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Performance Comparison of UFS Embedded Memory with Other Storage Technologies

Introduction

As mobile and portable computing evolves, so does the demand for faster, more efficient storage solutions. That's why universal flash storage (UFS) was pioneered. Created by JEDEC as a new standard, UFS was built in the pursuit of similar performance levels of embedded storage options.

However, every memory technology has its benefits and limitations. In this article, we'll compare UFS against eMMC, as well as traditional secure digital (SD), microSD and microSD Express cards, highlighting its key performance niches and providing something of a benchmarking standard for the technology.

Overview Of Storage Technologies

UFS implements a serial interface architecture based on MIPI M-PHY and UniPro protocols, utilizing:

- Full-duplex data transfer capabilities
- Command Queue Engine (CQE) for concurrent operations
- Multi-lane operation support (up to two lanes in current implementations)
- NAND flash memory arrays with advanced controller architecture

There's no shortage of storage technologies on the market. However, these characteristics and use cases highlight other competing technologies, primarily eMMC solutions.

eMMC

eMMC is commonly found as embedded storage in budget to mid-range smartphones, tablets, and internet of things (IoT) devices, offering a good balance of performance and cost. Factors to note include:

- Parallel interface architecture
- 8-bit data bus
- Single-direction data transfer
- Simpler command structure

Alternative Non-Embedded Storage to Consider

While UFS embedded memory primarily competes with eMMC solutions, it is worth giving a little consideration to other storage options which may offer similar functionality:

Traditional SD and microSD Cards

Traditional SD cards are most widely used in consumer cameras, mobile phones, and portable devices, and are becoming something of a legacy technology. You will still find them used in older devices, and where cost and universal compatibility are more important than maximum performance. They offer:

- Serial interface with up to 4-bit data bus
- Half-duplex operation
- Fixed command structure
- Limited command queuing capabilities

SD Express/ microSD Express

SD Express cards are primarily used in high-end cameras, gaming devices, and professional recording equipment. They shine where fast data transfer speeds are crucial, but backward compatibility with regular SD slots is needed. Their key characteristics are:

- PCIe NVMe interface implementation
- Backwards compatibility with legacy SD hosts
- Single-lane PCIe operation
- Optional support for NVMe protocol

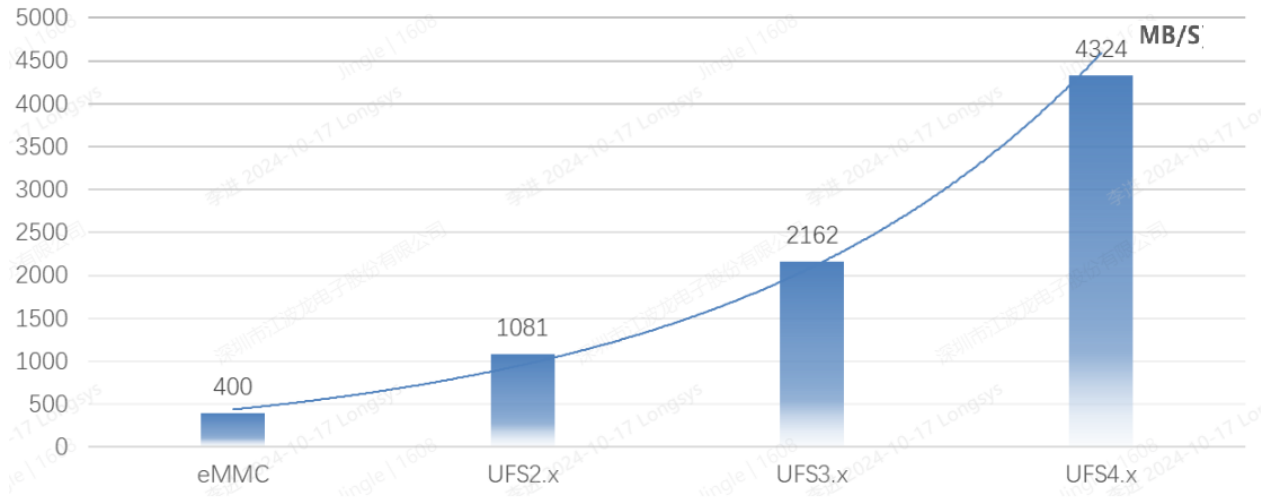
As you can see, embedded storage technologies are the primary storage choice for modern applications, with removable card-based storage, such as traditional and express cards, remaining mostly as a legacy technology for backward compatibility.

Performance Analysis: UFS vs eMMC

Let's begin by analyzing the basic performance of these two key technologies, beginning with their sequential read/write performances.

Technology	Sequential Read	Sequential Write
UFS 2.1	Up to 750MB/s	Up to 380MB/s
UFS 2.2	Up to 850MB/s	Up to 450MB/s
UFS 3.1	Up to 2100MB/s	Up to 1200MB/s
UFS 4.1	Up to 4200MB/s	Up to 2800MB/s
eMMC 5.1	Up to 400MB/s, but highly variant based on manufacturer and card	Up to 250MB/s, but highly variant based on manufacturer and card

Obviously, these performance benchmarks are highly dependent on the manufacturer for the technology. In the following graph, you can see performance evolution of UFS technology from eMMC.



However, read and write speeds are not the only metric to consider. UFS demonstrates significant advantages in random access operations:

- 4K Random Read: Up to 160,000 IOPS
- 4K Random Write: Up to 40,000 IOPS

Meanwhile, comparative metrics for eMMC solutions are as follows:

- eMMC: 15,000-20,000 IOPS (read)

Additionally, the unique UFS architecture offers superior latency metrics through:

- Parallel command execution,
- Advanced command queuing, and
- Reduced protocol overhead.

This leaves us with average latency for UFS and eMMC solutions as follows:

UFS 3.1	< 100µs
eMMC	300-500µs

UFS vs eMMC Power Efficiency Analysis

The suitability of a product for an application isn't only about performance, but also its subsequent power management. UFS implements sophisticated power management features, which include:

- Multiple power modes with rapid transition capabilities
- Dynamic power scaling based on workload
- Efficient idle state management

This leaves us with these comparative power metrics (at maximum performance):

UFS 3.1	• 570-780mW
eMMC	• 400-600mW

The advanced power states in UFS also offer significant idle power advantages:

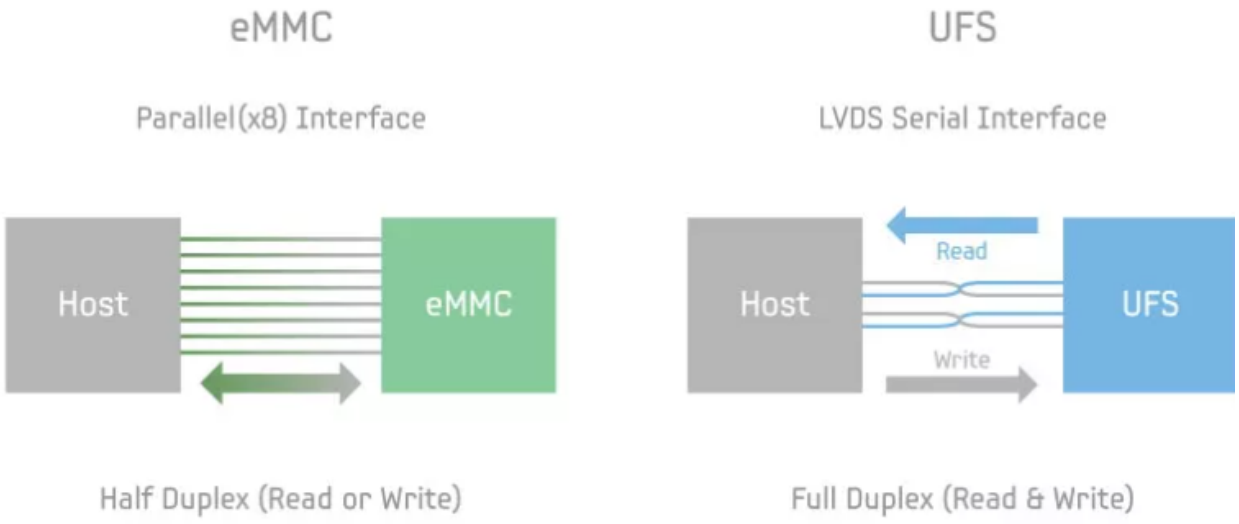
- DeviceSleep (DEVSLP) state: < 1mW
- Hibernate state: < 0.1mW
- Fast recovery times from low power states

Putting Performance to the Test: UFS vs. Competing Embedded and Non-Embedded Technologies

With the technical specifications in hand, below we will look at how UFS memory cards perform against competing technologies from the point of view of real-world applications and uses.

UFS vs. eMMC

UFS first gained prominence as a modern evolution of flash storage technology in the Android smartphone ecosystem around 2016, bringing it into direct competition with eMMC options. As a full-duplex interface, UFS allows for simultaneous reads and writes. eMMC, with either a parallel or half-duplex interface, only allows one operation at a time.



Architecturally, UFS can leverage a faster interface with those separate read/write paths, as opposed to eMMC's single, slower path. This results in faster performance, more suited to high-performance needs and high-end devices than eMMC. eMMC, meanwhile, is cost-effective with adequate basic performance, making it a viable choice for budget and mid-range devices.

While UFS technologies average a premium of 50-250% in cost per GB compared to eMMC, they justify this price difference through significantly better reliability and performance metrics. While it is dependent on the manufacturer, of course, UFS typically offers uncorrectable bit error rates (UBER) that are 10-100 times better than eMMC. The superior endurance ratings of UFS memory (particularly in the 3.1 and 4.1 specifications) support up to 3000 P/E cycles.

UFS vs. non-embedded microSD and SD technologies

Below we will consider SD Express and traditional SD options as a group, with similar performance profiles and applications, and benchmark that against what UFS can offer.

These storage technologies are primarily used to expand the onboard storage capacity of mobile devices. With slower read/write speeds, they often fall short in high-performance applications. Additionally, while they are also increasing in capacity, as there is still a market for these non-embedded options their size and cost constraints mean this scaling will be outpaced by UFS's potential. They are best viewed as a storage solution only. Their stability and reliability can be affected by insertion/removal, dust, and vibration.

UFS, on the other hand, offers exceptional performance and stability, ideal for modern devices, which must run an assortment of applications and games. It can be used as a primary onboard storage solution, offering high performance, compact design, and reliable stability.

UFS storage solutions generally represent a 20-100% cost premium over comparable SD card technologies. However, they deliver superior reliability, with UBER rates approximately 10-100 times better than SD Express. The endurance advantage is equally compelling, with UFS memory supporting 2-6 times more program/erase cycles than typical SD card technologies. This makes UFS the more cost-effective choice for long-term deployment in systems with frequent write operations, despite the higher upfront cost.

What About SSDs?

While solid state drives (SSDs) also represent a valuable storage technology, with immense capability on speed and size and seamless data flow via PCIe buses, they lack the small profile and versatility required for mobile devices and are typically more appropriate to computer-based applications.

UFS excels in mobile and automotive environments due to its compact size, low power consumption, and specialized performance benefits. SSDs, on the other hand, are ideal for general computing tasks due to their larger capacities, faster speeds, and versatility across computing devices.

The FORESEE UFS Difference: Lexar Enterprise's Innovations

The FORESEE UFS has become a cornerstone of Lexar Enterprise's mission to offer high-performance, reliable, and innovative storage solutions across industries and applications. The FORESEE UFS offers:

- File-based optimization
- Host-initiated defrag
- Host performance booster
- Write booster

Additionally, FORESEE UFS offers some key technological innovations:

1. A smart FTL algorithm with multiple tasks in parallel, to improve user experience.
2. A self-adaptive thermal throttling algorithm with multiple levels, to control peak current.
3. An efficient, low power entry/exit strategy, to balance power consumption and latency.
4. An innovative data caching technique, to improve write amplification.

These innovations combine into a product well suited for high-end mobile device applications, offering:

- **High-Performance Storage**: Supporting protocols like UFS 2.2 and UFS 3.1, our UFS solutions offer significant performance improvements over traditional eMMC solutions.
- **Energy Efficiency**: Lexar Enterprise is committed to offering solutions that balance performance with power efficiency, extending the battery life of devices.
- **Capacity**: Solutions are offered from 64GB to 1TB, catering to a wide range of customers, from consumer to enterprise applications.
- **Operating Temperature Range**: FORESEE UFS products operate from -25°C to +85°C, making them suitable for use in various environments. For harsh environments, Lexar Enterprise offers higher temperature ranges like industrial UFS (from -40°C to +85°C) and automotive applications (-40°C to +105°C).

Each UFS is designed to stringent international standards, ensuring reliability and consistency with reduced failure risk and better user experience. These solutions have been deployed in a variety of real-world applications, from smartphones and tablets to smart TVs, wearable devices, AR/VR devices, and IoT devices (UFS 2.2). Additionally, the Industrial Wide-Temperature and Automotive Grade 2 UFS 3.1 series is ideal where consistency, low power consumption, and high-performance are needed, such as automotive applications, with AEC-Q100 qualified options ensuring stringent quality.

The Future of UFS Technology

As UFS technology improves, we can look forward to:

- **Faster Data Transfer Speeds**: Especially with advanced features like command queuing and power gating.
- **Better Power Efficiencies**: Utilizing the M-PHY hibernate mode provides the lowest M-PHY power consumption with HS-burst recovery time in microseconds.
- **Higher Storage Capacities**: Storage capabilities will increase with time and demand.
- **Safety with Security**: JEDEC, the standards body for both eMMC and UFS, has introduced support for inline encryption (IE) and replay protected memory block (RPMB) to protect data confidentiality

and reduce attack vectors native to the UFS specification. Expanded encryption mechanisms are also expected.

There is a growing need for faster data transfer rates in various industries, especially in consumer electronics like smartphones and tablets, that UFS technology can satisfy. The development of newer UFS standards, such as UFS 5.0 and 4.1, also stimulates improved performance and reduced power consumption, further driving market expansion.

Paired with consumer expectations for ever-faster data access and better user experiences, the opening of new market opportunities, and the increased demand for high-capacity, high-performance storage for data centers and cloud computing, we expect the demand for improved UFS technology to expand significantly in coming years.

Currently, the Asia-Pacific region, particularly countries like China, Japan, and South Korea, are leading in the adoption of these advanced storage solutions.

To meet these evolving demands, Lexar Enterprise is focused on evolution in the following arenas:

- **Increased Speed and Bandwidth**: Use of the MIPI M-PHY 5.0 and UniPro 2.0 specifications allow us to double the interface bandwidth, enabling theoretical speeds of up to ~4.2GB/s for both read and write operation.
- **Energy Efficiency**: Lexar Enterprise is developing firmware features such as Write Booster, low power management, thermal throttling, and Host Performance Booster to ensure that flash memory chips deliver in all categories.
- **Adoption in Emerging Markets**: The UFS market is expected to expand into automotive, industrial, and emerging markets, demanding broad compatibility across use cases.
- **Security Features**: As data security grows in importance, Lexar Enterprise intends to introduce further data encryption and security measures.

Lexar Enterprise's Development Roadmap for UFS Solutions

With these goals in mind, Lexar Enterprise is working towards the expected debut of UFS 5.0 by 2027, where we expect sequential read speeds to reach close to 10GB/s. UFS 4.1 is expected in 2026, with speeds reaching 8GB/s.

Additionally, Lexar Enterprise expects expanded AI capabilities (a major market selling point for smartphones), and the introduction of the high-capacity, lower cost QLC UFS to revolutionize the UFS market.

Conclusion

UFS technology offers clear performance advantages over more traditional storage options, especially where high throughput and low latency must be balanced for high performance. As the technology matures, we expect to see continued improvements in performance metrics and power efficiency, solidifying UFS's position as a leading storage solution for next-generation devices.

About Lexar Enterprise

Building upon the foundation and credibility of the well-established Lexar brand, Lexar Enterprise designs and manufactures memory and storage solutions specific to the high-level B2B market. Lexar Enterprise's FORESEE product line provides world-class, durable memory and storage solutions tailored for OEMs, system integrators, industrial, automotive, and commercial customers in the Americas, offering a diverse lineup of products, including:

- OEM, consumer, and industrial-grade storage solutions.
- Mobile memory solutions for commercial and industrial-grade applications.
- Solid-state drives and memory modules for OEM, consumer, and industrial-grade applications.

With a commitment to innovation, performance, quality, and reliability, Lexar Enterprise is perfectly positioned to deliver superior products and support to meet the evolving data storage needs of businesses and industrial applications.