An Introduction to:

NAND Flash Form Factors

A Hyperstone White Paper
from the Fundamentals of
Reliable Flash Storage Series

This white paper explains the different governing bodies that set the specifications and standardize the different form factors.

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4th. Edition

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List of abbreviations

AHCI – Advance Host Controller Interface
ATA – Advanced Technology Attachment (Parallel or Serial)
ECC – Error Correction Code
eMMC – Embedded Multi-Media Card
FFU – Field Firmware Update
HDD – Hard Disk Drive
IDE – Integrated Drive Electronics
I/O – Input/Output
kb/Mb/Gb/Tb kilo/Mega/Giga/Tera bits ($10^3/10^6/10^9/10^{12}$)
kB/MB/GB/TB kilo/Mega/Giga/Tera Bytes ($10^3/10^6/10^9/10^{12}$)
(e)MMC – (embedded) Multi Media Card
NVM(e) – Non-Volatile Memory (embedded)
OS – Operating System
PCIe – Peripheral Component Interconnect Express
SCSI – Small Computer System Interface
SD – Secure Digital
SMART – Self-Monitoring, Analysis and Reporting Technology
SSD – Solid State Drive
UFS – Universal Flash Storage
USB – Universal Serial Bus

1 Abstract

Most form factors are defined by governing bodies that set the different specifications to standardize them, and to enable interoperability. These governing bodies address the physical specifications of the form factors, as well as the connectors. There are also some cases where form factors encompass multiple interface protocols or are a result of a proprietary solution becoming a quasi-standard. Finally, proprietary solutions also exist to serve specific needs not covered by any standards.

The current flash memory form factors will be presented, and explained succinctly with some additional details (size, connectors, interface, performance, market, etc.).As form factors and interfaces often correlate, the paper is organized according to the interfaces, as this is often the first requirement of the memory system imposed by the host side.

2 Introduction

This paper provides an overview of flash memory system form factors. A NAND flash memory-based storage system is generally composed of a NAND flash and a memory controller. This configuration is the most common. However, a few managed NAND solutions integrate NAND flash and some additional functionality, like ECC on the same die. In the context of this paper, all systems are equivalent.

Meanwhile, many different generations of NAND flash memories exist. For planar memories, they were the results of several process shrinks on one side, and adding multiple voltage threshold steps to the memory, making them multi-level cells. For each new generation of memory, the management of the NAND flash is increasingly complex. More recently, 3D NAND flashes have appeared, and increased density is the result of stacking memory cells vertically rather than shrinking the process. All in all, the important factor to remember is that the price per mega-bit of NAND flash memory is continuously decreasing, usually to the detriment of reliability and memory retention. The memory controller, in charge of the management of the memory, dictates a lot of the characteristics of the system, like reliability, performance, robustness to power failure and so on, and implements additional countermeasures to ensure system reliability. That way, the controller can enable the use of newer and cheaper generations of flashes, and still offer sufficient reliability for systems and applications.

3 Flash Memory Controller

The controller is the heart of any NAND flash storage system. It ensures that data received from the host is sent to the flash and can be retrieved later. It translates and amends read/write/status commands of the mass storage protocol to different read/write/status commands of the flash components. Also, it translates host Logical Block Addresses (LBAs) or sector addresses (usually sectors of 512 bytes) that are managed by the file system to physical locations or addresses on the flash organized in blocks and pages (usually 4 to 16 KB). The controller ensures compatibility at both ends, and manages all inherent flash deficiencies.

The flash controller is inherently associated with the memory system interface and form factor. Obviously, the host interface is dictated by the form factor, but also some physical characteristics. These characteristics drive the type of application and domain in which the memory system can be used, as requirements for automotive systems differ to those for commercial systems.

Key take-away: The flash memory system form factor dictates a lot of characteristics of the flash controller. Conversely, the flash controller characteristics play a major role in the type of application and domain of the memory system.

4 Interface to Host

The host-side interface manages the communication and data traffic received from and sent to the host system. Details depend on the chosen host interface protocol or standard. For any given host interface, a set of form factors will then be available to the system integrator. The final decision for the form factors can be dictated by the form factor of the systems being replaced, by mechanical or thermal constraints imposed by a particular domain or application, or by other factors such as cost, performance, robustness, availability or mechanical preferences.

All protocols differ in several respects – not only performance and compatibility, but also robustness and signal transmission quality, driver strength, and error correction for noise on the line. Also, certain standards may or may not include features such as health monitoring (e.g. SMART for ATA-based protocols) or firmware update options, sanitization or security. As they are associated with the host interface, those features are inherently associated with the form factors. There is sometimes confusion between the card form factor, the connector, the interface and the host protocol. Some terms like USB can define the interface and the connector, while others, like SD, define the card form factor, the interface and the connector (although many versions exist).

Interface / Protocol	Standardization entities for protocol and/or form factors	Interface speed range	Form factors
P-ATA	Parallel ATA (PATA) CompactFlash Association	8.3 MB/s (PIO 2) to 166 MB/s (UDMA7)	CF Cards 2.5" SSD PCMCIA cards
SATA	SATA International Organization (SATA-IO), JEDEC for some form factors (MO-xxx)	150 MB/s (SATA 1.0) to 600 MB/s (SATA 3.0)	M.2 2.5" SSD M0-297 MO-300 (mSATA) CFast
PCIe / NVMe	PCI-Sig, NVM Express, SATAe based on PCIe, CF-Express based on PCIe, coming: SDx based on PCIe	2 GB/s to 4 GB/s (G3-4L)	PCI-card 2.5" drive M.2 Cfexpress future SD card
USB	USB Implementers Forum (USB-IF)	12.5 MB/s (Full Speed) to 1.25 GB/s (Superspeed+)	USB Flash drive or disk eUSB module custom form factors
SD	SD Association	10 MB/s to 624 MB/s UHS III	SD Card miniSD Card microSD Card
eMMC	JEDEC	100 MB/s (4.41) to 400 MB/s (5.1)	100 to 163 ball BGA packages
UFS	JEDEC	300 MB/s (G2-1L) to 1.2 GB/s (G3-2L)	UFS module (similiar to eMMC) UFS card (similiar to microSD)

Table 1 Interface and form factor overview

Key take-away: *The system host and the domain or application will generally be major drivers to decide on the interface and the form factor. It is important to weight the different options to evaluate what is the best scenario for a specific application.*

5 NAND Flash Form Factors Overview

Form factors do not always correlate with a particular host interface. It is necessary to differentiate between the physical standard, the host interface standard and the protocol standard.

One example is M.2 (an evolution from Intel’s Next Generation Form Factor (NGFF). M.2 is a form factor that supports SATA, PCIe and USB interfaces, with AHCI, NVMe or USB protocol stacks.

Outdated form factors	Current popular industrial form factors
Miniature card	Slim SATA (MO-297), mSATA (MO-300)
Memory Stick Pro (Sony)	CFexpress
Memory Stick Micro M2 (Sony)	PCIe
MultiMedia card	M.2
PC-card aka PCMCIA	UFS
SmartMedia card	NVMe
XQD	1.8 inch, 2.5 inch, 3.5 inch SSD
	Disk-on-board (DoB)
	Disk-on-module (DoM)
	SD card, Micro SD card
	eMMC (100, 153, 169 ball BGA)
	USB 2.0, USB 3.0, eUSB (2.0 and 3.0)
	CompactFlash (CF) based on PATA
	CFexpress (follow-up on xQD)
	SATA 2/3 in 2.5 inch SSD, CFAST
	SATA Express

Table 2 Outdated and current form factors overview

6 Governing Bodies

The standards are generally developed by standardization committees. For certain form factor standards, there is cooperation between different groups.

Organization	Description
ANSI	ATA Parallel and Serial (from IDE), SCSI
CFA	CompactFlash Association (CF, CFAST, XQD, CFexpress)
JEDEC	SSD, UFS, eMMC
MIPI-A	MIPI Alliance (M-PHY used for UFS)
MMCA	Multi Media Card Association (for earlier version of eMMC)
P-ATA	Parallel ATA
PCI-SIG	PCI Special Interests Group (PCIe)
PCMCIA	Personal Computer Memory Card Association (PC-card aka PCMCIA card)
SATA-IO	SATA International Organization (SATA, SATA-e)
SDA	Secure Digital Association
USB IF	USB Implementers Forum
4C-Entity (related to SD)	Governs the right for CPRM (Content Protection for Recordable Media) and CPPM (Content Protection for Pre-recorded Media)

Table 3 Governing Bodies Overview

Key take-away: The flash memory system form factors are for most defined by governing bodies that set the standards. They define the physical characteristics of the system and the connectors as well as the interface itself, or borrow it from another standardization committee.

7 Form Factors

The following chapters concentrate on the form factors most commonly found in industrial and/or very demanding applications (Industrial Automation, Telecommunications Infrastructure, POS and Automotive).

7.1 SD Card and microSD Card

This is the most widely used removable card form factor and interface.

This form factor was introduced in the late 1990s as an alternative to MultiMediaCard. It exists in three different form factor formats: SD, Mini SD and Micro SD (also written as uSD or µSD). They are extensively used for digital cameras, navigation systems (SD) and smartphones (uSD). Historically the majority of SD cards were sold to be used in digital cameras. Micro SD cards were mostly sold for mobile phones, and have surpassed the use of full-size SD cards.

On top of the form factors, there are also different generations of SD specifications. Each generation has a different number of pins for their connectors.

Card speed	Pin numbers	Bus interface	Bus speed	SD spec version	Remarks
Default speed	9		12.5 MB/s	1.01	
High speed	9		25 MB/s	2.00	
UHS-I	9	SDR12	12.5 MB/s	3.01	
	9	SDR25	25 MB/s		
	9	SDR50, SDR50	50 MB/s		
	9	SDR104	104 MB/s		
UHS-II	17	FD156	156 MB/s	4.10	Full duplex
	17	HD312	312 MB/s		Half duplex
UHS-III	17	FD312	312 MB/s	6.00	Full duplex
	17	FD624	624 MB/s		Full duplex
PCIe based	18	G3-L1	1 GB/s	7.00	

Table 4 SD Specifications and modes

The physical characteristics of the different SD cards are listed below.

Form factor	Dimensions (L×l×T)	Interface	Connector	Remarks
SD	32.0×24.0×2.1 mm	UHS-I	9 pins	
		UHS-II	17 pins	
		UHS-III	17 pins	
mSD	21.5×20.0×1.4 mm		11 pins	Almost disappeared
uSD	15.0×11.0×1.0 mm	UHS-I	8 pins	
		UHS-II	16 pins	
		UHS-III	16 pins	

Table 5 Physical characteristics of SD cards

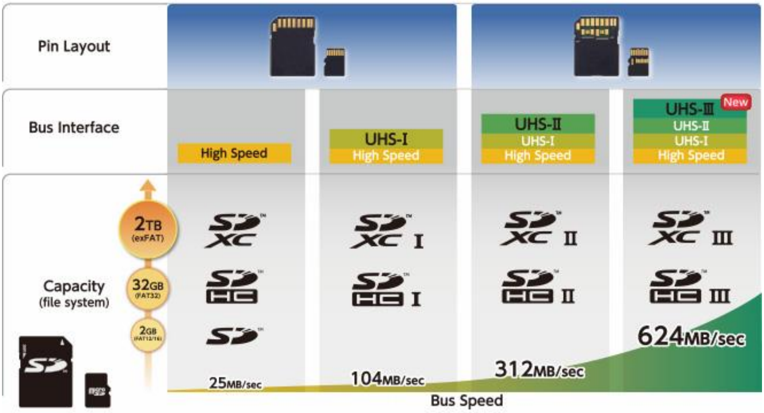


Fig. 1 SD Pin Layout bus interface and capacity overview (SD Association 2017)

7.2 eMMC

eMMC is an all-in-one solution. Both the flash memory and its controller are present in the same package. eMMC exists in 100, 153 and 169 ball packages. It is employed in compact systems, like cell phones for example. eMMC is based on an 8-bit parallel interface. The main drawback of this form factor is that it is soldered to the PCB. In the event of an issue stemming from either the memory or its controller, the entire PCB would need to be replaced.

eMMC rev.	Bus speed	Remarks
eMMC 4.3	52 Mb/s	Add sleep mode, write protect, reliable write, etc.
eMMC 4.41	100 Mb/s	Add DDR, TRIM, high-priority interrupt, multiple partition, etc.
eMMC 4.5	200 Mb/s	Add Sanitize and Cache commands, high-speed mode HS200
eMMC 5.0	400 Mb/s	Add FFU, health monitoring, high-speed mode HS400
eMMC 5.1	400 Mb/s	Add command queueing, secure write

Table 6 eMMC specifications overview

In most industrial applications, ruggedness is prioritized over performance, hence eMMC 4.5 is still widely used. By contrast, consumer applications are often driven by performances with eMMC5.x as a key enabler, for example in smartphones.

7.3 UFS

UFS was developed by JEDEC to supersede eMMC. Starting with UFS 2.1, the physical interface uses the M-PHY physical layer, developed by the MIPI Alliance, with upscalability to 5.8 Gb/s per lane. It uses a full-duplex LVDS interface, and implements a SCSI stack and SCSI Tagged Command Queueing.

UFS rev.	Bus speed	Remarks
UFS 1.1	300 MB/s	
UFS 2.1	1.2 GB/s	Based on Unipro 1.6, MIPI (M-PHY 3.0)

Table 7 UFS Specifications overview

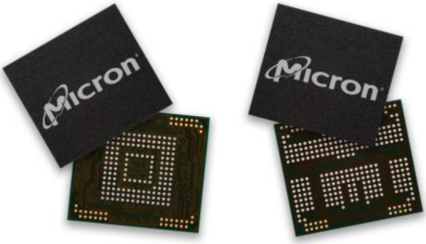


Fig. 2 Micron Universal Flash Storage (UFS) 2.1 based on Micron™ 3D NAND flash memory (ElectronicDesign, 2016)

7.4 USB

Certainly, the most recognized aspect of USB is its connector. The USB form factor doesn't define the shape of the card, but only specifies the interface and connector. USB exists in different flavors according to the generation of the specifications.

USB rev.	Speed grade	Bus speed	Actual max. workload	Remarks
USB 1.0	Low speed	1.5 Mb/s		
USB 1.1	Full speed	12 Mb/s		
USB 2.0	High speed	480 Mb/s	35 MB/s	On-the-go specs
USB 3.0	Super speed	5 Gb/s	400 MB/s	aka USB 3.1 Gen1 or USB 3.1 5 Gb/s
USB 3.1	Super speed 10 Gb	10 Gb/s	900 MB/s	aka USB 3.1 Gen2 or USB 3.1 10 Gb/s

Table 8 USB generations overview

The USB interface is used across many types of devices and has defined a USB mass storage device class. Designed initially for HDD, it was extended to support flash drives. Most computer systems can boot directly out of a USB flash drive or run applications directly from the

USB drive. The hot-plugging and relative sturdiness of the plugs make it a favorite in a lot of portable applications.

Many different connector form factors were defined by USB-IF. They exists in different types (A, B, C), different sizes (Standard, Mini, Micro), and as plugs or receptacles. Type B is mostly found on printers or the USB hub on the upstream port. It is mostly irrelevant for flash memories.

The connectors used for USB flash drives are mostly as follows:

Most common connector for USB Flash memory	Remarks
Type A Standard USB plug (most common), USB 2/USB 3	USB-IF std
Type A Mini USB plug, USB 2/USB 3	USB-IF std
Type A Micro USB plug, USB 2/USB 3	USB-IF std
Type C USB plug (most recent)	USB-IF std
eUSB connector (de facto standard)	De facto std
Proprietary connector	M.12, for example for heavy industrial applications

Table 9 Connectors for USB flash Memory

7.5 ATA

When ANSI adopted IDE, originally developed by IBM, it renamed it ATA for Advanced Technology Attachment. The ubiquitous parallel cable could be found in most computers. A major issue appeared when computers were integrated into smaller cases. The ATA was later renamed as PATA (P-ATA) in order to distinguish it from the new generation of interface, called SATA, for Serial ATA.

Different generations of the ATA interface have been developed. The most recent ones are summarized below. Ultra DMA or UDMA also evolved in parallel, to define the protocol between a host and a device.

ATA generation	**Description**	**UDMA**
ATA-3	Increased reliability, but remembered for introduction of SMART (Self-Monitoring Analysis and Reporting Technology). Still largely adopted nowadays even for other interfaces	n/a
ATA/ATAPI-4	Data transfer up to 33 MB/s – added AT Attachment Packet Interface (ATAPI)	UDMA-2
ATA/ATAPI-5	Data transfer up to 66 MB/s	UDMA-4
ATA/ATAPI-6	Data transfer up to 100 MB/s	UDMA-5
ATA/ATAPI-7	Data transfer up to 133 MB/s	UDMA-6

Table 10 ATA Generations overview

7.5.1 CF/ PATA

Compact Flash has been around since the mid-1990s, but has since been replaced in a number of consumer products by smaller form factor options. However, it is still a very popular format for professionals and also in industrial environments, as the card is simply sturdier than other cards.

CF revision	Speed	
CF 4.1	Up to 133 MB/s	Up to UDMA-6
CF 5.0	Up to 133 MB/s	Up to UDMA-6
CF 6.0	Up to 167 MB/s	Up to UDMA-7

Table 11 CF generations overview

Fig. 3 Hyperstone´s F9 Compact Flash controller

7.5.2 PATA SSD

PATA 2.5 inch SSDs are typically used in industrial grade SSDs. They offer the following advantages, if a custom solution is developed:

- Fixed Bill of Materials (BOM)
- Long-term availability
- Specific choice of NAND flash

Industrial grade SSDs are typically available for a much longer period of time than consumer SSDs.

7.5.3 CFexpress

CFexpress is based on PCIe Gen3 (up to two lanes) and NVMe (v1.2). It increases the bandwidth to 2GB/s.

CFexpress 1.0 benefits from:

- Performance of PCIe ×2
- NVMe low latency stack
- Support for native NVM Express® SMART commands

The form factor is similar to XQD 2.0 form factor, i.e. 38.5 × 29.8 × 3.8 mm. XQD was introduced by the CF Association to offer a higher bandwidth and counter the evolution in SD and CFAST cards – it is slightly smaller than a CFAST card and bigger than an SD card. Originally meant to replace CF and CFAST cards, it was adopted by Nikon, Sony and Sandisk. However, since 2016, it is only used by Sony in consumer applications.

Form factor	Dimensions (L×l×T)	Interface		
XQD 1.0	38.5×29.8×4.0 mm		Up to 150 MB/s	
XQD 2.0	38.5×29.8×3.8 mm	PCIe Gen3 and USB3	Up to 450 MB/s	

Table 12 XQD generations overview

7.5.4 SATA

Serial ATA or SATA was meant to replace Parallel ATA or PATA in computers. The main issue with PATA was linked to the wide bus, which has to be routed.

There are different generations of SATA.

	Raw bit rate	**Maximum transfer rate**	**Remarks**
SATA 1.0	1.5 Gb/s	150 MB/s	
SATA 2.0	3 Gb/s	300 MB/s	
SATA 3.0	6 Gb/s	600 MB/s	8 b/10 b encoding
SATA 3.1	6 Gb/s	600 MB/s	mSATA
SATA 3.2		1969 MB/s	SATA Express SATA M.2 USB 3.1

Table 13 SATA generations overview

SATA drives are found in many different form factors. The most common is the 2.5 inch SSD drive.

7.5.5 CFast

CFAST has the same form factor as Compact Flash, but is based on the Serial ATA (SATA 2) interface instead of PATA. The pin-out is different from a CF card, though, with a 7-pin data connector and a 17-pin power connector.

CFAST and CF cards are not directly compatible, but an adaptor can be used. As SATA can also emulate PATA command protocol, it is possible to use a CFAST card in older CF systems. For CFAST 1.0/1.1, the maximum transfer rate is the same as SATA 2.0, 300 MB/s, therefore it gives better performance than CF/PATA, which is limited to a maximum transfer rate of 167 MB/s at best.

CFAST 2.0, introduced in 2014, uses SATA 3.0 (600 MB/s).

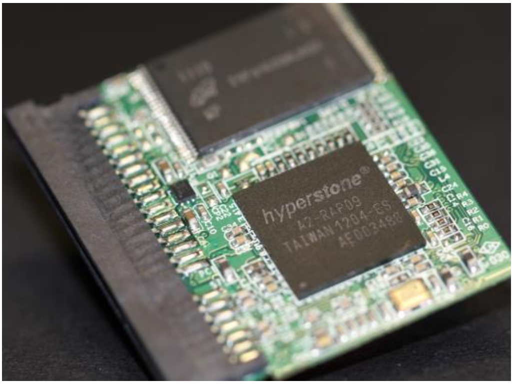


Fig. 4 Hyperstone CFAST Card

7.5.6 2.5. Inch Drive

Popular formats for HDD were the 3.5, 2.5 and 1.8 inch drives. The size indication is actually the size of the rotating disk in the HDD, and not the size of the casing.

SDD has widely adopted the 2.5 inch disk drive format so that an HDD can be replaced easily with a 2.5 inch SATA 3 AHCI SSD drive. This gives a very effective path to upgrade the memory of a laptop. These drives can also be used externally.

7.5.7 mSATA

mSATA is a smaller form factor than the SATA SSD. It comes as a PCB board, in three different formats:

- Half-Slim MO-297 (54 × 39 × 4 mm) (about half the size of a credit card)
- mSATA MO-300A (30 × 51 × 8 mm)
- mSATA-mini MO-300A (30 × 26.8 × 4 mm)

It also looks like the mini-PCIe card, but they are not directly electrically compatible. The mSATA bandwidth is the same as SATA 3, 6 Gb/s.

mSATA are smaller devices than SATA SSDs, and are used in lower-power devices like netbooks, but also in commercial applications. The main advantages of mSATA are:

- Small form factor
- Low power consumption
- Vibration resistance
- Fast boot and shut-down

The mSATA specification also describes how to map mSATA to mini-PCIe.

The interface of mSATA is the same as the regular Serial ATA – the cards simply look different.

7.5.8 SATA express (SATAe)

SATA 3.2 introduced SATA Express specifications. In order to significantly increase the bandwidth in a timely manner, SATA-IO decided to base SATA Express on PCIe. A connector was defined for backward compatibility that can support both SATA 3 x2 and PCIe x2 interfaces.

SATA Express supports three different device interfaces:

- Legacy SATA 3 interface
- PCIe using AHCI
- PCIe using NVMe

7.5.9 Micro SSD

The specification for Micro SSD (aka µSSD) was developed by SATA-IO, and uses a JEDEC standard form factor. It defines the electrical pin-out of a BGA for a SATA3 interface. As per eMMC or UFS, the package is soldered directly onto the motherboard, removing the need for connectors.

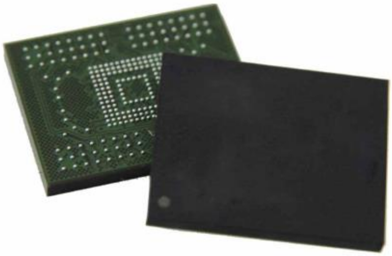


Fig. 5 Example of a Micro SSD

7.6 PCI Express

PCI Express version	Raw bit rate	Bandwith/lane	Max bandwidth (16×)	Remarks
PCI-e 1.0	2.5 GT/s	256 MB/s	4 GB/s	
PCI-e 2.0	5 GT/s	500 MB/s	8 GB/s	
PCI-e 3.0	8 GT/s	~1 GB/s	~16 GB/s	128 b/130 b encoding
PCI-e 4.0	16 GT/s	~2 GB/s	~32 GB/s	End of 2017

Table 14 PCIe generations overview

PCIe is a point-to-point technology in which each serial link has a full duplex pair of differential signals, known as lanes.

7.6.1 PCIe Cards

PCIe cards are defined by their number of lanes. There are four different card formats ×1, ×4, ×8 or ×16. All the cards are composed of a first set of 11 pins, then a key notch, and finally the remaining number of pins according to the number of channels.

Number of lanes	Number of pins (per side)	Width
×1	18	25 mm
×4	32	39 mm
×8	49	56 mm
×16	82	89 mm

Table 15 PCIe card specifications

7.6.2 Mini PCIe

The PCI Express Mini Card was developed by PCI-SIG to replace the Mini PCI form factor. The Mini PCIe card supports both 1×PCIe and USB 2 interfaces. A Mini PCIe card can be used in the PCIe slot using a passive adaptor.

Another even smaller card exists, half the length, which is called a Half Mini Card (HMC).

The form factor for mSATA and Mini PCIe is similar, and both cards can fit in the mPCIe slot. However, they use different interfaces, respectively SATA and PCIe, and the host connected to the PCIe slot must support the corresponding interface.

7.7 M.2

The M.2 specification emerged to replace mSATA cards on PCs. It was initially developed by Intel and known as Next Generation Form Factor (NGFF) – this is strictly a form factor. PCI-SIG originally defined the M.2 form factor, then SATA-IO adopted M.2 in the SATA 3.2 specifications. These specifications also defined SATA Express

M.2 is therefore more flexible than the previously defined mSATA form factor. It supports not only SATA, but also PCIe and USB 3 interfaces. As a result, it extends the possible applications. It can also be found supporting different host protocols, either AHCI or NVMe.

As a result, it is difficult to define M.2 as easily as most other card form factors. Many variants of M.2 cards exist. It can have up to 4× PCIe lanes, one SATA 3 and one USB 3 port. Both SATA and PCIe buses can be used at the same time (if supported by both host and device).

There are numerous form factors for the cards, for example: M.2 2280, which is 22 mm wide and 80 mm long. This is one of the most used formats. But the following formats also exist: M.2 1630, M.2 2230, M.2 3030, M.2 2242, M.2 3042, M.2 2260, M.2 22110.

There are also multiple connector and key IDs for each.

Key ID	Supports	
B	SATA	
M	PCIe (×2 or ×4) and SATA	
B+M	SATA or PCIe	
A	PCIe (×2) and USB	
E	PCIe (×2) and USB	
A+E	PCIe (×2) and USB	

Table 16 Key IDs for M.2

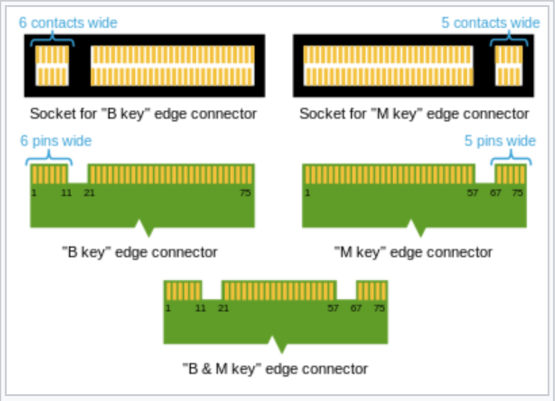


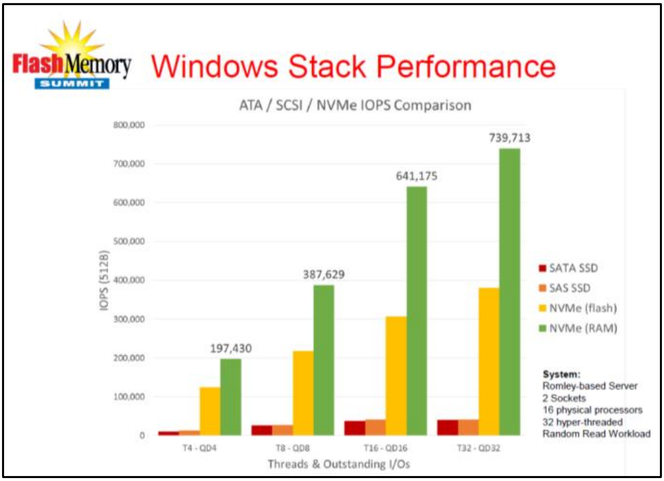
Fig. 6 Visual Display of key IDs for M.2
(Marshall, R. 2014 cited in Wikipedia, 2014)

7.8 NVMe

Non-Volatile Memory Express, or NVMe, is a host protocol. Before discussing it, IDE and AHCI will be summarized. Integrated Drive Electronics (IDE) was designed for the PATA drive. It lacks a lot of the newer features (such as hot-plugging and native command queueing).

Advanced Host Controller Interface (AHCI) was designed to control SATA drives. It also includes other modes like PATA emulation and RAID. It was originally created for HDD, and therefore not optimized for SSD. It is a more advanced protocol than IDE, and support Native Command Queueing (NCQ) and hot-plugging. Its performances are also better than IDE. NVMe was created from the ground up with SDD in mind. It takes advantage of the low latency of SSD compared to the high latency of HDD. AHCI added some latency, which was not a problem with HDD. NVMe also enables more parallelism. It supports multiple queues and higher queue depths. As a result, NVMe is a stack adapted to the characteristics of the SSD.

The two graphs that follow from a presentation from Microsoft show the great benefits of NVMe, both in terms of bandwidth and latency.

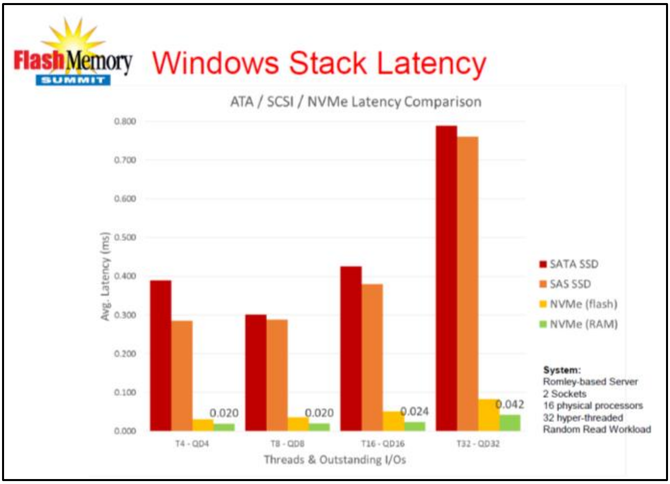


Windows Stack Performance

ATA / SCSI / NVMe IOPS Comparison

System:
Romley-based Server
2 Sockets
16 physical processors
32 hyper-threaded
Random Read Workload

Fig. 7 Windows Stack Performance (Ellefson, J 2013 cited in Flash Memory Summit Presentation, 2013)



Windows Stack Latency

ATA / SCSI / NVMe Latency Comparison

System:
Romley-based Server
2 Sockets
16 physical processors
32 hyper-threaded
Random Read Workload

Fig. 8 Windows Stack Performance (Ellefson, J 2013 cited in Flash Memory Summit Presentation, 2013)

7.9 Disk on Module

A Disk-on-Module (DoM) is an SSD with a 40-pin Parallel ATA interface, which typically plugs directly into a motherboard. It is primarily used in industrial applications.

The DoM form factor was created in the 1990s, but it is still used today.

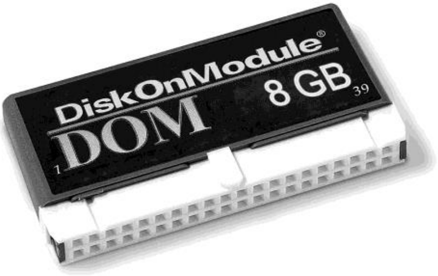


Fig. 9 Disk on Module (DoM)

7.10 Disk-on-Board

DoB solutions provide a fully functional storage subsystem based on NAND flash components. The interface to the main processor is enabled via a flash controller supporting required standards using discrete components enables system designers to define all components used according to their needs. A so-called "Fixed BOM" can be achieved and is under full control of the organization.

The DoB is developed through close collaboration between the end customer, the flash controller company and the NAND flash manufacturer. This makes it a custom solution, designed to address particular challenges. All necessary changes can be discussed well in advance directly with the responsible partners (controller and NAND), avoiding third parties with their own agendas.

This has become a popular form factor in highly demanding environments. As it is generally designed for long product lifetime, it is important to make sure that the controller firmware can be updated to benefit from the newest flash management technologies over the whole lifetime of the solution (best reliability, data quality and read/write performance), and that tools are available to monitor the health of the NAND flash and to enable maintenance scheduling

8 Summary

Flash memory systems are available in many different form factors. Each form factor has specific mechanical characteristics and a logical host interface. The choice of form factor is driven by these, and generally driven by the system level. The host must accommodate the interface, and the system level design must be designed for the particular form factor. Also to be considered alongside the NAND flash memory types are other characteristics, such as, performance, endurance, reliability, End-of-life, temperature, cost and flash type.

A lot of those characteristics are driven by the NAND flash memory controller. It is a major contributing factor, and it needs to be chosen wisely according to the system requirements. For example, industrial requirements are very different from commercial applications in many ways. Many alternatives for storage systems and their controllers exist in terms of interface options, form factors and quality levels. If the storage system is vital for your application and holds sensitive data, or if failure would result in costly down-time, you need to choose your controller carefully - know your requirements.

9 Figures

10 List of Sources

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