WHITE PAPER

Silicon Motion's Ferri-UFS

sets new performance standard for Flash-based storage in automotive applications

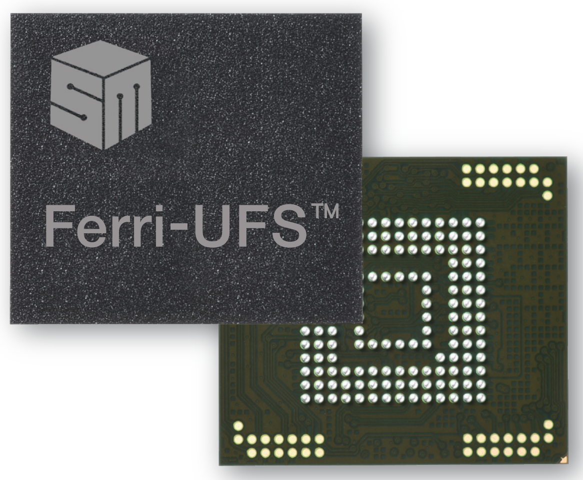
The car is in transition. Once a device primarily for mobility, it is becoming a mobile entertainment and productivity space. Eventually, with the introduction of fully autonomous vehicles, the car will become a type of robot.

These changes will heighten the value that the car buyer attaches to the on-board computing systems for infotainment, safety, system control, the user interface and communications between vehicles and to the outside world. Many of these computing systems will depend increasingly on ready access at high speed to vast amounts of data storage capacity.

The increase in demand for both capacity and speed has driven previous generational shifts in data storage technology in the vehicle, from the old desktop computer-style Hard Disk Drive (HDD) with a PATA or SATA interface to solid-state (semiconductor) storage technologies: first SD cards, then eMMC storage.

Now the next shift is under way in the automotive sector, from eMMC, now at version 5.1 of the specification, to Universal Flash Storage (UFS), a move which promises to provide automotive OEMs with higher Read/Write speeds – between three and four times faster than eMMC v5.1 – and random IOPS performance (input / output operations per second) as much as 2.5 times faster.

This white paper describes the reasons why the UFS interface is a better operational fit for tomorrow's car designs than eMMC, and explains the important performance parameters, product specifications and supplier considerations to take into account when evaluating embedded UFS storage devices for use in automotive applications.



High-level factors driving the shift to UFS technology

The automotive market has been an important consumer of eMMC storage devices since around 2010: while memory devices based on the eMMC interface were first adopted in the mobile phone in the first decade of the 21st century, automotive manufacturers followed the mobile market's lead because of the longer operating lifetime and higher reliability that eMMC devices offered compared to PATA or SATA hard disk drives, which contain moving mechanical parts that are prone to damage when used in the harsh operating environment of an automobile.

Automotive IVI System Trends

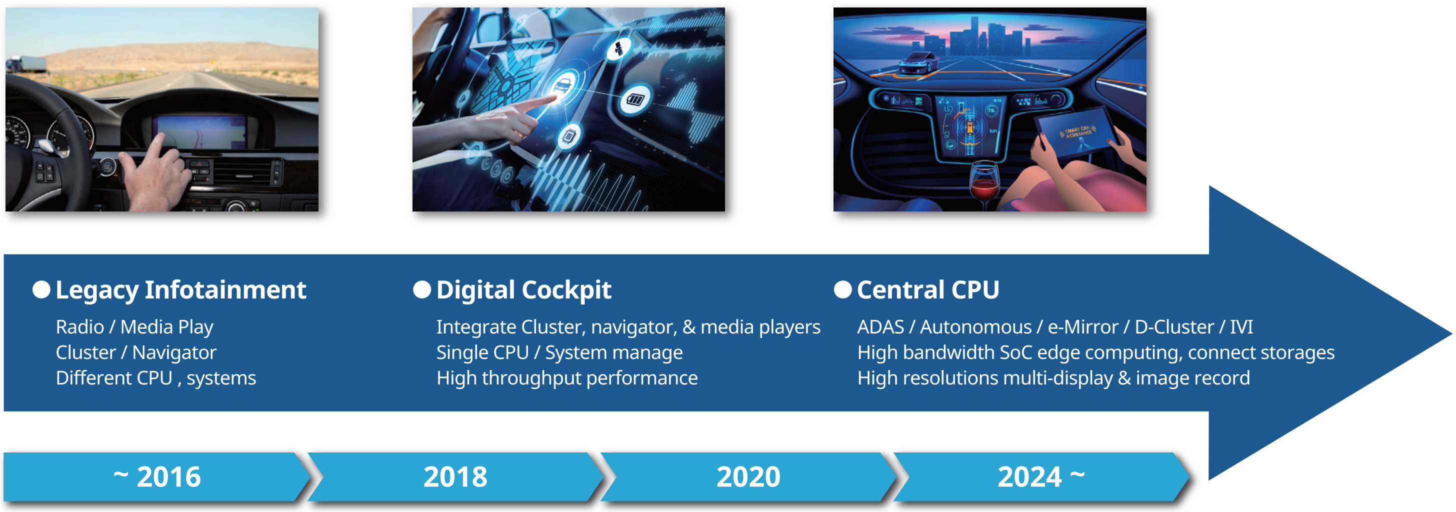


Fig. 1: the architecture of automotive IVI systems is set to change substantially. (Image credit: Silicon Motion)

Automotive designers are now reaching the limits of the eMMC interface's performance, however, as they develop new in-vehicle infotainment (IVI) systems capable of supporting more autonomous driving capabilities, larger and more sophisticated graphical user interfaces, and demanding media applications such as high-definition video playback.

To design the next generation of IVI system, automotive designers are rethinking the architecture. In earlier, simpler IVI systems, it was feasible to use a multi-processor architecture in which each element – such as the instrument cluster, the Center Information Display (CID) and media system, and the navigation system – was controlled by its own, discrete processor chip (see Figure 1).

For new car designs, automotive manufacturers are developing the 'Digital Cockpit', using a highly integrated architecture in which all display functions including the instrument cluster, the media system, navigation and connectivity are controlled by a single, very high-performance processor. In this architecture, data has to flow at a much higher rate into and out of the single processor than it did in the earlier distributed, multi-processor architecture.

And the performance provided by the eMMC interface is simply not adequate to the demands that this single-processor architecture imposes on it. Automotive manufacturers are therefore looking beyond eMMC to the next generation of data storage interface. As Figure 2 shows, a standard dual-channel UFS interface offers a far greater maximum throughput than fifth-generation eMMC.

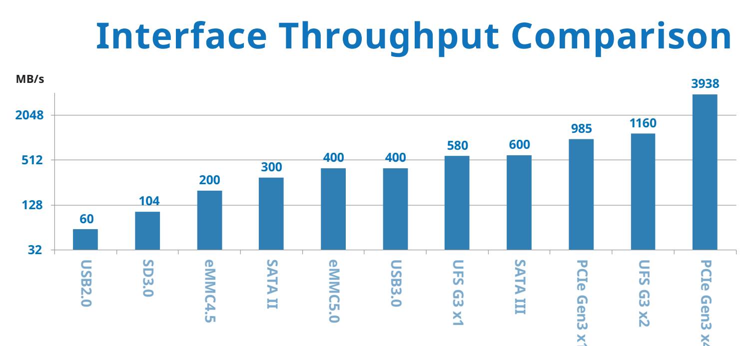


Fig. 2: a dual--channel UFS interface offers a dramatic improvement in throughput compared to the legacy eMMC5.x specification. (Image credit: Silicon Motion)

This theoretical higher data throughput is reflected in the performance attributes of commercially available storage products. A comparison between the performance of Its eMMC-based and UFS storage products is shown in Figure 3.

	Ferri-eMMC (eMMC v5.1)	Ferri-UFS (UFS v2.1)
Maximum interface speed	3.2Gbps	11.6Gbps
Mode of operation	Half-duplex	Full duplex
Multi-tasking support	Read or Write	Concurrent Read and Write
Maximum sequential Read speed	300MB/s	800MB/s
Maximum sequential Write speed	80MB/s	250MB/s
Maximum random IOPS	20,000/10,000	50,000/20,000

Fig. 3: the Ferri-UFS products from Silicon Motion offer data throughput rates more than three times faster than its Ferri-eMMC products

Now the automotive market can benefit from proven UFS interface technology and from abundant supplies of high-performance UFS NAND storage products – although as this paper describes below, crucial differences in product attributes and the supply chain distinguish UFS storage products for automotive applications from those in use in consumer devices.

Ferri-UFS™ product offers easy replacement for eMMC storage devices

The higher data throughput supported by the UFS interface specification compared to eMMC v5.0 or v5.1 provides performance at the product level which is superior by a factor of more than three, as Figure 2 shows. UFS-based storage supports concurrent Read and Write operations, improving multi-tasking support and providing the end user with lag-free switching from one application to another. Very high sequential Read speeds provide for a smooth, glitch-free experience of applications such as High Definition video streaming. A maximum random IOPS rating of 50,000 means that users enjoy the sensation of instant response from even the most compute-intensive applications.

As a result, many automotive manufacturers are now considering the migration of design platforms from eMMC-based storage devices to UFS storage. Automotive users of the Ferri-eMMC™ series from Silicon Motion, for instance, can migrate to the Ferri-UFS™ series and benefit from a simple and quick design integration process.

The Ferri-UFS product, part number SM671, is a highly integrated solution which combines a feature-rich Flash controller confirming to the latest UFS2.1 specification, and standard NAND Flash memory. It supports the UFS v2.1 specification's advanced features such as HS-Gear3 x 2-lane mode, and the command queue function. In addition, Ferri-UFS products can be customized via firmware to provide specific features and applications required by the OEM.

The SM671, in an 11.5mm x 13mm x 1.2mm 153-ball BGA package, is available with memory capacity options ranging from 16GB up to 256GB. It is automotive-qualified to AEC-Q100 Grade 3 for operation at up to 85°C (with Grade 2 qualification pending as of Q2 2019). Its performance is impressively fast: both data-transfer rates and initialization time are more than fast enough for the next generation of automotive IVI designs.

Automotive market considerations

As described above, UFS storage products such as the Ferri-UFS series provide high memory density at an attractive price thanks to their use of the latest standard 3D TLC NAND Flash.

For the automotive market, however, the considerations of **performance and price** have to be balanced with the need for **ultra-high quality and reliability.**

Silicon Motion satisfies this requirement through a combination of:

- **The application of stringent quality processes and criteria**
- **The implementation of proprietary reliability and data-integrity features**

Strict quality criteria

The quality processes are measured against an overall defect rate for production units shipped to customers, of <10ppm – a defect rate which Silicon Motion has met for every customer in every year since it began supplying the automotive market in 2014.

Strict criteria are also applied to the specification of the controller and NAND dies used in Ferri-UFS products. The die selection is made only from high-yield wafers drawn from mature (rather than leading-edge) production processes, by which stage all defects and quality issues have normally been well characterized and so can readily be detected. This means that the production process for a Ferri-UFS product starts with known-good dies.

In addition, every part of the Ferri-UFS supply chain, from the foundry which fabricates the controller to the factory which sorts the wafers to the test and validation facility to Silicon Motion itself are all certified for IATF 16949. Automotive traceability requirements are fully supported – for instance, the Ferri-UFS device's controller die includes a unique chip ID stored in one-time programmable memory so that it can be traced back to its original wafer lot and wafer map.

The Silicon Motion commitment to automotive quality feeds through all the way to final assembly, which takes place on a fully automated line. Test chambers are used to screen every block in every production unit for defects at an operating temperature specified by the customer (see Figure 4). This screening allows Silicon Motion to identify all cells at risk of becoming an early bad block, so that they can be quarantined by the NAND controller before shipment to the customer.

All production units are also exposed to extended temperature testing and high/low voltage testing.

It is because Silicon Motion uniformly applies these processes and criteria to all Ferri-UFS products for the automotive customers that production shipments consistently achieve the target <10ppm defect rate.

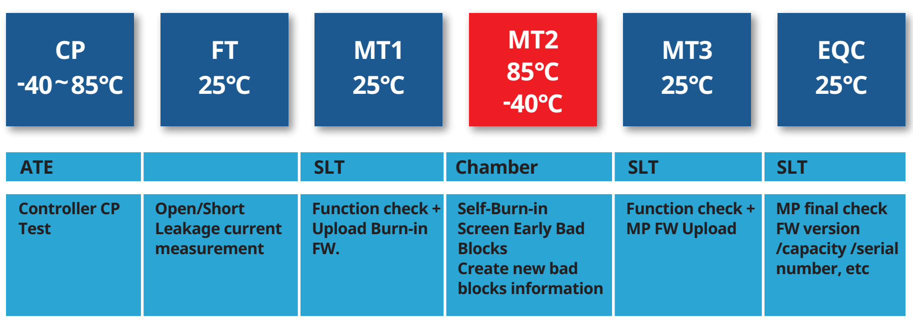


Fig. 4: comprehensive high- and low-temperature test routines are applied to every part shipped to an automotive customer. (Image credit: Silicon Motion)

High data integrity and reliability

In the automotive environment, reliability and a long operating lifespan are core considerations for system designers. For users of UFS storage devices, this calls for close evaluation of two parameters: endurance, and data integrity.

This is because of the inherent characteristics of high-density 3D NAND Flash: fabricated in advanced processes with circuit features of 19nm or smaller, the cells in the 3D TLC NAND Flash in Ferri-UFS products are prone to wear with every program/erase cycle which has the potential to lead to data loss. They are also prone to Read and Write errors unless error-correction functions are implemented.

Silicon Motion addresses the issue of **endurance** through the implementation of sophisticated global wear levelling technology in its NAND controller. In addition, it features advanced technology for prolonging data retention, including:

- **Static Data Refresh – automatically scans cells at a temperature-dependent rate. (Data loss accelerates at extreme operating temperatures.) This function re-writes data in cells at risk of data loss.**
- **Early Retirement – automatically analyses blocks and identifies those at high risk of premature data loss, and retires them from the memory array.**

The effect of these and other lifespan operations is to achieve an endurance rating of 3,000 Program/Erase cycles, surpassing the benchmark typically set by the automotive industry for IVI storage applications.

Data integrity is ensured through the application of error correction technology superior to that typically used in consumer NAND devices. Silicon Motion's advanced LDPC ECC (Error Correction Code) engine eliminates soft errors occurring in Read and Write operations.

Silicon Motion also implements Enhanced Write Protection which offers permanent, temporary and power-on protection options. Special procedures to protect data in the event of unexpected power loss – a relatively common occurrence in the automotive environment – ensure that data that is being written as power goes down is safely stored before the Ferri-UFS device powers down.

These features are backed by 8+1 error detection code applied to the Ferri-UFS SRAM memory.

Finally, the reliability of the total solution provided by Silicon Motion includes its own arrangements for manufacturing and shipping products to meet automotive OEMs' strict just-in-time requirements. These arrangements include full production redundancy assured by the availability of back-up suppliers for every part of the production process, from the suppliers of NAND Flash and controller wafers to chip assembly operators, screening and module assembly.

Conclusion: how the Ferri-UFS series of products meets the requirements of the automotive industry

Data-intensive applications in the car, such as IVI systems, are now undergoing a transition in data storage technology from their current reliance on eMMC-based storage devices to new UFS products using higher-density 3D TLC NAND Flash.

Now Silicon Motion has introduced the Ferri-UFS (SM671) series of products to provide a solution which meets the highest quality and reliability demands while offering the high performance needed to operate effectively in new single-processor architectures deployed in the digital cockpit.

Benefiting additionally from superior data integrity features such as an LDPC ECC engine and from the NAND Flash know-how of the world's leading merchant supplier of SSD/eMMC/UFS controller solutions as well as a robust, redundant supply chain, the Ferri-UFS product line provides a secure way to implement high-performance UFS data storage technology in IVI systems and other compute-intensive applications in the vehicle of tomorrow.

For more information about Ferri Family, please go to **www.siliconmotion.com** or send email to **ferri@siliconmotion.com**

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