An Equalization Scheme for 10Gb/s 4-PAM Signaling over Long Cables

July 28, 1997

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Goals

- Networking high speed computers for 1 to 20 meter distance ranges at lower cost and complexity.
  - Parallel buses are costly for long distances.
  - Optical fibers are also not beneficial for such small ranges.
  - Serial links on copper cables are an attractive solution for this kind of application.

- Exploring the bandwidth limitations of CMOS serial links.
  - Most commercial multi gigabit transceivers are bipolar or GaAs.
  - CMOS technology is getting cheaper, faster and more common.
Challenges

- System Architecture
- Circuit Implementation
- Simulation Results
- Conclusion
Challenges

- Circuit issues:
  Noise, limited transistor speed, parasitics, transistor mismatches...

- Signal reflection, due to imperfect line terminations, corrupts the received symbol (reflection ISI).

- Major Problem: Frequency dependent attenuation in electrical links due to skin effect resistance.

  → The -3dB BW of 12 meter RG55B/U coax is <1GHz.
Frequency dependent attenuation causes ISI.

- Only channel eigen-waveforms result in no ISI.
- Generation and detection of eigen-waveforms is not feasible due to circuit limitations at high frequencies.
- Trapezoidal pulses are used as basis waveforms.
- Higher symbol rate results in more ISI.
Outline

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4-PAM is used for data communication in the serial link.
   → Symbol rate reduces to half that of the binary transmission.
   → Lower symbol rate results in less ISI and reduced HF limitations.
   → Higher level PAM was not used because of:
      limited transmitter swing, minimum detectable signal
      and reflection ISI.

4Sym-->5Sym conversion guarantees clock recovery.

Gray code mapping of levels reduces BER by 20% vs. linear mapping.

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<th>Gray</th>
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Linear

Gray
To cancel the long tail of pulse response, a symbol-spaced pre-emphasis 3-tap FIR filter is implemented at the transmitter.

\[
Vo(n) = Vi(n) - a \cdot Vi(n-1) - b \cdot Vi(n-2) - c \cdot Vi(n-3)
\]

To equalize the high frequency components, a subsymbol-spaced 1-tap high-pass equalizer is implemented at the receiver.

Least square algorithm is used to find the best filter tap weights.
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An Equalization Scheme for 10Gb/s Signaling over Long Cables

Transmitter Design

- 2-b DACs generate the 4 levels, 8-b DACs determine the filter tap weights.
- Each driver generates a filtered symbol independent of other drivers.
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Receiver Design

D0 D1 D2
clk0 clk1 clk2 clk3

3x oversampling shown

Vo(n) = A.Vi(n) + B.(Vi(n) - Vi(n-1))
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Simulated Eye Diagrams

(a) Eye diagram at source
(b) Eye diagram at end of cable
(c) Equalized eye diagram at end of cable
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✅ Conclusion
Conclusion

- Main limitation on transmission rate is limited channel bandwidth.
  - Limited BW causes ISI on trapezoidal pulses.
  - Higher symbol rate results in more ISI.
  - 4-PAM reduces the symbol rate to half that of conventional 2-PAM.
- Two FIR filters are used to cancel ISI.
  - A 3-tap pre-emphasis filter @ transmitter to cancel the long tail.
  - A 1-tap equalizer @ receiver to sharpen the transition edges.
  - Receiver equalizer relaxes the swing and frequency constraints on the transmitter.
- Other approaches to the problem are being investigated.
- Using the above techniques, a data rate of 10Gb/s on a 12meter coax with -3dB BW of <1GHz is achieved in 0.35μm CMOS.
Thanks to:

Maria Hershenson, Stefanos Sidiropoulos, Robert Drost, Ali Hajimiri, Hirad Samavati, LSI Logic and MCC for their assistance.
Transmitter Symbol Generation

Current Pulse

(a) 2-bit DAC Module
(b) Differential Driver leg