XAUI TX/RX Jitter Specifications

Based on IEEE 802.3ae Draft 3.1

Howard Baumer, Jurgen van Engelen
Broadcom Corp.

July 26, 2001

TX General Specifications

- **AC Coupled, point-to-point, 100 Ohms Differential**
- **1UI = 320ps +/- 100ppm**
- **Output voltage limits**
  - 1600mV differential amplitude
  - -0.4V absolute minimum
  - +2.3V absolute maximum
- **Minimum Returnloss**
  - 10dB differential w.r.t. 100 Ohms
  - 6dB common mode w.r.t. 25 Ohms
  - Between 100MHz and 2.5GHz
- **20%-80% rise and fall time: between 60ps and 130ps**

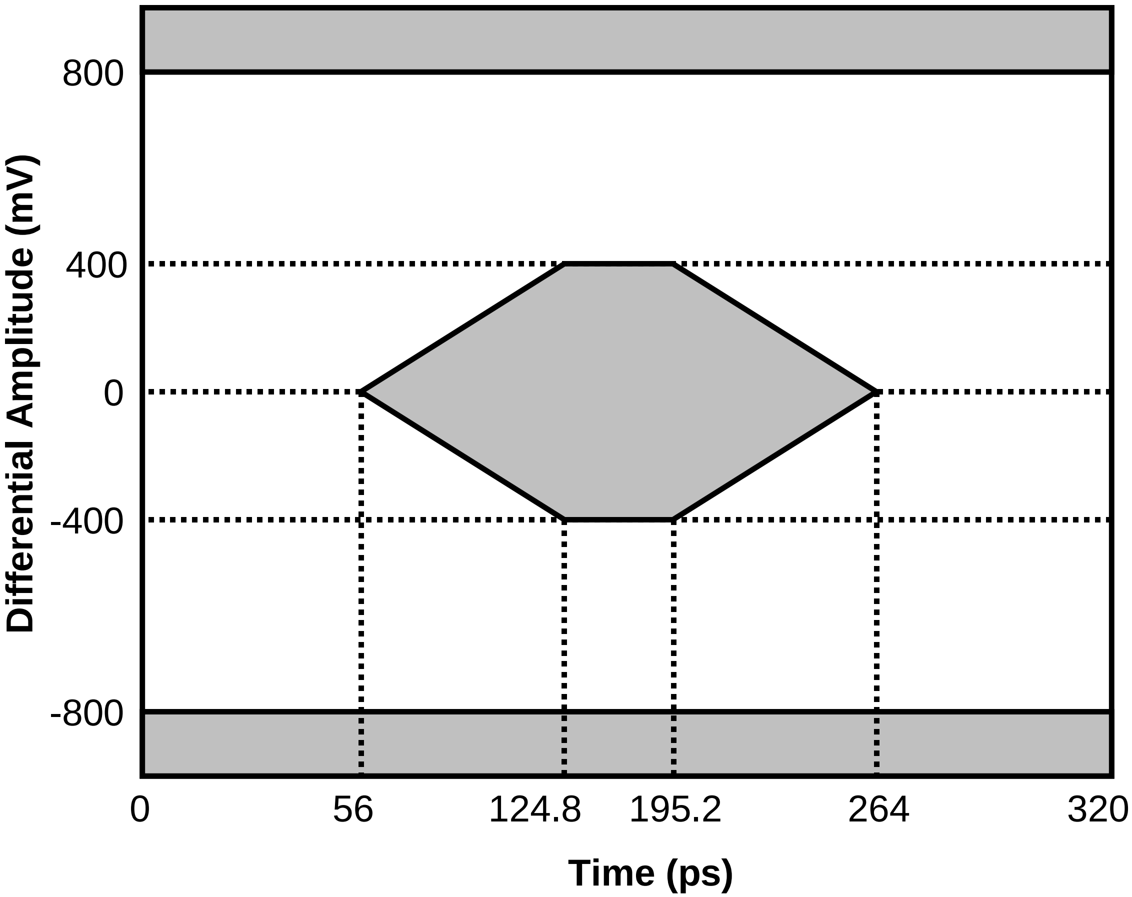
TX Jitter Specifications

- **Near-end maximum jitter**
  - 0.35 UI Total jitter
  - 0.17 UI Deterministic jitter
- **Far-end maximum jitter**
  - 0.55 UI Total jitter
  - 0.37 UI Deterministic jitter

TX Output Jitter	Symbol	peak-to-peak jitter		rms jitter*	
		UI	ps	mUI	ps
Near-end Total Jitter	TJ	0.35	112		
Near-end Deterministic Jitter	DJ	0.17	54.4		
Near-end Random Jitter (maximum)	RJ	0.35	112	25.2	8
Far-end Total Jitter	TJ	0.55	176		
Far-end Deterministic Jitter	DJ	0.37	118.4		
Far-end Random Jitter (maximum)	RJ	0.55	176	39.6	12.57

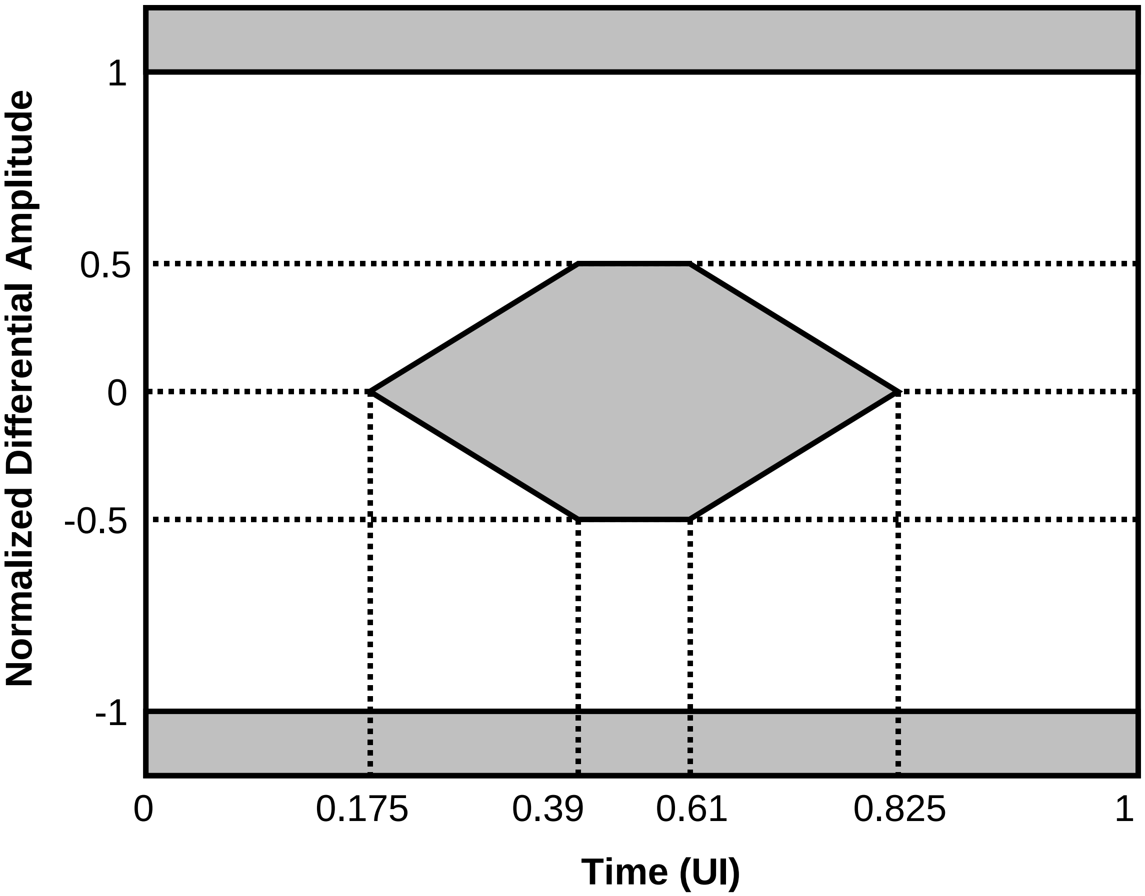
*rms jitter is calculated based on BER=10e-12: rms = (peak-peak)/14

TX Eye Near-end (Absolute)



- **Near-end Eye**
  - 800-1600mVppd
  - 0.35UI jitter
  - Max of 130ps rise time

TX Eye Near-end (Normalized)



- **Notes:**
  - Full scale amplitude refers to 800mV
  - 1UI = 320ps

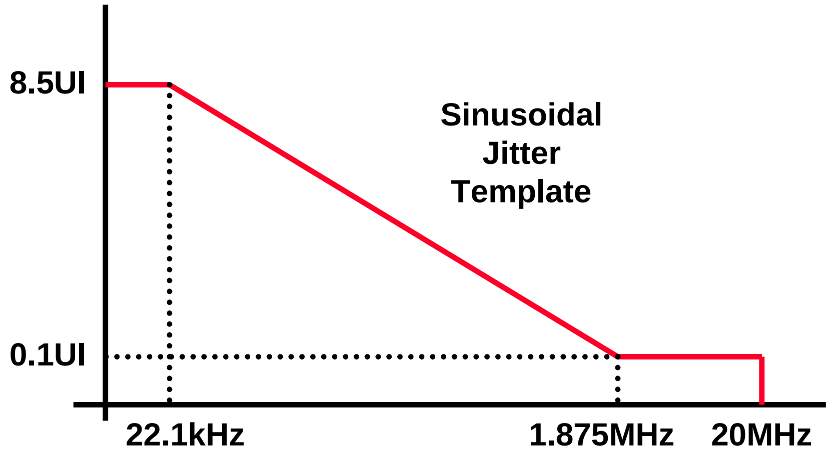
RX General Specifications

- **AC Coupled, point-to-point, 100 Ohms Differential**
- **1UI = 320ps +/- 100ppm**
- **Input voltage limits**
  - 2500mV differential amplitude (***will be changed!***)
- **Minimum Returnloss**
  - 10dB differential w.r.t. 100 Ohms
  - 6dB common mode w.r.t. 25 Ohms
  - Between 100MHz and 2.5GHz
- **Differential Skew Budget**

– Driver:	15ps	0.046UI
– Interconnect / Other:	60ps	0.188UI
– Total:	75ps	0.234UI

RX Jitter Specifications

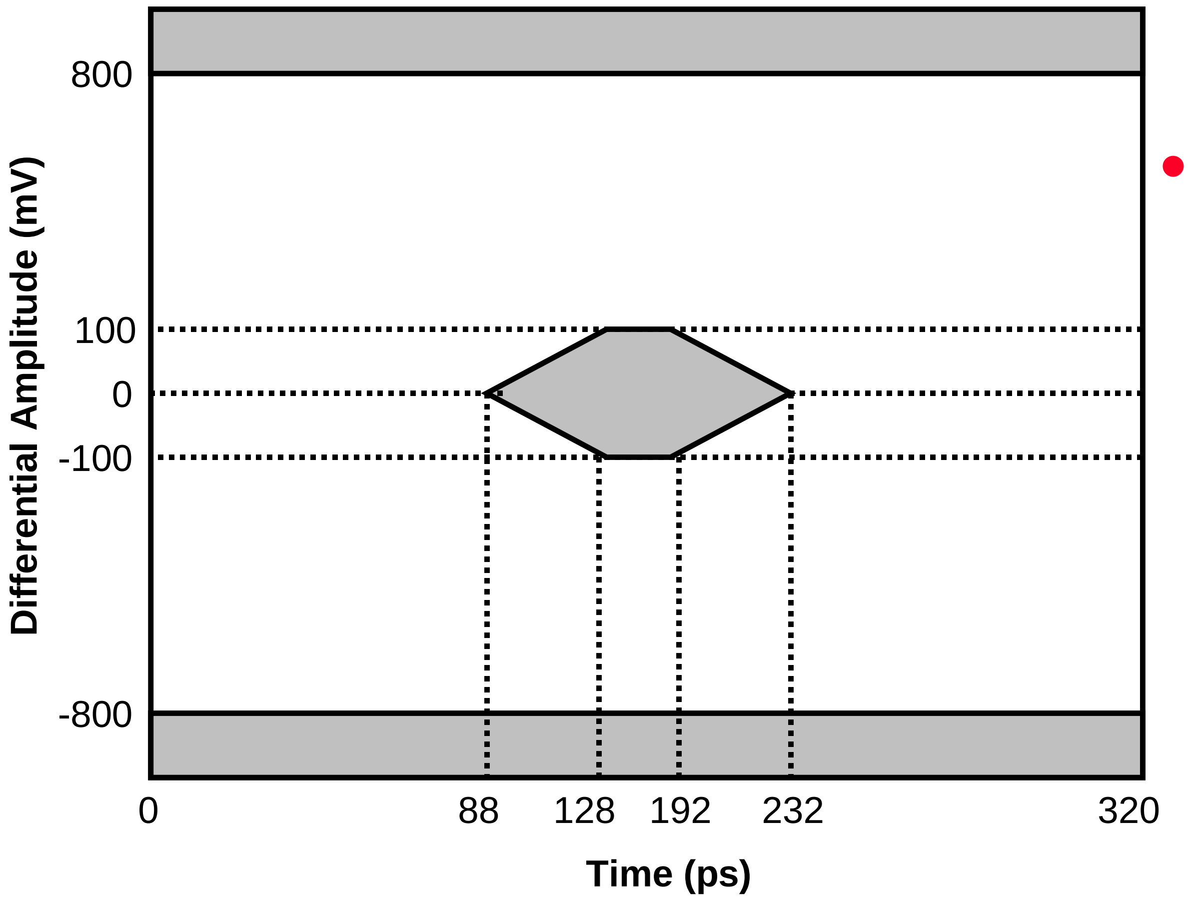
- **Maximum Jitter**
  - 0.65UI Total Jitter
  - 0.37UI Deterministic Jitter
  - 0.55UI Deterministic + Random Jitter
  - Random Jitter has single pole high-pass characteristic. f_c=20MHz
  - Template for Sinusoidal Jitter:



RX Jitter Tolerance	Symbol	peak-to-peak jitter		rms jitter*	
		UI	ps	mUI	ps
Total Jitter	TJ	0.65	208		
Deterministic Jitter	DJ	0.37	118.4		
Deterministic + Random Jitter	DJ + RJ	0.55	176		
Random Jitter (maximum)	RJ	0.55	176	39.6	12.57
Sinusoidal Jitter < 22.1kHz	SJ	8.5	2720		
Sinusoidal Jitter @ 22.1kHz	SJ	8.5	2720		
Sinusoidal Jitter @ 1.875MHz	SJ	0.1	32		
Sinusoidal Jitter @ 20MHz	SJ	0.1	32		
Sinusoidal Jitter > 20MHz	SJ	0	0		

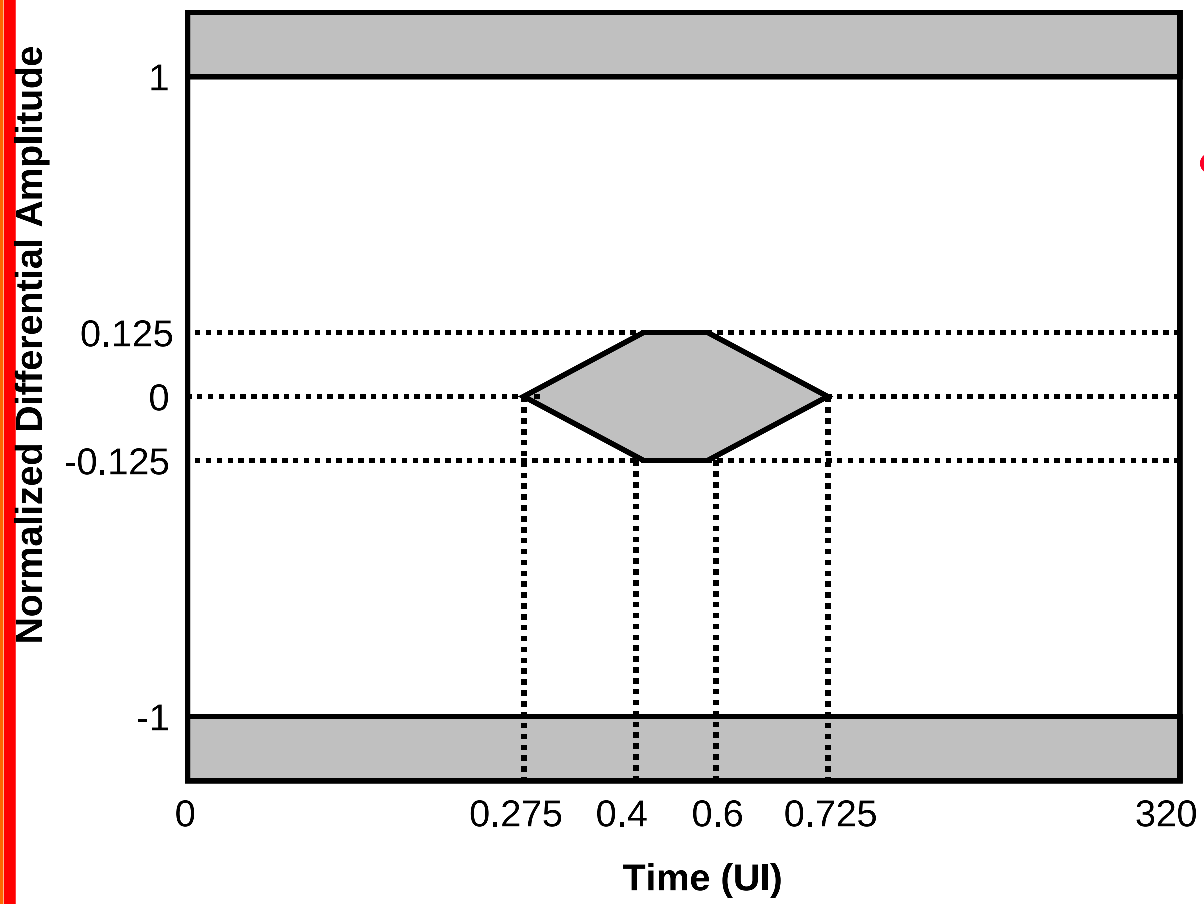
*rms jitter is calculated based on BER=10e-12: rms = (peak-peak)/14

TX Eye Far-end (Absolute)



- **Notes:**
  - 200mV to 1600mV peak-to-peak differential
  - 0.55UI jitter
  - Changed compared to IEEE Draft 3.0!

TX Eye Far-end (Normalized)

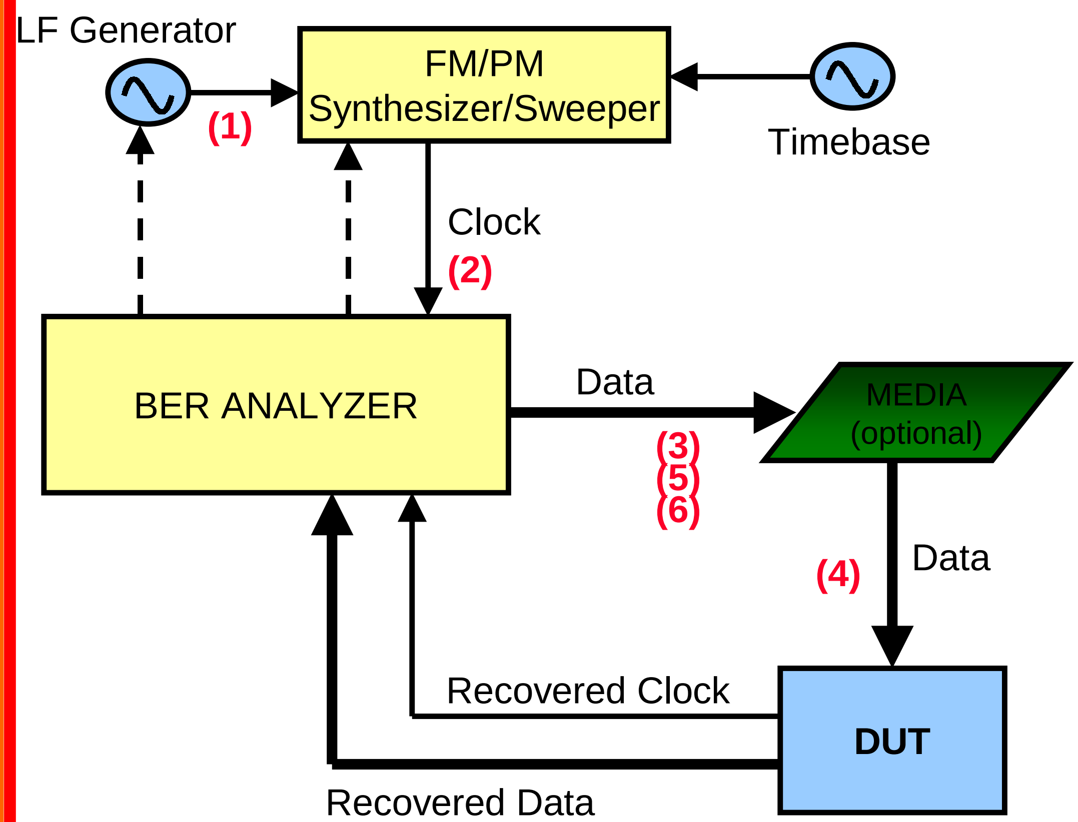


- **Notes:**
  - Full scale amplitude refers to 800mV
  - 1UI = 320ps
  - Changed compared to IEEE Draft 3.0!

Comments on Specification

- **Transmitter specification depends on media**
- **Jitter Tolerance specification not suitable for compliance testing**
  - Maximum TJ is specified as a sum of a DJ and a RJ component
  - The maximum DJ is specified, but the maximum RJ only implicitly
  - This specification results in an infinite amount of test points
- **A possible reduced set for compliance testing**
  - 0.55UI of RJ only + SJ template
  - 0.37UI of DJ + 0.18UI of RJ + SJ template
- **But… Testability with RJ is a problem**

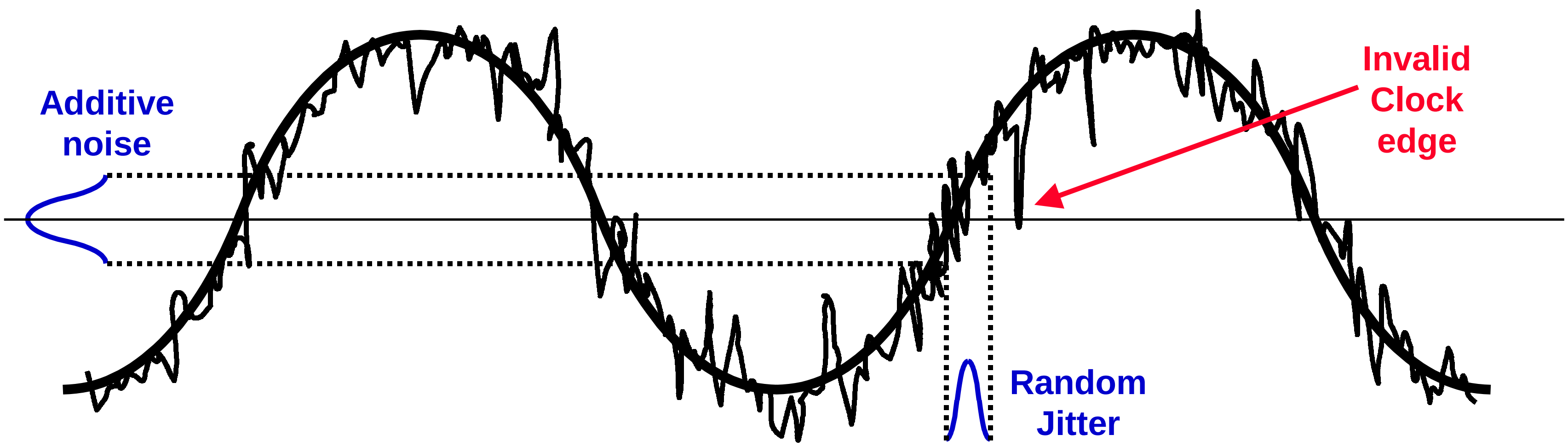
Typical Jitter Tolerance Set-Up



- **Jitter**
  - LF Generator creates SJ
  - Media creates DJ
- **How to introduce RJ?**
  - Add noise at synthesizer (1)
  - Add noise at BERT clock (2)
  - Add noise before media (3)
  - Add noise after media (4)
  - Variable delay line (5)
  - Cascaded limiting amps with additive noise (6)

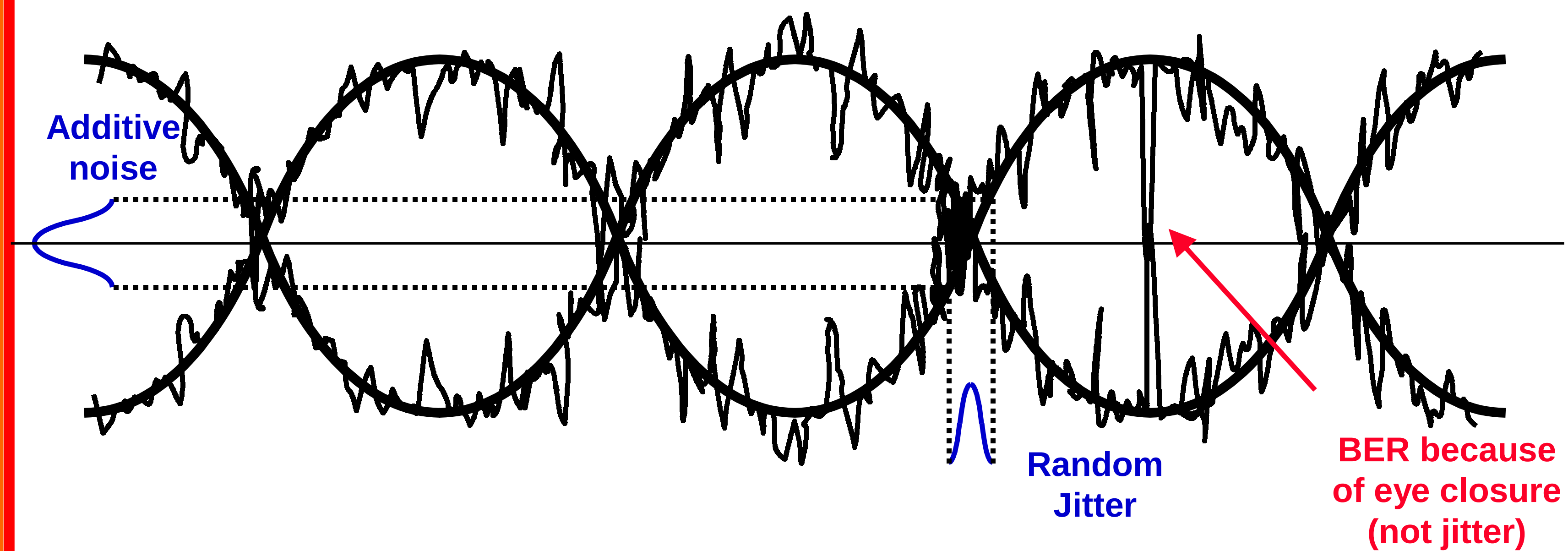
Problems with RJ testing

- **(1) Adding noise at synthesizer**
  - Ideal solution: Phase modulate clock with Gaussian noise
  - Problem: No wideband PM sysnthesizers available. (Noise is 20MHz–2GHz)
- **(2) Adding noise to clock**
  - Additive noise creates jitter at zero-crossings
  - Problem: Additive noise can cause unintended zero-crossings / clock edges



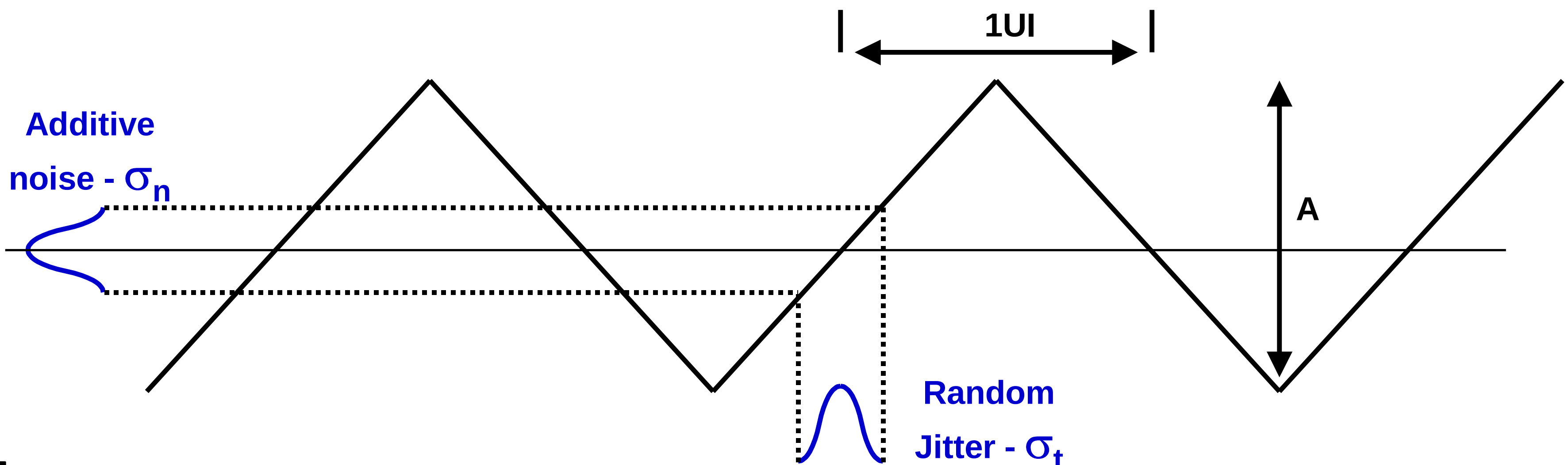
Problems with RJ testing

- **(3)-(4) Additive noise at signal**
  - Additive noise closes vertical eye too!
  - Similar to (2)
  - There is a finite probability that the noise causes an error at center of the eye



Problems with RJ testing

- **(3)-(4) Additive noise at signal**
  - Use ideal triangular wave (optimal)
  - The relation between noise and jitter is: σ_t = 1UI/A * $\boldsymbol{\sigma_n}$
  - For 40mUI rms jitter, you need 0.04*A rms noise.
  - The probability of an error due to jitter or due to eye closure is the same!
  - For sinewave / pulse signals the probability due to eye closure increases drastically. Because the slope increases and more additive noise is needed for the same jitter, or because the peak signal amplitude decreases.



Problems with RJ testing

- **(5) Variable delay line**
  - Voltage or current controlled delay line.
  - Need extremely wide band control (20MHz-2GHz)
  - Problem: most variable delay lines have a DC or LF control only.

- **(6) Cascaded limiting amplifiers with additive noise**
  - Jitter is added by additive noise
  - Limiting amplifier removes noise at the center of the eye, but leaves jitter untouched.
  - Cascading to add limited amount of jitter at each stage such that the vertical eye opening is not affected.
  - Problem: availability?

- **Other solutions?**

Jitter Decomposition

- **BER as a result of jitter is determined by:**
  - Transmitter:
    - ISI and Periodic Jitter: $DJ_{TX,pp}$
    - Random Jitter: $RJ_{TX,rms}$
  - Media:
    - ISI: $DJ_{MED,pp}$
    - Cross-talk and Noise: $RJ_{SNR,rms}$
  - Receiver:
    - ISI and Periodic Jitter: $DJ_{RX,pp}$
    - Random Jitter: $RJ_{RX,rms}$
- **Margin for low frequency drift, wander, etc.**
  - Sinusoidal jitter: SJ_{pp}

Jitter Decomposition (2)

- **Total Far-end Jitter: TJ_{FE}**
  - $TJ_{FE} = DJ_{FE,pp} + M^*(RJ_{TX,rms} +_{\textit{\textbf{rms}}} RJ_{SNR,rms})$
    - With $RJ_{SNR,rms} = \alpha^* SNR_{MED}$
    - And $DJ_{FE,pp} = DJ_{TX,pp} + DJ_{MED,pp}$

- **Receiver Jitter: TJ_{RX}**
  - $TJ_{RX} = DJ_{RX,pp} + M^*(RJ_{RX,rms})$

- **Total Jitter: TJ**
  - $TJ = TJ_{FE} + TJ_{RX} + SJ_{pp}$

- **Notes:**
  - M is the peak-to-peak to rms ratio for a certain BER: for $BER=10^{-12} \Rightarrow M=14.262$
  - α is the gain from additive noise to jitter at the signal transitions
  - SNR_{MED} is the signal to noise ratio of the media (vertical eye opening). For $BER=10^{-12} \Rightarrow SNR_{MED}=2/14.262$ (or 17.06dB)

Jitter Decomposition (3)

- **Notes:**
  - α depends on the slope at the signal transitions
  - But the slope at the signal transitions depends on where the noise is added in the media and the ISI of the media
  - Assume that the noise is added at the transmitter side:
    - α = 130ps/((0.8-0.2)*2*A) = 108.3ps/A = 0.3385UI/A
    - 130ps is the maximum 20%-80% peak-to-peak rise/fall time
    - A is the signal amplitude (not peak-to-peak)
  - For the SNR_{MED} assume 28dB
  - Now, $RJ_{MED,rms}$=0.3385UI * 0.04 = 13.48mUI

Jitter Decomposition (4)

- **Total Jitter:**
  - $TJ = TJ_{FE} + TJ_{RX} + SJ$
  - $TJ = DJ_{FE,pp} + DJ_{RX,pp} + M*(RJ_{TX,rms} +_{\boldsymbol{rms}} RJ_{SNR,rms} +_{\boldsymbol{rms}} RJ_{RX,rms}) + SJ_{pp}$
  - Assumption: The TX and RX clocks are generated by the same (type of) source, then $RJ_{TX,rms} = RJ_{RX,rms} = RJS_{SYS,rms}$
  - $TJ = DJ_{FE,pp} + DJ_{RX,pp} + M*(\sqrt{2}*RJ_{SYS,rms} +_{\boldsymbol{rms}} RJ_{SNR,rms}) + SJ_{pp}$
  - Assumptions:
    - $DJ_{FE,pp} = 0.37UI$
    - $DJ_{RX,pp} = 0.1UI$
    - $SJ_{pp} = 0.1UI$
    - $RJ_{SNR,rms} = 0.01348UI$
  - $TJ = 0.37 + 0.1 + M* (\sqrt{2}*RJ_{SYS,rms} +_{\boldsymbol{rms}} 0.01348) + 0.1\ UI$

Jitter Decomposition (5)

- **For a BER=10^{-12}:**
  - M=14 (approx.)
  - TJ < 1UI
  - TJ = 0.37 + 0.1 + 14* ($\sqrt{2}$*$RJ_{SYS,rms}$ $+_{\boldsymbol{rms}}$ 0.01348) + 0.1 UI < 1 UI

- **Then $RJ_{SYS,rms}$ < 19.58mUI = 6.2ps**

- **Note that this is a BER based on jitter only. Errors because of vertical closure (DJ + Noise) are not included.**

Conclusions

- RJ should be limited to 0.275UI pk-pk (0.275UI pk-pk = 14 * 0.0195UI rms, 0.0195UI rms = 6.24ps rms)
- Additive noise cannot be used directly to introduce random jitter on clock or data for jitter tolerance measurements.
- Current Jitter Tolerance specification is not suitable for compliance testing: infinite amount of combinations of RJ and TJ
- Need method to introduce RJ to signal for jitter tolerance measurement or a specific compliance measurement specification without RJ