High-Speed Serial Interface Circuits and Systems

Lecture 9: Tx Finite Impulse Response (FIR) Equalizer

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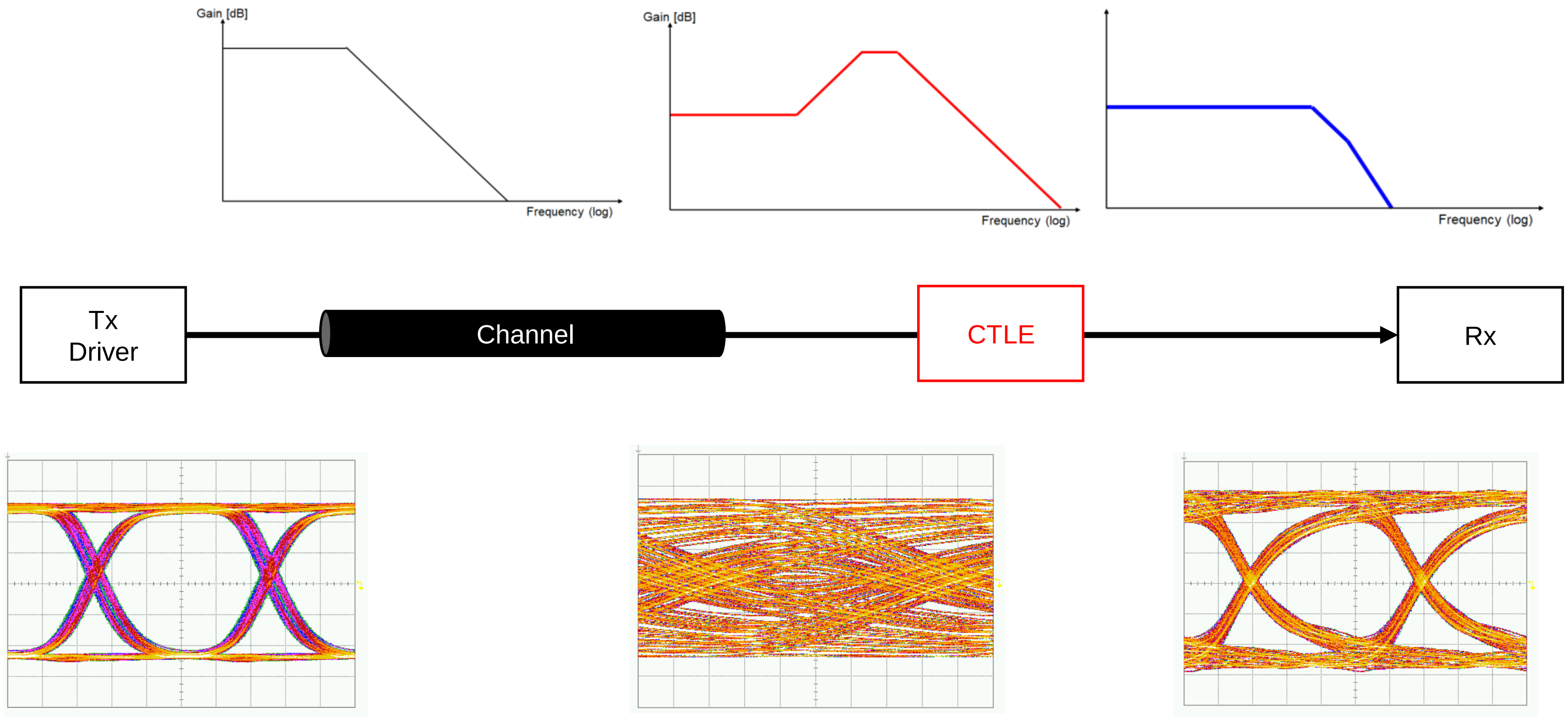
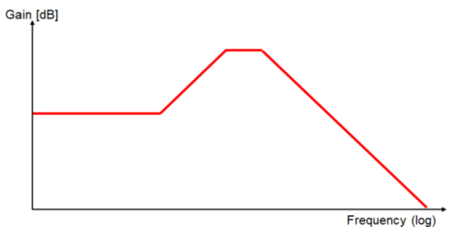
Tx FIR



Gain [dB]
Frequency (log)
Gain [dB]
Frequency (log)
Frequency (log)
Tx
Driver
Channel
CTLE
Rx

Tx FIR

CTLE



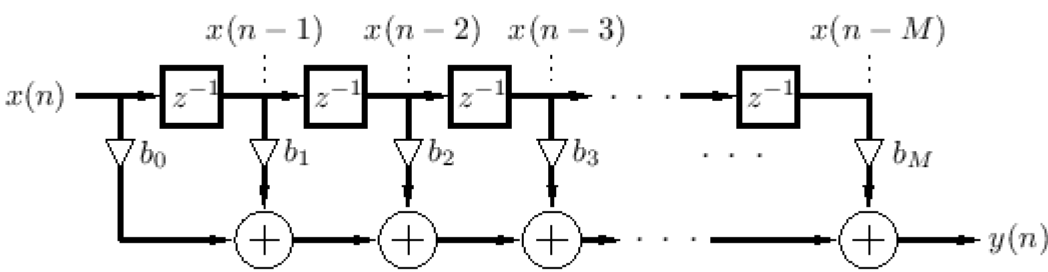
Discrete Time Domain Implementation?

s-domain analysis (CT) vs z-domain analysis (DT)

Bilinear transformation of s-domain filter into z-domain

(T: Unit Interval) $z = e^{sT} \sim \dfrac{1+\frac{sT}{2}}{1-\frac{sT}{2}}$ $\quad s \sim \dfrac{2}{T}\dfrac{z-1}{z+1} = \dfrac{2}{T}\dfrac{1-z^{-1}}{1+z^{-1}}$

➔ Possible to approximately implement with Finite-Impulse Response (FIR)



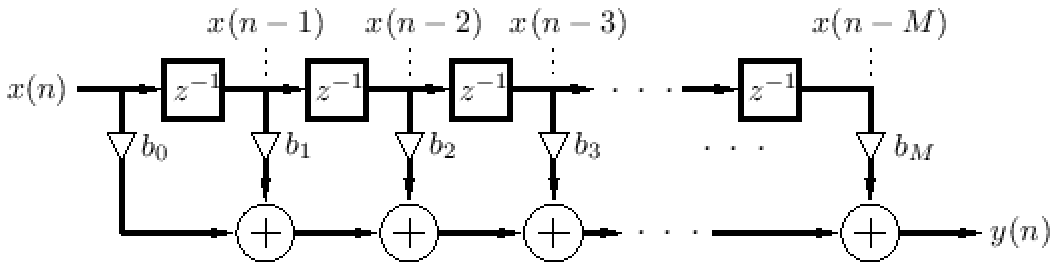
Tapped and Delay

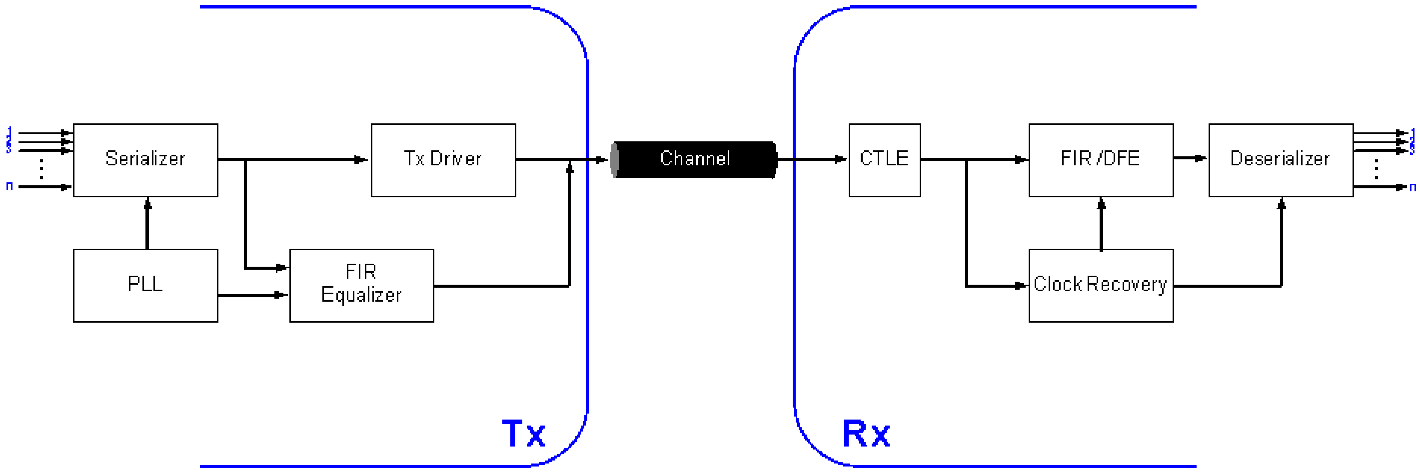
Simple to implement

No stability problem (No feedback)

Tx FIR

FIR

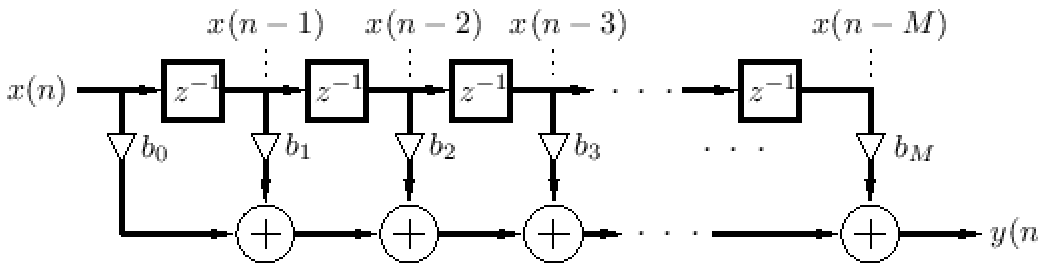




Tx FIR much easier to implement

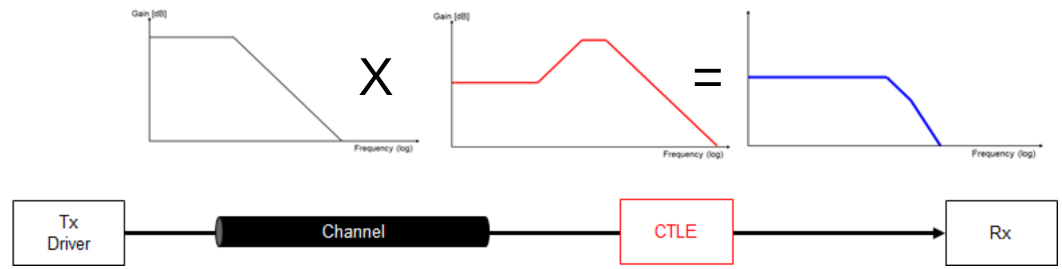
Tx FIR

FIR coefficient determination

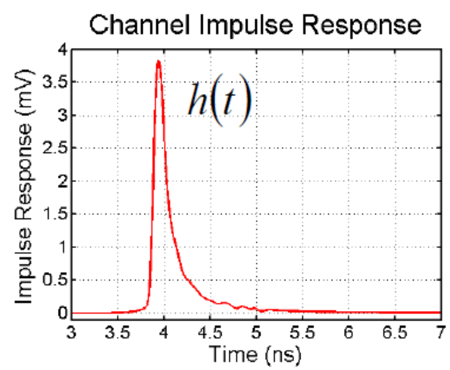


CTLE:

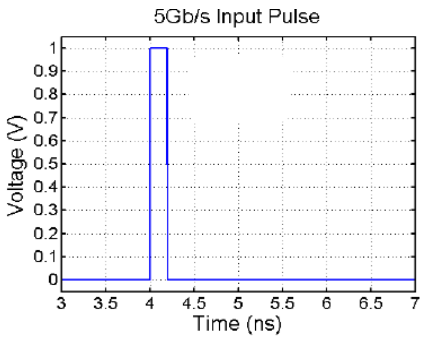
Frequency-domain analysis



Time-domain analysis for FIR



Tx FIR



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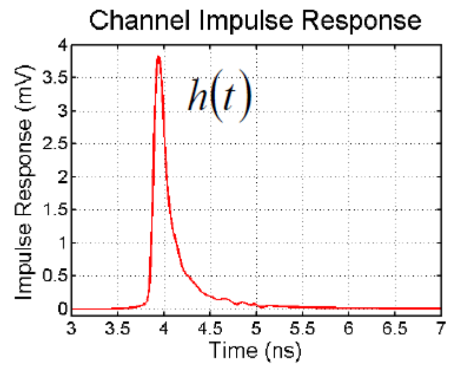

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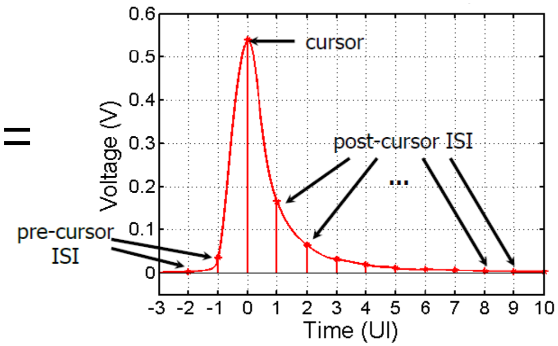
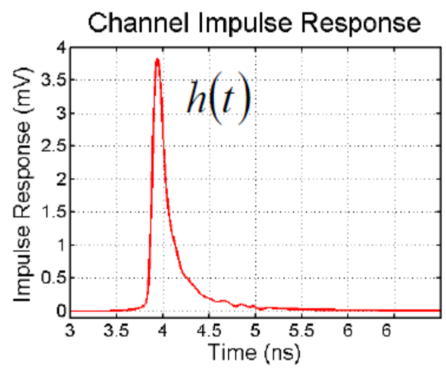
Pulse Response



Random
Bit Sequence

*



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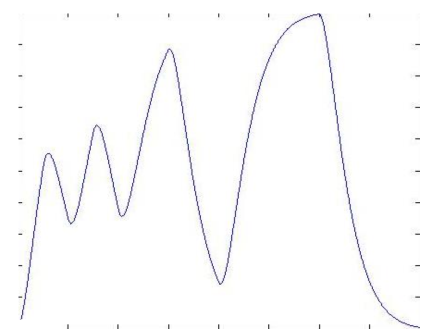
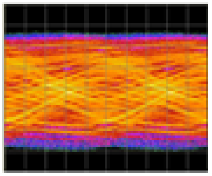
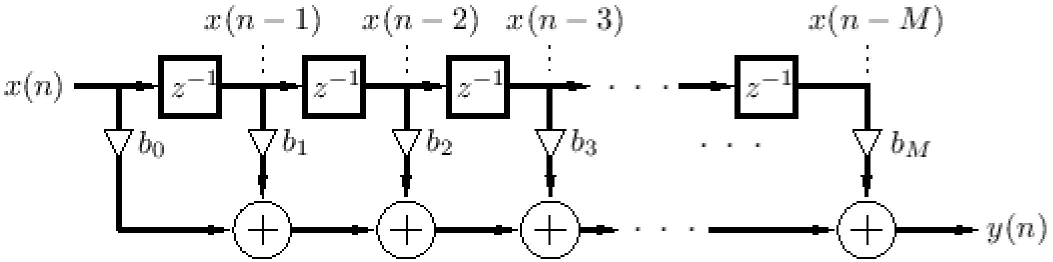




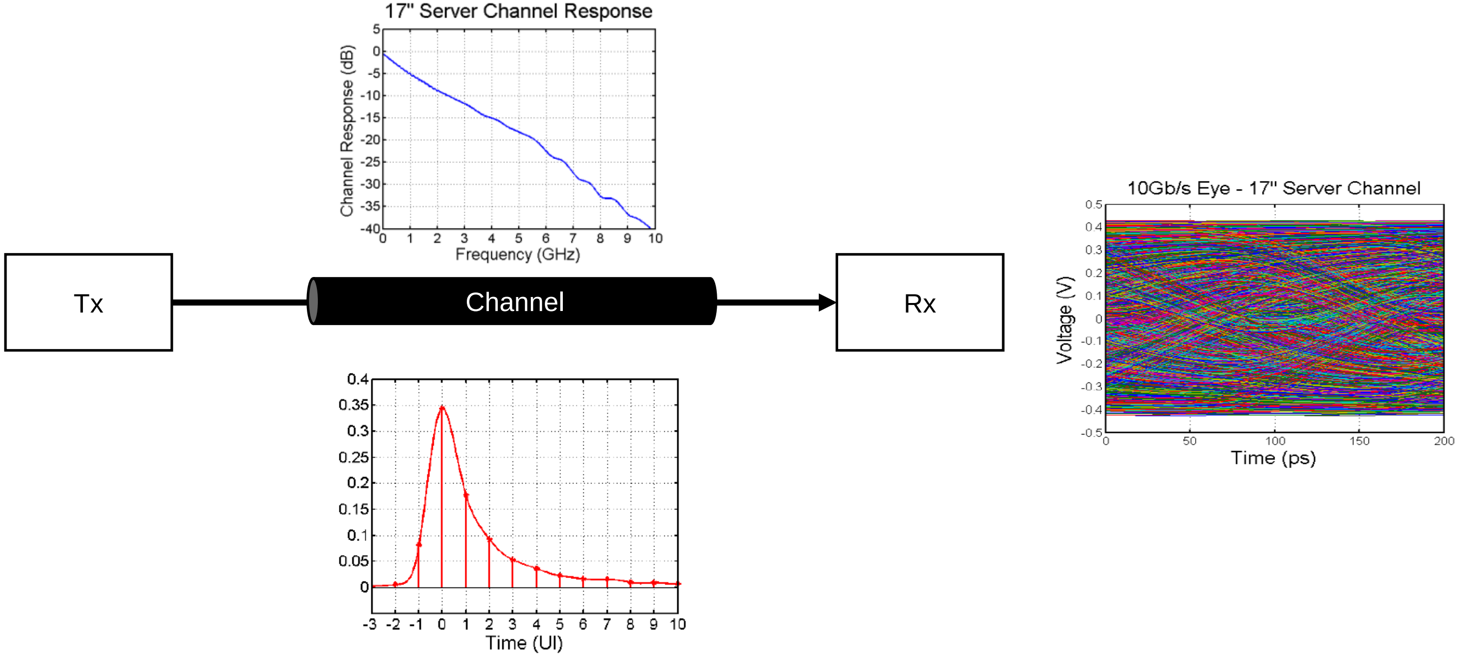
Inter-Symbol Interference

Tx FIR

FIR coefficient determination

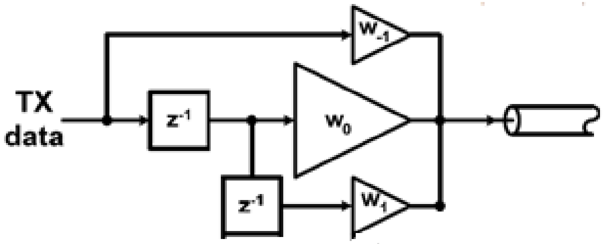


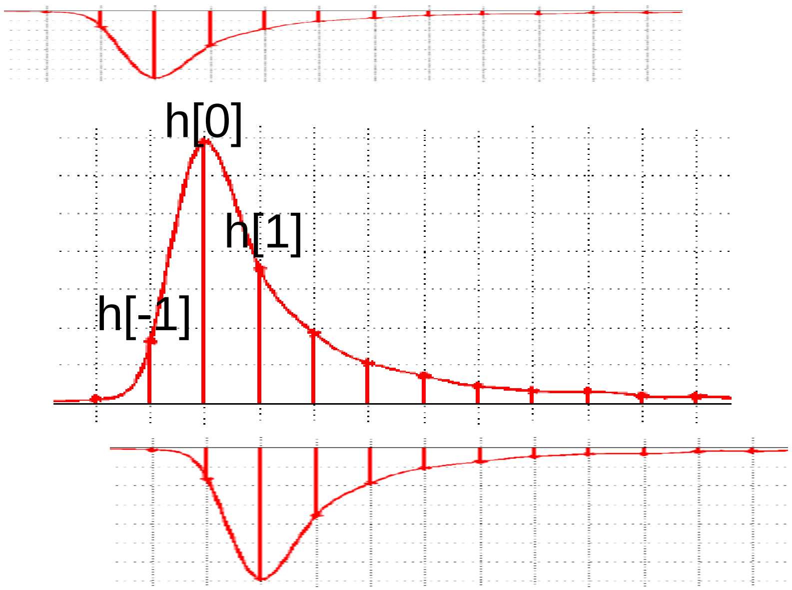
Example (From Prof. Palermo of TAMU class notes)



Tx FIR

Use 3-tap FIR for simplicity





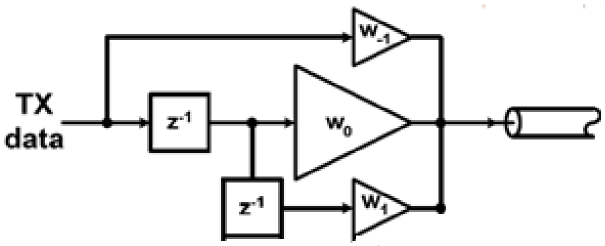
$$w_{-1}h[0]+w_0h[-1]+w_1h[-2]=0$$

$$w_{-1}h[1]+w_0h[0]+w_1h[-1]=1$$

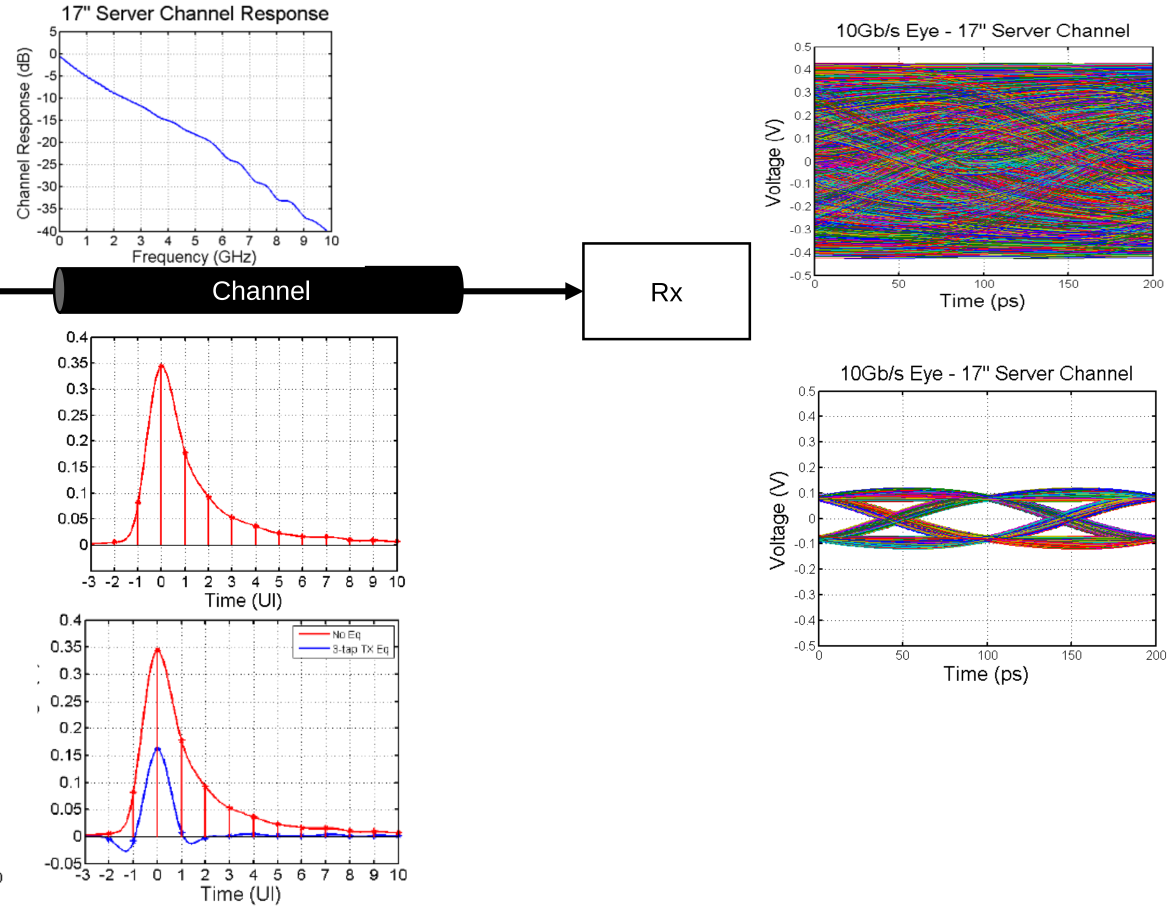
$$w_{-1}h[2]+w_0h[1]+w_1h[0]=0$$

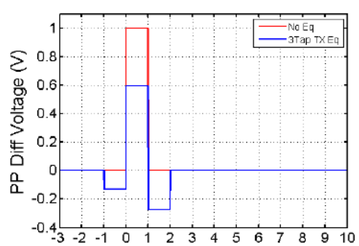
$$\begin{bmatrix} w_{-1} \\ w_0 \\ w_1 \end{bmatrix} \sim \begin{bmatrix} -0.13 \\ 0.60 \\ -0.27 \end{bmatrix}$$

Tx FIR

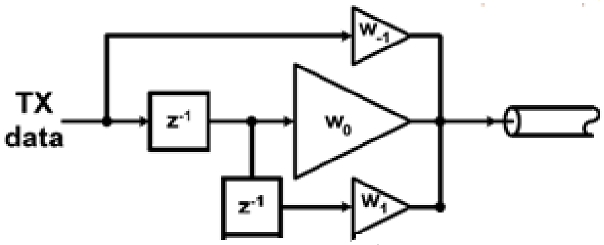


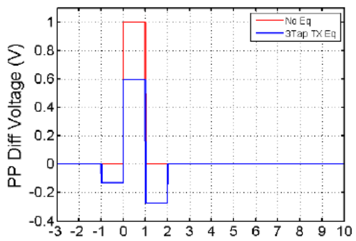
$$\begin{bmatrix} w_{-1} \\ w_0 \\ w_1 \end{bmatrix} = \begin{bmatrix} -0.13 \\ 0.60 \\ -0.27 \end{bmatrix}$$





Tx FIR





$$\begin{bmatrix} w_{-1} \\ w_0 \\ w_1 \end{bmatrix} = \begin{bmatrix} -0.13 \\ 0.60 \\ -0.27 \end{bmatrix}$$

$$W[z] = -0.13 + 0.60z^{-1} - 0.27z^{-2}$$

Corresponding frequency response?

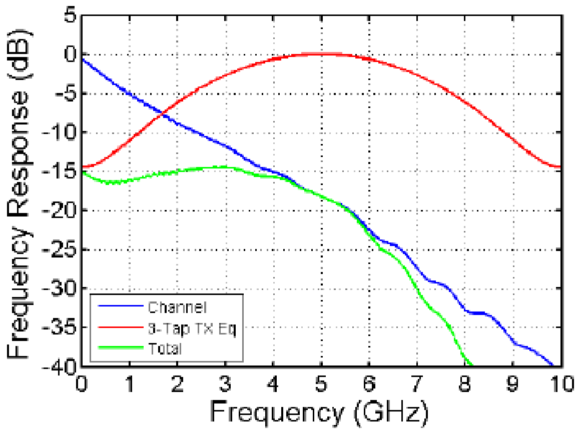
$$z = e^{sT} \quad ==> e^{j2\pi fT}$$

Low Frequency Response $(f = 0)$

$$z = 1 \quad H(f = 0) = 0.2 \quad ==> -14dB$$

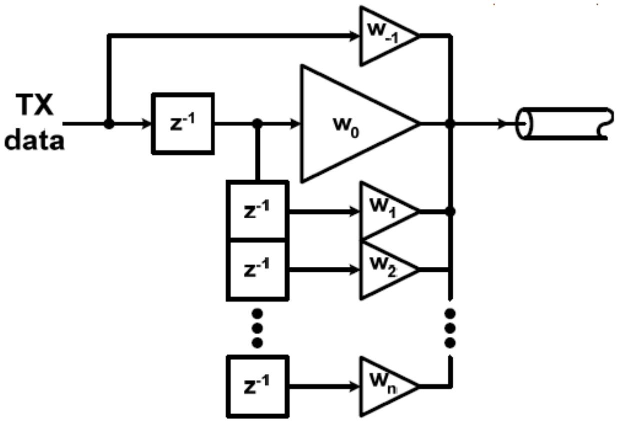
Nyquist Frequency Response $\left(f = \frac{1}{2T}\right)$

$$z = -1 \quad H(f = \frac{1}{2T}) = -1 \quad |H| = 0dB$$



FIR ➔ High Pass Filter

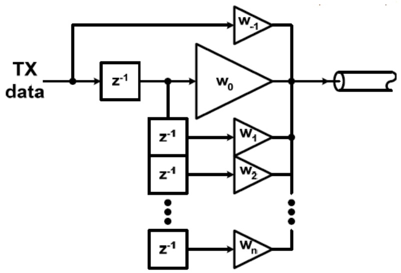
Tx FIR



Tap coefficients?

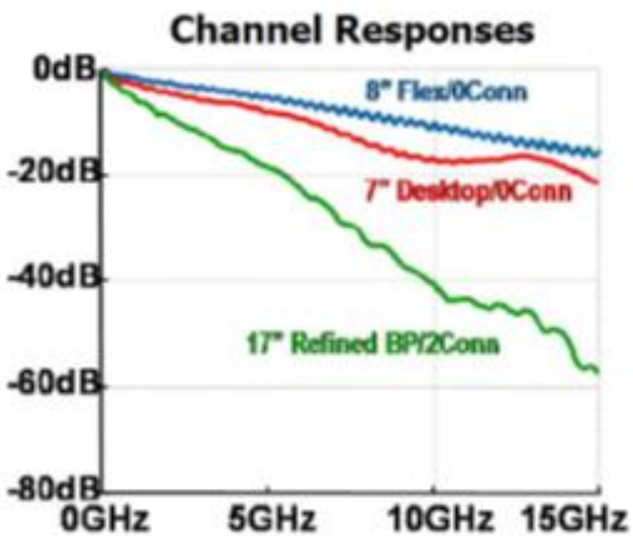
Minimum Mean-Square Error (MMSE) algorithm
for pre-, post-cursor reduction with the given tap number

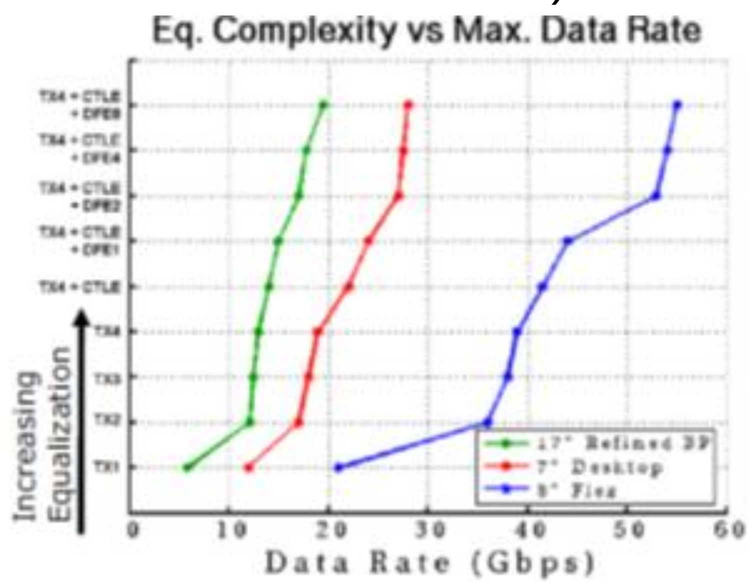
Tx FIR



How many taps?

(From Prof. Palermo of TAMU class notes)



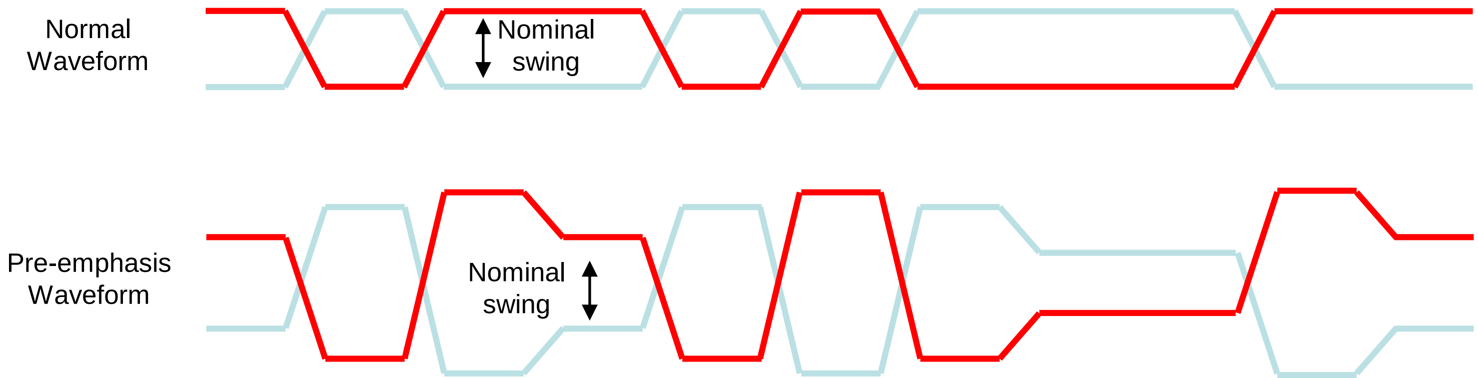


3-tap FIR gives significant performance enhancement

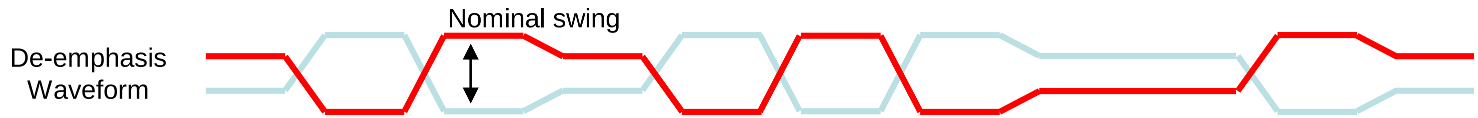
Tx FIR ➔ CTLE ➔ Decision-Feedback Equalizer (DFE)

Tx FIR

2-Tap FIR (main and 1st post-cursor) also called Pre-/De-Emphasis



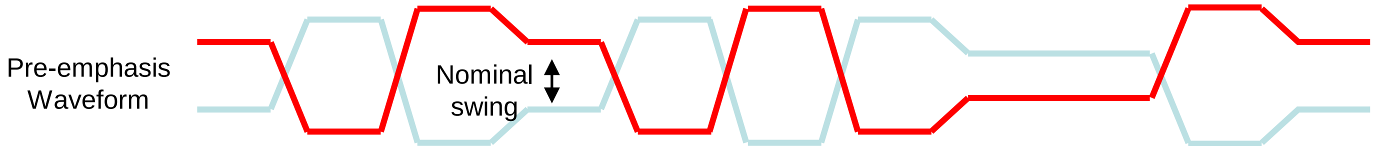
Pre-emphasis: Enhance high-frequency components

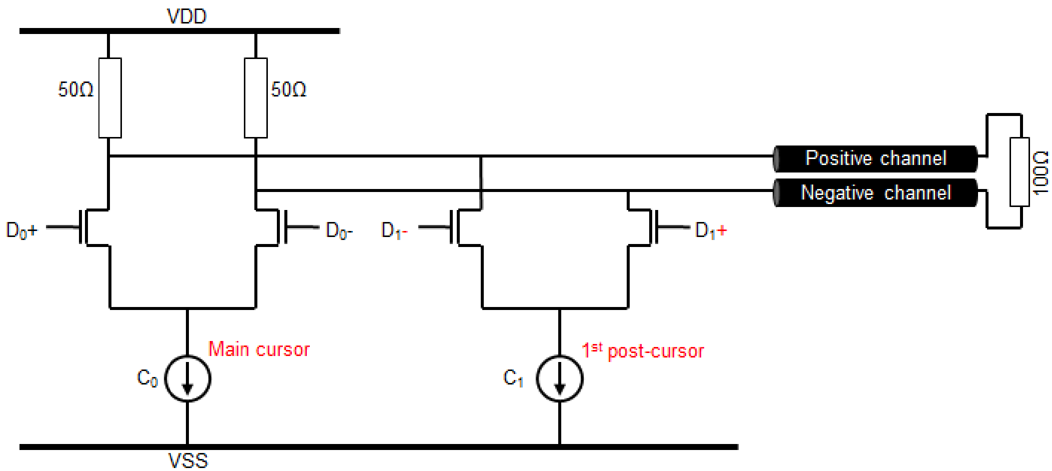


De-emphasis: Reduce low-frequency components

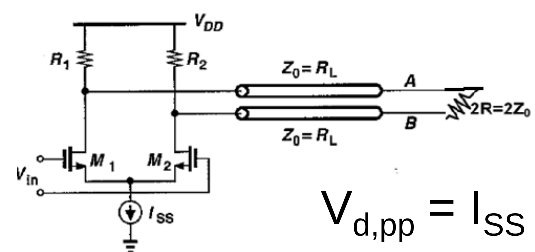
Tx FIR

- Tx FIR can be easily implemented with CML drivers





(Lecture 7)



$V_{d,pp} = I_{SS} R_L$

- $D_1 \neq D_0$ $\quad V_{d,pp} = (C_0 + C_1) \times 50$
- $D_1 = D_0$ $\quad V_{d,pp} = (C_0 - C_1) \times 50$

More taps can be implemented by adding parallel CML drivers with proper polarity

Tx FIR

Homework: (Due on 11/16)

An FIR filter has the z-domain system function given as
$H(z) = a + b\,z^{-1} + c\,z^{-2}$.

(a) Draw the block diagram for an NRZ transmitter equalizer implementing above system function. Your block diagram should contain only delay elements with delay T, the unit interval, and the drivers having the required gain.

(b) Determine how much high-frequency peaking above equalizer provides at the Nyquist frequency (=1/2T) compared to the DC gain. Use the linear scale.

(c) Show the circuit schematic of an differential current-mode driver implementing above equalizer.