Lecture 16: Equalization Introduction
Announcements

• HW4 due Wednesday 5PM
  • Any issues?

• Exam 1 is March 12
  • 9:10-10:10AM (10 extra minutes)
  • Closed book w/ one standard note sheet
    • 8.5”x11” front & back
  • Bring your calculator
Agenda

• Equalization theory and circuits
  • Equalization overview
  • Equalization implementations
    • TX FIR
    • RX FIR
    • RX CTLE
    • RX DFE
  • Setting coefficients
  • Equalization effectiveness
  • Alternate/future approaches
High-Speed Electrical Link System
Link with Equalization

 Serializer → TX FIR Equalization → Channel → RX CTLE + DFE Equalization → Deserializer

 DTx[N:0] → TX Clk Generation (PLL) → Channel → RX Clk Recovery (CDR/Fwd Clk) → DRx[N:0]
Channel Performance Impact

Channel Responses

10Gb/s Pulse Responses

10Gb/s Eye - Desktop Channel

10Gb/s Eye - Refined BP Channel

10Gb/s Eye - Legacy BP Channel
Channel Performance Impact

**Channel Responses**

- 7" Desktop/0Conn
- 17" Refined BP/2Conn
- 17" Legacy BP/2Conn

**10Gb/s Equalized Pulse Responses**

- 7" Desktop/0Conn
- 17" Refined BP/2Conn
- 17" Legacy BP/2Conn

**10Gb/s Eye - Desktop Channel w/ Eq**

**10Gb/s Eye - Refined BP Channel w/ Eq**

**10Gb/s Eye - Legacy BP Channel w/ Eq**
TX FIR Equalization

- TX FIR filter pre-distorts transmitted pulse in order to invert channel distortion at the cost of attenuated transmit signal (de-emphasis)

\[
V_{out}(0) = \left[ I_{-1}D(1) + I_0D(0) + I_1D(-1) + I_2D(-2) \right] \left( \frac{R_{TERM}}{2} \right)
\]

“A Low Power 10Gb/s Serial Link Transmitter in 90-nm CMOS,” A. Rylyakov et al., CSICS 2005
6Gb/s TX FIR Equalization Example

Pros
- Simple to implement
- Can cancel ISI in pre-cursor and beyond filter span
- Doesn’t amplify noise
- Can achieve 5-6 bit resolution

Cons
- Attenuates low frequency content due to peak-power limitation
- Need a “back-channel” to tune filter taps
RX Equalization #1: RX FIR

**Pros**
- With sufficient dynamic range, can amplify high frequency content (rather than attenuate low frequencies)
- Can cancel ISI in pre-cursor and beyond filter span
- Filter tap coefficients can be adaptively tuned without any back-channel

**Cons**
- Amplifies noise/crosstalk
- Implementation of analog delays
- Tap precision

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RX Equalization #2: RX CTLE

- **Pros**
  - Provides gain and equalization with low power and area overhead
  - Can cancel both pre-cursor and long-tail ISI

- **Cons**
  - Generally limited to 1st order compensation
  - Amplifies noise/crosstalk
  - PVT sensitivity
  - Can be hard to tune
RX Equalization #3: RX DFE

• **Pros**
  - No noise and crosstalk amplification
  - Filter tap coefficients can be adaptively tuned without any back-channel

• **Cons**
  - Cannot cancel precursor ISI
  - Critical feedback timing path
  - Timing of ISI subtraction complicates CDR phase detection

![Refined BP Channel 6Gb/s Pulse Responses](image1)

- **6Gb/s Eye - Refined BP Channel w/ No Eq**
- **6Gb/s Eye - Refined BP Channel w/ RX DFE Eq**

![Graphs](image2)
Equalization Effectiveness

- Some observations:
  - Big initial performance boost with 2-tap TX eq.
  - With only TX eq., not much difference between 2 to 4-tap
  - RX equalization, particularly DFE, allows for further performance improvement
    - Caution – hard to build fast DFEs due to critical timing path
Next Time

• Equalization theory and circuits
  • Equalization implementations
    • TX FIR
    • RX FIR
    • RX CTLE
    • RX DFE
  • Setting coefficients
  • Equalization effectiveness
  • Alternate/future approaches