Choosing a mobile-storage interface: eMMC or UFS

Hezi Saar - July 14, 2016

It is easy to forget just how rapidly the mobile landscape has evolved. Consider that just twelve short years ago, the Motorola Razr was released. With a 0.3-megapixel camera, a 176×220 screen, and five megabytes of embedded storage, this sleek feature phone was a global sensation, with 110 million devices sold worldwide.

Fast forward to the present day, and it is an entirely different landscape. Smartphones now boast up to 41-megapixel cameras. Ultra-High-Definition (UHD) screens sport resolutions of 2160×3840 pixels, and storage capacities run into the hundreds of gigabytes.

There has been a paradigm shift in how we consume digital information, with a convergence of technologies making mobile our primary compute platform.

From computer-aided design and 4K video editing to console-level gaming, users now expect their mobile devices to handle the most complex of tasks, as if they were sitting in front of an enterprise-grade workstation.

The demands being placed on mobile devices have presented something of a challenge for storage OEMs. As operating systems, applications and user expectations grow in complexity, data transfer bandwidth is being stretched to the breaking point. A range of new standards are now beginning to hit the market, which pave the way for the next generation of high-performance mobile storage.

The De Facto Standard

eMMC (embedded MultiMediaCard) has become the de facto standard across the mobile landscape for embedded mobile storage. Developed by the MultiMediaCard group and ultimately handed over to JEDEC, eMMC is an embedded, non-volatile memory system, comprising of flash memory and a flash memory controller.

Utilized in everything from smartphones and tablets to sat-navs and cameras, eMMC remains the dominant force in the world of embedded mobile storage, while Secure Digital (SD) has become the leading standard in the removable storage arena.

In order to meet evolving demands, the eMMC standard has progressed in parallel with other mobile technologies, with each iteration bringing successive performance enhancements. From 100MB/s (eMMC v4.3) to 400MB/s (eMMC v5.1), the standard has kept pace with the evolving landscape and eMMC 5.1 can service a wide range of applications (Figure 1).
The eMMC 5.1 can enable high speed connectivity with advanced features such as command queueing and inline encryption. Command queueing allows requests and responses to be handled in a non-sequential order. New requests can be sent without waiting for a response for the previous request. A single request is split into Submit CMD and Execute CMD, allowing Submit CMDs to be sent for all requests without waiting for response or data. This allows the device to start caching data buffers. It also allows the device to handle requests more efficiently, for example, in the case where successive pages are requested these commands can be treated as a single request, the cache buffer for the channels can be buffered simultaneously. This pre-buffering enables lower latency when a device gets the execution command itself.

However, as with any technology, there are physical limitations. eMMC is bound by an 8-bit parallel interface, and the scaling of the interface performance for new, demanding mobile and mobile-influenced applications is now nearing its limits.

Enter Universal Flash Storage (UFS). Back in 2008, while JEDEC began looking at serial interfaces as a means for future storage requirement, the Mobile Industry Processor Interface (MIPI) Alliance was working on its own high-performance specifications to enable chip-to-chip, camera, and display interfaces.

In 2010, JEDEC collaborated with the MIPI Alliance, and in 2012, the Universal Flash Storage (UFS) standard was published. Since then we have seen a few enhancements of the standard, with v2.1 being the latest version for embedded UFS, and v1.0 for removable UFS cards.

Some vendors have been aiming to repurpose desktop-class NVMe storage for mobile purposes; however, the unique requirements - power and performance - of mobile SoC architecture calls for a more considered approach, making UFS the only real candidate as the next mainstream standard in embedded flash storage due to its high-performance, low-power and scalability.
At a high-level, UFS moves away from a parallel interface to differential-signaling serial interface, removing the performance and manufacturing/routing barriers inherent to eMMC.

Due to the parallel 8-bit interface used for eMMC, read and write operations are sequential, or half-duplex. The new UFS 2.1 standard has dedicated read and write paths, allowing for full-duplex operation. Essentially, UFS 2.1 can read and write simultaneously.

The combination of the serial interface and full-duplex data transfers mean that UFS 2.1 can achieve two to four times the peak bandwidth of eMMC 5.1 and in a more power-efficient manner. There are already two iterations of UFS 2.1: high speed-gear2 allows for a peak bandwidth of 5.8Gbps over two lanes, while high speed-gear3 has a peak bandwidth of up to 11.6Gbps over two lanes.

UFS also utilizes Command Queue (CQ), similar to eMMC 5.1, allowing it to harness the multi-tasking features of mobile operating systems and multi-core CPUs. This feature allows multiple read and write commands to be executed by the UFS device in parallel, significantly increasing command processing speeds.

Overall the latest version of the standard - UFS 2.1 - can achieve a 40% increase in sequential read speeds, a 20% increase in sequential write speeds, and a 73% improvement in input/output operations per second for random reads compared to the eMMC v5.1 standard.

The net result of these advancements is that overall system performance and user experience is vastly enhanced. UFS 2.1 improves system boot times by 15%, and application loading and switching times by 30%, compared to that of eMMC.

The statistics speak for themselves, but it is important to note that performance is not the be all and end all in the search for a next-generation mobile storage standard.

The Holy Grail of Mobile Storage

Ask a consumer what key requirements they might look for in a mobile storage solution, and they would most likely reply ‘capacity’ or ‘performance’.

However, these are only two factors that must be taken into consideration. Advancements in battery technology have remained relatively stagnant compared to other components in the mobile
technology stack, meaning that manufacturers have been forced to find ways to improve performance and add capacity without drawing additional power.

In a mobile environment, high bandwidth and low-power consumption form the Holy Grail of performance for storage. It is a balancing act unique to the mobile system architecture and requires careful consideration from a design perspective.

Unlike other storage interfaces, UFS has been designed specifically to walk this tightrope. The data transfer protocol uses the MIPI M-PHY physical layer specification to form its interconnect layer. M-PHY is a high-speed interface, tailored specifically to unique challenges that mobile systems present, such as:

- Selection of high speed gears to match the burst speed needed
- Selection of high speed gear and dual rates that allows EMI mitigation for the system integrator
- Availability of low speed communication for control
- Variety of low-power modes with different latencies to reduce total power
- Support for lowest standby power to maintain lowest system power consumption
- Low latency and no need in training sequence, which is ideal for burst traffic common to the mobile device implementation

As designs become more sophisticated and users choose to hold private, corporate or medical information on them, data protection is another key requirement for consumers. The inline cryptography function within the latest UFS standard provides security for data exchanged between the SoC and UFS storage device. Using available resources to complete the cryptographic operation helps in keeping system cost down.

**Understanding the Relationship Between Performance and Power Consumption**

As previously mentioned, increased bandwidth cannot afford to be at the expense of additional power consumption when it comes to mobile. It is not simply a case of how fast you can transmit data from point A to point B; it is about how you transmit that data in the most economical fashion. And this is where UFS truly rises above other competing standards.

UFS consumes less power than other mobile storage solutions for most standard applications. This is because its physical layer has been optimized for high-speed burst transmissions. While power consumption is higher than eMMC in active mode, UFS is able to rapidly transmit more data, allowing a return to an idle state faster. Due to its near-zero power draw in idle mode, the accumulative effect of this efficient transition between active and power saving states, is a significant reduction in overall power consumption.
Furthermore, UFS enables asymmetric lane configuration when needed. Using higher bandwidth and/or more lanes in one direction is typical of certain storage modes, such as reading high content media from the device, or storing streaming video. This enables more effective communication between the SoC and the storage device and leads to power reduction and battery savings.

Mobile devices pack multiple ICs in a tight area, which leads to major electromagnetic interference (EMI) concerns for integrators of these devices. JEDEC UFS has the ability to modify transmission rate and frequencies by utilizing MIPI M-PHY flexibility in selection of six different high speed gears and rates, which eases system integration and avoids EMI issues.
Figure 5: MIPI M-PHY high speed gears and rates allow flexibility in meeting power and EMI system constraints

<table>
<thead>
<tr>
<th>High-speed GEARs</th>
<th>Rate A – Series (Gbps)</th>
<th>Rate B – Series (Gbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS-G1 (A/B)</td>
<td>1.248</td>
<td>1.4576</td>
</tr>
<tr>
<td>HS-G2 (A/B)</td>
<td>2.496</td>
<td>2.9152</td>
</tr>
<tr>
<td>HS-G3 (A/B)</td>
<td>4.992</td>
<td>5.8304</td>
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</tbody>
</table>

**Scalability + Flexibility = Futureproof**

If history has taught us anything, it is that the demands placed on performance are growing at an exponential rate. Scalability is therefore critical to any new storage standard. The M-PHY interface currently used in UFS v2.1 supports data rates between 1.25Gbps and 5.8Gbps per lane and typically uses up to two receive and two transmit lanes, meaning that UFS is well positioned to meet future needs.

This flexibility lends itself to mobile systems. Requirements differ from device to device, meaning the need to balance between performance and power is even more acute. System level factors such as peak power and thermal signature must be taken into consideration. A system with UFS 2.1 as the storage device can utilize different high-speed gears. This flexibility allows vendors to choose optimal performance based on power budget and other system level considerations.

It was noted earlier that JEDEC has already published a standard for removable UFS cards. While SD card is currently the dominant standard in the removable storage arena, its performance capabilities do not stack up to UFS. The disparities in performance would become painfully obvious if the two standards were included on the same device; that approach is avoided by system integrators to maintain customer satisfaction utilizing the high performance UFS device. Lastly, UFS is the only next-generation mobile storage standard available in both embedded and removable formats, making it a strong contender to dominate the mobile storage market in coming years.

**Moving into the Mainstream**

Building on the foundations laid by the successful eMMC standard, JEDEC’s new UFS standard provides benefits not offered in other mobile storage interfaces.

Full-duplex serial implementation and command queuing offer bleeding-edge performance, but not at the expense of power consumption. Mobile storage architecture requires a holistic approach, looking at the capabilities and bottlenecks of the entire system. Using MIPI M-PHY allows scalability and flexibility in data rates, catering to a wide range of requirements.
Since it was released, eMMC has become the definitive standard for mobile storage applications. Striking an ideal balance between performance and cost, the standard is likely to remain a mainstream solution in low- to mid-range devices for the next few years.

As the high end market transitions from eMMC to UFS, a popular approach is to use the two standards side-by-side, using the eMMC device for mainstream markets and connecting the UFS embedded or removable card in high-end markets.

While UFS will cater to the high-end market at first, the need for high-performance, low-energy storage will likely see the standard quickly move into the mainstream. UFS usage in high-end phones is starting to trickle to mainstream mobile markets, and in the near future expected to be used in automotive and consumer applications.

—Hezi Saar serves as a staff product marketing manager at Synopsys and is responsible for its DesignWare MIPI controller and PHY IP product line. He brings more than 16 years of experience in the semiconductor and electronics industries in embedded systems.

Also see:

- UFS closing in on mobile apps
- Which mobile protocol is ideal for your next-generation design?
- Application simplifies eMMC compliance testing