Solid State Storage

in Military and Aerospace Applications

Revision history:

Rev.	Date	Changes	Sign
1.0	28-MAR-14	Document created	EB
1.1	24-MAY-14	Minor updates and grammatical corrections	EB
1.2	30-JAN-15	Updated MLC capacity	EB
1.3	07-JUL-16	Updated MLC and SLC capacity and P/E numbers Updated footer notes	CG HT
1.4	24-APR-17	Udpates for capacity updates and for eMLC	HT

Abstract

This document describes the different types of Solid State Storage available on the market today. The types are evaluated from a technical and commercial standpoint with respect to the relevance for their use in military and aerospace applications. The most important benefits and concerns with the different storage technologies are discussed.

1 FLASH based Solid State Storage

1.1 Introduction

There are currently 2 main types of FLASH memory used in solid state storage devices: Multi-Level Cell (MLC) and Single Level Cell (SLC). The SLC technology stores a single data bit per memory cell. The Multi-Level Cell technology stores data by programming a memory cell with two or more bits by altering the programming level of the cell. Hence, a two-bit cell can be visualized as follows:

State	Corresponding Data Value
Fully erased	00
Partially erased	01
Partially programmed	10
Fully programmed	11

Table 1, Two-bit memory cell.

MLC technology is evolving very quickly, and there are several variants on the market. Tri-level (TLC) and Enterprise MLC (eMLC) are two such derivatives. There are also more exotic variants based on 3D memory cells in development, but these are not commercially available yet and not covered by this article.

1.2 SLC Memory

SLC memory is primarily used in Military applications. Since only a single bit is stored per memory cell, SLC technology offers low data density compared to other memory technologies. The main benefit of SLC technology is very high reliability due to the robustness of the single bit programming. Most SLC SSDs are guaranteed for over 100 000 program-erase cycles and very long data retention periods in excess of 10 years. Some vendors also offer extremely wide temperature range (-50°C to +115°C) and even space qualified SSDs.

Due to the relatively low-volume market (compared to MLC technology used in the commercial market), the SLC technology is typically lagging by one or two generations compared to MLC technology. Until 1-2 years ago, SLC were outperforming MLC based SSDs on write performance due to more efficient programming of single level cells. This is no longer the case;

due to previous generation controllers typically used on SLC SSDs in combination with higher capacity MLC based SSDs typically having an internal architecture with multiple memory banks allowing for parallel access to the memory cells for increased performance.

Due to low volume, low capacity and very specialized designs, the SLC based SSDs are significantly higher cost per gigabyte compared to any other storage technology. The prices are relatively stable and does not show the downward trend experienced in other memory technologies.

1.3 MLC Memory

MLC based memory is now the most commonly used throughout the industry, both for commercial and industrial applications. Due to the multi-bit per cell technology, it is possible to create much higher memory densities using MLC technology compared to SLC. A lot of effort is put into developing ever increasing capacities and higher performance SSDs by the vendors in this market segment. The technology drive is pushed by the exponentially increasing storage demand in the consumer and professional markets. The technology follows Moore's law with capacities doubling every 12-18 months while prices are cut in half at approximately the same rate for commercial grade parts.

The demand for increased capacity and performance also in the industrial and military markets have resulted in a wide offering of MLC SSDs supporting extended temperatures and rugged environments. Although MLC technology by nature is less robust than SLC technology, the rapid development of MLC FLASH controllers has mitigated much of this concern. Both controllers and FLASH is offered as full industrial grade components. Serious vendors of MLC based industrial SSDs now offer very reliable SSDs with extended temperature range, -40°C to +85°C, conformal coating, and mechanically stabilized designs.

Due to better controllers and parallelized designs, the performance of the MLC based SSDs now outperform the SLC technology. Sustained write speeds in excess of 500MB/s with 6 Gbit SATA 3 interfaces possible..

The combination of excellent performance, high capacity, good reliability and competitive pricing makes MLC based SSDs an attractive alternative for many military and industrial applications.

MLC technology is more susceptible to memory cell wear-out than SLC technology. Typical MLC based SSDs guarantee 3000 to 5000 write-erase cycles per memory cell. Advanced FLASH controllers have algorithms to ensure that the wear is equally distributed over all the memory cells in the device. Further, most SSD vendors include 5-15% over-capacity in the FLASH. These spare memory cells are not directly accessible by the user, but are used by the controller as backup cells to replace memory cells which are starting to see signs of wear.

1.4 eMLC Memory

The term “Enterprise MLC” (or sometimes referred to as “Enhanced MLC”) is used for SSDs targeted for high endurance applications such as use in data center and high performance servers. eMLC is enhanced technology to mitigate the write endurance issues encountered with standard MLCs. By enhancements to the memory cells, the number of guaranteed program-erase cycles is increased to 20 000 to 30 000 cycles, thus improving write endurance by a factor of 5-10 compared to standard MLC technology.

Due to the improved write endurance, eMLC is commonly used in enterprise applications (hence the name), where 24/7 operation is required.

eMLC is currently only marketed for the 0 to +70°C temperature range, as this is what is required for enterprise environments. Some vendors still use industrial grade components in their designs.

1.4.1 eMLC drives at extended temperatures

Galleon Embedded Computing have performed extensive testing on eMLC drives from several manufacturers, and have found that it is possible to select devices which will pass functional and performance tests at room temperature.

However, the testing has also proven that eMLC drives wear out is actually worse than MLC when at high temperatures. i.e. the key advantage of eMLC is lost when the drive is stored or operated at high temperatures.

As a result of this testing, Galleon no longer offers eMLC drives for our rugged recording products, where high temperature operation is typically required.

2 SSD Comparison Chart

The below table lists key parameters for the various SSDs discussed in the previous sections.

Parameter	Commercial Grade MLC	Industrial Grade MLC	Enterprise Grade eMLC	Military Grade SLC
FLASH Technology	MLC	MLC	eMLC	SLC
Max Capacity*	2TB	10TB	1TB	2TB
Temperature range**	0 to +50°C	-40°C to +85°C	0°C to +70°C	-55°C to +115°C
Write endurance (program erase cycles)	3K-5K	3K-5K	25K-30K	>100K
Secure Erase***	no	yes	no	Yes
Conformal Coating Options	no	yes	no	yes

Table 2, SSD Comparison Chart.

* Available per January 2015
** As specified by factory reported on individual drive level
*** On select models only.

3 Write Endurance Considerations

In some cases, the write endurance characteristics of MLC SSDs are a concern. The average daily program-erase cycles experienced by a memory cell are highly dependent on the application and usage model. Let's consider two example scenarios:

a) A mission data recorder is used to store video captured in-flight. The capacity of the storage media is equivalent to the amount of data captured during the flight. In this case, data is sequentially written to the storage media until the media is full, and/or the flight is complete. After the flight, the data is copied to ground based storage and the storage media is erased and prepared for the next flight. Each flight represents a single write-erase cycle. The entire capacity is written once, and read once, per flight. Due to over-provisioning, the full capacity write only writes to 85-90% of the actual memory cell capacity. Assuming the storage media is used for one flight per day, 365 days per year, the media will wear out after 10 years. SLC based SSDs on the other hand would last over 100 years if used in this application! Note that we are considering write endurance only in this example, and not taking other factors like temperature variations, humidity, vibration, etc, into account.

b) Let us now consider an instrumentation recorder which is used to record experiments of some sort. The recorded data will continuously be written to the storage media until a trigger stops the recording. The storage media is used as a ring-buffer, and will start over from the beginning immediately when the full capacity is reached. Each full capacity write represents a program-erase cycle. Contrary to scenario a) above, the media will be programmed and erased multiple times during each experiment. Assuming the data rates are such that the media is filled once per 30 minutes of recording, a 24-hour experiment will be equivalent to 48 program-erase cycles. If used 8 hours per day every day (including weekends), the media will be worn out in less than six months when using standard MLC SSDs. However, if SLC based SSDs were used, the usable timeframe would be extended to 15 years or more with this usage pattern.

Consequently, the selection of storage media type is highly dependent on the usage model being applied.

There are, however, other factors which might further complicate the picture. Let us assume scenario b) above one more time:

Let us also assume that we use MLC technology SSDs. Given the example above, the media would wear out in 6 months in this case, given a certain storage capacity and average data rate. Now, if we could double the capacity of the SSD, the time to fill the entire capacity would be twice as long, and consequently the time to wear out the media would increase from 6 months to 1 year, everything else being equal. Note that the same also applies to a), since only ½ the capacity of the media would be used per flight. Using higher capacity storage media than what is strictly required could be cost effective in use-cases where media wear-out is a concern.

Note that write endurance (and data retention) is adversely affected by high temperatures. This negative effect of high temperature on wear out is much greater with eMLC drives than with MLC or with SLC drives (as mentioned in section 1.4.1 above).

4 Galleon SSD Offerings

Galleon offers the full range of solid state storage media, from commercial grade MLC to military grade SLC. The offerings are continually monitored and updated as required, when old SSDs go obsolete and new variants enter the market. The Galleon product is based on combining multiple SSDs into a single Removable Data Module (RDM).

Galleon RDM P/N	Type	Capacity	Operating temp range*	Comments
XSR-RDM-xxxxC-x01	MLC	1TB, 2TB, 4TB	0°C to +50°C	Low cost. Very high performance. Commercial grade, MLC. Not conformal coated.
XSR-RDM-xxxxL-x01	MLC	1TB, 2TB, 4TB, 8TB	-40°C to +71°C	Good performance. Industrial grade, MLC. Conformal coating. Excellent price/performance ratio.
XSR-RDM-xxxxI-x01	MLC	1TB, 2TB, 4TB, 8TB, 10TB, 20TB	-40°C to +71°C	Good performance. Industrial grade, MLC. Conformal coating. Good price/performance ratio. Very high capacity. US Manufacturer
XSR-RDM-xxxxS-x01	SLC	1TB, 2TB, 4TB, 8TB	-50°C to +75°C	Extremely high endurance. Good performance. Military grade, SLC. Conformal coating. Highest cost.

Table 3, Galleon SSD Offerings.

xxxx Unformatted drive capacity in GB (i.e. 1000 = 1TB)
* Operating temperature when installed in the Galleon XSR recorder/server

5 Lifecycle Management Considerations

Due to the very rapid development in the Solid-State Storage market, classic lifecycle management with 10-15 years' scope is not feasible for SSDs, with the possible exception of military grade SLC devices where vendors try to extend the lifecycles of the offered products by stocking FLASH chips and controllers to support existing programs.

Galleon continuously monitor the SSD market space and add new SSD options as they become available. Simultaneously, it is necessary to phase out parts which are announced End of Life (EOL), or simply become unavailable in the market. The latter is typically the case for commercial grade SSDs which are discontinued by the vendors with no notice.

In such cases, Galleon strives to offer functionally (FFF) equivalent products with equal or better performance on all relevant parameters compared to the discontinued product.

Before a new SSD vendor or part is offered as part of Galleon's product offering, the SSD go through extended test and qualification in Galleons laboratories validating drive build quality, component selection, performance, etc, as well as thorough scrutiny of the vendors' quality management system, previous delivery performance, and so on.

6 Questions or Comments

This whitepaper will be updated on a regular basis as SSD technology evolves.

Any questions or comments to the contents are welcome and appreciated. Please contact Espen Bøch, Galleon VP of Sales and Marketing at eboch@galleonec.com or send your feedback to info@galleonec.com

7 References

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