NVMe® Adoption by SD™ & microSD™ Memory Cards

Sponsored by NVM Express organization, the owner of NVMe specifications
Speaker

• Chair of SWG at SDA since 2018
• Developed SD Express since Nov 2016
• Contributor to SDA since 2012

• Technologist, Systems Design Engineering @ Western Digital
• Contributed for the development of new generations of market leading SD and microSD cards.
• Handled product management and product requirements for various flash memory solutions
• Before joining Western Digital, worked at KLA-Tencor, RSIP, Gyrus-ACMI and Intel.

• Earned M.Sc. in Electrical Engineering from the Technion – Israel Institute of Technology.
Legal Disclaimer

**Forward-Looking Statements**

During our meeting today we will be making forward-looking statements.

Any statement that refers to expectations, projections or other characterizations of future events or circumstances is a forward-looking statement, including those relating to industry trends, standardization plans and any SD Association’s related plans. Actual results may differ materially from those expressed in these forward-looking statements due to various factors. We undertake no obligation to realize these forward-looking statements, which speak only as of the date hereof.
SD Association

• 20 years + created innovative specifications meeting industry and consumer needs

• Strategically maintains the relevance and value of industry leading SD memory cards for consumer and industrial uses
  - ~800 members related to removable cards eco-system (cards, connectors, memory devices and host vendors)
  - A unique structure with Technical, Marketing and Compliance capabilities all working together to meet industry needs
SD Card Specifications Evolution

- **2000**: SD Card Introduced (SD Ver.1.10)
- **2004**: microSD Introduced (SD Ver.1.20)
- **2005**: High Speed mode of 25MB/s (SD Ver.1.10)
- **2006**: SDHC Introduced (SD Ver.2.00)
- **2009/10**: UHS-I mode 104MB/s, SDXC (SD Ver.3.00/3.01)
- **2010**: SDHS Introduced
- **2011**: UHS-II mode 312MB/s (SD Ver.6.00)
- **2017**: UHS-III mode 624MB/s
- **2018/19**: SD Express & microSD Express (PCIe®3/NVMe®) 985MB/s, SDUC (SD Ver.7.00/7.10)
- **2020**: Boot/TCG/RPMB (SD Ver.9.00)
- **2022**: SD Express w/PCIe4x2 ~4GB/s (SD Ver.8.00)

>6 Billion SD & microSD cards sold by 2021*. SD is the de-facto worldwide removable memory card standard

Technology and Market Evolution

➔ Evolving technology trends push memory interface requirements to higher sequential and random performance levels

➔ Evolving removable memory devices with higher performance enables new usage models and market opportunities
Technology and Market Evolution

- Multi-core processors – high processing power with multitasking
- Very high-definition video (imaging) and graphics (gaming)
- Higher speed interfaces – Internal and external (USB-C, PCIe® 4 & 5)
Technology and Market Evolution

- NVMe®/PCIe® is gaining popularity as the de-facto highly capable memory interface standard for the next generation computing, mobile computing, gaming and more.

- The flash memory technology continues to evolve allowing higher performance access and higher capacities in small devices.
Technology and Market Evolution

• Despite growth of cloud services, there is a continuously growing demand for embedded and removable memory at the edge

• 5G Networks – more generated data…

increase data collection at the edge

• High-performance removable cards enable new usage models: system memory expansion, flexible (replaceable) system memory, an application running on extended memory, multiple simultaneous access, and simply faster access
Technology and Market Evolution

➔ Evolving technology trends push memory interface requirements to higher sequential and random performance levels

➔ Evolving removable memory devices with higher performance enables new usage models and market opportunities
New Memory Capabilities Open New Opportunities

• Special Imaging - VRs, 360°, drones, extreme cameras (high performance)

• IoT (low power, security, some with high performance, boot)
New Memory Capabilities Open New Opportunities

- Gaming (high performance, high capacity)

- Mobile computing (very high performance, high capacity)
New Memory Capabilities Open New Opportunities

- Multi-channel Dash cameras and Surveillance cameras
  (multi-stream recording, high capacity, high endurance)

- Extra high-resolution imaging – 8K/12K raw
  (high performance, high capacity)

- New Fast Boot, TCG and RPMB features open new opportunities for cards bound to hosts as either replacing embedded or adding secure applications – like semi-embedded memory for IoT, low-cost compute, gaming
SD Express: Running Towards New Horizons

PCle® and NVMe® Memory Card Interfaces

Delivers performance and advanced protocol required for the next generation of memory-intensive high-performance applications
SD Express Cards

SD Express cards are SD cards that support both: PCIe®/NVMe® interface and the standard legacy SD (UHS-I) interface, allowing backward compatibility.

- SSD grade performances and features
- PCIe/NVMe – a continuously innovated market-wide platform
- Scalable SW stack widely supported
- Bus mastering and reduction ram and cost
- Low power options for mobile implementations
- Leveraging existing investments for card and products manufacturers

PCIe/NVMe like in SSD

SD Memory Card

- Most popular removable card in consumer market
- Enhanced features added: Command Queue, Cache
- SD UHS-I operation mode supported

A small PCIe/NVMe card in reliable small SD form factor including backward compatibility with existing SD UHS-I products

Gaming  Imaging  Automotive  IoT  ….
SD Express Card Main Characteristics

NVMe® + PCIe® interface, in addition to:

- SD interface (UHS-I up to 105MB/s)
- May be initiated directly either from the PCIe/NVMe or SD
- ESD protection up to 4KV on all pads
  - Same as legacy SD card requirements
- Hot Plug In/Removal support is mandatory
- Device Tx coupling capacitors to be placed on the host side
The card may be initiated either through the SD interface or through PCIe®/NVMe® interface.

If SD is initiated first – the host may check if the card support PCIe and switch to PCIe if supported.
PCle® Identification Class

PCle/NVMe® interface is compatible with the existing PCIe/NVMe standard

SD Express card in PCIe mode of operation identifies itself as:

- Standard Non-Volatile Memory subsystem – NVM Express® Interface
- Base Class=01h, Sub Class=08h and Programming Interface = 02h

From PCIe-SIG Spec

<table>
<thead>
<tr>
<th>Base Class</th>
<th>Sub-Class</th>
<th>Programming Interface</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>05h</td>
<td>00h</td>
<td>ATA controller with ADMA interface - single stepping (see Note 2)</td>
<td></td>
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<tr>
<td>05h</td>
<td>02h</td>
<td>ATA controller with ADMA interface - continuous operation (see Note 2)</td>
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<tr>
<td>06h</td>
<td>00h</td>
<td>Serial ATA controller - vendor-specific interface</td>
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</tr>
<tr>
<td>06h</td>
<td>01h</td>
<td>Serial ATA controller - AHCI interface (see note 7)</td>
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<tr>
<td>06h</td>
<td>02h</td>
<td>Serial Storage Bus Interface</td>
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<tr>
<td>07h</td>
<td>00h</td>
<td>Serial Attached SCSI (SAS) controller - vendor-specific interface</td>
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</tr>
<tr>
<td>07h</td>
<td>01h</td>
<td>Obsolete</td>
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<tr>
<td>07h</td>
<td>08h</td>
<td>Non-volatile memory subsystem - vendor-specific interface</td>
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</tr>
<tr>
<td>07h</td>
<td>09h</td>
<td>Non-volatile memory subsystem - NVMeHCl interface (see note 8)</td>
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<tr>
<td>09h</td>
<td>00h</td>
<td>Universal Flash Storage (UFS) controller - vendor-specific interface</td>
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<tr>
<td>09h</td>
<td>01h</td>
<td>Universal Flash Storage Host Controller Interface (UFSHCI) (see Note 6)</td>
<td></td>
</tr>
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</table>

From PCIe-SIG Spec
SD Express Card Spec Evolution

• SD7.0 and SD7.1
  ▪ Introduced the full-size SD Express and microSD Express, respectively, supporting the PCIe® 3.1 interface up to 985MB/s

• SD8.0
  ▪ Introduced the full-size SD Express supporting PCIe 4.0 x2 interface up to 4GB/s
    ▪ microSD with PCIe 4.0 will probably follow *(not yet announced by SDA)*

• SD9.0
  ▪ Introduced TCG, RPMB and Boot features to SD
SD Express Cards Pinout

=1st row: conventional SD in SD mode or PCIe® side band (PERST#, CLKREQ#, REFCLK+/-) in PCIe mode
=2nd row: PCIe 1st lane differential IO’s in PCIe mode – SD 7.X
=3rd row: PCIe 2nd lane differential IO’s in PCIe mode – SD8.0
SD Memory Card Bit Rates
Allowed Power States (Max Power)

- Max Current for each power rail depends on the bus mode
- Supported power states are defined according to the card type

<table>
<thead>
<tr>
<th>Card Type</th>
<th>G3L1</th>
<th>G3L2 / G4L1</th>
<th>G4L2</th>
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<tr>
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<td>1.8W</td>
<td>2.8W</td>
<td>4.0W</td>
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<td>1.44W</td>
<td>2.5W</td>
<td>3.2W</td>
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<td>0.72W</td>
<td>1.8W</td>
<td>2.8W</td>
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<td>1.44W</td>
<td>2.5W</td>
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<td>0.72W</td>
<td>1.8W</td>
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<td></td>
<td></td>
<td>1.44W</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.72W</td>
</tr>
</tbody>
</table>

SD7.x ➔ 0.72 through 1.8W (same power levels as legacy SD spec)
SD8.0 ➔ 2.5W through 4.0W

* PCIe® interface supports low power sub-states
PCle® and NVMe® Interfaces – Test Advantages

Many Bus Analyzers, Protocol Analyzers, Test Suites are in the market…

• SD Express Test Fixtures – for SD7.x
  (SD8 will be released soon)

• Enables Host and Card vendors to test their SD Express’s PCIe interface using standard test equipment

• The set is available for borrow by our members at our approved labs

(GRL and Allion)
SD9 New Features - background

• SD Express opens new opportunities and use cases for SD and microSD memory cards. Some of the potential usages:
  ▪ Chromebooks (as its system memory or memory expansion), drones, surveillance cameras, dash cameras, gaming consoles, virtual reality (VR) headsets/glasses, small IoT modules and more

• The Right-to-Repair legislation in EU and other areas – demands new serviceability requirements and storage is one of the targeted components

• SD memory cards may replace embedded devices in small systems (i.e. IoT, Drones) and SD Express enhances this opportunity for devices that needs higher speed memory

• Use of SD as semi-embedded memory may allow:
  ▪ Reduced memory components
  ▪ Easy memory upgrade and improved serviceability options
SD9.0 – What does it include?

• **Boot**
  - Fast Boot and Secure Boot features give cards the ability to serve as a device’s boot code memory by using a simple and easy fast boot code uploading process, along with secured methods of providing boot code updates.

• **TCG Storage**
  - A secured storage method defined by the **Trusted Computing Group** adding a self-encrypted drive capability.

• **Replay Protected Memory Block (RPMB)**
  - Offers a secured hidden memory accessible only through a secured authentication process and provides a secured write-protect mechanism, secured boot code update and replay protection security mechanism.

• **SD9.0 features provide enhanced features that may open new opportunities for SD cards usually tightly bound to a specific host product as:**
  - Semi-embedded devices replacing the soldered embedded memory (IoT, Chromebooks etc)
  - As a secured memory for OEM applications (ie Gaming, Automotive, VR etc)
How To Implement SD Express Host

SD Express Capable Host

SD Host Controller (at least 3.0)

PCIe Port (Hot Plug Supported)

New

VDD2_ON

PRSNT#

PCIe*/NVMe*/ Interface_Enable

Interrupts

Card Insertion

Card Removal

SD Interface

VDD2_ON

PCIe Tx +/-, PERST#, CLKREQ#

REFCLK+/-, PERST#, CLKREQ#

PCie

SD/PCIe Sel

4-bit Signal Switch for 1st row Signals

New

SDCLK

SDCMD

DAT[3:0]

Supply control

VDD1_ON

VDD1

3.3v

VDD2

1.8v

SD Express Card Socket

VDD2_ON

Card Detect SW

PCIe®/NVMe®_ Interface_Enable

VDD2_ON

New

New

PCIe

Second Row

First Row

Flash Memory Summit

nvm EXPRESS
SD Express Host - other possible methods
SD Express Host - other possible methods

PCIe®/NVMe® Host Direct Connection to SD Express

SD Express Card Socket

SD Interface

PCIe/NVMe Interface
A glimpse into the future

- SD Express Cards ➔ New speed classes
- microSD Express Card’s natural evolution ➔ PCIe® 4.0 support
- SD Association plans to open the org for specifications of new FF’s with or without SD interface
Thank You

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Questions?
SD Express and SD 9.0 Materials Freely Available

SD Express Host Implementation Guideline

Update to existing SD Driver –
As explained in Implementation Guideline

SDA Brochure – updated for SD9.0

Whitepapers:
- SD Express Memory Cards with PCIe® and NVMe™ Interfaces
- SD Express and microSD Express Cards: The Best Choice for Your Future Product Designs
- Boot, TCG and RPMB – The New Security Features Introduced in SD 9.0

... and more at https://www.sdcard.org/