Solid-state drive technology in HP ProBook and EliteBook Notebook PCs

Technical white paper

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Executive summary

Compared to traditional hard disk drives (HDDs), solid-state drives (SSDs) can deliver a range of benefits in an enterprise environment, including enhancements to performance and productivity, battery life, and durability.

This white paper provides an overview of SSDs and presents a business case for their use in an enterprise environment. It also addresses historical concerns such as write reliability and performance and describes how these have been mitigated in modern SSDs through measures such as wear leveling, garbage collection and the use of the TRIM command.

HP is clearly a thought leader in the SSD space and has implemented an exhaustive qualification program designed to ensure that the SSDs used in 2011 HP ProBook and EliteBook Business Notebook PCs can meet your needs.

Target audience: This document provides a high-level overview of SSD technology and is intended for end-users, field representatives, and channel representatives.

Introduction

SSDs use solid-state memory to store persistent data. These devices typically use the same interfaces as conventional HDDs and are implemented in the same form factors; however, while an HDD includes spinning media and moving read/write heads, the SSD uses solid-state memory – typically DRAM or NAND flash memory – to store data.

DRAM-based SSDs are volatile, typically requiring an internal battery along with a backup disk system to ensure data persistence. In the event of system power loss, a battery in the SSD allows DRAM data to be written to a backup disk; when power returns, the data is restored. By contrast, NAND flash memory is non-volatile and is able to retain data during a power outage.

Note
In the future, technologies such as HP Memristor may supplant NAND flash.
For more information, visit the HP website.

This white paper focuses on the use of NAND flash. The following NAND flash technologies are widely available:

- Multi-level cell (MLC) – MLC flash can store two bits of information per cell; its typical lifecycle is around 3,000/5,000 write/erase cycles.
- Single-level cell (SLC) – Since SLC flash only stores one bit of information per cell, product density is lower and write speeds are faster compared with MLC; less error detection/correction circuitry is required in the flash controller.
SSD versus HDD comparison

Key characteristics of SSDs and HDDs may be compared as follows:

- **Performance**: Since SSDs can start working almost immediately with no need to spin up and seek for a particular sector, application launch and run times are faster. Indeed, the average access time for an SSD can be as low as 0.1 ms, while for an HDD it is typically 16 – 20 ms; as a result, depending on platform and configuration, your notebook’s operating system can boot in as little as 10 seconds.

  Faster data access is beneficial for applications with high random I/O requirements; however, there may be less outright benefit with highly sequential data.

  Due to their excellent random read/write performance, SSDs allow you to meet high IOPS demand with fewer devices.

- **Power consumption**: Since SSDs are more power-efficient than HDDs, power consumption tends to be lower, which can enhance battery life in a business notebook PC. Cooling costs are also lower.

- **Durability**: With no moving parts, SSDs are much more resistant to bumps, drops, shocks, or temperature changes. Furthermore, the lack of moving parts means that an SSD is also quieter.

- **Lifecycle**: SSDs support a limited number of write cycles over their lifecycles. However, the impact of this limitation can be mitigated through the implementation of a range of technologies (see Typical uses cases for SSDs)

The following scenarios typify the benefits that can be achieved with SSDs.

**Productivity**

Chris develops multimedia content and wishes to optimize the performance of his EliteBook 8760w Mobile Workstation. As a result, he has paired an SSD with a high-capacity hard drive. He keeps his OS, applications, and current projects on his SSD and uses his hard drive for completed projects and reference content. This combination gives him the performance he wants along with the storage capacity he needs.

**Battery life/reliability**

Dan is a frequent business traveler who spends a lot of time away from AC power. While battery life is critical for him, he also demands the highest levels of reliability since he rarely has access to his IT support staff. He has equipped his HP EliteBook 8460p with an SSD to optimize battery life and improve overall system reliability.

**Boot**

Carol is a corridor warrior who spends her time moving from meeting to meeting. It is important for her to be ready to give a presentation at the drop of a hat. She has been frustrated in the past with slow boot times that meant she had to stall while waiting for her presentation to come up. With her new HP EliteBook 2760p equipped with a high-performance SSD, she is able to boot the machine in seconds and access her files much faster than on her previous system.

- Enhancing write reliability and performance).

- **Data retention**: While wear-durability calculations have shown that an SSD can be expected to maintain its data over the life of a PC, you cannot assume data will be maintained indefinitely once power has been removed. For this reason, an SSD should not be used to archive data.

**Form factors**

Traditionally, SSDs designed for use in servers and PCs have used the same interfaces and form factors as HDDs in order to preserve interoperability and backwards-compatibility. Thus, such SSDs are typically offered in the following form factors:
• Most commonly: 2.5-inch nominal width
• Less commonly: 3.5-inch, 1.8-inch, or Joint Electron Devices Engineering Council (JEDEC) MO-300 (mSATA)

Given that there is no need for SSDs to accommodate relatively large rotating platters, there is a growing demand for alternate, more cost-effective form factors. Moreover, while current interfaces tend to be Serial-Attached SCSI (SAS) or Serial ATA (SATA), faster options (such as PCI Express) are available. Thus, for example, mSATA\(^1\) was introduced in 2009 to support smaller SATA SSDs via mini-PCI Express.

Other SSD implementations include the following:

• **Self-encrypting drive**: Designed for applications requiring strong security, a self-encrypting drive (SED) provides built-in security features, such as Advanced Encryption Standard (AES) 256-bit encryption and hardware-based user authentication. Encryption takes place on-the-fly, with little or no performance penalty.

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\(^1\) Use cases for the mSATA drive include operating system and application installation.
- **Hybrid drive**: In effect, a hybrid drive is a large HDD coupled with NAND flash acting as cache memory. The HDD’s platters are normally at rest and only spin up when NAND flash is nearly full of write data or when read data not currently stored in NAND flash has been requested.

  Just as with a standard cache, frequently-accessed data is stored in the NAND flash portion of the hybrid drive. During operation, NAND flash may read more data from the HDD than requested, acting as a lookahead; in addition, data required for boot may be stored on NAND flash immediately prior to shutdown.

**Business case**

Most IT departments are challenged to cut the spiraling costs associated with running an enterprise data center. Efforts typically center on server consolidation, along with the creation of pools of networked storage or storage array networks (SANs). In this scenario, storage is often tiered, providing support for high-performance applications through to lower-performance, high-capacity applications. This range of use cases creates opportunities for the adoption of SSDs.

Although HDDs have been the proven industry standard for storage, SSDs can provide a viable alternative for many use cases, allowing you to select a cost-effective storage medium that meets your particular business needs while also providing a satisfactory user experience.

Storage based on DRAM technology has been used in the enterprise environment for some time, generally to accommodate I/O-intensive workloads. While DRAM technology is expensive, the introduction of NAND flash memory – and its rapidly decreasing cost per KB – has led to the increased use of SSDs for a range of use cases, including I/O-intensive applications where high-performance can translate to higher revenue for the business. Furthermore, space constraints and manageability and flexibility issues in the data center make SSDs an ideal complement to blade technologies.

Increasingly, data is being pushed from the back-end (the enterprise data center) to the front. As a result, the notebook PCs that are grabbing this data must be able to keep pace, meeting needs for performance, lower power consumption, and durability. Since they consume less power and require less cooling, SSDs can become integral components of this scenario, while also fitting nicely into corporate green IT initiatives.

Despite gains in performance, power consumption, and durability, the adoption of SSDs in business notebook PCs has been slowed by their perceived higher cost per GB. However, when productivity is the key requirement, SSDs can deliver true business value, helping to balance performance across the enterprise environment.

**Typical uses cases for SSDs**

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Enhancing write reliability and performance
Historically, perceptions concerning write reliability and performance may have inhibited the broader adoption of SSDs. In response, vendors have been introducing technologies to improve these characteristics.

Wear leveling
Since NAND flash cells can only support a limited number of erase cycles before becoming unusable, it is critical for SSDs to include a wear-leveling mechanism designed to distribute erasures evenly throughout memory.

Note
The need for wear-leveling is exacerbated by the behavior of typical file systems that have been developed for use with HDDs. Such file systems may rewrite data structures repeatedly in the same area.

While the even distribution of dynamic (changing) data can extend the lifecycle of an SSD, some wear-leveling implementations periodically move static data to make less-used cells available for other data.

Mitigating the effects of write amplification
Write performance in an SSD can be impacted by a phenomenon known as write amplification, which is a result of the following SSD characteristics:

- Data can only be written into an empty NAND flash cell. Thus, if you wish to write to a particular cell and are unsure of its state, you must first erase the cell.
- While writes to an SSD are sector-level (4 KB); however, due to mechanical limitations, erases are block-level (128 x 4 KB = 512 KB).
- Cells that are deleted by the user or the operating system are not erased.

When you first receive an SSD, all its NAND flash cells are in an erased state; thus, writes can initially be performed sequentially. However, later writes require a read-erase-modify-write cycle, as shown in Figure 1.

Note
With HDDs, blocks can be over-written individually.
In this example, a sector that had previously been deleted is to be rewritten with new data. The read-erase-modify-write cycle is performed as follows:

1. The block (512 KB) containing the deleted sector is read from NAND flash; meanwhile, the new data is temporarily stored in the SSD’s cache.
2. After the block is written to cache, the original data in NAND flash is erased.
3. Within cache, the new data is added to the block, replacing the deleted data.
4. The updated block is written back to NAND flash.

Thus, for each write operation, you must move or write data multiple times, leading to write amplification. Since each SSD can only support a finite number of writes, write amplification shortens the life of the device; in addition, write amplification consumes NAND flash bandwidth, which can reduce throughput for random writes.

**Mitigation**

SSD vendors have introduced a range of measures to mitigate the impact of write amplification during write operations. For example, some vendors have implemented a firmware-based garbage collection feature that, in effect, de-fragments NAND flash while the SSD is idle, without intervention from the user or operating system. With sufficient idle time, the unused portions of the SSD can be restored to as-new condition, thus minimizing the number of erasures required during write operations. However, there are penalties involved in the use of garbage collection: since it works in the background, there may be an impact on battery-life; moreover, garbage collection involves additional writes that can prematurely age NAND flash cells. Moreover, although it operates in the background, the garbage collection process itself adds write amplification.

Since 2009, SSDs used in HP Business Notebook PCs have support for garbage collection built into firmware.

Though not recommended by HP, third-party software products are can be used for garbage collection on SSDs that do not provide this feature in firmware. However, such products may require the entire contents of the SSD to be backed up before garbage collection can be performed.
Using the TRIM command

Note
While garbage collection is managed by the drive, the TRIM command is sent by the device driver.

An SSD is blind; it is unaware which sectors are being used and which are free – this information is maintained by the file system, to which the SSD has no access.

When a user or the OS deletes a file, the file system merely flags the area as being not in use; no data is physically deleted. Since the SSD is unable to communicate with the file system, it is unaware that space has been freed-up, which ultimately leads to write amplification.

However, with the introduction of the ATA TRIM command, the OS is now able to notify the SSD when sectors have been freed up. Following a delete operation – and, ideally, prior to a subsequent write – the SSD copies the block containing the deleted data to cache, erases the affected NAND flash, and only rewrites blocks containing data that is still being used. Thus, the TRIM command can enhance write performance by minimizing the requirement for read-erase-modify-write cycles.

In addition, note that blocks that have been trimmed using the TRIM command are omitted from garbage collection, further reducing write amplification.

Caveats
The TRIM command must be supported by both the SSD and the OS.

The following SSDs, all of which support the TRIM command, are used in 2011 HP Business Notebook PCs:
- Intel Postville (X18-M G2, X25-M G2) and Postville Refresh (320)
- Samsung PM810 and PM830
- Micron C300 and C400

Table 1 outlines how the above SSDs are enabled at the system-level, via either a particular driver or a vendor-supplied tool, depending on the particular platform.

Table 1. Enabling TRIM support on particular Windows platforms

<table>
<thead>
<tr>
<th>Driver or tool</th>
<th>Windows XP/Vista</th>
<th>Windows 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microsoft in-box driver</td>
<td>Unsupported</td>
<td>Intel/Samsung/Micron SSDs</td>
</tr>
<tr>
<td>Intel Matrix Storage Manager (MSM)</td>
<td>Unsupported</td>
<td>Unsupported</td>
</tr>
<tr>
<td>Intel Rapid Storage Technology (RST) 9.6 or later</td>
<td>Unsupported</td>
<td>Intel/Samsung/Micron SSDs</td>
</tr>
<tr>
<td>Intel Solid-State Drive (SSD) Toolbox</td>
<td>Intel SSDs</td>
<td>N/A</td>
</tr>
<tr>
<td>Samsung TEA tool</td>
<td>Samsung SSDs</td>
<td>N/A</td>
</tr>
<tr>
<td>Micron Real SSD manager</td>
<td>Micron SSDs</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Note
Linux kernel 2.6.28 and later supports the TRIM command.

Additional caveats include:
- The TRIM command cannot be used with a RAID volume.
- If disk encryption has been implemented, the TRIM command reveals which blocks are in use.

Upgrading an unsupported SSD
Some vendors are providing firmware upgrades that allow older drives to support the TRIM command. A supported OS is still required.

Over-provisioning
SSDs are often over-provisioned to accommodate features such as garbage collection, wear-leveling, and bad-block mapping. For example, a vendor might market an SSD with 128 GB of usable capacity as an over-provisioned 120 GB drive.

Note
Over 7% of additional over-provisioning can be available via the difference in the nominal value of a GB (1,000,000,000) and its binary value (1,073,741,824).

HP value-add
HP has become a thought leader in the SSD space, ensuring that devices deployed in HP Business Notebook PCs can achieve high levels of performance and productivity, battery life, and durability.

Part of this value-add is the way in which SSDs are qualified for use in notebooks.

SSD qualification
To ensure SSDs used in HP Business Notebook PCs are capable of achieving the high standards required, HP works with SSD vendors and original device manufacturers (ODMs) to qualify products at both device- and system-levels. As part of this effort, HP has developed robust testing schema so that only the best SSD products are used, regardless of vendor.

Initially, vendors are given very specific specifications and guidelines to help them deliver an SSD that meets HP requirements. For example, mean time between failures must be at least 1.2 million hours, while performance must satisfy HP standards.

During the development stage of an SSD device, the HP SSD engineering team works with vendors to perform a range of functional compatibility tests and reliability demonstration tests (RDTs). After all hardware and firmware issues have been identified and, if possible, resolved, the team releases the SSD for system-level testing.

Following the release, ODMs are responsible for working with the HP team and SSD vendors to ensure the SSD is capable of achieving the specified requirements for use in an HP Business Notebook PC. ODMs follow the HP test plan to perform device qualification via an HP test tool.

1 At this stage, the root cause of any unresolved issue is not related to the SSD’s hardware or firmware. Instead, it may be caused by the system BIOS, system hardware, or the storage driver.
Testing includes the following areas:

- SSD functional testing: Standby/resume, hibernation/resume, reboot, and more
- Mechanical testing: Shock, vibration, and more
- Electromagnetic interference (EMI)/electrostatic discharge (ESD)
- Wireless WAN (WWAN)/radio frequency (RF)

After the SSD has passed the system-level testing, it is approved for production.

SSD offerings

SSDs are available in select HP Business Notebook PCs and as an after-market option (AMO).

Factory-built notebooks

The following SSDs are available in select HP ProBook and EliteBook models:

- 128 GB
- 160 GB
- 256 GB

After-market options

The following SSDs are available as after-market options (AMOs) for select HP ProBook and EliteBook models:

- 128 GB
- 160 GB
For more information

For more information on HP business laptops, tablets, and notebooks, refer to www.hp.com/go/notebooks.