Thermal Throttling

White Paper

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1. Introduction

Solid-state drives (SSDs) are a type of data storage device that use a non-volatile solid-state memory, such as a flash memory, to store data. As SSD performance demands increase, power requirements generally increase, while physical size requirements for SSDs generally stay the same or become smaller.

When SSDs are subjected to sustained workloads from sequential writes over a long period of time at high temperatures, data errors are likely to occur. Near the end of a drive's operational lifetime, occurrences of erroneous data can exponentially increase due to their physical characteristics. To make things worse, SSDs used in industrial applications must be able to tolerate higher ambient temperatures, which naturally hinder heat dissipation. This can potentially put data stored on the SSD at the risk of being corrupted and hardware components in danger of being damaged, both of which lead to significant reduction in the life expectancy of the drive.

To solve the problem, Apacer equips SSD products with a built-in thermal sensor to monitor the temperature of the SSD via S.M.A.R.T. commands. This ensures superior data writing performance via drive throttling, i.e. reducing the speed of the drive when the device temperature reaches the threshold level, so as to improve data reliability, provide sustained performance while overheating, and prolong a product's lifespan.

The thermal management technique presented in this article can be applied to any thermal-sensor-equipped SSD, whether it supports commercial-grade temperature operating ranges (0°C to 70°C) or industrial-grade temperature operating ranges (-40°C to 85°C).

2. Thermal Management

Apacer's thermal management is comprised of two techniques: hardware implementation of a thermal sensor and firmware configuration of thermal throttling. Apacer's thermal sensor is designed to monitor the temperature of an SSD. When the SSD processes a large number of read/write operations continuously, its temperature may increase to a certain level which could lead to drive malfunctions. To prevent hardware components from being damaged by the drive operating at high temperature, the thermal throttling feature is implemented to control the temperature of the drive to not exceed its maximum threshold temperature by reducing its performance. That is, the drive will throttle itself back and run slower to make sure the read/write requests are correctly executed when it is running too hot.

In the following sections, how much of an impact the location of thermal sensor on a circuit board has on throttling will be elaborated, followed by a flow chart demonstrated to explicate the procedure of thermal throttling.

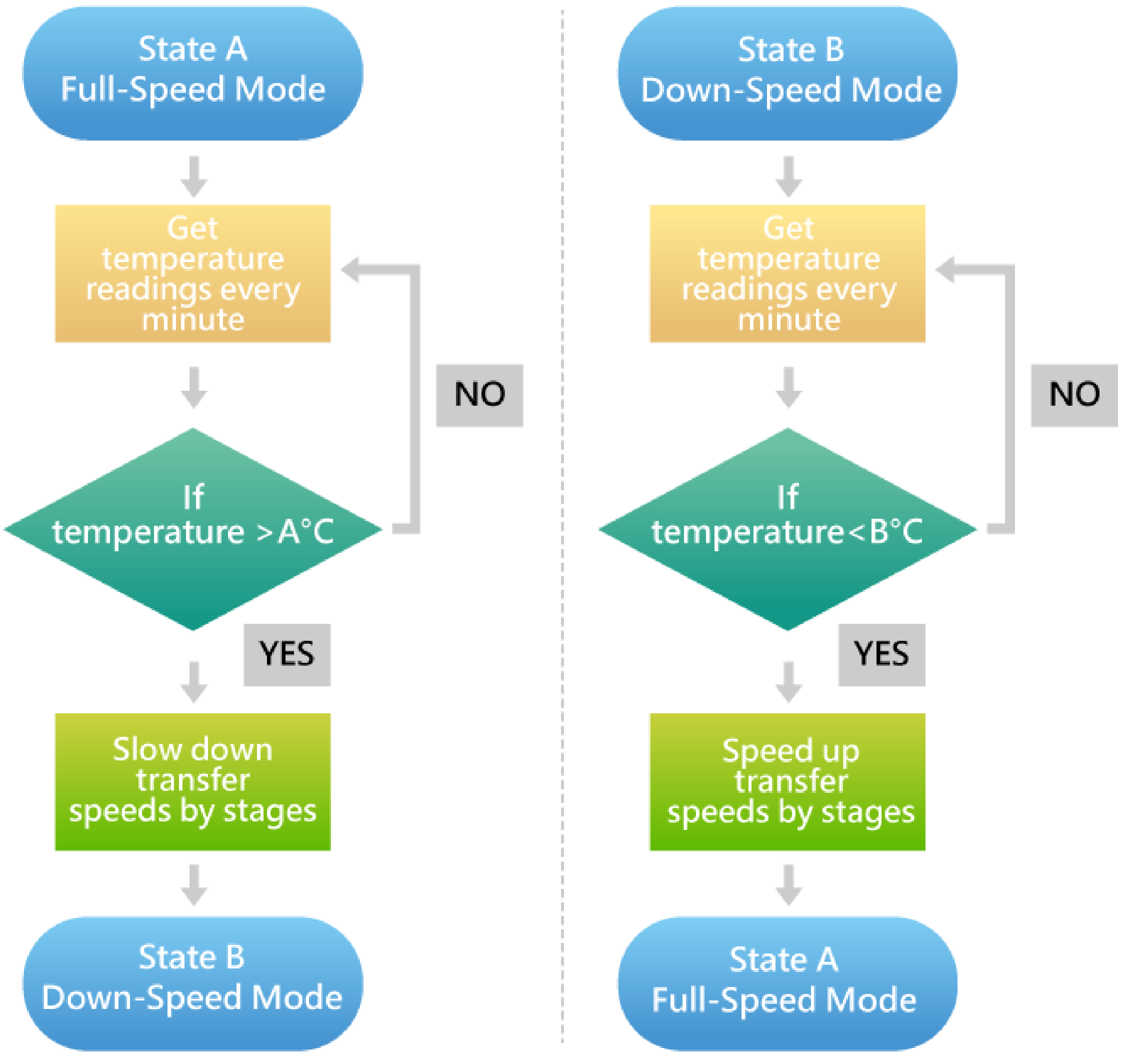
2.1 Deployment of Thermal Sensor

For Apacer SSD products featuring built-in thermal sensors, device temperature values used by the thermal throttling feature are based on the temperature sensor located on the device PCB and are accessible through S.M.A.R.T. attributes. Depending on where the thermal sensor is located, the temperature which can be read by the sensor varies and has different impacts on throttling.

The construction of an SSD contains two key components: the controller and the NAND flash non-volatile memory. The ideal design is to deploy the sensor next to the controller because the temperature of the device largely depends on the controller, where most of the heat is generated. With the sensor next to the controller, the time when the drive is close to throttling can be reflected in the temperature reading of the drive. On the other hand, if the sensor is placed near the storage chips, it may not be an adequately suitable indicator of whether the drive is close to throttling or not, but the good part about this is that it's possible to see if the drive is getting hot enough to potentially corrupt data.

With either deployment of the thermal sensor, Apacer has managed to configure the thermal sensor to read the temperature of the drive via S.M.A.R.T. commands and alert the host system to throttle back on flash access when the temperature rises beyond its maximum limit.

2.2 Thermal Throttling Flow Chart



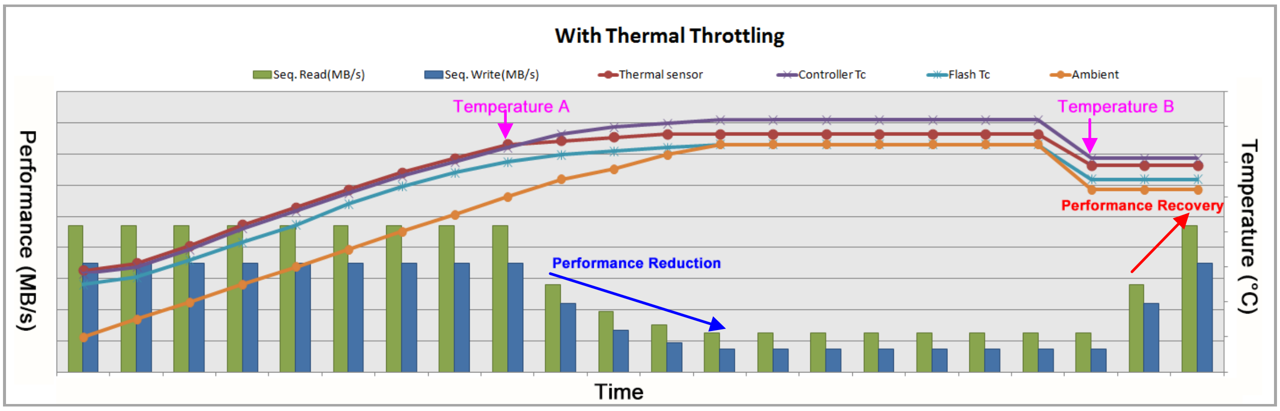
3. Test Result Comparison

The temperature of an SSD can be monitored via a thermal sensor implemented on the drive. However, predicting data reliability with the sensor only is insufficient. Without the configuration of thermal throttling, both data and drive can be endangered as the temperature continues to increase the more the flash memory is accessed.

In the following sections, test results are offered to explain the different impacts between SSDs with and without thermal throttling.

3.1 SSD with Thermal Throttling[1]

For an SSD configured with thermal throttling, it is accessed at full speed in initial phase of the test according to the flow chart. As the drive continuously experiences a large number of requests, its temperature indicated by the red line increases to the maximum threshold temperature of A°C.



When the temperature exceeds the threshold value, the drive starts to throttle by decreasing in performance by multiple stages, thereby allowing the device to cool down. It measures the temperature level again and, if it is greater than or equal to the previous reading, it goes one step further, reducing the performance by one more level until it reaches a low steady state.

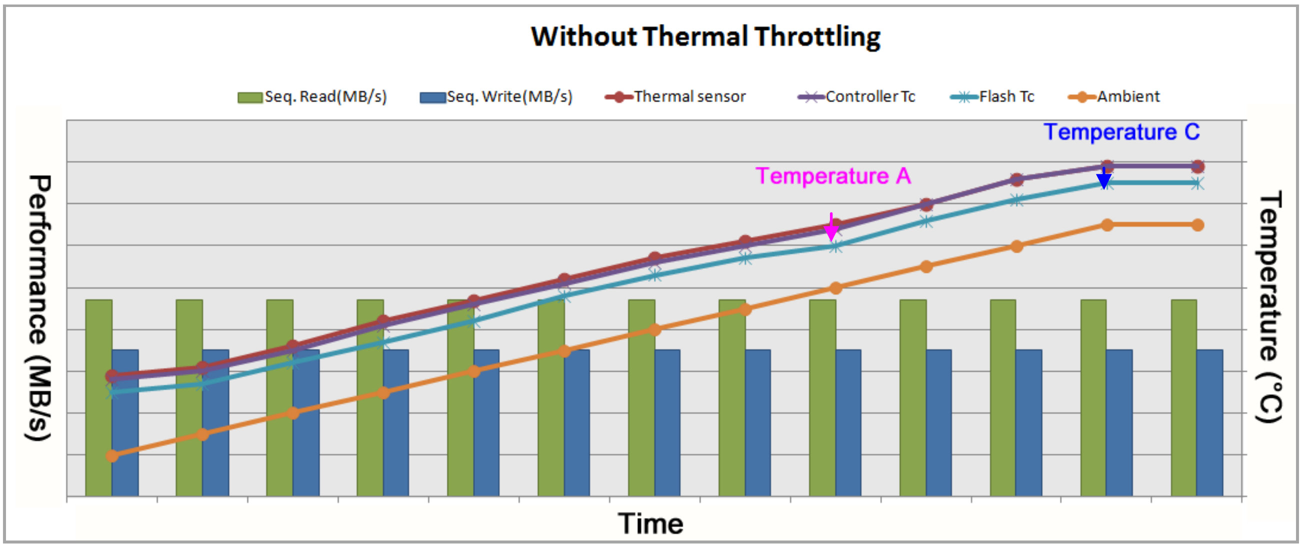
[1] The diagram shown here is used for demonstration only. Test result may vary from different platforms and actual configurations.

As described in the diagram above, the SSD starts to give a consistent thermal reading above Temperature A after a distinct decline in transfer rates, and does not cool down below the minimum threshold value of B°C after running at a slower speed for a period of time. With the temperature dropping below Temperature B, the drive recovers to its maximum performance level, which is the same as the transfer speeds recorded at the beginning of the test.

3.2 SSD without Thermal Throttling[2]

The SSD which is not configured with thermal throttling is also accessed at full speed in the initial phase of the test. As the drive continues to be accessed, the drive temperature goes on rising and increases above Temperature A with the performance remaining at top speed along the way as recorded from the beginning of the test.

Unlike the SSD with thermal throttling, the SSD without the thermal mechanism does not throttle back on sequential read/write when the drive temperature exceeds the maximum threshold value of A°C. Instead, the temperature keeps climbing until it reaches a high steady state at Temperature C and then stops rising by giving a consistent thermal reading of C°C.



[2] The diagram shown here is used for demonstration only. Test result may vary from different platforms and actual configurations.

4. Conclusion

SSDs are considerably fast and can perform tasks within a matter of seconds, but the downside is that they cannot maintain top speed without overheating. Thermal sensors are therefore required to be placed on a circuit board to monitor the temperature of the drive.

When the temperature exceeds the maximum threshold level, thermal throttling will be triggered to reduce performance step by step to prevent hardware components from being damaged. Performance is only permitted to drop to the extent necessary for recovering a stable temperature to cool down the device. Once the temperature decreases to the minimum threshold value, transfer speeds will rise back to an optimum performance level.

Thermal throttling is an ideal way to prolong an SSD’s operational lifetime and improve data integrity.

Revision History

Revision	Description	Date
1.0	Official release	3/31/2017
1.1	- Updated the document template - Removed the description that thermal throttling can prevent overheating	9/27/2018
1.2	Textual revisions.	1/11/2019

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