# Adaptive Crosstalk Cancellation Block for SERDES and its AMI Implementation

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# Agenda

- Crosstalk in differential buffers
- Overview of Crosstalk Cancellation block
- Need for Adaptive Crosstalk Cancellation
- AMI Modeling of Crosstalk Cancellation block
- Simulation results and Conclusion

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# Crosstalk in Differential PCB Interconnects

- Crosstalk from neighboring channels at high frequencies causes Crosstalk-Induced Jitter (CIJ).
- Depends on the length, width and spacing of the traces.
- However, it is also a function of data-pattern. Faster switching increases crosstalk.
- Cancellation of crosstalk can result in smaller spacing between the traces or higher BER

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# Crosstalk Induced Jitter (CIJ)

- CIJ causes Far End Crosstalk (FEXT) and Near End Crosstalk (NEXT). FEXT is more dominant for PCB traces.

- Far End Crosstalk (FEXT) from aggressor channel to the victim channel is proportional to the derivative of aggressor channel impulse response:

$$h(t)_{FEXT} = -K\frac{\partial h(t)_{aggressor}}{\partial t}$$

# Crosstalk Induced Jitter (CIJ)

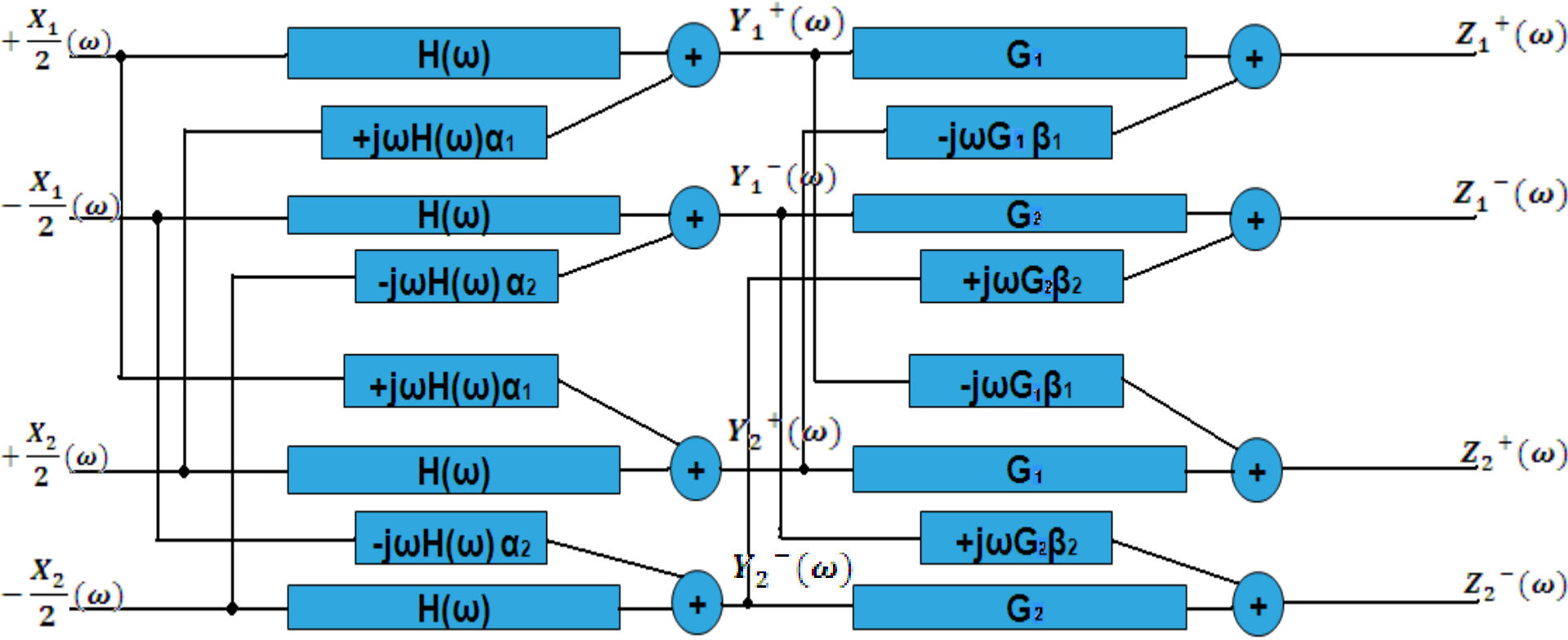
$$h(t)_{FEXT} = -K\frac{\partial h(t)_{aggressor}}{\partial t}$$

- Here K is the crosstalk coupling coefficient that depends on length, height and spacing between traces.

- Crosstalk also depends on data transitions. More transitions increase crosstalk

# CIJ Cancellation using MIMO

## - Block Diagram of crosstalk cancellation at Rx




- MIMO: Multiple Input Multiple Output
- Based on inverse system modeling

# CIJ Cancellation using MIMO

- Output as a function of Inputs can be expressed as:

$$\begin{bmatrix} Z_1^{+}(\omega) \\ Z_1^{-}(\omega) \\ Z_2^{+}(\omega) \\ Z_2^{-}(\omega) \end{bmatrix}$$

$$= \begin{bmatrix} h(\omega) & 0 & j\omega h(\omega)\alpha_1 & 0 \\ 0 & h(\omega) & 0 & -j\omega h(\omega)\alpha_2 \\ j\omega h(\omega)\alpha_1 & 0 & h(\omega) & 0 \\ 0 & -j\omega h(\omega)\alpha_2 & 0 & h(\omega) \end{bmatrix} \begin{bmatrix} G_1 & 0 & -j\omega G_1\beta_1 & 0 \\ 0 & G_2 & 0 & +j\omega G_2\beta_2 \\ -j\omega G_1\beta_1 & 0 & G_1 & 0 \\ 0 & +j\omega G_2\beta_2 & 0 & G_2 \end{bmatrix} \begin{bmatrix} +\frac{X_1}{2}(\omega) \\ -\frac{X_1}{2}(\omega) \\ +\frac{X_2}{2}(\omega) \\ -\frac{X_2}{2}(\omega) \end{bmatrix}$$

$$= \begin{bmatrix} G_1 h(\omega)(1+\omega^2\alpha_1\beta_1) & 0 & j\omega G_1 h(\omega)(\alpha_1-\beta_1) & 0 \\ 0 & G_2 h(\omega)(1+\omega^2\alpha_2\beta_2) & 0 & -j\omega G_2 h(\omega)(\alpha_2-\beta_2) \\ j\omega G_1 h(\omega)(\alpha_1-\beta_1) & 0 & G_1 h(\omega)(1+\omega^2\alpha_1\beta_1) & 0 \\ 0 & -j\omega G_2 h(\omega)(\alpha_2-\beta_2) & 0 & G_2 h(\omega)(1+\omega^2\alpha_2\beta_2) \end{bmatrix} \begin{bmatrix} +\frac{X_1}{2}(\omega) \\ -\frac{X_1}{2}(\omega) \\ +\frac{X_2}{2}(\omega) \\ -\frac{X_2}{2}(\omega) \end{bmatrix}$$

- **If α1= β1  α2= β2, crosstalk becomes zero!!**

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# Need for Adaptive Crosstalk Cancellation

- Limitations:
  - Coupling coefficient needs to be known to the receiver.
  - Power required for crosstalk cancellation block
- Proposal
  - Determine crosstalk coupling coefficient on the fly based on crosstalk activity.
  - If the coupling coefficient is too small then the cancellation scheme can be switched off to save power.

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# Adaptive CIJ Cancellation: AMI Implementation

- Crosstalk is a function of channel length, spacing between channels and amount of data transitions. The number of data transitions varies with data pattern.
- Effectively, crosstalk between two interconnects keeps varying with data pattern.
- Effective coupling coefficient can be considered directly proportional to the transitions in the data-pattern.

# Adaptive CIJ Cancellation: AMI Implementation

$$\frac{Z_1}{2}^{+}(\omega) = Gh(\omega)(1+\omega^2\alpha_1\beta_1)\frac{X_1}{2}(\omega) + j\omega Gh(\omega)(\alpha_1-\beta_1)\frac{X_2}{2}(\omega)$$

$$G_i = \frac{1}{1+sR_iC_i}\Big| i = 1,2 \qquad \beta_i = R_iC_i$$

- Apply bilinear transformation to Gi **(fs – sampling rate)**
  - To be coded as FIR filter

$$G_i = \frac{1+z^{-1}}{z^{-1}\left(1-\frac{1}{\tan\left(\frac{1}{2RiCif_s}\right)}\right)+1+\frac{1}{\tan\left(\frac{1}{2RiCif_s}\right)}}$$

- Training sequence is be used to train the crosstalk cancellation block
  - Input is applied only at one channel, and the crosstalk signal is measured at the output of other channel
  - Intent is to minimize (zero) the crosstalk at other channel

# Adaptive CIJ Cancellation: AMI Implementation using Varactor

- Integrate the crosstalk signal to obtain Vf (Reverse-bias voltage) that would control the capacitance of the varactor (voltage dependent capacitor)
- Compute Ci using Varactor equation

$$C_i = \frac{C_0}{\sqrt{1 + \frac{V_f}{V_{bi}}}}$$

  - With $C_0$ (0 bias capacitance) = 0.025 and $V_{bi}$ (Built in voltage potential)= 0.5 as constants.
  - Ci modifies the crosstalk cancellation block Gi such that the crosstalk becomes zero.

$$G_i = \frac{1}{1 + sR_iC_i} \Big| i = 1, 2$$

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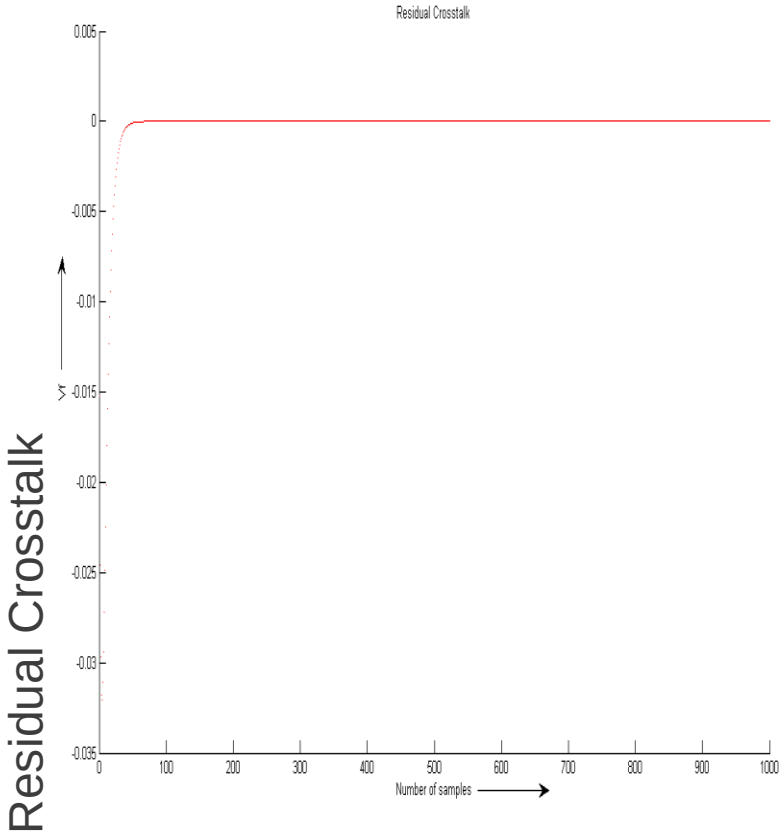
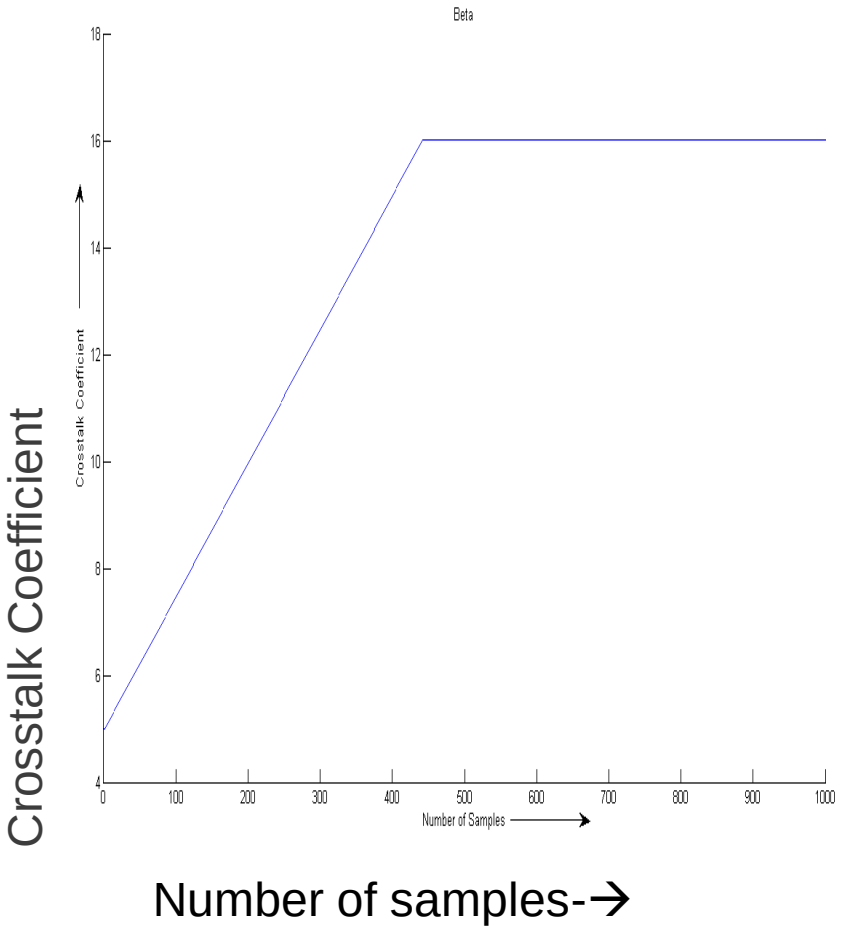
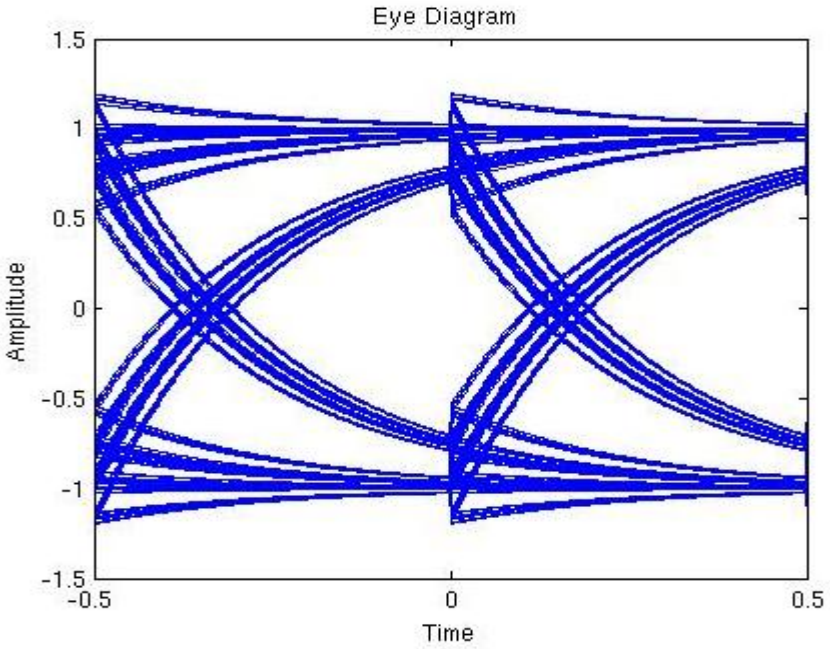
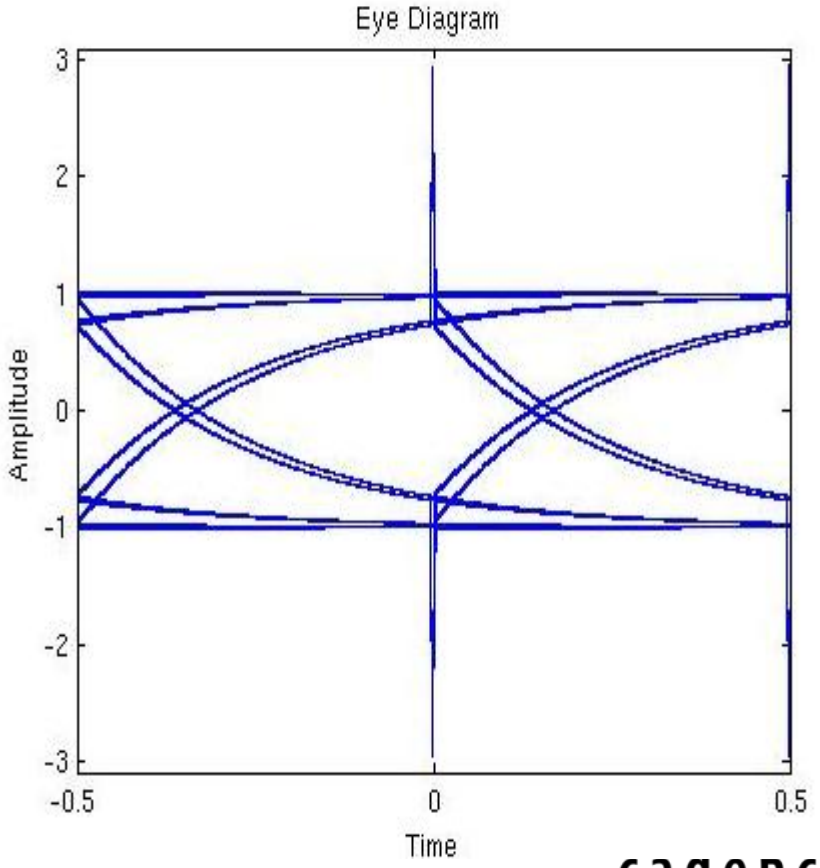
# MATLAB Simulation:
# - Adaptive Crosstalk Cancellation



# MATLAB Simulation:
# - Adaptive Crosstalk Cancellation

| Without Crosstalk cancellation | With Crosstalk cancellation |
| --- | --- |
|  |  |







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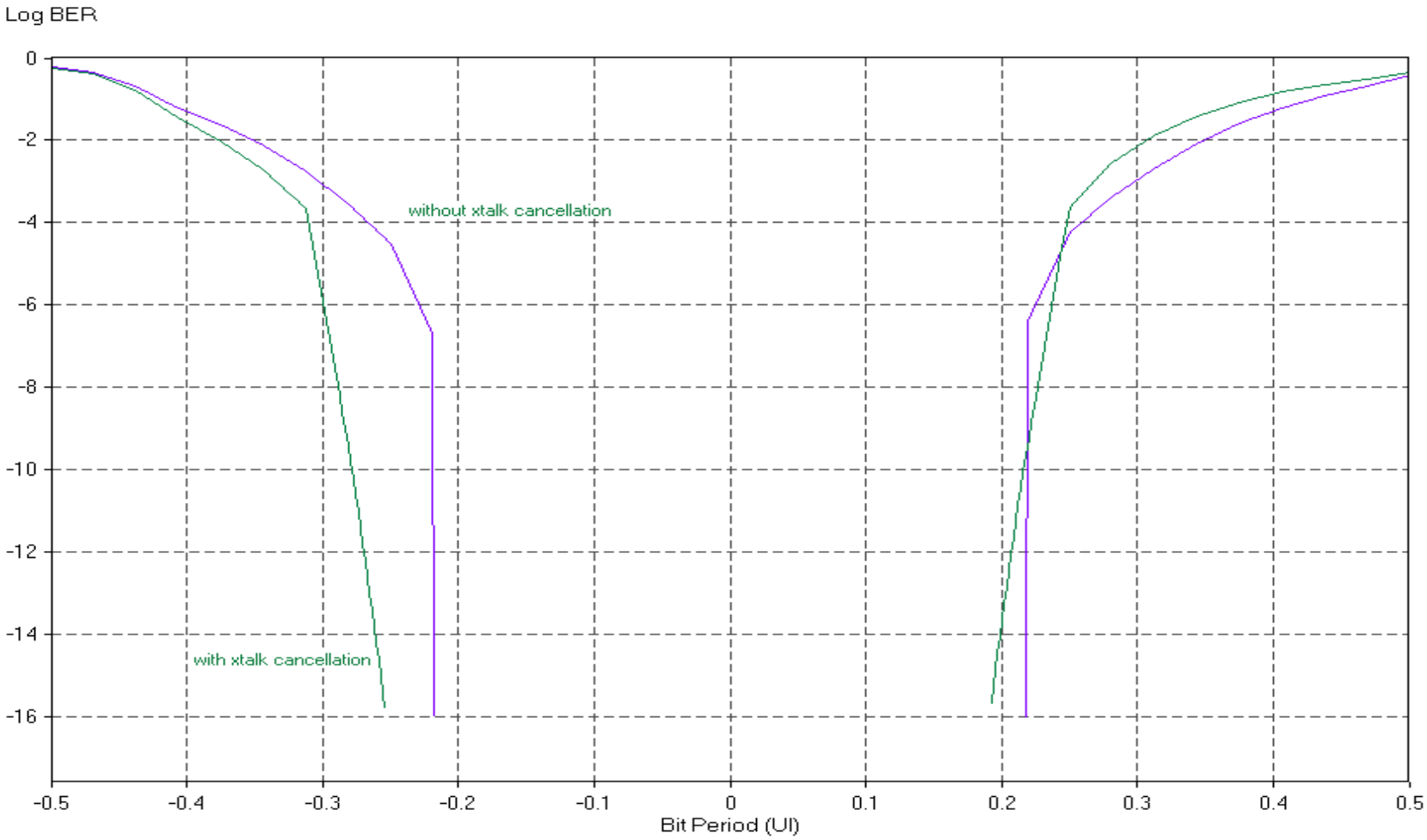
# AMI Simulation:
# - Adaptive Crosstalk Cancellation



# Conclusion

- At higher data-rates, crosstalk is becoming issue for differential buffers.
- Crosstalk induced jitter can be cancelled by crosstalk cancellation block
- Since crosstalk jitter is pattern dependent, it is important that crosstalk cancellation adapts itself based on data-induced jitter