Link Analysis Jitter Algorithm in the Presence of Receiver Non-Linearity[1]

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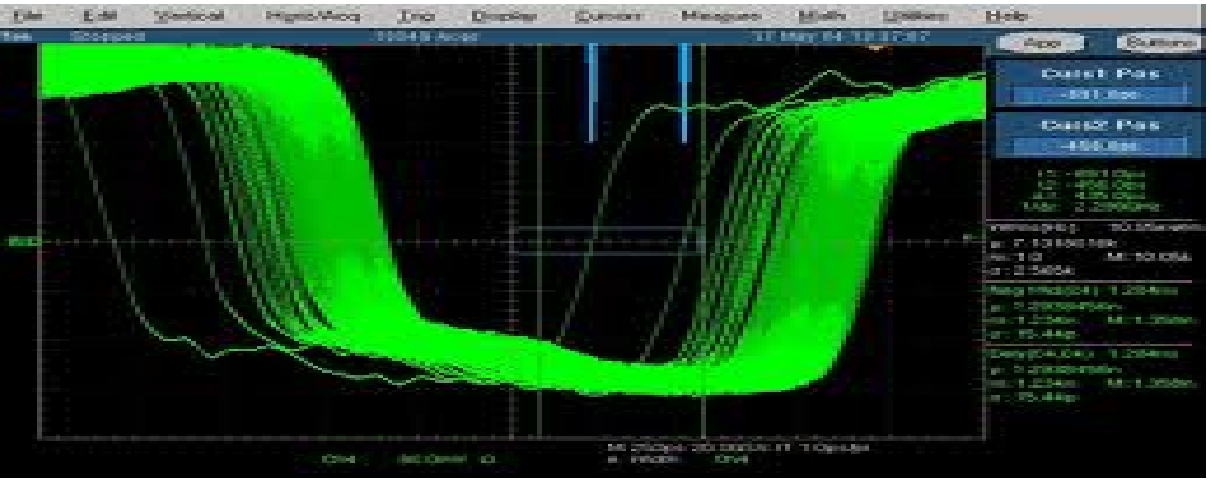
Presented at the International Conference on Consumer Eletronics, ICCE Las Vegas, Nevada, January 8-11, 2016

[1] The authors thank National Science Foundation, Award 1429941, for providing partial MRI support for this research.

Outline:

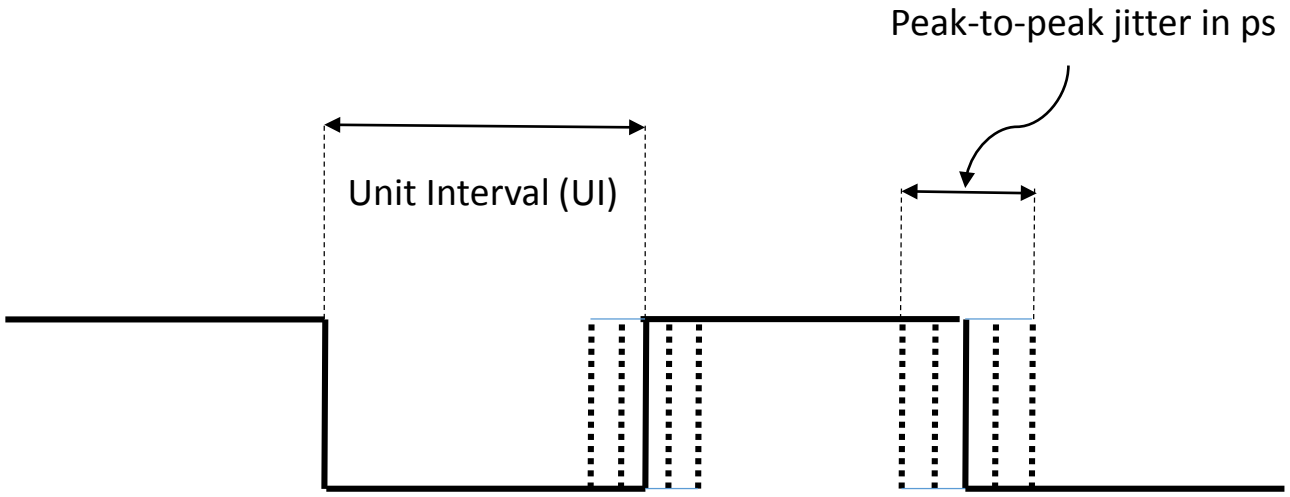
- Background on Jitter
- Jitter based on segment analysis
- Hash maps
- Non-linearities in CMOS
- Statistical non-linearities
- Conclusions

What is Jitter?

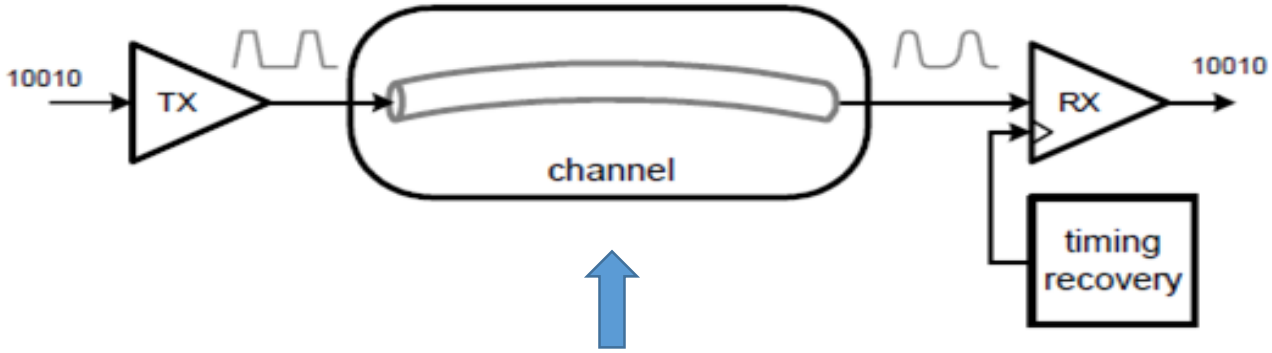


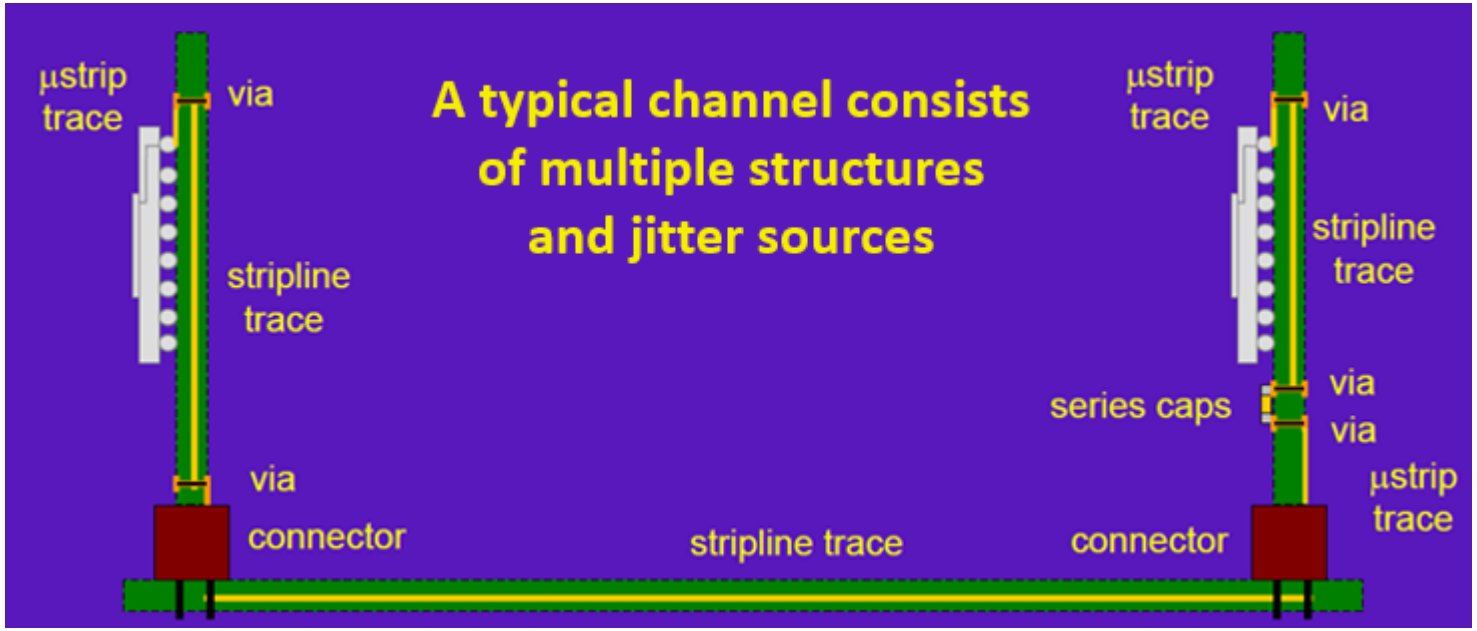
<u>Significant</u> and <u>undesired</u> deviation of a bit in communication systems

- Unit of time that corresponds to the transmission or reception of 1 bit of data
- UI is represented as Δt_{bit}

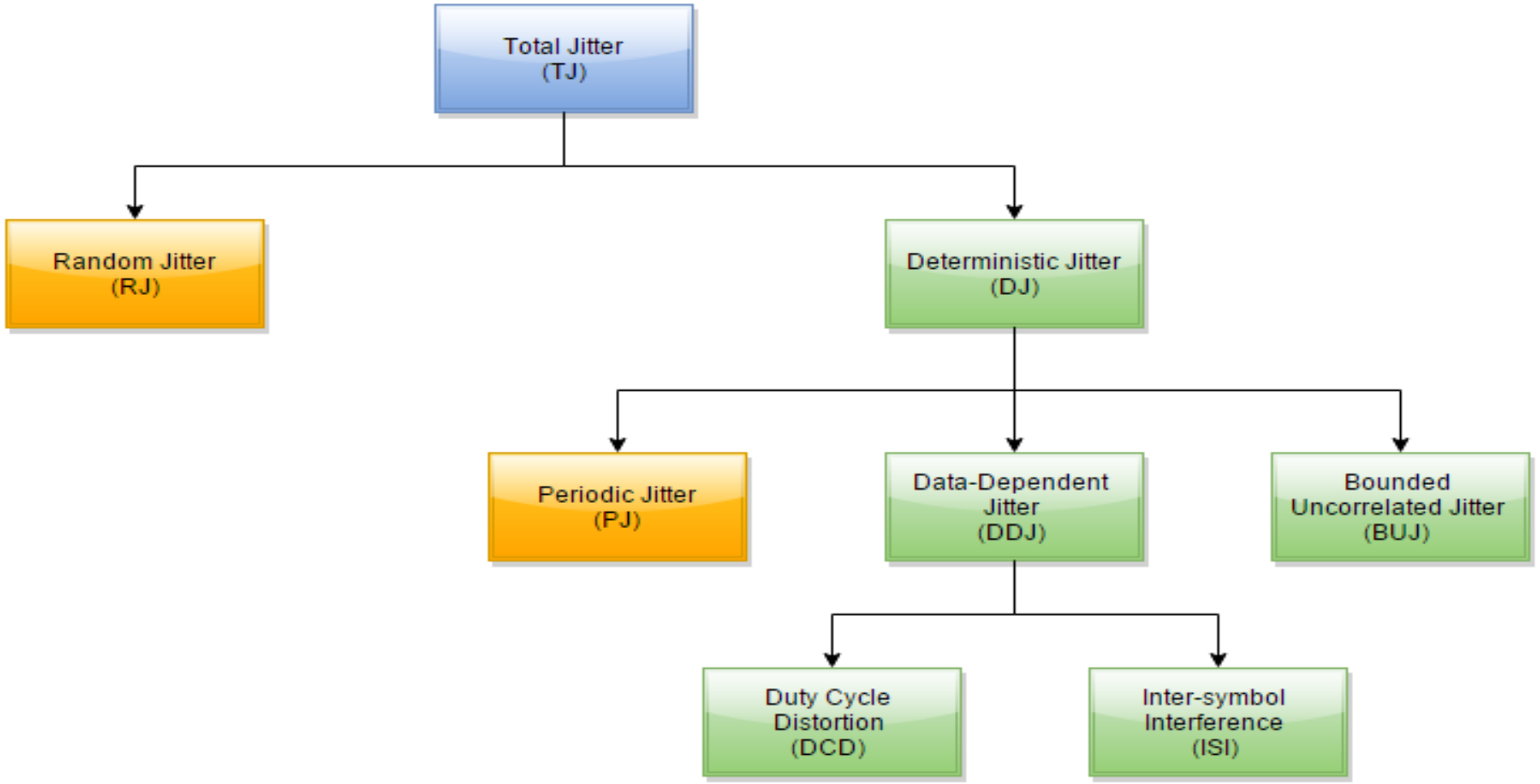


Where Jitters happens

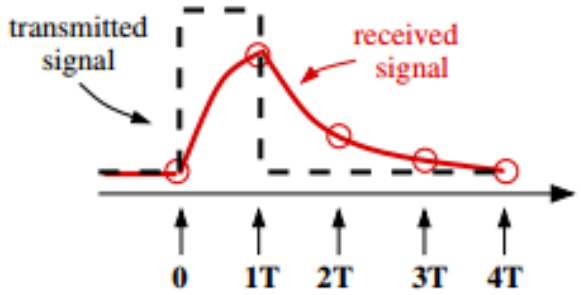


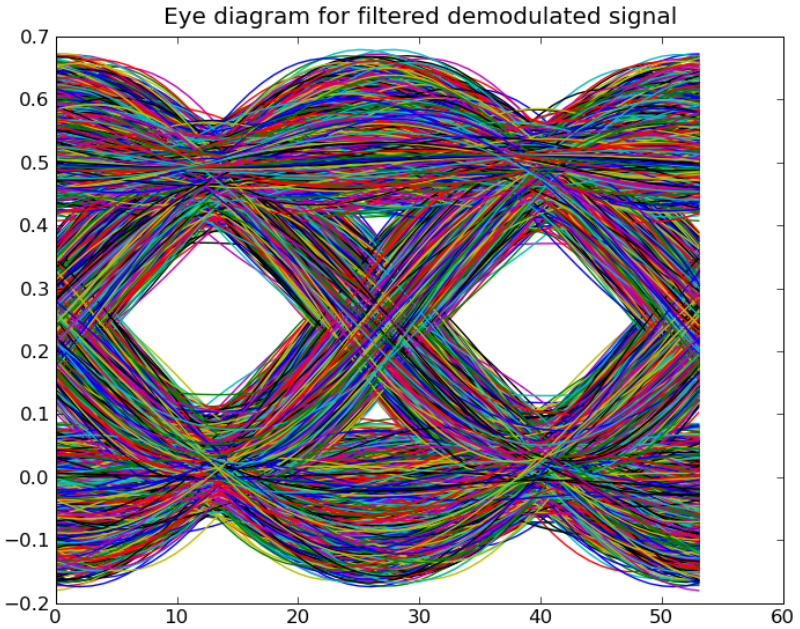


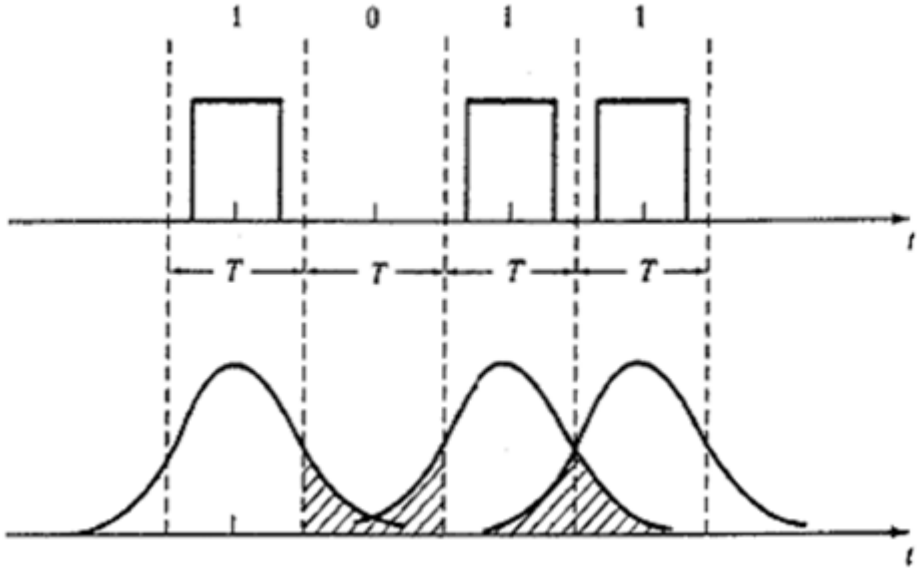
Components of Jitter



Inter-symbol Interference (ISI)

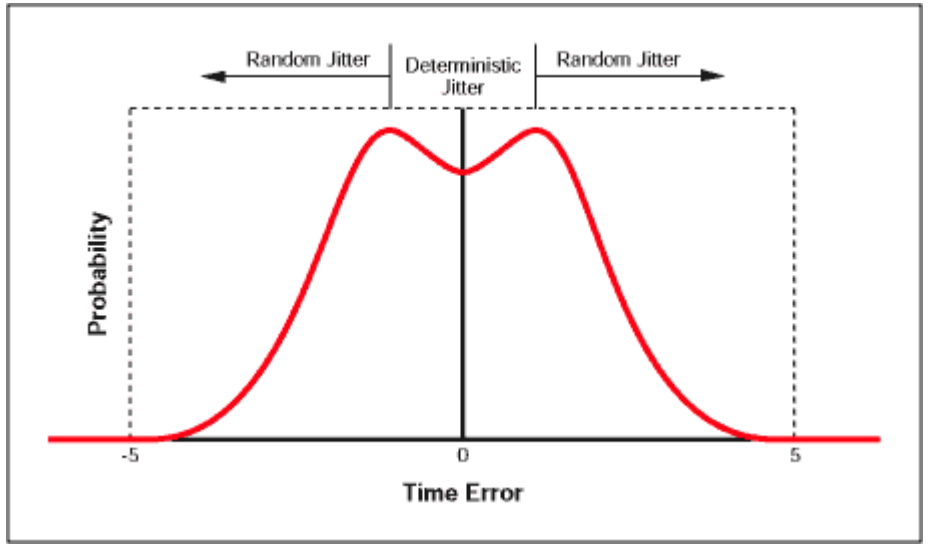


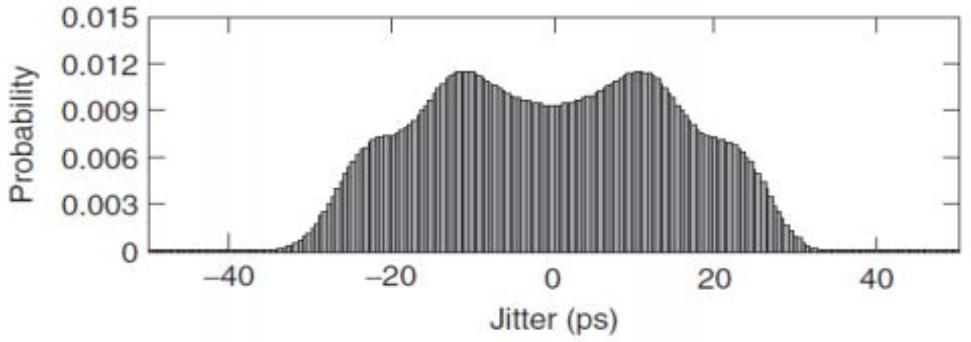




Total Jitter

- Total jitter is the algebraic sum of all constituent forms of jitter

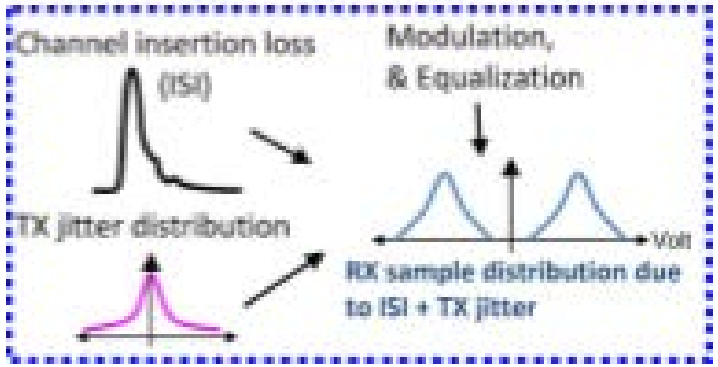




$$PDF_{TJ}(t) = PDF_{RJ}(t) * PDF_{DJ}(t)$$

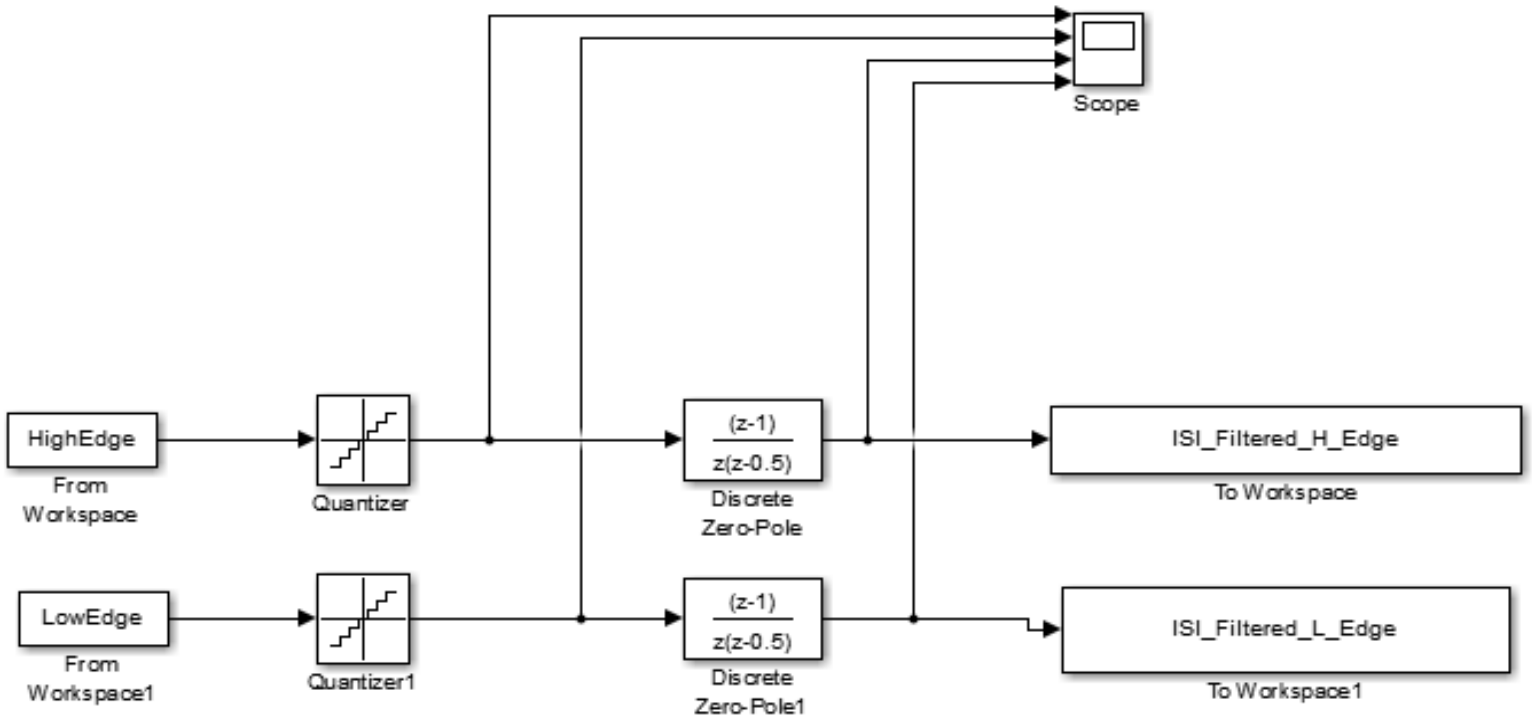
Statistical Signal Analysis

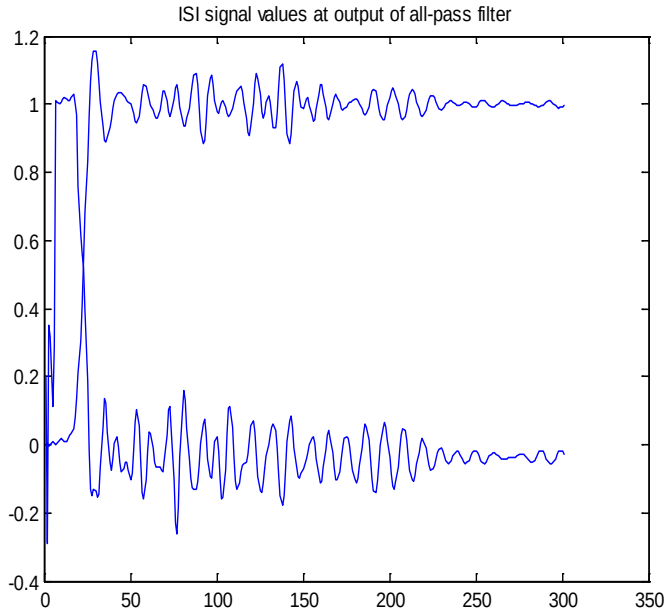
Assumptions for Statistical analysis:



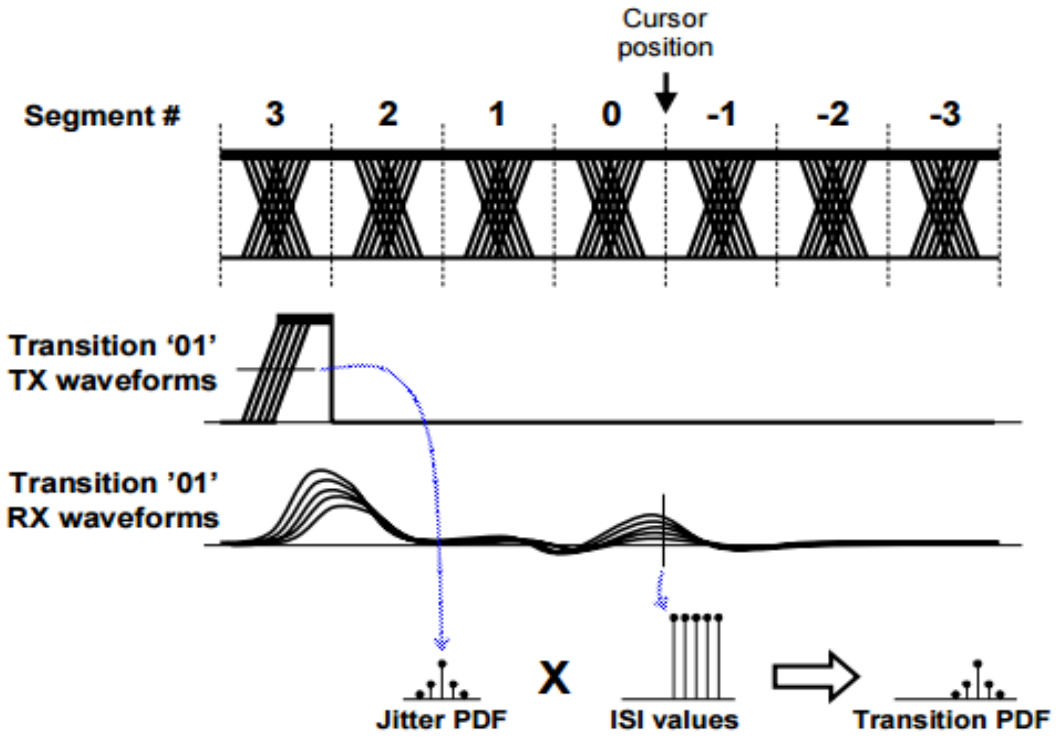
- System must be linear and time-invariant
- Noise and jitter distributions must be:
  - Stationary (Statistics do not change with time)
  - White (i.e. uncorrelated), but possibly non-Gaussian
  - Independent of data sequence
- Data over all channels are uncorrelated with each other

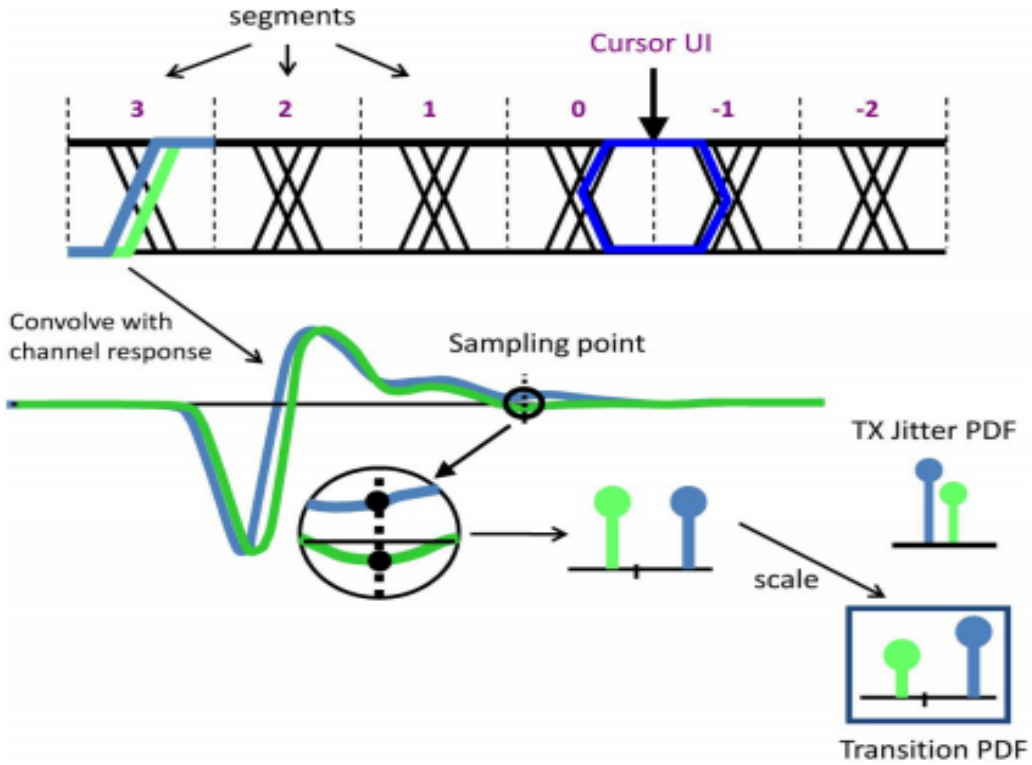
Simulink block for ISI values





Link Analysis Algorithm (B. Casper, Intel) Transition PDF (TPDF) Formation

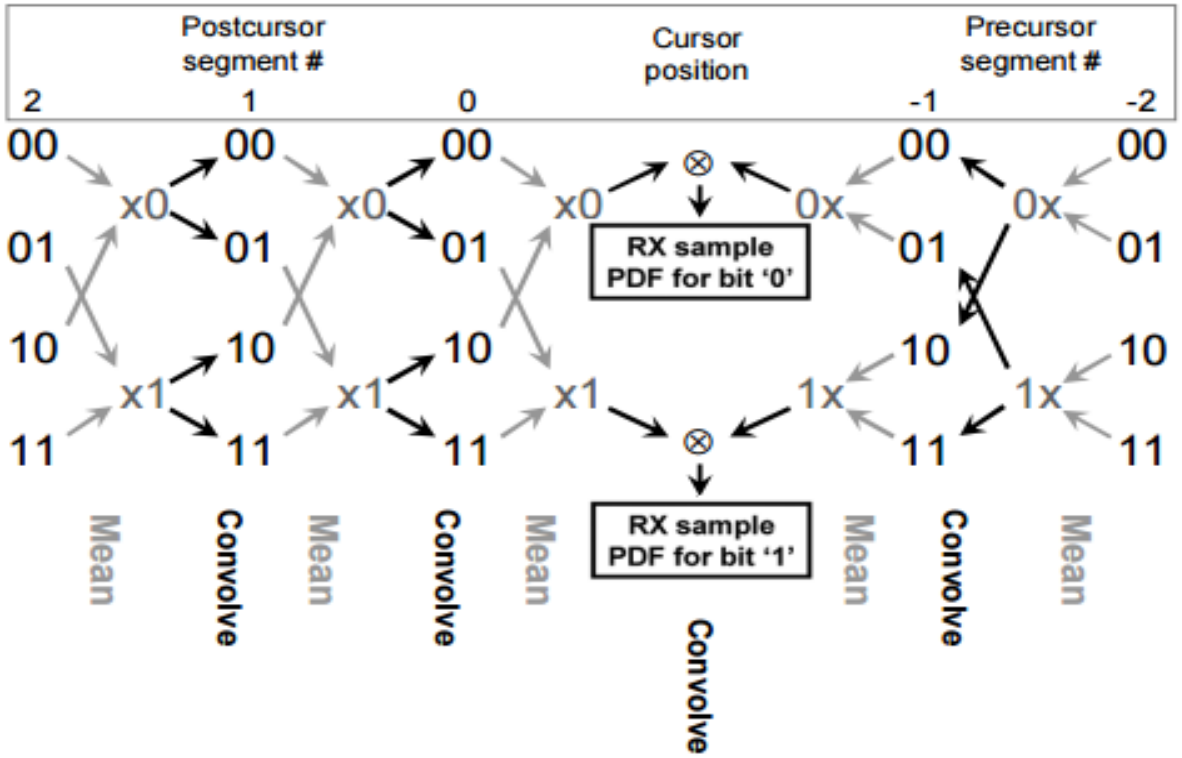




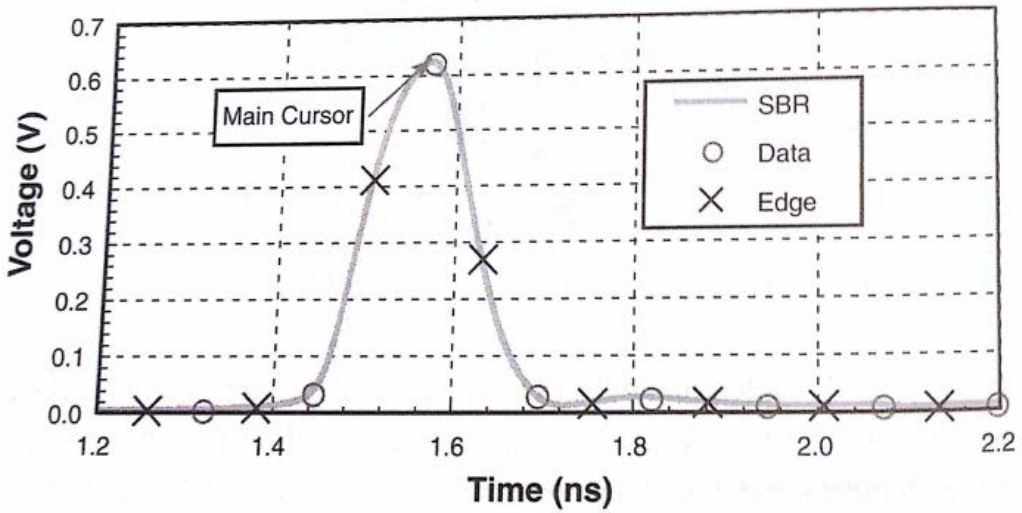
(B. Casper et. al, Intel)

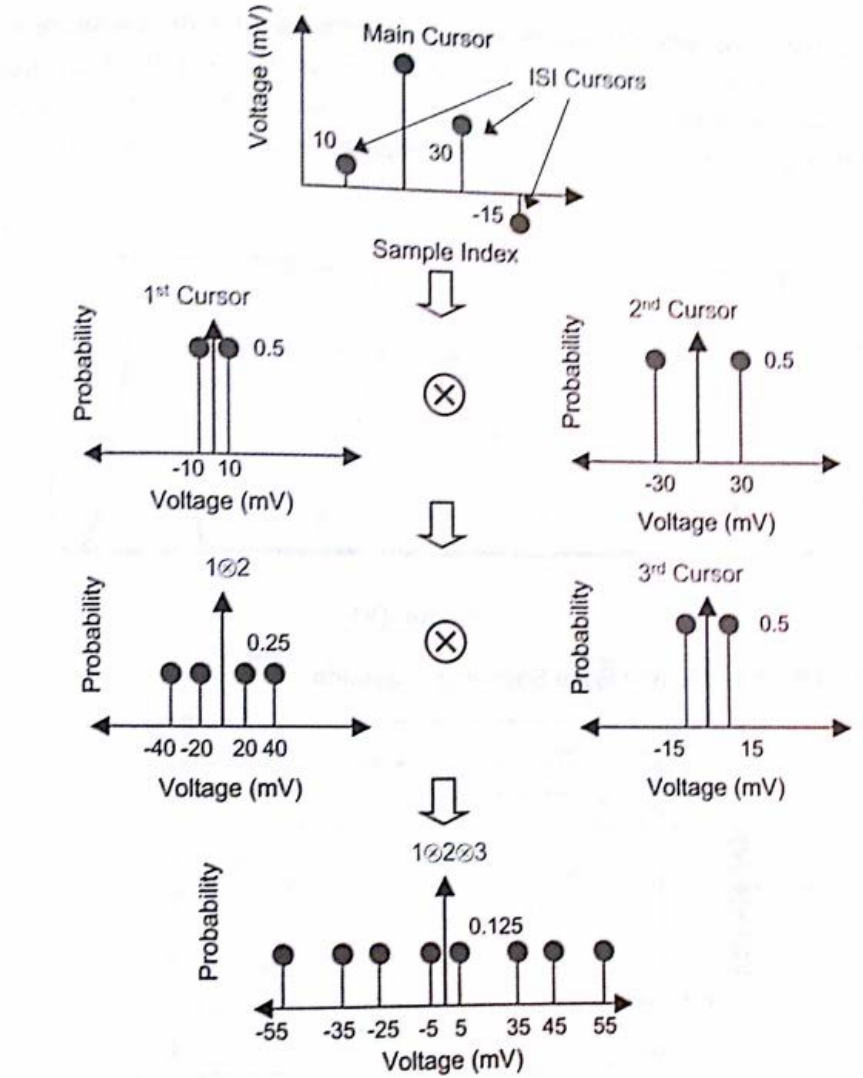
Link Analysis Algorithm Stages (B. Casper et. al, Intel)

- ISI Recursive Convolution
- Formation of Transition PDFs
- Segment-based analysis
  - Averaging of PDFs
  - Convolution of PDFs
  - Mapping to 256 bins



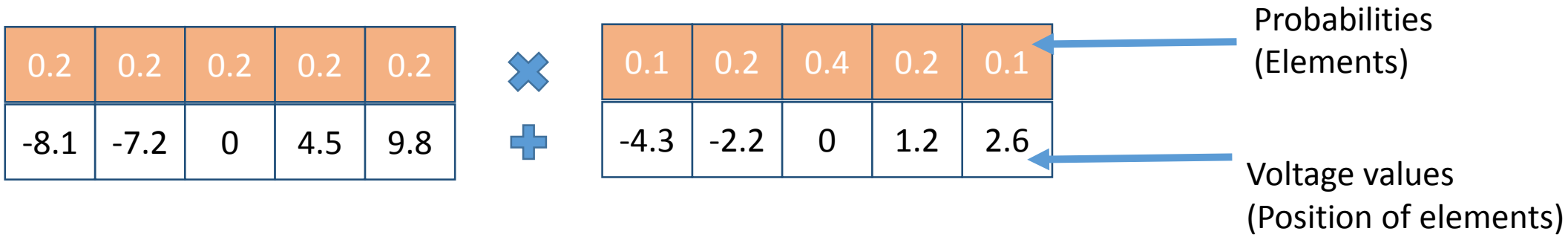
ISI PDF Calculation (Recursive Convolution)





Convolution with dissimilar indexes

- “Flip” and “Shift” operation
- Product of elements and summation of position values



Three parts

- Product and Summation
- Elimination of duplicate voltages using HashMap
- Mapping in bins (buckets) using HashMap

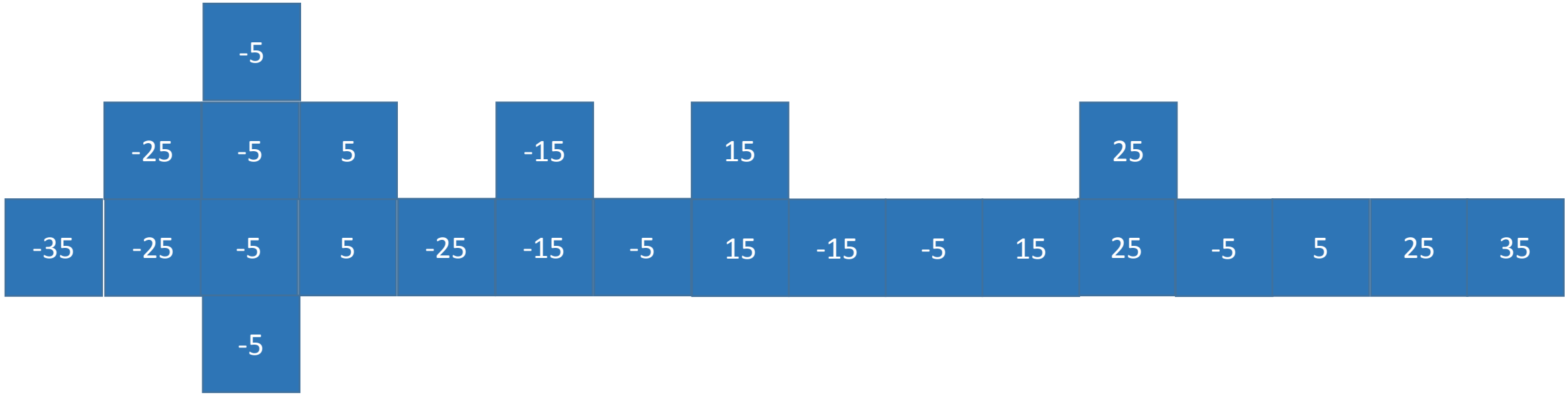
Elimination of duplicate voltages using HashMap

A.Voltage = [-15,-5,5,15] and B.Voltage = [-20,-10,10,20]

A.Prob = [0.25,0.25,0.25,0.25] and B.Prob = [0.25,0.25,0.25,0.25]

C.Voltage = [-35,-25,-5,5,-25,-15,-5,15,-15,-5,15,25,-5,5,25,35]

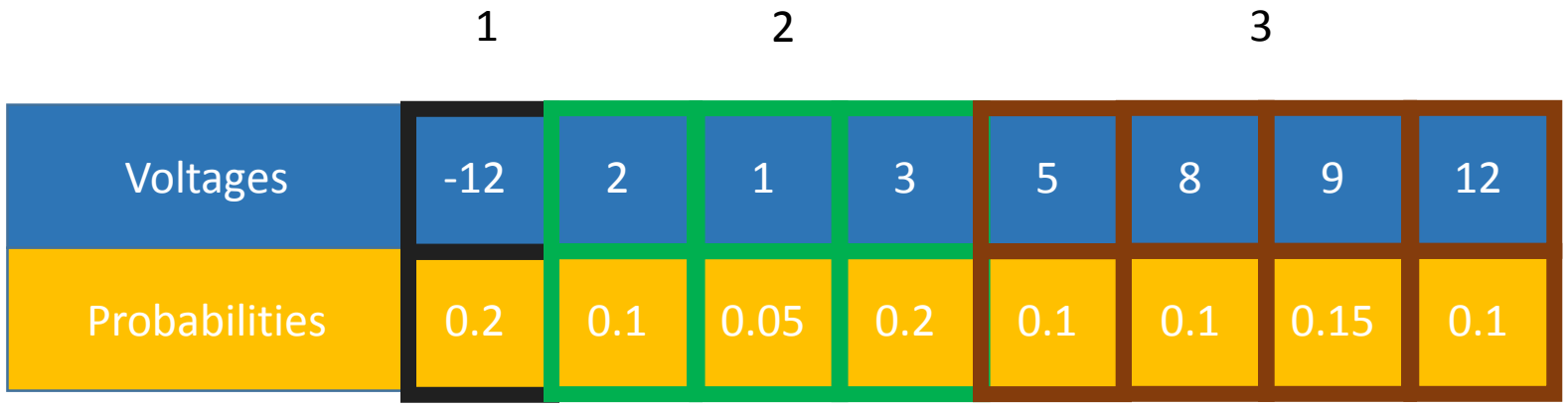
C.Prob = [0.0625,0.0625,0.0625,0.0625, …]



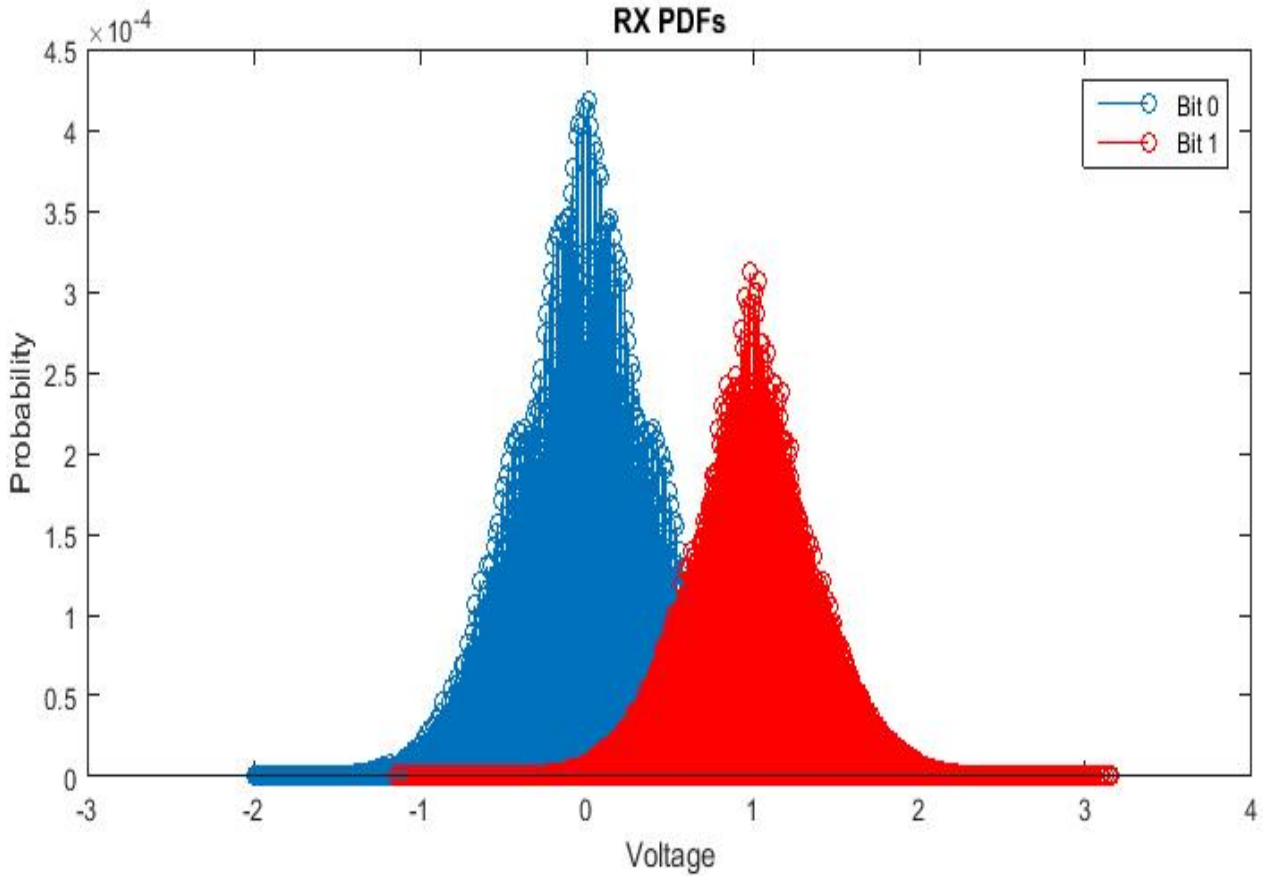
Example of Mapping

- Max Voltage = 12mV and Min Voltage = -12mV
- Size of bucket = 8

Therefore, number of buckets = 3



PDF for 0-bit (Blue) and 1-bit (Red) after Link Analysis



Receiver's Non-Linearity

- Most jitter analysis techniques are developed for linear models
- Non-linearity → Crucial factor to improve accuracy of jitter modeling techniques
- Two ways to incorporate non-linearity:
  1 – Power series: Concatenating LTI model with a polynomial function
  2 – Volterra series: For modeling frequency dependent non-linearity

Power Series Approach

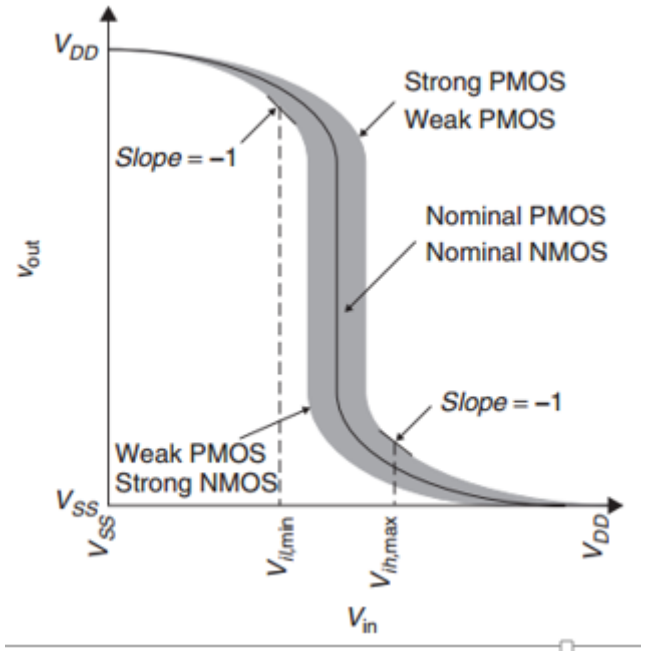
- This method of non-linearity matches closely with actual receiver circuits

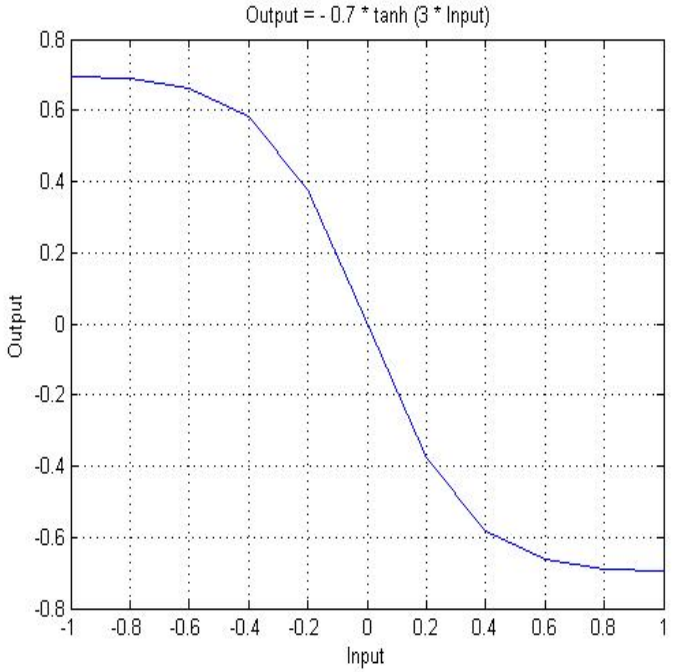
- $Y = \sum_n \alpha_n X^n$
  - Where α_n represents coefficients of nth order nonlinearity
  - n is odd for differential signaling

- $Y = \alpha_1 X^1 + \alpha_3 X^3 + \alpha_5 X^5 + \cdots$

CMOS Receivers

$$Y = -0.7 * \tanh(3 * X)$$





$$\tanh x = x - \frac{x^3}{3} + \frac{2x^5}{15} - \frac{17x^7}{315} + \cdots = \sum_{n=1}^{\infty} \frac{2^{2n}(2^{2n}-1)B_{2n}x^{2n-1}}{(2n)!}, |x| < \frac{\pi}{2}$$

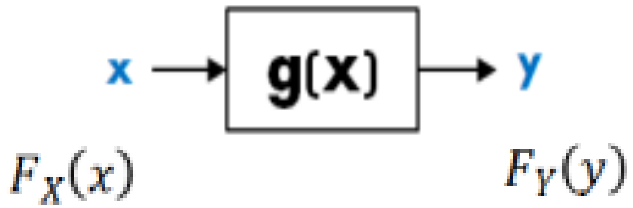
PDF Modification for Non-linearity

- PDF at the output of linear block can be obtained by the statistical signaling approach
- For non-linear functions,

$$F_y(y) = \frac{F_x(x_1)}{|g'(x_1)|} + \frac{F_x(x_2)}{|g'(x_2)|} + \cdots + \frac{F_x(x_n)}{|g'(x_n)|}$$

- For monotonic function g(x),

$$F_Y(y) = \left|\frac{dx}{dy}\right| F_X(x)$$

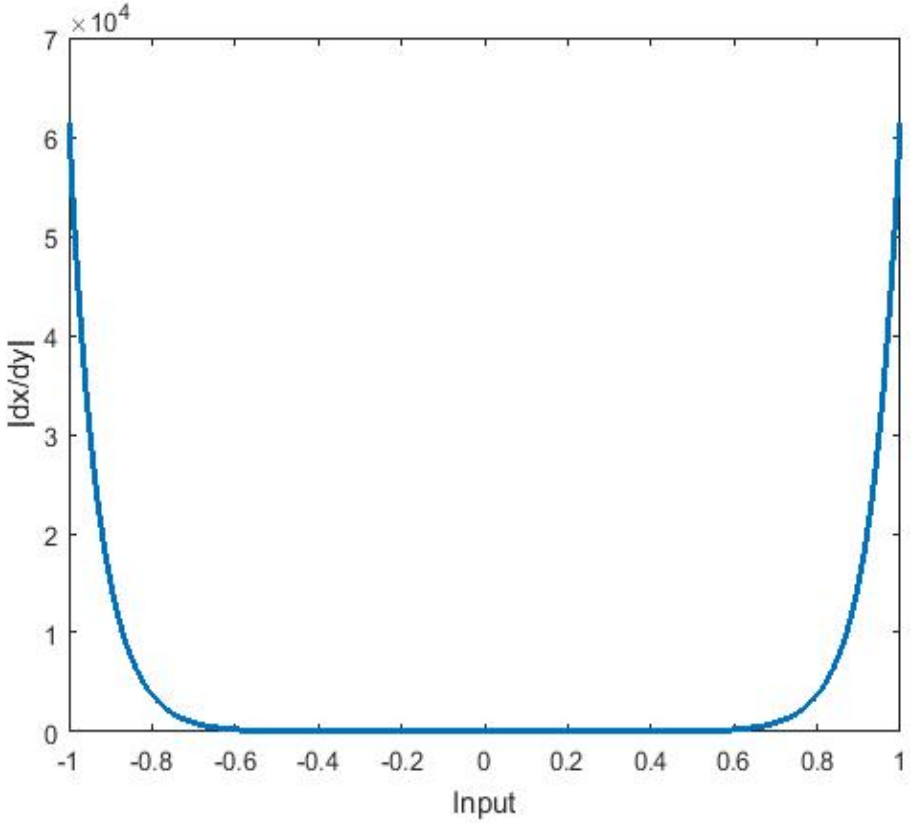


CMOS Receivers

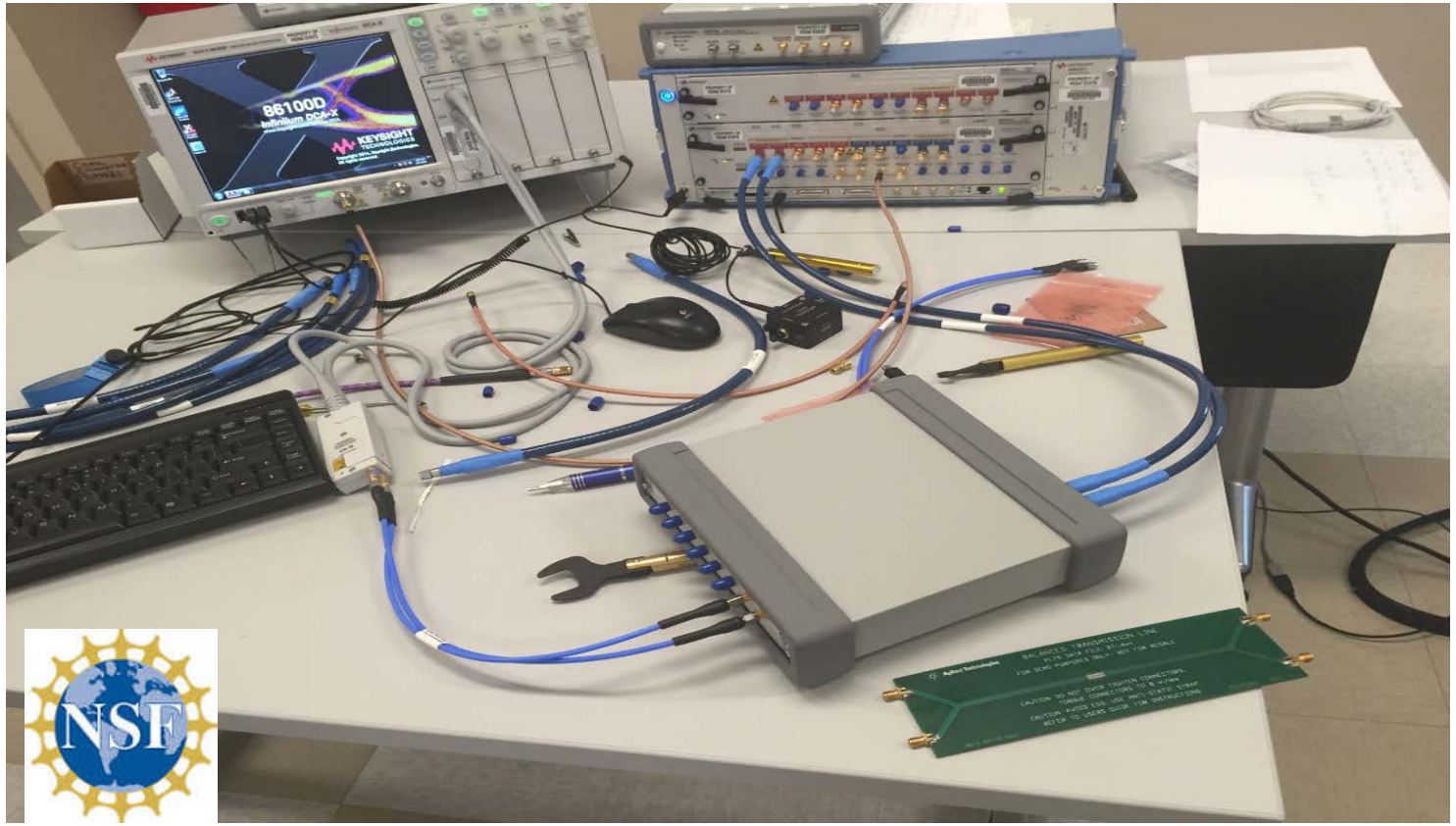
For $y = -0.7 * \tanh(3x)$

$$\left|\frac{dx}{dy}\right| = \left|\frac{1}{2.1 * \operatorname{sech}^2(3x)}\right|$$

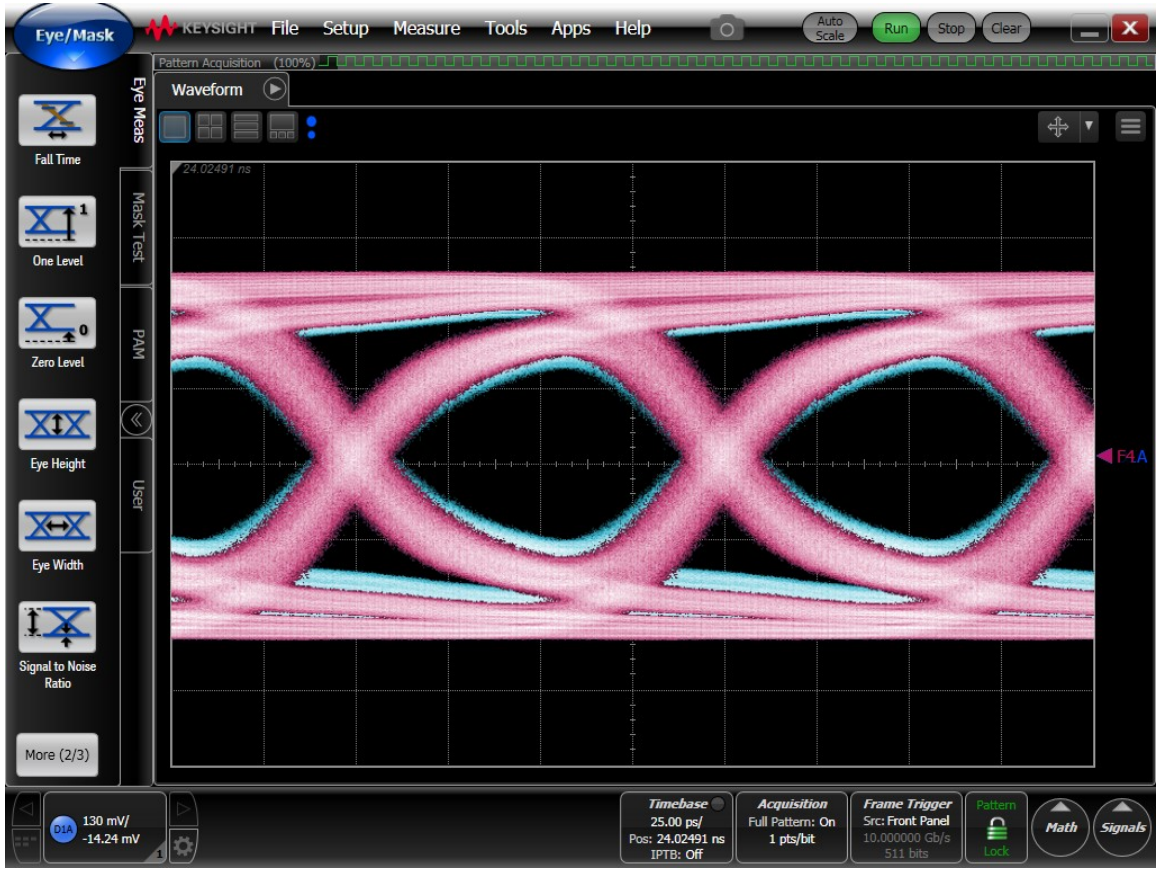
$$F_Y(y) = \left|\frac{1}{2.1 * \operatorname{sech}^2(3x)}\right| F_X(x)$$

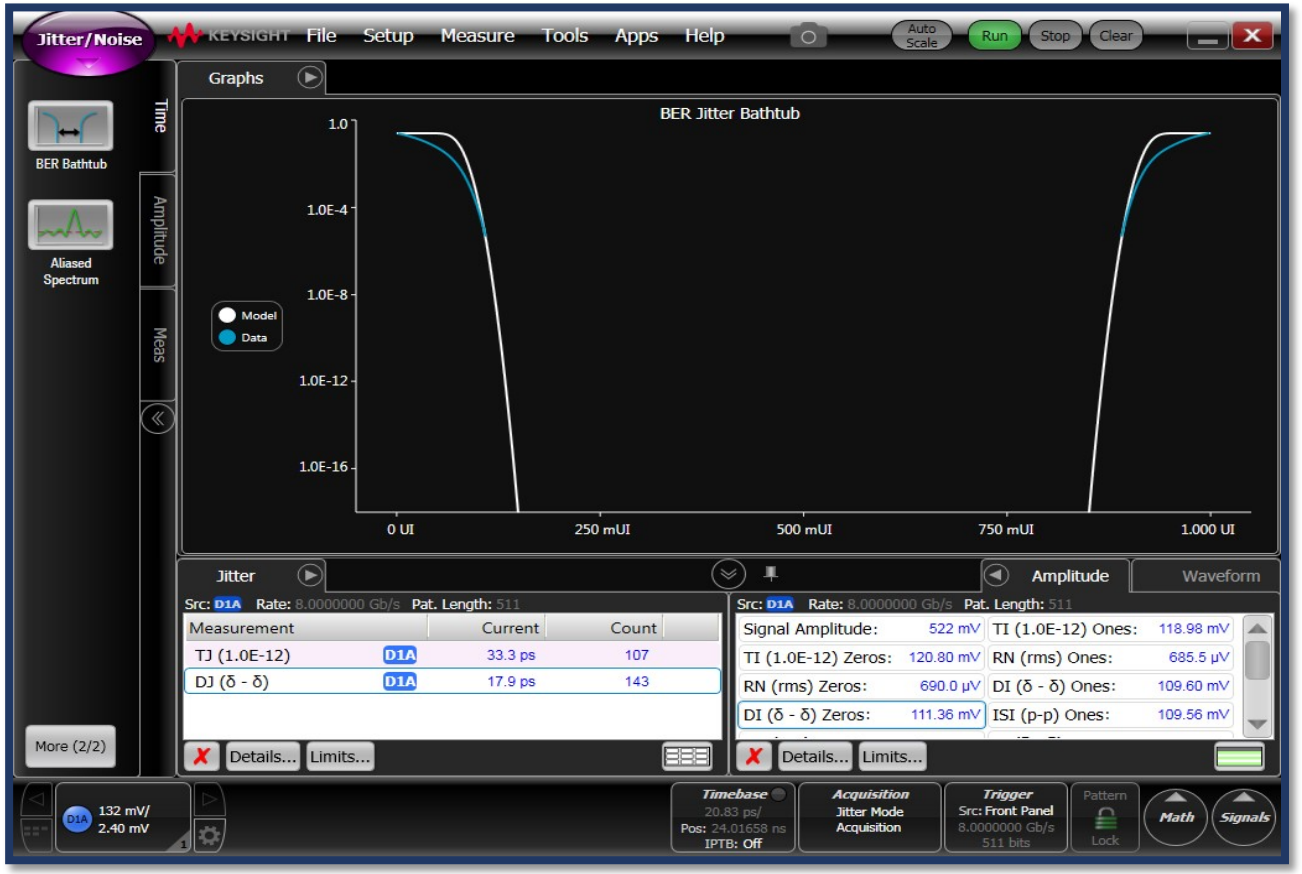


Measuring the eye diagram, jitter, with a high end BERT and DCA

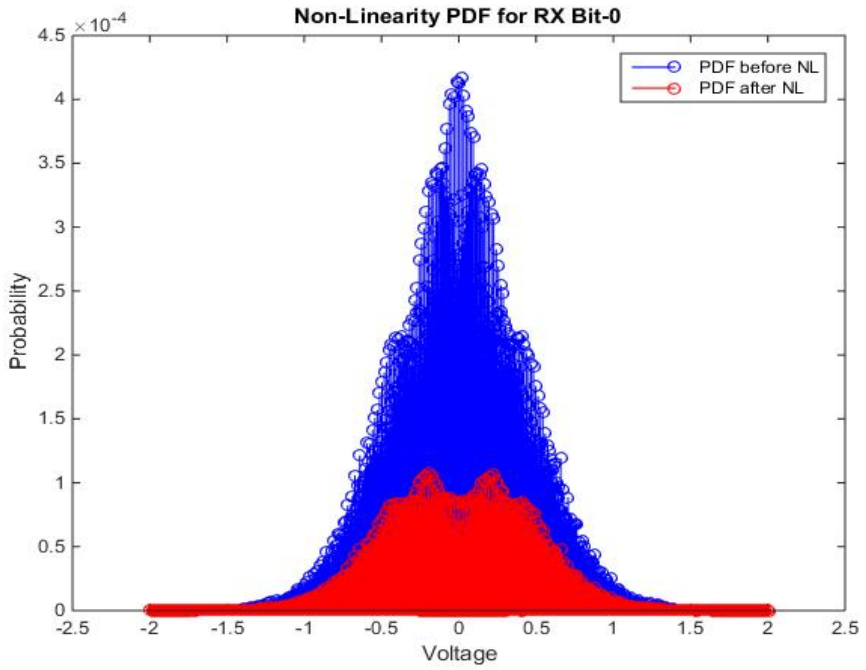


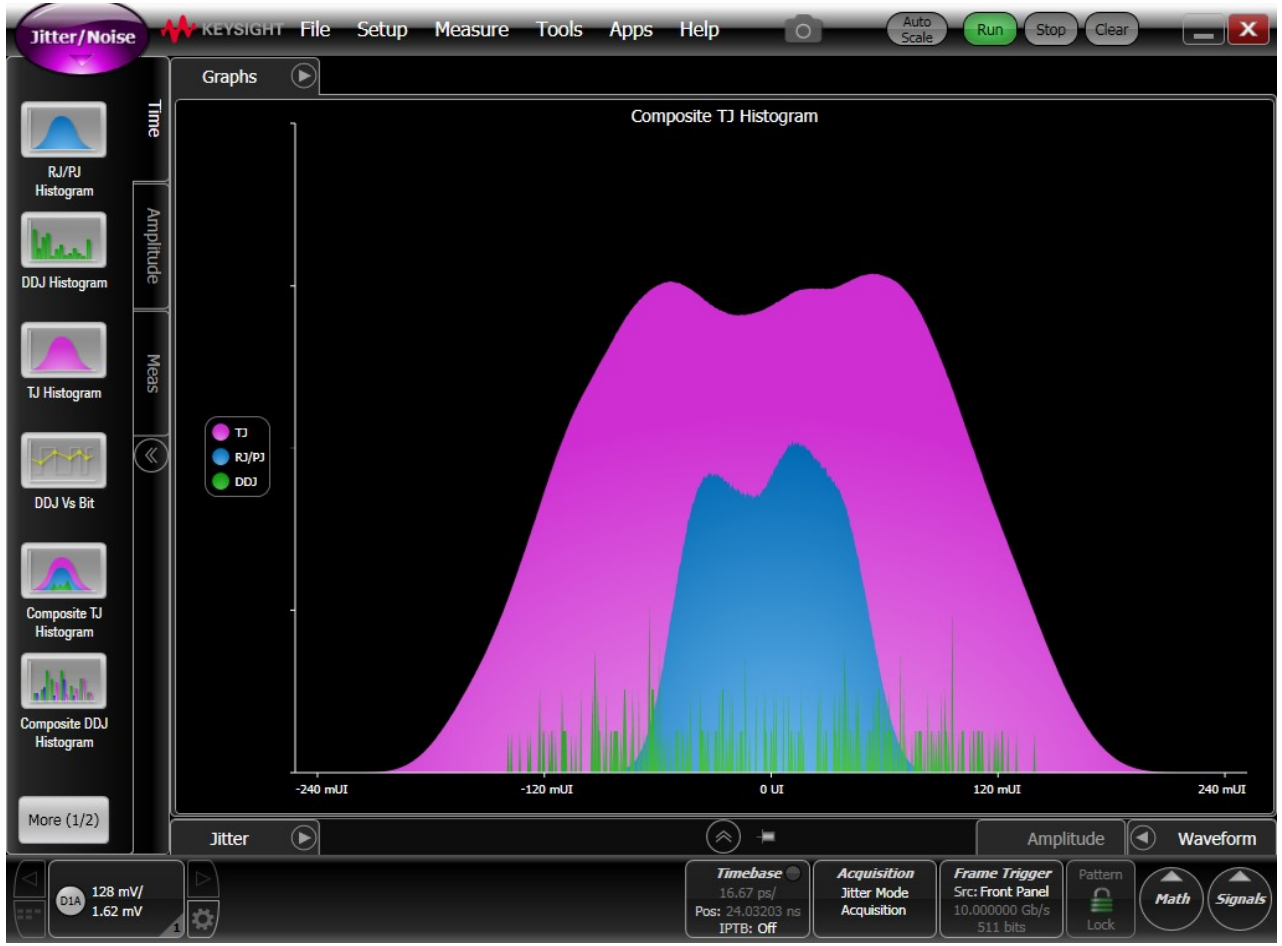
Measuring the eye diagram, BERT and DCA



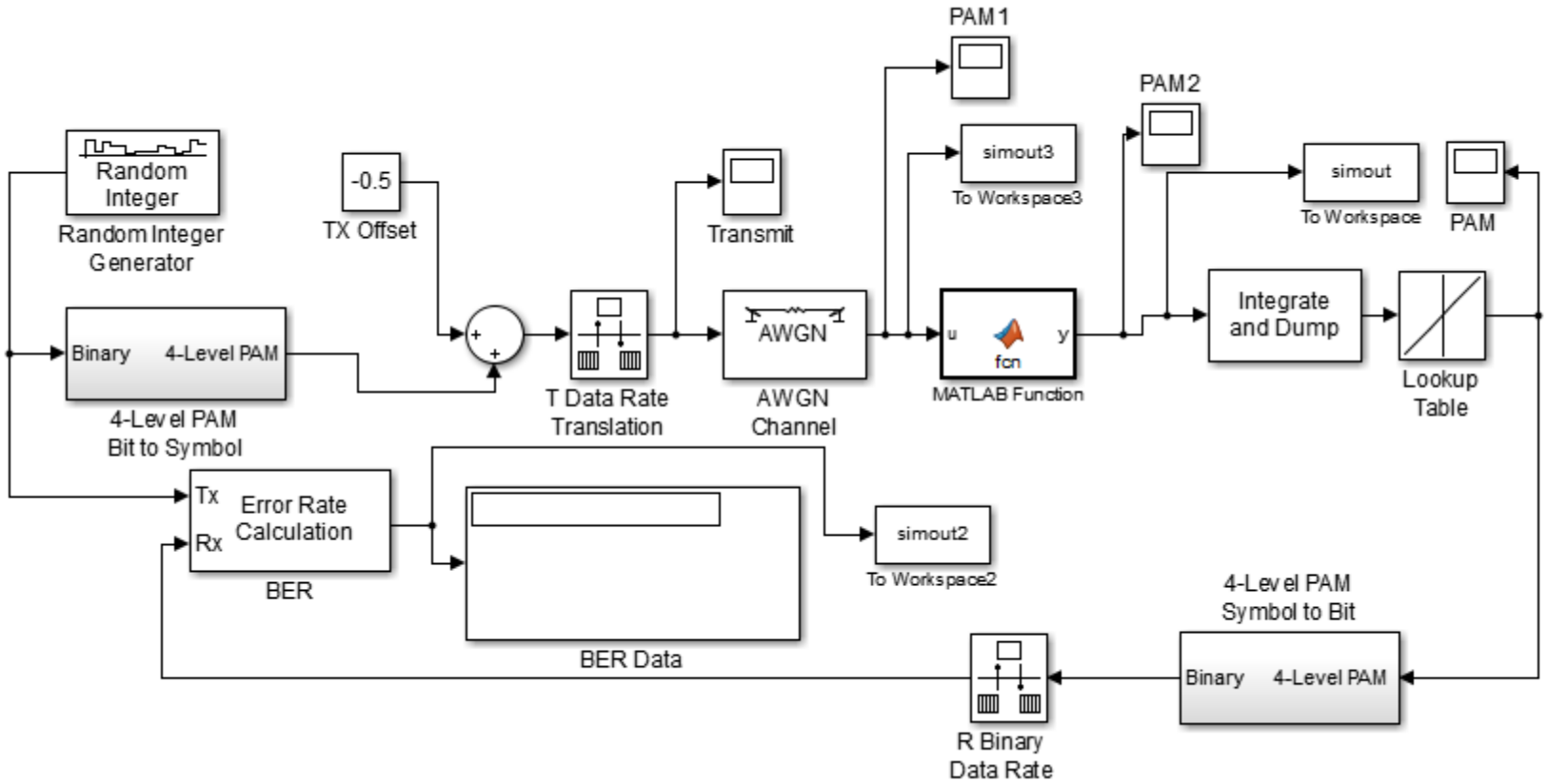


Incorporating Link Analysis and non-linearity

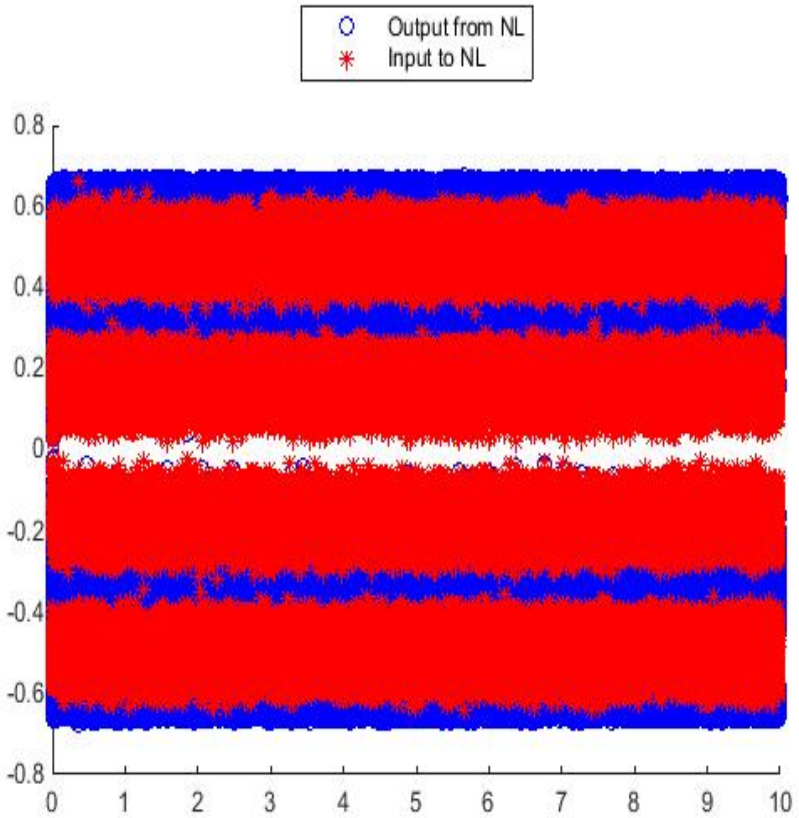


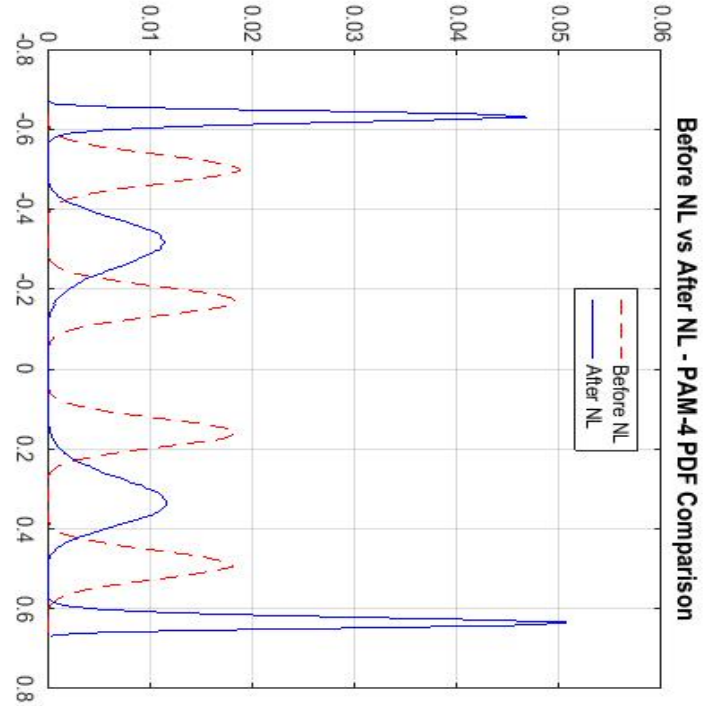


Simulink Block Diagram for PAM-4 Scheme



Constellation Points and PDF Plot for PAM-4





Conclusion

- Segment-based approach is successfully implemented using Hash maps
- Effects of non-linearity contributed by CMOS receivers for NRZ has been obtained
- Initial measurement with a high-end BERT and DCA seem to correlate with the MATLAB approach

Future Scope

- The non-linear PDF modification can further be applied to frequency-dependent non-linearity models
- Improve timing efficiency in link analysis approach
- Extend the nonlinear approach to the upcoming PAM-4 standards
- Correlate the approach to BERT and DCA measurements