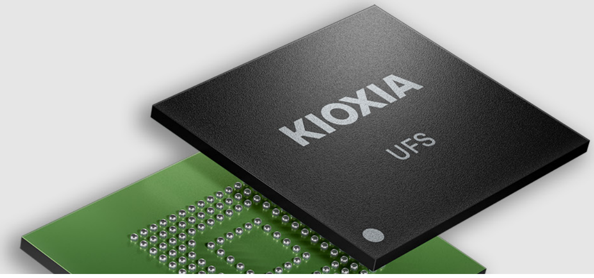
KIOXIA



Technical Brief

Understanding the WriteBooster Feature

How It Enables/Disables the pSLC Buffer in UFS Devices[1] to Enhance Write Performance with Minimal Impact on Reliability

The electronics that have evolved in many modern-day devices are very smart, store more data and enable 'near-instantaneous' access to information. Universal Flash Storage (UFS) is a product category for a class of embedded products targeted for applications that require high-speed performance at low power consumption, and is widely used in smartphones today. UFS devices were first introduced in 2013[2] by KIOXIA Corporation (formerly Toshiba Memory Corporation) and were based on version 1.1 of the UFS specification issued by JEDEC®. To date, UFS adoption has extended to other major market segments that include industrial, Internet of Things (IoT) and automotive based on its high performance, strong reliability, cost competitiveness and long life expectancy.

In 2020, version 3.1 (v3.1) of the UFS specification was standardized at JEDEC. In earlier UFS versions (i.e., v2.1 and v3.0), there was no capability available to temporarily enable/disable a Pseudo SLC (pSLC)[3] Write Buffer. To improve reliability without the use of a pSLC Write Buffer, some UFS suppliers would write data directly into Multi-Level Cell (MLC) or Triple-Level Cell (TLC) NAND flash memory. This approach negatively impacts performance. In other cases that required faster write performance, UFS suppliers would use a pSLC Write Buffer to write to NAND flash memory. This approach improves performance but negatively impacts reliability.

What is required is a capability that combines the best of both writing methods where better overall reliability and extra write performance can be enabled when needed. The UFS v3.1 specification addresses this objective through its WriteBooster feature – a capability that delivers added write performance for storing data and considers how that additional performance will impact reliability when pSLC Write Buffers are used. This tech brief presents this information, and provides use case examples to showcase how the WriteBooster feature can be used in other market segments.

How WriteBooster Delivers Added Write Performance

The WriteBooster feature utilizes a pSLC Write Buffer to improve write performance. When the WriteBooster feature is enabled by the host, the UFS device will temporarily write data to the pSLC Write Buffer that has a finite capacity size and can fill up. If the capacity becomes full, the pSLC Write Buffer will no longer be able to store data. If this occurs, data that was intended to be stored in the pSLC Write Buffer will be written to the User Area (which is typically TLC), and in turn performance will be reduced. To recover the space used by the pSLC Write Buffer, the host can direct the UFS device to flush data from the pSLC Write Buffer to the User Area when the UFS device is in idle or hibernate mode (Figure 1).

Figure 1 below depicts three WriteBooster operations:

- Case 1 shows that the WriteBooster is disabled when the fWriteBoosterEn flag set to '0.' During this operation, the UFS device will write data to the User Area and delivers typical write performance.
- Case 2 shows that when the host needs to increase write performance, it can enable the WriteBooster feature by setting the fWriteBoosterEn flag to '1.' The UFS device will continuously write all data to the pSLC Write Buffer for as long as there is space in the buffer to store it. For this operation, it is advised for the host to direct the UFS device to flush data from the pSLC Write Buffer and move it to the User Area before the pSLC Write Buffer capacity depletes.
- Case 3 shows the UFS device in data flush mode during idle time. For this, the host sets the fWriteBoosterBufferFlushEn flag to '1.' For this operation, the host can also enable the UFS device to flush data in hibernate mode by setting the fWriteBoosterBufferFlushDuringHibernate flag to '1.'

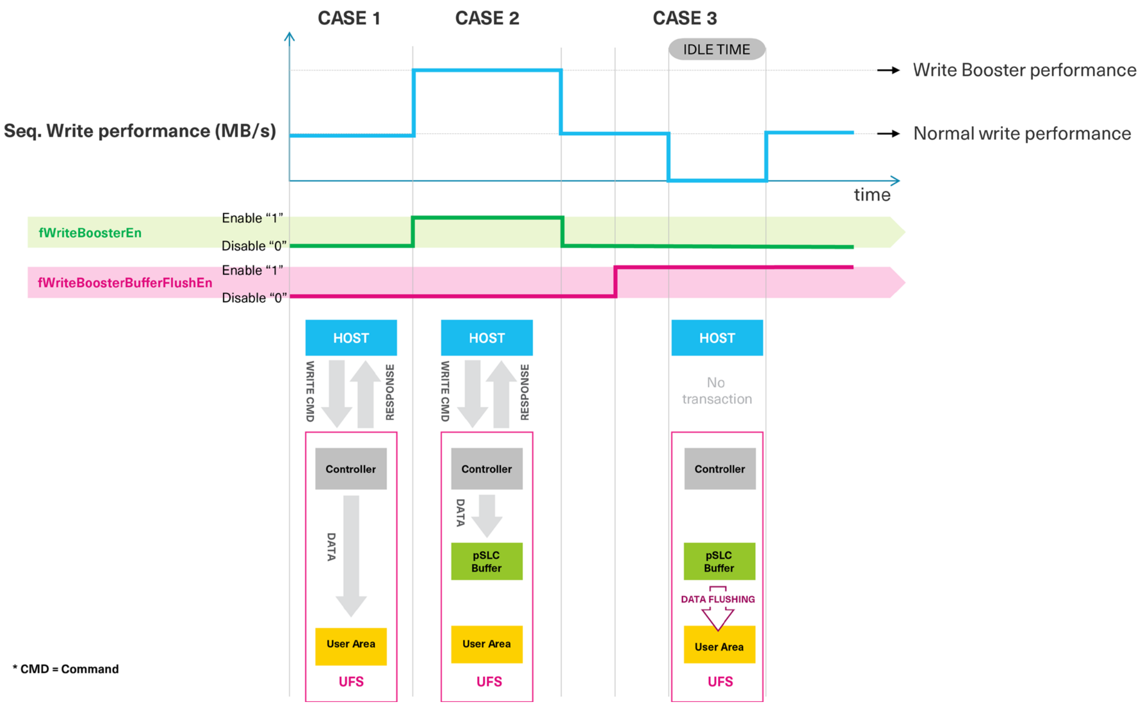


Figure 1 showcases the effects of the WriteBooster feature when disabled, enabled and when data is flushed

Reliability Consideration Associated with WriteBooster

Although using the pSLC Write Buffer can significantly increase write performance, there is a reliability consideration that should be taken into account when the WriteBooster feature is enabled.

In Figure 2 below, the top WriteBooster image shows how a pSLC buffer worsens the Write Amplification Factor[4] (WAF) since data is written to the pSLC buffer first, and then written to the TLC user space. The bottom image represents normal write operations without the WriteBooster feature enabled and shows that the pSLC buffer is not being used. For this operation, data is written directly to the TLC user space.

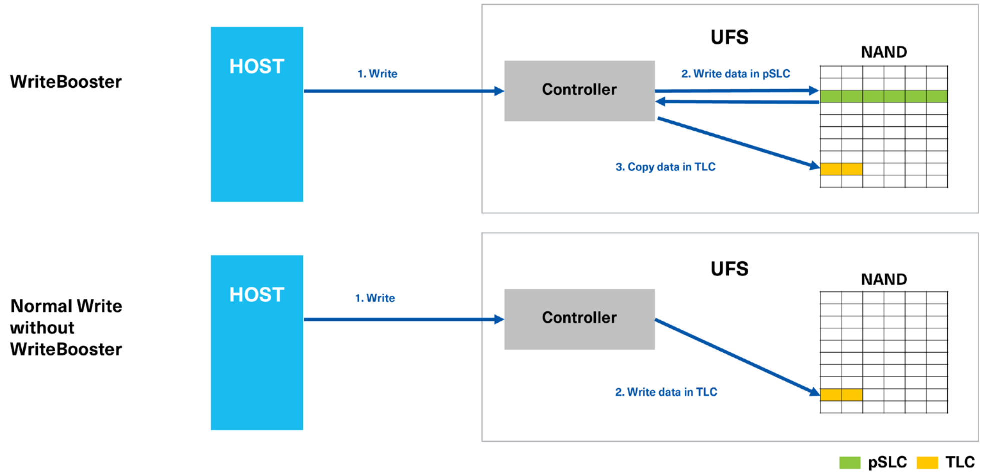


Figure 2 depicts write operations with and without the WriteBooster Feature enabled

For the Figure 2 example above when the WriteBooster is enabled, data will first be temporarily written to the pSLC buffer causing an increase to the WAF. This is a result of writing to a 1-bit per cell pSLC buffer area in a TLC-based UFS device. As more data is written, the pSLC buffer will eventually become full. When this occurs, the pSLC buffer will need to be flushed to the TLC User Area. Additionally, the flush operation will temporarily cause a drop in write performance as it is being executed in the background.

To avoid this performance degradation, the WriteBooster feature can be enabled specifically for data that requires high bandwidth, addressing the endurance and performance degradation issues. The host can enable or disable the pSLC buffer through the fWriteBoosterEn flag. So when high performance is needed, the host can enable the WriteBooster feature, and to avoid a worsening WAF, the WriteBooster feature can be disabled when this higher performance is not needed. The host can also control WriteBooster flush timing during idle time through either the fWriteBoosterBufferFlushEn flag or the fWriteBoosterBufferFlushDuringHibernate flag.

WriteBooster Use Case Examples

Today, more people use their smartphones to do tasks that were traditionally performed on personal computers, and in some cases, smartphone performance may exceed that of PCs. The WriteBooster feature performs a task exactly as its name implies – it specifically boosts the sequential write performance in UFS devices. When the WriteBooster feature is enabled, write performance can reach over 1 gigabyte per second (GB/s), making it comparable to PCIe® Gen3 SSD performance. It's somewhat like putting an SSD into a smartphone to emulate a PC. As 5G smartphones become mainstream, the WriteBooster feature can unlock the full bandwidth of 5G and its high network speed, delivering faster 4K movie downloads and increasingly immersive mobile gaming experiences.

The WriteBooster feature can also improve the programming times of UFS devices during the manufacturing process. To achieve high volume production, UFS devices are typically programmed with customer specific data or an operating system. These images can be very large and take several minutes to program one UFS device if the device is not equipped with the WriteBooster feature. When the device is equipped with WriteBooster enabled, the write performance delivered can be two to three times faster[5], significantly improving manufacturing efficiency. As mentioned previously, the WriteBooster feature has a finite capacity size, if a customer's image size is larger than the WriteBooster capacity, the entire image may not be stored and the WriteBooster feature should not be used.

A final use case can be seen in Over-The-Air (OTA) updates, which provide a more efficient way for OEMs to fix software bugs and update revisions, and offer a very convenient mechanism for consumers to receive software updates. OTA update technology is widely used in the mobile market and is making its way into automotive and IoT markets with such products as In-Vehicle Infotainment (IVI) systems and smart speakers. The OTA update technology will pause the use of certain UFS device features at times in order to update the device, so update times need to be as fast as possible. The WriteBooster feature can significantly decrease OTA update times.

Summary

The UFS v3.1 specification includes a WriteBooster feature that provides the best writing method where better overall reliability and extra write performance can be enabled when needed. The feature not only delivers added write performance for storing data, but also considers how that additional performance can impact reliability when write buffers are used. This capability has a positive effect on such use cases as downloading movies, updating mobile gaming details, improving manufacturing efficiencies and speeding up OTA update times, to name a few.

With high performance, low power consumption and a full-duplex architecture, UFS has become the most widely deployed flash memory in smartphones today, and continues to be adopted into other applications. UFS devices provide small storage form factors, large storage densities, fast transfer rates and low power consumption (for battery-operated UFS devices as a means to extend batter-life).

General information for KIOXIA managed flash memory types is available here.

NOTES:

[1] Universal Flash Storage (UFS) devices are based on the UFS specification, of which, v3.1 specification is the current release issued by JEDEC and published in January 2020.

[2] Source: KIOXIA, as of February 2013, https://www.prnewswire.com/news-releases/toshiba-ships-samples-of-industrys-first-universal-flash-storage-devices-190309341.html.

[3] Pseudo SLC is a capability within NAND flash memory that effectively converts Triple-Level Cell (TLC) NAND flash memory (3-bits per cell) or Multi-Level Cell (MLC) NAND flash memory (2-bits per cell) to Single-Level Cell (SLC) type cells (1-bit per cell). When configured to pSLC NAND technology, each cell's reliability, specifically Write/Erase (W/E) endurance and data retention characteristics, substantially improve. The trade-off is a reduction of bits available for storage in the area allocated for pSLC.

[4] The Write Amplification Factor (WAF) is an estimation formula used to help define the ratio of physical writes made to flash memory divided by the logical writes delivered from the host, and is dependent upon the workload or size of data written from the host.

[5] Source: https://business.kioxia.com/en-us/news/2020/memory-20200225-1.html. The comparison included one UFS device supported by the UFS v3.1 specification and a capacity size of one terabyte versus one UFS device supported by the UFS 3.0 specification and a capacity size of 256GB. Definition of capacity - KIOXIA Corporation defines a kilobyte (KB) as 1,000 bytes, a megabyte (MB) as 1,000,000 bytes, a gigabyte (GB) as 1,000,000,000 bytes and a terabyte (TB) as 1,000,000,000,000 bytes. A computer operating system, however, reports storage capacity using powers of 2 for the definition of 1Gbit = 2^{30} bits = 1,073,741,824 bits, 1GB = 2^{30} bytes = 1,073,741,824 bytes and 1TB = 2^{40} bytes = 1,099,511,627,776 bytes and therefore shows less storage capacity. Available storage capacity (including examples of various media files) will vary based on file size, formatting, settings, software and operating system, and/or pre-installed software applications, or media content. Actual formatted capacity may vary.