

Preface

Solid State Drives (SSDs) are gaining momentum in enterprise and client applications, replacing Hard Disk Drives (HDDs) by offering higher performance and lower power. In the enterprise, developers of data center server and storage systems have seen CPU performance growing exponentially for the past two decades, while HDD performance has improved linearly for the same period. Additionally, multi-core CPU designs and virtualization have increased randomness of storage I/Os. These trends have shifted performance bottlenecks to enterprise storage systems. Business critical applications such as online transaction processing, financial data processing and database mining are increasingly limited by storage performance.

In client applications, small mobile platforms are leaving little room for batteries while demanding long life out of them. Therefore, reducing both idle and active power consumption has become critical. Additionally, client storage systems are in need of significant performance improvement as well as supporting small robust form factors. Ultimately, client systems are optimizing for best performance/power ratio as well as performance/cost ratio.

SSDs promise to address both enterprise and client storage requirements by drastically improving performance while at the same time reducing power.

Inside Solid State Drives walks the reader through all the main topics related to SSDs. Chapter 1 provides an overview of the SSD market and applications, including a review of client PC, tablet, and enterprise computing usage models.

A Solid State Drive is a very complex system: Chap. 2 contains an overview of the main blocks, including hardware and software.

Chapters 2 and 3 cover different SSD implementations with host interfaces ranging from SAS/SATA to PCI Express (PCIe). SAS/SATA offer compatibility with legacy storage infrastructure. However, for many applications, NAND Flash read and write speeds are exceeding the capabilities of these legacy interconnects. PCIe SSDs overcome this bottleneck and deliver unparalleled performance while, at the same time, reducing latency, power and cost by eliminating the traditional storage infrastructure and attaching directly to a platform's PCIe I/O interconnect.

SSDs and HDDs can also be combined together in various forms, as explained in Chap. 4 where "hybrid" storage is analyzed.

At the end of the day, a SSD is made up of NAND memories and a controller. Therefore, to understand SSDs it is important to understand all the basics of NAND Flash technology (Chap. 5) as well as design (Chap. 6).

To realize a low-power high-speed SSD, the overall performance of the NAND Flash memory and the NAND controller should be optimized by co-designing both NAND and controller circuits. Chapter 7 describes the most advanced circuits in this field. Furthermore, 3D-integration in the SSD system becomes a key topic and an example of low power 3D-integrated SSD is shown.

When aiming to replace HDDs, particularly in enterprise applications, another key consideration is reliability. SSDs are complex electronic systems prone to wear-out and failure mechanisms mainly related to NAND. SSD reliability is analyzed at different levels in Chap. 8. The basic physical mechanisms affecting the traditional floating-gate cells and the possibility of anomalous erratic behavior is discussed, as well as disturbs arising because several cells share the same control lines. Solutions adopted to improve system reliability are presented, such as the use of RAID and protection against power loss during write operations. Test methods for endurance and retention verification are also described.

The physical constraints of Flash memory pose a lifetime limitation on these storage devices. Multilevel Flash technologies (MLC) further degrade endurance, as 2 bits are stored in the same physical cell. As a result, NAND devices may experience an unexpectedly short lifespan, especially when accessing these devices at high frequencies. In order to enhance the endurance, wear leveling algorithms are used to evenly erase blocks. Chapter 9 describes some existing wear leveling algorithms, highlighting their pros and cons.

Despite all the possible Flash management algorithms run by the memory controller, the residual BER needs to be properly managed in order to achieve a reliable system. That is why *Error Correction Codes* (ECCs) are so important in SSD design. Two main issues arise when an ECC is used inside an SSD. First, the ECC engine should not limit the performance of the drive. This requirement is addressed with a hardware ECC implementation that supports multiple devices (channels) in parallel. Second, ECC must avoid erroneous corrections when the error correction capability of the code is overcome; that is, it must have a high detection property.

Nowadays, the most popular ECC approach in commercial SSDs is BCH, which is covered in Chap. 10. As the NAND technology scales down, NAND raw BER becomes worse and a more powerful ECC is needed. Chapter 11 covers LDPC codes which are capable to get closer to the Shannon limit; in other words, they can handle higher BER at the expense of a higher complexity.

SSD security is another key requirement because sensitive data must be protected against external attacks. Unfortunately, existing methods in the HDD world cannot be applied to SSDs. These days encryption is the most popular method to secure SSDs. Chapter 12 covers encryption basics and their application to solid state drives.

Finally, Chap. 13 covers Flash signal processing techniques. When NAND raw BER overcomes the Shannon limit, NAND-controller interaction jumps to a deeper

level. In other words, parameters like retention time, floating gate coupling, number of erase cycles, etc., need to be considered during runtime.

We are in the midst of an exciting storage market transition, where Flash is expanding its reach to replace HDDs with dramatically faster and more efficient SSDs. After reading this book, the reader will get a comprehensive look at SSD applications and technologies. As you'll see, a Solid State Drive is a complex mix of digital and analog circuits working in concert with firmware and I/O software protocols. We hope you enjoy this tour inside Solid State Drives.

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