Continued Investigations of VEC associated with high loss AUI-C2M Version 1.2

Presented to IEEE P802.3dj Task Force 09/16/2024

Associated comments: 564, 577, 561

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Based on draft release of IEEE P802.3dj™/D1.0/1.1

Abstract: VEC (Vertical Eye Closure) at 212G and 33dB channels is challenging. This is a continuation of the presentation offered in July (calvin_3dj_02a_2407) and will hopefully trigger dialogs around retention of this valuable measurement. There has been discussions about VEC or EECQ, however the combination of EQ based noise amplification/poor SNR is pushing measurement science to it's limits.

Supporters/Collaborators (Version 1.2)

Useful References:

IEEE 05/24 Contribution: https://www.ieee802.org/3/dj/public/24_05/calvin_3dj_01b_2405.pdf
IEEE 07/15 Contribution: https://www.ieee802.org/3/dj/public/24_07/calvin_3dj_01b_2407.pdf
IEEE 07/15 Contribution: https://www.ieee802.org/3/dj/public/24_07/calvin_3dj_02a_2407.pdf
RAN: https://www.ieee802.org/3/dj/public/24_07/ran_3dj_01b_2407.pdf
Diminico: https://www.ieee802.org/3/dj/public/23_11/diminico_3dj_01_2311.pdf
Averaging and standard deviation: https://math.stackexchange.com

Instrumentation used in this contribution

- M8042A/M8050A PG
  - No Tx de-emphasis
- M8067A-005/003-Trace (1mm)
  - 31.1dB @53.125GHz – (35mm + 185mm Traces)
  - 2X pair of 1mm 8” phase matched cables (1.2dB each)
  - Net TP1a test channel loss 33.5dB
- UXR 1104B Real-Time scope
  - DSP/SW Clock Recovery
  - ~SIRC: 60GHz 4th order Bessel Thomson rolling off to -9dB @ 90GHZ
- N1000A+N1046A Sampling scope
  - Prototype Clock Recovery
  - SIRC: 60GHz 4th order Butterworth

Overview

May 2024 (P802.3dj D1.0) reviewed Jitter and VEC operations at TP2 (~27dB)

Instrument grade ISI structures.. SDD22 < -15dB

12Edge Jitter operations (instrument grade ISI structures.. SDD22 < -15dB)

- ✓ Physical CDR
- ✓ Oversampled/DSP CDR

VEC operations

× 1E-5 VEC ✓ 1E-3 VEC

July 2024 (P802.3dj D1.1) we repeated the above operations at TP1a (~33dB)

Instrument grade ISI structures.. SDD22 < -15dB

12Edge Jitter operations (instrument grade ISI structures.. SDD22 < -15dB)

- ✓ Physical CDR
- ✓ Oversampled/DSP CDR

VEC operations, not so successful (~12dB).

× 1E-5 VEC × 1E-3 VEC ✓ 1E-2VEC

September 2024 (VEC associated with high loss AUI-C2M Version 1.2) << This presentation

Examine VEC limitations at higher TP1a loss profile

Discuss noise management methods

IEEE 802.3dj D1.1 TP0d->TP1a loss

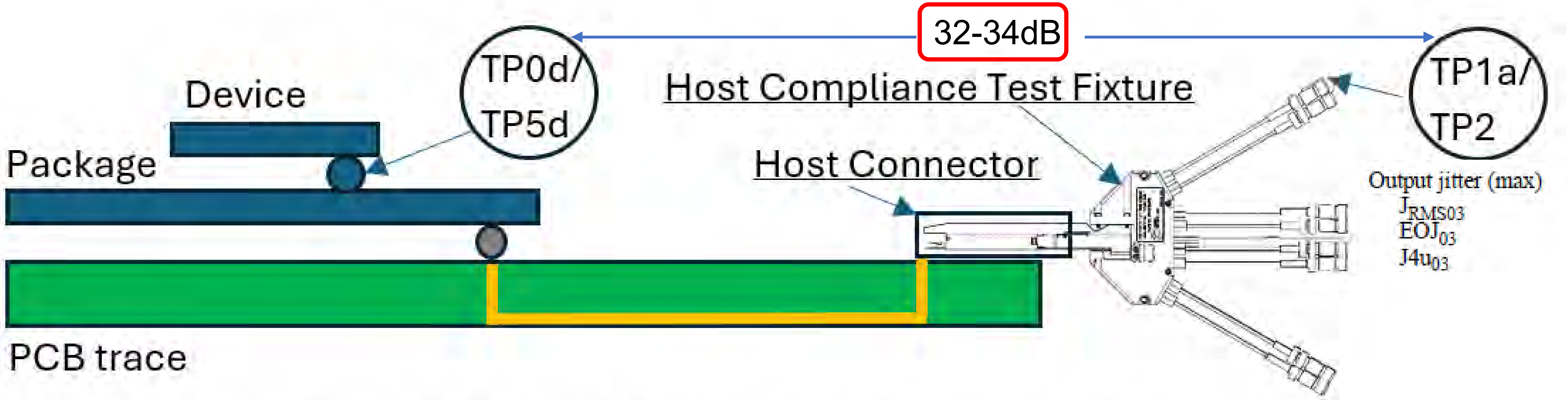


Figure 1: Typical 802.3dj host test point model

Slew rate is reduced proportionally as channel bandwidth is reduced (loss), however noise is only reduced proportional to the sqrt of the reduction of the bandwidth and then magnified by the Reference Receiver EQ

https://www.ieee802.org/3/dj/public/23_11/lusted_3dj_04_2311.pdf pg 5 (32dB)
https://www.ieee802.org/3/dj/public/24_07/ran_3dj_01b_2407.pdf pg 10 (34dB)

Noise Effects: 33 dB @ 106.25 GBd COM equalized Equivalent-Time Instrument

- Noise is attenuated less than transition time over these high loss (~33dB) channels.
  - The combination of Instrument noise and DUT noise get magnified by CTLE+FFE EQ choices.

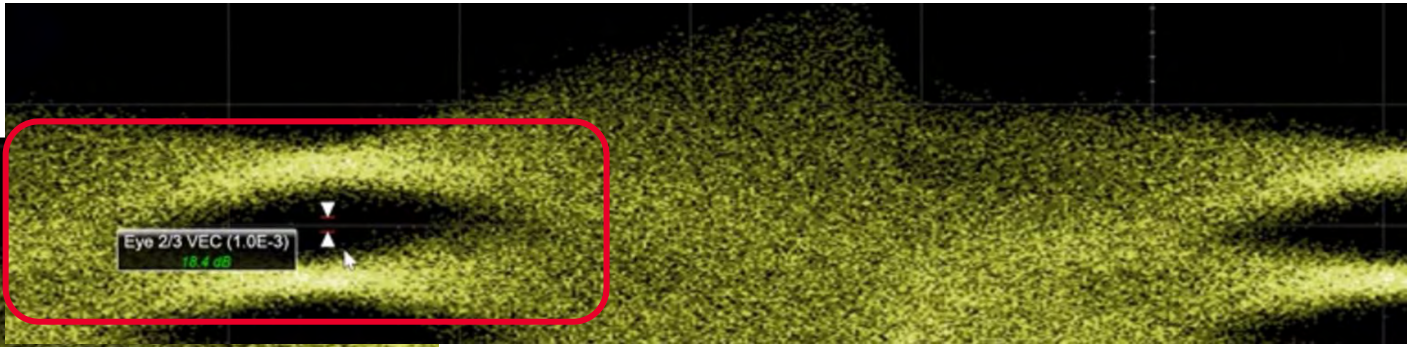
A2 =SQRT(SUM(A1:AA1*A1:AA1))

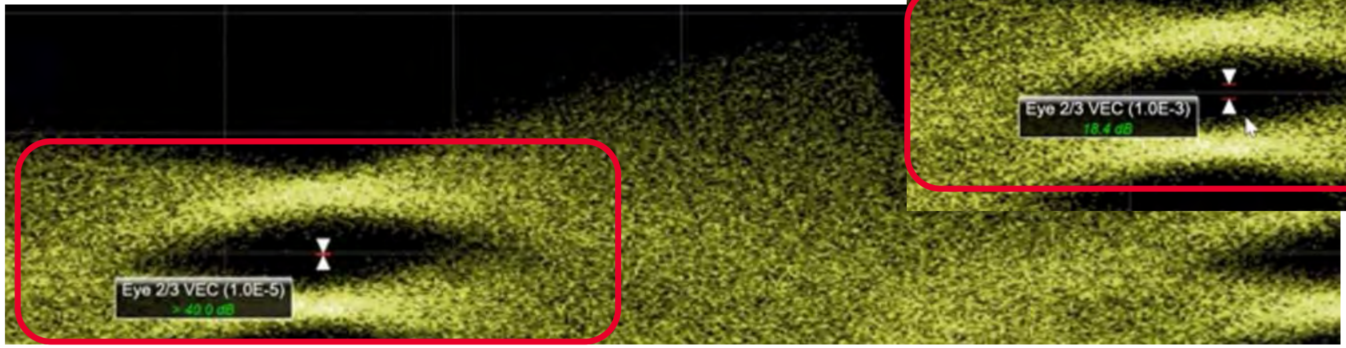
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	-0.03263	0.101036	-0.23523	0.523068	-1.10297	1.8787	0.185796	-0.15182	-0.02455	-0.05032	0.005931	-0.13186	0.075157
2	2.280701												

	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1	-0.02611	-0.02615	0.010943	-0.01892	0.060504	-0.10064	0.079796	-0.01562	-0.01354	0.012606	-0.03159	0.064086	-0.0581	0.022
2														

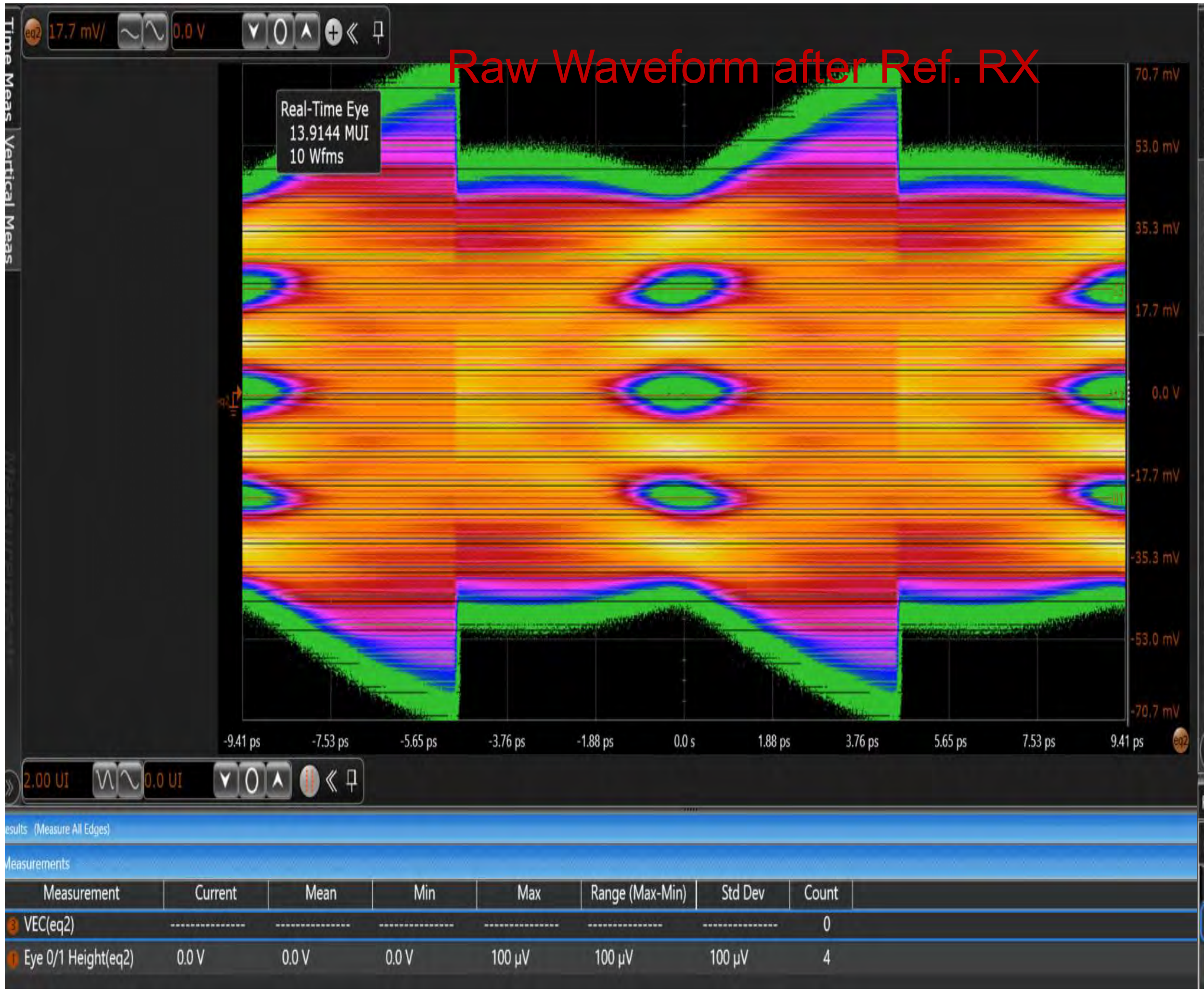
  This 27 tap (COM Optimized) Rx FFE (not including the CTLE) is magnifying noise by 2.28x

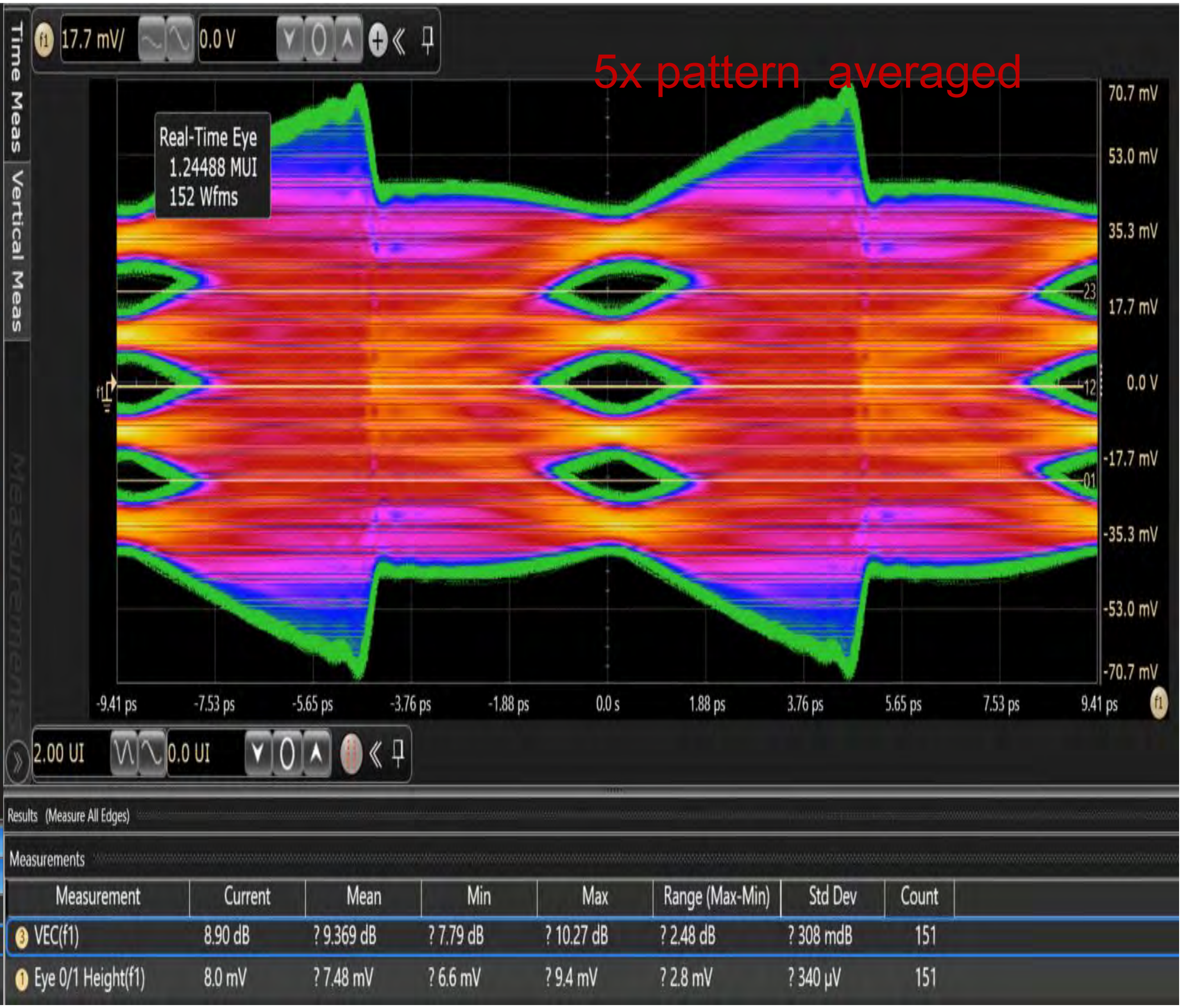
  - EQ in the presence of noise. Then adjusting (de-convolving/adjusting) the noise after the fact are central to the problems associated with EH closure at typical BER’s.
  - Sensitivity problem: We need to perform noise management before we render an eye diagram so it’s open at the probability we are trying to hit.
  - Post MLSD methods under consideration





VEC Results 33 dB @ 106.25 GBd COM equalized Real-Time Instrument





Good correlation between MMSE results and measurements when noise reduction is enabled.

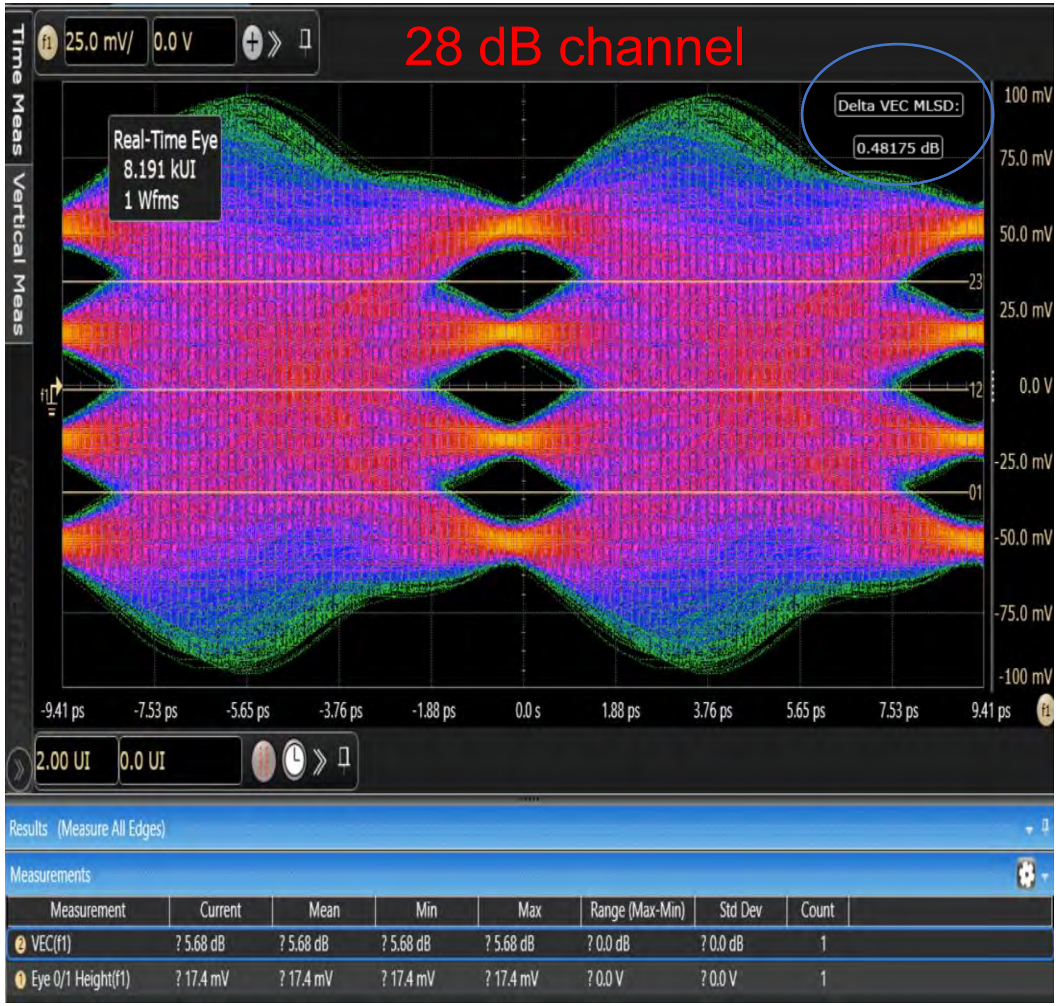
- **This points out that noise is the issue.**
- VEC operations require noise levels well below current instrument capabilities.
- A typical Tx sigma-n of 1.5mV RMS is not uncommon. After a 33dB channel this is cut roughly by 7. 200uV should be the new Sigma-n at the TP1a test point.
- Pattern averaging removes all kinds of noise: DUT, crosstalk, scope, etc but can be used in moderation.
- Averaging 5X removes %60 of the noise, as seen on slides 7 and 9.
- Other Noise Methods:
  - Noise Dual Dirac approach.
  - MLSE COM delta approach.

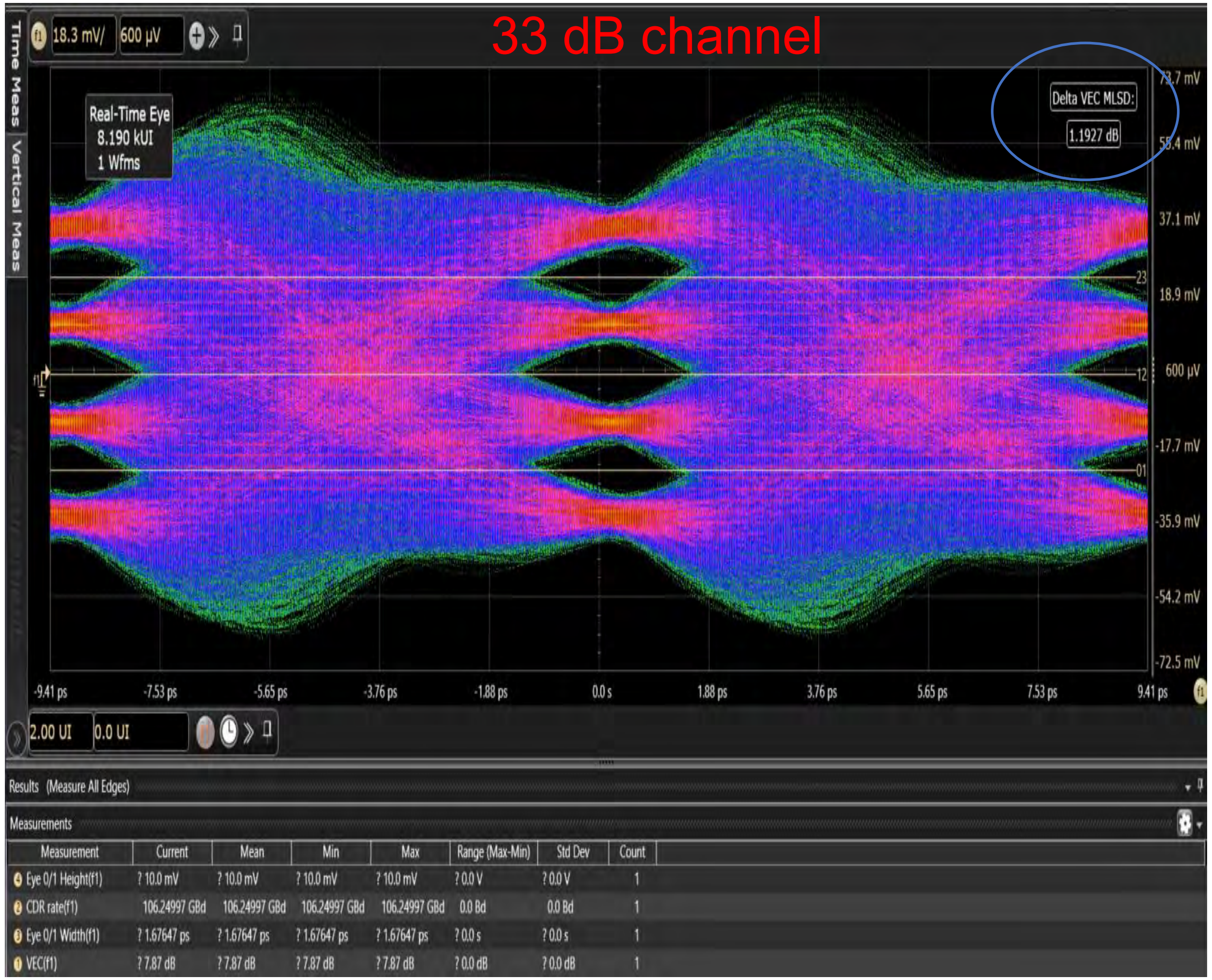
VEC @ 2E-5

28 dB channel @ 106.25 GBd				
	COM results	Infiniium offline		Infiniium online
VEC	6.33 dB	no pattern avg	13.15 dB	15.54 dB
		with pattern avg	5.68 dB	6.25 dB
EH	15.85 mV	no pattern avg	6.5 mV	5.55 mV
		with pattern avg	17.4 mV	16.2 mV

33 dB channel @ 106.25 GBd				
	COM results	Infiniium offline		Infiniium online
VEC	8.55 dB	no pattern avg	29.87 dB	closed eye
		with pattern avg	7.87 dB	9.37 dB
EH	8.69 mV	no pattern avg	0.6 mV	0 mV
		with pattern avg	10 mV	7.48 mV

Eye diagrams with delta VEC

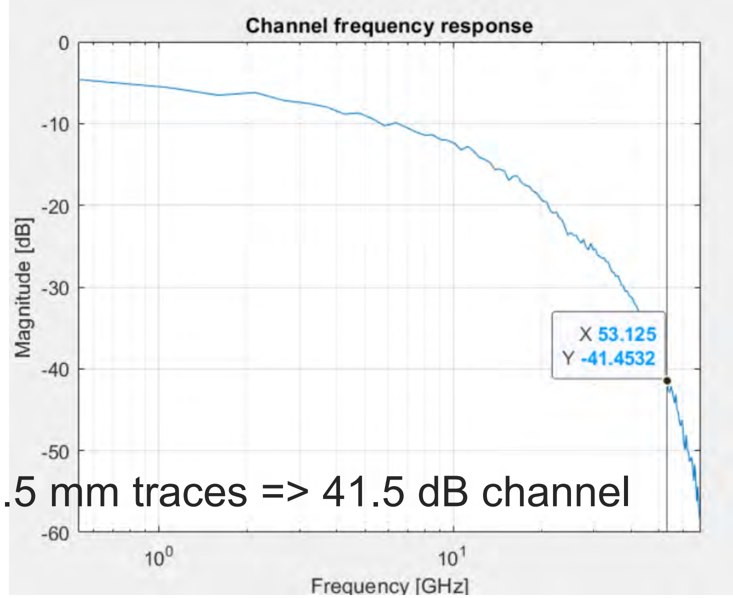




VEC vs SER correlation when using MLSD

- Low-loss channels don’t need MLSD (CTLE+FFE+DFE good enough).
- COM predicts modest VEC reduction (0.35-1 dB) for high-loss channel.
- COM predicts big VEC reduction for very high-loss channel.
- Noise again shows up as a limiting factor on performance.

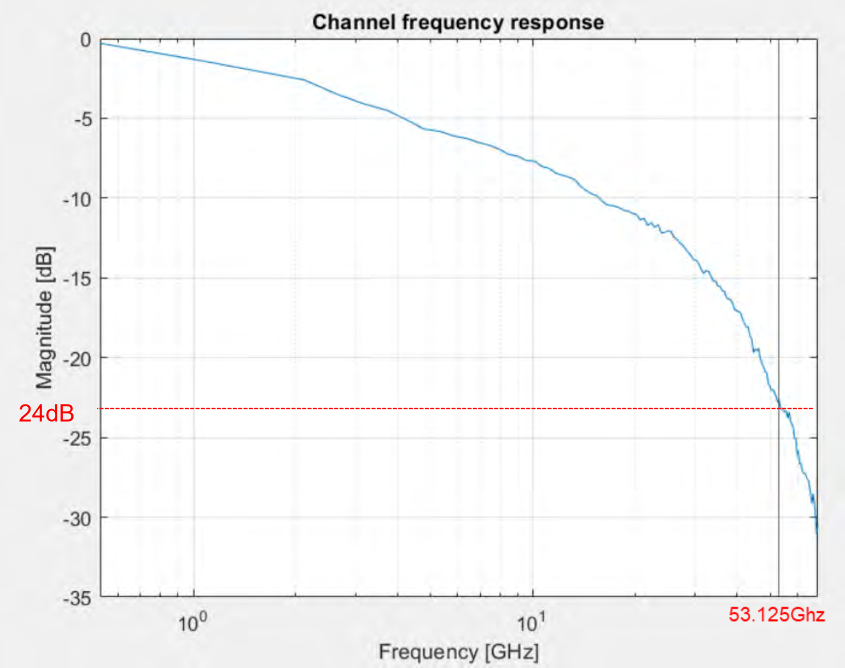
FFE length = 23; FFE pre = 5; MLSD length = 10	VEC COM	Delta VEC MLSD	SER PR-MLSD (no avg)	SER PR-MLSD (5 pattern avg)
7.5 dB channel	4.36 dB	-0.0027dB	1.39E-02	4.10E-03
28 dB channel	5.74 dB	0.35 dB	1.80E-03	2.28E-05
33 dB channel	6.92 dB	1.02 dB	1.40E-03	1.14E-05
41.5 dB channel	24.15 dB	7.91 dB	1.35E-02	1.40E-04

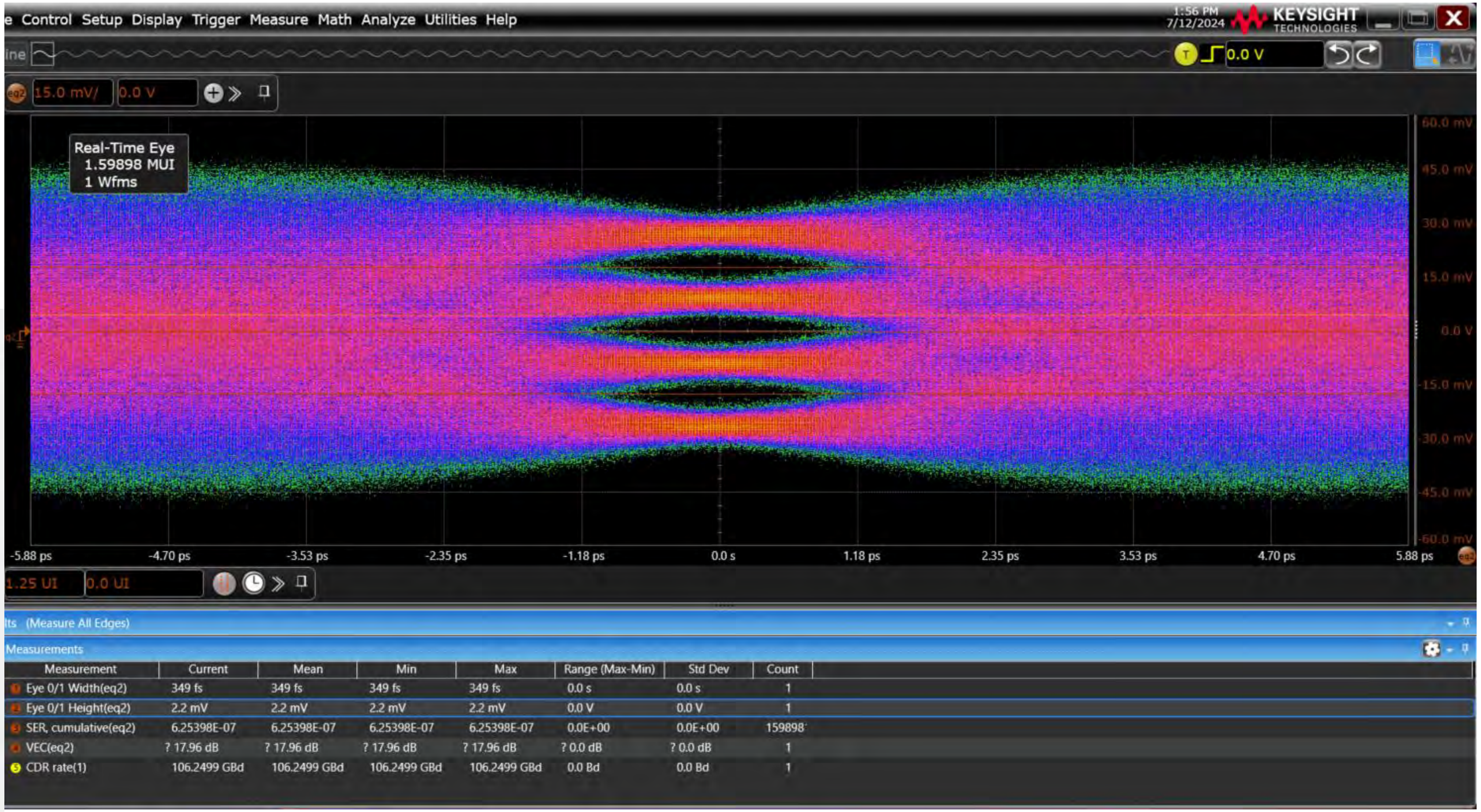


35+222.5 mm traces => 41.5 dB channel

```
VEC_COM =

    7.0328


VEC_MLSE =

    7.0437


dVEC =

   -0.0109

 Die to die loss =  dB
run time = 0.404101 min
WC All cases  PASS ... VEC = 7.044 dB
WC All cases  PASS ... EH = 8.104 mV
WC All cases  PASS ... COM = 5.105 dB
WC All cases DER = 2.794e-08 at COM threshold
 redo string is: eval(['My_var_0 = ' getappdata(0,'cmd_str')])
```

Real-Time 24dB VEC

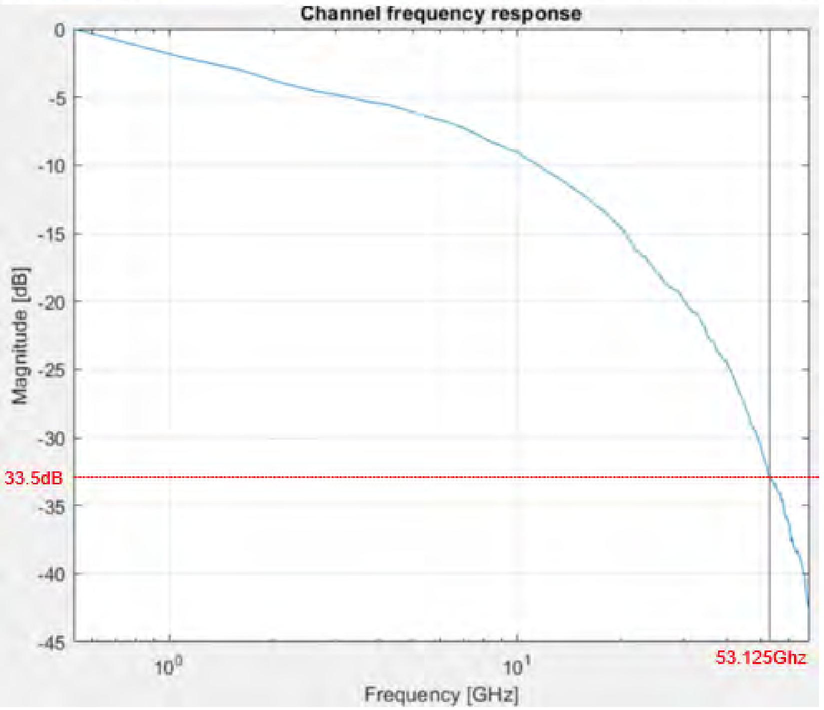


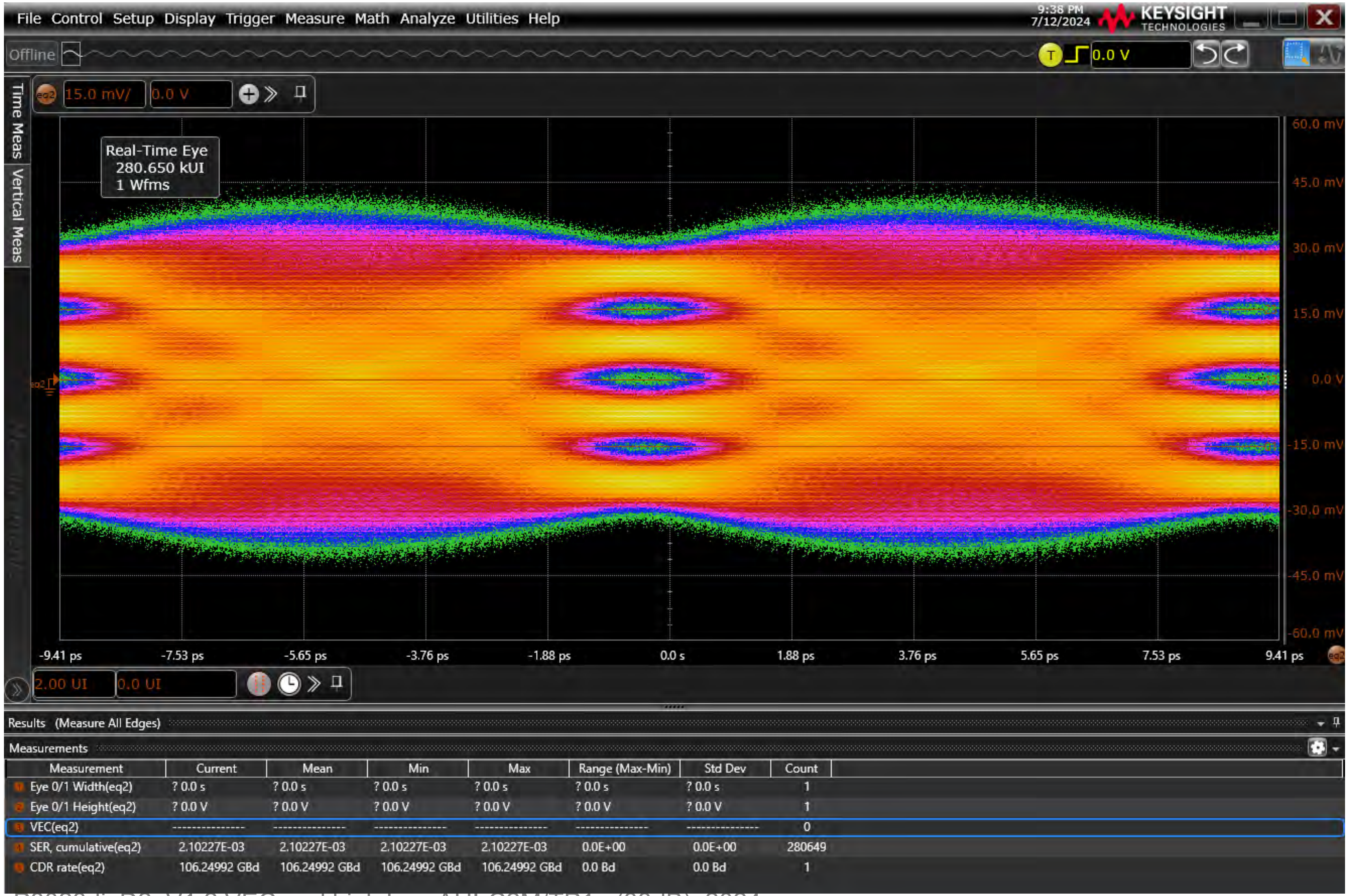


Measurement	Current	Mean	Min	Max	Range (Max-Min)	Std Dev	Count
Eye 0/1 Width(eq2)	349 fs	349 fs	349 fs	349 fs	0.0 s	0.0 s	1
Eye 0/1 Height(eq2)	2.2 mV	2.2 mV	2.2 mV	2.2 mV	0.0 V	0.0 V	1
SER, cumulative(eq2)	6.25398E-07	6.25398E-07	6.25398E-07	6.25398E-07	0.0E+00	0.0E+00	159898
VEC(eq2)	? 17.96 dB	? 17.96 dB	? 17.96 dB	? 17.96 dB	? 0.0 dB	? 0.0 dB	1
CDR rate(1)	106.2499 GBd	106.2499 GBd	106.2499 GBd	106.2499 GBd	0.0 Bd	0.0 Bd	1

Real-Time 33dB VEC

```
VEC_COM =

    8.7541


VEC_MLSE =

    7.9876


dVEC =

    0.7665

 Die to die loss =  dB
run time = 0.396597 min
WC All cases  PASS ... VEC = 7.988 dB
WC All cases  PASS ... EH = 6.673 mV
WC All cases  PASS ... COM = 4.418 dB
WC All cases DER = 9.992e-07 at COM threshold
 redo string is: eval(['My_var_0 = ' getappdata(0,'cmd_str')])
```



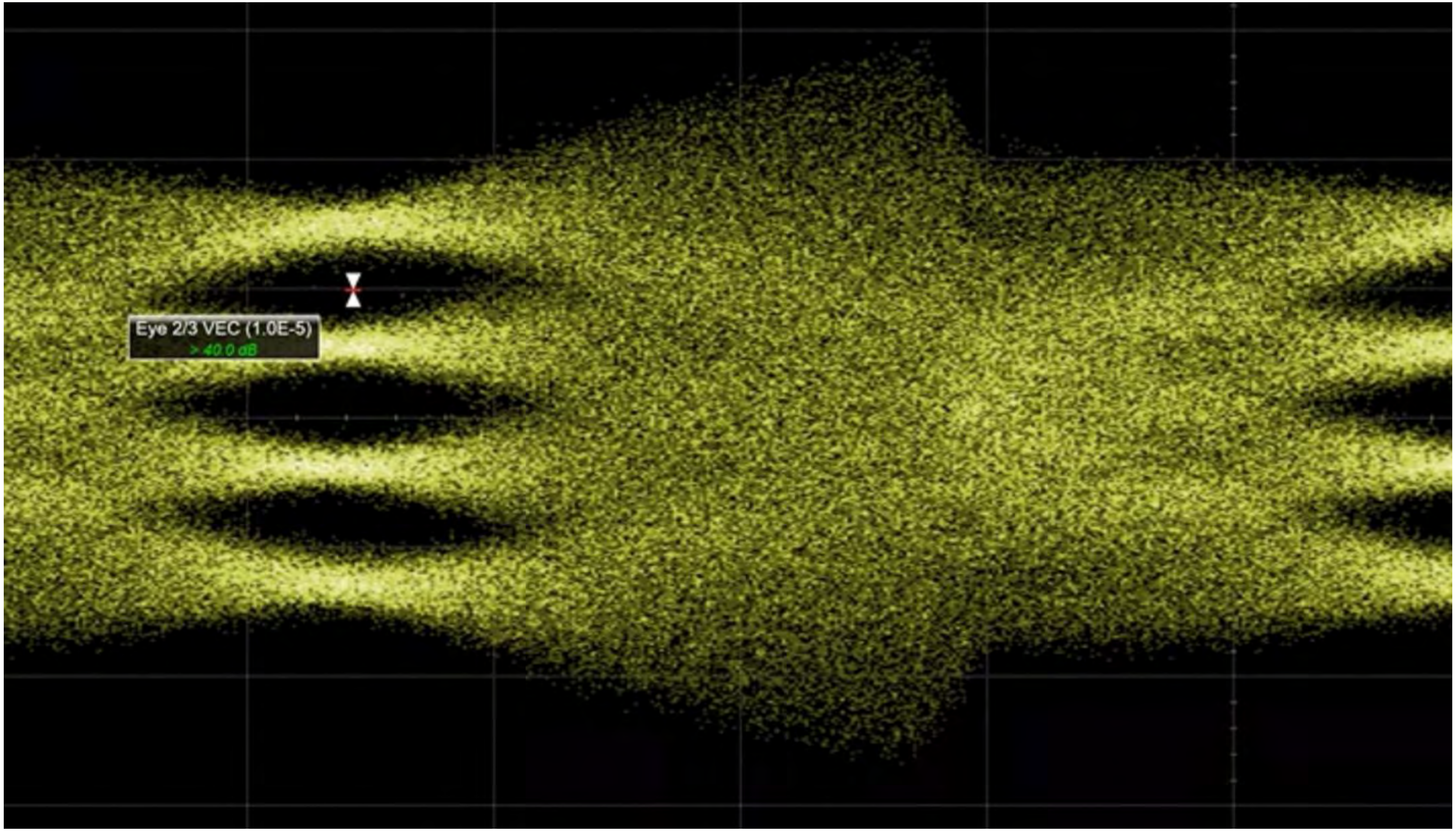


Summary

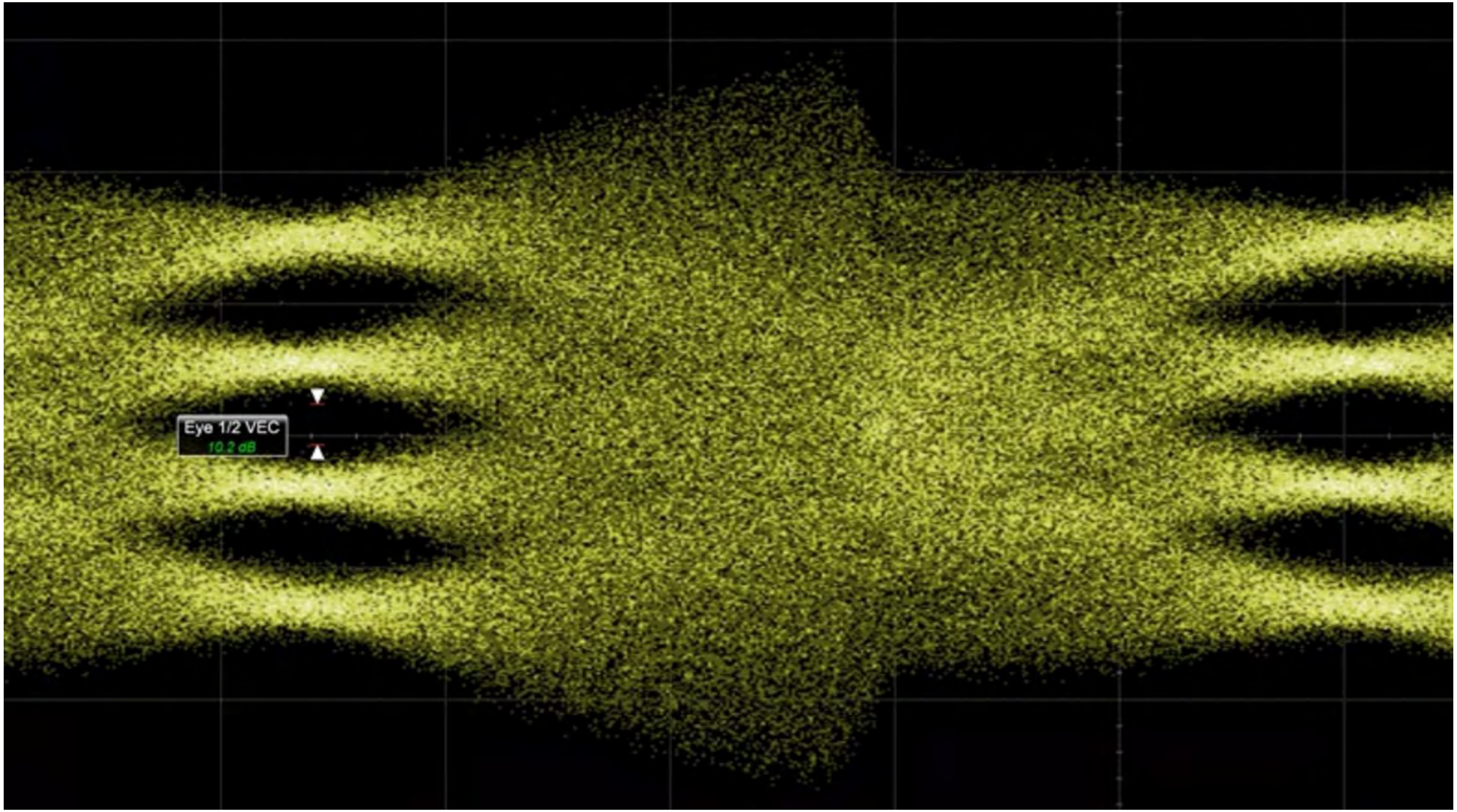
- Clock recovery and eye rendering regardless of end goal (EH, VEC, EECQ) is in an emerging state. It is possible today (it's been possible for years) to perform RT-Instrument CDR operations at TP1a given the same ERL consideration from the earlier contribution. It should be considered work in progress on the ET-Instruments (see contribution: calvin_3dj_02a_2407)
- Eye Height and derivative VEC or EECQ have been a very effective tool to offer parametric evaluation of post EQ signal properties. It's just gotten more challenging at TP1a (33dB).
- The combined impact of a contemporary Reference Receiver EQ amplifies signal noise and makes the ability to evaluate EH operations at a BER of 1E-5 impossible.
- Possible work-arounds.
  - Get a scope with 100uV of intrinsic noise. >> not likely in this projects time-line.
  - Evaluate the BER at 1E -2. >> Would this still be meaningful?
  - Settle on a method of waveform averaging for overall signal and instrument noise reduction.
  - Fully Incorporate MLSE into VEC.
  - Other ideas?

Thank you

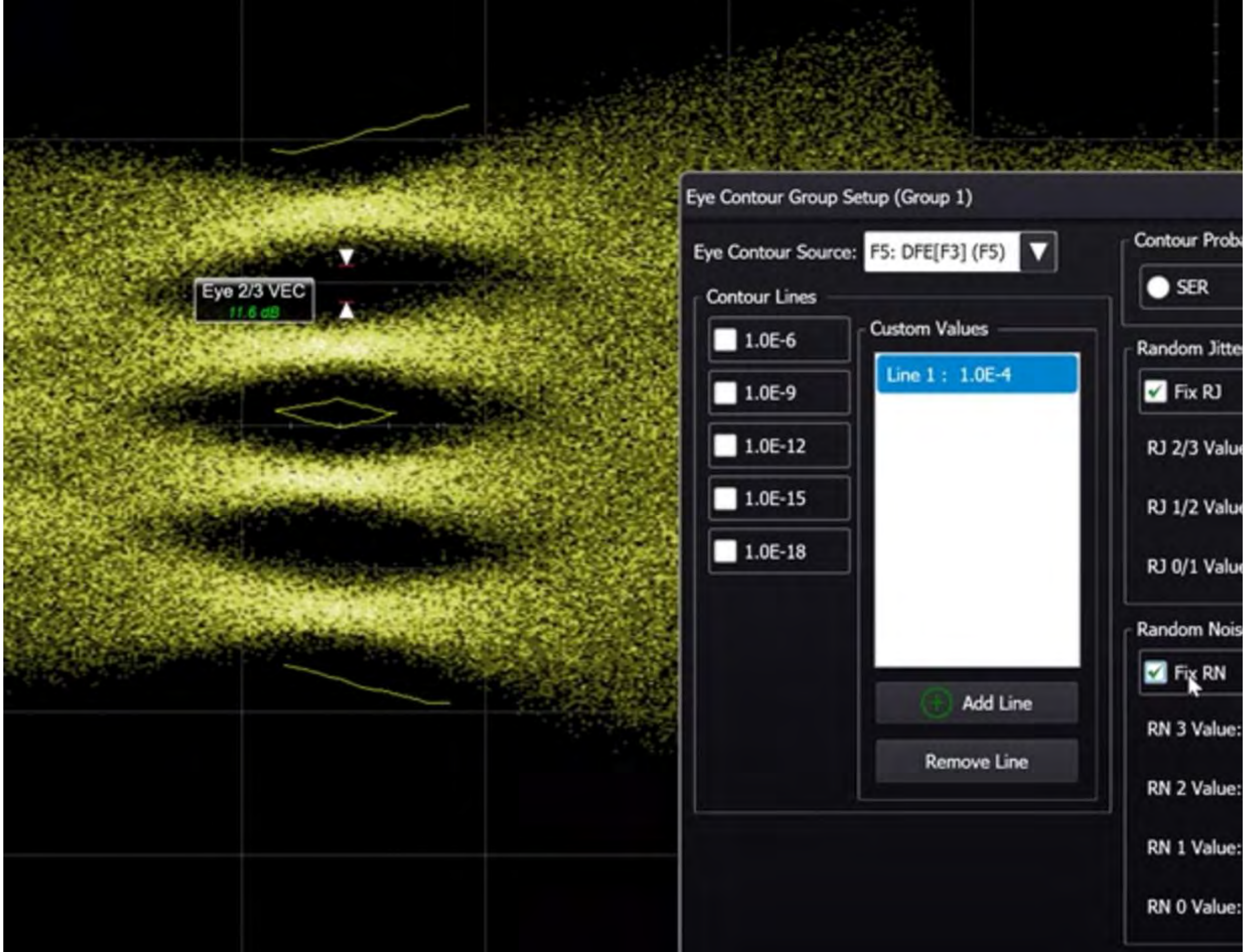
Backup

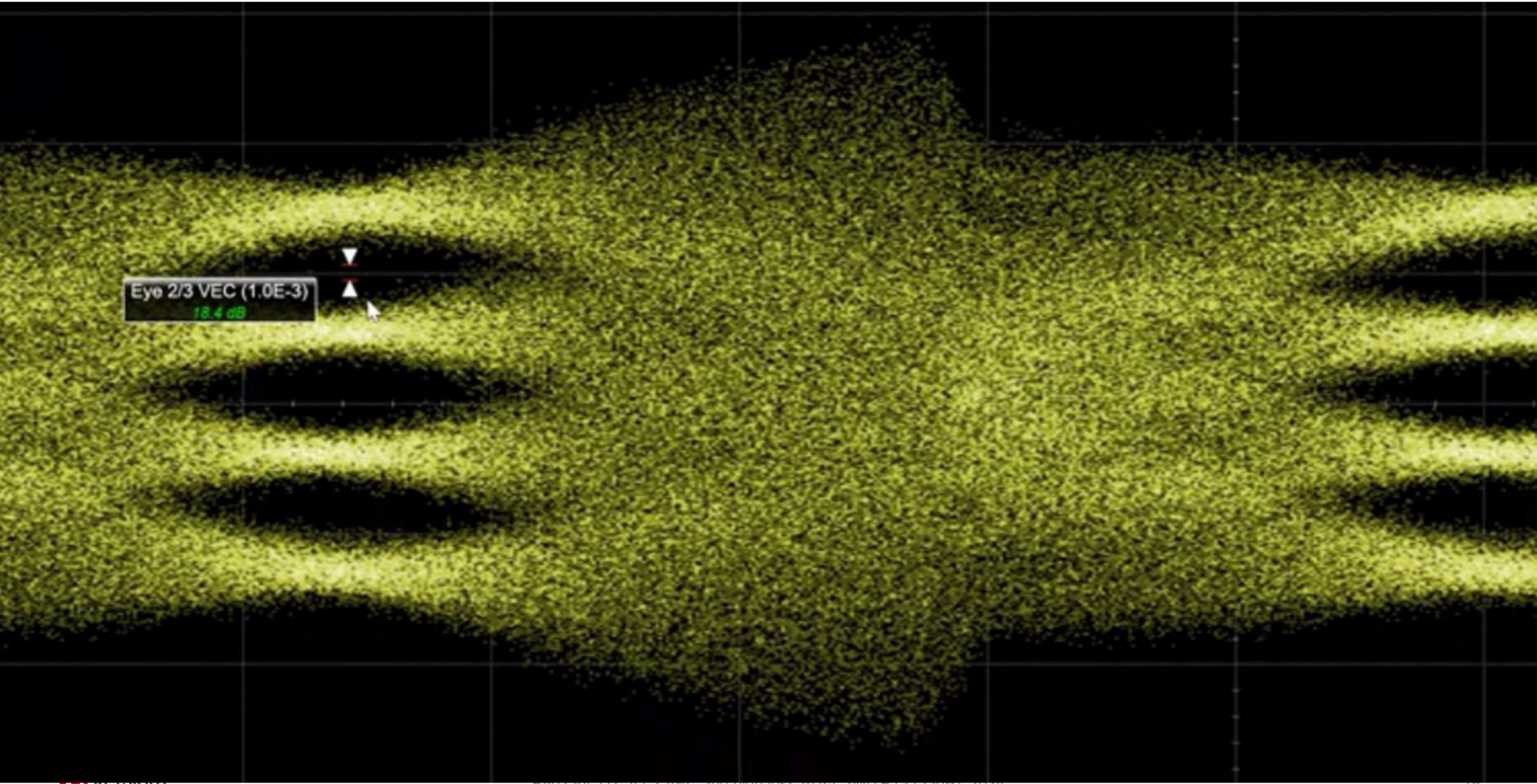


Backup



Backup


Eye 2/3 VEC
11.6 dB
Eye Contour Group Setup (Group 1)
Eye Contour Source:
F5: DFE[F3] (F5)
Contour Lines
1.0E-6
1.0E-9
1.0E-12
1.0E-15
1.0E-18
Custom Values
Line 1 : 1.0E-4
Add Line
Remove Line
Contour Prob
SER
Random Jitte
Fix RJ
RJ 2/3 Valu
RJ 1/2 Valu
RJ 0/1 Valu
Random Nois
Fix RN
RN 3 Value:
RN 2 Value:
RN 1 Value:
RN 0 Value:


Eye 2/3 VEC (1.0E-3)
18.4 dB