Outline

- Review of 100B-T
- Review of 1000B-T
- Review of 10GB-T
- Application of 10GB-T Technology to SAS
Target Media: 100m of Cat5

Pair Usage: 2 Pairs Half-Duplex

Line Code: MLT3
  - Tri-Level (-1,0,+1) with Redundancy for Spectrum Control
  - 1 Bit per Symbol

Line Rate: 125 MHz

Encoding: 4B/5B
  - Run-length Limiting to Aid in Timing Recovery
  - Adds 25% Time Redundancy
1000B-T System Topology

Twisted Wire Pair

TX_H(A) -> H -> RX_S(A)
RX_H(A) -> H -> TX_S(A)
TX_H(B) -> H -> RX_S(B)
RX_H(B) -> H -> TX_S(B)
TX_H(C) -> H -> RX_S(C)
RX_H(C) -> H -> TX_S(C)
TX_H(D) -> H -> RX_S(D)
RX_H(D) -> H -> TX_S(D)

Magnetic Hybrid or Resistive Bridge
1000B-T System Topology

- **Target Media:** 100m of Cat5e (Cat5e specs FEXT)
- **Pair Usage:** 4 Pairs Full-Duplex (2x Pairs, 2x Duplex)
- **Line Code:** PAM-5 (2x Bits/Symbol)
  - Five-Level (-2,-1,0,+1,+2)
  - 2 Bits per Symbol
  - Requires Higher SNR!
- **Line Rate:** 125 MHz (Same)
- **Encoding:** 4-D Viterbi Code (Gains 1.25x)
  - No Time Redundancy => Low Bandwidth PLL for Timing Recovery
  - Takes Advantage of Amplitude Redundancy over 4 Pairs
  - $(5^4) > 2 \times (2^2^4)$ gives Coset Separation
  - 6 dB of Coding Gain
Transmit Spectra of 100BaseTX and 1000BaseT
Cable Attenuation: 24dB @ 100MHz
Reflections due to Impedance Mismatch (Echo)
Near-End CrossTalk (NEXT)
Far-End CrossTalk (FEXT)
Noise Ingress from adjoining cabling (Alien NEXT/FEXT)
1000B-T Noise Environment

Alien NEXT/FEXT

TX_{N}(A) ----> RX_{N}(A)  ----> RX_{S}(A)  ----> TX_{S}(A)
TX_{N}(B) ----> RX_{N}(B)  ----> RX_{S}(B)  ----> TX_{S}(B)
TX_{N}(C) ----> RX_{N}(C)  ----> RX_{S}(C)  ----> TX_{S}(C)
TX_{N}(D) ----> RX_{N}(D)  ----> RX_{S}(D)  ----> TX_{S}(D)

- Black: Attenuation
- Green: ECHO
- Blue: NEXT
- Red: FEXT

03/16/04
10GB-T System Topology

- **Target Media:**
  - 100m of Cat7
  - 55m – 100m of Cat6 Augmented

- **Pair Usage:**
  - 4 Pairs Full-Duplex (Same)

- **Line Code:**
  - DSQ-128 + LDPC (1.5625x)
    - Two-Dimensional 128 Points (Equiv ~11 PAM)
    - 3.125 Bits per Symbol per Pair
    - Requires Higher SNR!

- **Line Rate:**
  - 800 MHz (6.4x)
    - Increases Signal Attenuation by >30 dB

- **Encoding:**
  - (2048,1723) Block LDPC (Same)
    - No Time Redundancy = > Low Bandwidth PLL for Timing Recovery
    - Requires THP (Tomlinson-Harashima Precoding)
    - Provides 9 dB of Coding Gain
10GB-T vs 1000B-T Implementation Complexity

- **DSP**
  - 7-10x Number of Adaptive Filter Taps
  - Must Have FEXT Cancellation
  - Running at Equivalent of 6.4x Speed
  - Necessitates Block Signal Processing
    - FFT’s vs Trivial Time Domain Filters
    - Latency of LDPC Decoder plus Block Processing
    - Latency Spec’d at max 10usec

- **AFE**
  - 10B ENOB ADC at 800MHz vs. 8B at 125MHz
  - 6B DAC at 800MHz vs. 2B at 125MHz
  - Bandwidth of Hybrid, Analog Equalizer, AGC increased by 6.4x
  - Required TX and RX Jitter is 3-5ps rms vs 100-200ps
## 10GB-T vs 1000B-T Implementation Cost

<table>
<thead>
<tr>
<th></th>
<th>100B-T</th>
<th>1000B-T</th>
<th>10GB-T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital/DSP Gate Count</td>
<td>50k (1x)</td>
<td>500k (10x)</td>
<td>10M (200x)</td>
</tr>
<tr>
<td>Digital Power (90nm)</td>
<td>20 mW</td>
<td>150 mW</td>
<td>7.0 W</td>
</tr>
<tr>
<td>AFE Area</td>
<td>1x</td>
<td>2x</td>
<td>5x</td>
</tr>
<tr>
<td>AFE Power</td>
<td>150 mW</td>
<td>350 mW</td>
<td>7.5 W</td>
</tr>
<tr>
<td>Total Power (90nm)</td>
<td>170 mW</td>
<td>500 mW</td>
<td>14.5 W *</td>
</tr>
</tbody>
</table>

* Note: Power numbers are typical only, and are optimistic: other vendors estimates run as high as 20W in 90nm
4x Infiniband Cables and Connectors are:
- Expensive (e.g., 8m is > $200 retail)
- Bulky & Cumbersome
- Limited Reach
  (10m max without integrated equalization)

Solution:
Define a new PHY for external SAS connections
- Leverage Cat6 Ethernet Cables and Connectors:
  - Cheap (e.g., 8m is <$10.00 retail)
  - Flexible & Lightweight
  - Reach of 25m at 10G
Problems for SAS
  • 15w power dissipation probably unacceptable
  • 10usec latency probably unacceptable
  • Cost of 10M gates probably too high

However 100m Reach is Overkill

Can We Leverage 10GB-T Technology for Shorter Reach?

Target New Specs
  • Less Than 4W Power Dissipation
  • 25m reach
  • Sub 500 nsec latency
  • Assume still have to be spectrally compatible with 10GB-T
25m CAT6 UTP results

- Performance gain
  - SNR only 4dB better than 55m CAT6 or 100m CAT6 Screened UTP due to
    - Power Back off to coexist in the same bundle as 10GB-T long reach
    - Cross talk from higher power 10GB-T 55m links

- Complexity and Cost savings
  - 4dB SNR can be used for
    - 7-bit ADC and full power LDPC decoder (from 9-bit))
    - 8 bit ADC and power/area optimized LDPC decoder
  - 10dB Power Back Off saves transmitter power
  - Overall AFE power reduced by factor of 2
  - Reduced DSP filter taps by factor of 2

- Latency
  - Latency gets reduced to 1.5us – 2usec
Conclusion

- Long Reach Power = ~14.5W (Typical, not worst-case)
- Short Reach Power = ~ 7.0W (Typical, not worst-case)
- Did not meet power target of 4W
- Latency Reduced but still above target
- Cost is still prohibitive (10x 1000B-T)
Other Ideas?

- What if targeted 25m of screened Cat6?
  - Reduces Alien NEXT/FEXT, SNR margin improves by another 6.5 dB
  - Still can’t get rid of the LDPC decoder (b/c of the noise averaging on four pairs)
  - But could further reduce power by ~2W; still not there

- What if the PHY architecture was optimized for 25m on UTP Cat6?
  - Constrained to be spectrally compatible with 10GB-T
  - May be able to transmit at higher baud rate
  - Definitely could further reduce power/latency; merits investigation

- What if the PHY architecture was optimized, but also targets 25m of screened Cat6?
  - Definitely opens design space to very low-power, low-latency solutions
Conclusion:

- 10GB-T is not a PHY readily adapted for SAS applications
- The architecture is not optimized for short reach
- Other architectures optimized for short reach on UTP/STP may be able to hit cost/power/latency specifications for SAS

Comments / Questions?