The Transition to PCI Express*
for Client SSDs

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Agenda

- Why PCI Express* (PCIe*) for Client Storage?
- SATA Express Demystified
- Form Factors & Connectors
  - SATA Express card (i.e., Next Generation Form Factor – NGFF)
  - SFF-8639 for Enterprise
  - 2.5” SATA Express connector
  - Enabling inexpensive PCIe cabling
- Software Interface Options
  - The benefits of NVM Express
Why PCIe for Client Storage?

- SSDs can be built that exceed SATA Gen3 (600 MB/s) today

- Enabling SATA beyond 600 MB/s is a long term development effort
  - Single lane scaling beyond ~ 8Gbps is challenging & requires trade-offs
  - Multi-lane SATA requires a new connector and modified chipset SATA controllers to make multi-lane software transparent

- To enable higher speed client SSDs in near term (‘13 / ’14), PCIe is the only choice
  - PCIe has bandwidth lead (1 GB/s with Gen3)
  - PCIe has multi-lane for scalability (x2, x4, ...)
  - Software compatible PCIe SSDs can be built as a single port AHCI device

*PCIe can deliver the performance client SSDs need today.*
What is SATA Express?
SATA Express is pure PCIe. There is no SATA link or transport layer, so there’s no translation overhead – users will see the full performance of PCIe. Perhaps a good way to think about SATA Express is as the standardization of PCIe as an interface for a client storage device in an HDD-type form factor.


- SATA Express **IS** a marketing name
- SATA Express **DOES** define form factors / connectors that support either SATA or PCIe based SSDs/HDDs/hybrids
- SATA Express **DOES NOT** define the software interface
  - AHCI or NVM Express software interfaces may be used
Form Factor & Connector Landscape

- **CEM add-in card** supports high speed SSDs with up to 4 lanes of PCIe.
- **SATA Express card (i.e., NGFF)** is designed for the unique needs of Ultrabook™.
- **SFF-8639** designed for Enterprise use – supports 2.5” PCIe, SAS, SATA.
- **2.5” SATA Express Connector** designed for client SSDs & HDDs/hybrids.

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Optimizing for Ultrabook™

- mSATA is the small FF for SATA SSDs today
- mSATA has significant shortcomings looking ahead to the PCIe transition, specifically:
  - Too thick: z-height ~ 5mm
  - Challenging capacity: difficult to efficiently add NAND packages
  - Limited performance: only one lane
- Ultrabook™ needs an optimized form factor that addresses these issues
  - Path to < 2.5mm z-height
  - Efficient capacity scaling to enable small 32GB caches to 512GB SSDs
  - Scalable speed for future products (up to 4GB/s)
Introducing SATA Express card (also known as NGFF)

- The challenges for mSATA also apply to mobile add-in cards in general (i.e., PCI Express* Mini Card)

- SATA Express card is a common card edge connector family that supports multiple module sizes across different technologies:
  - SSDs/caches, Wi-Fi, WWAN, multi-comms, etc
  - SSD: Lane 0 muxed between PCIe & SATA for transition

- Three families of modules:
  - Socket 1: Wi-Fi only
  - Socket 2: SSD, cache, WWAN, other
  - Socket 3: storage only (SSD, cache)

- Which socket to use?
  - Socket 2: Flexible usage, 2 lanes only
  - Socket 3: 4 lanes for future scaling
SFF-8639 Connector for Enterprise

- SFF-8639 is an Enterprise backplane connector for 2.5” storage (SSD or HDD) covering PCIe, SATA, and SAS
  - 2.5” is critical Enterprise form factor due to hot swap backplanes
  - Dell’s 12th generation servers launched in March included SFF-8639

- SFF-8639 includes 6 lanes, only 4 lanes are used at one time (not muxed)
  - 4 lanes (red below) are PCIe, envisioned to connect to the CPU PCIe lanes
  - 2 lanes (blue below) are envisioned to connect to an HBA/RAID controller or chipset for SAS & SATA support

- Desire: Enable client PCIe SSDs to be used in Enterprise backplanes

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**SFF-8639**

Blue = SAS/SATA
Red = Enterprise PCIe
2.5” SATA Express Connector

• SATA Express is a 2.5” connector enabling transition from SATA to PCIe

• SATA Express includes 2 lanes muxed between SATA & PCIe on the host
  • The host chipset can dynamically or statically select SATA or PCIe
  • If SATA selected, enables two cabled SATA devices to be attached
  • If PCIe selected, one x2 PCIe device may be attached

• The SATA Express device connector is mechanically compatible to SFF-8639, enabling a client PCIe device to be used in an Enterprise backplane
Enabling Inexpensive Cabling

- PCI Express requires a reference clock when using spread spectrum
- A reference clock in a cable causes EMI issues, requiring a more expensive connector/cable solution
  - SATA and USB do not include a clock, SATA cables ~ $0.30 in volume
  - An equivalent PCIe cable with reference clock would add > $1 in BOM
- A PCI SIG ECN is under discussion to address issue, changes:
  - Requires use of large elasticity buffer
  - More frequent insertions of SKIP ordered sets (similar to SATA ALIGN)
  - Requires receiver changes (clock data recovery)
- This feature enables inexpensive PCIe cabling for 2.5” SATA Express, as well as other lower cost external cabled PCIe opportunities
Form Factor & Connector Wrap-up

• SATA Express card (i.e., NGFF) and 2.5” SATA Express connector support SATA & PCIe muxing to ease transition from SATA to PCIe in ’13 – ’15

• SATA Express card standardization ongoing in SATA-IO and PCI SIG, products in ‘13
  • SATA-IO focused on storage usages, PCI SIG focused on wireless usages
  • SATA-IO and PCI SIG collaborating to realize flexible usage model for OEMs
  • Expect SSD/cache SATA-based products in ’13, transitioning to PCIe in ’14

• 2.5” SATA Express connector completing definition in SATA-IO in Q3
  • ECN for independent clock + spread spectrum under development in PCI SIG to enable inexpensive PCIe SSD cabling solution

Get involved in SATA-IO and PCI SIG to drive next generation form factors & connectors for the PCIe storage transition.
Software Interface Options

- IDE was the legacy Parallel ATA programming interface
- AHCI was introduced as the Serial ATA programming interface in 2004
  - Designed for hard drives
  - Key features: Native Command Queuing support, power management features (Slumber, Partial, etc)
- NVM Express is the PCIe SSD programming interface, architected from the ground up for performance
  - Designed for SSDs, with scalability for future NVM technologies
  - Key features: Optimized interrupt architecture for scalable IOPs, large scale parallelism supported, deep queues, etc
- Client PCIe storage transition will be similar to SATA transition:

Flash Memory Summit 2012
Santa Clara, CA
NVM Express Overview

• NVM Express is a scalable host controller interface designed for Enterprise and client systems that use PCI Express* SSDs

• NVMe was developed by industry consortium of 80+ members and is directed by a 13 company Promoter Group

• NVMe 1.0 was published March 1, 2011

• Open source reference drivers for Linux and Windows are available

• Product introductions later this year, first in Enterprise
# Architectural Differences Between AHCI and NVM Express

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<tr>
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<th>AHCI</th>
<th>NVM Express</th>
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<tbody>
<tr>
<td>Uncacheable Register Reads</td>
<td>4 per command 8000 cycles, ~ 2.5 µs</td>
<td>0 per command</td>
</tr>
<tr>
<td>Each consumes 2000 CPU cycles</td>
<td></td>
<td></td>
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<tr>
<td>MSI-X and Interrupt Steering</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Ensures one core not IOPs bottleneck</td>
<td></td>
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<tr>
<td>Parallelism &amp; Multiple Threads</td>
<td>Requires synchronization lock to issue command</td>
<td>No locking, doorbell register per Queue</td>
</tr>
<tr>
<td>Maximum Queue Depth</td>
<td>1 Queue 32 Commands per Q</td>
<td>64K Queues 64K Commands per Q</td>
</tr>
<tr>
<td>Ensures one core not IOPs bottleneck</td>
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<td></td>
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<tr>
<td>Efficiency for 4KB Commands</td>
<td>Command parameters require two serialized host DRAM fetches</td>
<td>Command parameters in one 64B fetch</td>
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<td>4KB critical in Client and Enterprise</td>
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NVMe Delivers Cutting Edge Performance

- NVMe reduces latency overhead by more than 50%
  - SCSI/SAS: 6.0 µs 19,500 cycles
  - NVMe: 2.8 µs 9,100 cycles

- NVMe is defined to scale for future NVM
  - Host controller standards live for 10+ years
  - NVMe supports future memory developments that will drive latency overhead below one microsecond

Chatham NVMe Prototype

Prototype Measured IOPS

Cores Used for 1M IOPs

Linux *
Storage Stack

*Measurement taken on Intel® Core™ i5-2500K 3.3GHz 6MB L3 Cache Quad-Core Desktop Processor using Linux RedHat EL6.0 2.6.32-71 Kernel.
Summary

• PCIe can deliver the performance client SSDs need today

• There is a plethora of form factor / connector options to satisfy unique needs of each unique platform
  • SATA Express card (i.e., NGFF), CEM add-in card, 2.5” SATA Express, SFF-8639

• NVM Express is the best long term software interface for PCIe SSDs

• Get involved in the standards organizations driving the transition
  • SATA-IO: www.sata-io.org
  • PCI SIG: www.pcisig.com
  • NVM Express: www.nvmexpress.org