ECEN689: Special Topics in High-Speed Links Circuits and Systems
Spring 2010

Lecture 21: Crosstalk

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Announcements

- HW6 will be posted today and due Wednesday April 7
- Exam 2 will be either April 28 or 30
- Reading
  - Dally 6.1-6.3

Agenda

- Common noise sources
  - Crosstalk
  - ISI

Common Noise Sources

- Power supply noise
- Receiver offset
- Crosstalk
- Inter-symbol interference
- Random noise

Crosstalk

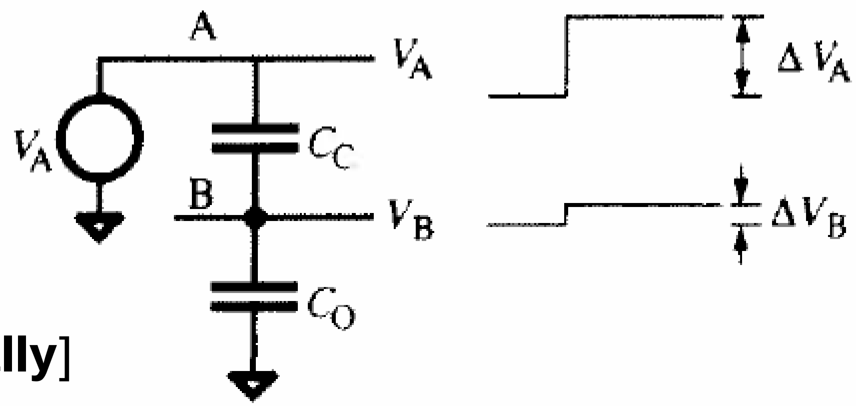
- Crosstalk is noise induced by one signal (aggressor) that interferes with another signal (victim)

- Main crosstalk sources
  - Coupling between on-chip (capacitive) wires
  - Coupling between off-chip (t-line/channel) wires
  - Signal return coupling

- Crosstalk is a proportional noise source
  - Cannot be reduced by scaling signal levels
  - Addressed by using proper signal conventions, improving channel and supply network, and using good circuit design and layout techniques

Crosstalk to Capacitive Lines

- **On-chip wires** have significant capacitance to adjacent wires both on same metal layer and adjacent vertical layers
- Floating victim
  - Examples: Sample-nodes, domino logic
  - When aggressor switches
    - Signal gets coupled to victim via a capacitive voltage divider
    - Signal is not restored



[**Dally**]

$$\Delta V_B = k_c \Delta V_A$$

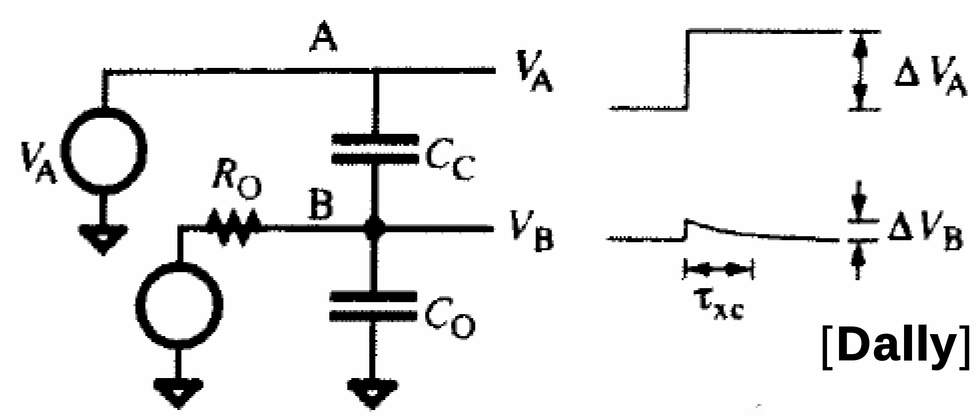
$$k_c = \frac{C_C}{C_C + C_O}$$

Crosstalk to Driven Capacitive Lines

- Crosstalk to a driven line will decay away with a time-constant

$$\tau_{xc} = R_O\left(C_C + C_O\right)$$

- Peak crosstalk is inversely proportional to aggressor transition times, t_r, and driver strength ($1/R_O$)



[**Dally**]

Ideal Unit Step:

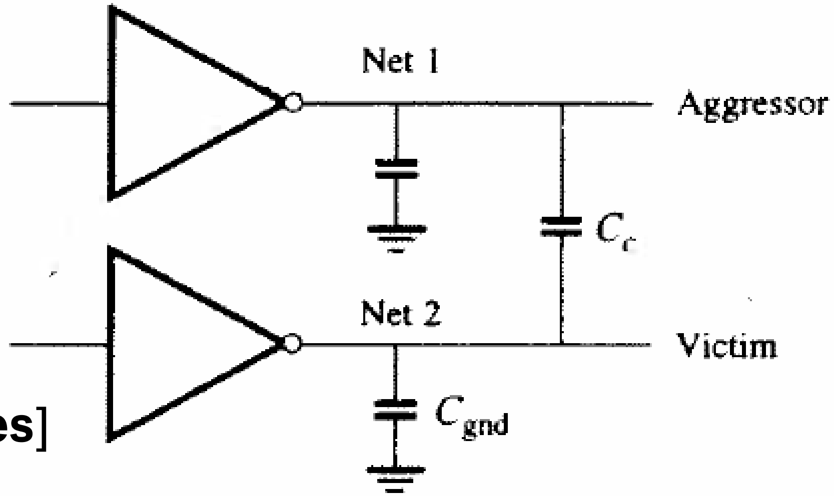
$$\Delta V_B(t) = k_c \exp\left(-\frac{t}{\tau_{xc}}\right)$$

Step with Finite Rise Time, t_r:

$$\Delta V_B(t) = \begin{cases} k_c\left(\frac{\tau_{xc}}{t_r}\right)\left[1 - \exp\left(-\frac{t}{\tau_{xc}}\right)\right] & \textbf{if } t < t_r \\ k_c\left(\frac{\tau_{xc}}{t_r}\right)\left[\exp\left(-\frac{t - t_r}{\tau_{xc}}\right) - \exp\left(-\frac{t}{\tau_{xc}}\right)\right] & \textbf{if } t \geq t_r \end{cases}$$

Capacitive Crosstalk Delay Impact

- Aggressor transitioning near victim transition can modulate the victim's effective load capacitance
- This modulates the victim signal's delay, resulting in deterministic jitter



[**Hodges**]

Aggressor Static : $C_L = C_{gnd} + C_C$

Aggressor Switching Same Way : $C_L = C_{gnd}$

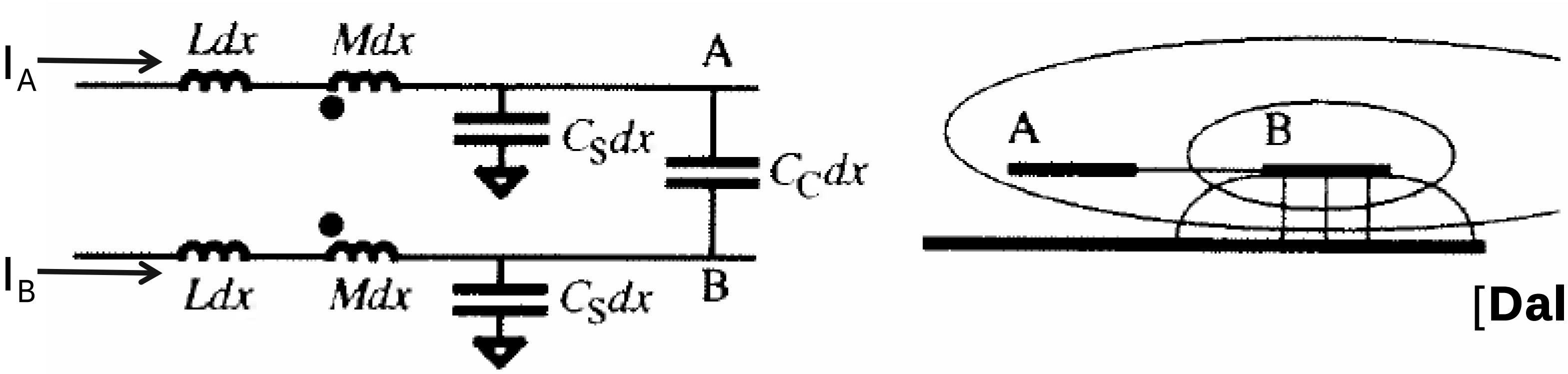
Aggressor Switching Opposite Way : $C_L = C_{gnd} + 2C_C$

Mitigating Capacitive (On-Chip) Crosstalk

- Adjacent vertical metal layers should be routed perpendicular (Manhattan routing)
- Limit maximum parallel routing distance
- Avoid floating signals and use keeper transistors with dynamic logic
- Maximize signal transition time
  - Trade-off with jitter sensitivity
- For differential signals, periodically “twist” routing to make cross-talk common-mode
- Separate sensitive signals
- Use shield wires
- Couple DC signals to appropriate supply

Transmission Line Crosstalk

- 2 coupled lines:



[Dally]

- Transient voltage signal on A is coupled to B capacitively

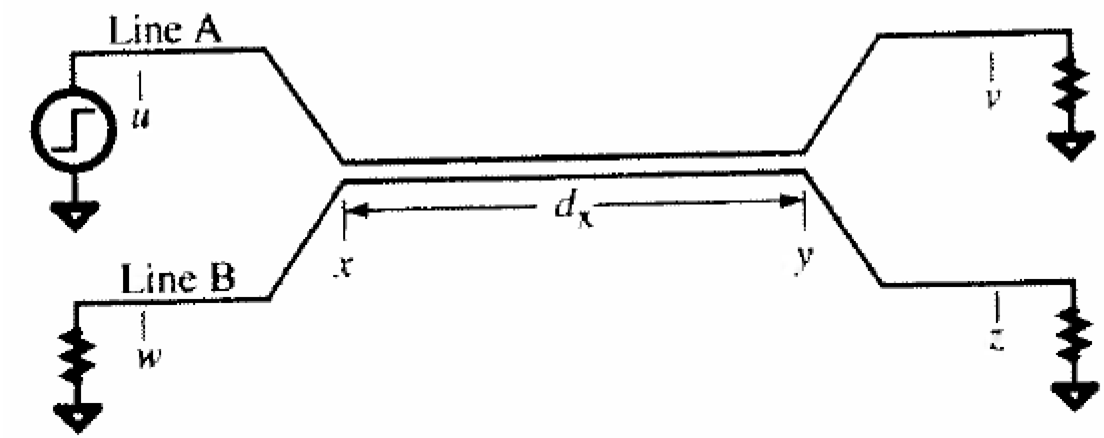
$$\frac{dV_B(x,t)}{dt} = k_{cx}\frac{dV_A(x,t)}{dt} \quad \text{where} \quad \boxed{k_{cx} = \frac{C_C}{C_S + C_C}}$$

- Transient current signal on A is coupled to B through mutual inductance

$$\frac{\partial I_A(x,t)}{\partial t} = -\frac{\partial V_A(x,t)}{L\partial x}$$

$$\frac{dV_B(x,t)}{dx} = -M\frac{dI_A(x,t)}{dt} = \frac{M}{L}\left[\frac{dV_A(x,t)}{dx}\right] = k_{lx}\frac{dV_A(x,t)}{dx} \quad \text{where} \quad \boxed{k_{lx} = \frac{M}{L}}$$

Near- and Far-End Crosstalk



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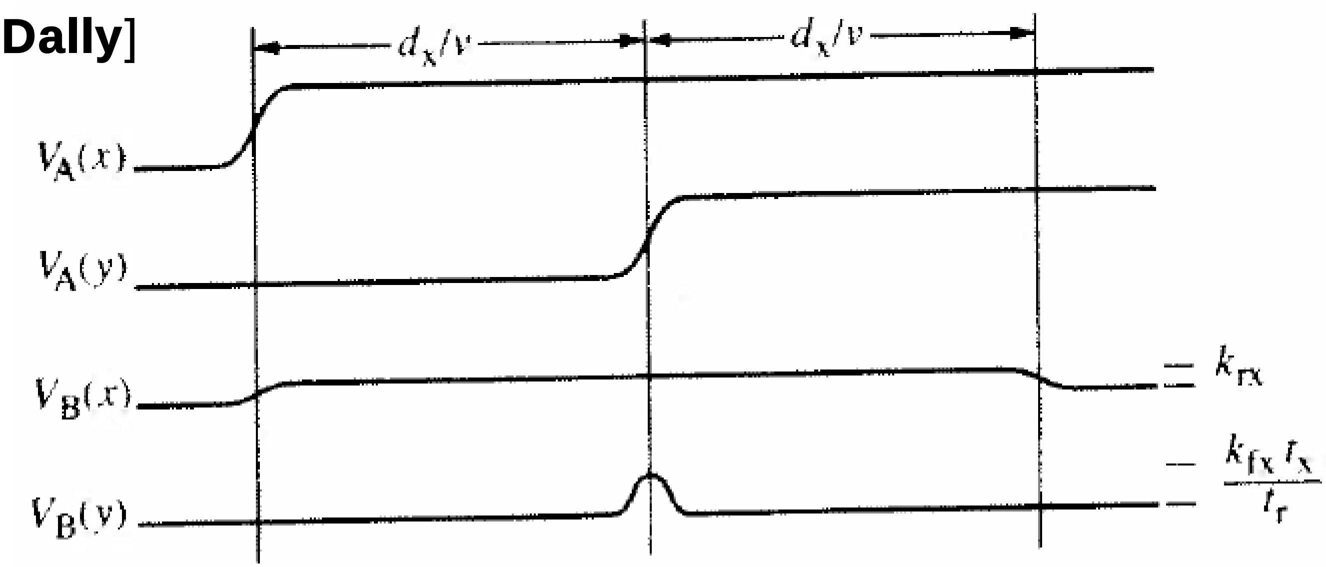


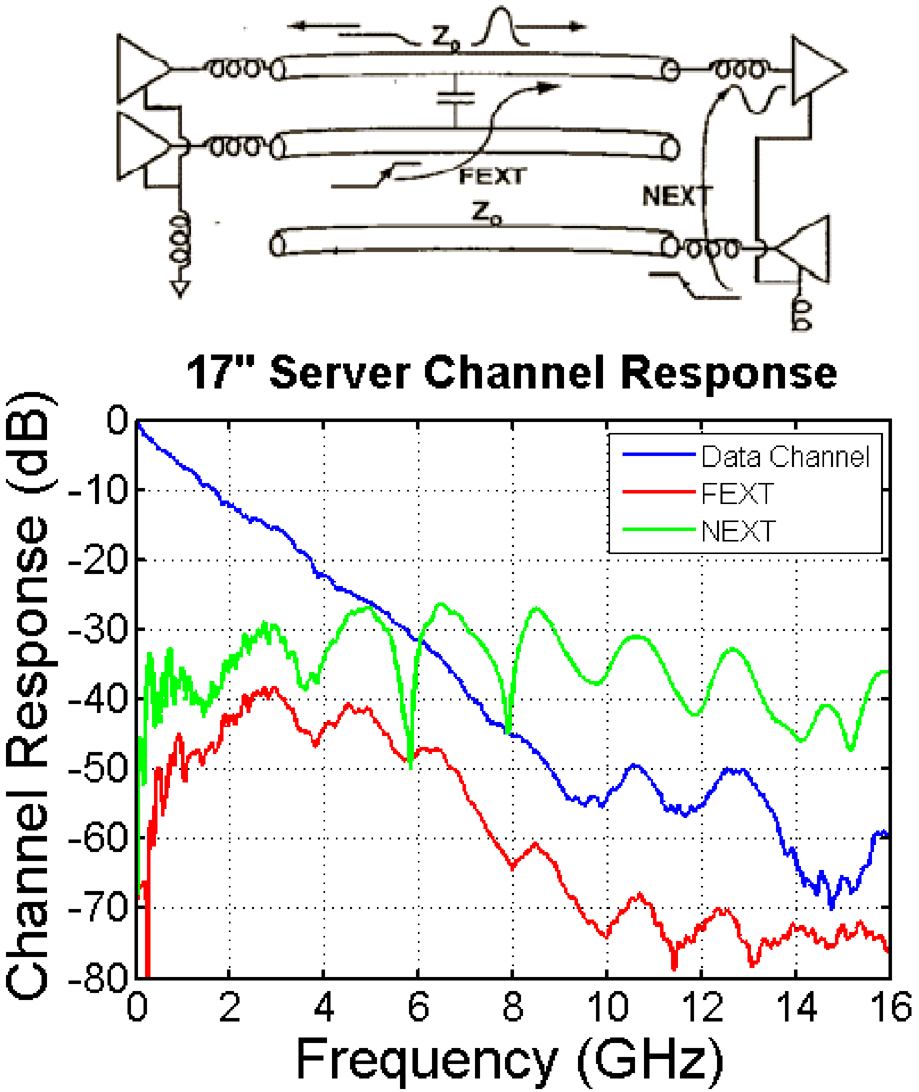
$$k_{rx} = \frac{(k_{cx} + k_{lx})}{4}$$

$$k_{fx} = \frac{(k_{cx} - k_{lx})}{2}$$

For derivation of k_{rx} and k_{fx}, see Dally 6.3.2.3

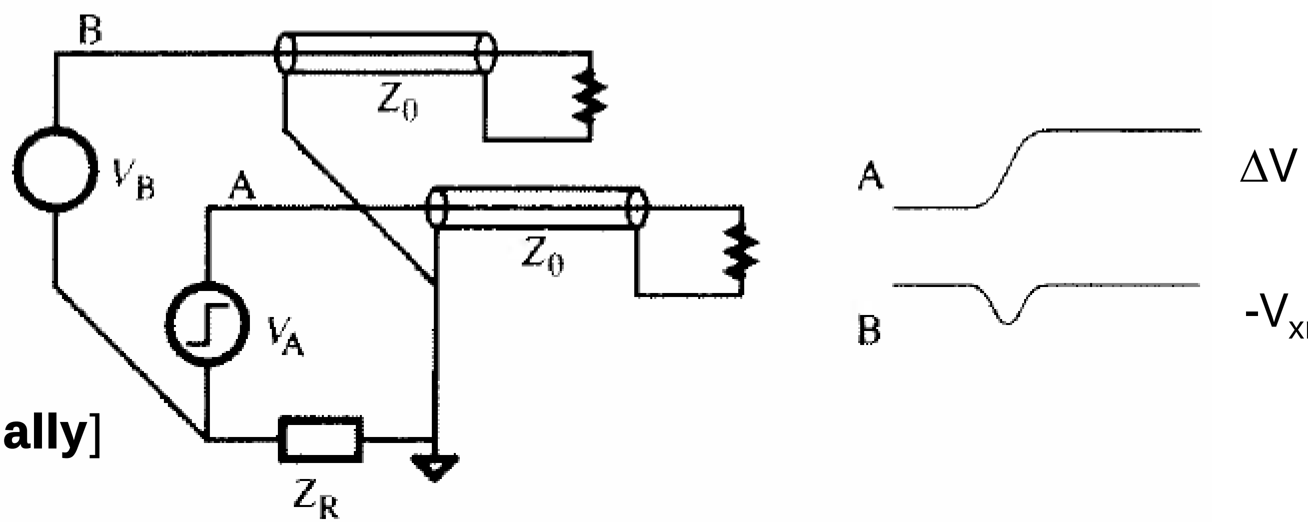
Off-Chip Crosstalk

- Occurs mostly in package and board-to-board connectors
- FEXT is attenuated by channel response and has band-pass characteristic
- NEXT directly couples into victim and has high-pass characteristic



Signal Return Crosstalk

- Shared return path with finite impedance
- Return currents induce crosstalk occurs among signals



[**Dally**]

$$V_{xr} = \Delta V \frac{Z_R}{Z_0} = k_{xr} \Delta V$$

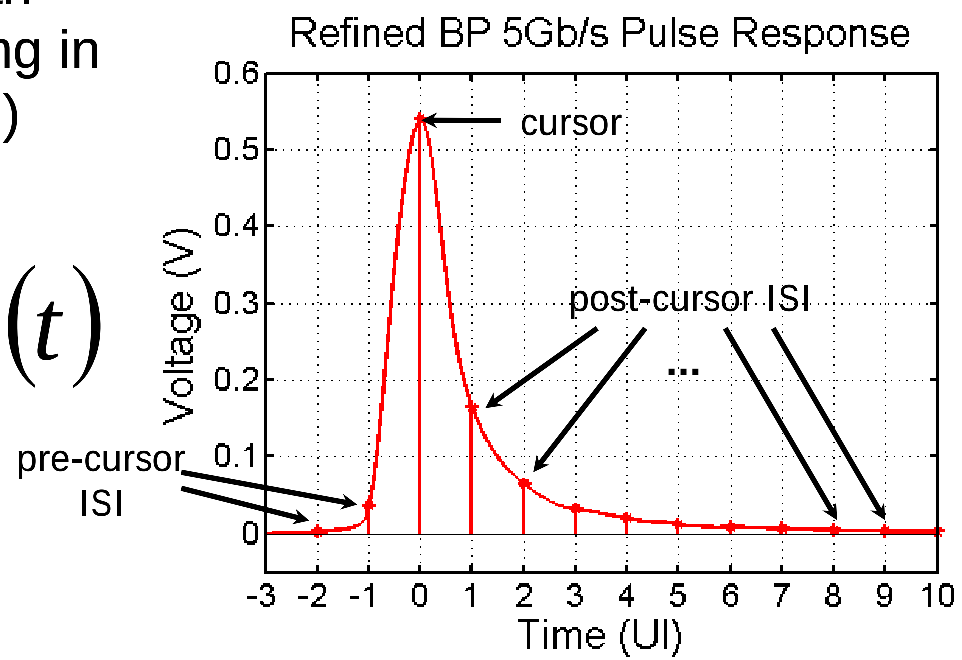
Common Noise Sources

- Power supply noise
- Receiver offset
- Crosstalk
- Inter-symbol interference
- Random noise

Inter-Symbol Interference (ISI)

- Previous bits residual state can distort the current bit, resulting in inter-symbol interference (ISI)

$$y^{(d_k)}(t) = c^{(d_k)}(t) * h(t)$$



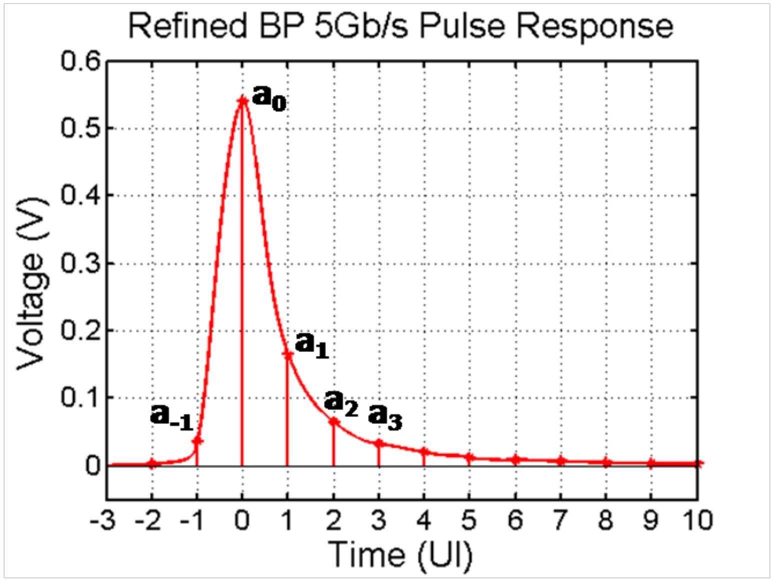
$y^{(1)}(t)$ sampled relative to pulse peak:

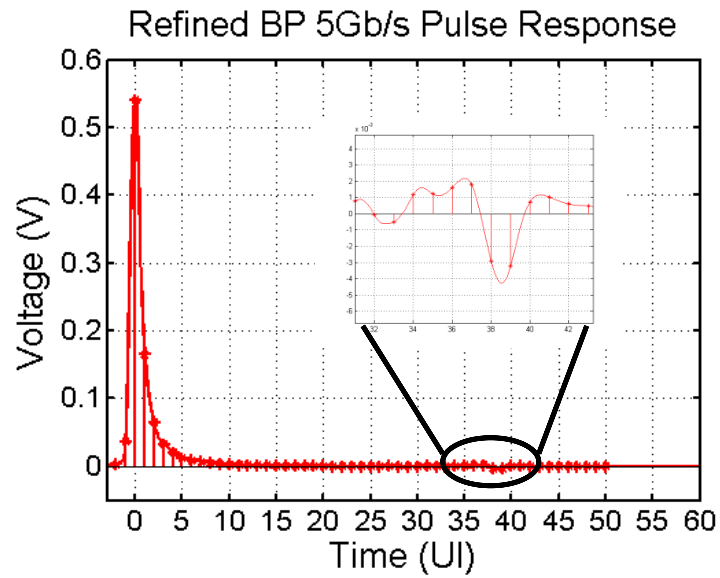
[... 0.003 0.036 0.540 0.165 0.065 0.033 0.020 0.012 0.009 ...]

k =[... -2 1 0 1 2 3 4 5 6 ...]

By Linearity: $y^{(0)}(t) = -1 * y^{(1)}(t)$

Peak Distortion Analysis Example



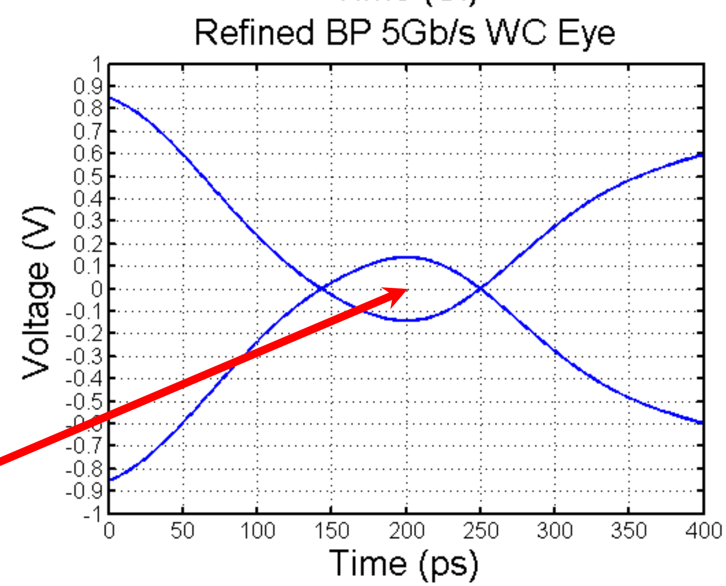


$$y_0^{(1)}(t) = 0.540$$

$$\sum_{\substack{k=-\infty \\ k\neq 0}}^{\infty} y^{(1)}(t-kT)\Big|_{y(t-kT)<0} = -0.007$$

$$\sum_{\substack{k=-\infty \\ k\neq 0}}^{\infty} y^{(1)}(t-kT)\Big|_{y(t-kT)>0} = 0.389$$

$$s(t) = 2(0.540 - 0.007 - 0.389) = 0.288$$



Next Time

- Noise Sources
- Timing Noise
- BER Analysis Techniques