTE Response 12dB @ 12.5GHz backed off to 12dB @ 6.25GHz



Rx AM = 10mV

PAM4 T=23

	HEYE	VEYE
LONG1	6.0%	5.3mV
LONG2	10.3%	10.4mV
SHORT	12.3%	11.8mV

PAM4 T=16

	HEYE	VEYE
LONG1	2.3%	3.5mV
LONG2	8.1%	8.1mV
SHORT	10.2%	9.6mV

More realistic PAM4 I/O model is not predicted to support the channels robustly even with T=16 and T=23 RS codes.

[1]From 802.3bj FEC study group

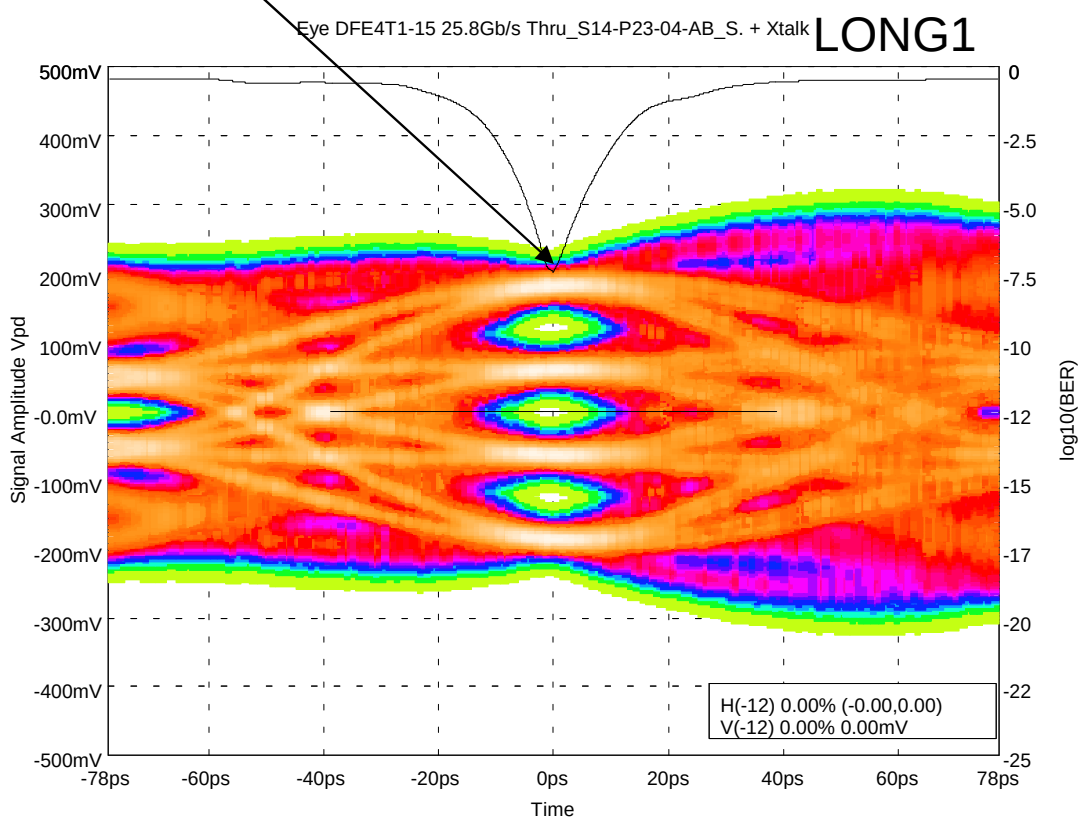
PAM4 results with no IO core or package (channels only)

Note : crosstalk uniformly swept across eye, BER floor drops to 2.6e-10 if crosstalk is held fixed at default phases.

PAM4 T=0

	HEYE	VEYE	BER FLOOR
LONG1	0%	0mV	1.7e-8
LONG2	0%	0mV	5.4e-13
SHORT	4.8%	3.5mV	1.6e-22

LONG1 Results Cross Checked vs. Freq. Domain MMSE SNR Analysis with finite equalizer



No Tx IC, Tx PKG, Rx PKG, Rx CTE, Rx IC responses used

Analysis	SNR	BER
Swept Xt Phase	~21.6dB	1.7e-8
Fixed Xt phase	**~22.7dB**	2.6e-10
MMSE FFE4/DFE15	**22.9dB**	1e-10
4-level ideal channel Noise only	~24.0	1e-12

MMSE results within 0.2dB of simulated result. Swept crosstalk phase degrades SNR ~1dB. Swept crosstalk phase is used to add margin to accommodate delay variations in channels.

Conclusions

- **Uncoded NRZ line signaling does not support Emerson Channels**
  - →Too much ILD (Reflections) and Crosstalk
- **Coded NRZ line signaling provides positive margin across the channels**
  - →NRZ channel recommendations remain 35dB max loss as based on previous studies, with ILD and crosstalk limits set so that proposed RS codes will give robust performance
- **PAM4 line signaling with a hard decision Rx slicer + RS block code is not predicted to support the Emerson channels robustly**
  - →Not robust even with a complex T=23 6% overclock RS code and Rx AM backed off to an unrealistically low value. PAM4 performance drops significantly with a more realistic I/O core model than that used in PAM4-NRZ comparisons.
  - →Uncoded simulation results are not consistent with data others have presented.[1] A cross check of simulation results found in this study agreed with a MMSE-DFE result within ~0.2 dB.[2]

[1] dabiri_01_1111, ran_01a_1111
[2] ewen_01_0311

Backup

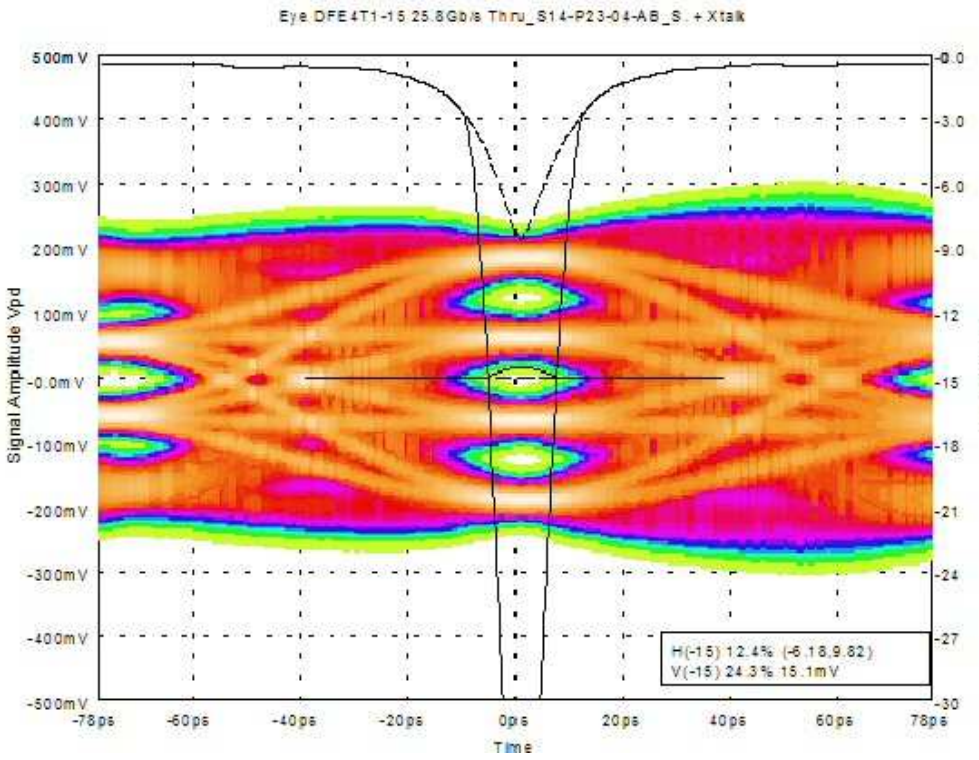
Eye diagrams

PAM4 with ideal I/O core on LONG1 and LONG2 channels

PAM4 and NRZ with ideal I/O core on LONG1 channel

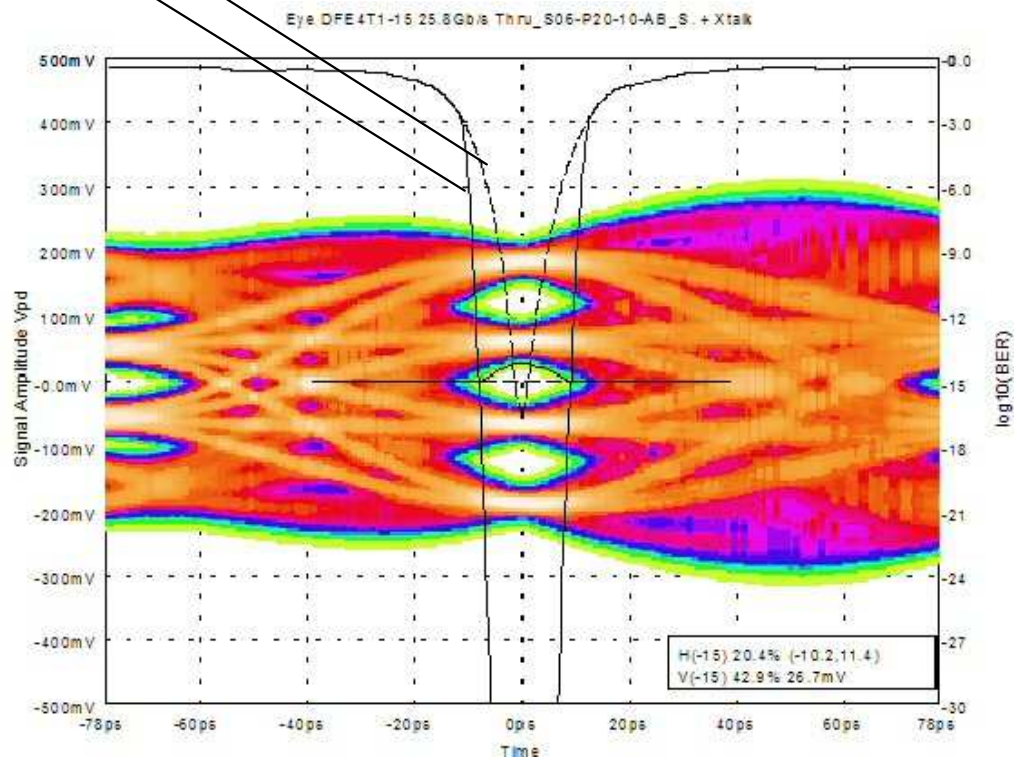
PAM4 on LONG1 and LONG2 Channels, I/O core deg=0

LONG1



T=7 RS code Uncoded

LONG2



More residual ISI from higher ILD / Reflection in LONG1 channel results in higher BER floor, 10mV less coded VEYE margin compared to LONG2 channel. HEYE and VEYE have very high sensitivity to channel changes when margin is low due to steepness of bathtub curve (bathtub quickly rises off eye center)

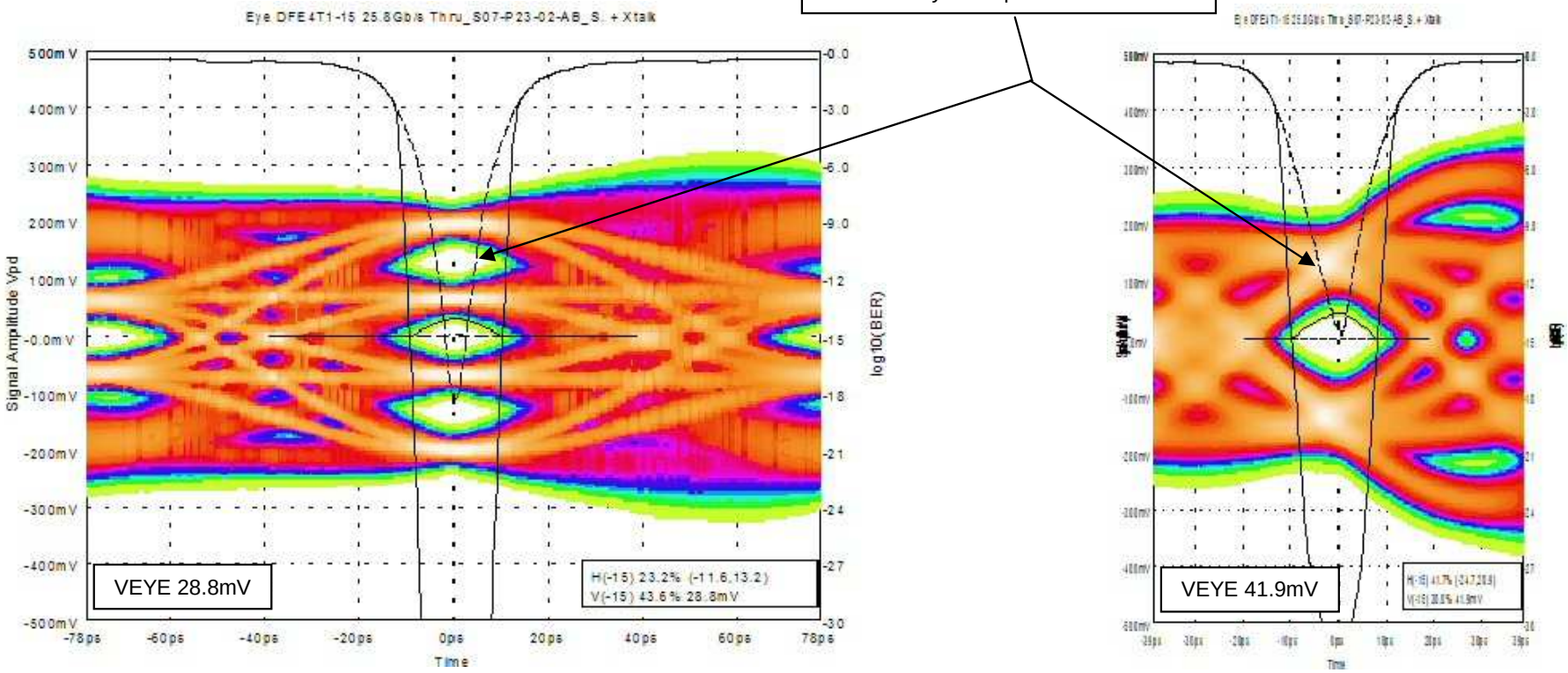
Channel results include Tx IC, Tx PKG, Rx PKG, Rx CTE, Rx IC responses

PAM4 and NRZ on SHORT Channels, I/O core deg=0

PAM4

NRZ bathtub rises slower in absolute time off eye center due to 3x less impact of ISI on veye collapse

NRZ



PAM4 starts out better than NRZ with positive uncoded VEYE margin, but once coding is added, NRZ gives more VEYE margin since the 3X smaller VEYE in PAM4 provides less eye opening compared to NRZ as long as the residual ISI in NRZ is < 3X that of PAM4.

Channel results include Tx IC, Tx PKG, Rx PKG, Rx CTE, Rx IC responses