00-103r0 Ultra-320 SCSI
Implementing 1.8x Transmit Pre-compensation

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Transmitter Pre-comp Design Issues

- Amplitude sensitivity to common-mode voltage.
- Effects on driver $Z_{\text{out}}$ and common-mode operating point.
- Feasibility of driving output stages harder.
- Feasibility of larger output stages.
- Slew rate issues.
- Effects on NEXT and FEXT.
- Power dissipation concerns.
- Power efficiency of a boost driver strategy.
- Can we drive more current with existing current-mode drivers?
- Simulation circuit for observing differential $V_{\text{swing}}$ and $I_{\text{cm}}$
  - Without terminator, negation swings smaller by 115mV
LVD $V_{\text{swing}}$ for $V_{\text{cm}}$ swept from 0v to 3.0V
- Currents are highly variable outside of the allowed common-mode range.

![Graph showing $V_{\text{swing}}$ versus $V_{\text{cm}}$ with increased driver amplitude at higher $V_{\text{cm}}$ values.]
LVD $I_{cm}$ for $V_{cm}$ swept from 0v to 3.0V

Currents are highly variable outside of the allowed common-mode range

Increasing driver amplitude
• Usable range (0.855V - 1.645V) $V_{\text{swing}}$ versus $V_{\text{cm}}$
• Linearity degrades with increasing signal amplitude

Increasing driver amplitude $\Rightarrow$ increases non-linearity
• Usable range (0.855V - 1.645V) $I_{cm}$ versus $V_{cm}$
• Linearity degrades with increasing signal amplitude
More drive with existing structures?

- Differential $V_{\text{swing}}$ becomes a strong function of $V_{\text{cm}}$.
- D.C. common-mode current increases (lower $Z_{\text{out}}$ for LVD current mode driver).
- Current sources are less ideal.
- Common-mode noise from 3.3V supply increases.
- Turning on and off a “boost driver” will result in common-mode glitches during driver enable and disable.
- Turning on and off a “boost driver” will result in a high frequency common-mode pulses on the bus.
More drive with existing structures?

- Consider a 11001100 data pattern, on a driver with 1.0mA of common-mode mismatch.
- An 80Mhz common-mode signal will be present on the bus, with levels 1.0mA and 1.8mA.
- Common-mode voltage waveform depends on the local common-mode line impedance and on common-mode reflections off of the terminator.

110011001100  
**differential waveform**

110011001100  
**Common mode waveform**
More drive with existing structures?

- A 68 wire cable can have up to 32 wires with identical common mode waveforms.
- Common-mode cross-talk is not helped by twisting wires.
- EM Radiation may become a concern.
- At 80MHz a 2 meter cable is an efficient antenna.
- Question: Can we allow more common-mode content on the bus?
- Die area increases
- SCSI pads already a large fraction of ASIC die area
Use larger current source structures?

- Capacitance would increase for an “off” driver
  - Estimate an increase of 1.2 to 2.5pF to ground on bus- and bus+.
  - Possible problem with 15pF limit in standard for some vendors.
  - Very likely problem with the tighter capacitance limits in some customer purchase specs for most vendors.
  - Backward compatibility problem (Fast-40 or Fast-80) for back-planes which were marginal with current generation drives.
  - More capacitance would invalidate all eye-diagram data taken to date.
- Some back-plane impedance would drop below 85 Ω with added capacitance.
- Need feedback from SCSI bus integrators on acceptability of higher LVD capacitance.
Thermal issues

- Chip heating will be greater as average drive is increased.
- Power delivered to bus increases by the product of the boost factor (1.5, 1.8, …) and the transition density (100% for a 101010 pattern).
- Larger thermal gradients across die, making line to line timing de-skew less accurate.
- Larger delta temperature between first bits in data transfer and those driven after thermal equilibrium is reached.
- In SCSI targets, LVD power already over half of die power.
- More elaborate thermal management on target PCBs?
- Added power in the pad ring will undermine the chip’s timing performance.
Thermal issues

- When LVD drivers are enabled on the bus, it takes over a millisecond to reach thermal equilibrium.
- Driver temperature also depends on adjacent heat sources (other enabled drivers).
- The temperature difference between REQ/ACK and Data will change over time.

Thermal profile of driver output stages parallel to die edge

- $T = 110$ Data_out After several milliseconds
- Temp is lower at “off” drivers
- $T = 85$ Bus_Free

D5 ON, D6 ON, D7 ON, CRC OFF, ATN ON, BSY OFF, ACK ON, RST OFF
Thermal issues

- CAD tools cannot cope with elements at different temperatures.
- Adding more heat to the pad ring makes timing optimization harder.

![Diagram showing thermal issues]

- Elements match
- Clock wire lengths match
- Q wire lengths match
- Flip-Flop temperatures different

Temperature perpendicular to die edge
Drivers Enabled

T = 85 Bus_Free
The higher swings must be obtained with the same rise and fall times as in U160 products.

Higher slew rates result, and will result in increased ringing at the transmitter.

Higher slew rates will increase the number of stubs which cause problem reflections.

Currently, any misalignment of pull-up and pull-down pre-drivers leads to a common-mode glitch during a data transition. With a “boost driver”, there are 4 pre-drivers to align instead of the current 2 pre-drivers.

Sensitivity of common mode transition noise to the ASIC chip package and board mismatches (between bus+ and bus-) will increase.
• Near End Cross-Talk (NEXT) will increase due to the greater $\frac{\partial I}{\partial t}$ on the driven wire pairs.
• Far End Cross-Talk (FEXT) will increase due to the larger voltage swings being driven.
• Ratio of coupled cross talk signal to quiescent signal will increase by the boost ratio (1.5, 1.8, …).
• Increased intra-chip coupling through power and ground rails from non-constant current driver.
Is a boost driver an efficient strategy?

- Worst case buses have substantial series resistance.
- Net load $R$ is $58 \, \Omega$.
- Adding 1.0mA to driver, adds 58mV to driver (cross-talk source).
- Adding 1.0mA to driver adds only 41mV at far terminator.
- Adding energy at the transmitter is inefficient.

![Diagram of circuit with resistors](image-url)
• “Boost only on transitions” is under consideration.
• Must tightly align edges on main driver and boost drivers.
• Slew rate increases to maintain rise/fall times
• Cross-talk increases
• “Decrement after count = N” is under consideration
• Secondary edge can be slower, reducing cross-talk.
• Slower edge harder to control for common mode transient.
• Edge type 1: (+/-nom level) \(\Rightarrow\) (-/+nom level) transition
• Edge type 2: (+/-reduced level) \(\Rightarrow\) (-/+nom level) transition
• Edge type 3: (+/-nom level) \(\Rightarrow\) (+/-reduced level)
• Timing de-skew can only adjust one class of transition edge.
Summary of Circuit Design Issues

2. Quantify added common mode signals and noise.
3. Quantify EM radiation issues and limits for cables with substantial in-phase common mode signals.
4. Quantify additional capacitance needed.
5. Quantify power increases, and resultant local junction temperatures.
6. Include temperature profile issues in timing budget.
7. Study optimal transmitter pre-comp drive levels.
8. Study possible transmitter pre-comp algorithms.
9. Investigate alternatives to transmitter pre-comp.
Summary of Committee Issues

1. How much more pin capacitance is acceptable for U-320 capable devices with respect to signal integrity?
2. How much more pin capacitance is acceptable for U-320 capable devices with respect to backward compatibility?
3. How much additional common mode content is acceptable on U-320 drivers?
4. What is the amplitude threshold at which an 80Mhz common mode signal become an FCC problem?
5. Consensus is needed on cross-talk measurements and limits.
6. Can transmitter pre-comp be left vendor specific, or can cross-talk interfere with signals driven by the receiver device?
Conclusions

1. A transmitter pre-comp which helps ISI without causing new problems is not trivial.

2. The high multipliers (1.5 - 1.8) are a major departure from existing LVD technology, and add a lot of risk to U-320.

3. There is a high likelihood that side effects of high ratio transmitter pre-comp will cause problems with backward compatibility and multi-vendor interoperability.

4. We should consider other alternatives.