Statistical Eye Simulation Requirements

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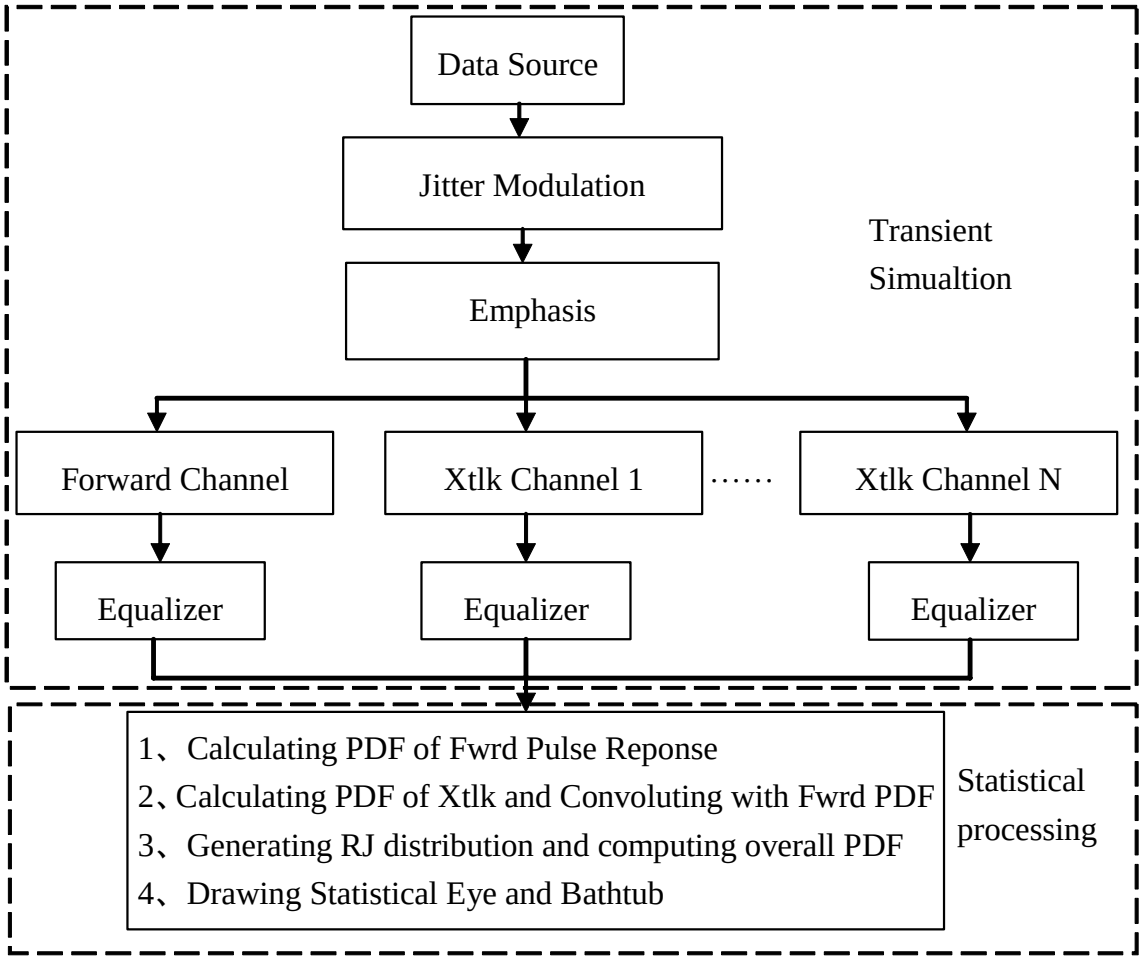
Statistical Eye Simulation Flow

Simulation flow:

- **Time domain simulation**
- **Statistical post-processing**

The data source could be signal source or real serdes model.

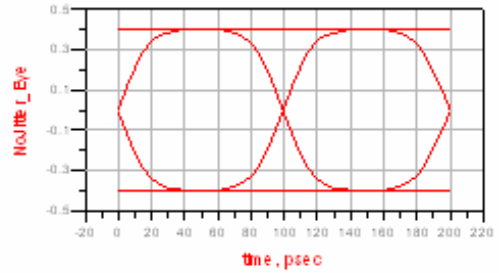


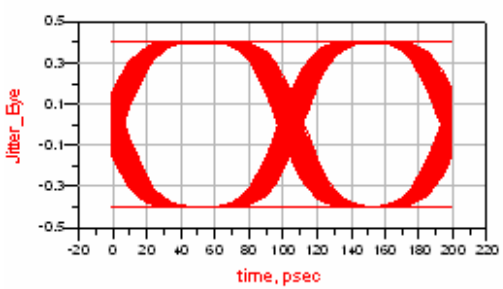
Simulation Requirements

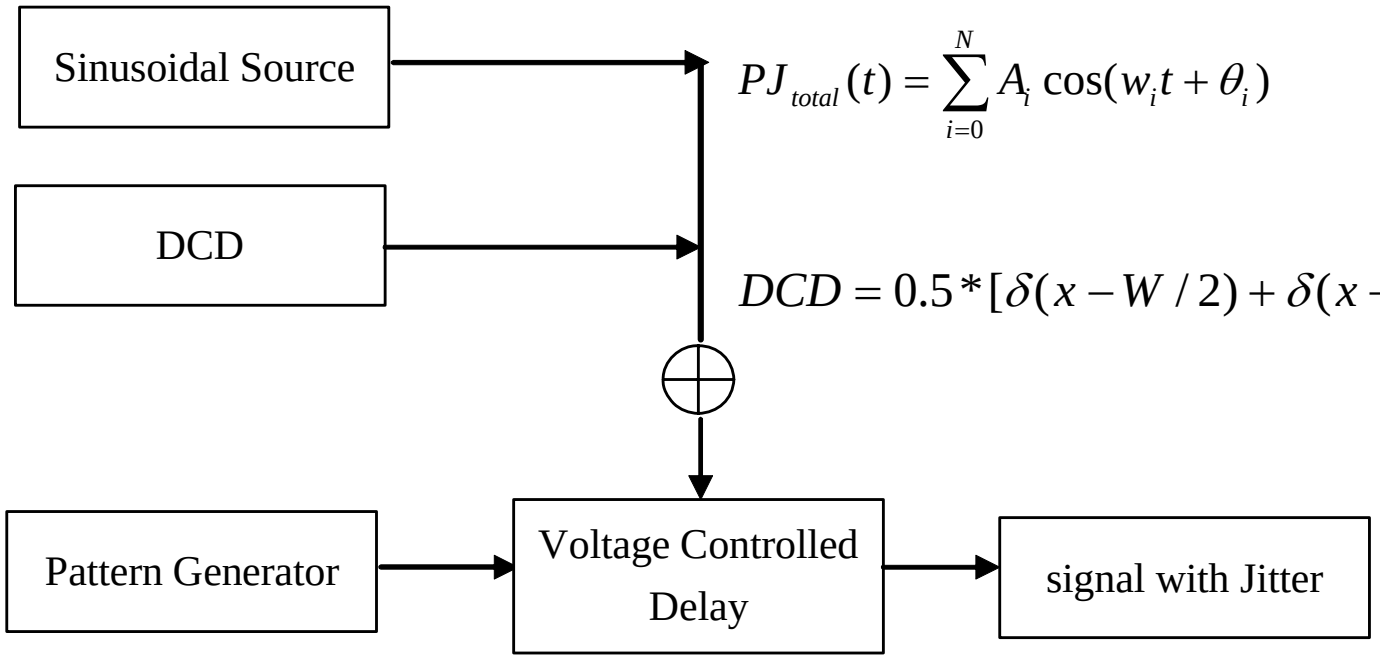
- **Simulation platform should support IBIS or Hspice serdes model.**
- **Simulation platform should simulate channel responses by using convolution method.**
- **Simulation platform should easily realize jitter modulation, equalizer and emphasis.**
- **Simulation platform should support equalizers, such as LFE, DFE and CTE.**
- **Powerful post-processing ability.**
- **Simulation platform may further support co-simulating with Matlab for user defined statistical processing.**

Jitter Modulation

- **Using Voltage Controlled Delay to add jitter**
- **Jitter at transmitter includes PJ, DCD**
- **RJ will be consider in statistical post-processing**





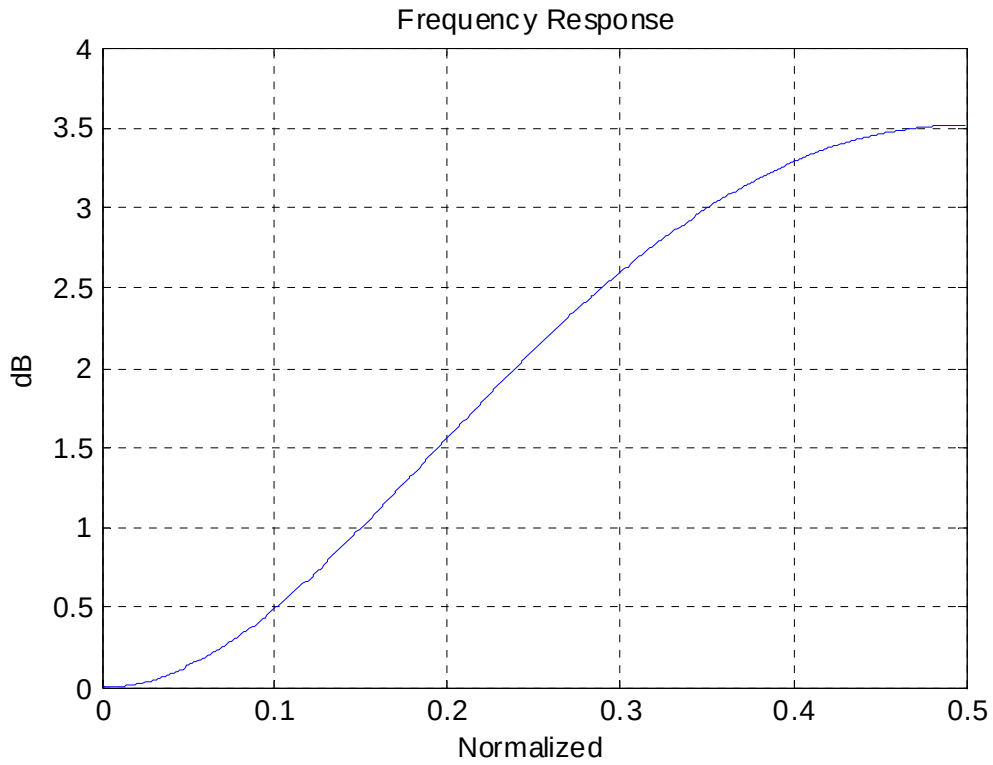


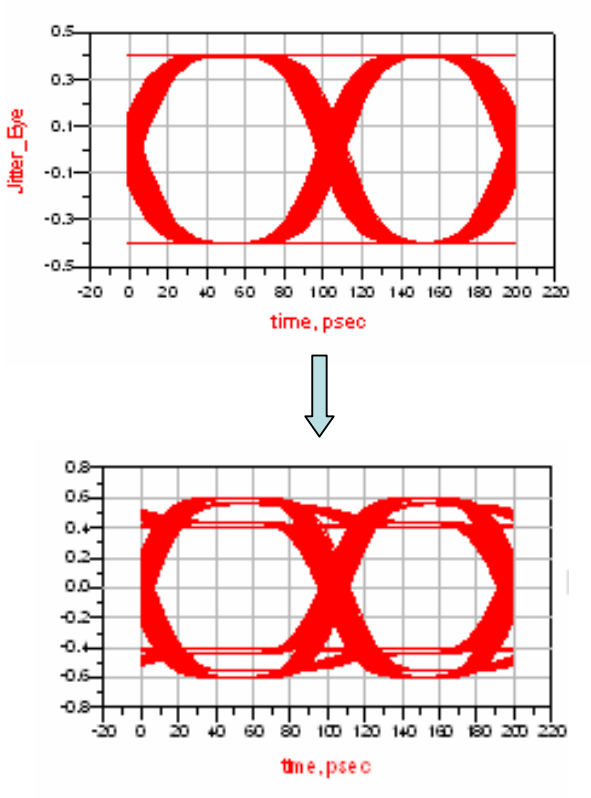
$$PJ_{total}(t) = \sum_{i=0}^{N} A_i \cos(w_i t + \theta_i)$$

$$DCD = 0.5 * [\delta(x - W/2) + \delta(x + W/2)]$$

Emphasis

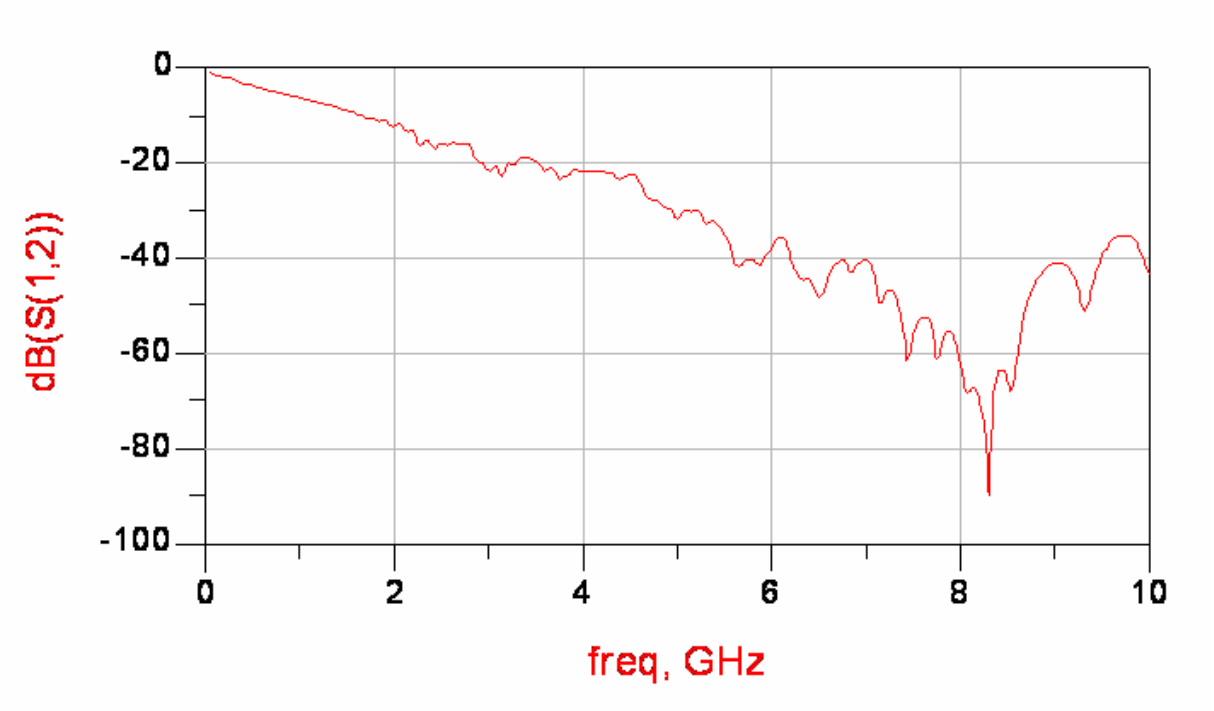
- Emphasis technique includes pre-emphasis and de-emphasis
- Both pre-emphasis and de-emphasis could be expressed as FIR filter



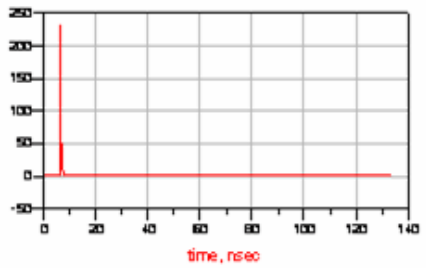


Channel Models

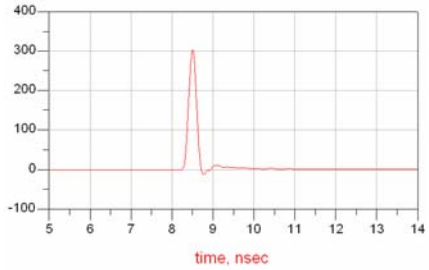
- Channel models, including fwrd and xtlks, could be expressed in S-parameter
- Supporting transient simulation with touchstone files



Impulse response

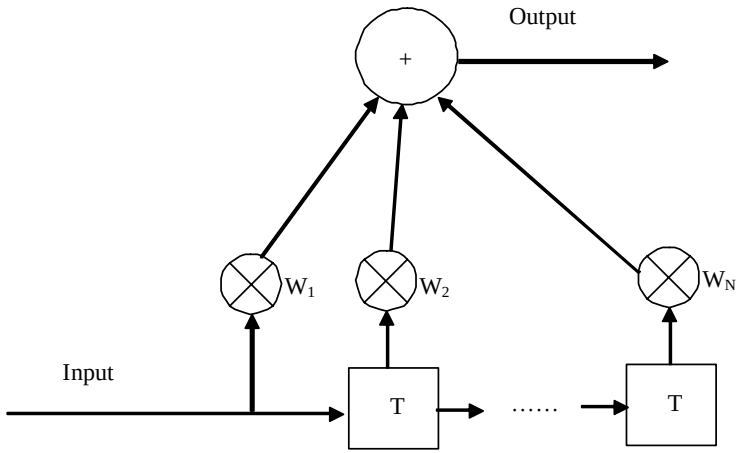


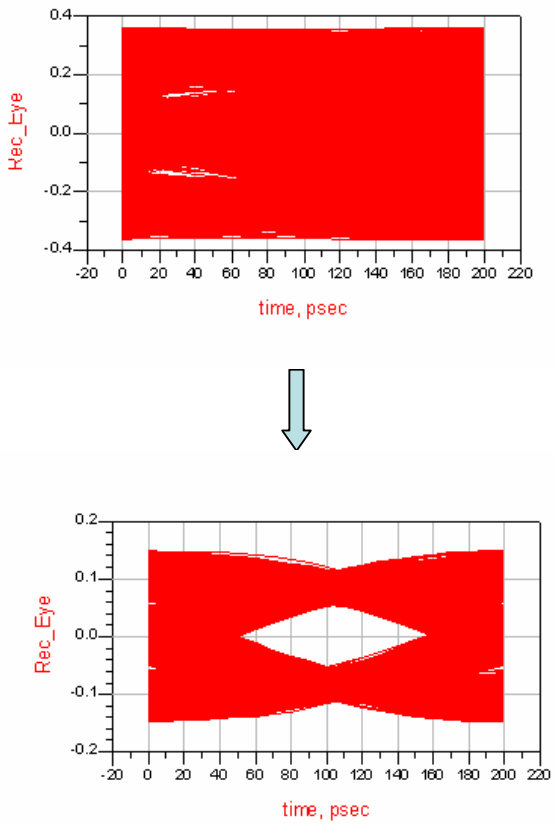
pulse response



Equalizer-LFE

LFE is linear feed-forward equalizer



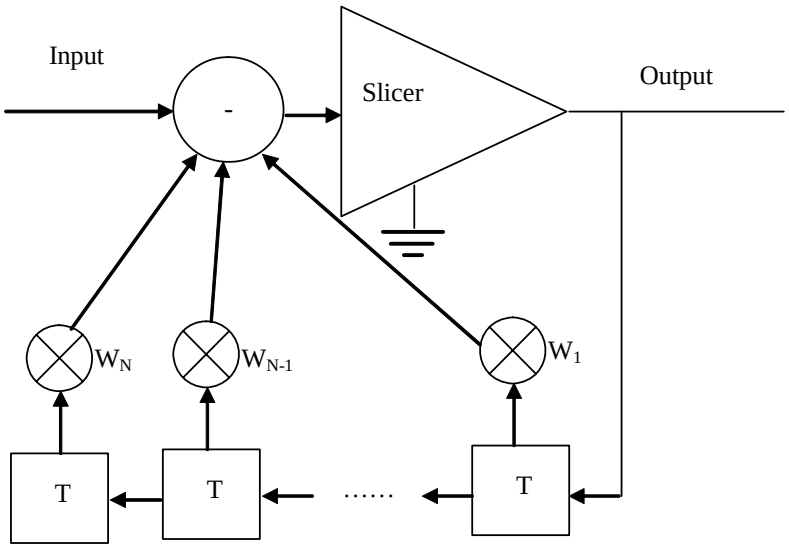


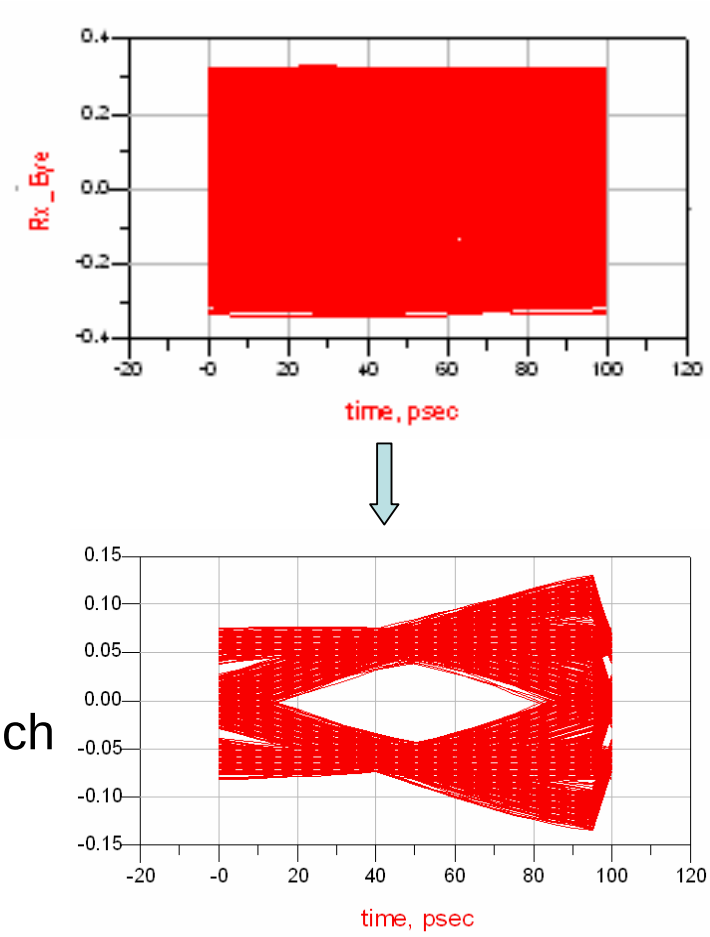
- discrete – usually just one tap per bit
- finite – not long enough to completely correct the impulse response
- May result in noise gain

$$V(T_0) = W_1 * V_{in}(T_0) + W_2 * V_{in}(T_{-1}) + \cdots + W_N * V_{in}(T_{N-1})$$

Equalizer-DFE

DFE is decision feed-back equalizer





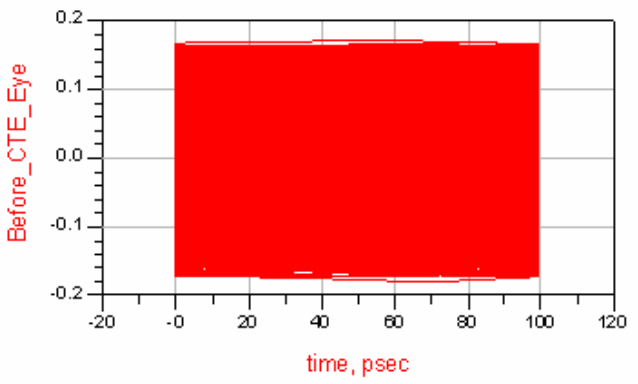
- DFE uses a feedback loop of the desired signal which is decoded from the output of a slicer
- DFE can further correct the residual ISI

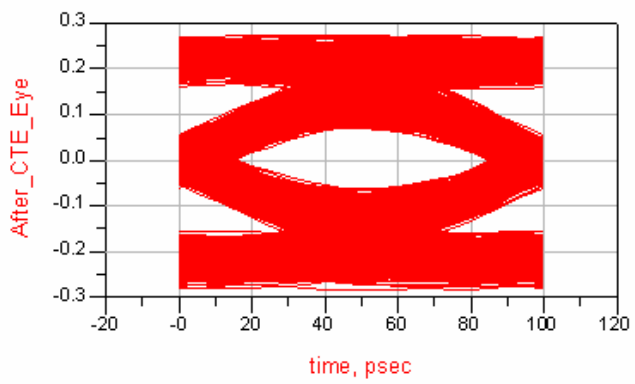
$$V(T_0) = V_{in}(T_0) - W_1 * D(T_{-1}) - W_2 * D(T_{-2}) - \cdots - W_N * D(T_{-N})$$

Equalizer-CTE

- CTE is continuous time equalizer
- CTE model is an ideal circuit with the desired pole, zero response.
- p0 and z0 are programmable

$$H_{CTE}(f) = a\frac{p_0}{z_0}\frac{(s+z_0)}{(s+p_0)}$$

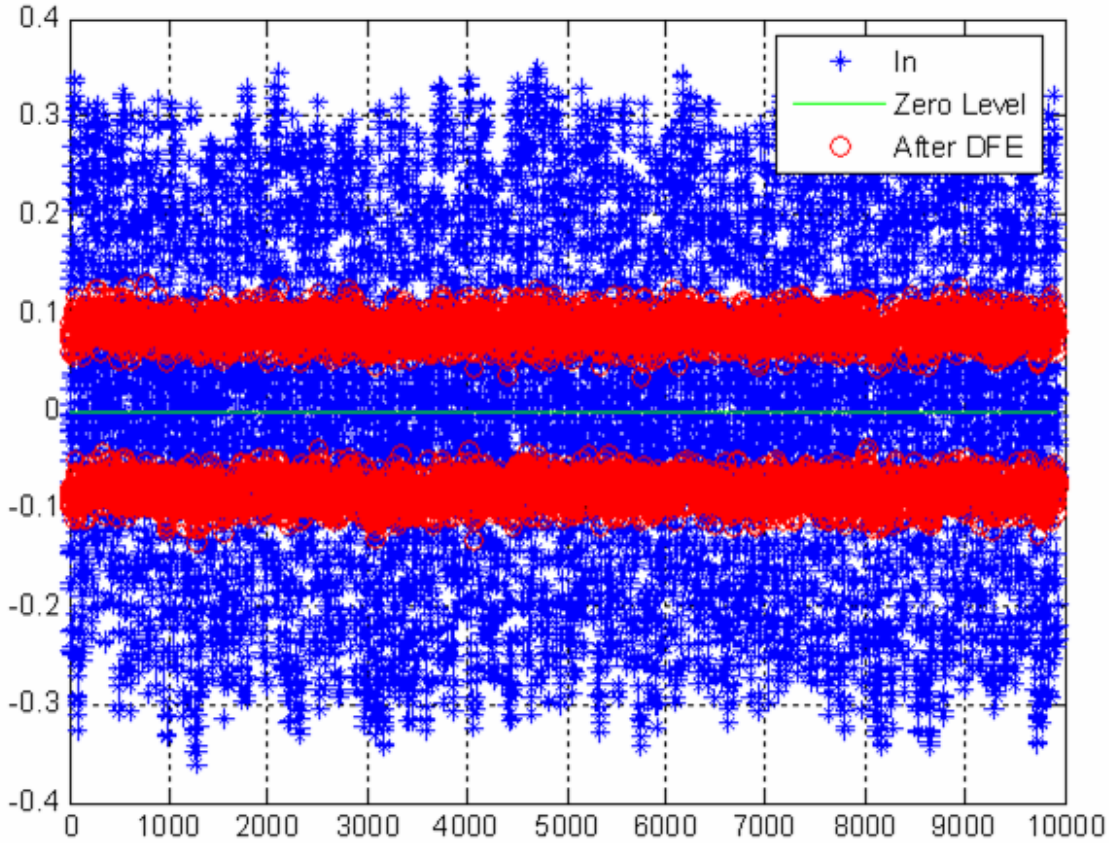




Equalizer-Algorithm

Calculating the optimal sampling point and equalizer coefficients

- **LMS adaptive algorithm**
- **Zero Forcing algorithm**

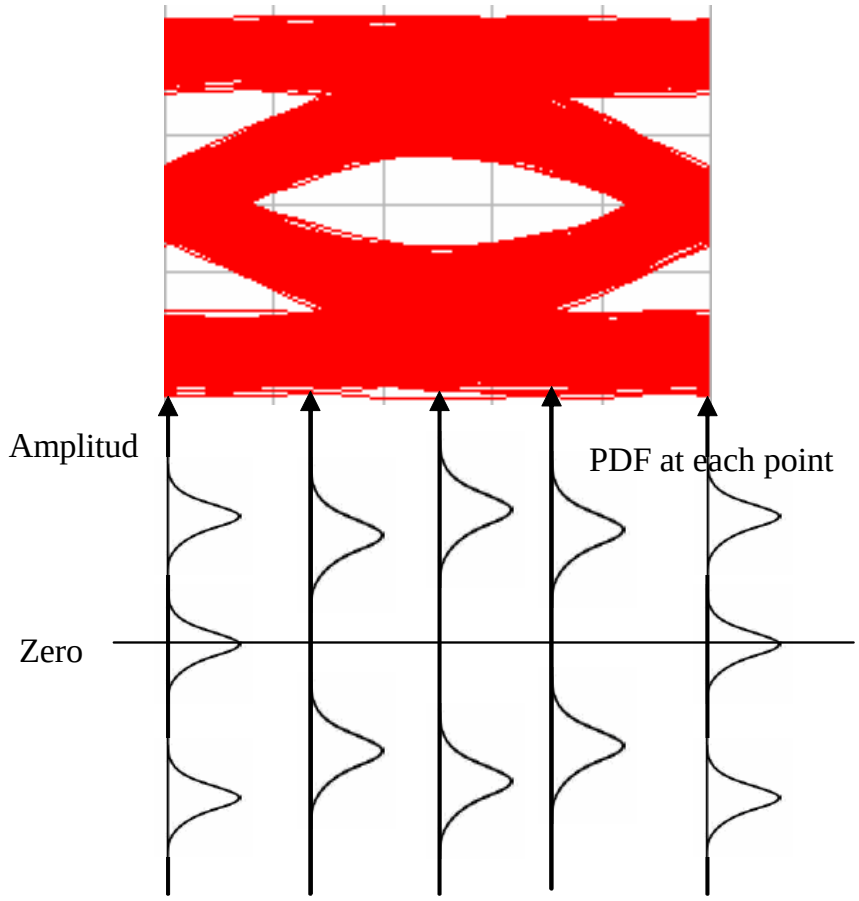


Statistical Post-processing

Calculating Forward channel PDF

1.Overlapping each bit at one UI range.

2. At each UI sampling point, computing PDF of Overlapping data.



Statistical Post-processing

Xtlk Convolution Method

1.Interpolating each Xtlk channel responses to small enough time interval

2. Overlapping each bit in one UI range

3. Computing PDF of Overlapping data at each UI sampling point

4. Averaging PDFs through whole UI sampling points to get the average PDF.

5. Repeating 1-4 for each aggressors.

6. Convolving average PDFs of all aggressors to get the whole crosstalk PDF.

Charles Moore presented convolution method in his paper "Computing effect of cross talk using Convolution" at 802.3ap.

http://grouper.ieee.org/groups/802/3/ap/public/channel_adhoc/moore_c1_0305.pdf

Statistical Post-processing

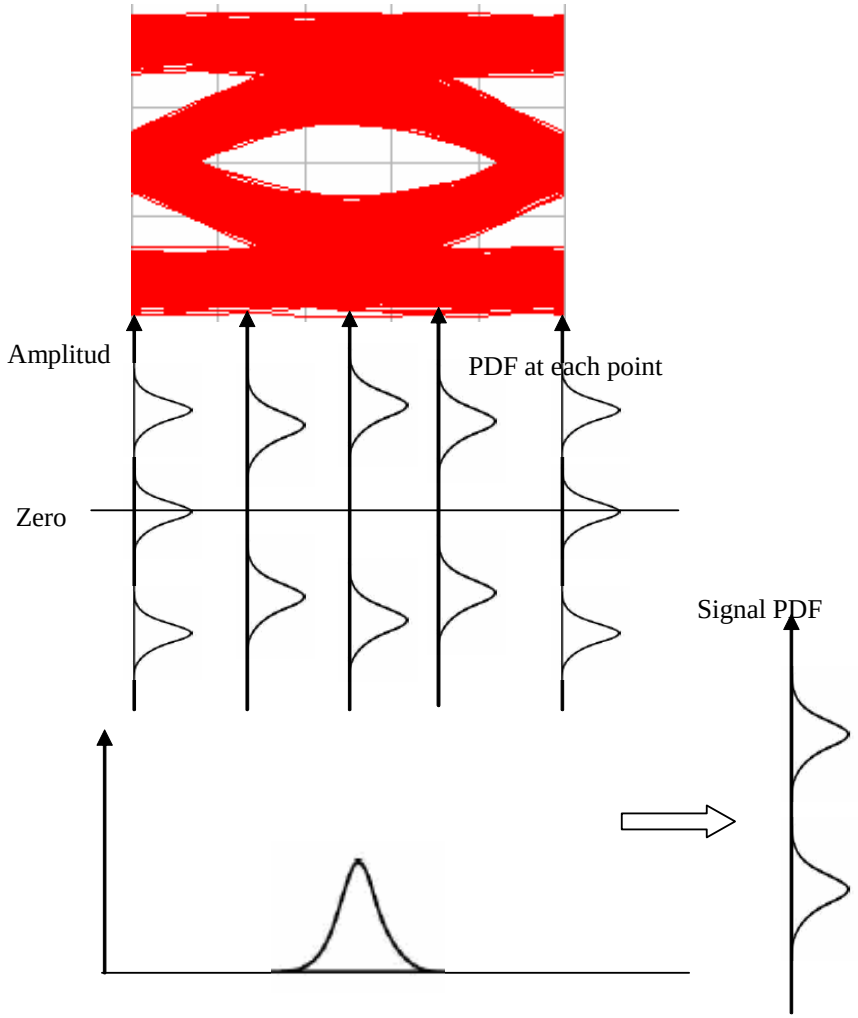
Random Jitter

Random Jitter distribution

$$P_{RJ} = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{t^2}{2\sigma^2}}$$

Overall PDF

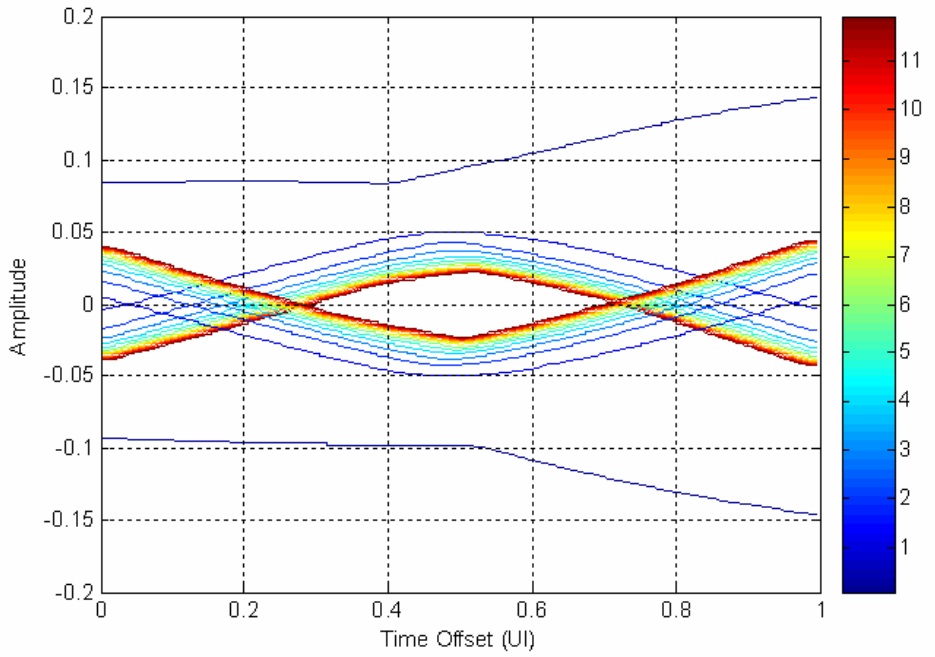
$$P(ISI,\tau) = \int_{-\infty}^{\infty} P(ISI,\tau+\upsilon)\cdot P_{RJ}(\upsilon)d\upsilon$$



Statistical Post-processing

Statistical Eye

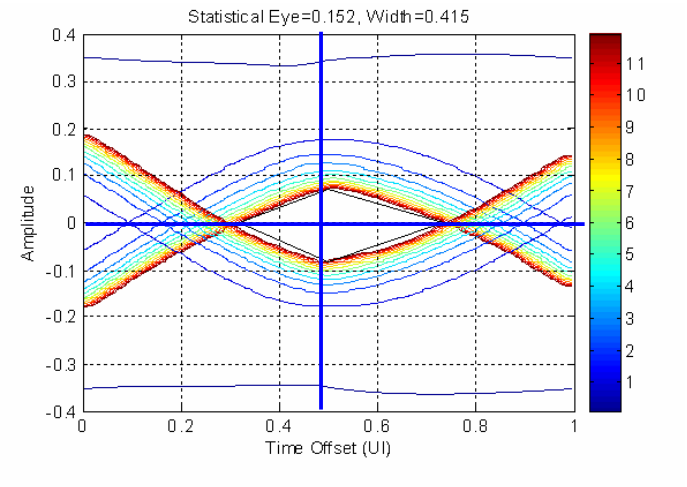
- Statistical eye is set of probability contours
- Horizontal axis is with respect to sampling point
- Vertical axis is with respect to signal amplitude
- Different colored lines represent BER

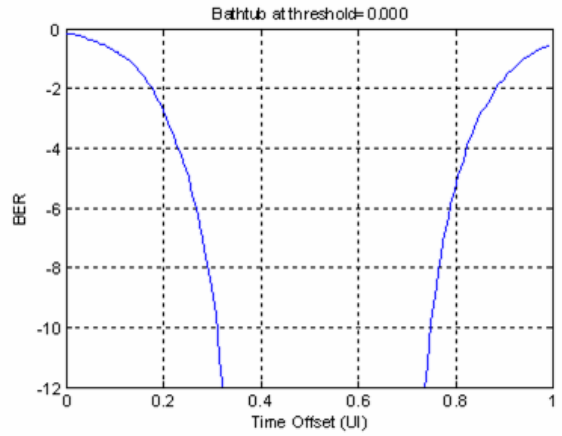


Statistical Post-processing

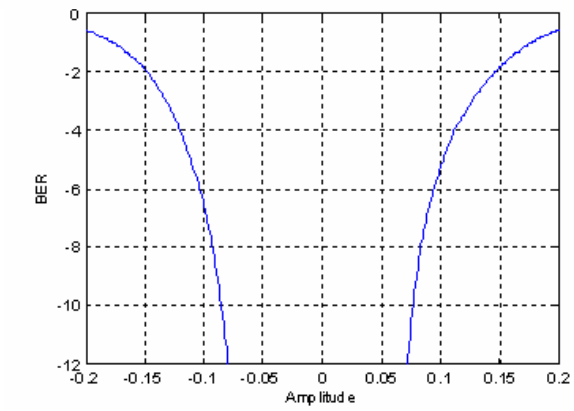
Bathtub

- Intercept through statistical eye along horizontal axis to get horizontal Bathtub at definite voltage
- Intercept through statistical eye along vertical axis to get vertical Bathtub at definite sampling time



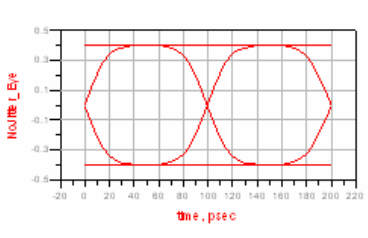


Horizontal

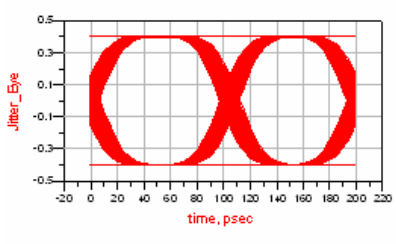


Vertical

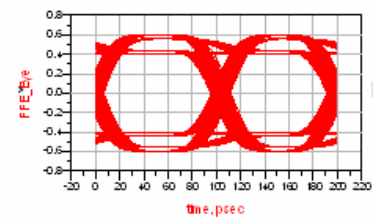
Overall Simulation Eye Flow



Transmitter Eye

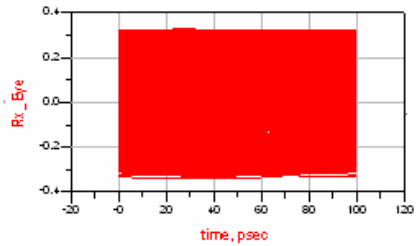


Eye after Jitter Modulation

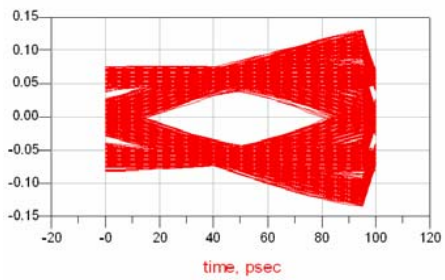


Eye after Emphasis

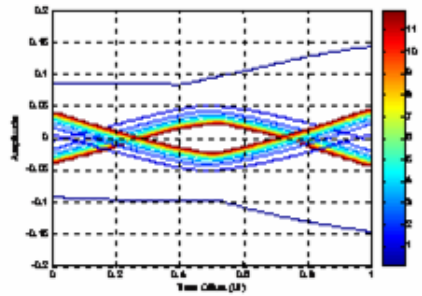
Channel

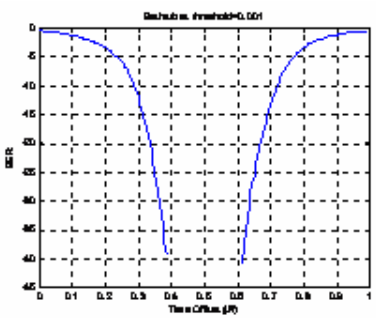


Eye after Channel



Eye after Equalizer





Example - Channel pre-simulation

Assumed conditions:

10Gbps NRZ, PRBS 23, 100000 bits, amplitude 800mvpp, Tr(f) = 24ps

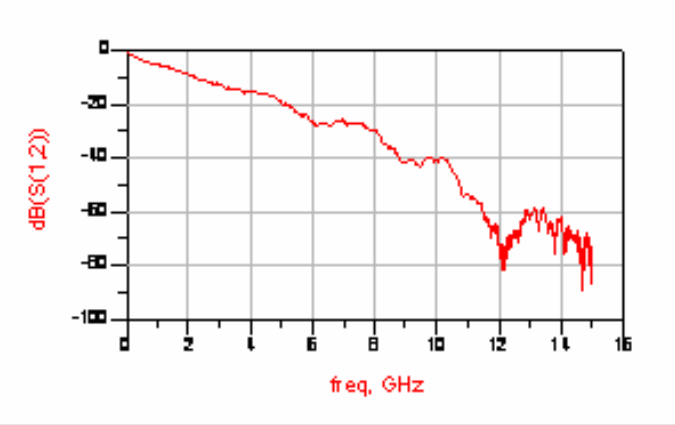
0.15UIpp DJ = 0.05UI DCD+0.1UI PJ, 0.15UIpp RJ @10^{-12}BER

BER = 1e-12 (2*Q=14.069)

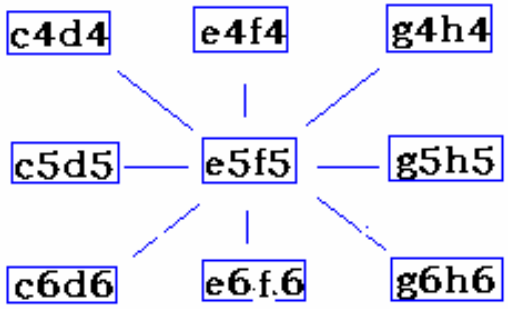
3tap de-emphasis, 5tap DFE

Slice voltage: 10mV

Forward Channel



Eight crosstalk channels



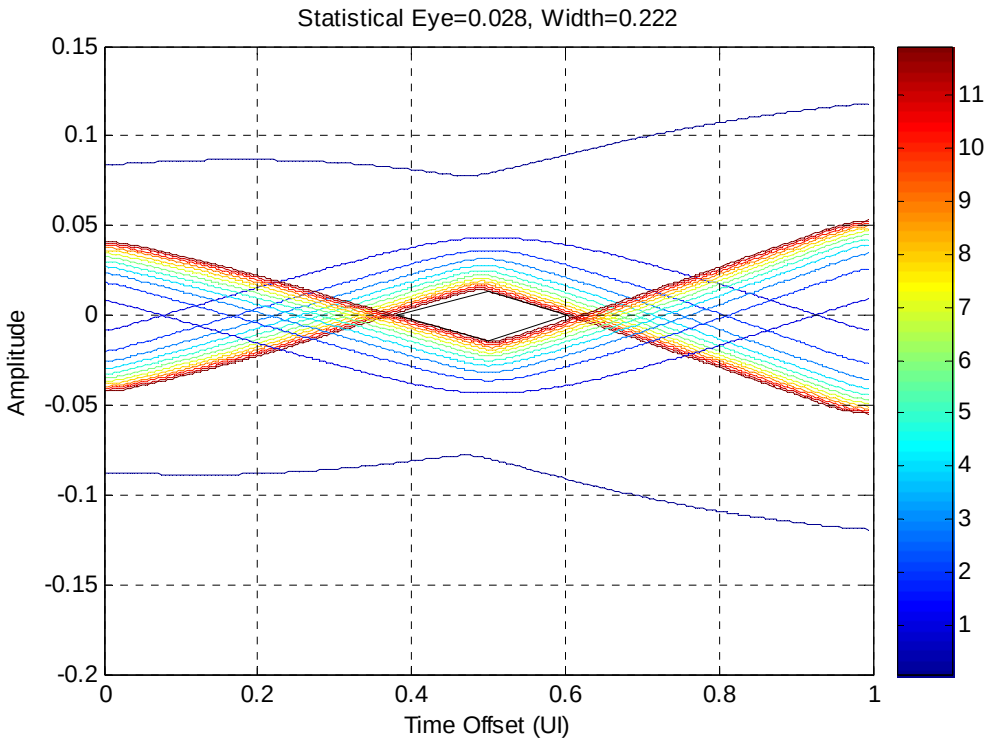
Example - Channel pre-simulation

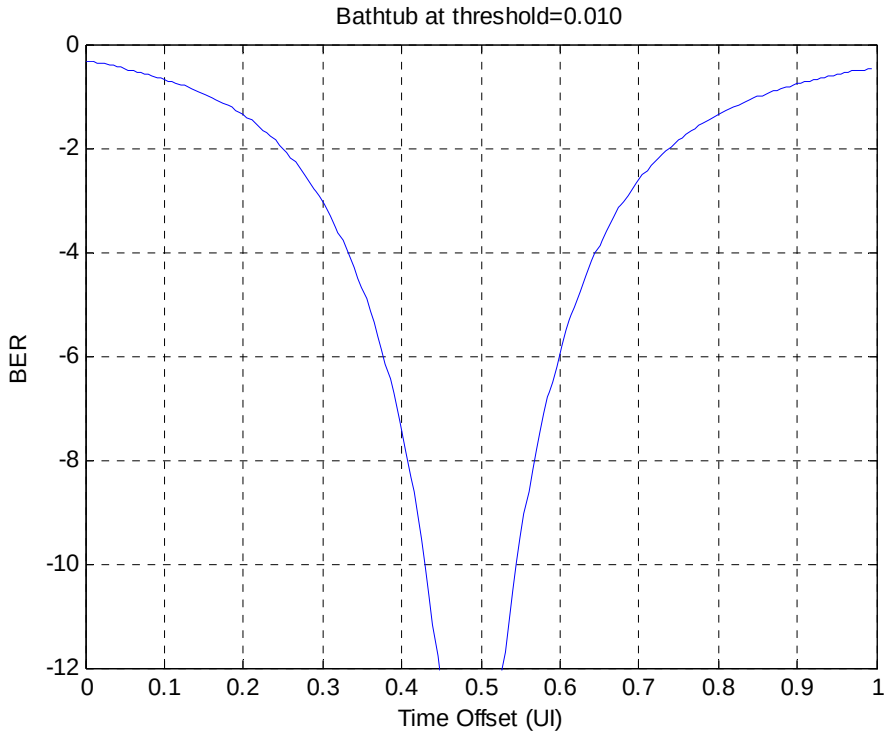
- Simulation result:

  28mv eye-height

  0.222UI eye-width

- It shows that the channel could undertake 10Gbps data transmission





Conclusion

- **Basic method of statistical eye simulation has been presented here**

- **An ideal platform to realize statistical eye simulation:**
  - ✓ Jitter Modulation at transmitter
  - ✓ Pre-emphasis or de-emphasis
  - ✓ Supporting Forward channel, Xtlk channel models
  - ✓ Equalizer
  - ✓ Statistical post-processing