



## SD Express Cards with PCIe® and NVMe™ Interfaces

White Paper | June 2018

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## Executive Summary

In June 2018, the SDA released SD7.0 introducing two major new functions:

**SD Express:** Incorporates the PCIe® and NVMe™ interfaces, known worldwide for its high bandwidth and low latency storage, into SD memory cards alongside legacy SD interfaces

**SD Ultra Capacity (SDUC):** Extends the potential maximum SD memory card capacity from 2TB to up to 128TB

In anticipation of the next generation of high performance mobile computing requirements, adding the PCIe technology and the advanced NVMe protocol delivers faster access to data files than today's SD platform, achieving speeds of up to 985 MB/s that support content applications and data generated by highly capable system architectures. This new protocol allows SD Express memory cards to serve as *removable Solid State Drives (SSD)*.

These speeds are essential for high-resolution content applications such as: super-slow motion video, RAW continuous burst mode photography, 8K video capture and playback, 360 degree video, speed hungry applications running on cards and mobile computing devices, ever-evolving gaming systems, multi-channel IoT devices, numerous automotive storage needs, to name a few.

In addition to many performance advancements, SD Express maintains the long-standing advantage of SD's backward compatibility and interoperability. The PCIe interface was added in addition to the existing SD (UHS-I) interface, allowing a card with SD Express to operate interchangeably in new SD Express capable hosts as well as billions of existing SD host products in the market today.

# The Insatiable Need for More Capacity, Performance and Modern Protocols

In the SD 7.0 specification, the SDA extended the limits of traditional SD memory cards' capacity to meet the ever-growing needs of users everywhere. The new SDUC surpasses SDXC's 2TB maximum, allowing SD cards to store data up to 128TB, regardless of form factor, either micro or full size, or interface type including UHS-I, UHS-II, UHS-III or SD Express. However, the SD Express card with its PCIe and NVMe interfaces is the revolutionary addition to SD7.0 specification.

A few major market conditions have raised the requirements for removable memory cards with higher speeds, improved protocols and interfaces:

## Applications Demand Capacity

- Demand for higher capacity memory grows continuously with the advancement of applications such as higher resolution videos, 3D graphic games, social media, drones, action cameras, 360° cameras, virtual reality, and streaming video content that is stored on SD memory cards for offline usage.
- Higher capacity cards require ever-faster speeds to move content quickly.

## Evolving Mobile Computing Infrastructure

- Growing performance levels of input/output (IO) communication interfaces with either wireless such as Wi-Fi/Wi-Gig, or wired such as USB 3.
- Rapid developments in application processor technology, including multi cores, speed, RAM increases, etc.
- Embedded storage is transitioning to more advanced protocols. opening new opportunities, including UFS, PCIe and NVMe.
- These evolving technology trends push removable memory interfaces requirement for additional higher random and sequential performance requirements.

## Client Computing, Imaging and Automotive

- Client computing is moving rapidly from SATA to PCIe Gen3, multi-channel and Gen4.
- Various memory related emerging markets require high-speed memory interfaces and multi-channel operations. A sample of markets include autonomous vehicles and connected cars with multi sensors data collection and processing, multi-channel video capture for IoT devices.
- The imaging market is already trending toward UHS-II/III or PCIe.

These evolving technology trends signal a demand for memory cards with high performance sequential and random access provided by SD Express.

The major operating systems now allow applications to start-up directly from an SD memory card. SD memory cards may now be used in Google Android devices as embedded memory or extended system storage for video/audio content as well as for storing and running apps. Running Android applications from a card requires higher random performance and sequential performance capabilities.

In 2016 and 2017, SDA introduced the Application Performance Classes A1 and A2 to ensure a certain level of random performance of SD memory cards under given conditions. While the sequential and random performance of the existing SD interface may be good enough for most of today's uses of cards, new applications will undoubtedly require ever-higher performance levels that can be achieved with SD Express using its added higher performance PCIe and NVMe interfaces.

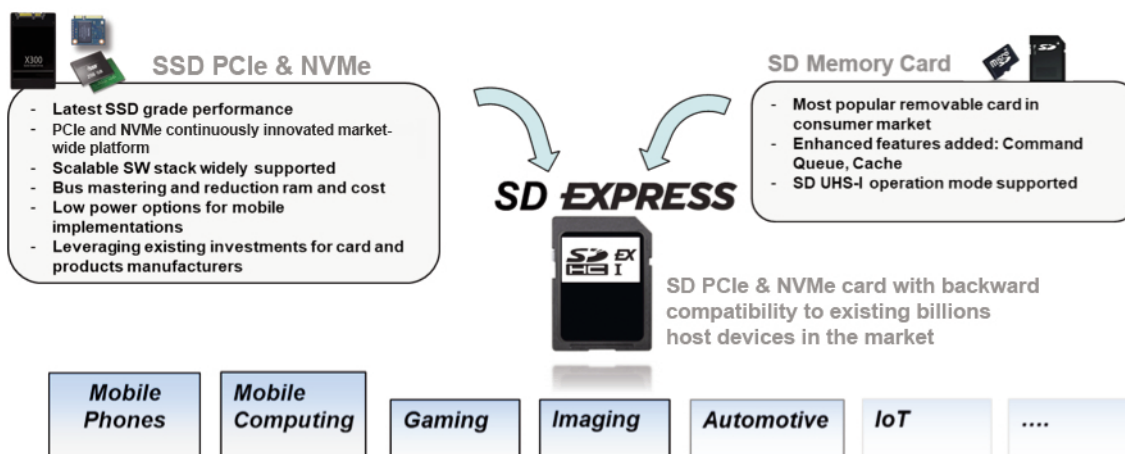


# SD Express with PCIe and NVMe Benefits Everyone

SD Express includes a UHS-I interface with the PCIe and NVMe interfaces. Use of PCIe Gen3 and NVMe v1.3 with SD was defined, for example initialization process, pin allocation etc., but the general idea is utilization of the existing well-known and familiar protocols defined by PCI SIG and NVMe Forum. By relying on successful protocols already in the marketplace, the SDA gives the industry an advantage by leveraging existing test equipment and saving in development processes. When companies use existing building blocks and existing designs, this translates to cost savings and an improved bottom line.

With existing support of major operating systems and popularity of drivers supporting PCIe and NVMe, the market adoption of SD Express should be easy.

Figure 1 shows the strength of SD Express by combining PCIe and NVMe with SD:



# Understanding SD Express

SD Express is:

- Same SD trusted full sized form factor was introduced, first, with SD7.0
- The full size SD Express card uses the same pins and connectors as defined for existing SD UHS-II. See Figure 2.
- Features new PCIe and NVMe interfaces. The differential interface of single lane PCIe Generation 3 is using the same pads as of the SD UHS-II differential interface pads found in the second row of pins. Next, PCIe REFCLK along with the side band signals CLKREQ# and PERRST# are shared with the existing SD UHS-I, leverage the first row of pins.
- The first row is also the SD UHS-I interface, delivering full backward compatibility and interoperability with billions of existing SD host devices.
- SD Express will not support UHS-II interface.
- SD7.0 specification defines a full size form factor using two power supplies, a traditional 3.3 volt and 1.8 volt. SD7.0 also allows an optional 1.2v supply, for future form factors that requires additional pin #18. The future optional 1.2 volt will allow additional power/performance optimization.

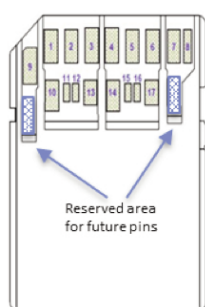


Figure 2 –SD Express full sized card pin layout

Figure 3 shows the bit rate performance levels of SD Express:

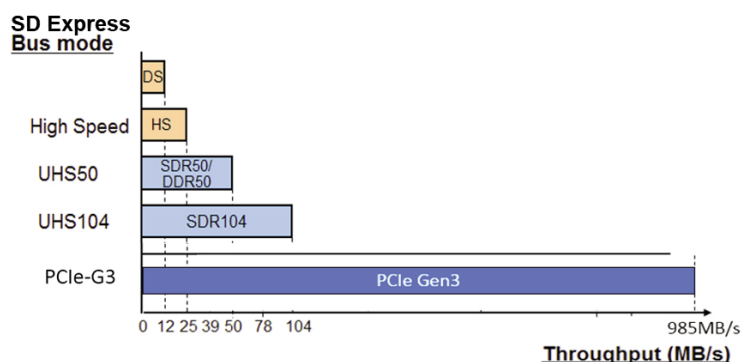


Figure 3 - Bit rates for SD Express memory cards

The SD Express interface and initialization process is flexible, allowing an SD Express compatible host to initialize the card through either legacy SD interface, or PCIe interface. The initialization through SD legacy is highly recommended, since it allows advanced notice about the card's capabilities and saves redundant re-iterations of non-supported card or protocol.

SD Express identified to SD Express PCIe and NVMe host as "Standard NVMe device" (Mass Storage controller→Solid State Controller→NVM Express device). Therefore, standard NVMe drivers may access the SD Express card.

Cards using SD Express may consume up to maximum of 1.80 Watts from the host, representing the accumulated wattage from the two power supplies.

The following SD protocol features are supported partially by the PCIe and NVMe interfaces, assuming use of NVMe version 1.3. In the future, NVMe may fully support these features:

- Password Lock/Unlock: Card may be password locked/unlocked only through the legacy SD interface. Locked card does not allow access to the memory neither through the SD nor through the PCIe and NVMe interface.
- Write Protect features: Card may be set to write protected mode through legacy SD interfaces. A write-protected card does not allow any write operation to it neither through its SD nor through the PCIe and NVMe interfaces.

The following traditional SD features are not supported through the PCIe interface:

- SD CPRM Security: If SD Express host accesses card through the PCIe interface that includes CPRM encrypted files, it will read them as encrypted data, which is the same result when inserting the card to any SD host that does not support CPRM.
- Speed Classes: Speed Class, UHS Speed Class and Video Speed Class are not supported or necessary through the PCIe interface.

## New Options for System Developers

PCIe and NVMe standards are highly capable protocols enabling various features and choices for system implementer to use. Here are a few examples of potential usage of PCIe and NVMe. Note that the given capabilities are not related to SD Express but to the nature of PCIe and NVMe capabilities.

### Bus Mastering

- Bus mastering (first-party DMA) is natively supported in PCIe, see Figure 4.
- This feature allows inter chip communication between devices.
- For example, a modem can send IO requests directly to the storage without any help from the Application Processor (AP):
  - AP can move to low power mode and save overall battery life
  - Better latency path from modem to storage device

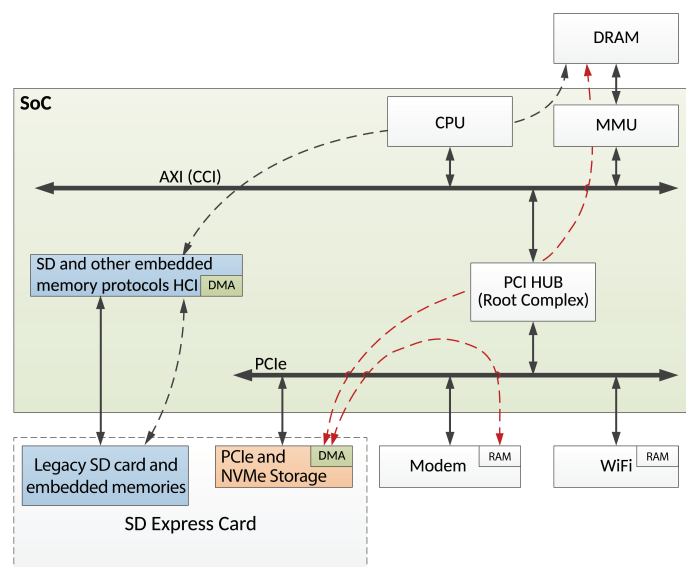


Figure 4 – Bus mastering of PCIe

### Multi Queue Support, Without Locking Mechanism

- NVMe can have a dedicated command queue in DRAM for every CPU core, see Figure 5.
- Other legacy embedded memory interfaces has one command queue in the Host controller.
- Synchronization and locking are needed in legacy protocols to mutual access the single queue.
- Legacy interface's host controller is a system bottleneck in the architecture .

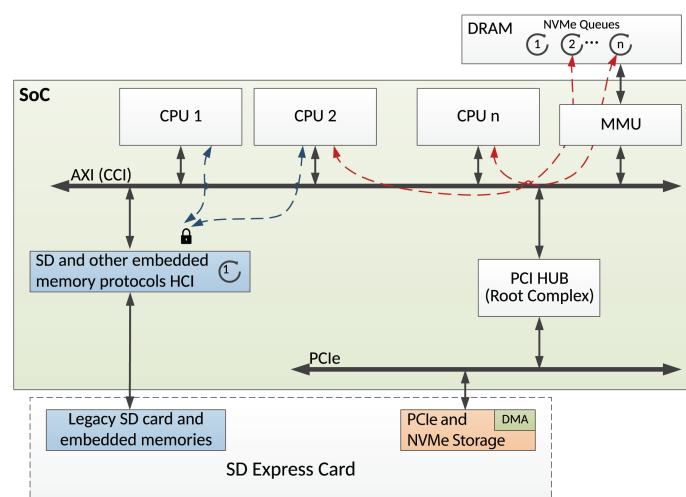


Figure 5 – Host controller synchronization lock vs Multi Queue support of NVMe

## Host Memory Buffer (HMB)

- High performance architecture usually requires extra controller resources. For example, embedded SRAM which is quite expensive compared to DRAM, see Figure 6
- HMB and Bus Mastering native NVMe and PCIe features are most useful in significantly improving storage performance with limited overall cost penalty. This is accomplished by using host DRAM resources as direct extension of controller internal RAM.
- The allocated DRAM size is subject to host device policy
- Important: In the future, as the SD Express becomes even faster, the use of the DRAM vs SD card's memory may become system flexible. Instead of using the host's DRAM by the card saving card's SRAM, the SD Express card may become an extension of the host's DRAM, using the fast SD Express flash memory as host's resource, saving DRAM.

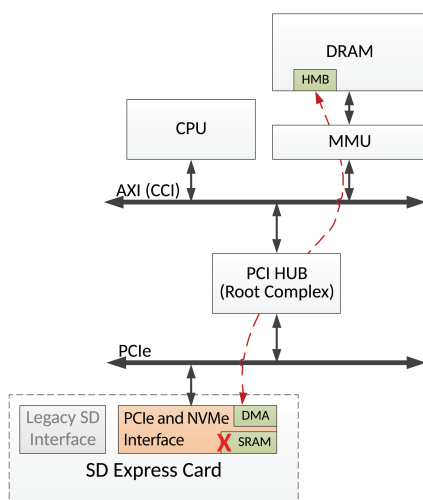


Figure 6 – Host memory buffer description

## Tips for Host Product Manufacturers

With use of the PCIe and NVMe interfaces, host product manufacturers can now consider using existing SD interface and PCIe and NVMe building blocks to utilize the new SD Express host interface development.

The only challenge with this design is the switching mechanism and/or pullups/pulldown IO controls of the shared signals – REFCLK, CLKREQ# and PERRST#. This IO control circuit may be quite simple; however, it requires thorough study and understanding of both interfaces in each stage of the initialization process and normal operation of each of the two modes.

## Consumer Impact

Consumers will continue matching the card to their product for best performance. Manufacturers will use SDA symbols and logos on the product, its packaging and in the owner's manual). All SDHC, SDXC and SDUC memory cards with SD Express will have SD UHS-I interface and symbols allowing read and write operation on legacy SD interfaces. However, in order to reach maximum performance using its PCIe and NVMe interfaces, the host must support SD Express. Therefore, matching the SD Express host to and SD Express card is required to enjoy the best performance and the best user experience.

In Figure 7, the SD Express marking is as follows:



Figure 7 - Various combinations of host and card marks

Card types and expected maximum performance capabilities are outlined in Figure 8:

Card type	Host type	SD - up to UHS50	SD UHS104	SD-UHS-II	SD-UHS-III	SD Express
SD - up to UHS50		Up to 50MB/s	Up to 50MB/s	Up to 50MB/s (basic SD interface)	Up to 50MB/s (basic SD interface)	Up to 50MB/s (basic SD interface)
SD - UHS104		Up to 50MB/s	Up to 104MB/s	Up to 104MB/s (basic SD interface and if host supports it)	Up to 104MB/s (basic SD interface and if host supports it)	Up to 104MB/s (basic SD interface and if host supports it)
SD-UHS-II		Up to 50MB/s	Up to 104MB/s (if supported by card)	Up to 156MB/s (Full Duplex) Up to 312MB/s (Half Duplex)	Up to 156MB/s (Full Duplex) Up to 312MB/s (Half Duplex if supported by host)	Up to 104MB/s (basic SD interface and if host supports it)
SD-UHS-III		Up to 50MB/s	Up to 104MB/s (if supported by card)	Up to 156MB/s (Full Duplex) Up to 312MB/s (Half Duplex if supported by card)	Up to 624MB/s (Full Duplex)	Up to 104MB/s (basic SD interface and if host supports it)
SD Express		Up to 50MB/s	Up to 104MB/s (if supported by card)	Up to 104MB/s (basic SD interface and if host and card support it)	Up to 104MB/s (basic SD interface and if host and card support it)	Up to 985MB/s (PCIe Interface)

Figure 8 - Maximum Performance of SD Express host and card combinations

## Summary

With SD memory cards used for higher capacity as well as speed intensive applications and massive storage for devices of all types, there is a growing need for a big jump in random and sequential performance levels as well as more modern protocols. The SD Express feature introduced in SD7.0 includes the added PCIe and NVMe interfaces enabling new opportunities for SD memory cards and opens a whole new world of uses while keeping backward compatibility to billions of existing SD host. The SDA made adoption easier thanks to allowing existing knowledge by using given building blocks and available test equipment.