

### Introduction to the Universal Flash Storage Association

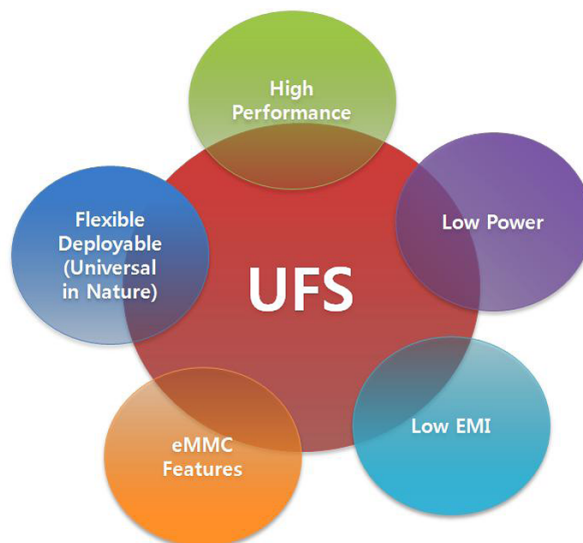
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#### Executive Summary

Universal Flash Storage (UFS) is the next generation, high-performance non-volatile storage standard. The UFS standard is defined by JEDEC and incorporates standards from the MIPI® Alliance (M-PHY and UniPro<sup>SM</sup>) for data transport. UFS utilizes the SCSI Architecture Model supporting multiple commands, including command queuing which enables multi-threaded programming. UFS further supports features of e•MMC, the JEDEC embedded storage memory format introduced in 2006. The MIPI M-PHY combines high speed SerDes I/O (up to 5.8Gbps per lane) with multiple operating states to achieve very low power consumption.

Building on elements of existing standards will hasten the adoption of UFS by simplifying development and deployment at all levels - from ICs to firmware, system software, test and measurement.

The Universal Flash Storage Association (UFSA) is chartered to promote UFS and certify compliance and compatibility of UFS products.



## Introduction

Mobile platforms use Non-volatile memory for application (typically embedded on the circuit board) and user storage (embedded and/or removable). Storage devices have to supply fast data transfers of large multimedia files such as video, music and photos as well as actively running multiple applications. Application performance depends heavily on multi-threaded memory transfer rates.

Universal Flash Storage (UFS) is the next generation, high-performance Non-volatile storage standard. [1] The UFS standard is maintained by JEDEC, relies on the MIPI® Alliance M-PHY and UniPro<sup>SM</sup> for transport and borrows from the SCSI command set. [2]. Building on elements of existing standards will hasten the adoption of UFS by simplifying development and deployment at all levels - from ICs to firmware, system software, test and measurement.

The Universal Flash Storage Association (UFSA) is chartered to promote UFS and certify compliance and compatibility of UFS products. [3] The governance and members hail from all aspects of the mobile memory eco-system representing device and application processor (SOC) developers, component suppliers, Silicon IP providers, instrumentation suppliers and test and measurement services. UFS is the most advanced specification for both embedded and removable flash memory-based storage in mobile devices such as smartphones and tablet computers. The maximum I/O rate for UFS will be 1.45Gbps (UFS1.1) scalable to 5.8Gbps with UFS2.0.

## Key Features of UFS

UFS provides a number of features to support either embedded or removable storage.

### Embedded Memory Features

Boot partitions and boot operation is supported. Non-volatile can be partitioned into multiple logical units (LUNs) with full management of partition attributes. The new UFS standard supports multiple commands with command queuing. These features enable multi-threaded programming. Conventional flash-based memory cards and embedded flash solutions process one command at a time limiting random read/write access performance.

**Supports well-known SCSI command set**

UFS uses widely adopted SCSI Architecture Model supporting multiple commands, including command queuing which enables multi-threaded programming. This provides a well-known high-performance protocol used in USB 3.0 and SAS to enable asynchronous operation and high instruction operations per second (IOPS). Previous Non-volatile standards (e.g. e•MMC) process one command at a time, limiting random read/write access performance. Additional commands include Write Protection options, including permanent and power-on write protection, secure operations such as purge and erase, RPMB security function, and hardware reset.

**Simplified Host Controller Interface (HCI)**

The UFS Host Controller Interface (JESD223) allows greater system design flexibility by simplifying the host processor requirements. A set of common OS drivers and a common register set are defined and can also be customized.

**Extendable performance with low power**

UFS utilizes MIPI M-PHY and UniPro standards for the Physical and Link layers which were defined to provide high-speed connectivity for mobile devices with maximum energy efficiency. The M-PHY roadmap currently defines three speed “gears” from 1.46Gbps (Gear 1) to 5.83Gbps (Gear 3). UFS offers the promise for significant reductions in device power consumption. It will satiate the ever-growing demand for versatile storage solutions and improved device performance.

**UFS supports embedded and removable card formats**

### Mobile Memory Market

Mobile product shipments (currently dominated by smartphones) represent 75% of the \$30B Non-volatile Memory market. Tablet PCs are forecast to outpace the remaining mobile segments.

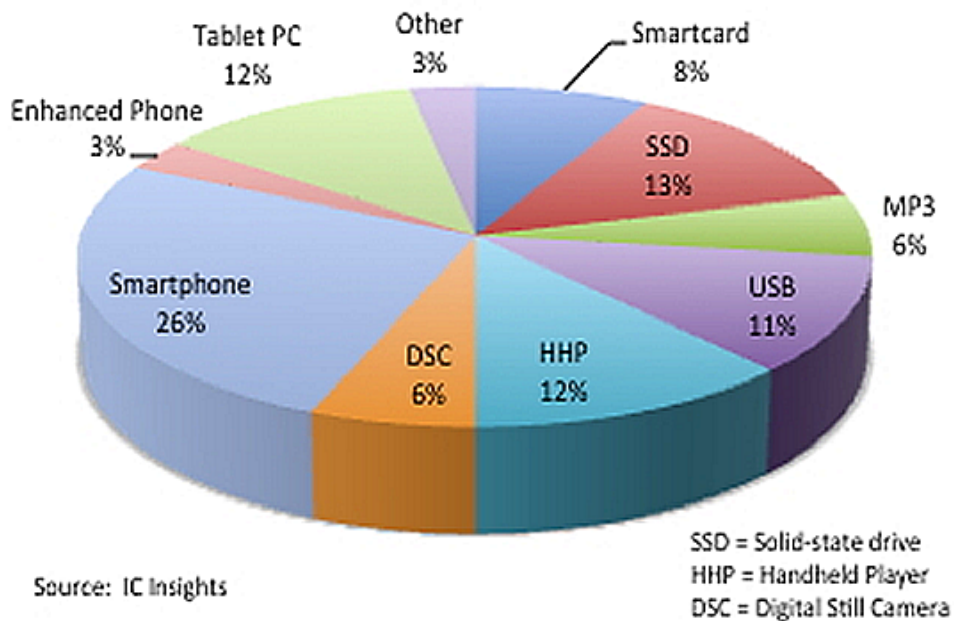


Figure 2. Non-volatile Market by segment 2013 Forecast [4]

### Application drivers for Performance and Memory Density

#### Portable Performance

Portable storage performance was once thought to only affect media transfer times. But today’s popular smartphone and tablet applications (e.g. Google Maps, Twitter, Facebook, eMail, web browsers, etc.) are dependent on the entire system, including the Non-volatile component. Kim, et. al. [5] performed a detailed study of the impact of the mobile storage subsystem on a range of applications and WiFi modes. Application load time, response time and task switching are affected by all aspects of the storage system: software drivers, file manager, and Input / Output Operations per second (IOPS).

## **High Resolution Imagery**

Multi-shot with imaging processing is used to create high-resolution pictures in the form-factor limitations of thin mobile devices. Support for high-resolution displays like QXGA (2048px x 1536px) and WQXGA (2560px x 1600px) with high capacity content will demand more data transfer rate and storage capacity. New media applications such as high frame-rate video, panoramic images and real-time image overlays are examples of new features in smartphones, tablets and digital cameras. Playing HD (1080p) and future UHD (4K) movies from a UFS storage device will enable longer run time between battery charging.

The professional digital camera market currently provides resolutions up to 5120 pixels x 2700 pixels with 60fps video capture rates. These devices currently use SSDs for data storage, but smaller, lighter, more reliable storage solutions would be desirable.

## **Game Consoles**

A new generation of game consoles based on tablet PC chipsets will drive growth for memory solutions that can provide data transfer rate and storage for real-time image overlays and multiple-window displays.

## **Tablet Computers will replace desktop and laptop PCs**

The trend to replace desktop machines with tablets is well underway. Microsoft Surface was the first tablet to run a desktop OS (Windows 8.0). The latest Blackberry Q10 combines touchscreen with Bluetooth attached keyboard and pointing device. There are speculations that Apple will introduce a tablet version of the MacBook Pro. In addition to embedded storage for application data, these devices will require high-density user storage. A removable form factor solution will enable faster adoption. The SATA interface used in laptop and ultrabook SSDs is not suitable for mobile power requirements. UFS can fulfill the need for high performance storage, small form factor, and battery-saving power demand for mobile computing products.

## **Professional Tablets**

The market for ultra-high resolution tablets with UHD (4K) and UHD (8K) will be driven by professional applications for architecture, civil engineering and medical imaging. Examples of future professional tablets were on display at CES 2013.

## Mobile Memory Roadmap

Key features of current and near-term mobile storage standards from JEDEC are depicted in Table 1. The current generation of e•MMC offers 200MB/s data transfer rates with 200MHz single ended I/O. The next generation (e•MMC 5.0) will use DDR I/O to provide 400MT/s (1 Byte / transfer).

<b>Feature</b>	<b>e•MMC v4.51</b>	<b>UFS 2.0</b>	<b>SATA3</b>
Max Data Transfer Rate	200 MB/s	> 1000 MB/s	> 500 MB/s
Topology	Half Duplex	Full Duplex	Point to point
Command Set	Native	SCSI	SCSI
Boot Partition	Yes	Yes	No
RPMB	Yes	Yes	No
Partitions	Up to 4	Up to 8 (LUNs)	1 (device level)
Command Queuing	No	Yes	Yes
Power Consumption	Standby: <0.5 mW Active: ~1 mW	Standby: <0.5 mW Active: ~1 mW	Standby: 5 mW Active: 6 W
Multi-task Support	Single Function	Multiple LUN	No
e•MMC Features	Yes	Yes	No
Secure Trim / Erase	Yes	Yes	No

Table 1. Comparison of Mobile Memory Standards [4]

*Note: The current published UFS specification is 1.1. UFS 2.0 is scheduled for release in Q32013.*

## UFS Details

### High Performance

UFS utilizes high-speed SerDes 8b/10b I/O with rates up to 5.8 Gbps). Such performance allows an HD movie, for example, to be played instantaneously and at full speed.

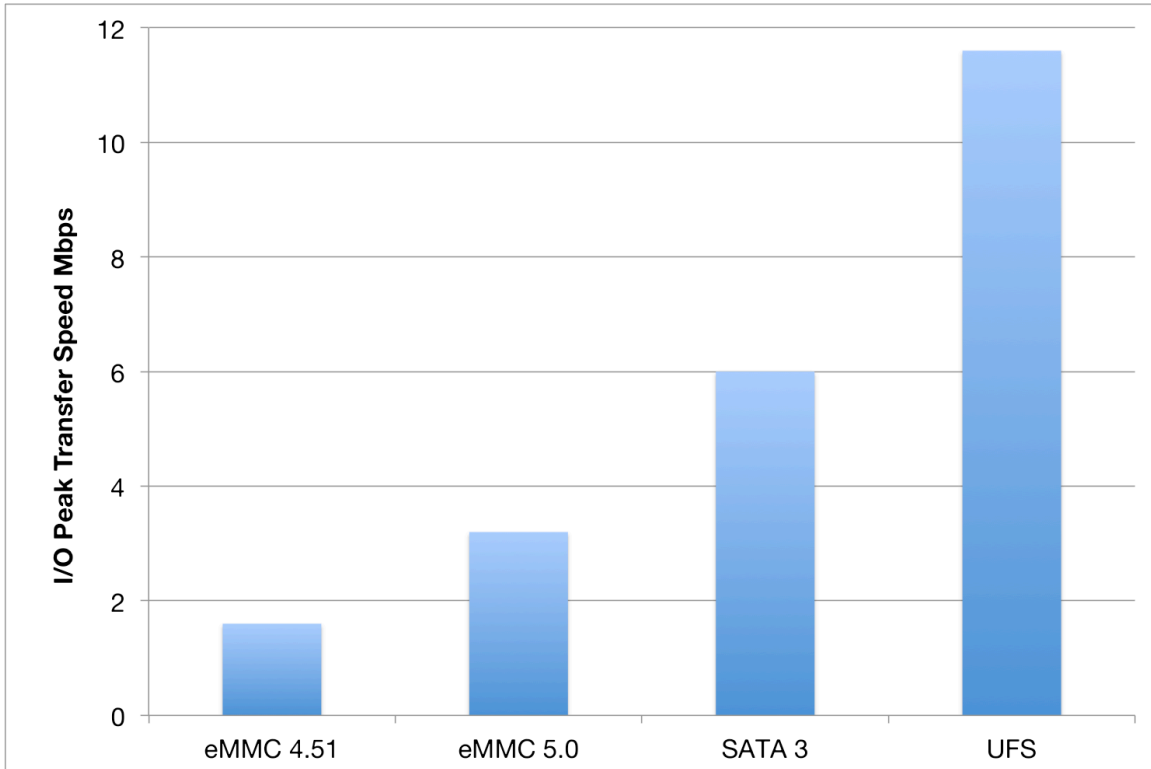


Figure 3. Peak I/O Data Transfer Rate for Mobile Standards

### Low Power Consumption

UFS will consume less power than other mobile storage solutions for a typical application. UFS offers near-zero idle power consumption and power-performance tradeoffs under software control. Multiple operational states in the MIPI M-PHY encompass high-speed burst and low-speed transfers, with sleep and hibernate modes. The specifications enable efficient transitions between the multiple active and power save modes allowing a higher degree of performance power optimization than other storage standards.

### UFS Implementation

In the diagram below, the implementation of a UFS host or device is simplified to the M-PHY, digital (UniPro) core and the interface to either the SoC or the Non-volatile memory. We will examine each of these in detail.

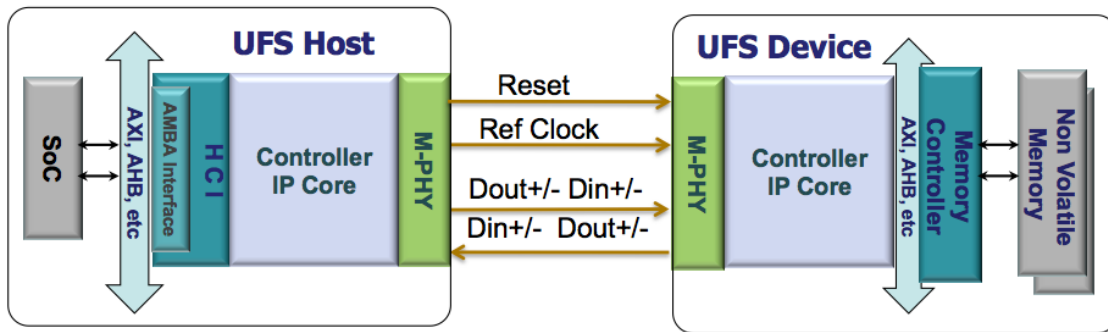
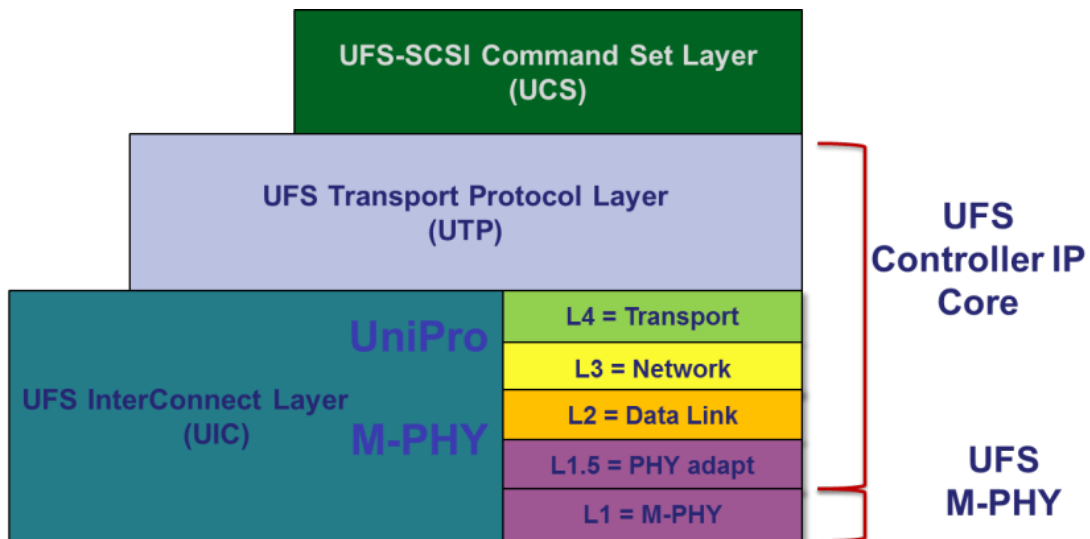


Figure 4. UFS to UFS Interface

### UFS Layered Architecture

There are three major layers in the UFS architecture: UCS, UTP and Interconnect (UniPro + M-PHY). The command set layer (UCS) is the interface to the software application and incorporates the SCSI standard as the baseline protocol for UFS specification. The Transport Layer (UTP) is responsible for encapsulating the protocol into the appropriate frame structure for the interconnect layer. The Interconnect Layer (UIC) is a combination of digital and analog IP.

Figure 5. UFS Layered Architecture





## e•MMC Compatibility

UFS inherits important features of e•MMC to allow easy migration [4]

Feature	e•MMC v4.51	e•MMC v5.0	UFS v1.1	UFS v2.0
Command queue	Packed commands	Packed commands	Yes	Yes
Queue Priority	No	No	Yes	Yes
ContextID	Yes	Yes	Yes <sup>1</sup>	Yes <sup>1</sup>
Data Tag	Yes	Yes	Yes <sup>1</sup>	Yes <sup>1</sup>
Real Time Clock	Yes	Yes	Yes	Yes
Dynamic Capacity	Yes	Yes	Yes <sup>2</sup>	Yes <sup>2</sup>
Power Off Notify	Yes	Yes	Yes <sup>1</sup>	Yes
Large Sector	Yes <sup>3</sup>	Yes <sup>3</sup>	Yes 4KB min	Yes 4KB min
Security Extension	Yes	Yes	Yes	Yes
Notes: 1 SCSI Group Number 2 SCSI Unmap 3 For capacity greater than 250GB, native sector size is 4KB				

Table 2. Migration from e•MMC to UFS

### Embedded Device Requirements

The embedded UFS device will have a separate hardware reset pin, which will be active low. The reset pin will be disabled by default and either permanently disabled or enabled via a parameter on UFS device. The embedded device will support both the PHY and soft reset as well. The embedded device will implement the internal power on reset to comply with the PHY.

### Removable Device Requirements

The removable UFS device will not have a dedicated reset pin, but will support both PHY and soft reset. The removable UFS device will implement the internal power on reset to comply with the PHY.

## **UFS Compliance & Test**

JEDEC creates and publishes industry standards, but does not certify compliance or provide testing services. The device or silicon vendor is responsible (to the customers) for ensuring compliance. This can be difficult for many standards where different devices will be used together in an end product. Private vendor testing, public “interop”, and contract test services can be used but it is time-consuming and difficult to ensure full compatibility.

UFSA has implemented a certification process that includes test lab accreditation and compliance test specifications. The UFS Certification Logo gives device suppliers and OEMs a means to communicate compliance and inter-operability.

UFSA, based on JESD224 [2], defines the test procedures and identifies the basic set of tests to be performed. Configurations for Device, Host and Device + Host interoperation are defined.

Commercial test labs are certified for full speed analysis of I/O (M-PHY) and protocol tests. High-speed test certification covers test fixtures, oscilloscopes, bit error rate (BER) testers, waveform generators, network analyzers and time domain reflectometers. Protocol test certification covers host and device snoop fixtures, scopes, protocol generators and analyzers as well as “golden” samples for host and device. The Unipro link layout, UFS Transport Layer (UTP) and hardware and software stacks are considered during full interoperability testing. Certified test labs are authorized to issue Certificates of Compliance to IC, IP and validation hardware providers.

## Summary

The UFS architecture increases performance while maintaining the low power consumption of existing solutions such as e•MMC. The added performance benefits enable UFS to replace e•MMC as the mobile storage standard.

The use of the well-known SCSI Architecture Model combined with command queuing and multi-thread programming should result in wide market adoption.

The M-PHY and UniPro combined with a low active power level and a near-zero idle power offers the promise for significant reductions in device power consumption.

With all these unique features, UFS will be a preferred storage solution in almost any portable electronic device.

## References

1. [JEDEC.org](http://www.jedec.org) (See JESD220, JESD223, JESD224)
2. [MIPI Alliance](http://www.mipi-alliance.org)
3. [Universal Flash Storage Association](http://www.uniflash.org)
4. [Insights April 17, 2013](#)
5. [Kim H, Agrawal N, Ungureanu C, Revisiting Storage for Smartphones, 2012](#)