Virtual RPM

A simple, accurate and relevant performance measurement for SSDs in client PCs

White Note

Executive Summary

The term virtual RPM (vRPM) is a synthetic measurement of performance for solid state drives (SSDs) in client PCs. It was created to give users a simple tool to compare the performance of a SSD to a HDD, which is determined by its revolutions per minute (RPM), and to other SSDs.

The vRPM metric is calculated based on three criteria:

1. Understanding the client PC usage model
2. Quantifying how HDDs operate inside PCs based on a functional model of their RPM
3. Quantifying how much faster a virtual HDD would have to rotate in order to replicate the client PC performance of an SSD.

The result of this calculation allows end users to answer three questions:

- How fast is a particular SSD?
- How does it compare with HDDs?
- How does it compare with other SSDs?

Client PC Usage Model

Client PCs running full-featured operating systems, such as Windows Vista, create an intense amount of random read and write traffic to their storage devices.

A collection of the usage patterns of typical productivity applications (Office 2007 and Photoshop CS2 under Windows Vista) is shown in **Fig. 1**. It clearly shows that nearly the entire read and write traffic is random Thus, client PC storage performance is almost exclusively dependent on random read and write performance.

The read to write ratio is 50:50, ±10 percent depending on the application. The read transfer sizes vary between applications. The vast majority of write random transfer sizes, however, is 16KB or smaller. In fact, over 50 percent of random writes handle 4KB or smaller transfer sizes.

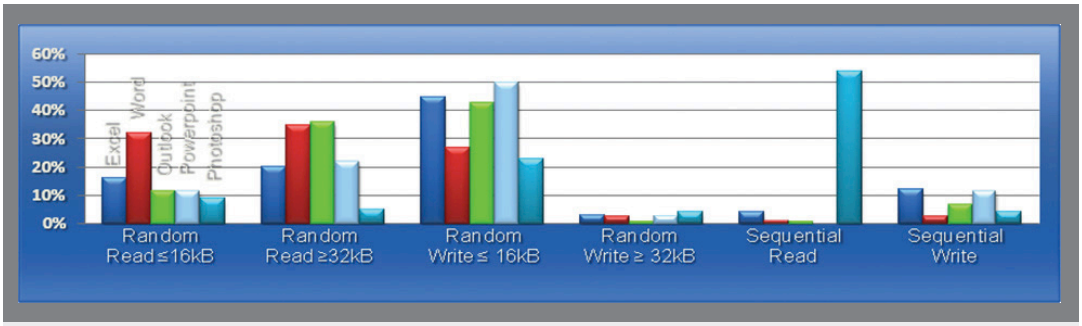

Fig. 1
Client PC usage model captured under Windows Vista, Office 2007 and Adobe Photoshop CS2. Note that nearly all of the traffic is random and more than 50 percent of random writes are 4KB or smaller.

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Random Performance

When a system requests to read from/write to a HDD, four components of latency in its general timing flow slow down performance as shown in **Fig. 2**.

1. Command overhead: the time to interpret and process the command, typically <0.1ms
2. Seek time: the time to move the head to the appropriate cylinder to prepare to receive data, typically 7–15ms in portable drives
3. Rotational latency: the time to rotate the platter beneath the head so that the data can be read or written (dependent on how fast the media rotates, 30 divided by the RPM rate to achieve the latency in seconds)
4. Data transfer time: the time to move the data across the interface, less than <0.1ms for small transfer sizes.

As this traffic is exclusively random, the number of transactions per second that can be completed is simply the inverse of the total completion time. Items 1 and 4 are nearly 100x smaller than items 2 and 3 and thus can be ignored, resulting in the equation shown in **Fig. 3**. HDD input/output per second (IOPS) is proportional to RPM.

For high performance client PC HDDs, the best seek times are approximately 7ms. Thus IOPS is proportional to RPM as shown in **Table 1**.

For the purposes of all vRPM calculations, only raw media performance is considered. Volatile caching algorithms (such as using DRAM) can be implemented in both SSDs and HDDs, and show tremendous performance gains in specific scenarios. However for general productivity applications, flush cache commands are issued with such frequency that the benefits of write caching are constrained for the end user.

Fig. 2
HDD General Timing Flow

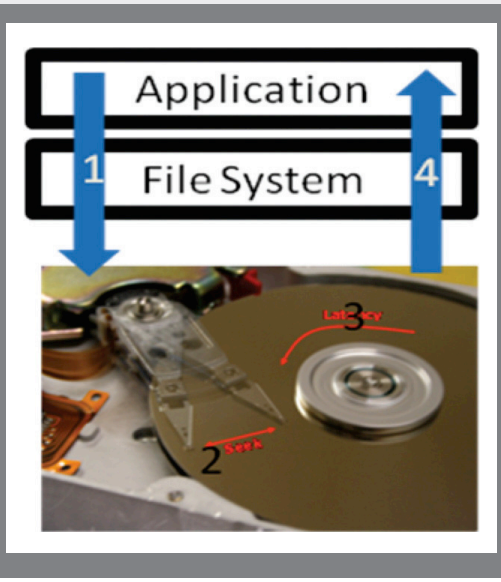

Fig. 3
HDD IOPS Calculation for Small Transfer Size

$$\text{HDD IOPS} = \frac{1}{\text{seek} + \frac{30}{\text{RPM}}}$$

Table 1
Example of HDD Small Transfer IOPS as a Function of RPM for a HDD with a 7ms Seek Time.

Mobile HDD RPM	Read/Write IOPS
4,200	32
5,400	42
7,200	97

SSD Performance

NAND flash, on which SSDs are built, has asymmetric read and write performance. Its read latency is more than 10x better than its write latency. This is due to the block erase nature of write commands. They are occasionally delayed by garbage collection to free space for writing.

As a result, the random read performance of an SSD is much higher than its random write performance, as shown in **Table 2**.

For the client PC usage model with a read to write ratio of approximately 50:50, a net IOPS number can be calculated by using the weighted read and write performance shown in **Fig. 4**.

Using this equation, the net PC IOPS can be calculated as shown in **Table 3**.

Calculating vRPM

The beauty of vRPM is its simplicity. It answers the question "How fast would you have to spin a virtual HDD to achieve the level of performance seen by an SSD in a client PC?" in a measurement, RPM, with which users are familiar.

This question is answered by inverting the equation in Fig. 3, correlating it to the SSD small transfer size (mean) and solving it for RPM as shown in **Table 4**.

vRPM specific metric can be calculated by OEMs, end users or 3rd parties as shown in **Fig. 5**.

Where:

- SSD IOPS (Write) is the sustained (to the SSD media) 4kB random write rate for QD=1 (WinXP/Vista) and QD=tbd for Win7
- SSD IOPS (Read) is the sustained (from the SSD media) 8kB random read rate for QD=1 (WinXP/Vista) and QD=tbd for Win7
- 50 is the product factor in the calculation.

Table 2
Client PC SSD Performance
(2009 rates are estimated)

SSD Generation	Read IOPS	Write IOPS
2006/7	5,000	10
2008	10,000	100
2009	20,000	400

Table 4
Client PC SSD Performance in vRPM
(2009 rates are estimated)

SSD Generation	Read IOPS	Write IOPS	PC IOPS	vRPM
2006/7	5,000	10	20	1,000
2008	10,000	100	200	10,000
2009	20,000	400	785	40,000

Fig. 4
Actual PC IOPS Performance for an SSD in a Client PC with a 50:50 Read/Write Ratio

$$\text{PC\_IOPS (mean)} = \frac{1}{\frac{0.5}{\text{WRITE IOPS}} + \frac{0.5}{\text{READ IOPS}}}$$

Fig. 5
vRPM Formula for Client PCs

$$\text{vRPM} = \frac{50}{\frac{0.5}{\text{WRITE IOPS}} + \frac{0.5}{\text{READ IOPS}}}$$

Table 3
Client PC SSD Performance Estimates

Generation	Read IOPS	Write IOPS	PC IOPS
2006/7	5,000	10	20
2008	10,000	100	200
2009	20,000	400	785

The Importance of vRPM

RPM has become a de facto measurement of speed in the HDD storage world for client PCs. Logically, the SSD cannot be measured as a function of how fast it revolves, since it has no rotating parts. Virtually, however, it can be. And in order to explain its tremendous benefits over the HDD, it should use the same metric.

SanDisk has introduced vRPM, or Virtual RPM, for this very reason. In similar fashion, the ISO sensitivity parameter used in analog film was adopted for use in digital photography. vRPM purposely uses a language that users understand. This enables them to compare “oranges” to “oranges”, the performance of SSDs to others SSDs, and “oranges” to “apples”, the performance of SSDs to HDDs.

The results of vRPM calculations, as shown in this document, help users grasp the tremendous benefits of SSDs over HDDs when performing random read operations. In turn, these benefits can be shown to directly enhance the user experience and productivity on client PCs equipped with SSDs.

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