

# 1.6Tbps output jitter decomposition associated with high loss AUI-C2M channel conditions Version 1.2

Author: John Calvin Contributors: Jorge Pires, David Gines, Mike Beyers, Luis Boluna Based on draft release of IEEE 802.3dj<sup>™</sup>/D1.0/1.1/1.2

Abstract: Performing JNu operations near the limits of current channel profiles is a highly technical proposition, and may require some methodology revisions. This contribution will offer an overview of current state of the art jitter decomposition methods and offer some technical proposals designed to reduce the channel based jitter amplification impact on random jitter.

Supporters/Collaborators (Version 1.2)

Mike Dudek (Marvell) Luke Wang (Credo) Mark Kimber (Semtech) Adee Ran (Cisco) Geoff Zhang (AMD) Richard Mellitz (Samtec)

Reference: Previous IEEE P802.3dj version 1.2. <u>https://www.ieee802.org/3/dj/public/24\_05/calvin\_3dj\_01b\_2405.pdf</u> IEEE 802.3dj\_07/15/2024:Calvin\_1.6Tbps\_JNu operations / high loss channels

## 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 4<sup>th</sup> order Bessel Thomson rolling off to -9dB @ 90GHZ

### N1000A+N1046A Sampling scope

Prototype Clock Recovery

SIRC: 60GHz 4<sup>th</sup> order Butterworth

### **Overview**

The draft 1.0 P802.3dj comment resolution sessions have indicated interest in consolidating physical layer Jitter operations at C2M and CR interfaces.

The question of whether 12Edge Jitter operations can be accurately evaluated in a worst case AUI-C2M (33dB) configuration is the focus of this contribution.

Slew rate decreases by 2 when you cut bandwidth by a factor of 2. However, the noise only drops by sqrt(2). So the jitter due to noise increases by sqrt(2)

The operations demonstrated in this contribution focus on both Real-Time instrumentation (Keysight UXR 1104B), digital clock recovery (1'st order 4MHz) and a 60GHz 4'th order Bessel, as well as its Equivalent-Time counterpart (DCA N1046/N1071) with early experimental CDR capability.

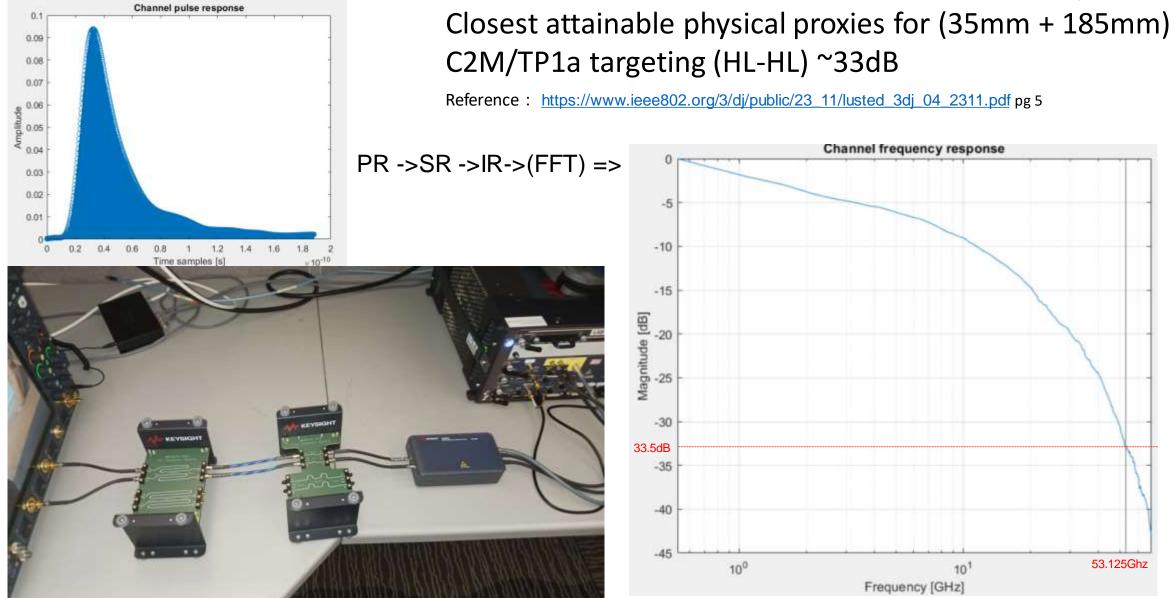
Signal generation in this contribution is with a Keysight M8042A PG transmitting a PRBS13Q test pattern, no TX EQ, with a single <u>ended</u> <u>amplitude</u> of 300mV at the source.

elbek Recovery	
Clock recovery applies to pr Time Eye, serial data analys jitter measurements.	
Clock Recovery Applies To	
All Waveforms	Clock Recovery Source Real-Time Fre
Individual Waveforms	Channel 1
Preset	
802.3dj	
Clock Recovery Method	
+ First Order PLL	
Clock Skew	SSC Setup
-544 fs 🔨 🔿	> Auto
Nominal Data Rate	Nominal Symbol Rate
212.50000000 Gb/s	106.25000000 G8d
PLL Specification	
	Ο ΟΙΤΕ
Loop Bandwidth	Loop Bandwidth
4:000 MHz	4.000 MHz
Loop Bandwidth Divisor	Loop Bandwidth Divisor
26.5625 k	26.5625 k
	ndent

The signal path interconnect is all performed via 1mm interconnects.



## Channel configuration and Real-Time instrument used in this study:



IEEE 802.3dj 07/15/2024:Calvin\_1.6Tbps JNu operations / high loss channels

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Ch 1	J3u Table (22	20 Patterns)		Ŷ	Ch 1 Jrms Tal	ble (220 Patte	erns) To L3		C To LO	Ch 1 EOJ Tab	le (220 Patte To L2	rns) To L3
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Ch 1 n To L0 186.458 mUI	J3u Table (22	20 Patterns)		( Fron To L0	Ch 1 Jrms Tat			Fron	To LO			
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Ch 1 n To L0 206 186.458 mUI 206 208.866 mUI 309 296.663 mUI 293	J3u Table (22 To L1 301. 0.057 mUI 291. 0.189 mUI 210.	20 Patterns) Fo L2 To 569 mUI 292.3 097 mUI 194.9	20 mUI 62 mUI	Fron To L0 All 18.0363 mUl L3 15.6103 mUl L2 31.7025 mUl L1 45.0907 mUl	Ch 1 Jrms Tal To L1 32.0104 mUI 46.8044 mUI	To L2 41.0386 mUI 45.9578 mUI	To L3 62.7275 mUI 30.3389 mUI	Fron All L3 L2 L1	To L0 17.0513 mUI 5.37965 mUI 3.82602 mUI	To L1 10.5830 mUI 3.88568 mUI	To L2 10.7893 mUI 610.675 μUI	To L3 10.3853 mUI 5.72331 mUI 3.88568 mUI
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Ch 1 n To L0 206 186.458 mUI 206 208.866 mUI 309 296.663 mUI 293 295.663 mUI 293 295.663 mUI 293 295.663 mUI 293 293 293 293 293 295 295 295 295 295 295 295 295	J3u Table (22 To L1 301. 0.057 mUI 291. 0.189 mUI 210.	20 Patterns) Fo L2 To 569 mUI 292.3 097 mUI 194.9	20 mUI 62 mUI	Fron To L0 All 18.0363 mUl L3 15.6103 mUl L2 31.7025 mUl L1 45.0907 mUl	Ch 1 Jrms Tal To L1 32.0104 mUI 46.8044 mUI	To L2 41.0386 mUI 45.9578 mUI 31.7113 mUI	To L3 62.7275 mUI 30.3389 mUI	Fron All L3 L2 L1	To L0 17.0513 mUI 5.37965 mUI 3.82602 mUI	To L1 10.5830 mUI 3.88568 mUI	To L2 10.7893 mUI 610.675 μUI	To L3 10.3853 mUI 5.72331 mUI 3.88568 mUI
Ch 1        n      To L0      1        1 186.458 mUl      119.790 mUl      206        208.866 mUl      309      296.663 mUl      293        296.663 mUl      293      293      293	J3u Table (22 To L1 301. 3,195 mUI 301. 2,057 mUI 291. 3,189 mUI 210.	20 Patterns) Fo L2 To 569 mUI 292.3 097 mUI 194.9 147 mUI 109.1 147 mUI 109.1	213 □ 80 mUI 62 mUI 96 mUI	Fron To L0 All 18.0363 mUl L3 15.6103 mUl L2 31.7025 mUl L1 45.0907 mUl L0	Ch 1 Jrms Tal To L1 32.0104 mUI 46.8044 mUI 62.9715 mUI	To L2 41.0386 mUI 45.9578 mUI 31.7113 mUI	To L3 62.7275 mUI 30.3389 mUI 13.6287 mUI	Fron All L3 L2 L1	To L0 17.0513 mUI 5.37965 mUI 3.82602 mUI	To L1 10.5830 mUI 3.88568 mUI	To L2 10.7893 mUI 610.675 μUI	To L3 10.3853 mUI 5.72331 mUI 3.88568 mUI
Ch 1        n      To L0      1        1 186.458 mUl      119.790 mUl      206        208.866 mUl      309      296.663 mUl      293        296.663 mUl      293      293      293        Jults      (Measure All Edges)      asurements      293        ACVrms(er)      ACVrms(er)      200      200	J3u Table (22 To L1 301. 0.057 mUI 291. 0.189 mUI 210. 0 Current 84.23 mV	20 Patterns) Fo L2 To 569 mUI 292.3 097 mUI 194.9 147 mUI 109.1 Mean 84.23 mV	0 L3 □ 80 mUI 62 mUI 96 mUI 96 mUI 96 mUI 84.23 mV	Fron To L0 All 18.0363 mUl L3 15.6103 mUl L2 31.7025 mUl L1 45.0907 mUl L0 Max 84.23 mV	Ch 1 Jrms Tal To L1 32.0104 mUI 46.8044 mUI 62.9715 mUI 62.9715 mUI	To L2 41.0386 mUI 45.9578 mUI 31.7113 mUI n) Std Dev 0.0 V	To L3 62.7275 mUI 30.3389 mUI 13.6287 mUI	Fron All L3 L2 L1	To L0 17.0513 mUI 5.37965 mUI 3.82602 mUI	To L1 10.5830 mUI 3.88568 mUI	To L2 10.7893 mUI 610.675 μUI	To L3 10.3853 mUI 5.72331 mUI 3.88568 mUI
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IEEE 802.3dj 07/15/2024:Calvin\_1.6Tbps JNu operations / high loss channels

## **Output jitter (max) analysis**

Draft Amendment to IEEE Std 802.3-2022 IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force IEEE Draft P802.3dj/D1.0 10 April 2024

#### Table 179–7—Summary of transmitter specifications at TP2 (continued)

Parameter	Subclause reference	Value	Units
Transmitter steady-state voltage, v <sub>y</sub> (min) Host designation Host-Low Host designation Host-Nominal Host designation Host-High	179.9.4.1.2	TBD TBD TBD	v v v
Transmitter steady-state voltage, $v_f(\max)$	179.9.4.1.2	0.6	v
Linear fit pulse peak ratio, $R_{peak}$ (min) Host designation Host-Low Host designation Host-Nominal Host designation Host-High	179.9.4.1.2	TBD TBD TBD	Ξ
Level separation mismatch ratio R <sub>LM</sub> (min)	179.9.4.2	0.95	-
Transmitter output waveform absolute value of step size for all taps (min) absolute value of step size for all taps (max) value at minimum state for $c(-3)$ (max) value at minimum state for $c(-1)$ (max) value at minimum state for $c(-1)$ (max) value at minimum state for $c(0)$ (max) value at minimum state for $c(0)$ (max)	179.9.4.1.4 179.9.4.1.4 179.9.4.1.5 179.9.4.1.5 179.9.4.1.5 179.9.4.1.5 179.9.4.1.5 179.9.4.1.5	0.005 0.025 -0.06 0.12 -0.34 0.5 -0.2	
Signal-to-noise-and-distortion ratio, SNDR (min)	179.9.4.6	31.5	dB
Signal-to-residual-intersymbol-interference ratio, SNR <sub>ISI</sub> (min)	179.9.4.3	26.7	dB
Output jitter (max) TBD	179.9.4.7	TBD	UI

Ch 1 J3u Table (220 Patterns)							
To LO	To L1	To L2	To L3				
186.458 mUI			64 - 1997 - Alberta Alb				
119.790 mUI	206.195 mUI	301.569 mUI					
208.866 mUI	309.057 mUI		292.380 mUI				
296.663 mUI		291.097 mUI	194.962 mUI				
	293.189 mUI	210.147 mUI	109.196 mUI				
	To L0 186.458 mUI 119.790 mUI 208.866 mUI	To L0      To L1        186.458 mUI      206.195 mUI        208.866 mUI      309.057 mUI        296.663 mUI      206.195 mUI	To L0      To L1      To L2        186.458 mUI      119.790 mUI      206.195 mUI      301.569 mUI        208.866 mUI      309.057 mUI      291.097 mUI	To L0      To L1      To L2      To L3        186.458 mUI      119.790 mUI      206.195 mUI      301.569 mUI        208.866 mUI      309.057 mUI      292.380 mUI        296.663 mUI      291.097 mUI      194.962 mUI			

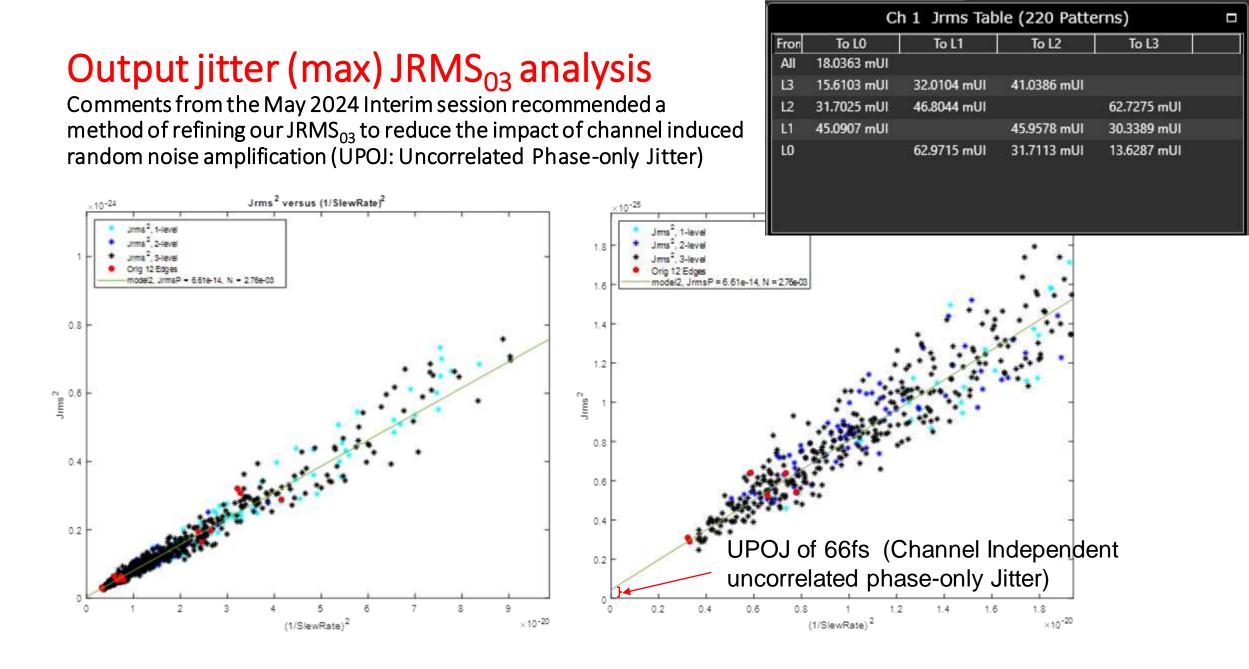
 $J3U_{03}$  is formed from a composite of targeted L3->0 and L0->3 uncorrelated edge jitter. The composite result has some questions but the the individual values are solid.

Similarly  $EOJ_{03}$  is formed from a composite of targeted L3->0 and L0->3 Even/Odd jitter elements. The composite value here is WIP, but the individual L3->0 and L0->3 values are correct.

Draft Amendment to IEEE Std 802.3-2022 IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task I	IEEE Draft P802.3dj/D1.1 11 July 2024		
Table 176E–1—Summary of host output specifie	cations at TP1	a (continued)	
Output jitter (max) J <sub>RMS03</sub> EOJ <sub>03</sub> J4u <sub>03</sub>	176E.6.9	0.023 0.025 0.135	UI UI UI

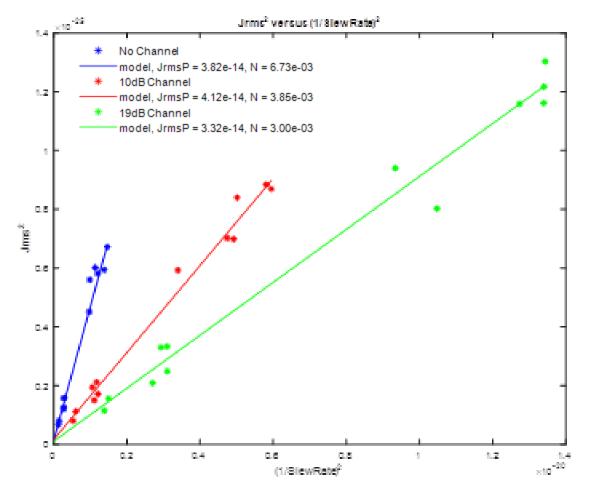
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	Ch 1 EOJ Table (220 Patterns)								
Fron	To LO	To L1	To L2	To L3					
Fron All	17.0513 mUI	,	. 30						
L3	5.37965 mUI	10.5830 mUI	10.7893 mUI						
L2	3.82602 mUI	3.88568 mUI		10.3853 mUI					
L1	5.37965 mUI		610.675 µUI	5.72331 mUI					
LO		17.0513 mUI	3.82602 mUI	3.88568 mUI					



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## **UPOJ: Uncorrelated Phase-only Jitter**



The uncorrelated phase only jitter (UPOJ), when extrapolated back to the y-intercept (via linear regression), observes relatively stable UPOJ values ranging from 38fs, 41fs to 33fs. This process clearly benefits from more statistical sample points (previous slide), but nicely converges to a reasonable UPOJ number which appears to be channel independent.

# Channel configuration and Equivalent-Time (ET) instrument used in this study:

- Physical Clock Recovery (CR) with early experimental systems are complex at TP1a (106GBd at 33.5dB), but reliable at TP2 (24dB).
- Driven with a 600mV Differential Tx signal.
- Low return loss channel (-15dB max)
- Phase Detector sensitivity in the CR is operating at it's design limits.



Jitter/Noise		사 кеүзіднт File		Measure	Tools	Apps	Help O	Auto Scale	Run Stop Single	Clear 📃 🗙
C A		Pattern Acquisition (100°							Way	veforms (Average) : 3
	Time	ļU	Output Jitter							
	ne	Src: 1A Rate: 106.27 Intrinsic RN Removed:	'200 GBd Pat. 686 μV	Length: 8191						TF SP LJM
RJ/PJ Histogram F		Measurement	To L0	To L1	To L2	To L3				
	⊳	😑 J3u (All)	300 mUI							
la d	Amplitude	J3u (R03/F30)	175 mUI							
المسلسليال	litua	From L3	175 mUI	190 mUI	360 mUI					
DDJ Histogram	de	From L2	180 mUI	300 mUI		340 mUI				
	=	From L1	300 mUI		320 mUI	185 mUI				
		From L0		320 mUI	200 mUI	180 mUI				
	Meas	😑 Jrms (All)	35 mUI							
TJ Histogram	as	Jrms (R03/F30)	27 mUI							
		From L3	26 mUI	29 mUI	50 mUI					
		From L2	28 mUI	38 mUI		50 mUI				
	Ŵ	From L1	42 mUI		44 mUI	28 mUI				
DDJ Vs Symbol		From L0		45 mUI	30 mUI	27 mUI				
ŕ		😑 EOJ (All)	28 mUI							
		EOJ (R03/F30)	17 mUI							
		From L3	4 mUI	4 mUI	28 mUI					
Composite TJ		From L2	11 mUI	10 mUl		0 UI				
Histogram		From L1	16 mUI		20 mUI	10 mUI				
		From L0		28 mUI	22 mUI	17 mUI				
Jul. 1										
Composite DDJ Histogram										
		Details Limits [	+ -]							
More (1/2)							Image: A state of the state			D C 💽 PWaveform
26.8 mV	1	CDR 🗠				Í	Timebase 🔘	Acquisition	Frame Trigger	Pattern
		106.25000 GBd 🔒					1.57 ps/ Pos: 16.00900 ns	Jitter Mode Acq 8 pts/UI	Src: Front Panel 106.27200 GBd	Math Signals
1B 2.25 mV	1	1 LBW: 4.000 MHz 5	₽				IPTB: 26.568000 GHz		8191 UI	Lock

# J3u comparison at 33dB

- This is two separate systems Real-Time (RT) and Equivalent-Time (ET) with the same model of generator and same model of ISI structures.
- "today" We are seeing similar jitter decomposition at 33dB on RT and ET based instrumentation.
- J3u03 on ET of 175mUI –vs- 186mUI on RT is typical variance.

To L3

292.380 mUI

194.962 mUI

109.196 mUI

Fron

All

12

10

To LO

18.0363 mUI

15.6103 mUI

31.7025 mUI

45.0907 mUI

Ch 1 J3u Table (220 Patterns)

To L2

301.569 mUI

291.097 mUI

210.147 mUI

To L1

206.195 mUI

309.057 mUI

293.189 mUI

To LO

186.458 mUI

119,790 mUI

208.866 mUI 296.663 mUI

10

Measurement	To LO	To L1	To L2	To L3
😑 J3u (All)	300 mUI			
J3u (R03/F30)	175 mUI			
From L3	175 mUl	190 mUI	360 mUI	
From L2	180 mUI	300 mUI	-	340 mU
From L1	300 mUI	144	320 mUI	185 mU
From L0	÷ 1	320 mUI	200 mUI	180 mU
🖨 Jrms (All)	35 mUl			
Jrms (R03/F30)	27 mUi			
From L3	26 mUI	29 mUI	50 mUI	122
From L2	28 mUI	38 mUI		50 mU
From L1	42 mUI		44 mUI	28 mU
From L0	-	45 mUI	30 mUI	27 mU
🖨 EOJ (All)	28 mUI			
EOJ (R03/F30)	17 mUl			
From L3	4 mUl	4 mUI	28 mUI	
From L2	11 mUl	10 mUl	-	0 U
From L1	16 mUl	- (44)	20 mUI	10 mU
From L0		28 mUI	22 mUI	17 mU

ľ.	Ch 1 EOJ Table (220 Patterns)						
Fron	To LO	To L1	To L2	To L3			
All	17.0513 mUI						
13	5.37965 mUI	10.5830 mUI	10.7893 mUI				
12	3.82602 mUI	3.88568 mUI		10.3853 mUI			
L1	5.37965 mUI		610.675 µUI	5.72331 mUI			
LO		17.0513 mUI	3.82602 mUI	3.88568 mUI			

Ch 1 Jrms Table (220 Patterns)

62.9715 mUI 31.7113 mUI

To L2

41.0386 mUI

45.9578 mUI

To L3

62.7275 mUI

30.3389 mUI

13.6287 mUI

To L1

32.0104 mUI

46.8044 mUI

## Summary

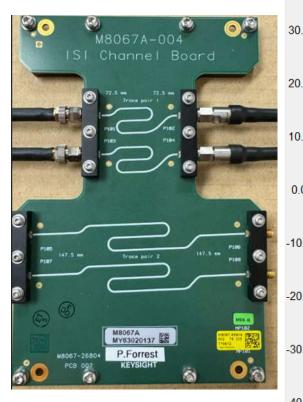
- With an un-equalized 600mV differential signal launch through a 33.5dB signal path representing a worst case TP1a condition, observing proper 1'st order 4MHz CDR and 60GHz 4BT Reference Receiver with no TX EQ, Jitter (Clause 162.9.4.7) can effectively be performed.
- Delicate noise management efforts are needed to reduce/remove the channel amplification effects on random noise originating in transmitters.
- Single level and two level transitions (defined in Clause 162.9.4.7) suffer from SNR losses after 33dB, and are marginally useful. The three level transitions are easily extracted however and extraction of J3u<sub>03</sub>, JRMS<sub>03</sub> and EOJ<sub>03</sub> are all viable validation methods using evolutionary steps from prior Clause 179 and162.9.4.7 methods.
- Steps to isolate true DUT phase jitter by eliminating the vertical noise contribution from the jitter are demonstrated here and offer an accurate (albeit sensitive) method of determining JRMS-"uncorrelated phase only jitter (UPOJ)" behavior. This needs additional effort to refine and to extend to the J3u operations.

## Thank you

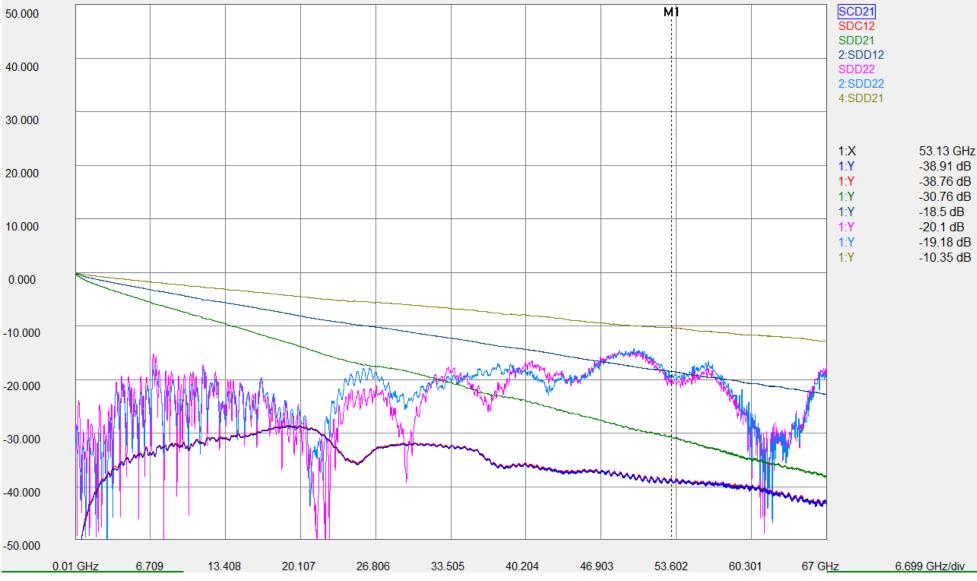


# Backup

 M8067A-005 ISI trace Performance



## <sup>10.000</sup>**M**8067A-005 Trace 1, Trace 2, Trace 2 + Trace 1





IEEE 802.3dj 07/15/2024:Calvin\_1.6Tbps JNu operations / high loss

# **Backup "Support of 178.9.2 Transmitter characteristics"**

Draft Amendment to IEEE Std 802.3-2022 IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force IEEE Draft P802.3dj/D1.1 11 July 2024

Unless otherwise specified, transmitter signal measurements are made for each lane separately using a fourth-order Bessel-Thomson low-pass response with a 3 dB bandwidth of 60 GHz, with AC-coupled connection from TP0v to the test equipment.

- Tx: 300 mV SE amplitude. 106.25GHz clock recovery. PRBS13Q (IEEE/PRBS13Q\_Lane0\_bit).
  4PAM Gray coded. No de-emphasis. No impairments.
- Channel: 35 mm ISI board (approx.. 6.5 dB channel loss at 53 GHz counting cables).
- Real-Time instrumentation test case.

Test case	VEC [dB]	J3u all [mUI]	Jrms all [mUI]
No BW limit (113 GHz brick)	7.79	153	18.3
70 GHz brick	6.94	160.6	17.4
60 GHz Butter. 75 GHz brick	6.06	137.8	15.4
60 GHz Bessel. 90 GHz brick	5.67	125.2	15.2



23