Reducing jitter utilising adaptive pre-emphasis FIR filter for high speed serial links

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Agenda

• Background
• High speed serial links on copper channels
• Frequency dependant distortion
• Deterministic jitter
• Adaptive pre-emphasis
• Pilot signaling and peak detection
• Simulation results
• Experimental results
• Conclusion
Background

- $M$-data lines combined into a high speed serial data line
- Less skew between lines
- Higher bandwidth capability
- Lower pin count and cost of implementation
### High speed serial links

<table>
<thead>
<tr>
<th>Reference</th>
<th>Data rate</th>
<th>Technology</th>
<th>Pre-emphasis</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1]</td>
<td>1 Gb/s</td>
<td>CMOS</td>
<td>None</td>
</tr>
<tr>
<td>[2]</td>
<td>5 Gb/s</td>
<td>CMOS</td>
<td>3-tap</td>
</tr>
<tr>
<td>[3]</td>
<td>10 Gb/s</td>
<td>CMOS</td>
<td>5-tap</td>
</tr>
<tr>
<td>[4]</td>
<td>10 Gb/s</td>
<td>BiCMOS</td>
<td>None</td>
</tr>
</tbody>
</table>


Frequency dependant distortion: Package parasitics

- Introduces frequency dependant devices

Inductance a problem:
- Thicker bond wires
- Use multiple bond wires
- Use tape bonding

\[ L_{\text{Bondwire}} \approx 1 \text{ nH/mm} \]

\[ C_{\text{pad_sub}} \approx 45-50 \text{ fF} \]
Frequency dependant distortion: Copper backplane channel

- Copper channel loss: \( \alpha_{tot} = \alpha_c + \alpha_d \)
- Conductor loss due to skin effect: \( \alpha_c = 8.686 \frac{R_{skin}}{Z_o W} \)
- Where \( R_{skin} \) represents a frequency dependent resistor attenuating the signal:
  \[
  R_{skin} = \frac{\sqrt{\pi f \mu \sigma}}{\sigma}
  \]
- Loss due to dielectric: \( \alpha_d = \frac{\pi f}{c} \left( \frac{\varepsilon_{eff} - 1}{\varepsilon_r - 1} \right) \frac{\varepsilon_r}{\varepsilon_{eff}} \tan \delta \)
Frequency dependant distortion: Copper backplane channel
Frequency dependant distortion: Channel response

- Loss of 50 dB @ 10 GHz
- Severe frequency dependent distortion
Deterministic jitter

- Deterministic jitter:
  - Duty cycle distortion
  - Data dependent jitter
- DDJ caused by this frequency dependent distortion
- DDJ causes uncertainty in pulse edges

\[ f_{DJ}(t) = \frac{1}{2} \left[ \delta \left( t - \frac{D}{2} \right) + \delta \left( t + \frac{D}{2} \right) \right] \]
Pre-emphasis and implementation
Adaptive pre-emphasis

- Conventional pre-emphasis
  - Externally adjustably filter taps
  - Fixed filter taps

- Adaptive pre-emphasis
  - Automatically finds optimal filter taps
  - Does not require a characterised channel

Requires characterised channel
Pilot signaling and peak detection

1. Reset all filter taps
2. Initialise $h(n)$ to maximum
3. Update $h(n)$ by decreasing with LSB
4. Transmit pilot signal $P(n)$
5. Peak detection at receiver
6. Error calculation
7. If Error $< 0$ then Yes, else No

P(0)

P(1)

P(2)

P(3)

Pilot signaling and peak detection

- Representing the channel and FIR filter as impulse response

\[ I_{CHN}(n) = \sum_{k=0}^{N} c_k \delta(n - k) \]

\[ I_{FIR}(n) = \sum_{k=0}^{N} h_k \delta(n - k) \]

- For the first pilot signal:

\[ y(n) = [h_0c_0, h_0c_1, h_0c_2, h_0c_3] \]

- For the second pilot signal:

\[ y(n) = [h_0c_0, h_0(c_0 + c_1) + h_1c_0, h_0(c_1 + c_2) + h_1(c_0 + c_1), h_0(c_2 + c_3) + h_1(c_1 + c_2)] \]
Design and implementation overview

- 50 Ω termination
- CML DFF
- CML XOR
- Filter tap No. 1
- 6-bit current mode DAC
- 7-bit counter
- Comparator
- Pulse generators
- Differential amplifier
- Control logic
- Pilot signal generator
- FIR pre-emphasis driver
- CML multiplexer
- Data in
- CLOCK in
- TX
- RX

7 μA / 0.35 mV

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Department of Electrical, Electronic & Computer Engineering
Kgoro ya Merero ya Mohlagase, Elektroniki & Bointšinere bja Khomphutha
Mathematical simulation results •

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Mathematical simulation results

Ideal data transmitted

Data received without pre-emphasis

Data received with pre-emphasis

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Mathematical simulation results
Circuit simulation results •
Circuit simulation results

(a) Voltage vs. Time

(b) Voltage vs. Time

(c) Voltage vs. Time

(d) Voltage vs. Time

(e) Voltage vs. Time

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Experimental results

- Approximately 1600 transistors
- Area = 0.725 mm²
- 1000 µm x 670 µm
- 340 µm x 160 µm
Experimental results • •

TX
OUT+
OUT-
EOC IN
CLK
DATA
ADJ OUT
Shift IN
Shift OUT
ADJ OUT

RX
IN−
IN+

4 Biasing pads
11 mm

2 Biasing pads
11 mm

1.5 mm
Experimental results

- Transmitter
  - Working with a single filter tap
  - 14% smaller swing
  - Unable to move to other states
- Receiver
  - Pulses generated from TX signals
  - Correct pulse width – too low amplitude to switch CMOS logic
Experimental results

- Pulse generation circuit depends on an RC time constant
  - Used in a feedback loop
  - R determines:
    - Charge rate
    - Discharge rate
  - R → Biased PMOS transistor
    - Achieve constant charge and discharge rate
    - Too slow, hence CMOS output buffer not properly switched.
    - Corner analysis
Experimental results

- Static power dissipation
  - Transmitter
    - Power dissipation = 36 mW
      - Calculated ≈ 32.5 mW (with one active filter tap)
  - Receiver
    - Power dissipation = 19.8 mW
      - Calculated ≈ 18 mW

<table>
<thead>
<tr>
<th>Speed</th>
<th>Swing</th>
<th>Filter taps</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated</td>
<td>5 Gb/s</td>
<td>300 mV</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>10 Gb/s</td>
<td>200mV</td>
<td>6</td>
</tr>
</tbody>
</table>
Conclusion

- Possible “easy” solution for bandwidth problems
  - One button high speed serial link
- Speed tests still need to be performed
- Pulse generation circuit should be redesigned
  - Produce higher integrity signal

- 2 international IEEE conference articles

- 1 local conference article

- International Journal paper submission
Acknowledgement

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