Designcon 2000 Presentation

Signal Integrity: How to Measure It Correctly?

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Why Are Correct Measurements of Signal Integrity (SI) Important ?

- SI has many components / root causes
- SI root causes represent physical origins
- To diagnose and fix SI induced failure and performance degradation, details are needed
- SI simulation models need to be verified through correct measurements
- SI simulation alone can not warrant a working design

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Outline

- Introduction
- Signal Integrity and Jitter
- Jitter Classification Scheme
- Jitter Models
- Autocorrelation Algorithm
- Tailfit Algorithm
- Practical Case Studies
- Conclusion

(Patents for these algorithms are pending)

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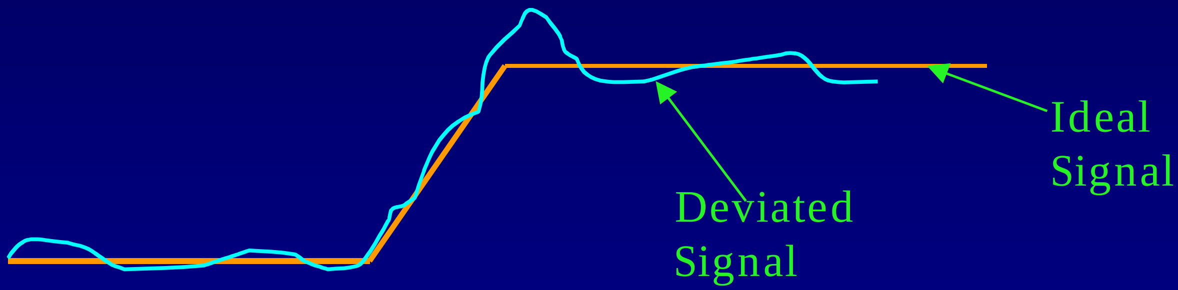
Signal Integrity

- What is signal integrity?

  Any signal waveform deviation from ideal



- Signal integrity can have many root causes

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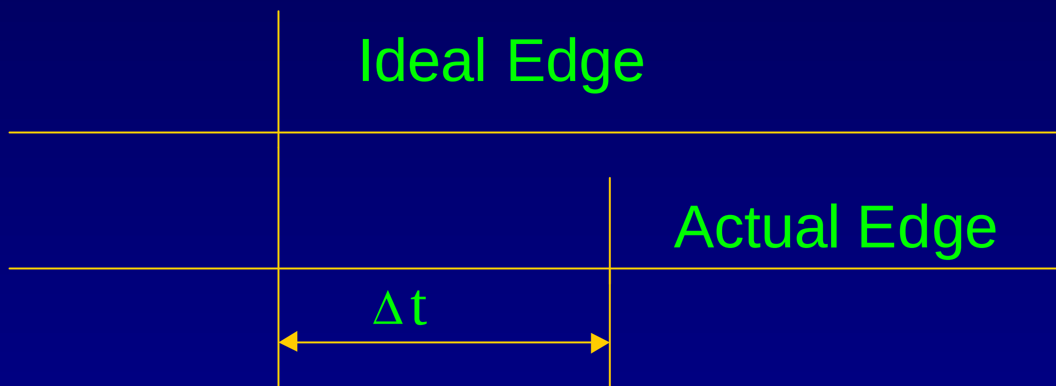
Jitter

- What is Jitter ?

  Any edge deviation from ideal



- Jitter can have multi root causes

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Signal Integrity Root Causes

- Crosstalk
- Ringing
- Reflection
- EMI
- Ground bounce
- Switch power supply noise
- Thermal noise
- White, flicker, random noise

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Signal Integrity ⟷ Jitter

- Jitter is Signal Integrity for an edge transition
- Jitter and Signal Integrity share common root causes
- Jitter is an important term to represent Signal Integrity

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Jitter: Views from Signal Theory

- Jitter is a stochastical process
- Jitter has a distribution
- Jitter has many different components

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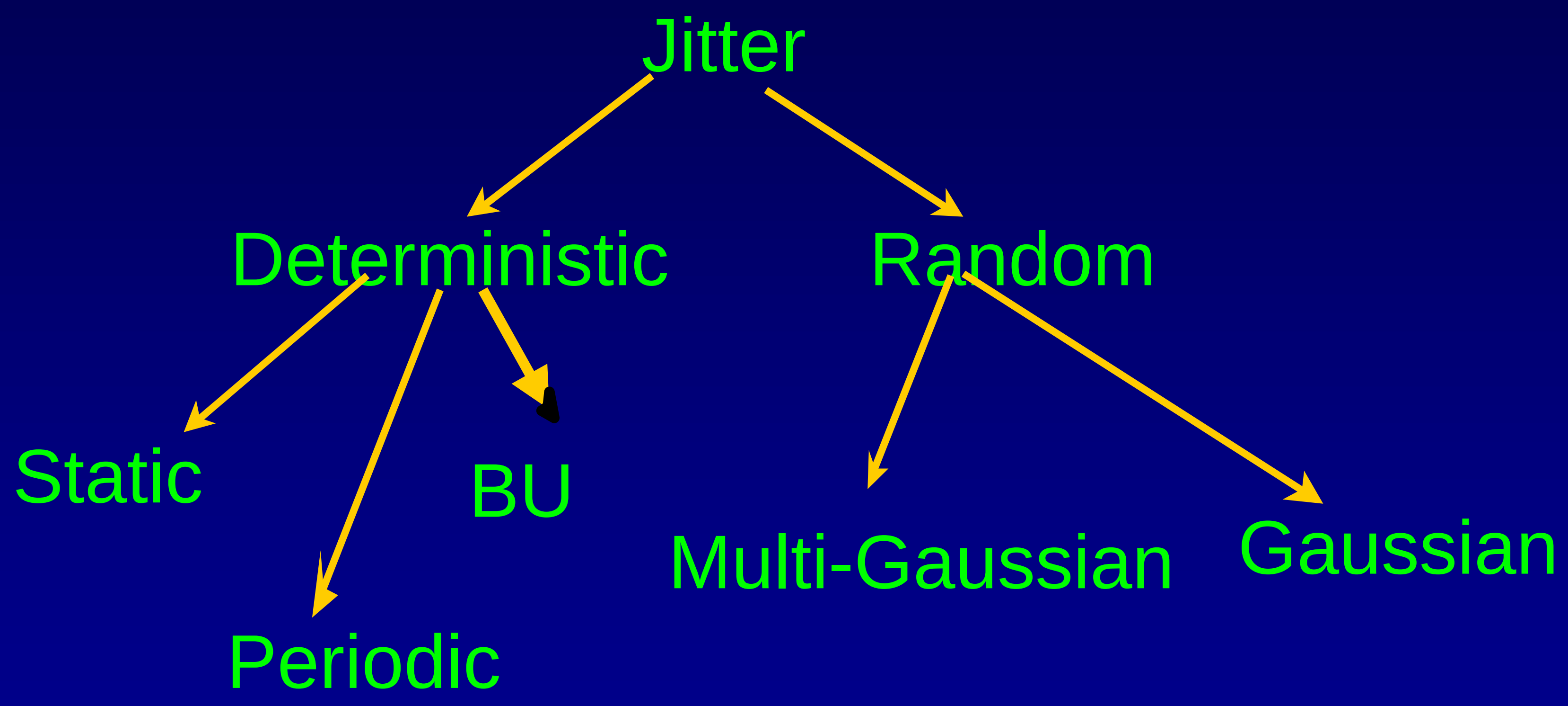
Jitter Classification Scheme (Stochastic Process Based)



BU: Bounded uncorrelated

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Jitter Components
⇕
SI / Physical Root Causes

DCD+ISI	PJ	BUJ	RJ
Reflection	Modulation	Crosstalk	White Noise
Limited Bandwidth	EMI		Thermal Noise
Ringing	Ground Bouncing		Flicker & Shot Noise

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Jitter Models

DCD+ISI : Depends on specific jitter / SI source

PJ: Sinusoidal

BUJ: Truncated Gaussian

RJ : Gaussian or multi Gaussians

TJ (Total Jitter): Convolutions of all the independent jitter component models

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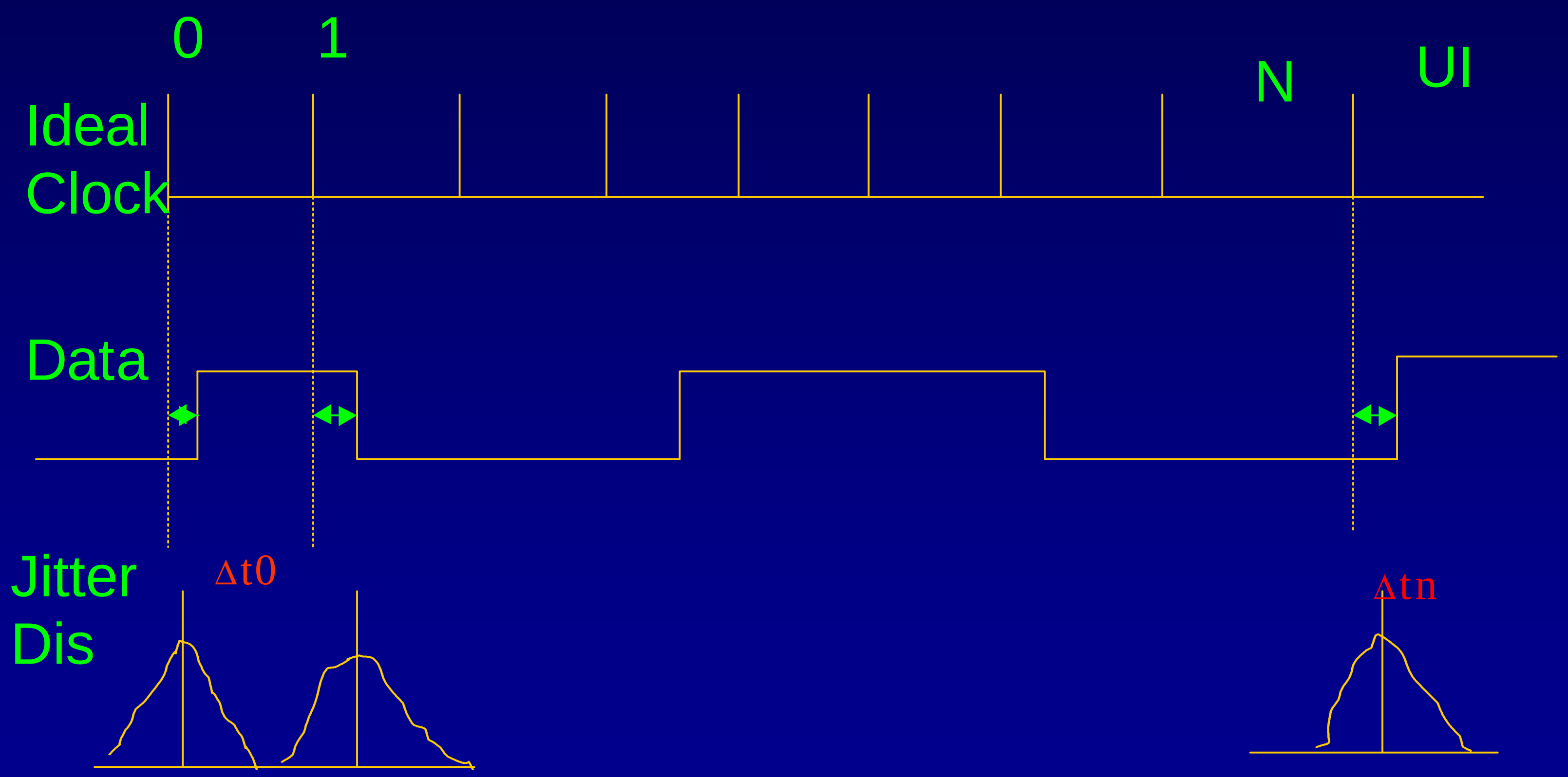
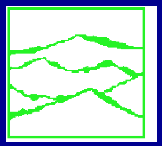
Challenge: Jitter Separation

- In real practice, jitter components: deterministic and random, are always present
- High entropy state: expect difficulties in recovering signals
- Correct methods were lacking until recently

Jitter Separation , N-Span and Autocorrelation Approach





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DCD+ISI Separation Based On *Mean*

- DCD+ISI (or DDJ) is obtained through pattern match and mean calculation

$$DDJ = MAX\{MAX(ABS(dt_n))\}$$

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RJ & PJ Separation Based On *Variance*

- PJ and RJ is calculated through FFT of the auto-correlation record

$$VAR(\Delta t(n)) = c - 2 * Rxx(\Delta t(n))$$

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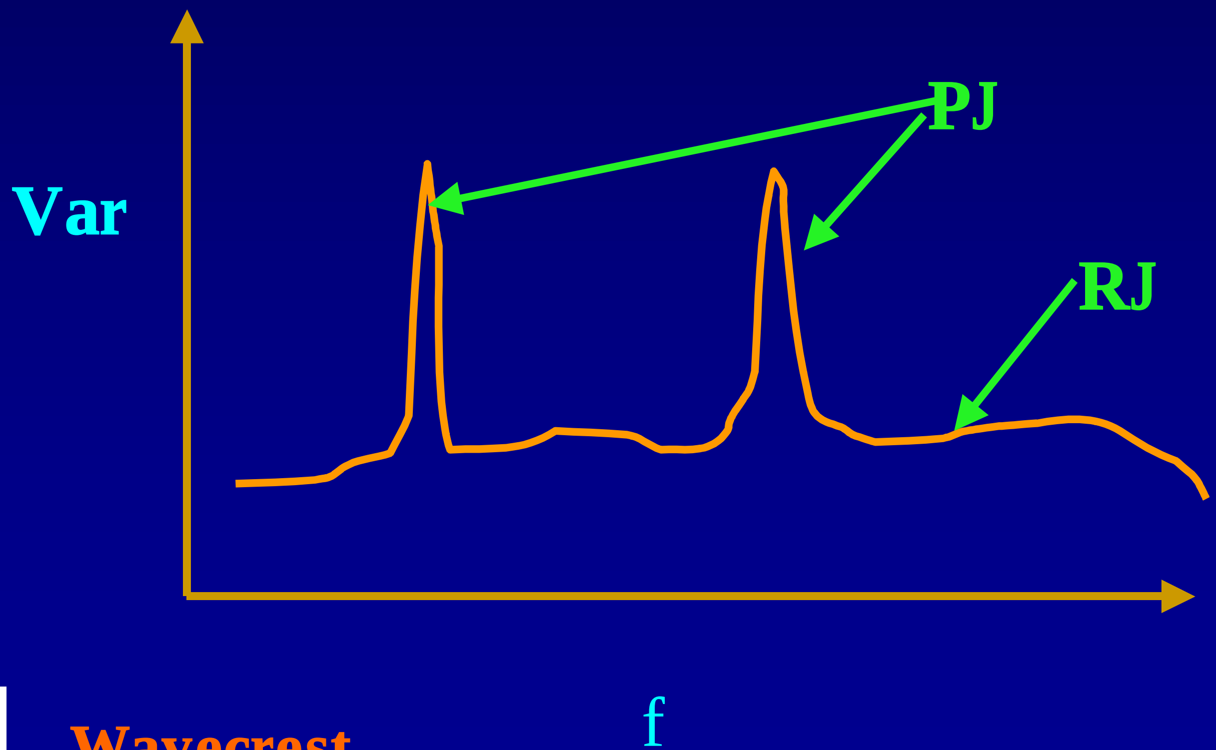
Variance Spectrum

- PJ separation through "sliding" filter
- RJ calculation through "residue" integration



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DJ-RJ Separation Based on Time-Domain *Histogram Distribution*

- What can we learn from a single jitter histogram distribution about DJ and RJ ?
- Histogram is a scaled Probability Density Function (pdf) for jitter processes.
- To calculate the total pdf, individual pdfs needs to be ***convolved***, not ***added***.

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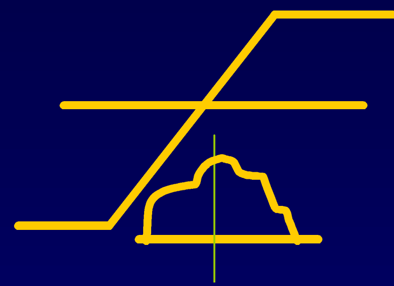
Traditional Ways of Using Jitter Histogram: What Goes WRONG?



- Statistical standard deviation
  (an overestimate for RJ)
- pk-pk (sample size dependent TJ)
- In general (for a joint DJ and RJ histogram), these are not correct ways, and RJ, TJ numbers obtained from this statistics are WRONG !

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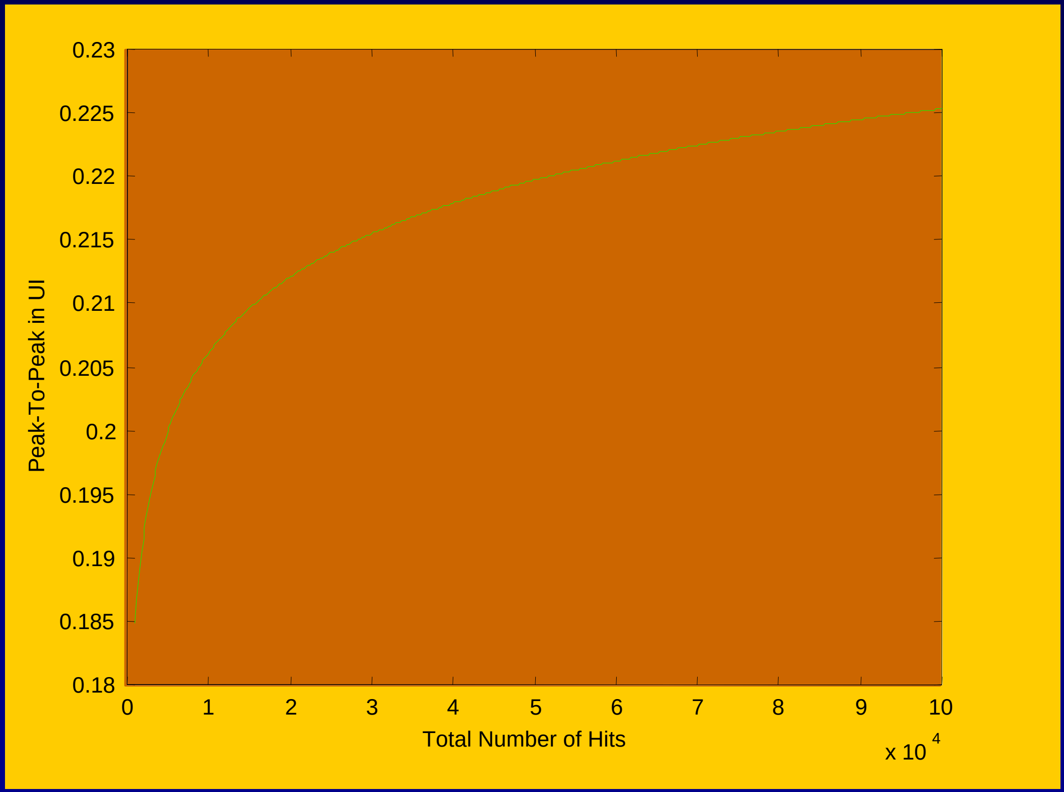
What Does Peak-Peak Look Like?

- For a random Gaussian distribution



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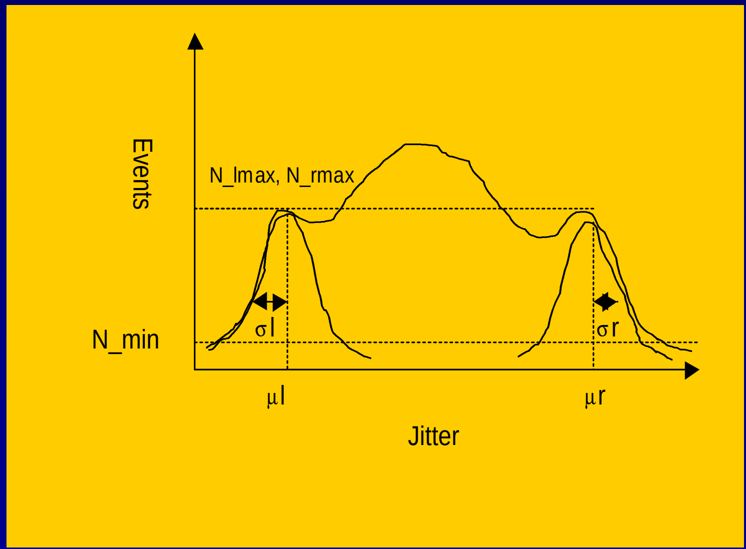
Standard Deviation (SD) ≠ RJ sigma

- For a histogram distribution with both DJ and RJ components,

$$SD = \frac{1}{N-1}\sum_{n=1}^{N}\left(\overline{\Delta t} - \Delta t_i\right)^2$$

$$> \quad s^2$$



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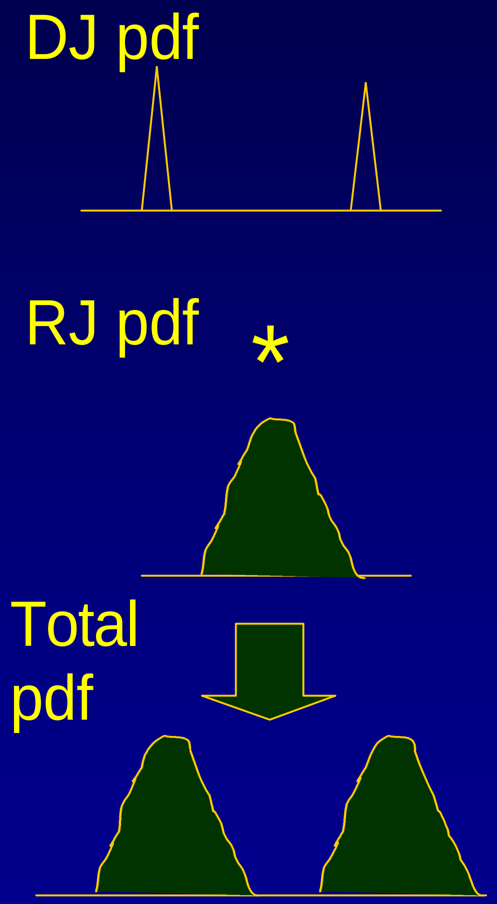
What Is The Correct Method: Tailfit !

- Total jitter pdf = DJ pdf * RJ pdf (* means ***CONVOLUTION)***
- RJ pdf is a Gaussian:

$$p(\Delta t) = \frac{1}{\sqrt{2\pi}} e^{-\frac{(\Delta t - \mu)^2}{2\sigma^2}}$$

- ***Tail parts*** of distribution preserve information on RJ process.



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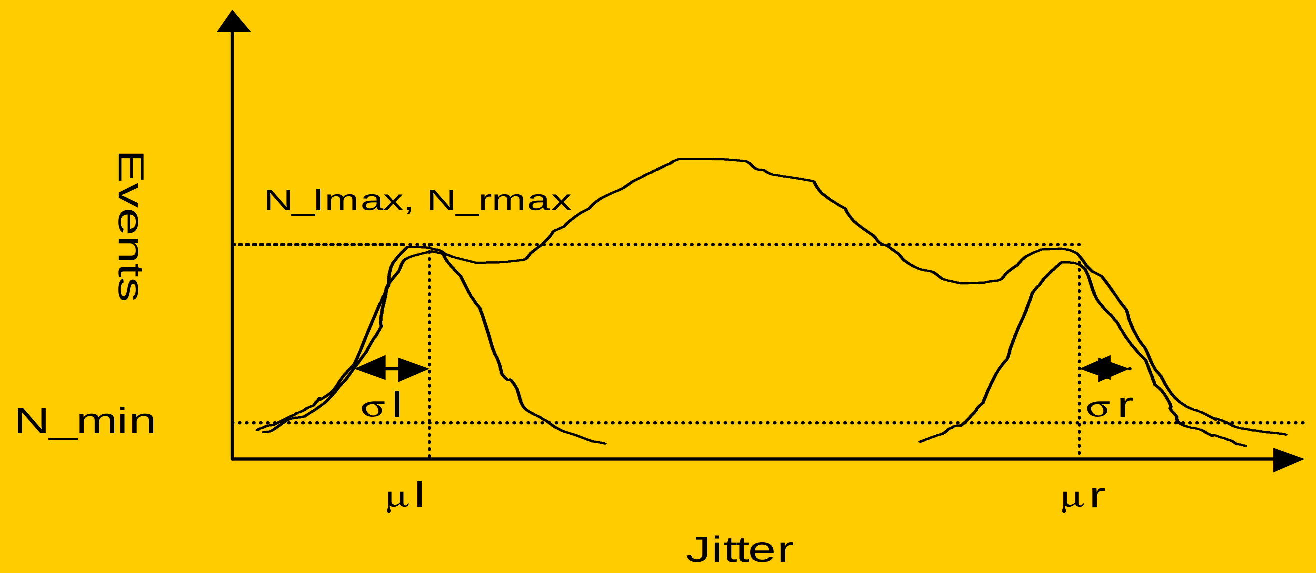
Tailfit Algorithm



$$RJ = (s_l + s_r)/2$$

$$DJ = m_r - m_l$$

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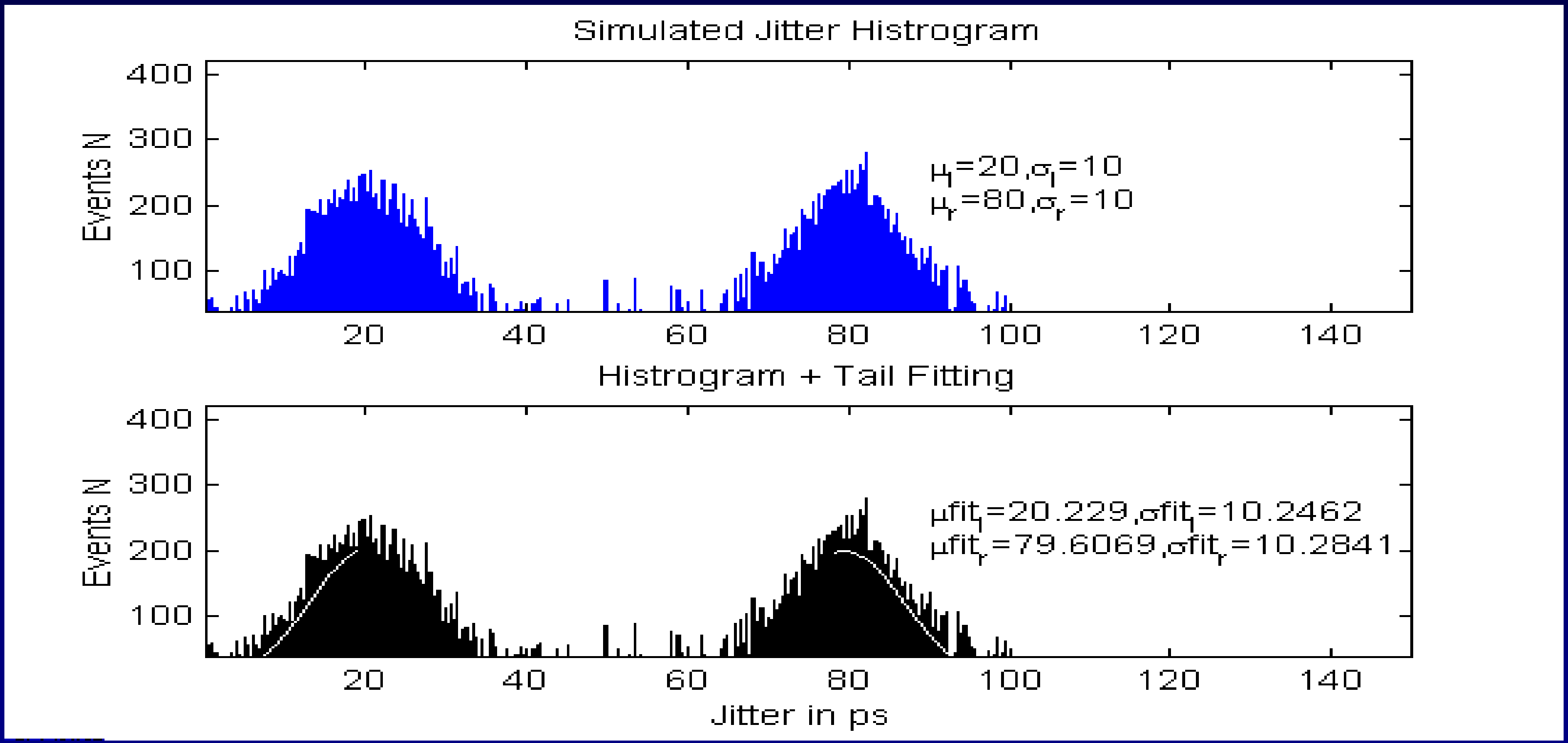
Monte Carlo Simulation



- **15% fluctuation -> only < 4% error in DJ and RJ**
- **For a 10,000 hits histogram, repeating the simulation 100 times, 1 σ error for DJ is ~5%, and ~17% for RJ.**

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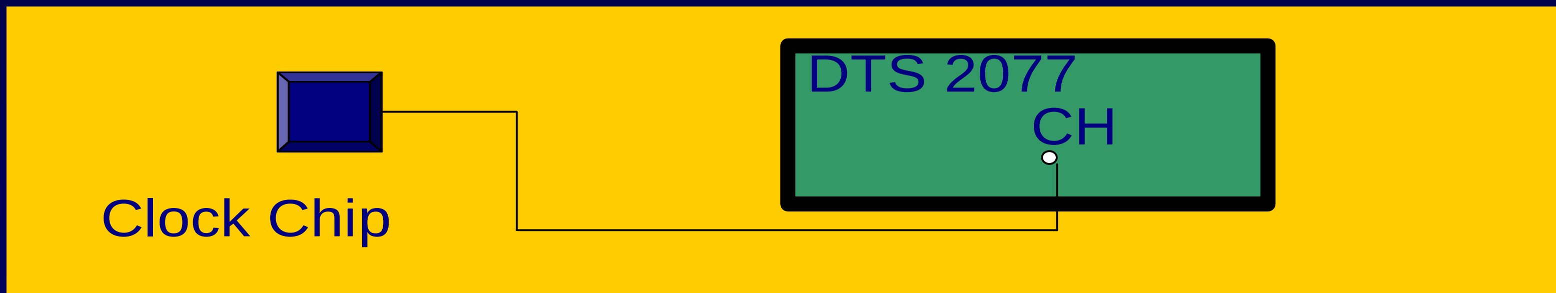
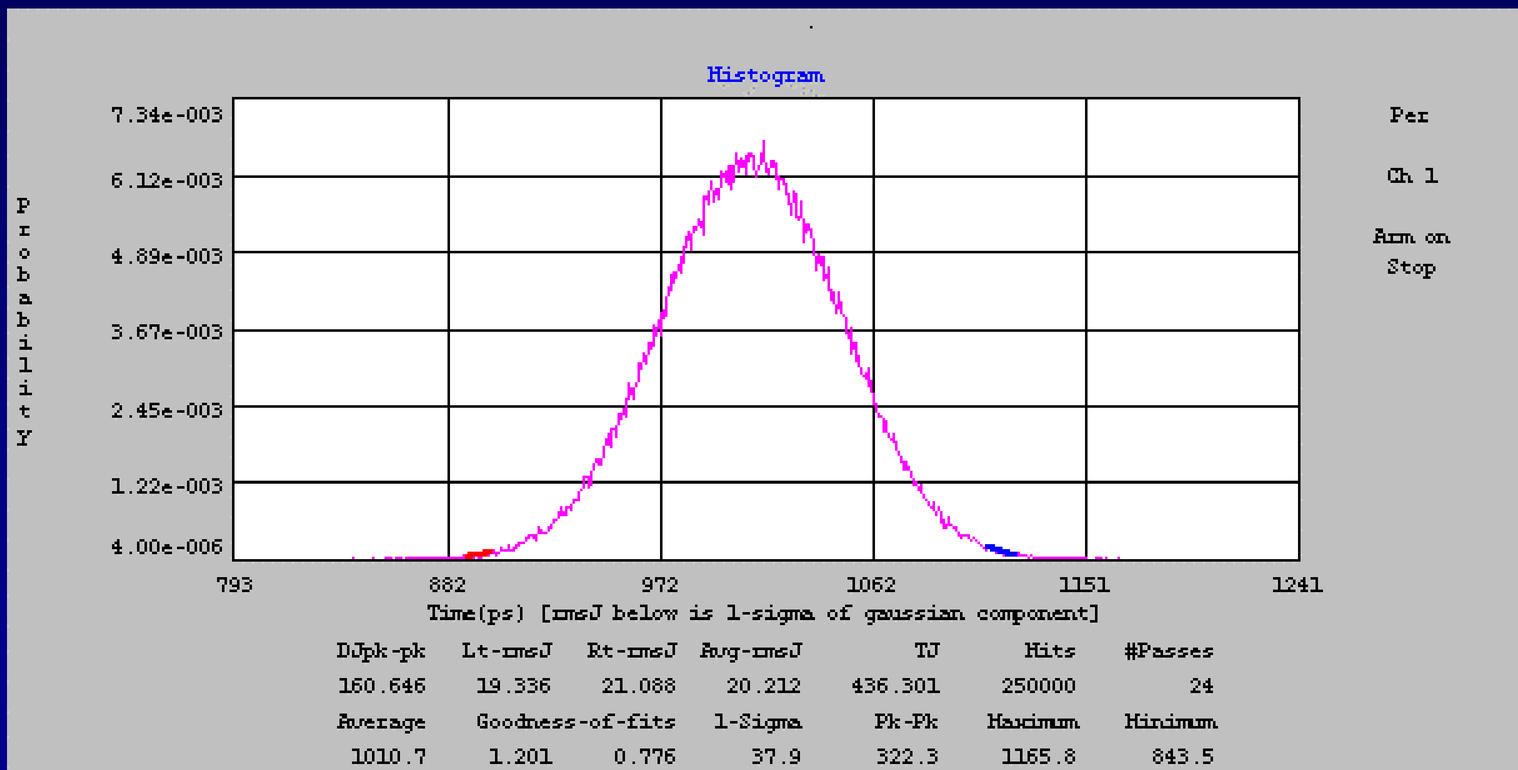
Case Studies

a.) Clock Signal





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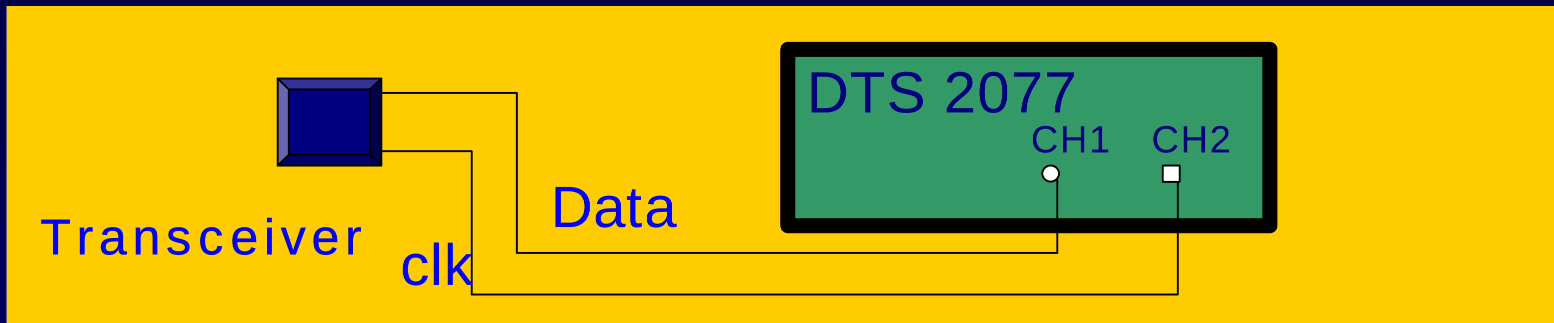
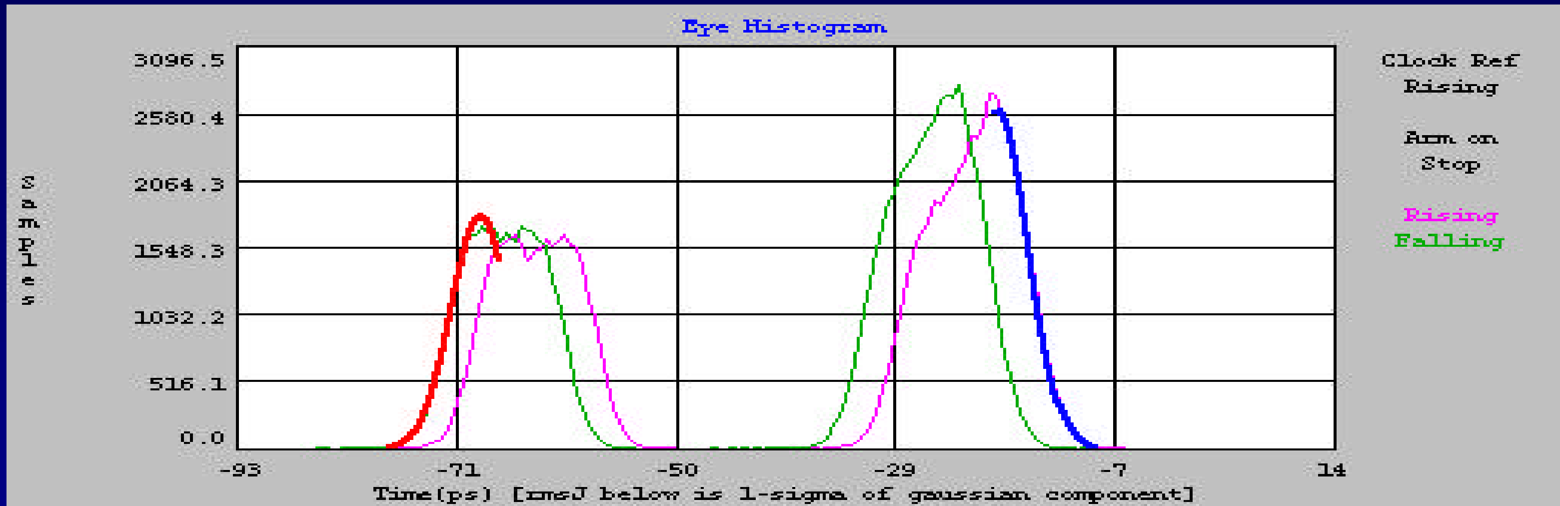
b.) Data Signal (clock to data, BERT Equivalent)





Effective DJ: 27.231 Effective RJ: 3.139

	DJpk-pk	Lt-rmsJ	Rt-rmsJ	Avg-rmsJ	TJ	Pk-Pk	1-Sigma
Data	51.914	2.879	2.931	2.905	92.239	78.1	21.136
Clock	2.274	2.286	5.713	4.000	85.498	23.2	2.892
	#Passes	Goodness-of-fits		Hits	UI		Clk-Data skew
Misc	41	4.188	2.263	168020	999.991		-39.757

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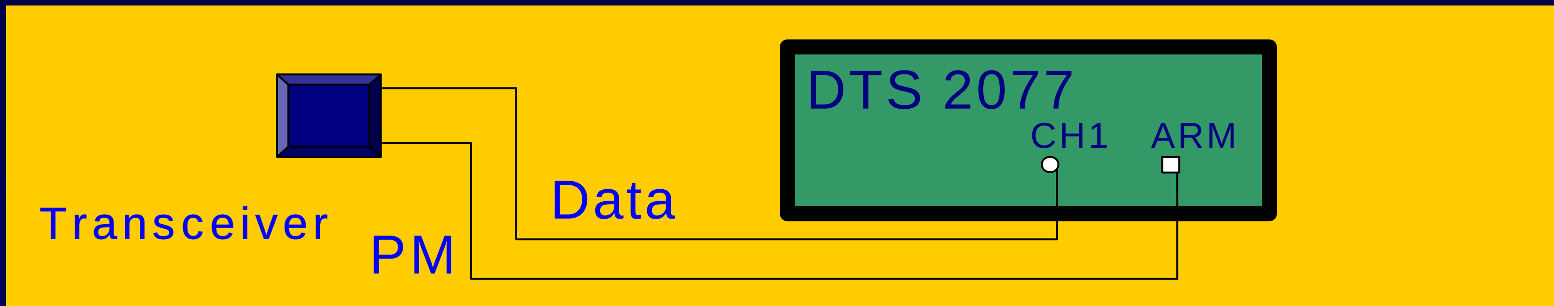
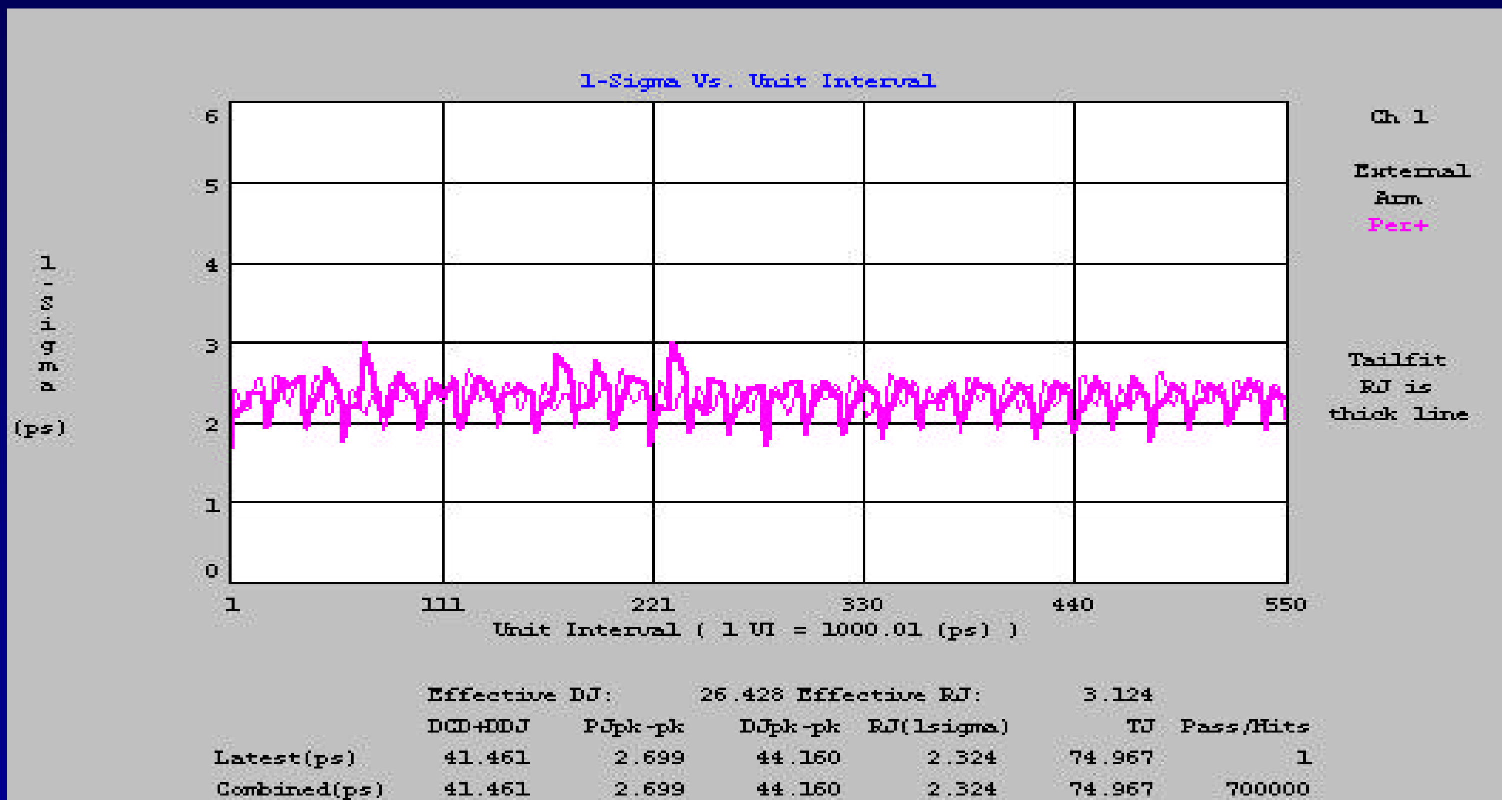
c.) Data Signal (data to data, with pattern marker)





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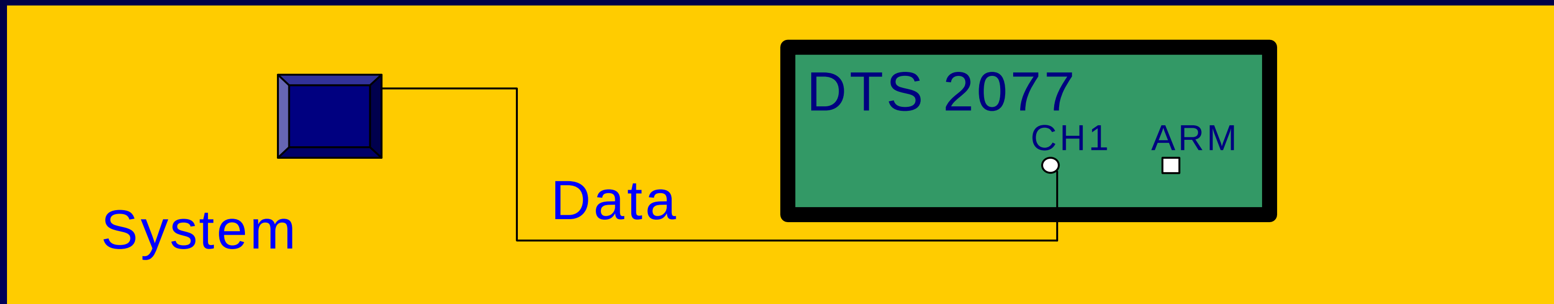
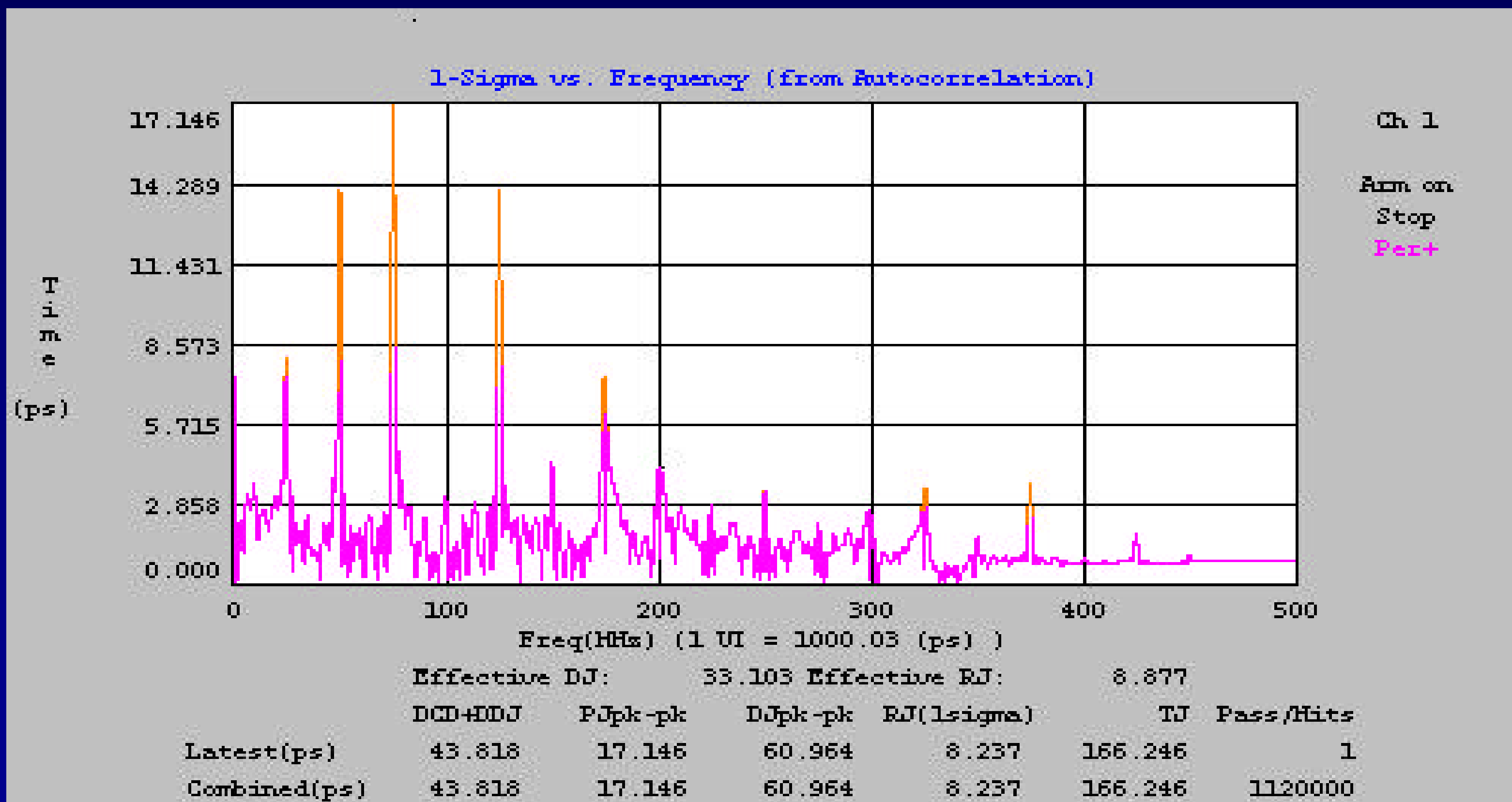
d.) Data Signal (data only, no pattern marker, or bit clock)





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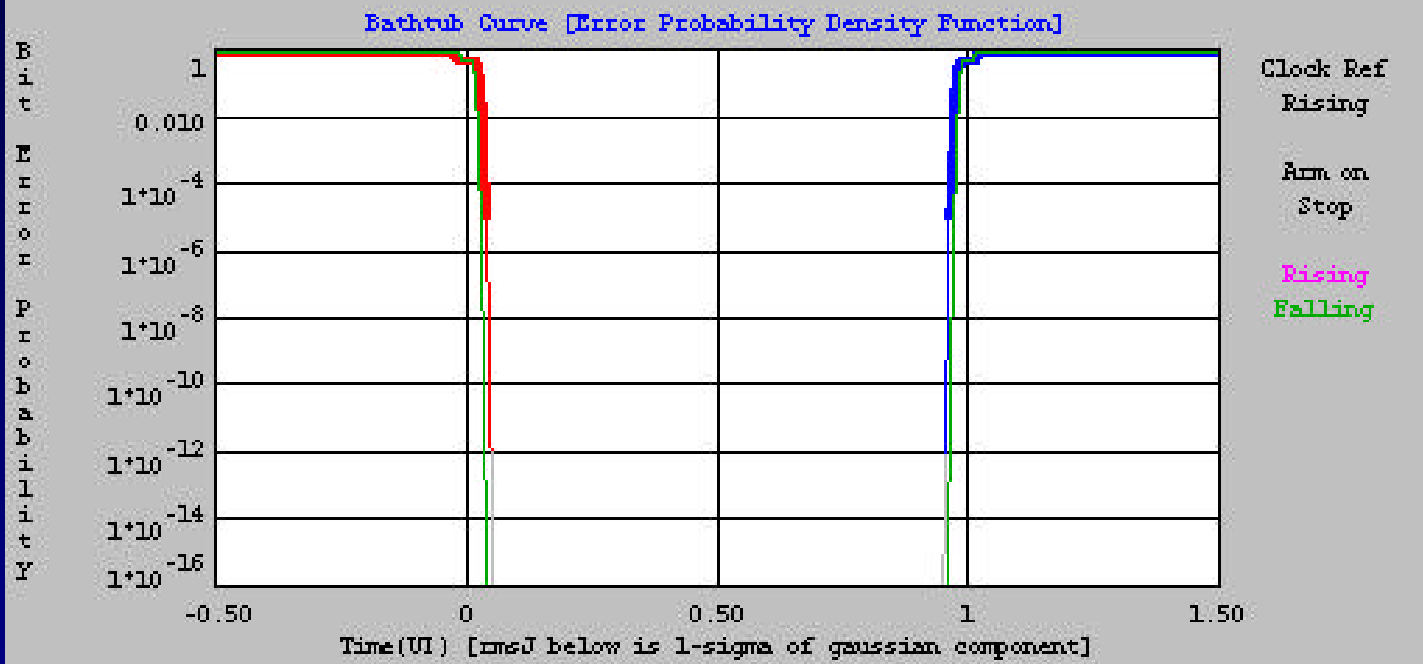
Bit Error Rate (BER) Prediction

- System performance degraded if DJ/RJ are big
- BER curves are essential to quantify system reliability, performance, and stability.
- ***ONLY*** with DJ and RJ pdfs, may BER curve be calculated

BER Curves



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Conclusion

- New algorithms are developed to measure SI/jitter components based on either signal or a time series jitter histogram distributions
- These algorithms are accurate, repeatable, and robust
- It can be applied to SI measurements and SI tool/model verifications
- It can be applied to datacom, telecom, fiber optics, clock, PLL, data bus, …. jitter testing

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