Mobile Device Innovations: Application Performance Class Expansion and New Low Voltage Signaling for SD Memory Cards

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Executive Summary

In February 2017, the SD Association (SDA) released the SD 6.0 specification with a variety of new functions that may be implemented in SD memory cards. While complementary, each of the new features may be used independent of the others: Application Performance Class 2 (A2); Command Queuing, Cache and Self-Maintenance, new protocol functions that allow performance improvements; Ultra High Speed III (UHS-III), providing up to 624 megabytes per second transfer rates; and Low Voltage Signaling (LVS), allowing SD memory card operation with hosts that support only 1.8V signaling.

This document provides the background and details on the new App Performance Class A2 and related new features as well as LVS. UHS-III is explained in a separate document available on our website.

In November 2016, the SDA released the SD 5.1 specification to answer new market needs with Application Performance Class, introducing Application Performance Class 1 (A1) (see related white paper) as its first and basic class. The new A2, introduced in SD 6.0 specification, is the next class level and provides more flexibility in the market for cost-performance optimization per product or application need and various market segments. The newly introduced functions of Command Queuing, Cache, and Self-Maintenance are SD protocol functions that enable higher performance levels.

LVS introduces new 1.8V signaling to let an LVS host device start in UHS-I/1.8V mode directly, without traditional 3.3V initialization process after power up. The LVS card is usable by both conventional hosts connected by 3.3V signaling and LVS hosts connected by 1.8V signaling. An LVS host cannot use conventional cards except when UHS- II mode is available using UHS- II cards. This new feature lets product manufacturers take advantage of new SOC designs enabling smartphones to offer higher performance with less power consumption.

As with all SD features, consumers are encouraged to match their SD memory card's performance level to their product's requirements.

This document provides the background and details on the new App Performance Class A2 and related new features as well as LVS. UHS-III is explained in a separate document available on our website.

Background on Market Situations

General

Most of today's mobile operating systems (Win-Mobile and Android) allow application data to be saved on removable cards or run applications from cards. When Google released Android Marshmallow in 2015, it expanded microSD memory card support by offering Adoptable Storage Devices, which allows users to run applications from the installed memory card. It's helpful to know there are some basic performance requirements based on a combination of random and sequential memory access that optimize user experiences when using memory cards as storage and/or to run applications.

Product manufacturers may use the Application Performance Class (App Performance) with its associated symbol to define a certain level of minimum performance for customers, ensuring the SD memory card delivers the right performance with their products. This also helps consumers choose the proper card for their product at the point of sale.

The App Performance Class 1 (A1) was introduced in SD 5.1 specification to answer these evolving market needs by indicating a minimum basic level of performance. While today's A1 cards may meet most users' and application developers' needs, there may be a need for cards in the market with higher performance capabilities designed to meet higher host/product performance needs to give users and product developers more flexibility to optimize cost-performance needs for their product and applications requirements for their intended market segments.

Therefore, SD 6.0 specification introduces App Performance Class 2 (A2) with higher minimum random write/read performance levels and a new set of features that enables memory cards to achieve these higher levels. In short, SD memory cards are now used for running applications, and this use requires a combination of higher random + sequential performance.

The SDA initiated new SD specification enhancements to meet market requirements by:
- Standardizing a common language for consumers and product manufacturers, allowing best utilization of specific products with related best cost-effective card type
- Introducing the new concept of Application Performance with SD 5.1 specification, along with the first App Performance Class named A1
- Defining the next level of minimum performance named A2 with SD 6.0 specification, allowing users to match with the best cost-performance needs
- Improving SD memory card protocol, enabling higher random and sequential performance, with SD 6.0 specification

Application Performance Class 2 – A2

The Application Performance Class standard defines:
- App Performance symbol for use on cards, packaging and manuals
- Assured combination of minimum random + sustained sequential performance levels under certain conditions

App Performance Class SD memory cards

App Performance Class A1 and A2 SD memory cards must meet the performance measures as given in Table 1.

Application Performance Class	Pictograph	Minimum Random Read	Minimum Random Write	Minimum Sustained Sequential Write
Class 1 (A1)*	A1 APP PERFORMANCE	1500 IOPS	500 IOPS	10MBytes/sec
Class 2 (A2)**	A2 APP PERFORMANCE	4000 IOPS	2000 IOPS	10MBytes/sec

*The detailed preconditions and test are defined in SD Physical Spec ver. 5.1.
**The detailed preconditions and test are defined in SD Physical Spec ver. 6.0.

Table 1 Application Performance Classes and their related minimum Input-Output access Per Second (IOPS)

Note that the given performance levels are assured under the conditions defined in SD 5.1 specification for A1 and SD 6.0 specification for A2. Any SD memory card that indicates itself as an A1 or A2 card by the logo and in the internal SD Card Status register must meet the defined specification requirements. Please refer to the SD 6.0 Specification for further details. Figure 1 shows the new App Performance symbols in both short and long forms.
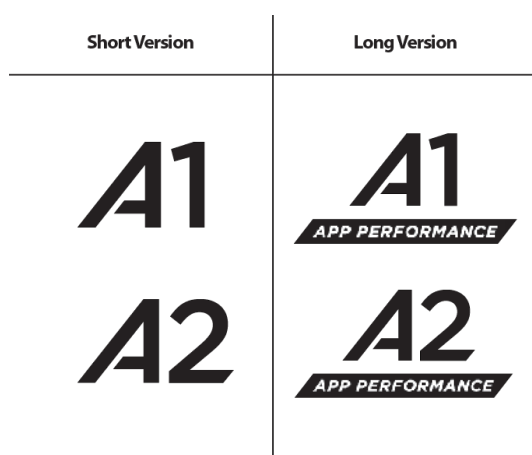

Short Version	Long Version
A1	A1 APP PERFORMANCE
A2	A2 APP PERFORMANCE

Figure 1 App Performance Logo

What is expected from product manufacturers and consumers?

Similar to the concept of Speed Classes, it is recommended that consumers choose the SD memory card with the Application Perf Class that is recommended by their product manufacturers, as indicated on the product, package or user manual.

There is an important new expectation for product manufacturers seeking A2 designation. While there was no need to support any new SD protocol functions for A1, A2 products must support the new functions of Command Queuing and Cache. Therefore, before referring customers to A2 cards, manufacturers must make sure that their product supports these functions.

Product manufacturers supporting SD memory cards and requiring certain minimum random and sequential performance levels that are satisfied by either A1 or A2 may check for the desired Application Performance Class level as follows:

1. Check the Application Performance Class type of the SD memory card in the SD Card Status and confirm whether it matches its requirement level.

2. The host may also perform an internal benchmark test and check for the absolute execution time to qualify the memory card. If it matches or exceeds the execution time expected from the corresponding Application Performance Class expected by the host, the card should be accepted for use.

An important note about A1 cards: The performance level that SD memory cards indicate during the Android's Card Adoption process is designed[1] to allow A1 SD memory cards to pass, but they cannot be guaranteed by Android. The reason is that the Android benchmark test is dependent on the device environment (i.e. clock speed, background apps, etc.), not only the memory card. Therefore, the SDA highly recommends that product manufacturers first test their devices with A1 SD memory cards before they would recommend their customers to use A1 SD memory cards, assuring acceptance during the card adoption process.

Note that in any case, an SD memory card indicates Application Performance Class support, it shall meet the SD standard specification for Application Performance Class conditions as defined in SD 6.0 specification.

[1]Refer to Application Performance Class White Paper on the detailed conditions for the Android Benchmark passing A1 cards

New SD protocol functions for A2

SD memory cards have been progressing in two aspects: greater storage capacity and faster bus speed. Figure 2 shows the progress of SD bus interface throughput. As SDA propels higher storage capacity and faster bus speed specifications, it enables applications to manage big data with an SD memory card.

Following are the three new features:

Command Queue
- Contributes mainly to random read performance
- Multiple tasks can be handled at one time with arbitrary order
- New tasks can be assigned during data transmission
- New commands (CMD43,44,45,46,47)

Cache function
- Contributes mainly to random write performance
- Card may use higher speed volatile memory to cache the host data during memory card access operation
- Data loss is allowed if it's not moved to non-volatile storage
- Cache flushing is triggered by host followed by up to 1 second of card's busy time.

Self-Maintenance
- Contributes to better memory access performance
- Allows internal background data management
- Initiated by card when there are no pending commands
- Initiated by host based on the maintenance event by the card

What is Command Queuing?

It is assumed that memory card performance may be improved if early information about the intended data transfers planned by the host is provided. By having such information, the card may optimize its internal memory management and even execute the commands in a different order than issued by the host. As such, a related performance improvement can be mainly seen in small random accesses.

Queue depth is the total number of commands that may be queued at one time. SD supports a queue depth of 32, which is quite common in similar standards (32 independent RD or WR commands without requiring any specific order of execution).

The Command Queuing (CQ) function defined in SD has met the following concepts:
- Minimum changes to the SD protocol (including state machines)
- No added pins to the I/O interface
- Backward compatibility to the legacy SD standard
- Functional similarity to existing, commonly used higher layers of CQ management, allowing re-use of widely implemented drivers in the industry for similar applications

The legacy SD protocol suffered from a command response type of protocol. It means that every command sequence looks like the following (see Figure 2). Host issues command → card response → data transfer (if associated) follows. The host is not allowed to issue the next operational command (except status) until the current command completes execution.
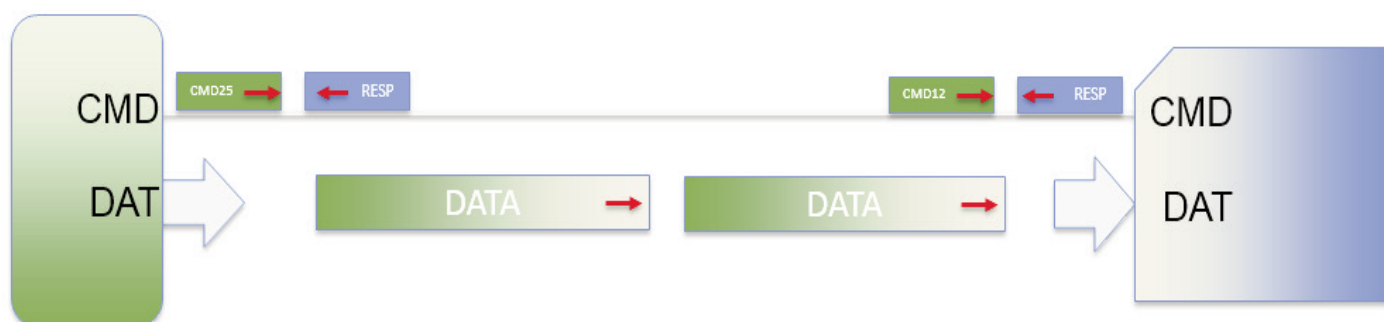

Figure 2 Legacy SD command response concept

Mobile Device Innovations: Application Performance Class Expansion and New Low Voltage Signaling for SD Memory Cards
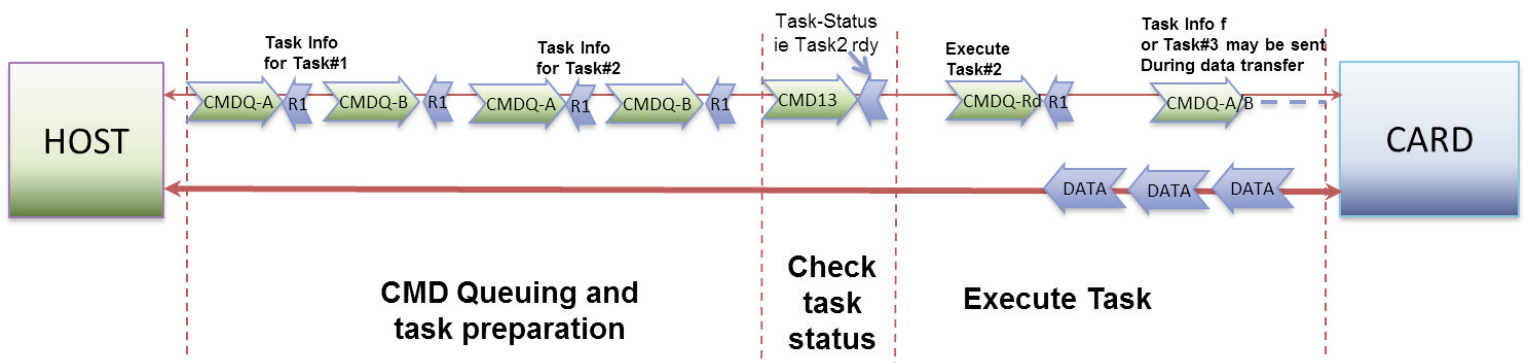
Figure 3 Flow example for data transfer with Command Queue

Such method eliminates delivery of any advanced information on the next command. SD bus interface is not efficiently utilized in this method.

The new CQ mechanism allows the SD memory card to accept several commands in a series (without their associated data) and execute them (with the data) whenever the memory card is ready. During the data transfer, additional commands may be sent to the card as long as the maximum number of queued commands does not exceed 32. Figure 3 shows an example of queuing two commands in a series, wherein the SD memory card executes the command that the card is ready and then transfers the third command during the data transfer of the ongoing executed command.

The advantages of CQ are:
- Advanced information on intended commands is provided to the card
- The card may manage and optimize its internal operations to prepare for the various commands in advance
- New information on next commands may be sent to the card during current command execution and during data transfer

Cache function

In order to overcome the relatively limited write speed operation of the flash memory, the Cache function allows the card to accumulate the data accepted by the host in a high-speed volatile memory (RAM) first, release the busy line and perform the actual write to the non-volatile memory in the background or upon flush command (refer to Figure 3).

Card may cache the host data during write and read operation:
- Cache size is card-implementation specific
- Flushing of contents stored in cache shall not take more than 1 second.
- Supported by OSs today (for embedded)
- Easy to implement on cards

Data loss is allowed if the data is not moved to non-volatile storage. In order to minimize data loss, the flush cache feature shall be supported and implemented by host before power down operation. The data is not guaranteed as long as the flush operation is not completed.
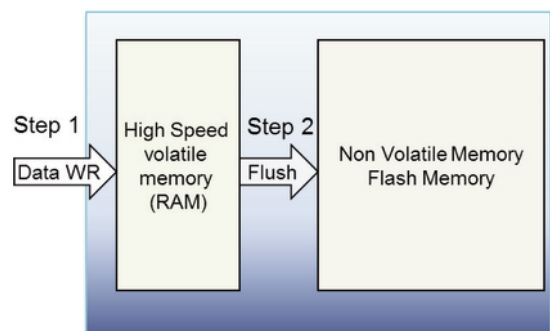

Figure 4 Data transfer with Command Queue – Example of flow

Self-Maintenance function

The Self-Maintenance operation of the card is an internal data management operation done on the memory to improve its performance (i.e. defragmentation). There are two cases when the Self-Maintenance may start its operation: card initiated and host initiated.

Card-Initiated

Card-initiated operation allows the SD memory card to perform internal maintenance operations while the host bus is idle. When a new command is received, the card must ensure that new command is serviced without violating SD standard timing (Read Command, 100ms; Write Command, 250ms).

Power-off notification function support is mandatory to ensure graceful shutdown, allowing the host to tell the card in advance about its intention to power off.

Host-Initiated

In host-initiated operation, the SD memory card indicates to the host the self-maintenance urgency level through four levels of urgency. The memory card could notify the host via Card Status when it's at middle or urgent level. Maintenance operation is triggered by the host via a specific command.

After the card's Self-Maintenance is initiated, it sets the busy line (prg state) for up to 1 second and then moves back to normal (tran state).

The self-maintenance urgency level may still be the same after a maintenance operation.

Low Voltage Signaling – Another new SD 6.0 specification feature

Silicon foundries have been fine-tuning system on a chip (SOC) integrated circuit technology for use in devices such as smartphones, with recent progress pushing the powerful chips to the 7-10 nanometer range. These SOC developments will enable smartphones to offer higher performance with less power consumption. Designing SOCs, which use finer processes and lower voltage supply, is easier when restricted to 1.8V signaling.

SD memory cards have used a 3.3V signaling interface since the SD standard was introduced in 2000 and through SD Specification 3.0, when 1.8V signaling was added with the UHS-I bus mode, the ultimate removable single-ended interface. UHS-I adopted 1.8V signaling because it is suitable for faster rise/fall time and lower electromagnetic interference. However, UHS memory cards still require 3.3V signaling to initialize the card so hosts need to support 3.3V signaling, too. UHS-II is another low-voltage interface option for host devices that implement an SD Connector with a second row and offer a 1.8V power supply. Therefore, UHS-II is a solution for higher performance applications which require more than UHS-I performance.

Now, SD Specification 6.0 introduces the Low Voltage Signaling (LVS) memory card that may support either 3.3V or 1.8V signaling with an auto detection mechanism of the host's operating signaling level. The new specification allows LVS cards to be backwards compatible to conventional 3.3V signaling hosts. It coincides with new SOC designs for LVS host devices that can start in UHS-I 1.8V mode directly after power up on the LVS card.

Low Voltage Interface Supported Card Types

LVS memory cards are compatible with conventional host devices, and may also support UHS-II and UHS-III host devices. Table 2 shows LVS card types defined by SD Specification 6.0.

LVS Types	Description
LV50	SD Memory cards supporting 50 MB/sec UHS-I Card
LV104	SD Memory cards supporting 104 MB/sec UHS-I Card
LV156	SD Memory cards supporting 156 MB/sec UHS-II Card
LV624	SD Memory cards supporting 624 MB/sec UHS-III Card

Table 2: LVS Card Types

LVS cards are designed to start command/response communication either with 3.3V signaling modes or 1.8V signaling modes. An identification sequence after power up, called LVS Identification, is used to select either signaling mode. LVS cards can identify LVS hosts via the LVS Identification by checking the specified clock period on SDCLK pin and signal lines level at clock edge. If an LVS host is identified, the LVS card selects 1.8V signaling; otherwise, it selects 3.3V signaling. An LVS host can identify an LVS card by checking the specified card signal level during the LVS Identification.

Host and Card Combination

Figure 5 shows host and card combinations:
- The LVS card is fully backwards compatible on connection. It is usable either by conventional hosts using 3.3V signaling or by LVS hosts that operate only with 1.8V signaling.
- An LVS host may operate only with the new LVS cards. However, conventional UHS-II cards may also operate if a UHS- II mode is available by the host and chosen by the user.

An LV symbol identifies LV Interface supported SD products for users. An LVS host will bear the LV symbol somewhere on the product, package or manual. LVS host device users need to use a corresponding SD memory card with an LV symbol for their LV-marked device. On the other hand, an LVS card is usable by any host, including hosts that do not carry the LV symbol.
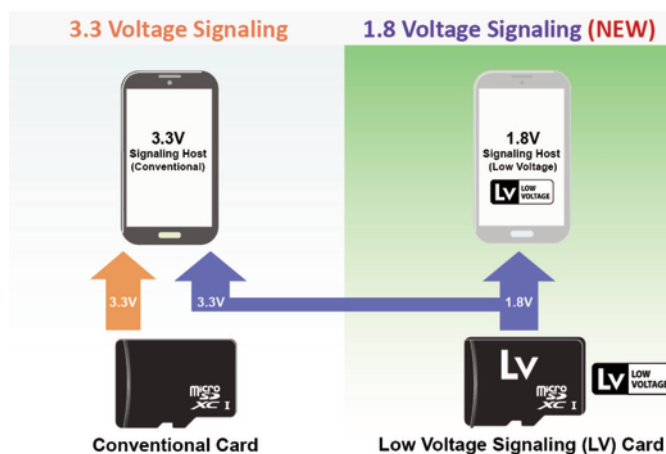

Figure 5: Host and Card Combination

Summary

Mobile use of SD memory cards continues to be robust and innovations found in SD 6.0 specification give the market more flexibility and capability. With the expanded usage of SD memory cards for storing applications and application data, there is a growing need for a combination of random and sequential performance levels. This demand becomes even stronger with the introduction of Android's Adopted Storage Device capability. SD 6.0 specification introduces the next Application Performance Class, A2. The new class assures higher levels of minimum performance under given conditions and expands SD memory card use for a wider range of higher performance devices and applications. It gives device manufacturers the ability to match the most effective cost-performance SD memory card to their needs.

Further, introducing LVS cards further increases manufacturers' options and flexibility in meeting the new low-power SOC needs while keeping full backwards compatibility to existing products.

The SDA has also created a clear method of communicating all SD memory card requirements so consumers can choose the right card for their device at the point of sale.