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Thermal Management for SQFlash

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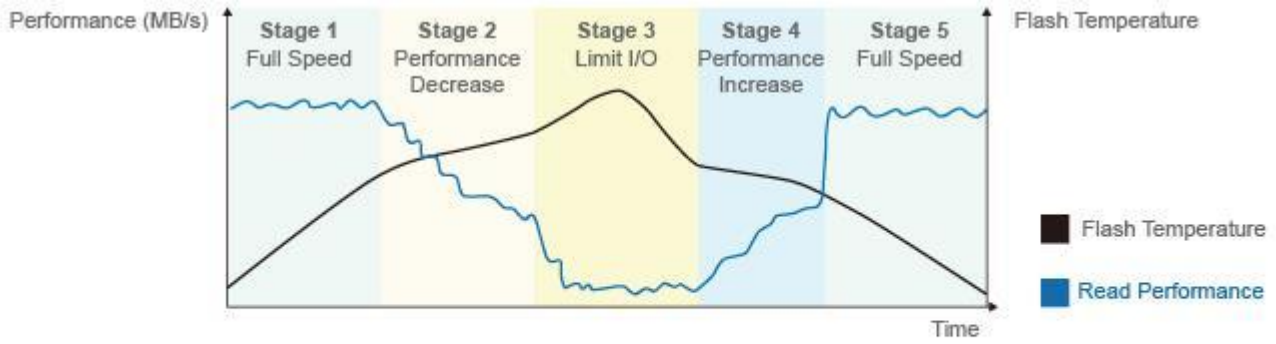
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Introduction

With the continuous increase in SSD performance requirements, particularly driven by PCIe market demand, interface bandwidth has grown several times beyond that of SATA-based solutions. This trend applies across industrial, enterprise, and data center applications, all of which demand higher throughput and lower latency. At the same time, market expectations for thinner and lighter systems have led to increasingly compact SSD form factors. The combination of higher performance density and reduced physical size significantly intensifies thermal challenges, resulting in elevated operating temperatures and an increased risk of thermal overheating in SSD devices.

When an SSD operates under excessive thermal conditions, prolonged high temperatures may lead to component degradation and adversely affect data integrity. To mitigate these risks, SQF implements a firmware-controlled thermal throttling mechanism designed to proactively manage device temperature. When the temperature of the controller exceeds predefined operating thresholds, the controller dynamically reduces performance to lower power consumption and heat generation. Through this multi-stage thermal management approach, the SSD operating temperature is maintained within an appropriate range, effectively preventing controller overheating while improving overall thermal efficiency.



How SQF Thermal Throttling Technology Works

When the controller temperature reaches the TT1 stage, thermal throttling is activated. The firmware initially reduces the flash clock frequency to the first throttling level and introduces command latency to lower power consumption and heat generation. Assuming the flash clock supports discrete frequency levels, the firmware continuously monitors the controller temperature after throttling is engaged. If the temperature continues to rise and reaches the threshold, the flash clock frequency is further reduced by one level. This stepwise frequency reduction is repeated each time the temperature exceeds the Thermal Abort stage, allowing the drive to gradually cool down under sustained thermal stress.

When the operating temperature reaches 82°C, the SSD transitions into TT1 stage. In this stage, the firmware reduces the internal clock rate to lower power consumption and heat generation. If the temperature continues to rise to 85°C, the device enters TT2, where the clock rate is further reduced to provide additional thermal relief. At higher temperature levels, enhanced protection mechanisms are applied. When the temperature reaches 95°C, the SSD enters Thermal Throttling Protect state. In this condition, the clock rate remains at the same level as TT2, while additional firmware command delays are introduced to further reduce thermal stress. If the temperature continues to increase to 98°C, the SSD enters Thermal Abort stage. In this critical condition, the device minimizes internal activity and aborts I/O operations by no longer accepting commands from the host. As a final safety measure, when the operating temperature reaches 100°C, or when the controller temperature exceeds 120°C, the SSD transitions into t5 (Thermal Fatal) state, triggering an immediate device shutdown to prevent permanent hardware damage.

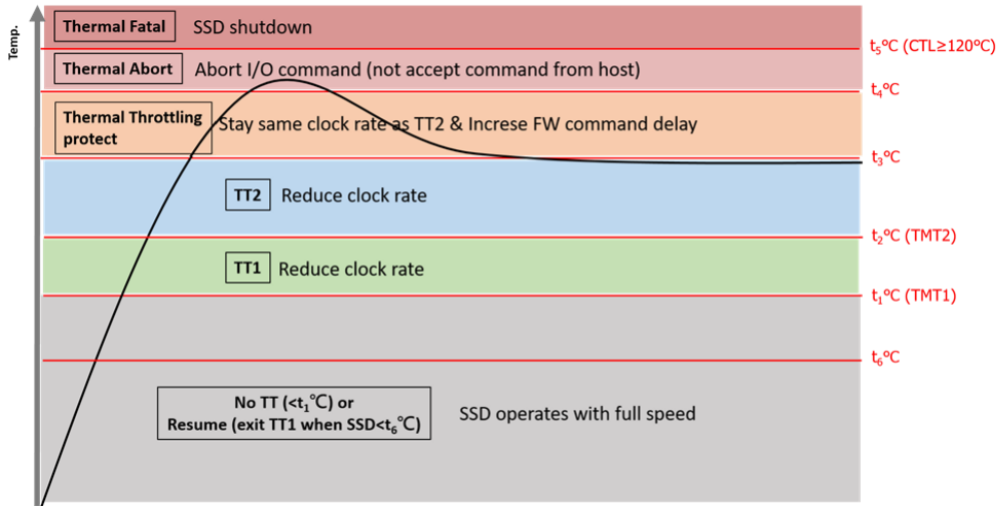


Fig.1 SQF Thermal Throttling Schematic

	Stage	Status	Operation temp. of Normal-temp. grade: 0~70°C	Operation temp. of Wide-temp. grade: -40~85°C
t1 / t6	**No TT / Resume**	SSD operates with full speed	<82 / <78°C	<82 / <78°C
t1	**TT1**	Reduce clock rate	82°C	82°C
t2	**TT2**	Reduce more clock rate	85°C	85°C
t3	**Thermal Throttling Protect**	Stay same clock rate as TT2 & Increase FW command delay	95°C	95°C
t4	**Thermal Abort**	Abort I/O command (not accept command from host)	98°C	98°C
t5	**Thermal Fatal**	SSD shutdown	100°C (or CTL≥120°C)	100°C (or CTL≥120°C)

Fig.2 SQF Thermal Throttling Temperature Setting

Verification of Thermal Throttling

i. Test Setup

Condition for H/W Platform:

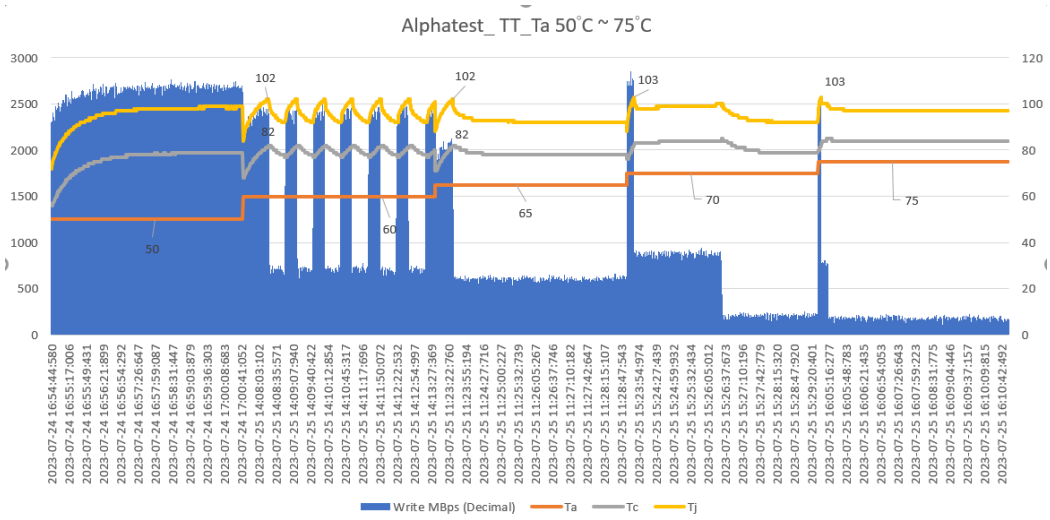
- AIMB-275 with SQF-C8MV4-2TDEFE

Condition for S/W Tool:

- Windows 10 Enterprise LTSC 64bit 1809 17763.107
- CrystalDiskInfo V8.15.2

ii. Test Results

Thermal throttling mechanism has a well balance between thermal control and drive performance.



Summary

Through these clearly defined thermal states, SQF SSDs implement a robust, multi-level thermal protection strategy that balances performance control and device safety across a wide range of operating environments.