Phase Only Jitter (179.9.4.6 proposed revisions)

Presented to IEEE P802.3dj Joint Electrical/Optical/Logic ad hoc
Version 1.1: January 09, 2025

Associated comments (D1.3): 305, 219, 220, 221

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

Abstract: Improvements to Output Jitter clause 179.9.4.6 , JHrms and Jnu with attention to making these operations more accurate and less sensitive to channel induced losses.

Supporters/Collaborators (Version 1.1)

Yasuo Hidaka (Credo)

Useful References:

IEEE 07/15 Contribution: https://www.ieee802.org/3/dj/public/24_07/calvin_3dj_01b_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

12 Edge Jitter

Characteristics with high loss (30 dB) channel

1. Jitter increases
2. Jitter more variable, both between and within edge types.

These effects not necessarily seen in simulation.

Instrument noise compensation important, but

- DUT noise small after channel, compared to instrument.
- Removing large percentage of measured noise is numerically sensitive to error.
- Results are still channel dependent, so issues not resolved, even if no scope noise.

PAM4 Jitter

Channel 1 | Various | No graphs

Ch 1 J4u Table (408 Patterns)

Fron	To L0	To L1	To L2	To L3
All	82.2959 mUI			
L3	95.0430 mUI	143.870 mUI	251.444 mUI	
L2	139.215 mUI	216.188 mUI		139.679 mUI
L1	203.456 mUI		155.391 mUI	89.6822 mUI
L0		225.838 mUI	105.534 mUI	66.7842 mUI

12 Edge Jitter

Jitter Increases with Physical Channels

Jitter is created through horizontal shifts (phase only jitter), *JH*,
and through vertical shifts (noise-to-jitter conversion), *JV*.

Phase Only Jitter (Horizontal)

- Due to clock variation only
- Does not change over channel
- This is often the desired metric

Noise-to-Jitter (AM-PM) Conversion (Vertical)

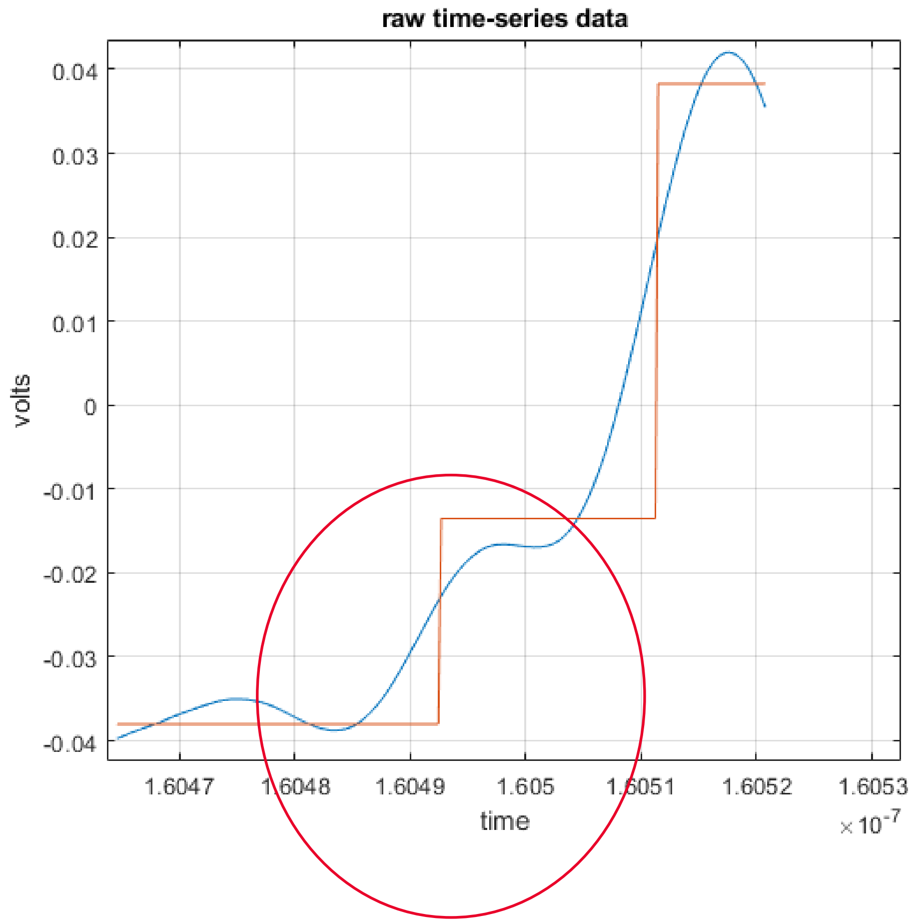
$$JV = \frac{N}{SR}$$

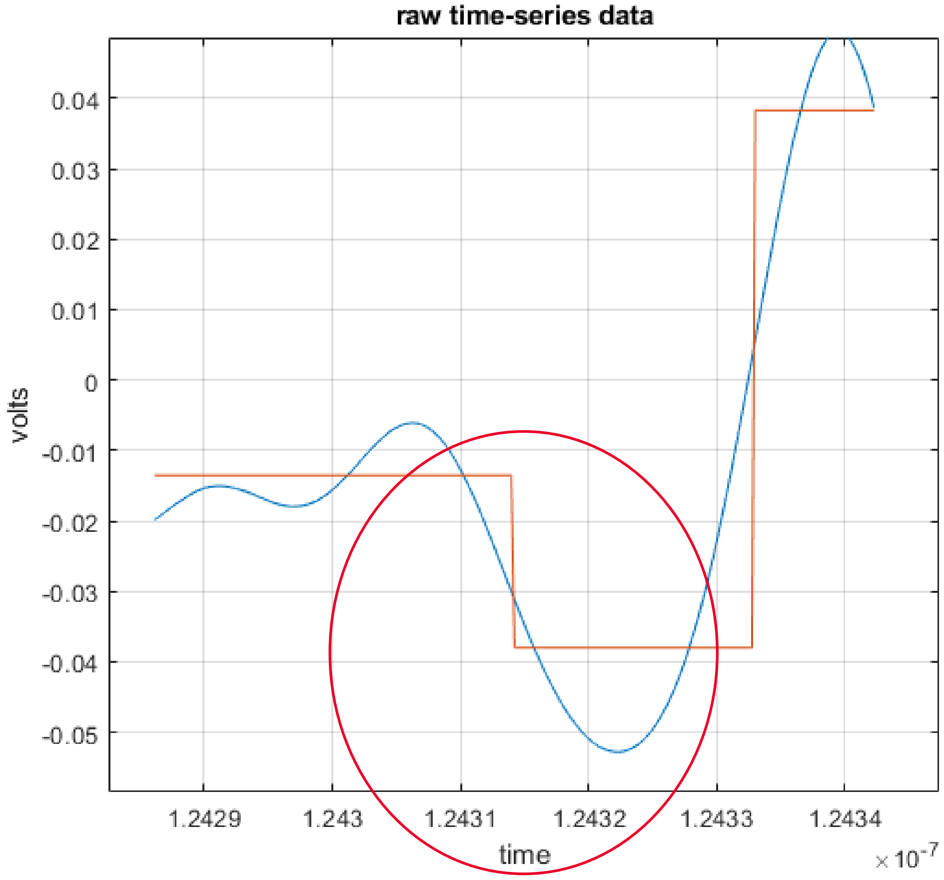
- Noise and slew rate are affected by channel
- This is the source of higher jitter and variability

These effects are not created by the measurement instrument.
However, instrument jitter and noise may lead to different
sensitivities to them.

12 Edge Jitter

Slew Rate Examples





Jitter Model

Horizontal versus Vertical Jitter

The RMS value of the total measured jitter *Jrms* is the geometric sum of *JHrms* (phase only *Jrms*) and *JVrms*.

$$J_{rms}^2 = JH_{rms}^2 + JV_{rms}^2$$

Time-interval errors for *JV* are equal to *N/SR*, where *N* is vertical noise and *SR* is an edge's slew rate. Which gives:

$$J_{rms}^2 = JH_{rms}^2 + \left(\frac{1}{SR}\right)^2 N_{rms}^2$$

This is a linear polynomial with y-intercept JH_{rms}^2 and slope N_{rms}^2

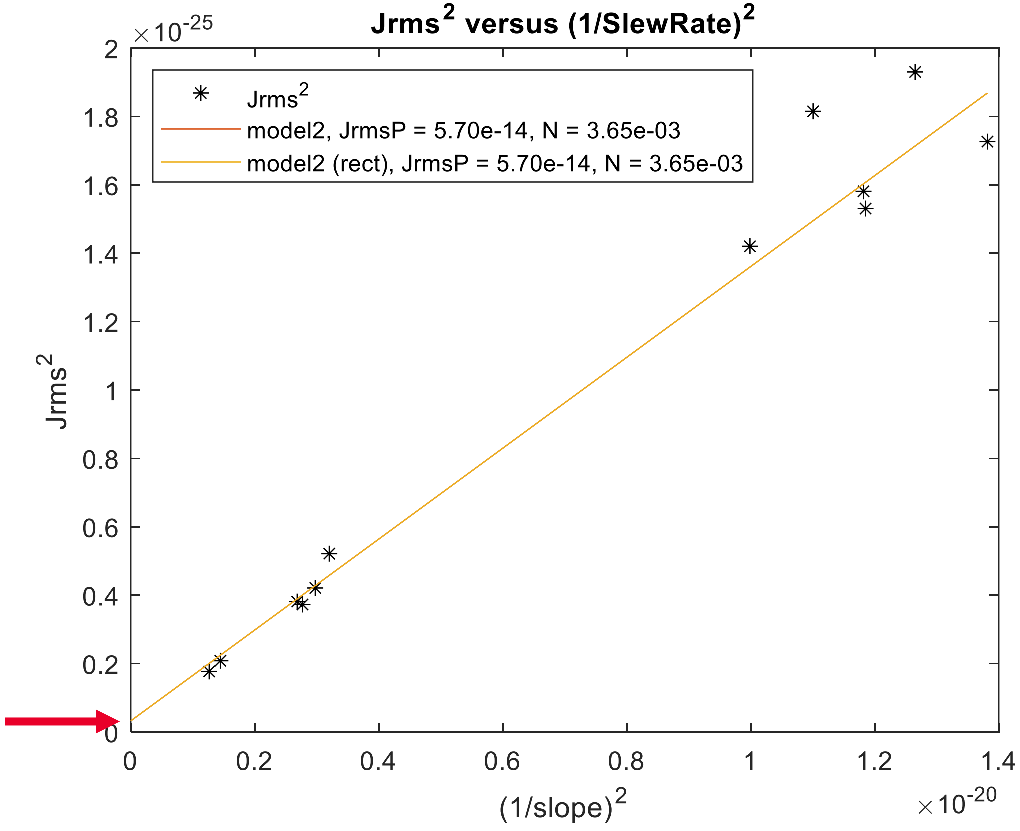
Jitter Model

Example: 12-Edge Jitter on PRBS13Q, 23dB channel

Model: $J_{rms}^2 = JH_{rms}^2 + N_{rms}^2/SR^2$

- Source: BERT with no impairments
- Real-Time Oscilloscope
- Measure Jrms at each of the 12 edges defined in IEEE Specification
- Note: composite dominated by single edge transitions
- Measure slew rate at each of those edges
- Fit model to (*$1/SR^2$*, *$Jrms^2$*) pairs

corresponds to *JHrms* of 57 fs (6mUI)



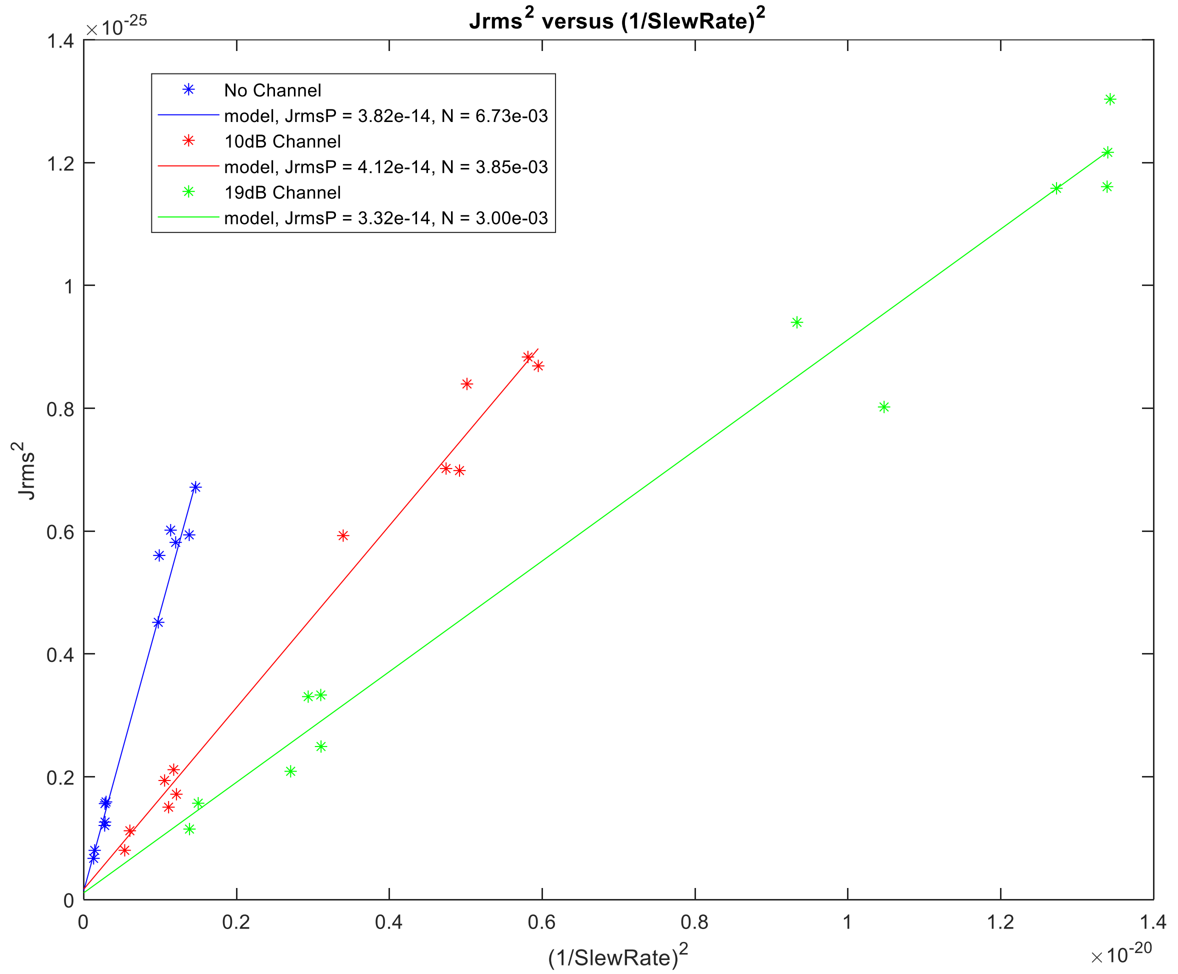
Jitter Model

Example: multiple channels

Model $$J_{rms}^2 = JH_{rms}^2 + N_{rms}^2/SR^2$$

Compare *JHrms* after 3 different channels

- As channel loss increases, DUT noise gets smaller. This is seen in shallower slopes in the model.
- But the slew rate gets smaller at a faster rate, meaning jitter goes up. This is seen in graph points going up and to the right.
- Longer channels also have more ISI, creating more variability.
- All models have the same y-intercept, since all datasets have the same phase only jitter.



Jitter Model

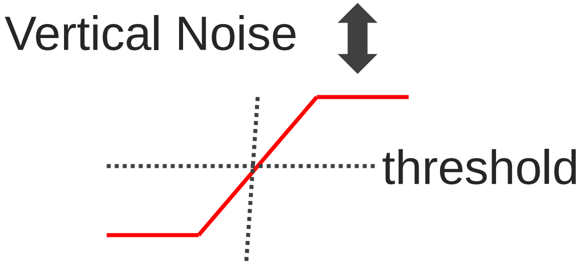
Making the method more robust

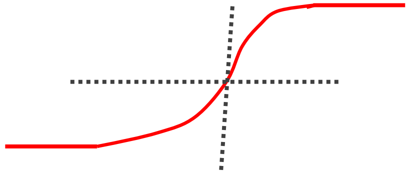
Numerical methods can be used to make the fitting more robust.

Example, use quadratic fit instead of a linear fit. This adds another degree of freedom to the model. The linear model assumes that edges are linear, so that noise-to-jitter conversion is equal to N/SR.

$$J_{rms}^2 = JH_{rms}^2 + \left(\frac{1}{SR}\right)^2 N_{rms}^2$$

$$J_{rms}^2 = JH_{rms}^2 + \left(\frac{1}{SR}\right)^2 N_{rms}^2 + \left(\frac{1}{SR}\right)^4 K_4$$





A curved edge amplifies noise-to-jitter conversion, creating more jitter than a linear edge does. (Not trying to model the edge, just adding another param to the model.)

Jitter Model

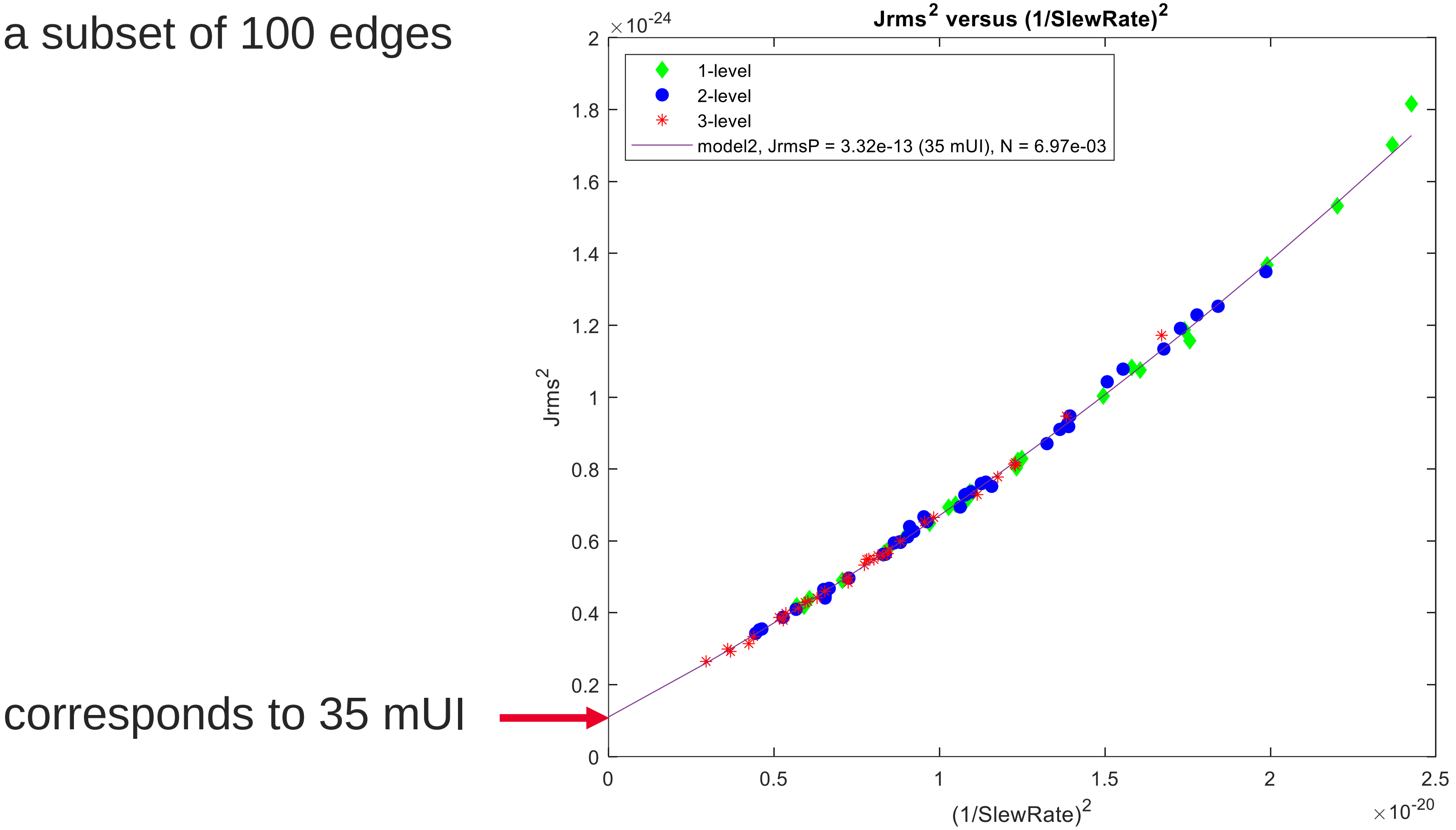
Example with non-zero JHrms

Measured data from BERT: PRBS9Q, 6548 patterns, 106.25 Gbaud PAM4, 31dB channel

RJ and PJ impairments added

Quadratic fit instead of a linear fit

Choosing a subset of 100 edges



Jitter Model

Measured data; PRBS9Q, 100 edges, Quadratic fit

All units in mUI, 106.25 GBaud
Source: BERT

Channel Loss: 0, 12, or 31 dB

			JHrms			Jrms03		
RJrms In	PJpp In	Expected JHrms	0 dB	12 dB	31 dB	0 dB	12 dB	31 dB
0	0	0	3	3	4	8	9	23
30	0	30	28	28	29	29	29	37
0	50	18	16	16	17	17	18	28
30	50	35	32	32	35	35	35	56

			JHrms	Jrms03
RJrms In	PJpp In	Expected JHrms	31 dB	31 dB
0	0	0	5	19
50	0	50	48	50
0	50	18	16	24
50	50	53	51	61

Jitter Model

JNU

Creating a model for JNU is ongoing research. One possible path is to use a dual-dirac decomposition, but this has not been verified. Use model fits to get the horizontal components of *RJrms* and *DJdd*, then,

$$JNUH = DJH_{dd} + Q * RJH_{rms}^2$$

Note that this is not used to extrapolate to a lower BER, this is just used to model the total jitter histogram.

Proposed revisions to 179.9.4.6 Output jitter

Consensus check with Ad-Hoc team

[Current Text]:

- The estimated probability distribution fJ(t) is calculated as specified in 120D.3.1.8.1, except that only the transitions R03 and F30 are used.
- JRMS03 is defined as the standard deviation of fJ(t).
- Jnu03 is defined as the time interval that includes all but 10–n of fJ(t), between the 5 × 10–(n+1) and the 1 – 5 × 10–(n+1) quantiles of fJ(t).

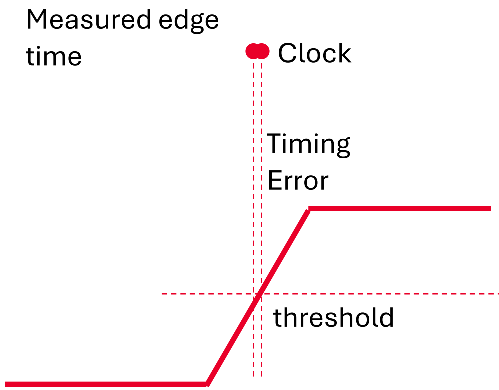
[Proposed Text]:

- The measured probability distribution fJ(t) is calculated as specified in 120D.3.1.8.1.
- JRMS is defined as the standard deviation of fJ(t).
- JHRMS is the measured RMS value of ***phase jitter*** and has all noise elements removed.   For example, JHRMS would correspond to the SQRT(Y-intercept) of a linear fit to a set of JRMS^2 values versus (1/Slew-rate)^2, using the edges defined in 120D.3.1.8.1 ***or any additional edges as needed.***
- Jnu03 is defined as the time interval that includes all but 10–n of fJ(t), between the 5 × 10–(n+1) and the 1 – 5 × 10–(n+1) quantiles of fJ(t), ***where fJ(t) restricted to 3 level transitions.***

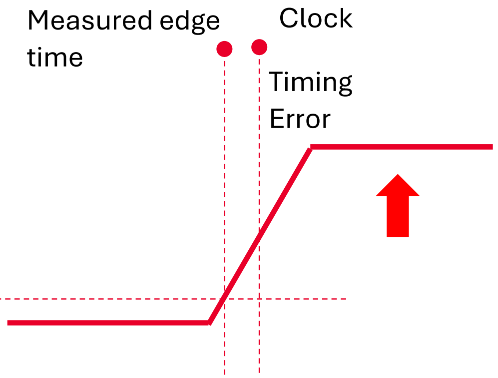
Appendix

12 Edge Jitter

Noise-to-Jitter Conversion



No Noise



Added Vertical Noise

Noise-to-Jitter (AM-PM) Conversion (Vertical)

$$JV = \frac{N}{SR}$$

- Noise and slew rate both reduced in channel
- Slew rate goes down faster than noise. creates **Higher Jitter.**
- Slew rates more variable due to ISI. creates **More Jitter Variability.**

Added Vertical Noise
And Lower Slew Rate