# NVMe Integration Test
# Sandisk WDC WDS250G2B0C-00PXH0 250GB

The NVMe Integration Test verifies drive reliability, performance, and functionality when integrated into a specific system.

**August 20, 2022**

## SUMMARY

The NVMe Integration Test verifies drive reliability, performance, and functionality when integrated into a specific system. The NVMe tested was the Sandisk WDC WDS250G2B0C-00PXH0 250GB installed in a HP system, model HP Z1 Entry Tower G5.

The user provided information that this NVMe drive is a client drive with 5 year warranty and 150TB TBW.

A total of 27 tests were run that attempted to verify 47 unique requirements.

| | |
|---|---|
| **REQUIREMENTS** | 47 |
| **PASSED** | 31 |
| **FAIL** | 16 |
| STARTED | Aug 19, 2022 - 19:46:41.808 |
| ENDED | Aug 20, 2022 - 14:52:33.192 |
| DURATION | 19:05:51.383 |

***This section is for the tester to update with their summary of the report.***

| TEST | RESULT |
|---|---|
| TEST 10: Drive Info | PASS |
| TEST 12: Drive Wear | FAIL |
| RQMT 112: Percentage Written shall be less than 80% | FAIL |
| TEST 13: Drive Health | FAIL |
| RQMT 117: Critical composite temperature time shall be 0 | FAIL |
| TEST 14: Drive Features | FAIL |
| RQMT 901: PCIe bus speed must be Gen3 8.0GT/s | FAIL |
| TEST 20: Short Selftest | PASS |
| TEST 21: Extended Selftest | PASS |
| TEST 30: Admin Commands | FAIL |
| RQMT 163: Admin Command maximum latency shall be less than 500 mS | FAIL |
| TEST 31: Background SMART Reads | FAIL |
| RQMT 402: Average latency of slowest 1,825 IO shall not increase more than 20% with concurrent SMART reads | FAIL |
| TEST 32: SMART Data Read and Written | PASS |
| TEST 40: Timestamp | FAIL |
| RQMT 410: Timestamp shall not stop counting | FAIL |
| RQMT 411: Timestamp shall be within 1.0 hour of host timestamp | FAIL |
| RQMT 412: Timestamp changes shall be within 1.0 % of host time change | FAIL |
| RQMT 413: Timestamp count is linear (Coeff > 0.99) | FAIL |
| TEST 100: Short Burst Performance | FAIL |
| RQMT 200: Short burst Sequential Write, QD32, 128KiB, bandwidth must be more than 1.5 GB/s | FAIL |
| RQMT 201: Short burst Sequential Read, QD32, 128KiB, bandwidth must be more than 1.5 GB/s | FAIL |
| TEST 101: Long Burst Performance | FAIL |
| RQMT 163: Admin Command maximum latency shall be less than 500 mS | FAIL |

| | |
|---|---|
| RQMT 401: Temperature at end of long burst IO shall be within 5C of temperature when IO started | FAIL |
| RQMT 220: Long burst Sequential Write, QD32, 128KiB, bandwidth must be more than 1.0 GB/s | FAIL |
| RQMT 221: Long burst Sequential Read, QD32, 128KiB, bandwidth must be more than 1.0 GB/s | FAIL |

| | |
|---|---|
| TEST 102: Non-Op Power State Times | PASS |
| TEST 103: Read Buffer | PASS |
| TEST 104: Data Deduplication | PASS |
| TEST 105: Data Compression | PASS |
| TEST 200: High Bandwidth Stress | PASS |
| TEST 201: High IOPS Stress | FAIL |

| | |
|---|---|
| RQMT 163: Admin Command maximum latency shall be less than 500 mS | FAIL |

| | |
|---|---|
| TEST 202: Drive Burst Stress | PASS |
| TEST 203: Read Disturb Stress | PASS |
| TEST 204: Temperature Cycle Stress | PASS |
| TEST 300: Big File Write Performance | PASS |
| TEST 301: Big File Read Performance | PASS |
| TEST 302: Address Alignment | PASS |
| TEST 303: Short Burst Performance Full Drive | FAIL |

| | |
|---|---|
| RQMT 200: Short burst Sequential Write, QD32, 128KiB, bandwidth must be more than 1.5 GB/s | FAIL |
| RQMT 201: Short burst Sequential Read, QD32, 128KiB, bandwidth must be more than 1.5 GB/s | FAIL |
| RQMT 203: Short burst Random Read, QD1, 4KiB, bandwidth must be more than 0.02 GB/s | FAIL |

| | |
|---|---|
| TEST 304: Long Burst Performance Full Drive | FAIL |

| | |
|---|---|
| RQMT 401: Temperature at end of long burst IO shall be within 5C of temperature when IO started | FAIL |
| RQMT 220: Long burst Sequential Write, QD32, 128KiB, bandwidth must be more than 1.0 GB/s | FAIL |
| RQMT 221: Long burst Sequential Read, QD32, 128KiB, bandwidth must be more than 1.0 GB/s | FAIL |

| | |
|---|---|
| TEST 900: Drive Parameter Change | FAIL |

| | |
|---|---|
| RQMT 007: Change in Power On Hours shall be within 1 hour of actual time change | FAIL |

# NVME INFORMATION

| VENDOR | MODEL | SIZE | VERSION |
|---|---|---|---|
| Sandisk | WDC WDS250G2B0C-00PXH0 | 250 GB | 1.4.0 |

| PARAMETER | VALUE |
|---|---|
| Serial Number | 2035A0805352 |
| Number Of Namespaces | 1 |
| Namespace 1 EUI64 | 001b44-8b49bc0ecb |
| Namespace 1 NGUID | e8238fa6bf530001-001b44-8b49bc0ecb |
| Namespace 1 Size | 250 GB |
| Namespace 1 LBA Size | 512 |
| Firmware | 211070WD |
| Firmware Slots | 2 |
| Firmware Activation Without Reset | Supported |
| Host Memory Buffer | Enabled. Size = 8,192 pages |
| Autonomous Power State Transition | Supported and Enabled |
| Volatile Write Cache | Enabled |
| Host Throttle Threshold TMT1 | Disabled |
| Host Throttle Threshold TMT2 | Disabled |
| Drive Throttle Threshold WCTEMP | 80 C |
| Drive Throttle Threshold CCTEMP | 85 C |

## Power States

| STATE | NOP | MAX POWER | ENTRY LATENCY | EXIT LATENCY |
|---|---|---|---|---|
| 0 | False | 3.5 Watts | Not Reported | Not Reported |
| 1 | False | 2.4 Watts | Not Reported | Not Reported |
| 2 | False | 1.9 Watts | Not Reported | Not Reported |
| 3 | True | 0.02 Watts | 3,900 uS (0.003 sec) | 11,000 uS (0.011 sec) |
| 4 | True | 0.005 Watts | 5,000 uS (0.005 sec) | 39,000 uS (0.039 sec) |

## PCIe

| PCI | VENDOR | VID | DID | WIDTH | SPEED | ADDRESS |
|---|---|---|---|---|---|---|
| Endpoint | Sandisk | 0x15B7 | 0x5009 | x4 | Gen1 2.5GT/s | Bus 1, device 0, function 0 |
| Root | | 0x8086 | 0xA340 | | | Bus 0, device 27, function 0 |

### SMART ATTRIBUTES

| PARAMETER | START | END | DELTA |
|---|---|---|---|
| Available Spare | 100 % | 100 % | |
| Available Spare Threshold | 10 % | 10 % | |
| Controller Busy Time | 16,447 Min | 16,906 Min | 459 |
| Critical Composite Temperature Time | 2 Min | 2 Min | |
| Data Read | 372,736.500 GB | 380,916.303 GB | 8,179.803 |
| Data Units Read | 728,000,976 | 743,977,155 | 15,976,179 |
| Data Units Written | 243,007,747 | 248,236,206 | 5,228,459 |
| Data Written | 124,419.966 GB | 127,096.937 GB | 2,676.971 |
| Host Read Commands | 9,598,589,573 | 9,812,400,999 | 213,811,426 |
| Host Write Commands | 5,328,909,298 | 5,420,271,806 | 91,362,508 |
| Media and Data Integrity Errors | 0 | 0 | |
| Number of Error Information Log Entries | 1 | 1 | |
| Percentage Used | 17 % | 18 % | 1 |
| Power Cycles | 154 | 154 | |
| Power On Hours | 1,799 | 1,812 | 13 |
| Thermal Management Temperature 1 Count | 0 | 0 | |
| Thermal Management Temperature 1 Time | 0 Sec | 0 Sec | |
| Thermal Management Temperature 2 Count | 0 | 0 | |
| Thermal Management Temperature 2 Time | 0 Sec | 0 Sec | |
| Unsafe Shutdowns | 23 | 23 | |
| Warning Composite Temperature Time | 57 Min | 57 Min | |
| Time Throttled | 3540 | 3540 | |

## SYSTEM INFORMATION

| PARAMETER | VALUE |
|---|---|
| Supplier | HP |
| Model | HP Z1 Entry Tower G5 |
| BIOS | R01 Ver. 02.12.00 |
| Hostname | fedora |
| OS | Fedora Linux 35 (Workstation Edition) |

# PERFORMANCE

### Short Burst Performance (2 seconds)

| IO PATTERN | EMPTY DRIVE | DRIVE 90% FULL |
|---|---|---|
| Random Write, QD1, 4KiB | 0.137 GB/s | 0.123 GB/s |
| Random Read, QD1, 4KiB | 0.033 GB/s | 0.020 GB/s |
| Random Write, QD32, 4KiB | 0.499 GB/s | 0.260 GB/s |
| Random Read, QD32, 4KiB | 0.566 GB/s | 0.226 GB/s |
| Sequential Write, QD32, 128KiB | 0.740 GB/s | 0.741 GB/s |
| Sequential Read, QD32, 128KiB | 0.856 GB/s | 0.859 GB/s |

### Long Burst Performance (10.0 minutes) - Empty Drive

| IO PATTERN | AVERAGE | FIRST SEC | FIRST 15 SEC | LAST 120 SEC |
|---|---|---|---|---|
| Random Write, QD1, 4KiB | 0.127 GB/s | 0.106 GB/s | 0.120 GB/s | 0.120 GB/s |
| Random Read, QD1, 4KiB | 0.029 GB/s | 0.025 GB/s | 0.028 GB/s | 0.028 GB/s |
| Sequential Write, QD32, 128KiB | 0.784 GB/s | 0.761 GB/s | 0.754 GB/s | 0.749 GB/s |
| Sequential Read, QD32, 128KiB | 0.901 GB/s | 0.830 GB/s | 0.858 GB/s | 0.859 GB/s |

### Long Burst Performance (10.0 minutes) - Drive 90% Full

| IO PATTERN | AVERAGE | FIRST SEC | FIRST 15 SEC | LAST 120 SEC |
|---|---|---|---|---|
| Random Write, QD1, 4KiB | 0.079 GB/s | 0.117 GB/s | 0.118 GB/s | 0.024 GB/s |
| Random Read, QD1, 4KiB | 0.031 GB/s | 0.021 GB/s | 0.030 GB/s | 0.029 GB/s |
| Sequential Write, QD32, 128KiB | 0.138 GB/s | 0.027 GB/s | 0.013 GB/s | 0.160 GB/s |
| Sequential Read, QD32, 128KiB | 0.908 GB/s | 0.872 GB/s | 0.870 GB/s | 0.868 GB/s |

# TEST 10: DRIVE INFO

| | | |
|---|---|---|
| REQUIREMENTS | 3 | |
| PASSED | 3 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 19, 2022 - 19:46:41.808 | Aug 19, 2022 - 19:46:42.046 | 0:00:00.237 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |

## DESCRIPTION

This test verifies the drive information can be read without errors. The NVMe information is read using the Get Log Page, Get Feature, Identify Controller, and Identify Namespace Admin Commands. If any Admin Command returns an error code the test fails.

## RESULTS

All requirements passed verification.

# TEST 12: DRIVE WEAR

| | | |
|---|---|---|
| REQUIREMENTS | 4 | |
| PASSED | 3 | 75.0% |
| FAILED | 1 | 25.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 19, 2022 - 19:46:42.047 | Aug 19, 2022 - 19:46:42.069 | 0:00:00.022 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 110 | Percentage Used shall be less than 80% | PASS |
| 111 | Available Spare shall be 100% | PASS |
| 112 | Percentage Written shall be less than 80% | FAIL |
| 113 | Percentage Warranty Used shall be less than 80% | PASS |

## DESCRIPTION

This test verifies the drive is not “worn out” prior to beginning a test run. Drive wear is determined by reading SMART attributes from log page 2. The Percentage Used SMART attribute is the primary reference of drive wear.

If the user provided information on the warranty and TBW then the Percentage Data Written and Percentage Warranty Used are verified. Percentage Data Written is defined as as 100 * (Data Written / TBW) where TBW (Terabytes Written) is the total amount of data that can be written to the drive during the warranty period. Data Written is the SMART attribute that reports the data written to the drive.

Percentage Warranty Used is defined as 100 * (Power On Hours / Warranty Hours) where warranty hours is the number of days in the warranty multiplied by 8 hours for client drives or 24 hours for enterprise drives.

## RESULTS

One or more requirements failed verification and are listed in the table above.

| PARAMETER | VALUE | NOTE |
|---|---|---|
| Percentage Used | 17% | SMART attribute |
| Percentage Data Written | 82.9% | Calculated |
| Percentage Warranty Used | 12.3% | Calculated |
| Data Written | 124.420 TB | SMART attribute |
| Terabytes Written (TBW) | 150 TB | User Input |
| Warranty | 5 years | User input |
| Power On Hours | 1,799 | SMART attribute |
| Warranty Hours | 14,600 | 5 * 365 * 8hr |

# TEST 13: DRIVE HEALTH

| | | |
|---|---|---|
| REQUIREMENTS | 5 | |
| PASSED | 4 | 80.0% |
| FAILED | 1 | 20.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 19, 2022 - 19:46:42.070 | Aug 19, 2022 - 19:46:42.092 | 0:00:00.021 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 114 | Previous Self-Test failures shall be 0 | PASS |
| 115 | SMART media and integrity errors shall be 0 | PASS |
| 116 | Percentage throttled shall be less than 1.0% | PASS |
| 117 | Critical composite temperature time shall be 0 | FAIL |

## DESCRIPTION

This test verifies drive health by looking for failed self-test results, critical warnings, media and data integrity errors, and excessive thermal throttling. Self-test results are read from Log Page 6. All other results are SMART attributes from Log Page 2.

This test defines excessive thermal throttling as a failure but excessive throttling could indicate an environment or system issue.

## RESULTS

One or more requirements failed verification and are listed in the table above.

A total of 20 prior self-test results were found and none failed. There were no critical warnings or media errors. Excessive thermal throttling was detected and should be reviewed.

| PARAMETER | VALUE | NOTE |
|---|---|---|
| Critical Warnings | No | |
| Media and Integrity Errors | 0 | |
| Self-test failures | 0 | |
| Percentage Throttled | 0.1% | Must be less than 1% |
| Power On Hours | 1,799 | |
| Throttled Hours | 0.98 | 0.1% of Power On Hours |
| Thermal Management Temperature 1 Time | 0 sec | 0.00 Hours |
| Thermal Management Temperature 2 Time | 0 sec | 0.00 Hours |
| Warning Composite Temperature Time | 57 min | 0.95 Hours |
| Critical Composite Temperature Time | 2 min | 0.03 Hours |

# TEST 14: DRIVE FEATURES

| | | |
|---|---|---|
| REQUIREMENTS | 5 | |
| PASSED | 4 | 80.0% |
| FAILED | 1 | 20.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 19, 2022 - 19:46:42.092 | Aug 19, 2022 - 19:46:42.115 | 0:00:00.022 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 900 | PCIe bus width must be x4 | PASS |
| 901 | PCIe bus speed must be Gen3 8.0GT/s | FAIL |
| 902 | Firmware activation without reset must be supported | PASS |
| 903 | RTD3 Entry Latency (RTD3E) must be less than 10,000,000 uS | PASS |
| 905 | Power State 0 Maximum Power (MP) must be less than 8 Watts | PASS |

## DESCRIPTION

This test verifies a set of requirements, specific to the drive being tested, that are defined by the tester. This allows the tester to verify features and limits that are specific for their environment. For example, the tester can verify a specific feature, such as crypto-erase, is supported. Another example, the tester can verify the maximum power for Power State 0 is less than their system's power target.

## RESULTS

One or more requirements failed verification and are listed in the table above.

| PARAMETER | VALUE | NOTE |
|---|---|---|
| PCI Width | x4 | Must be x2 |
| PCI Speed | Gen1 2.5GT/s | Must be Gen3 8.0GT/s |
| Firmware Activation Without Reset | Supported | Must be supported |
| RTD3 Entry Latency | 1,000,000 uS | Must be less than 10,000,000 uS |
| RTD3 Resume Latency | 500,000 uS | Must be less than 1,000,000 uS |
| Power State 0 Maximum Power | 3.5 Watts | Must be less than 8 Watts |

# TEST 20: SHORT SELFTEST

| | | |
|---|---|---|
| REQUIREMENTS | 13 | |
| PASSED | 13 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 19, 2022 - 19:46:42.116 | Aug 19, 2022 - 20:03:33.817 | 0:16:51.700 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 006 | IO reads and writes shall complete without data corruption | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |
| 200 | Short Self-test result is 0 (no errors) | PASS |
| 201 | Short Self-test run time less than specified | PASS |
| 202 | Short Self-test progress is monotonic | PASS |
| 203 | Short Self-test progress is roughly linear (Coeff > 0.8) | PASS |
| 204 | Short Self-test Power-On Hours match hours reported in log page 2 | PASS |

## DESCRIPTION

Self-test is a diagnostic testing sequence that tests the integrity and functionality of the controller and may include testing of the media associated with namespaces. There is a short self-test and an extended self-test. This test verifies the short self-test.

This test runs the self-test standalone and concurrent with a light IO workload. The light workload is a 50/50 mix of reads and writes with 4 KiB block size and queue depth of 1. The performance difference between standalone and concurrent operation is reported to determine if running a self-test in the background is practical. NVMe specification 1.4 [1] states performance can be degraded during the self-test but does not specify any limits this test can verify.

Self-test progress and results are reported in Log Page 6. This test regularly reads the progress from Log Page 6 and verifies it is monotonic and roughly linear. Roughly linear is defined as having a Pearson product-moment correlation coefficient greater than 0.9.

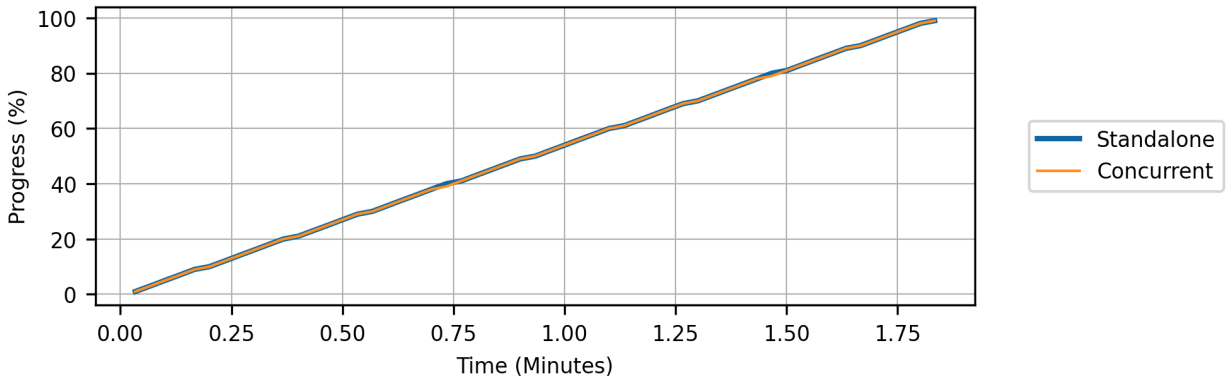
The short self-test run time limit is defined in the NVMe specification as 2 minutes or less.

## RESULTS

All requirements passed verification.

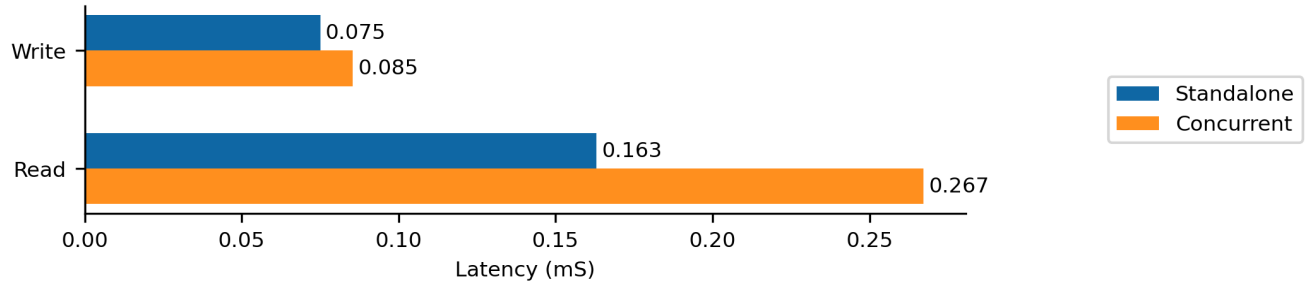
| PARAMETER | STANDALONE | CONCURRENT | LIMIT |
|---|---|---|---|
| Run Time | 1.851 Min | 1.850 Min | 2 Min |
| Progress Monotonocity | Monotonic | Monotonic | Monotonic |
| Progress Linearity | 1.000 | 1.000 | > 0.9 |

This plot shows the self-test progress reported in Log Page 6 which should be monotonic and roughly linear.

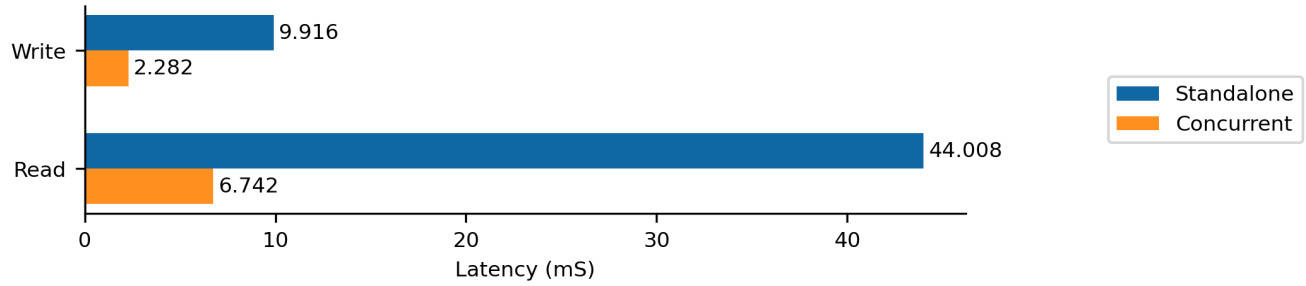



These bar charts show the difference in IO latency between stand-alone and concurrent operation. The tester must determine if the latency difference is acceptable since the NVMe specification does not define any limits.

### Average IO Latency

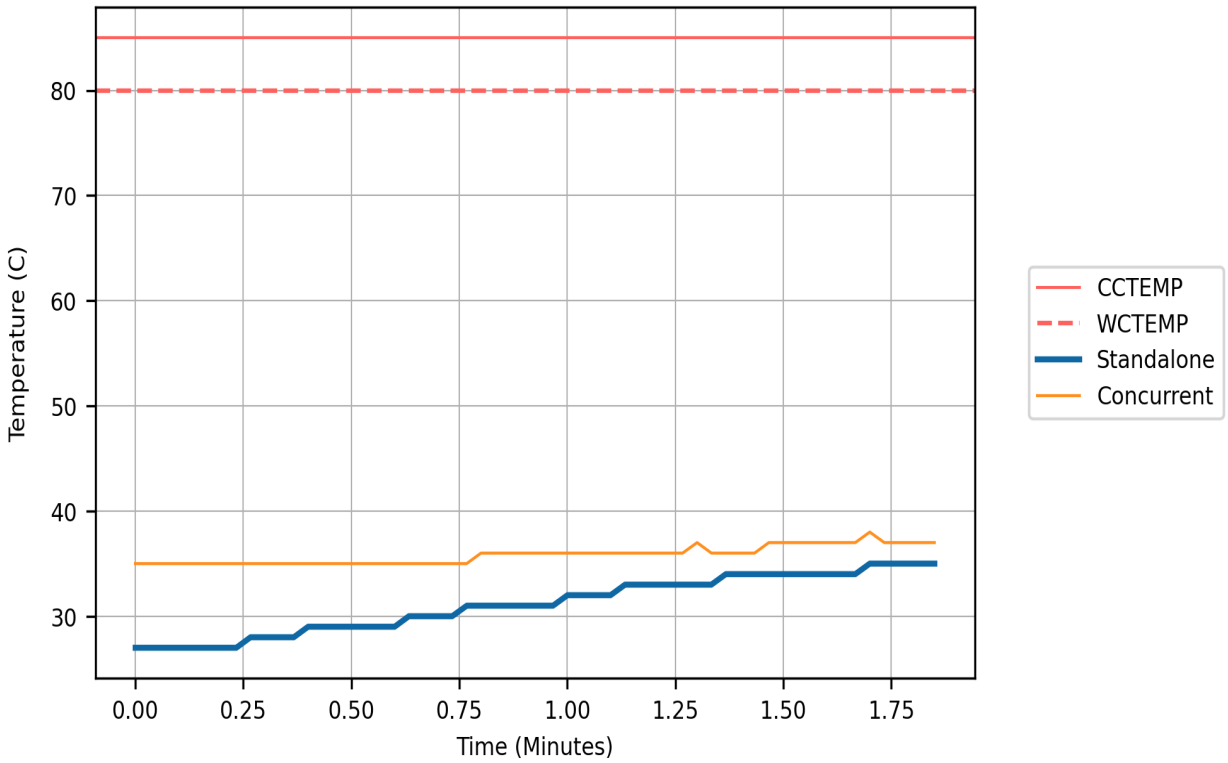



### Maximum IO Latency



## COMPOSITE TEMPERATURE

This plot shows the drive's composite temperature during the self-test to determine if over-heating is a concern. Thermal throttle limits are shown as red horizontal lines.



# TEST 21: EXTENDED SELFTEST

| | | |
|---|---|---|
| REQUIREMENTS | 13 | |
| PASSED | 13 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 19, 2022 - 20:03:33.824 | Aug 19, 2022 - 21:02:14.469 | 0:58:40.645 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 006 | IO reads and writes shall complete without data corruption | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |
| 210 | Extended Self-test result is 0 (no errors) | PASS |
| 211 | Extended Self-test run time less than specified | PASS |
| 212 | Extended Self-test progress is monotonic | PASS |
| 213 | Extended Self-test progress is roughly linear (Coeff > 0.8) | PASS |
| 214 | Extended Self-test Power-On Hours match hours reported in log page 2 | PASS |

## DESCRIPTION

Self-test is a diagnostic testing sequence that tests the integrity and functionality of the controller and may include testing of the media associated with namespaces. There is a short self-test and an extended self-test. This test verifies the extended self-test.

This test runs the self-test standalone and concurrent with a light IO workload. The light workload is a 50/50 mix of reads and writes with 4 KiB block size and queue depth of 1. The performance difference between standalone and concurrent operation is reported to determine if running a self-test in the background is practical. NVMe specification 1.4 [1] states performance can be degraded during the self-test but does not specify any limits this test can verify.

Self-test progress and results are reported in Log Page 6. This test regularly reads the progress from Log Page 6 and verifies it is monotonic and roughly linear. Roughly linear is defined as having a Pearson product-moment correlation coefficient greater than 0.9.

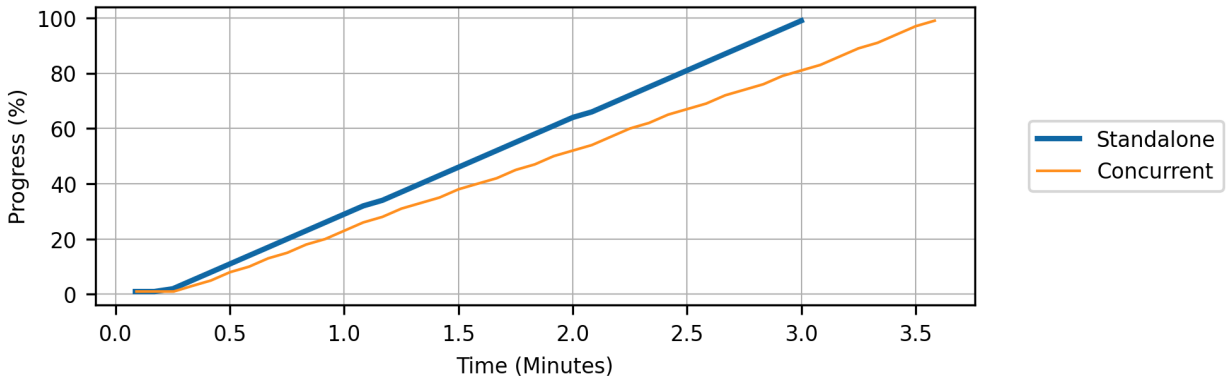
The extended self-test run time limit is from the Extended Device Self-test Time (EDSTT) field. The NVMe specification states EDSTT “this field indicates the nominal amount of time in one-minute units that the controller takes to complete an extended device self-test operation when in power state 0”. There is no maximum run time value defined in the specification therefore it is possible for an extended self-test to take longer than EDSTT and still comply with the specification. The EDSTT field is 44 minutes for this NVMe drive.

## RESULTS

All requirements passed verification.

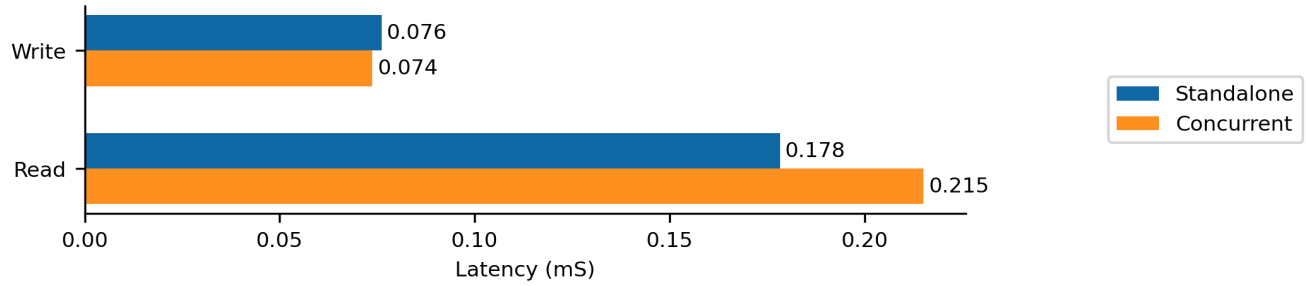
| PARAMETER | STANDALONE | CONCURRENT | LIMIT |
|---|---|---|---|
| Run Time | 3.033 Min | 3.600 Min | 44 Min |
| Progress Monotonocity | Monotonic | Monotonic | Monotonic |
| Progress Linearity | 0.999 | 0.999 | > 0.9 |

This plot shows the self-test progress reported in Log Page 6 which should be monotonic and roughly linear.

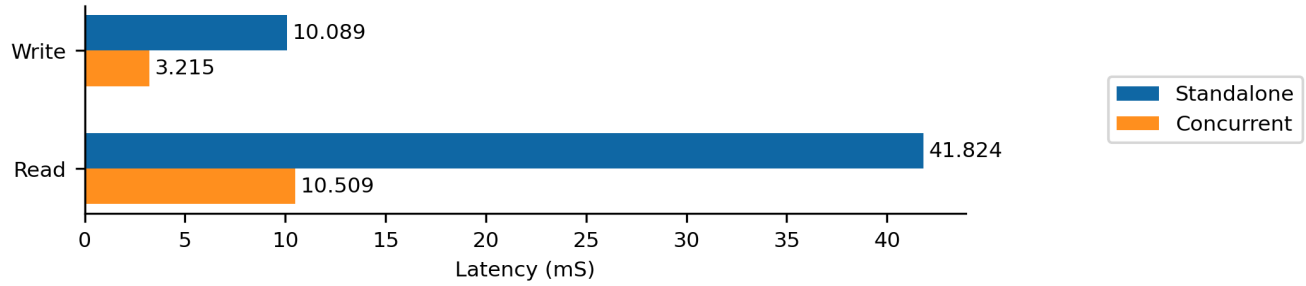



These bar charts show the difference in IO latency between stand-alone and concurrent operation. The tester must determine if the latency difference is acceptable since the NVMe specification does not define any limits.

### Average IO Latency

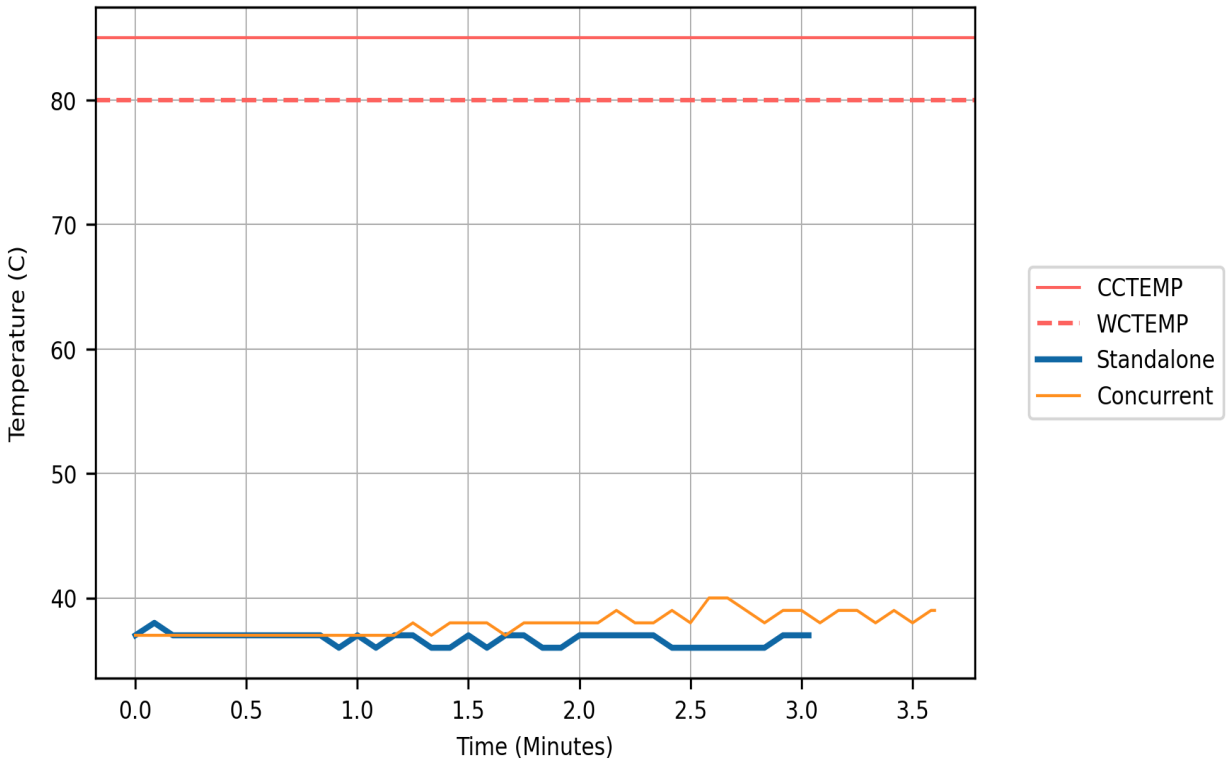



### Maximum IO Latency



## COMPOSITE TEMPERATURE

This plot shows the drive's composite temperature during the self-test to determine if over-heating is a concern. Thermal throttle limits are shown as red horizontal lines.



# TEST 30: ADMIN COMMANDS

| | | |
|---|---|---|
| REQUIREMENTS | 5 | |
| PASSED | 4 | 80.0% |
| FAILED | 1 | 20.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 19, 2022 - 21:02:14.479 | Aug 19, 2022 - 21:04:06.101 | 0:01:51.621 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | FAIL |

## DESCRIPTION

This test verifies the reliability and performance of Admin Commands that provide information about the drive: Identify Controller, Identify Namespace, Get Log Page, and Get Feature. Each Admin Command is run several thousand times to get a large sample for assessing reliability and performance.

Commands are run continuously with no interval between the commands. Although not a practical use case, this allows running a large sample quickly. Admin command latency is dependent on multiple factors including OS interrupts, power states, concurrent drive activity, and others. Therefore, the latencies reported in this test may not be worst case values.

The command information is verified by comparing each read instance against the initial value read. Static parameters, such as Model Number, were verified not to change. SMART counters, such as Data Read, were verified not to reset or decrement. Dynamic parameters, such as Timestamp, have no requirements.

## RESULTS

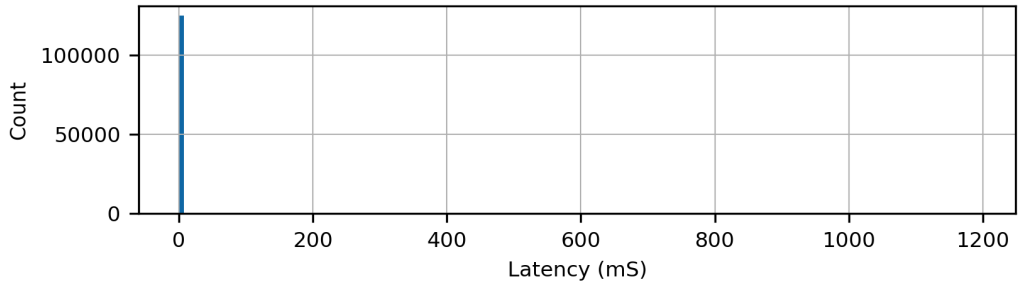
One or more requirements failed verification and are listed in the table above.

A total of 125,000 Admin Commands were completed with 0 reported errors.

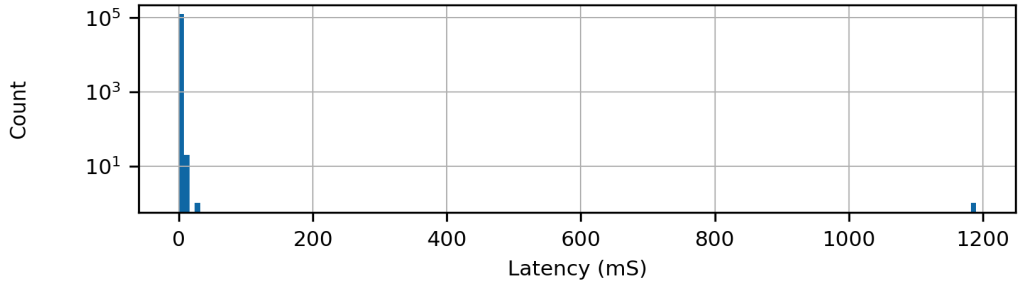
| PARAMETER | VALUE | LIMIT |
|---|---|---|
| Average Latency (All Commands) | 0.3 mS | 50 mS |
| Maxmimum Latency (All Commands) | 1189.6 mS | 500 mS |

Command latency was measured on the 23 command types shown in the histograms and bar charts below. Each command was run 5,000 times.

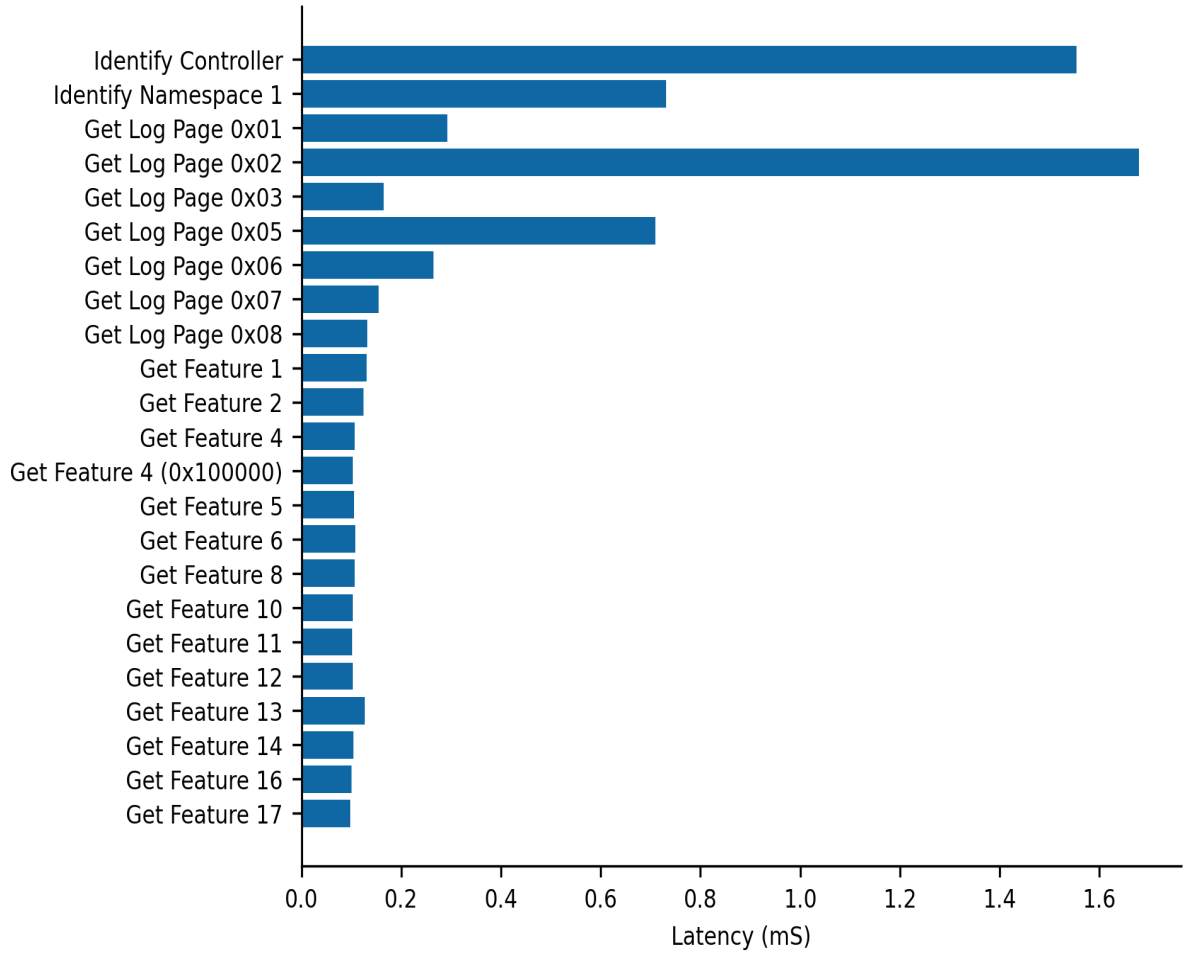
This histogram shows the distribution of Admin Command latencies for all command types.



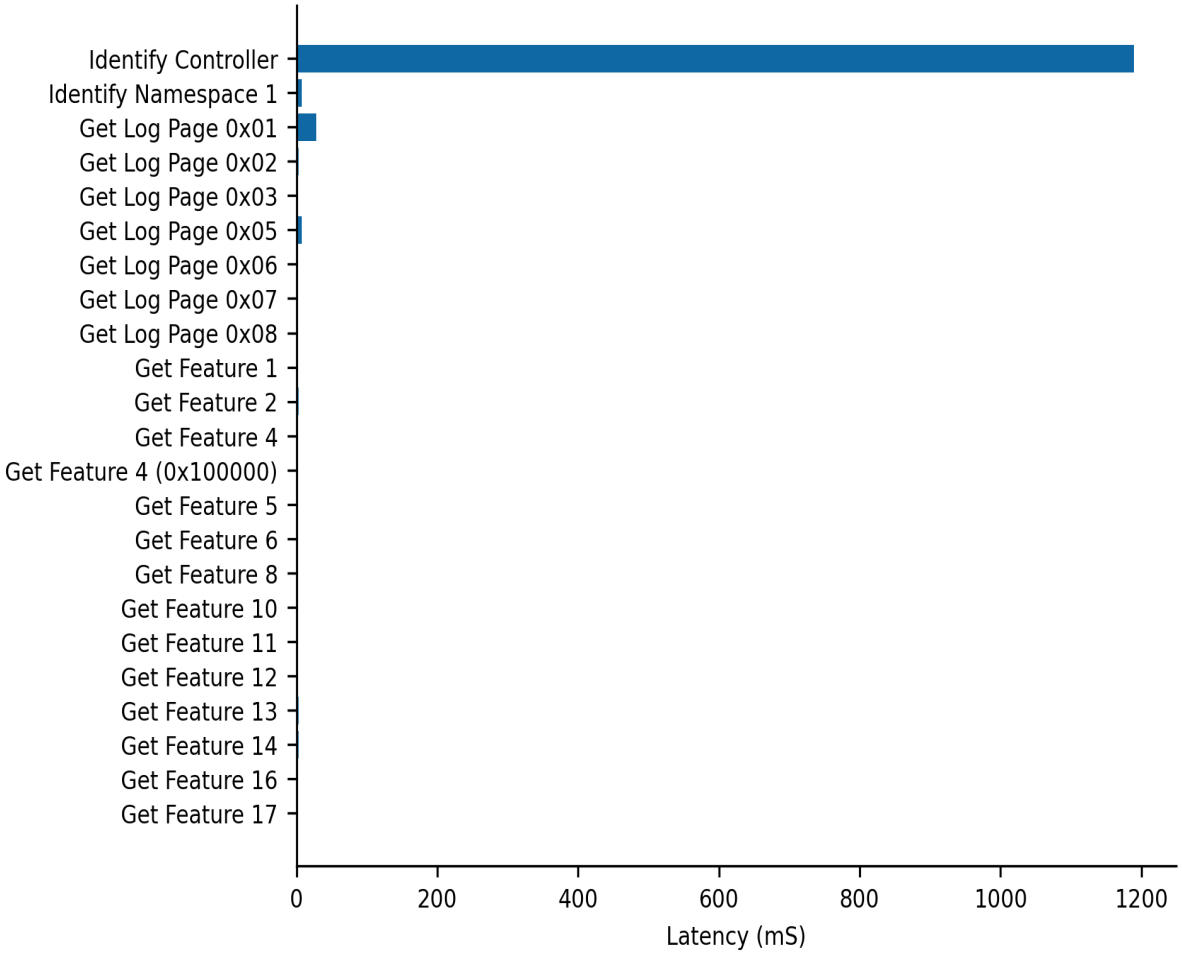

This histogram shows the distribution above on a log scale to better show outliers.




This bar chart shows the average Admin Command latencies for each command type.



This bar chart shows the maximum Admin Command latencies for each command type.



# TEST 31: BACKGROUND SMART READS

| | | |
|---|---|---|
| REQUIREMENTS | 8 | |
| PASSED | 7 | 87.5% |
| FAILED | 1 | 12.5% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 19, 2022 - 21:04:06.121 | Aug 19, 2022 - 22:00:24.352 | 0:56:18.231 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 006 | IO reads and writes shall complete without data corruption | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |
| 402 | Average latency of slowest 1,825 IO shall not increase more than 20% with concurrent SMART reads | FAIL |

## DESCRIPTION

This test verifies reading SMART attributes during normal operation has no adverse effects on IO read and writes. Adverse effects are functional errors, data integrity loss, or an unacceptable increase in IO latency. A typical Enterprise Use Case [7] reads SMART attributes in the background during normal operation to identify issues that may predict drive failures. Suspect drives can then be replaced prior to actually failing.

This test runs a total of 1,825 Get Log Page 2 commands to model one read per day for 5 years. The Get Log Page 2 commands are run at intervals of 500mS to ensure significant idle time between commands, to be closer to the actual use case.

This test runs a light IO workload of 50/50 reads and writes, random addressing, 4 KiB block size, and queue depth 2. This workload ensures an IO is always in flight but should not swamp the controller.

## RESULTS

One or more requirements failed verification and are listed in the table above.

A total of 3,650 Get Log Page 2 Commands were completed with 0 reported errors. Get Log Page 2 latency was measured on 1,825 commands run standalone and another 1,825 commands run concurrent with IO reads and writes.

| PARAMETER | STANDALONE | CONCURRENT | DELTA |
|---|---|---|---|
| Average Get Log Page 2 Latency | 1.92 mS | 1.65 mS | -0.28 mS |
| Maxmimum Get Log Page 2 Latency | 2.13 mS | 80.20 mS | 78.07 mS |

A total of 0 errors occured running IO standalone and 0 errors running concurrent.

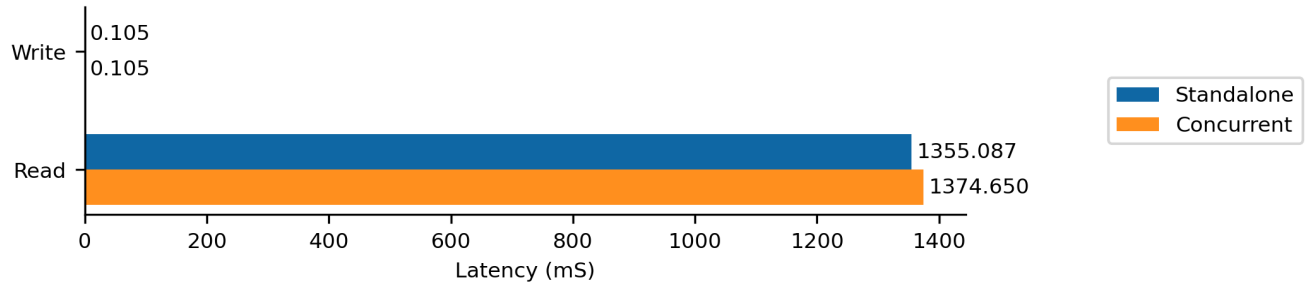
A total of 6,650,420 reads were completed standalone. Another 6,513,505 reads were completed concurrent with Log Page 2. In the tables and charts below the slowest IO are defined as the slowest 1,825 IO.

| PARAMETER | STANDALONE | CONCURRENT | DELTA |
|---|---|---|---|
| Read Average Latency | 1355.09 mS | 1374.65 mS | 19.56 mS (1.4%) |
| Read Average Commit Latency Slowest IO | 7.78 mS | 7.49 mS | -0.30 mS (-3.8%) |
| Read Maximum Latency | 5954.38 mS | 5783.31 mS | -171.07 mS (-2.9%) |

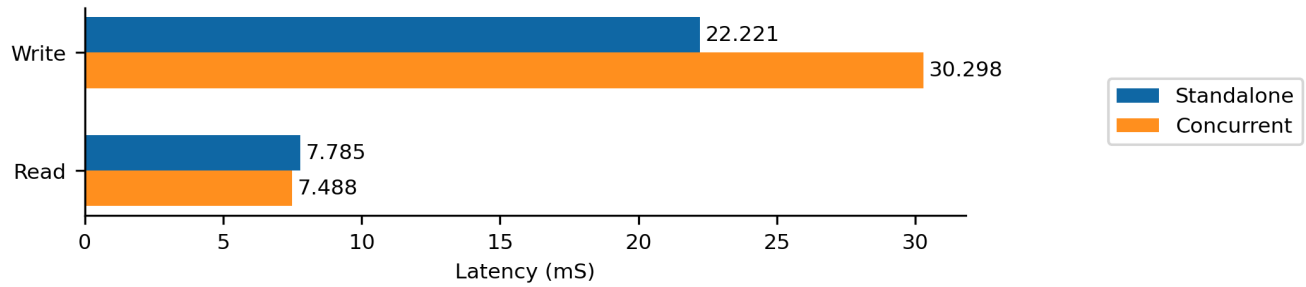
A total of 3,374,217 writes were completed standalone. Another 3,277,600 writes were completed concurrent with Log Page 2.

| PARAMETER | STANDALONE | CONCURRENT | DELTA |
|---|---|---|---|
| Write Average Latency | 0.11 mS | 0.10 mS | -0.00 mS (-0.3%) |
| Write Average Commit Latency Slowest IO | 22.22 mS | 30.30 mS | 8.08 mS (36.3%) |
| Write Maximum Latency | 1571.62 mS | 1704.95 mS | 133.33 mS (8.5%) |

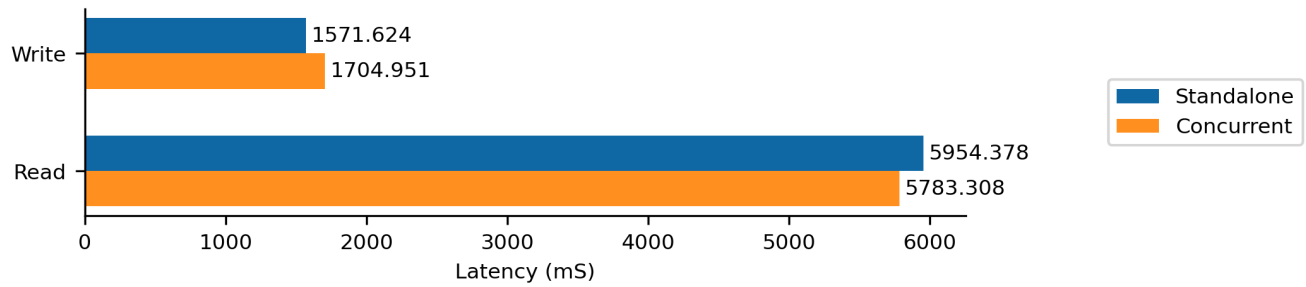
### Average IO Latency




### Slowest IO Latency




### Maximum IO Latency



# TEST 32: SMART DATA READ AND WRITTEN

| | | |
|---|---|---|
| REQUIREMENTS | 4 | |
| PASSED | 4 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 19, 2022 - 22:00:24.356 | Aug 19, 2022 - 22:03:41.074 | 0:03:16.717 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 005 | IO reads and writes shall complete without errors | PASS |
| 006 | IO reads and writes shall complete without data corruption | PASS |
| 150 | SMART attribute Data Written shall be within 512,000 bytes of data written | PASS |
| 151 | SMART attribute Data Read shall be within 512,000 bytes of data read | PASS |

## DESCRIPTION

This test verifies the accuracy of the Data Read and Data Written SMART attributes. The SMART attributes are compared against the disk counters reported by the python psutil package. To ensure a large enough sample for comparison, IO read and writes are run for three minutes in a high bandwidth configuration.

The SMART attribute resolution is 512,000 bytes according to the NVMe Specification 1.4 [1]. The current test limit has been set to the resolution of the SMART attributes.

## RESULTS

All requirements passed verification.

| PARAMETER | VALUE | DELTA | LIMIT |
|---|---|---|---|
| Bytes written from psutil counter | 29,956,304,896 | | |
| Bytes written reported by SMART | 29,956,096,000 | -208,896 | 512,000 |
| Bytes read reported by psutil counter | 55,924,752,384 | | |
| Bytes read reported by SMART | 55,924,736,000 | -16,384 | 512,000 |

The tables below include fio reported data to determine if anything other than fio was reading or writing the drive during the test. If the drive under test is the OS drive than additional read and writes are likely.

| PARAMETER | VALUE | DELTA |
|---|---|---|
| Bytes read reported by fio | 55,924,752,384 | 0 |
| Bytes written reported by fio | 28,881,977,344 | -1,074,327,552 |

# TEST 40: TIMESTAMP

| | | |
|---|---|---|
| REQUIREMENTS | 14 | |
| PASSED | 10 | 71.4% |
| FAILED | 4 | 28.6% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 19, 2022 - 22:03:41.074 | Aug 19, 2022 - 22:13:40.961 | 0:09:59.886 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 006 | IO reads and writes shall complete without data corruption | PASS |
| 008 | Thermal throttle time shall not increase | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |
| 410 | Timestamp shall not stop counting | FAIL |
| 411 | Timestamp shall be within 1.0 hour of host timestamp | FAIL |
| 412 | Timestamp changes shall be within 1.0 % of host time change | FAIL |
| 413 | Timestamp count is linear (Coeff > 0.99) | FAIL |

## DESCRIPTION

Timestamp Feature Identifier 0Eh is an optional feature that reports the number of milliseconds that have elapsed since the epoch: midnight, 01-Jan-1970, UTC. The timestamp is set to the current time by the host and then the drive increments the timestamp every millisecond. The test reads the Get Feature data structure to get the timestamp info and verify the timestamp has been set by the host and matches the current time.

On some drives, the timestamp may stop under some conditions such as entering into non-operational power states. This test verifies the timestamp has not stopped by reading the synch attribute in the Get Feature data structure.

The test samples the host and drive timestamps every second for several minutes of idle and IO traffic. This verifies the drive timestamp is accurate in multiple power states which is especially important since some stop in non-operational states.

This test uses the host timestamp as the reference. Therefore, any issues with the host timestamp may cause this test to fail.

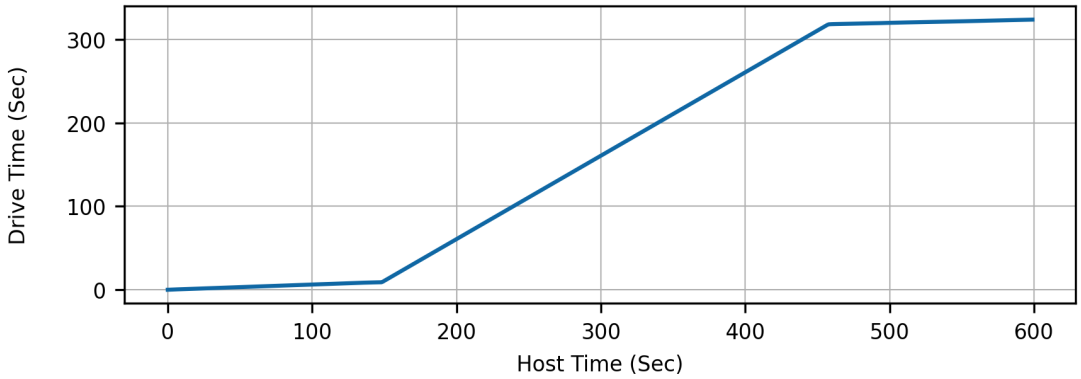
## RESULTS

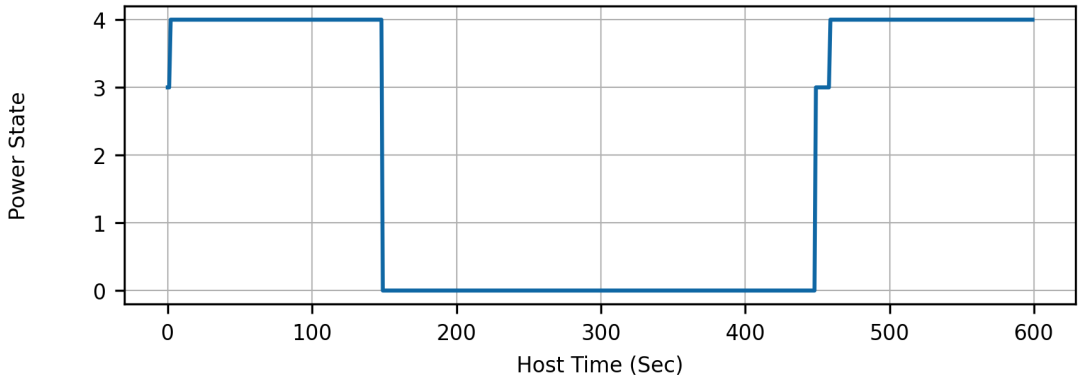
One or more requirements failed verification and are listed in the table above.

The timestamp synch attribute in the Get Feature data structure was set indicating the timestamp has stopped and may not be valid.

| PARAMETER | HOST | DRIVE | DELTA | LIMIT |
|---|---|---|---|---|
| Starting Timestamp | 1,660,920,667,704 mS | 1,660,971,821,109 mS | 14.2 hrs | 1.0 hrs |
| Timestamp Change | 599,757 mS | 323,973 mS | 45.98% | 1.0% |

The plot below shows the linearity between the drive and host timestamps. The measured Pearson product-moment correlation coefficent was: 0.978. Anything less than 0.99 indicates the host and drive timestamps do not track as expected. If the tracking is erratic it can be cross-referenced againt the power states in the second plot.



# TEST 100: SHORT BURST PERFORMANCE

| | | |
|---|---|---|
| REQUIREMENTS | 15 | |
| PASSED | 13 | 86.7% |
| FAILED | 2 | 13.3% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 19, 2022 - 22:13:40.972 | Aug 19, 2022 - 22:53:18.052 | 0:39:37.080 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 008 | Thermal throttle time shall not increase | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |
| 200 | Short burst Sequential Write, QD32, 128KiB, bandwidth must be more than 1.5 GB/s | FAIL |
| 201 | Short burst Sequential Read, QD32, 128KiB, bandwidth must be more than 1.5 GB/s | FAIL |
| 202 | Short burst Random Write, QD1, 4KiB, bandwidth must be more than 0.02 GB/s | PASS |
| 203 | Short burst Random Read, QD1, 4KiB, bandwidth must be more than 0.02 GB/s | PASS |
| 204 | Short burst Random Write, QD32, 4KiB, bandwidth must be more than 0.2 GB/s | PASS |
| 205 | Short burst Random Read, QD32, 4KiB, bandwidth must be more than 0.2 GB/s | PASS |

## DESCRIPTION

This test reports the bandwidth for short bursts of IO reads and writes. Short bursts avoid performance reducing behavior such as thermal throttling, excessive SLC write cache misses, and shortage of erased blocks for future writes. Short IO bursts result in high bandwidth measurements ideal for datasheet comparisons and benchmarking applications such as spreadsheets and word processors that intermittently read and write small to medium files.

This test runs a variety of block sizes and queue depths across four common IO patterns: random writes, random reads, sequential writes and sequential reads. The bandwidth should increase as block size and queue depth increase until the bandwidth saturates. This maximum bandwidth is expected to be different between reads and writes but not between random and sequential access types. There is no standard performance specification for drive datasheets so refer to the datasheet of the drive under test to determine the block size and queue depth to compare.

Each burst lasts for 2.5 seconds and is followed by an idle period to allow the drive temperature and background activity to return to the initial state. During the idle state the drive is likely to enter a non-operational power state. The latency to exit the non-operational power state would effect the measured bandwidth. To avoid the effects of exiting the power state, this test excludes the first 0.5 seconds of the burst.

No data integrity checking is done to avoid any effect the performance numbers.

The test uses the standard OS software stack which may limit the maximum block size or queue depth. For example, some Linux versions limit the block size to 128KiB.

## RESULTS

One or more requirements failed verification and are listed in the table above.

This table shows the minimum and maximum bandwidth for each IO pattern across all combinations of block sizes and queue depths.

| IO PATTERN | MINIMUM BANDWIDTH | MAXIMUM BANDWIDTH |
|---|---|---|
| Random Write | 0.137 GB/s | 0.741 GB/s |
| Random Read | 0.033 GB/s | 0.857 GB/s |
| Sequential Write | 0.123 GB/s | 0.754 GB/s |
| Sequential Read | 0.131 GB/s | 0.857 GB/s |

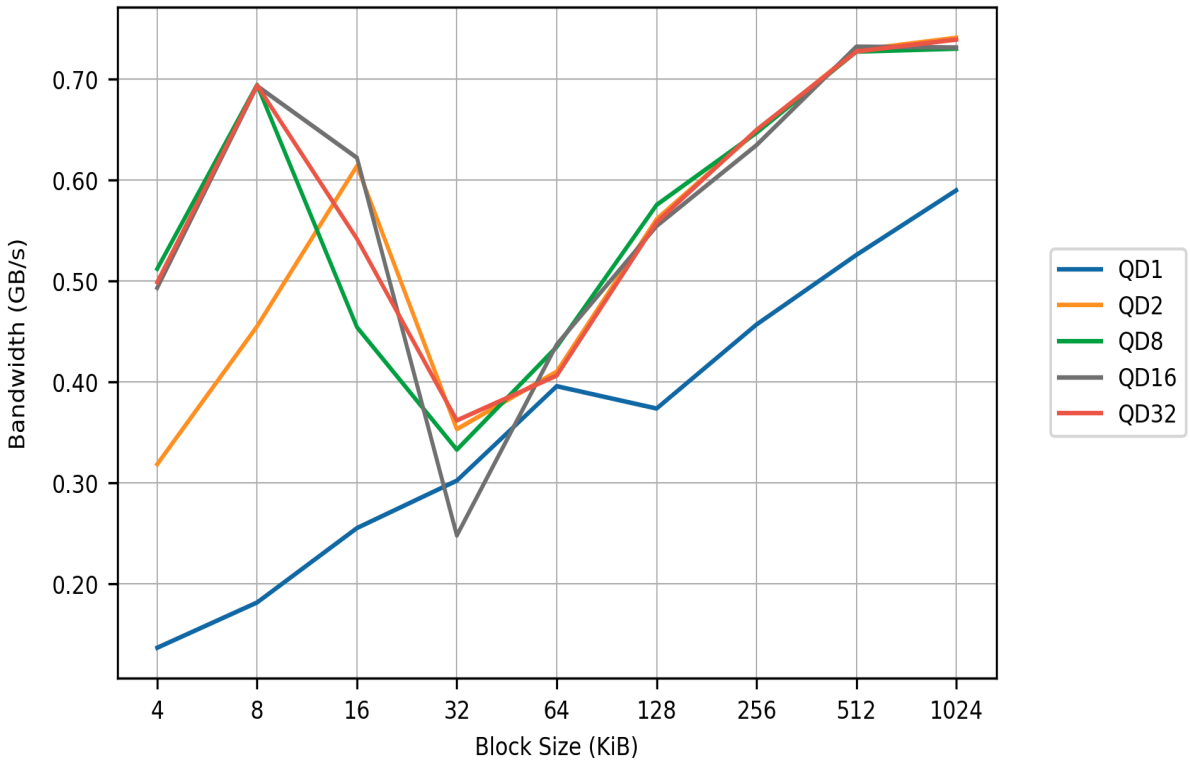
This table shows the bandwidth for several common datasheet and IO benchmark queue depths and block sizes.

| IO PATTERN | BANDWIDTH | LIMIT |
|---|---|---|
| Random Write, QD1, 4KiB | 0.137 GB/s | 0.020 GB/s |
| Random Read, QD1, 4KiB | 0.033 GB/s | 0.020 GB/s |
| Random Write, QD32, 4KiB | 0.499 GB/s | 0.200 GB/s |
| Random Read, QD32, 4KiB | 0.566 GB/s | 0.200 GB/s |
| Sequential Write, QD32, 128KiB | 0.740 GB/s | 1.500 GB/s |
| Sequential Read, QD32, 128KiB | 0.856 GB/s | 1.500 GB/s |

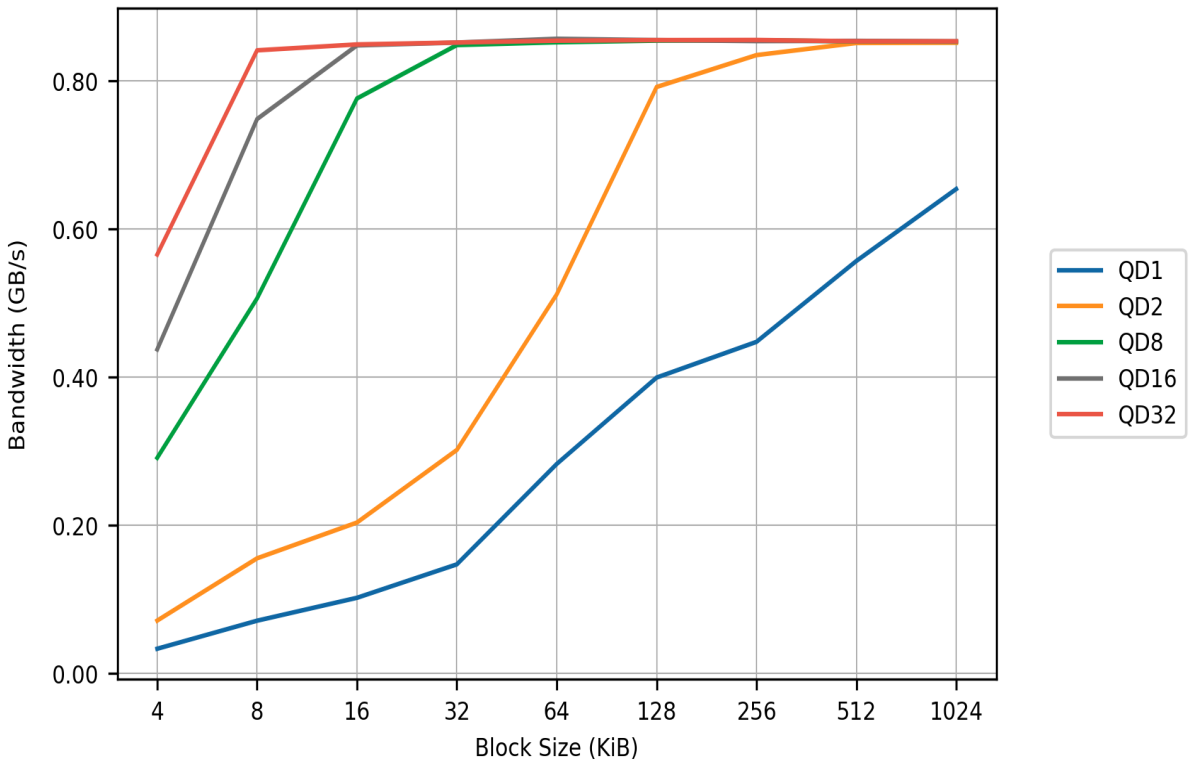
This table shows the IOPS for several common datasheet and IO benchmark queue depths and block sizes. The IOPS is the bandwidth divided by block size.

| IO PATTERN | IOPS | LIMIT |
|---|---|---|
| Random Write, QD1, 4KiB | 33,391 | 4,883 |
| Random Read, QD1, 4KiB | 8,147 | 4,883 |
| Random Write, QD32, 4KiB | 121,801 | 48,828 |
| Random Read, QD32, 4KiB | 138,103 | 48,828 |
| Sequential Write, QD32, 128KiB | 5,646 | 11,444 |
| Sequential Read, QD32, 128KiB | 6,530 | 11,444 |

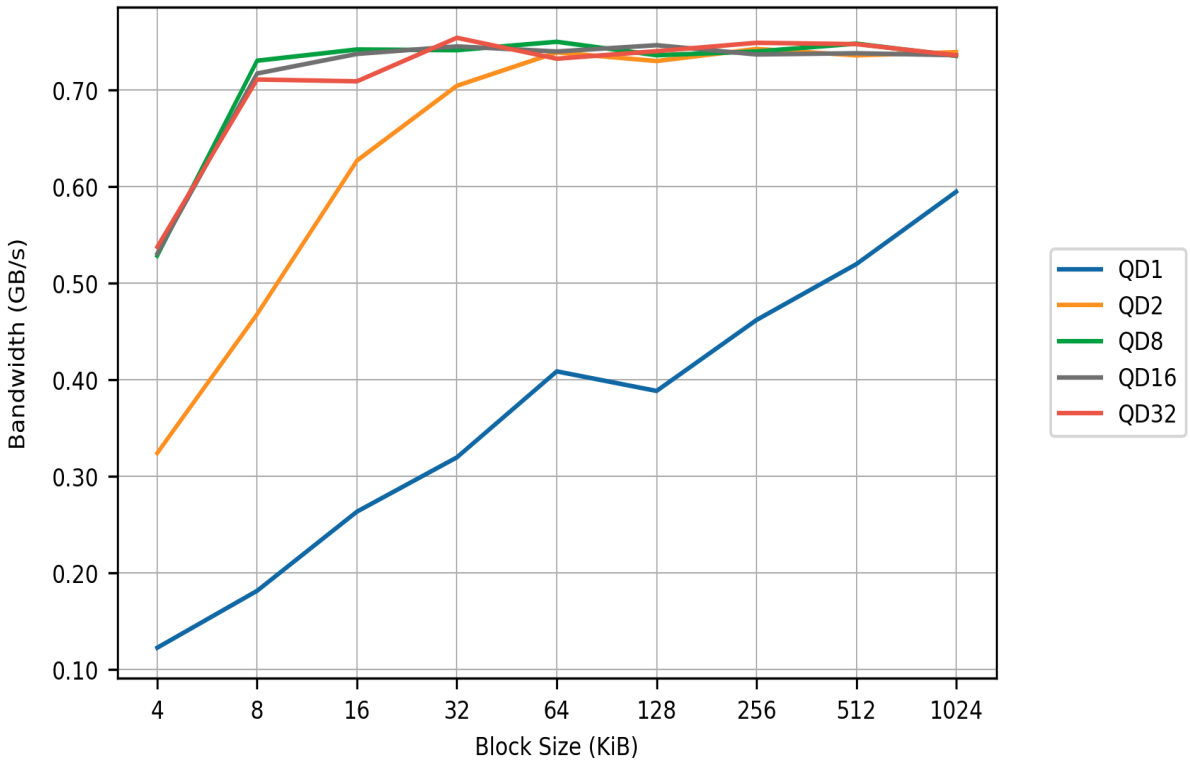
## Random Write Bandwidth



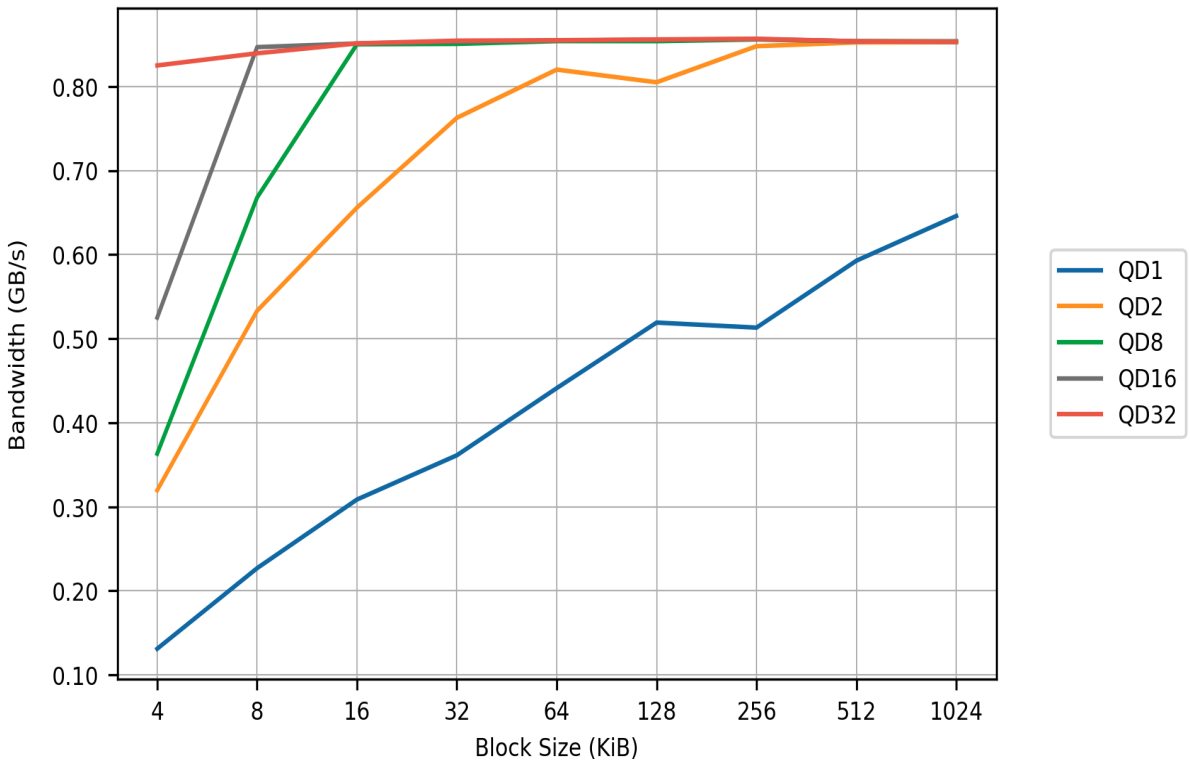

## Random Read Bandwidth



## Sequential Write Bandwidth




## Sequential Read Bandwidth



# TEST 101: LONG BURST PERFORMANCE

| | | |
|---|---|---|
| REQUIREMENTS | 11 | |
| PASSED | 7 | 63.6% |
| FAILED | 4 | 36.4% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 19, 2022 - 22:53:18.057 | Aug 20, 2022 - 02:01:25.670 | 3:08:07.613 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | FAIL |
| 220 | Long burst Sequential Write, QD32, 128KiB, bandwidth must be more than 1.0 GB/s | FAIL |
| 221 | Long burst Sequential Read, QD32, 128KiB, bandwidth must be more than 1.0 GB/s | FAIL |
| 401 | Temperature at end of long burst IO shall be within 5C of temperature when IO started | FAIL |

## DESCRIPTION

This test reports bandwidth and composite temperature for long bursts of IO. There are four IO patterns: random writes, random reads, sequential writes, and sequential reads. The plots are useful for gaining insight into drive behavior such as write caching, thermal throttling, and background garbage collection. For example, if thermal throttling occurs the plot can tell the time and amount of data read or written before the throttling started. It can also tell the reduction in bandwidth for each level of throttling.

The test reports different bandwidths for each IO pattern. The average bandwidth for the entire IO burst, first second, first 15 seconds, and last 120 seconds. The initial bandwidth is more relevant for use cases that do not continuously access the drive, such as office omputing. The end bandwidth is more relevant for uses cases that continuously access the drive.

## RESULTS

One or more requirements failed verification and are listed in the table above.

The table below provides the average and ending bandwidth. The ending bandwidth could be significantly lower if thermal throttling or excessive garbage collection occurs.

| IO PATTERN | AVERAGE | FIRST SEC | FIRST 15 SEC | LAST 120 SEC |
|---|---|---|---|---|
| Random Write, QD1, 4KiB | 0.127 GB/s | 0.106 GB/s | 0.120 GB/s | 0.120 GB/s |
| Random Read, QD1, 4KiB | 0.029 GB/s | 0.025 GB/s | 0.028 GB/s | 0.028 GB/s |
| Sequential Write, QD32, 128KiB | 0.784 GB/s | 0.761 GB/s | 0.754 GB/s | 0.749 GB/s |
| Sequential Read, QD32, 128KiB | 0.901 GB/s | 0.830 GB/s | 0.858 GB/s | 0.859 GB/s |

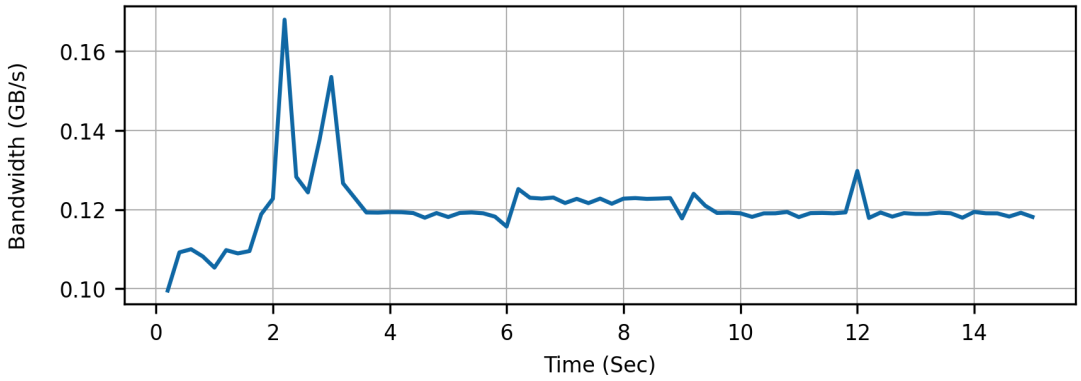
This table below reports the composite temperature during the IO burst. The expectation is the end and start temperatures should be within the delta limit. A higher temperature could indicate background operations are ongoing.

The table also includes the Throttle Time which is the sum for all throttle levels. Note that the units for throttle levels WCTEMP and CCTEMP is in minutes. Therefore, throttling for less than one minute may not be indicated for these levels.

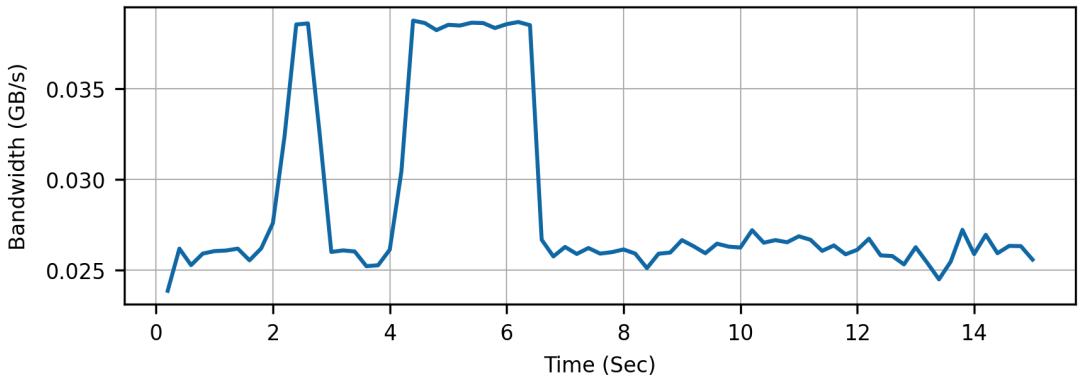
| IO PATTERN | THROTTLE | MAX | START | END | DELTA | LIMIT |
|---|---|---|---|---|---|---|
| Random Write, QD1, 4KiB | 0 sec | 46 C | 27 C | 32 C | 5 C | 5 C |
| Random Read, QD1, 4KiB | 0 sec | 40 C | 32 C | 32 C | 0 C | 5 C |
| Sequential Write, QD32, 128KiB | 0 sec | 53 C | 32 C | 27 C | -5 C | 5 C |
| Sequential Read, QD32, 128KiB | 0 sec | 60 C | 27 C | 27 C | 0 C | 5 C |

These plots show the initial bandwidth of the bursts.

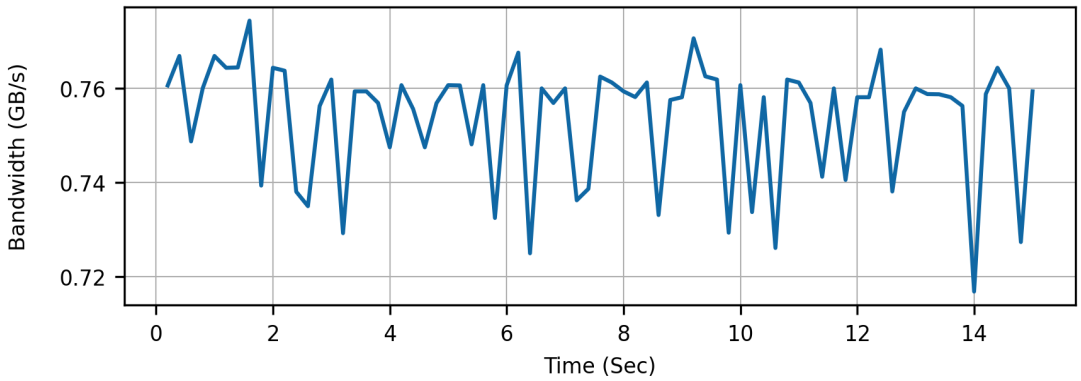
### Random Write (Initial Bandwith)



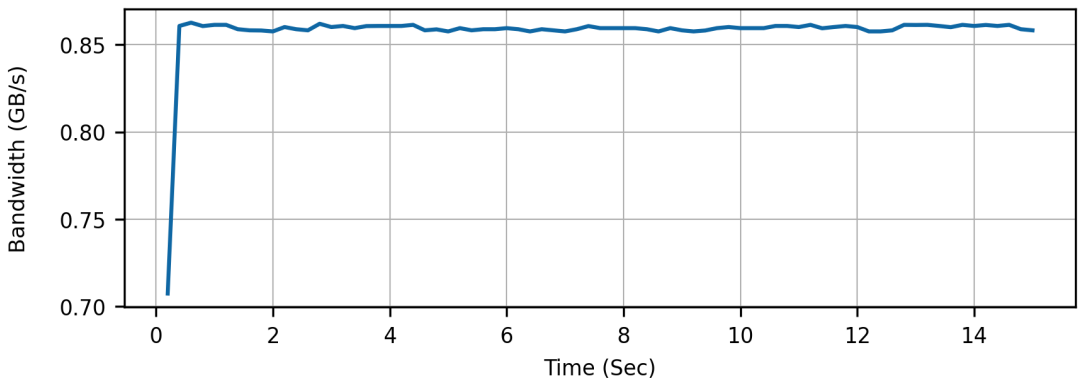

### Random Reads (Initial Bandwith)




### Sequential Write (Initial Bandwith)



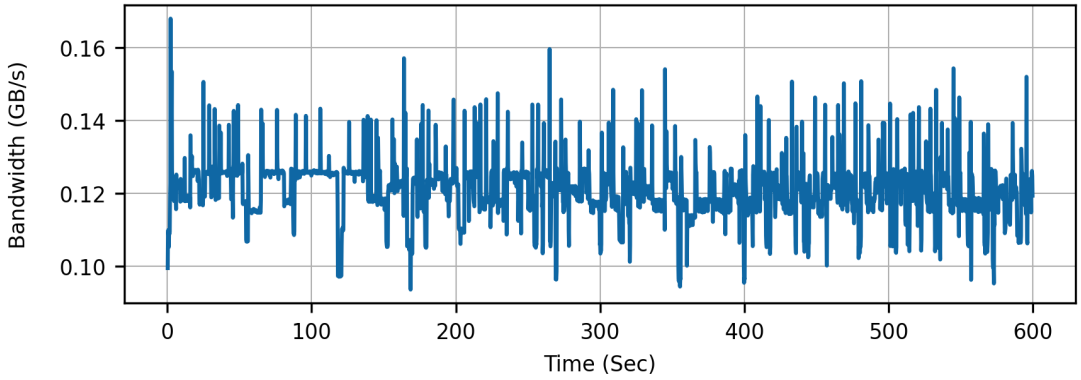

### Sequential Reads (Initial Bandwith)



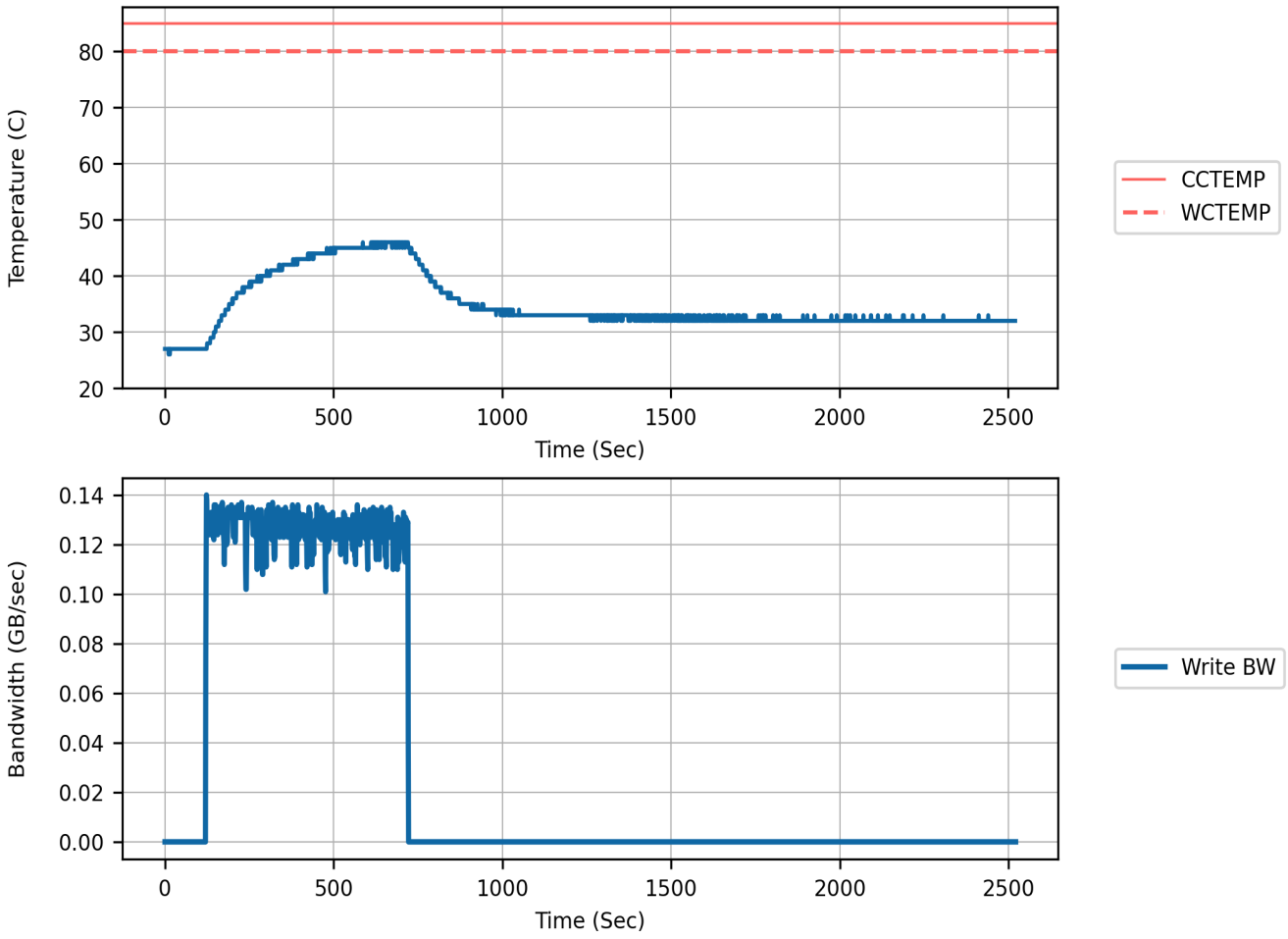
## RANDOM WRITES

These plots are for writes using random addressing, block size of 4 KiB, and queue depth of 1.

### IO Bandwidth



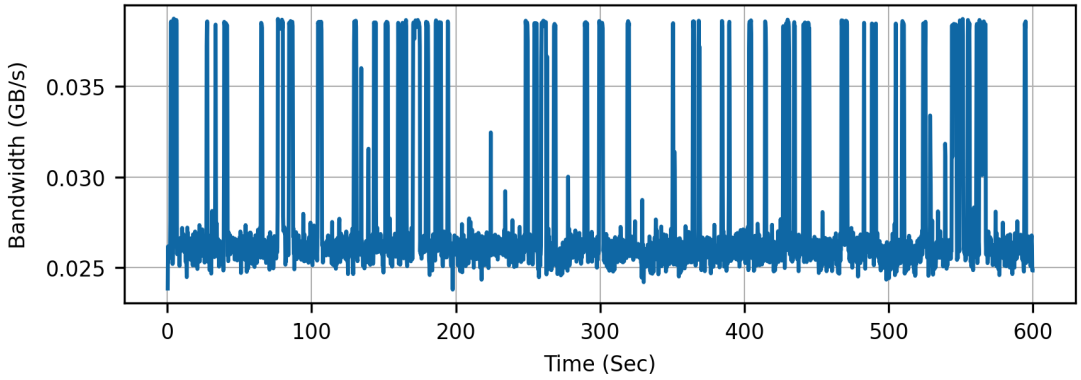

### Temperature and IO Bandwidth (Including Idle)



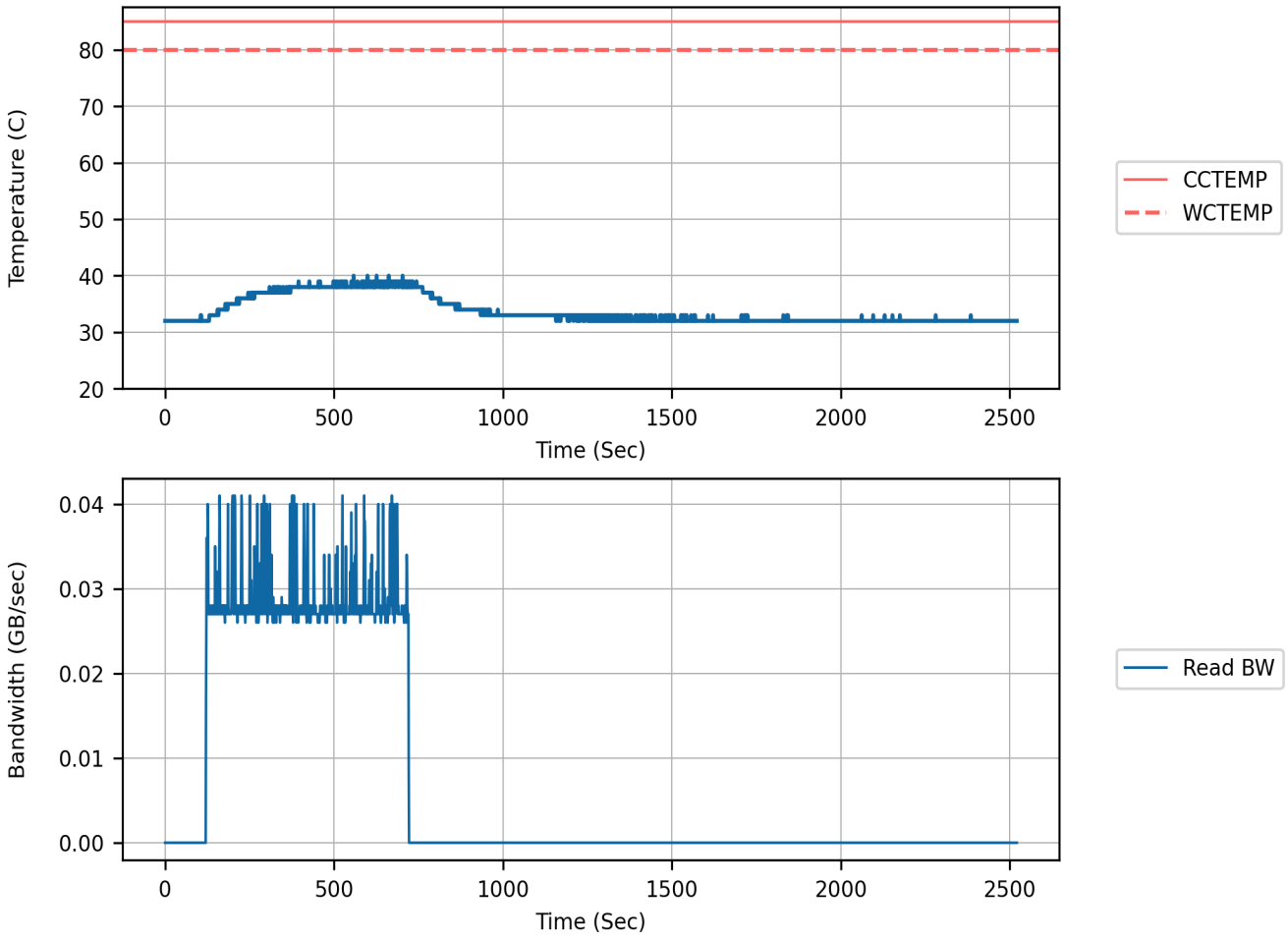
## RANDOM READS

These plots are for reads using random addressing, block size of 4 KiB, and queue depth of 1.

### IO Bandwidth



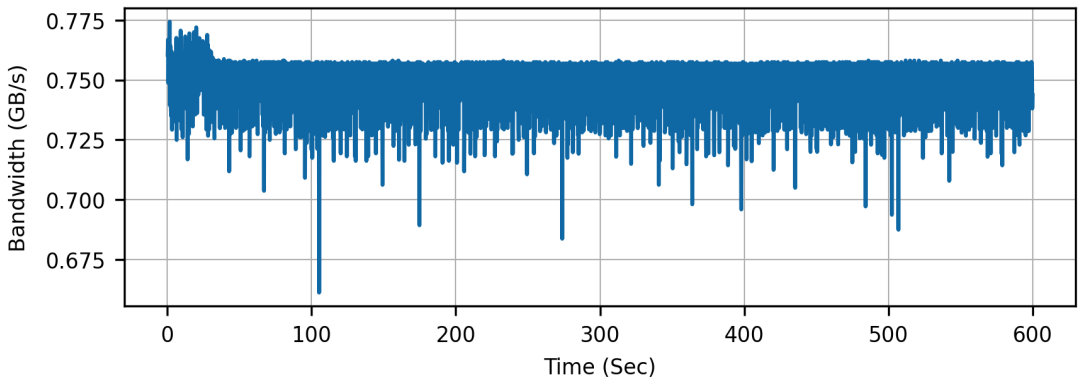

### Temperature and IO Bandwidth (Including Idle)



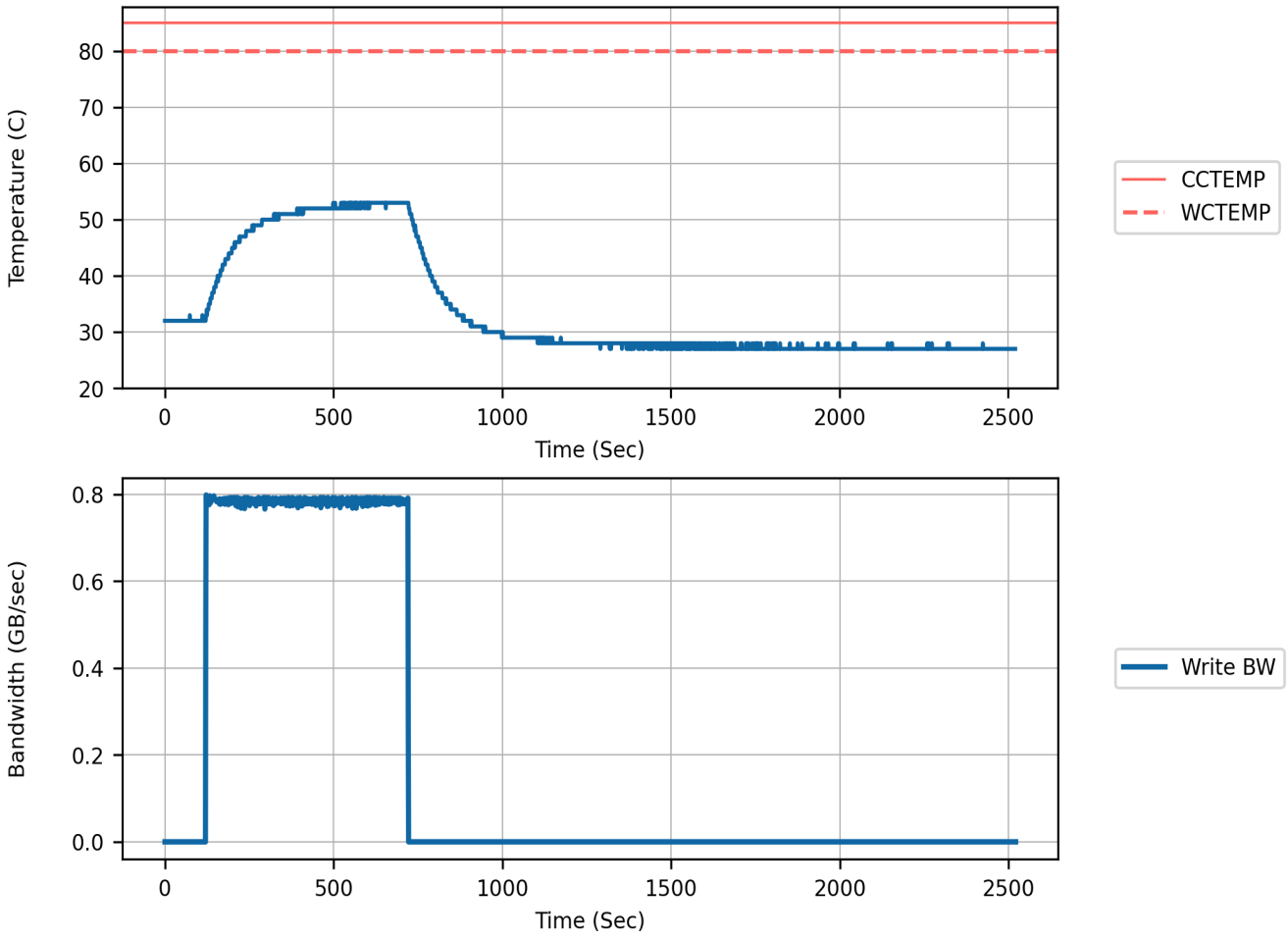
## SEQUENTIAL WRITES

These plots are for writes using sequential addressing, block size of 128 KiB, and queue depth of 32.

### IO Bandwidth



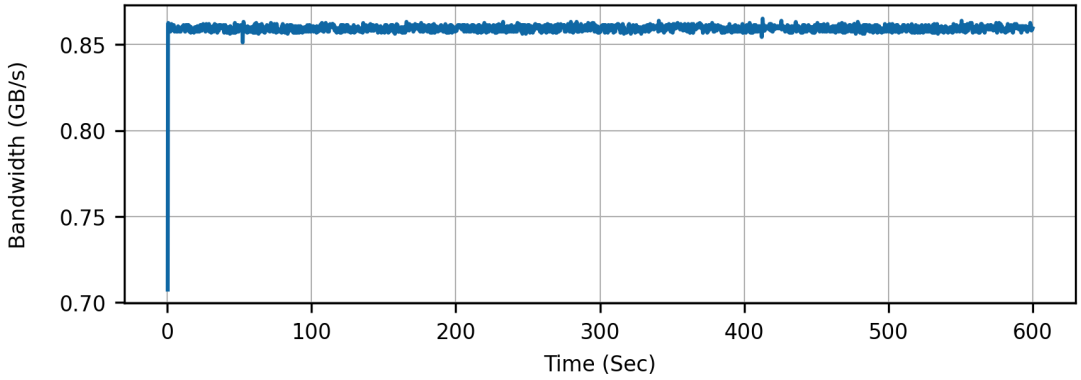

### Temperature and IO Bandwidth (Including Idle)



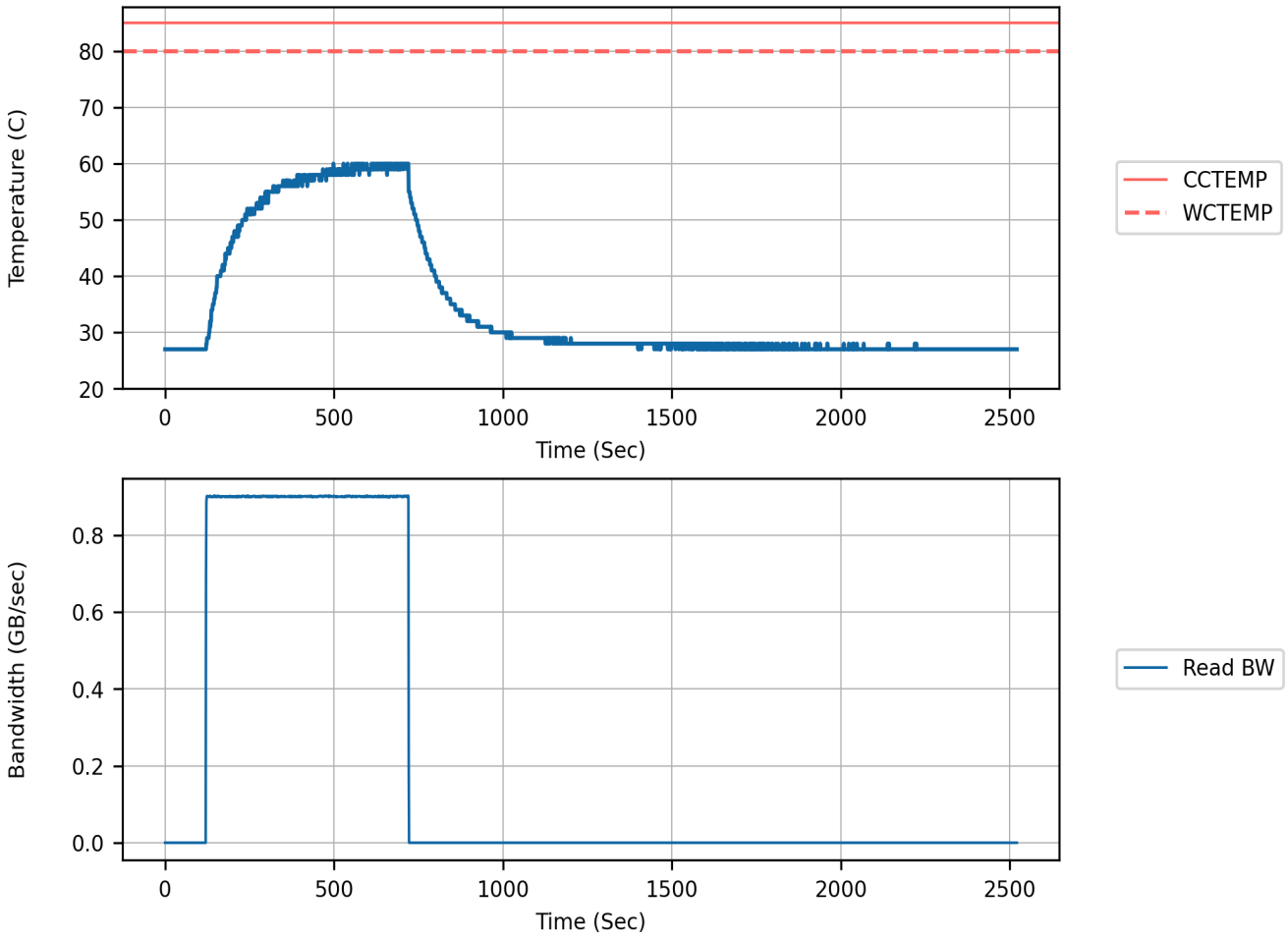
## SEQUENTIAL READS

These plots are for reads using sequential addressing, block size of 128 KiB, and queue depth of 32.

### IO Bandwidth




### Temperature and IO Bandwidth (Including Idle)



# TEST 102: NON-OP POWER STATE TIMES

| | | |
|---|---|---|
| REQUIREMENTS | 8 | |
| PASSED | 8 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 02:01:25.674 | Aug 20, 2022 - 02:45:40.161 | 0:44:14.487 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 008 | Thermal throttle time shall not increase | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |

## DESCRIPTION

This test reports the entry timeout and exit latency for non-operational power states. Exit latency is determined by measuring the latency of the first IO read after an idle period long enough that the drive transitions to a lower power state. Several samples are taken and the outliers are removed to avoid unrelated latency changes from OS interupts or drive accesses that take the drive out of idle.

The entry timeout is the idle time required for the drive to transition to a lower power state. The entry timeout is an OS setting that can be adjusted by the end user. Some systems, such as Windows laptops, typically have different values for battery and AC power. The test determines the entry timeout by increasing the idle time until the resulting IO read latency increases indicating a lower power state was entered.

If Autonomous Power State Transition (APST) is enabled, the drive will automatically transition to a non-operational power state. The value of Idle Time Prior to Transition (ITPT) defines the idle time required before transitioning. The Idle Transition Power State (ITPS) defines the state to transition to. Each Power State can have it's own ITPT and ITPS value.

If APST is disabled, the host OS will transition the drive to the lower power states. This appears to be the case for the inbox Windows driver. The Windows driver uses four parameters to determine the timeout and which state to transition to. The Primary and Secondary NVMe Idle Timeouts work the same as ITPT above. The Primary and Secondary NVMe Power State Transition Latency Tolerance define the state to transition to. The driver transitions to the lowest state where the sum of the entry and exit latency is less than the NVMe Power State Transition Latency Tolerance.

## RESULTS

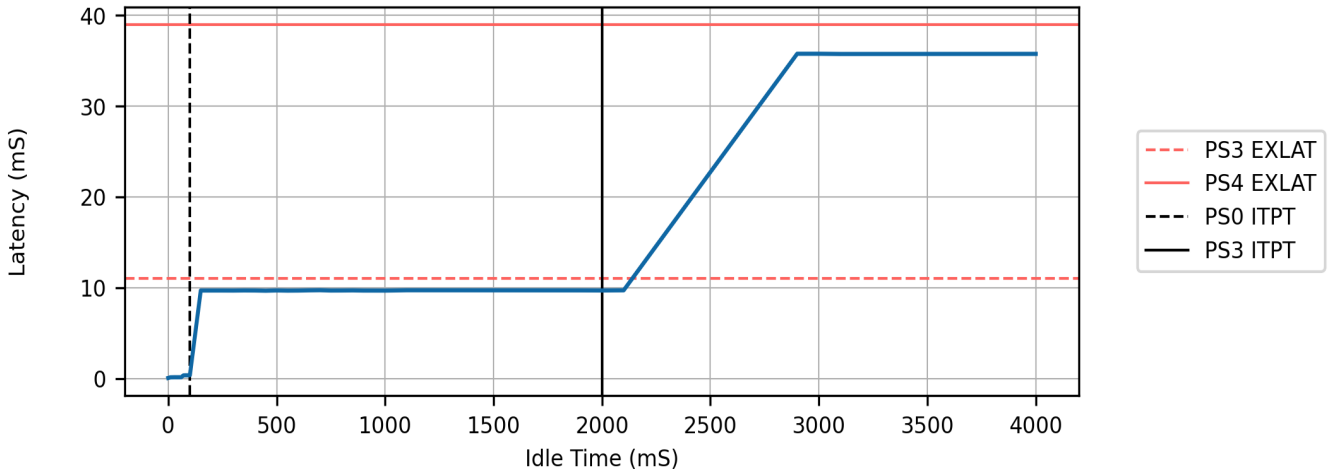
All requirements passed verification.

Autonomous Power State Transition (APST) is enabled. The drive is changing power states without host interaction based on the values of ITPT and ITPS.

In the table below a blank cell indicates the value is not reported or doesn't apply. Typically, latency values are not reported for operational power states.

| POWER STATE | NOP | ENTRY LATENCY | EXIT LATENCY | ITPT | ITPS |
|---|---|---|---|---|---|
| 0 | False | | | 100 mS | 3 |
| 1 | False | | | 100 mS | 3 |
| 2 | False | | | 100 mS | 3 |
| 3 | True | 3.9 mS | 11.0 mS | 2,000 mS | 4 |
| 4 | True | 5.0 mS | 39.0 mS | Disabled | |

The latency in the plot below is for the first read after the idle time. This should be less than or equal to the power state exit latency.



# TEST 103: READ BUFFER

| | | |
|---|---|---|
| REQUIREMENTS | 7 | |
| PASSED | 7 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 02:45:40.162 | Aug 20, 2022 - 02:46:13.763 | 0:00:33.601 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |

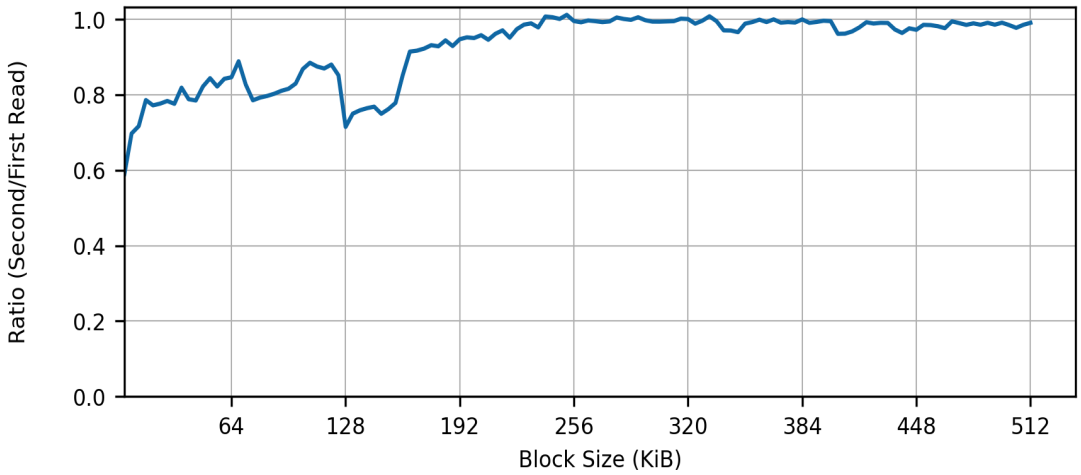
## DESCRIPTION

This test attempts to determine if the drive implements a read buffer by reporting the difference in read latency for two subsequent reads to the same address. Drives that have a read buffer should report much lower latency for the second read. Since these are performance measurements no data verification is done.

## RESULTS

All requirements passed verification.

This plot shows the ratio of two reads to the same address at different block sizes. Devices that buffer reads will have a faster second read. A ratio of 0.5 indicates the second read was twice as fast as the first read.



# TEST 104: DATA DEDUPLICATION

| | | |
|---|---|---|
| REQUIREMENTS | 9 | |
| PASSED | 9 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 02:46:13.768 | Aug 20, 2022 - 02:59:57.406 | 0:13:43.637 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 008 | Thermal throttle time shall not increase | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |

## DESCRIPTION

This test attempts to determine if the drive implements data deduplication. Data deduplication is a feature that reduces the amount of duplicate data written to the NAND flash resulting in lower write latency, extended drive life, and reduced garbage collection overhead [8, 9, 10].

This test reports the average latency for 2 GiB of writes with repeating and non-repeating data. Drives with data deduplication should have much lower latency for the repeating data pattern. The repeating data pattern uses the same psuedo-random pattern for every write. The non-repeating pattern uses a unique psuedo-random pattern every write. The repeating pattern size is the same as the block size. For example, the repeating pattern is a psuedo-random data pattern that is 4 KiB in size when the block size is 4 KiB. The writes are completed with a queue depth of 1 and block sizes of 4 KiB, 8 KiB, 32 KiB, and 128 KiB. Different block sizes are tried because any data deduplication chunk size would be unknown.

## RESULTS

All requirements passed verification.

### Write Latency vs Data Repeatability

| IO PATTERN | NONREPEATING | REPEATING | DELTA | % DELTA |
|---|---|---|---|---|
| Sequential Write, 4 KiB, QD1 | 32.260 mS | 30.051 mS | 2.209 mS | 6.8% |
| Sequential Write, 8 KiB, QD1 | 39.909 mS | 39.394 mS | 0.515 mS | 1.3% |
| Sequential Write, 32 KiB, QD1 | 82.602 mS | 80.056 mS | 2.547 mS | 3.1% |
| Sequential Write, 128 KiB, QD1 | 294.596 mS | 291.799 mS | 2.797 mS | 0.9% |

# TEST 105: DATA COMPRESSION

| | | |
|---|---|---|
| REQUIREMENTS | 9 | |
| PASSED | 9 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 02:59:57.409 | Aug 20, 2022 - 03:06:47.729 | 0:06:50.320 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 008 | Thermal throttle time shall not increase | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |

## DESCRIPTION

This test attempts to determine if the drive implements data compression. Data compression is a feature that reduces the amount of data written to the NAND flash resulting in lower write latency, extended drive life, and reduced garbage collection overhead [11, 12].

This test reports the average latency for 2 GiB of reads and writes with incompressible and compressible data. Drives with data compression should have lower latency for the compressible data pattern. The compressible data pattern is all 0s. The incompressible data pattern is a unique psuedo-random pattern every write. The read and writes are completed with a queue depth of 1, block size of 8 KiB for random addressing, and block size of 128 KiB for sequential addressing.

## RESULTS

All requirements passed verification.

### IO Latency vs Data Compressibility

| IO PATTERN | COMPRESSIBLE | INCOMPRESSIBLE | DELTA | % DELTA |
|---|---|---|---|---|
| Random Write, 8 KiB, QD1 | 41.998 mS | 42.194 mS | 0.196 mS | 0.5% |
| Random Read, 8 KiB, QD1 | 95.301 mS | 94.726 mS | -0.575 mS | -0.6% |
| Sequential Write, 128 KiB, QD1 | 269.013 mS | 298.168 mS | 29.154 mS | 9.8% |
| Sequential Read, 128 KiB, QD1 | 238.374 mS | 235.310 mS | -3.064 mS | -1.3% |

# TEST 200: HIGH BANDWIDTH STRESS

| | | |
|---|---|---|
| REQUIREMENTS | 9 | |
| PASSED | 9 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 03:06:47.731 | Aug 20, 2022 - 04:10:49.564 | 1:04:01.833 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 006 | IO reads and writes shall complete without data corruption | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |

## DESCRIPTION

The test verifies drive reliability while running high bandwidth IO stress for an extended time. Drive reliability is defined as completing all IO reads and writes without error or data corruption. This test does not verify any limits for drive temperature or thermal throttling eventhough extended periods of high temperature may reduce drive lifetime.

To achieve high bandwidth the test runs a 50/50 mix of reads and writes with a queue depth of 32 and block size of 128 KiB. Data verification is performed on all reads and writes to ensure no data corruption.

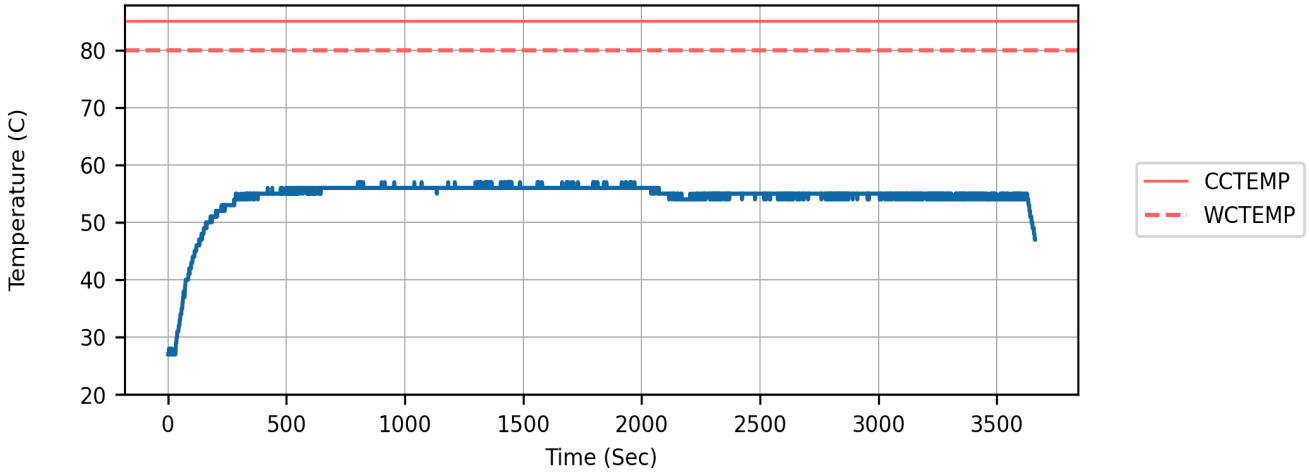
## RESULTS

All requirements passed verification.

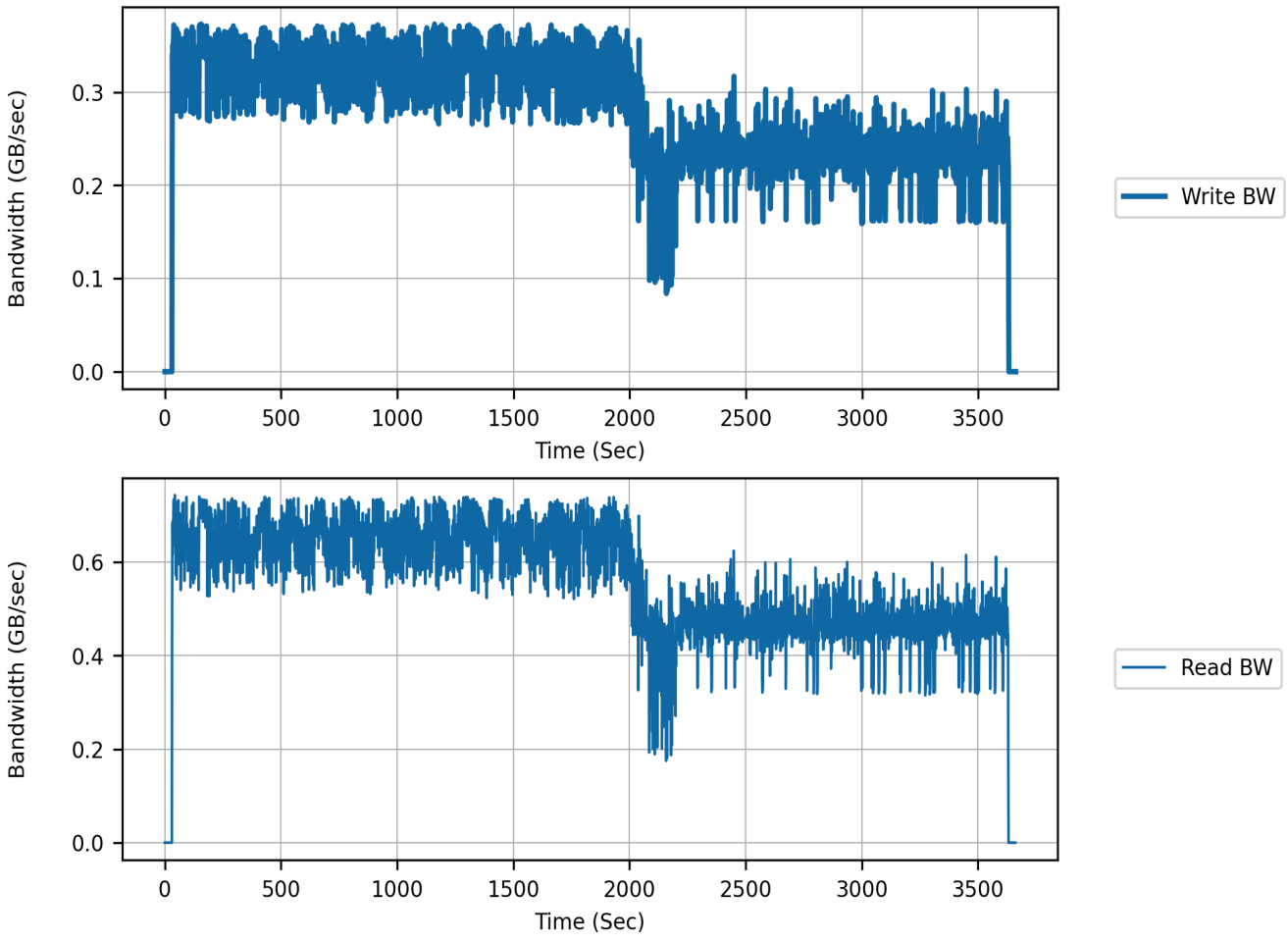
| IO RUN TIME | THROTTLE TIME | MAX TEMP | DATA WRITTEN | DATA READ |
|---|---|---|---|---|
| 60.00 min | 0 sec | 57 C | 1018.828 GB | 2032.916 GB |

This test has no requirements to verify for drive temperature or IO bandwidth. The plots of temperature and bandwidth below are only to provide a better understanding of the drive during the test. These plots were created from SMART data sampled throughout the test.

The plot below shows the composite temperature of the drive during the test. This includes the idle time before and after the IO.




The plots below shows the read and write bandwidth during the test. This includes the idle time before and after the IO.



# TEST 201: HIGH IOPS STRESS

| | | |
|---|---|---|
| REQUIREMENTS | 9 | |
| PASSED | 8 | 88.9% |
| FAILED | 1 | 11.1% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 04:10:49.568 | Aug 20, 2022 - 05:14:54.519 | 1:04:04.951 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 006 | IO reads and writes shall complete without data corruption | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | FAIL |

## DESCRIPTION

The test verifies drive reliability while running high IOPS stress for an extended time. Drive reliability is defined as completing all IO reads and writes without error or data corruption. This test does not verify any limits for drive temperature or thermal throttling eventhough extended periods of high temperature may reduce drive lifetime.

An IO workload of 50/50 mix of reads and writes, queue depth of 32, and block sizes of 512 or 4 KiB is run. All combinations of block sizes for reads and writes is run: 512/512, 512/4K, 4K/512, 4K/4K. Data verification is performed on all reads and writes to ensure no data corruption.

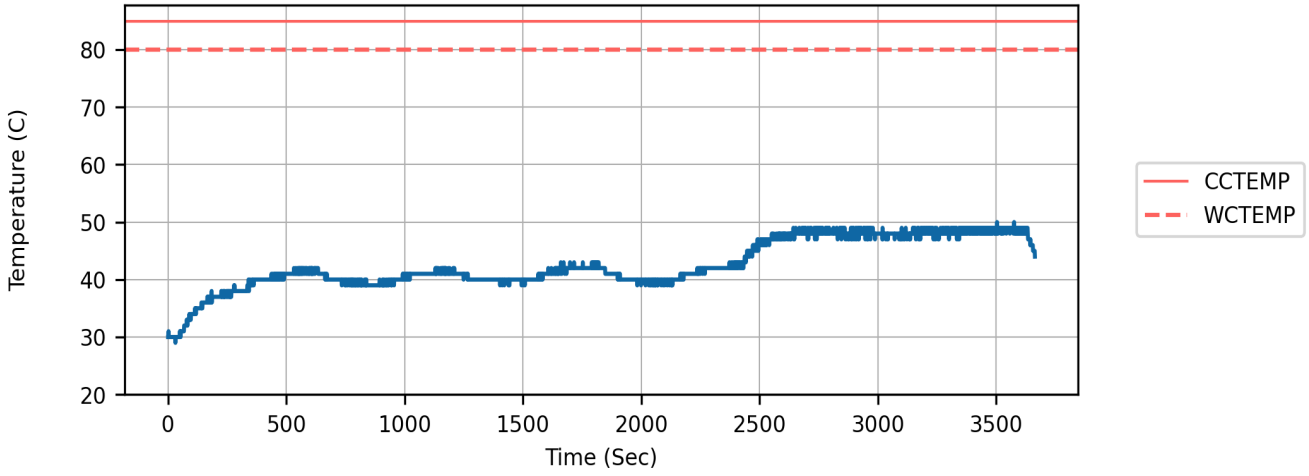
## RESULTS

One or more requirements failed verification and are listed in the table above.

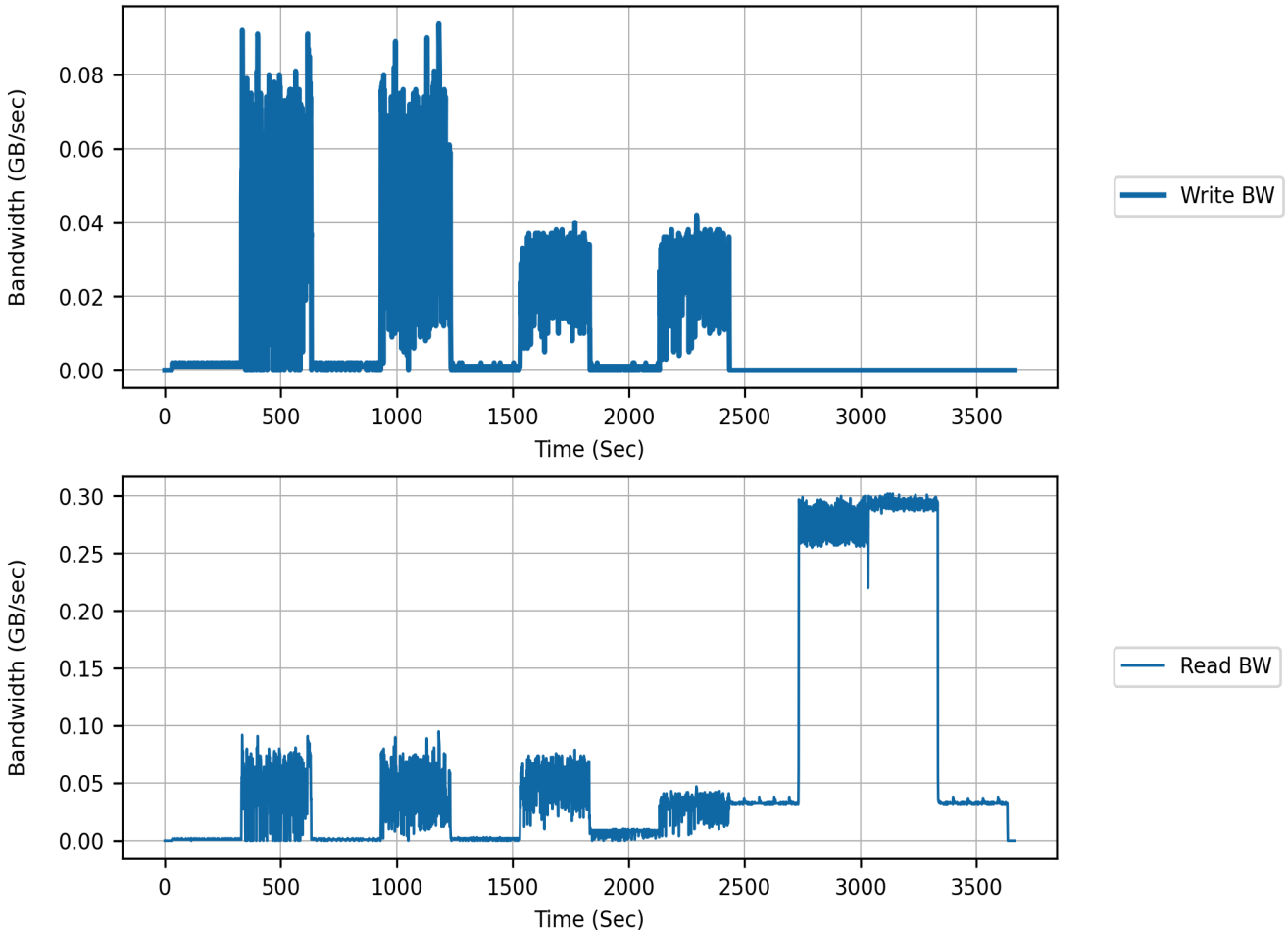
| IO RUN TIME | THROTTLE TIME | MAX TEMP | DATA WRITTEN | DATA READ |
|---|---|---|---|---|
| 60.00 min | 0 sec | 50 C | 44.993 GB | 245.549 GB |

This test has no requirements to verify for drive temperature or IO bandwidth. The plots of temperature and bandwidth below are only to provide a better understanding of drive and fio behavior during the test. These plots were created from SMART data sampled throughout the test.

The plot below shows the composite temperature of the drive during the test. This includes the idle time before and after the IO.




The plots below shows the read and write IOPS during the test. This includes the idle time before and after the IO.



# TEST 202: DRIVE BURST STRESS

| | | |
|---|---|---|
| REQUIREMENTS | 10 | |
| PASSED | 10 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 05:14:54.531 | Aug 20, 2022 - 06:49:43.553 | 1:34:49.022 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 006 | IO reads and writes shall complete without data corruption | PASS |
| 008 | Thermal throttle time shall not increase | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |

## DESCRIPTION

The test verifies drive reliability while running bursts of IO stress for an extended time. Drive reliability is defined as completing all IO reads and writes without error or data corruption. This test does not verify any limits for drive temperature or thermal throttling eventhough extended periods of high temperature may reduce drive lifetime.

The test runs short bursts of reads and writes followed by an idle period. The goal is to stress the power management features by constantly transitioning power states. A variety of burst lengths, idle times, queue depths, and block sizes are run. A 50/50 mix of reads and writes is used. Data verification is performed on all reads and writes to ensure no data corruption.

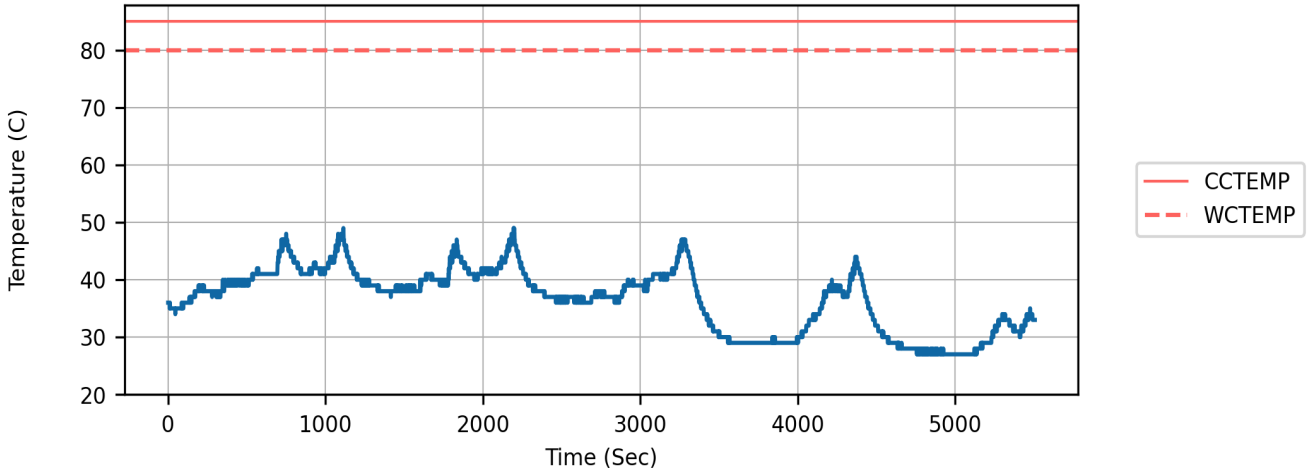
## RESULTS

All requirements passed verification.

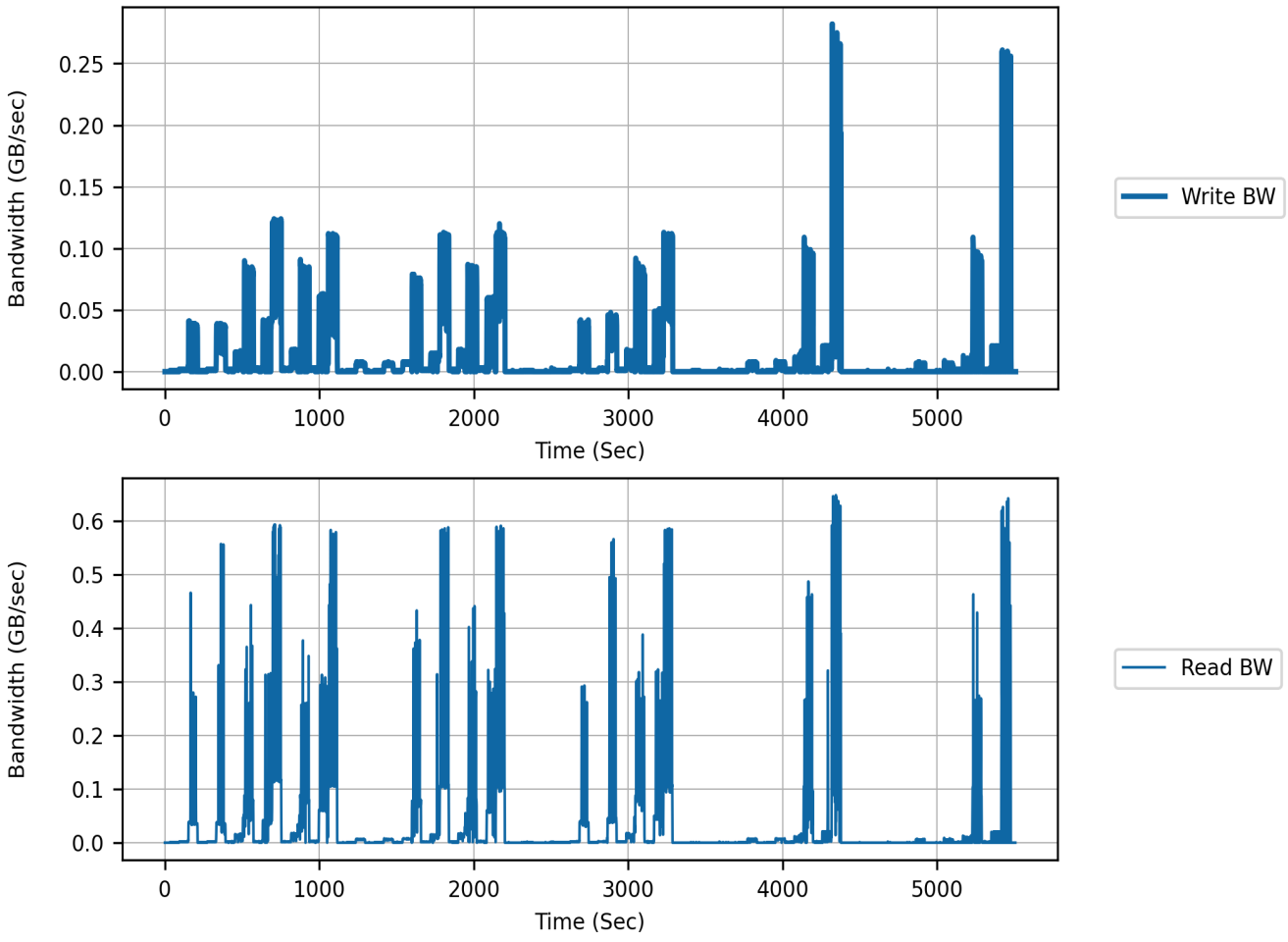
| IO RUN TIME | THROTTLE TIME | MAX TEMP | DATA WRITTEN | DATA READ |
|---|---|---|---|---|
| 90.00 min | 0 sec | 49 C | 95.574 GB | 176.829 GB |

This test has no requirements to verify for drive temperature or IO bandwidth. The plots of temperature and bandwidth below are only to provide a better understanding of drive and fio behavior during the test. These plots were created from SMART data sampled throughout the test.

The plot below shows the composite temperature of the drive during the test. This includes the idle time before and after the IO.




The plot below shows the read and write bandwidth during the test. This includes the idle time before and after the IO.



# TEST 203: READ DISTURB STRESS

| | | |
|---|---|---|
| REQUIREMENTS | 10 | |
| PASSED | 10 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 06:49:43.559 | Aug 20, 2022 - 06:54:11.123 | 0:04:27.564 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 006 | IO reads and writes shall complete without data corruption | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |
| 505 | The read disturb effect shall not cause functional failures | PASS |

## DESCRIPTION

Read disturb occurs in flash chips when a page read disturbs the voltage of other cells within the same block [13]. The more times a page is read, the more the voltage of neighbor cells may change. This test attempts to verify design mitigations that prevent read disturb from causing functional failures. However, since the physical layout and mapping of the drive are unknown it is not possible to guarantee the mitigations are tested.

The test first creates a file using large block sequential writes. The file is written twice to increase the odds that "new" blocks are used and only contain pages with data from the file.

The test then reads 4096 bytes at increments of 64 MiB. The large increment should ensure that only one page per block is read. The test loops through the file several thousand times reading the same pages over and over. After several thousand loops the test reads all of the pages in the file to verify no pages have been disturbed.

## RESULTS

All requirements passed verification.

| FILE SIZE | READ INCREMENT | PAGES PER FILE | READS PER PAGE |
|---|---|---|---|
| 1 GB | 64 MiB | 16 | 100,000 |

# TEST 204: TEMPERATURE CYCLE STRESS

| | | |
|---|---|---|
| REQUIREMENTS | 10 | |
| PASSED | 10 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 06:54:11.129 | Aug 20, 2022 - 09:28:22.312 | 2:34:11.182 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 006 | IO reads and writes shall complete without data corruption | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |
| 506 | Temperature Cycle IO Stress shall complete without errors | PASS |

## DESCRIPTION

This test runs IO reads that alternates between periods of high bandwidth IO and idle. This IO pattern causes the drive's composite temperature to cycle between low and high temperatures. The drive heats up during the IO and cools down during the idle time. The length of the IO and idle periods can be adjusted to maximize the change in temperature over the cycle. The IO stress is 100% reads with queue depth 32 and block size 128 KiB.

Temperature cycles exert mechanical stress on the drive from the thermal expansion and contraction. Extensive temperature cycles can be used as part of an reliability or functional stress strategy.

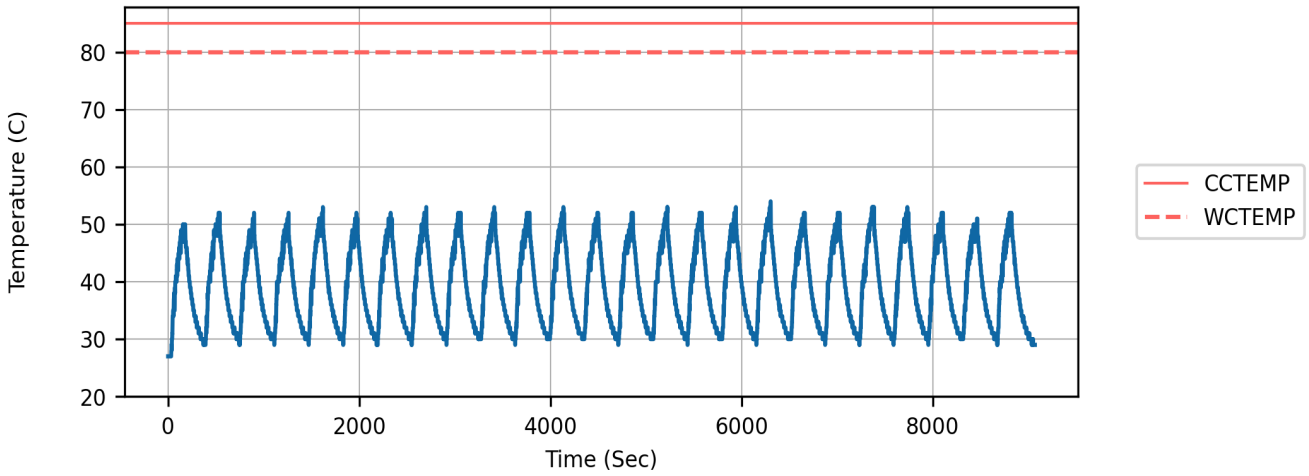
This test is not meant to replace standard component qualification tests such as JESD22-A104 or system environmental tests such as 4-corners.

## RESULTS

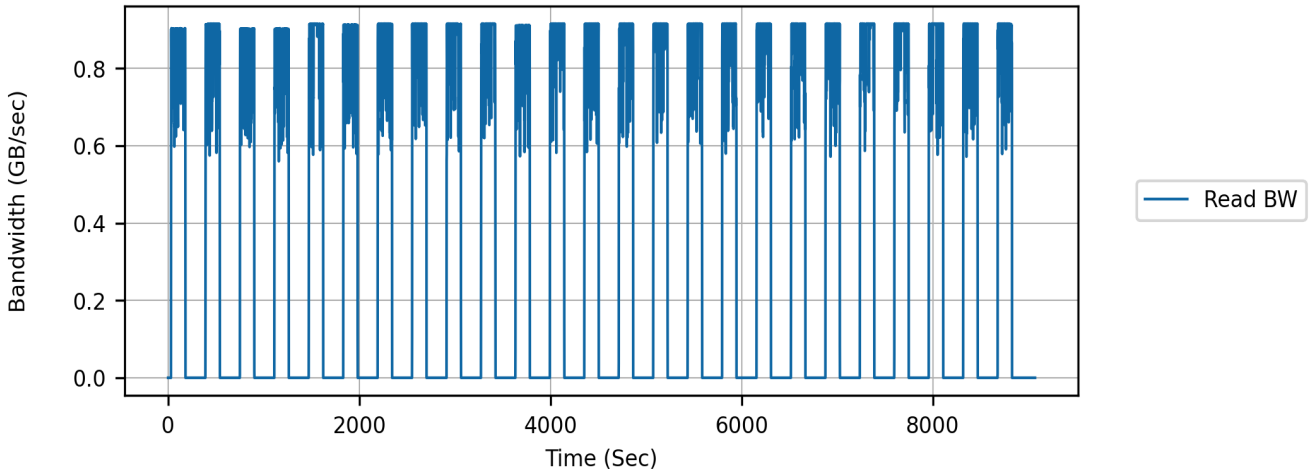
All requirements passed verification.

| IO TIME | IDLE TIME | NUMBER CYCLES | MIN TEMP | MAX TEMP |
|---|---|---|---|---|
| 150 sec | 210 sec | 25 | 27 C | 54 C |

The plot below shows the composite temperature of the drive during the test.




The plot below shows the IO bandwidth during the test.



# TEST 300: BIG FILE WRITE PERFORMANCE

| | | |
|---|---|---|
| REQUIREMENTS | 8 | |
| PASSED | 8 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 09:28:22.318 | Aug 20, 2022 - 10:16:34.367 | 0:48:12.048 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |

## DESCRIPTION

This test writes a big file using continuous, large block, high queue depth, sequential writes. The file size is 90% of the disk size. The total amount of continuous writes completed is 2 times the file size. A large amount of continuous writes can identify performance variation from several issues such as thermal throttling [4], slow garbage collection [5], write cache limitations [6].

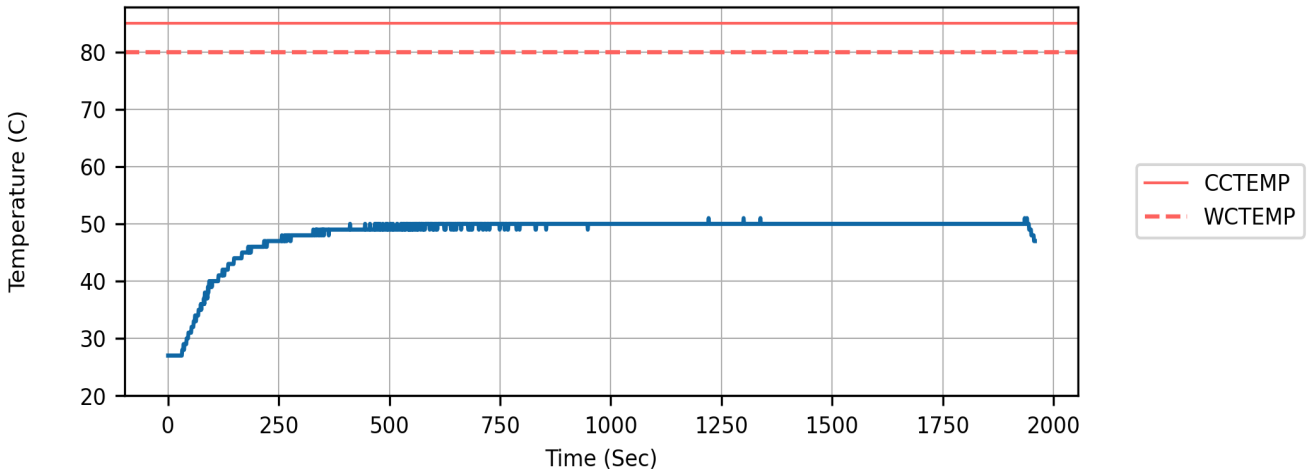
After the continous writes have completed, the test waits 180 seconds for background garbage collection to complete. The test then runs several bursts bursts of large block, high queue depth, writes with varying amounts of idle time between them. The different idle times can identify performance behavior of a write buffer or write cache.

## RESULTS

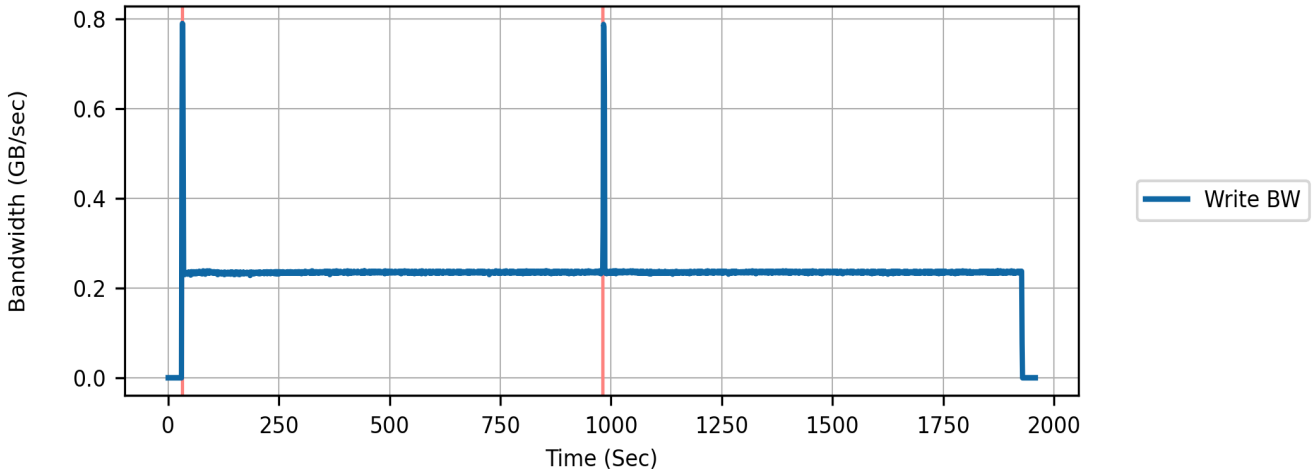
All requirements passed verification.

### Continuous Writes

The file size tested was 224.4 GB which is 90% of the disk size of 250.0 GB. A total of 448.8 GB were written to the file during at an average bandwidth of 0.24 GB. The plot below shows the composite temperature of the drive during the test along with the thermal throttle limits.




The plot below shows the write bandwidth during the continuous writes. The file was written a total of 2 times. The vertical red lines indicate each time a new file write begins.

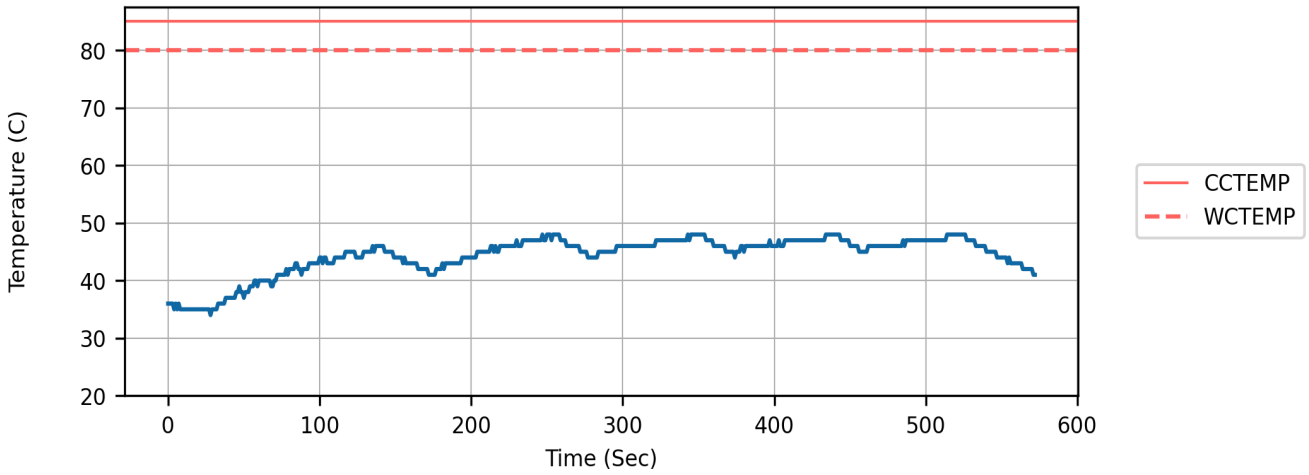


### Burst Writes

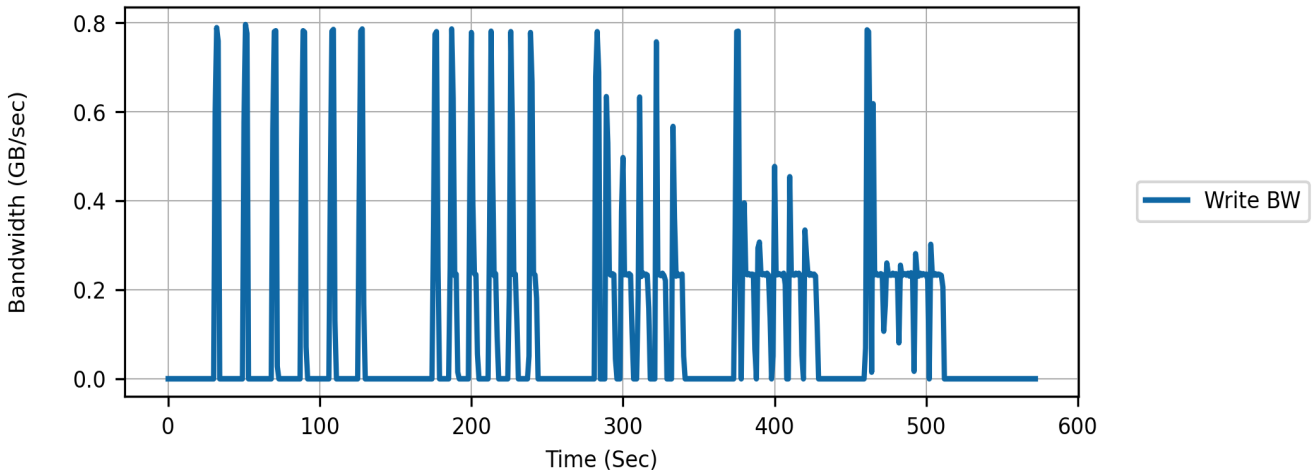
A total of 5 groups of bursts were completed. Each burst group has different idle times between bursts. For devices with write buffers, the bandwidth may decrease as the idle time reduces.

| Burst Group | Number of Bursts | Idle Delay | Average Bandwidth |
|---|---|---|---|
| 0 | 6 | 16 sec | 0.784 GB/s |
| 1 | 6 | 8 sec | 0.485 GB/s |
| 2 | 6 | 4 sec | 0.353 GB/s |
| 3 | 6 | 2 sec | 0.304 GB/s |
| 4 | 6 | 1 sec | 0.290 GB/s |

The plot below shows the composite temperature of the drive during the burst writes to the device. The burst workload should not result in thermal throttling.




The plot below shows the bandwidth during burst writes to the big file.



# TEST 301: BIG FILE READ PERFORMANCE

| | | |
|---|---|---|
| REQUIREMENTS | 8 | |
| PASSED | 8 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 10:16:34.369 | Aug 20, 2022 - 11:03:27.711 | 0:46:53.342 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |

## DESCRIPTION

This test reports the bandwidth and distribution of continuous large block sequential and random reads to a big file. The big file is approximately 90% of the disk size. The file is reads 2 times for each addressing mode. This allows comparison of the different addressing modes: sequential and random. Since this test reports performance measurements no data verification is done.

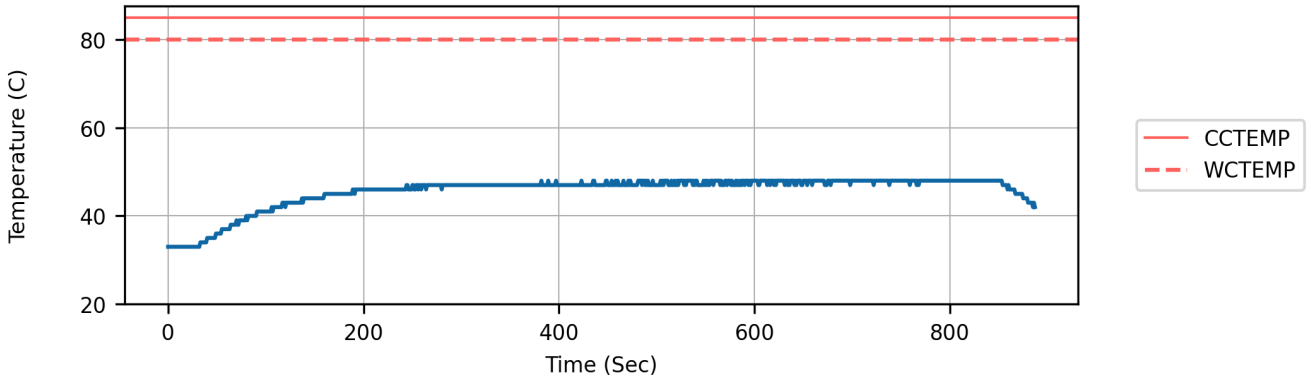
## RESULTS

All requirements passed verification.

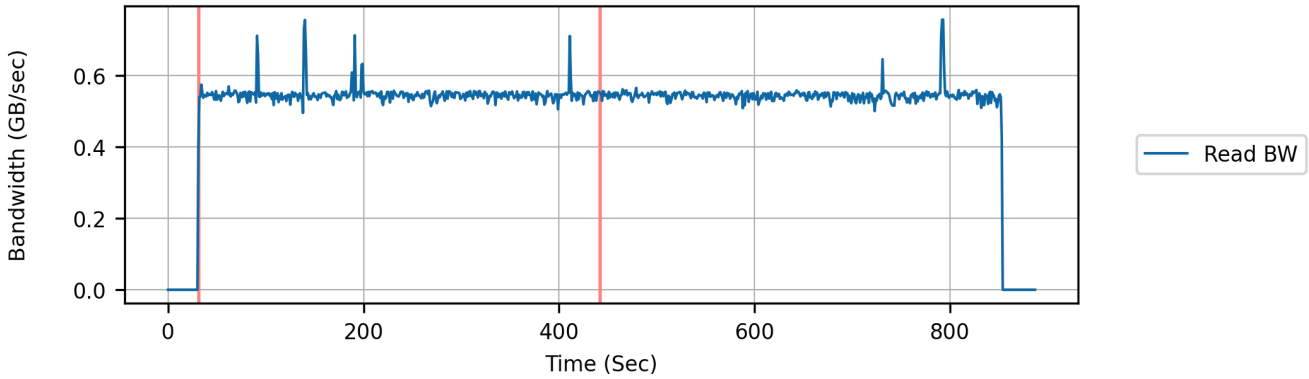
The file size tested was 224.4 GB which is 90% of the disk size of 250.0 GB.

### Sequential Reads

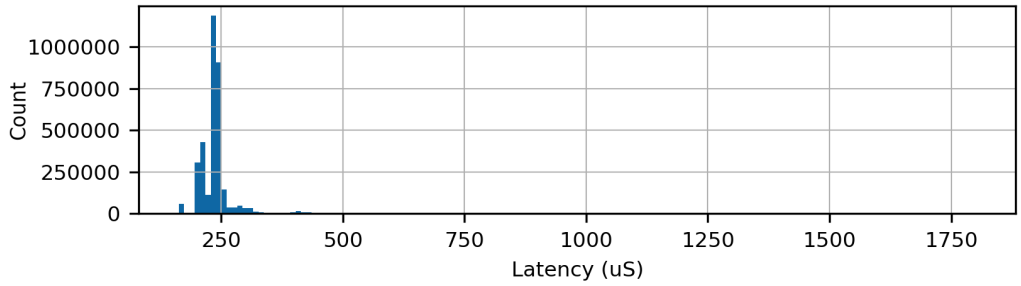
The plot below shows the composite temperature of the drive during the test along with the thermal throttle limits.



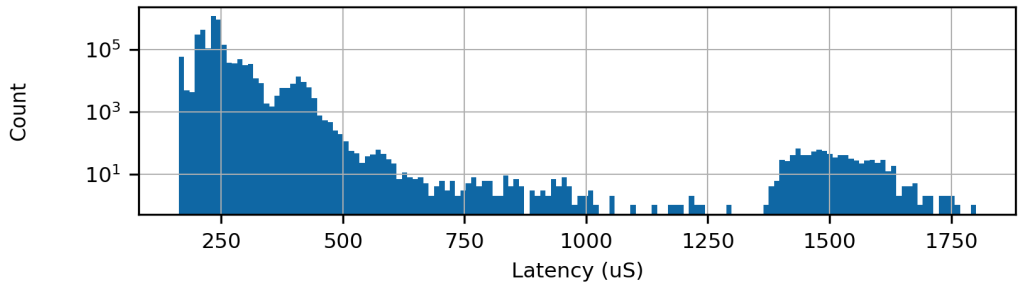

The plot below shows the read bandwidth during the sequential reads.




This histogram shows the latency distribution for 3,424,240 sequential reads. The reads have a block size of 128 KiB and queue depth of 1.

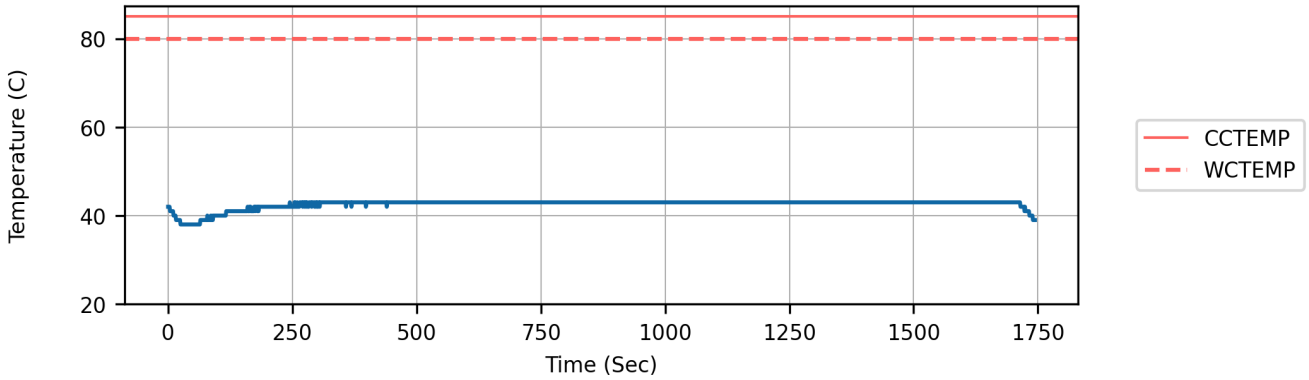



This histogram shows the same data as above except on a log scale to provide better visibility of outliers.

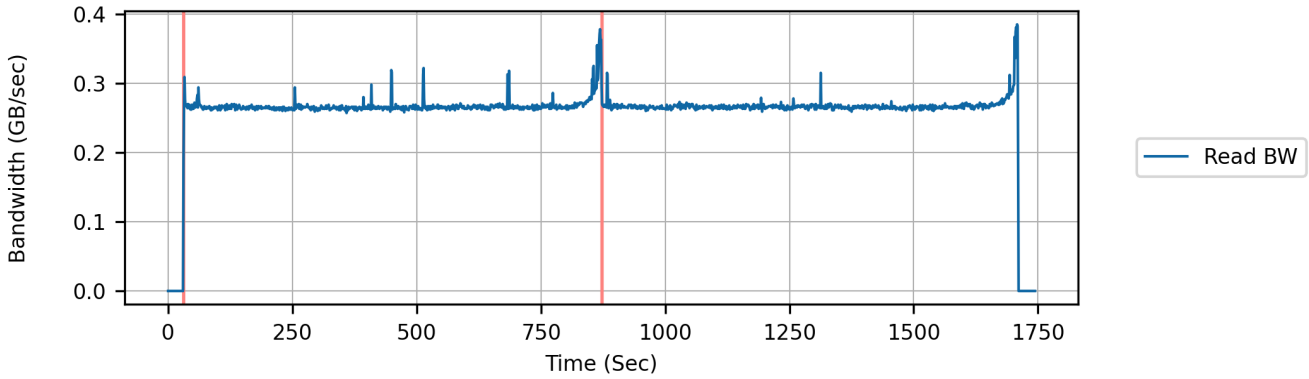


## Random Reads

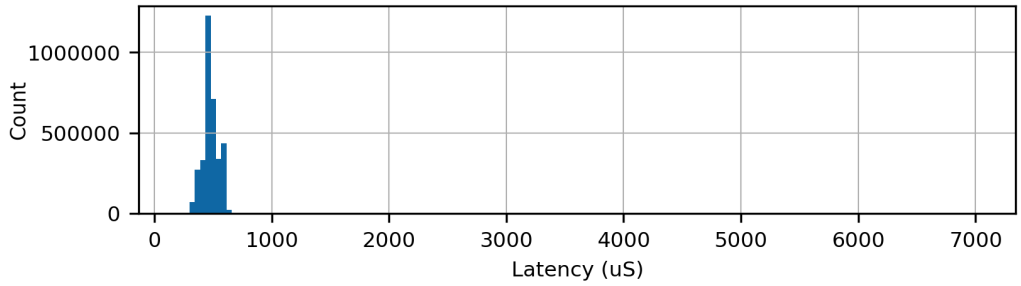
The plot below shows the composite temperature of the drive during the test along with the thermal throttle limits.



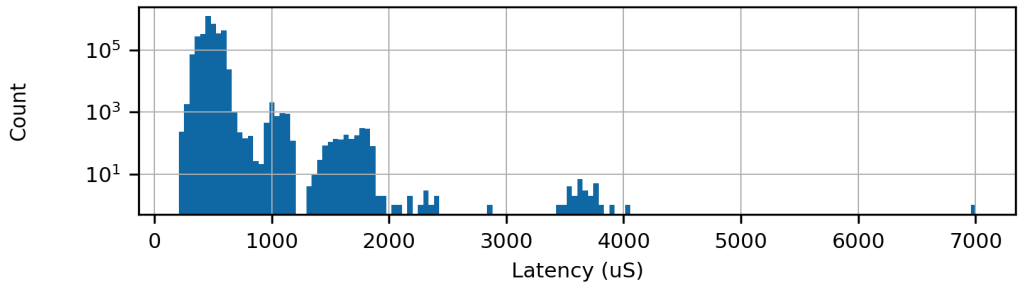

The plot below shows the read bandwidth during the random reads.




This histogram shows the latency distribution for 3,424,240 random reads. The reads have a block size of 128 KiB and queue depth of 1.




This histogram shows the same data as above except on a log scale to provide better visibility of outliers.



# TEST 302: ADDRESS ALIGNMENT

| | | |
|---|---|---|
| REQUIREMENTS | 7 | |
| PASSED | 7 | 100.0% |
| FAILED | 0 | 0.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 11:03:27.716 | Aug 20, 2022 - 11:04:48.456 | 0:01:20.740 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |

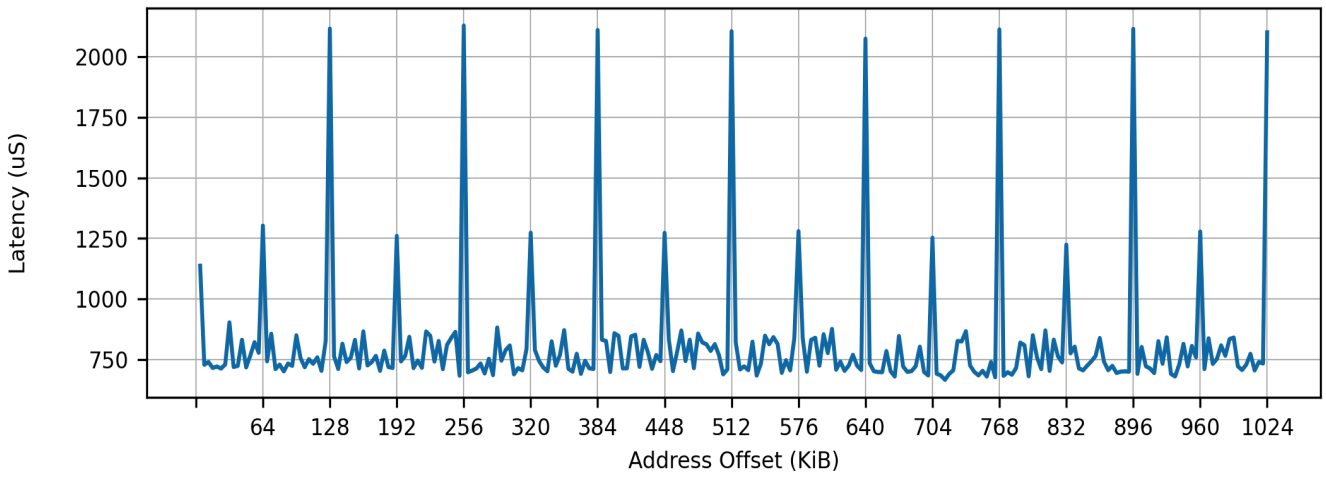
## DESCRIPTION

This test reports the read latency at different address offests to gather information about the device interleaving. A total of 256 address offsets are tested that are aligned on multiples of 4 KiB. A total of 1,040 reads are completed at each offset. The first 16 reads of each offset are excluded from the latency calculation to avoid any influence from power state exit latencies. A queue depth of 32 with block size of 4 KiB is used to saturate any specific IO path.

## RESULTS

All requirements passed verification.

This plot shows the latency of 1,024 IO reads at each of the 256 different address offsets.



# TEST 303: SHORT BURST PERFORMANCE FULL DRIVE

| | | |
|---|---|---|
| REQUIREMENTS | 15 | |
| PASSED | 12 | 80.0% |
| FAILED | 3 | 20.0% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 11:04:48.460 | Aug 20, 2022 - 11:44:25.543 | 0:39:37.082 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 008 | Thermal throttle time shall not increase | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |
| 200 | Short burst Sequential Write, QD32, 128KiB, bandwidth must be more than 1.5 GB/s | FAIL |
| 201 | Short burst Sequential Read, QD32, 128KiB, bandwidth must be more than 1.5 GB/s | FAIL |
| 202 | Short burst Random Write, QD1, 4KiB, bandwidth must be more than 0.02 GB/s | PASS |
| 203 | Short burst Random Read, QD1, 4KiB, bandwidth must be more than 0.02 GB/s | FAIL |
| 204 | Short burst Random Write, QD32, 4KiB, bandwidth must be more than 0.2 GB/s | PASS |
| 205 | Short burst Random Read, QD32, 4KiB, bandwidth must be more than 0.2 GB/s | PASS |

## DESCRIPTION

This test is the same as Short Burst Performance test except the drive capacity is almost full at the start. Full drives may have lower performance than empty drives because of a lower number of erased blocks available for writes and a smaller dynamic cache.

For additional details refer to the Short Burst Performance test.

## RESULTS

One or more requirements failed verification and are listed in the table above.

This table shows the minimum and maximum bandwidth for each IO pattern across all combinations of block sizes and queue depths.

| IO PATTERN | MINIMUM BANDWIDTH | MAXIMUM BANDWIDTH |
|---|---|---|
| Random Write | 0.027 GB/s | 0.745 GB/s |

| | | |
|---|---|---|
| Random Read | 0.020 GB/s | 0.867 GB/s |
| Sequential Write | 0.124 GB/s | 0.747 GB/s |
| Sequential Read | 0.138 GB/s | 0.867 GB/s |

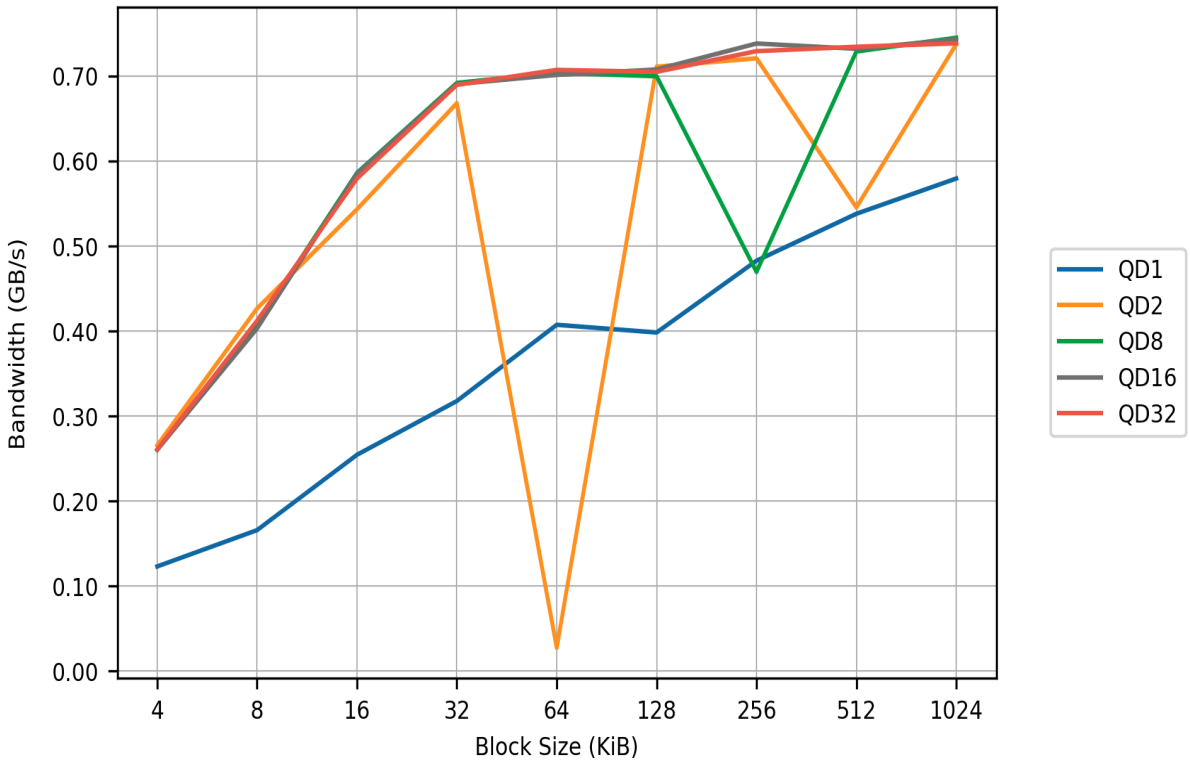
This table shows the bandwidth for several common datasheet and IO benchmark queue depths and block sizes.

| IO PATTERN | BANDWIDTH | LIMIT |
|---|---|---|
| Random Write, QD1, 4KiB | 0.123 GB/s | 0.020 GB/s |
| Random Read, QD1, 4KiB | 0.020 GB/s | 0.020 GB/s |
| Random Write, QD32, 4KiB | 0.260 GB/s | 0.200 GB/s |
| Random Read, QD32, 4KiB | 0.226 GB/s | 0.200 GB/s |
| Sequential Write, QD32, 128KiB | 0.741 GB/s | 1.500 GB/s |
| Sequential Read, QD32, 128KiB | 0.859 GB/s | 1.500 GB/s |

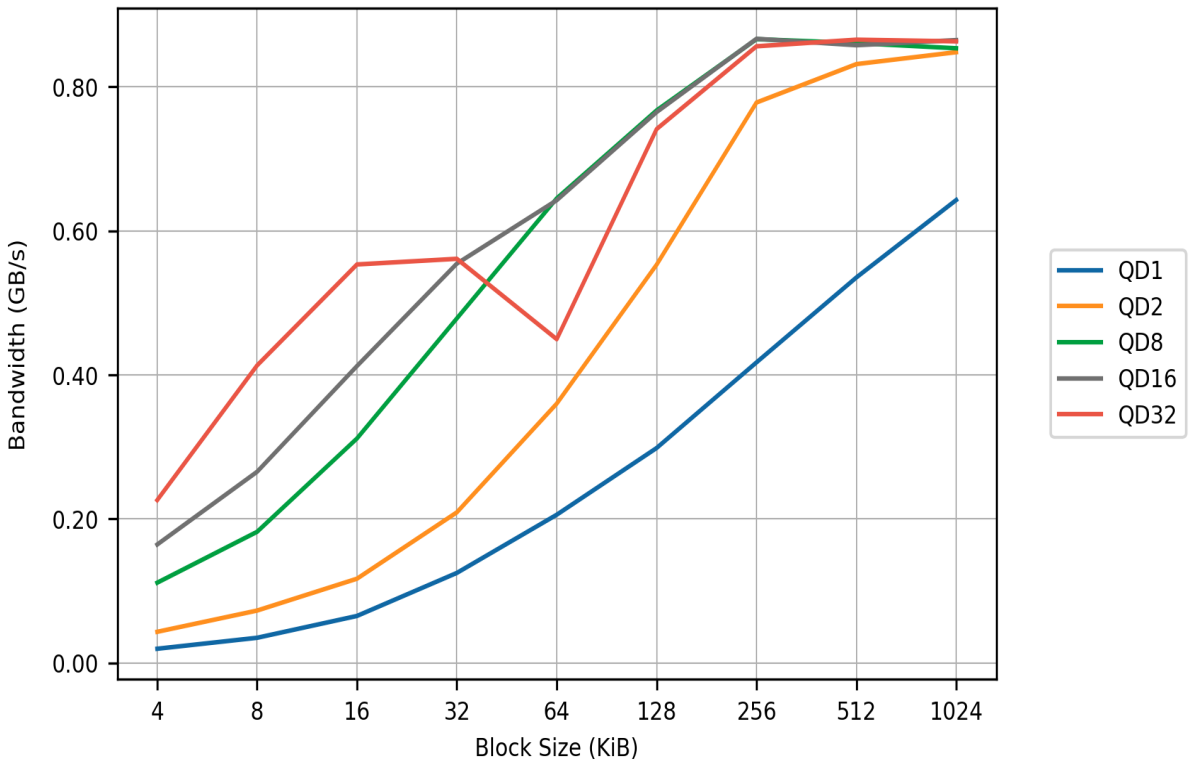
This table shows the IOPS for several common datasheet and IO benchmark queue depths and block sizes. The IOPS is the bandwidth divided by block size.

| IO PATTERN | IOPS | LIMIT |
|---|---|---|
| Random Write, QD1, 4KiB | 29,984 | 4,883 |
| Random Read, QD1, 4KiB | 4,766 | 4,883 |
| Random Write, QD32, 4KiB | 63,598 | 48,828 |
| Random Read, QD32, 4KiB | 55,170 | 48,828 |
| Sequential Write, QD32, 128KiB | 5,655 | 11,444 |
| Sequential Read, QD32, 128KiB | 6,556 | 11,444 |

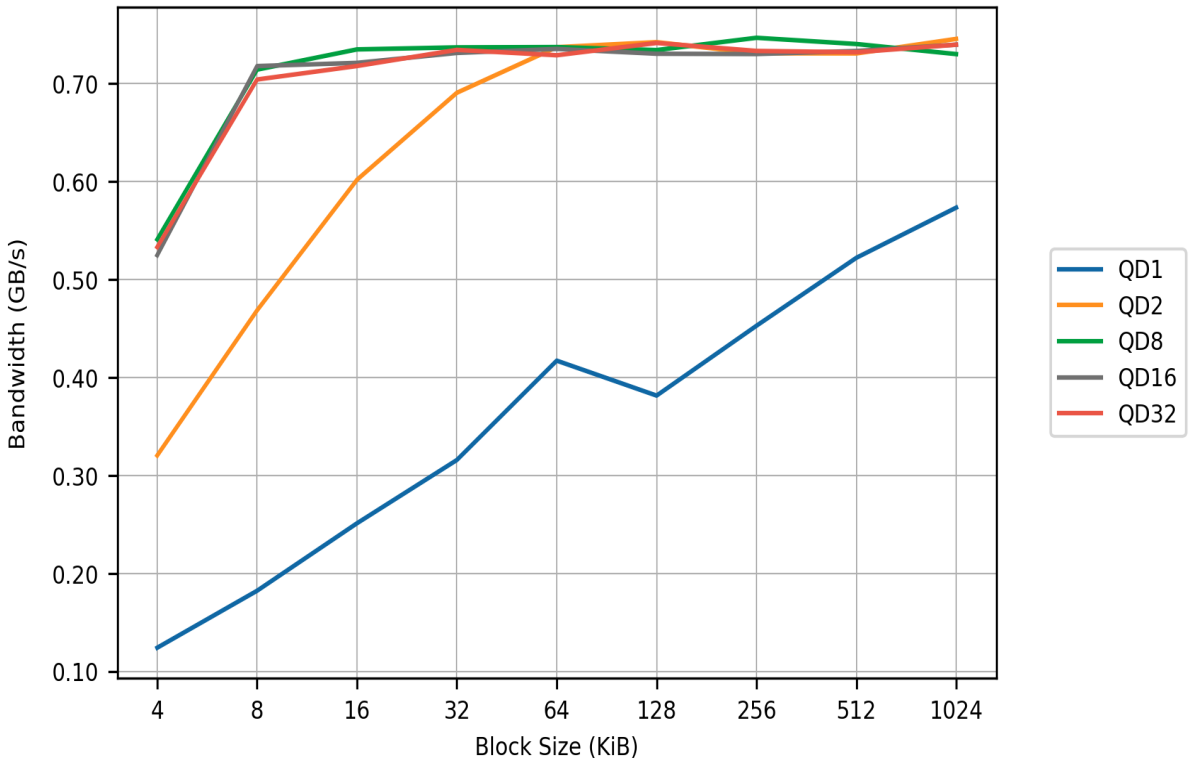
## Random Write Bandwidth



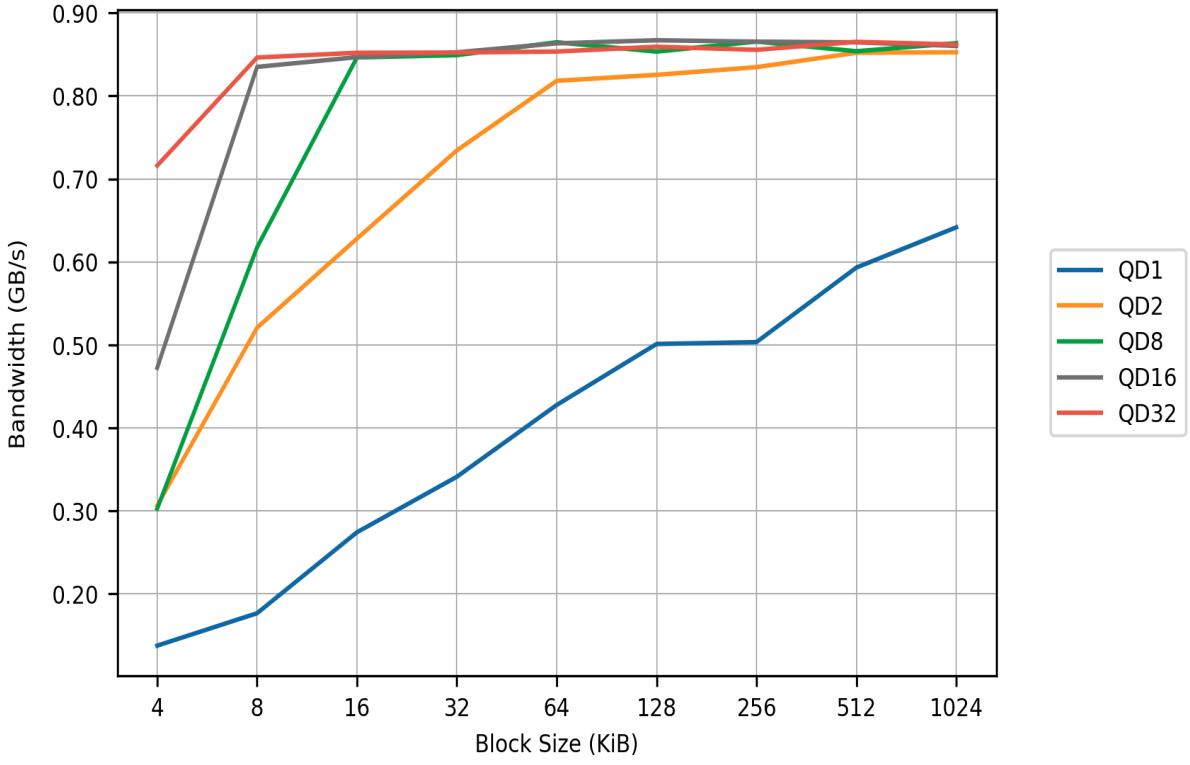

## Random Read Bandwidth



## Sequential Write Bandwidth




## Sequential Read Bandwidth



# TEST 304: LONG BURST PERFORMANCE FULL DRIVE

| | | |
|---|---|---|
| REQUIREMENTS | 11 | |
| PASSED | 8 | 72.7% |
| FAILED | 3 | 27.3% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 11:44:25.548 | Aug 20, 2022 - 14:52:33.119 | 3:08:07.571 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 005 | IO reads and writes shall complete without errors | PASS |
| 160 | Admin Commands shall reliably complete without error | PASS |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |
| 220 | Long burst Sequential Write, QD32, 128KiB, bandwidth must be more than 1.0 GB/s | FAIL |
| 221 | Long burst Sequential Read, QD32, 128KiB, bandwidth must be more than 1.0 GB/s | FAIL |
| 401 | Temperature at end of long burst IO shall be within 5C of temperature when IO started | FAIL |

## DESCRIPTION

This test is the same as Long Burst Performance test except the drive capacity is 90% at the start. Full drives may have lower performance than empty drives because of a lower number of erased blocks available for writes and a smaller dynamic cache.

For additional details refer to the Long Burst Performance test.

## RESULTS

One or more requirements failed verification and are listed in the table above.

The table below provides the average and ending bandwidth. The ending bandwidth could be significantly lower if thermal throttling or excessive garbage collection occurs.

| IO PATTERN | AVERAGE | FIRST SEC | FIRST 15 SEC | LAST 120 SEC |
|---|---|---|---|---|
| Random Write, QD1, 4KiB | 0.079 GB/s | 0.117 GB/s | 0.118 GB/s | 0.024 GB/s |
| Random Read, QD1, 4KiB | 0.031 GB/s | 0.021 GB/s | 0.030 GB/s | 0.029 GB/s |
| Sequential Write, QD32, 128KiB | 0.138 GB/s | 0.027 GB/s | 0.013 GB/s | 0.160 GB/s |
| Sequential Read, QD32, 128KiB | 0.908 GB/s | 0.872 GB/s | 0.870 GB/s | 0.868 GB/s |

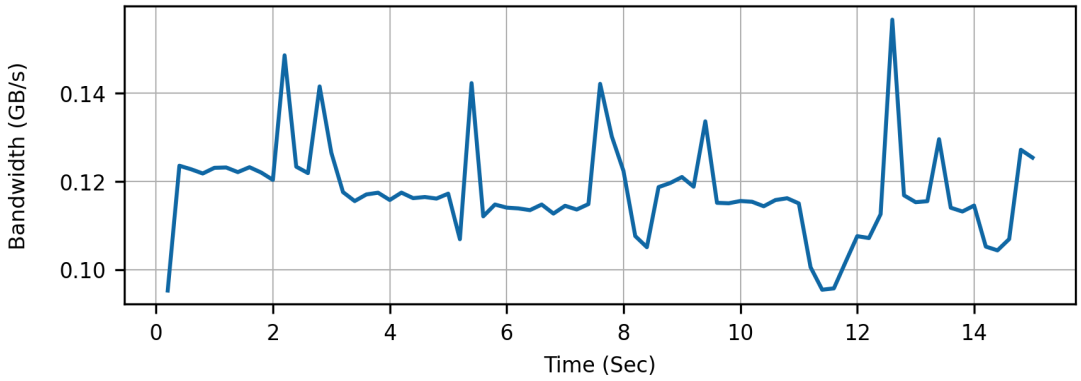
This table below reports the composite temperature during the IO burst. The expectation is the end and start temperatures should be within the delta limit. A higher temperature could indicate background operations are ongoing.

The table also includes the Throttle Time which is the sum for all throttle levels. Note that the units for throttle levels WCTEMP and CCTEMP is in minutes. Therefore, throttling for less than one minute may not be indicated for these levels.

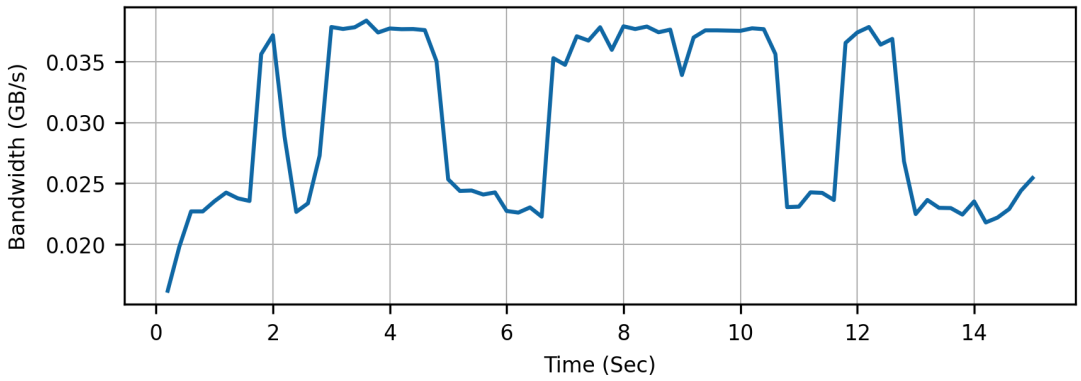
| IO PATTERN | THROTTLE | MAX | START | END | DELTA | LIMIT |
|---|---|---|---|---|---|---|
| Random Write, QD1, 4KiB | 0 sec | 50 C | 26 C | 31 C | 5 C | 5 C |
| Random Read, QD1, 4KiB | 0 sec | 42 C | 32 C | 32 C | 0 C | 5 C |
| Sequential Write, QD32, 128KiB | 0 sec | 51 C | 31 C | 32 C | 1 C | 5 C |
| Sequential Read, QD32, 128KiB | 0 sec | 62 C | 32 C | 32 C | 0 C | 5 C |

These plots show the initial bandwidth of the bursts.

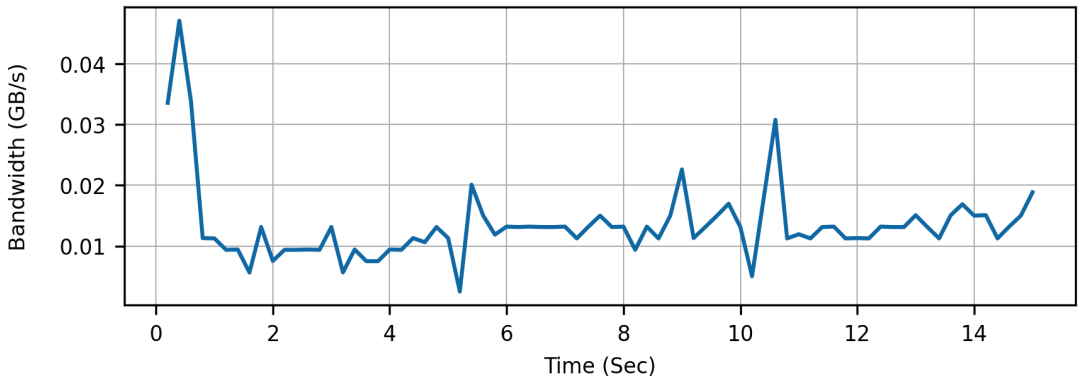
### Random Write (Initial Bandwith)



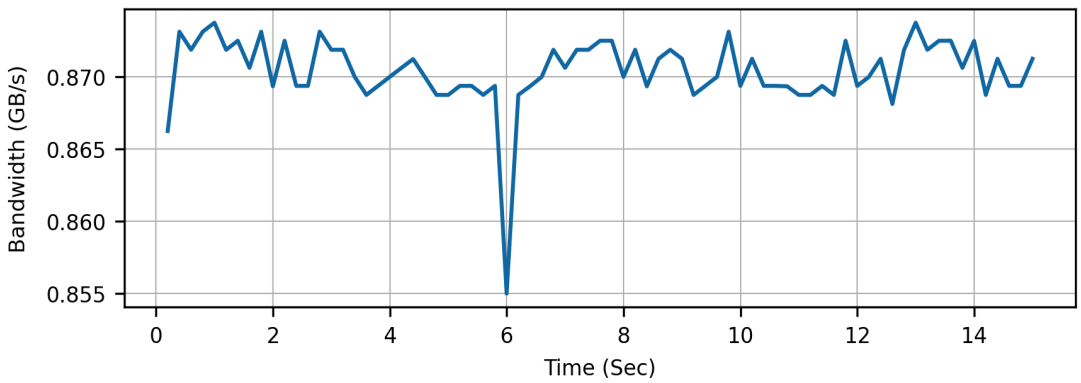

### Random Reads (Initial Bandwith)




### Sequential Write (Initial Bandwith)



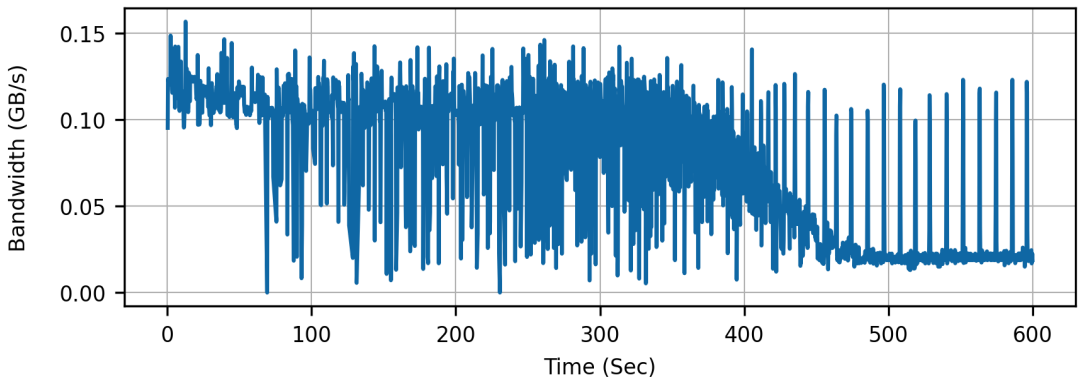

### Sequential Reads (Initial Bandwith)



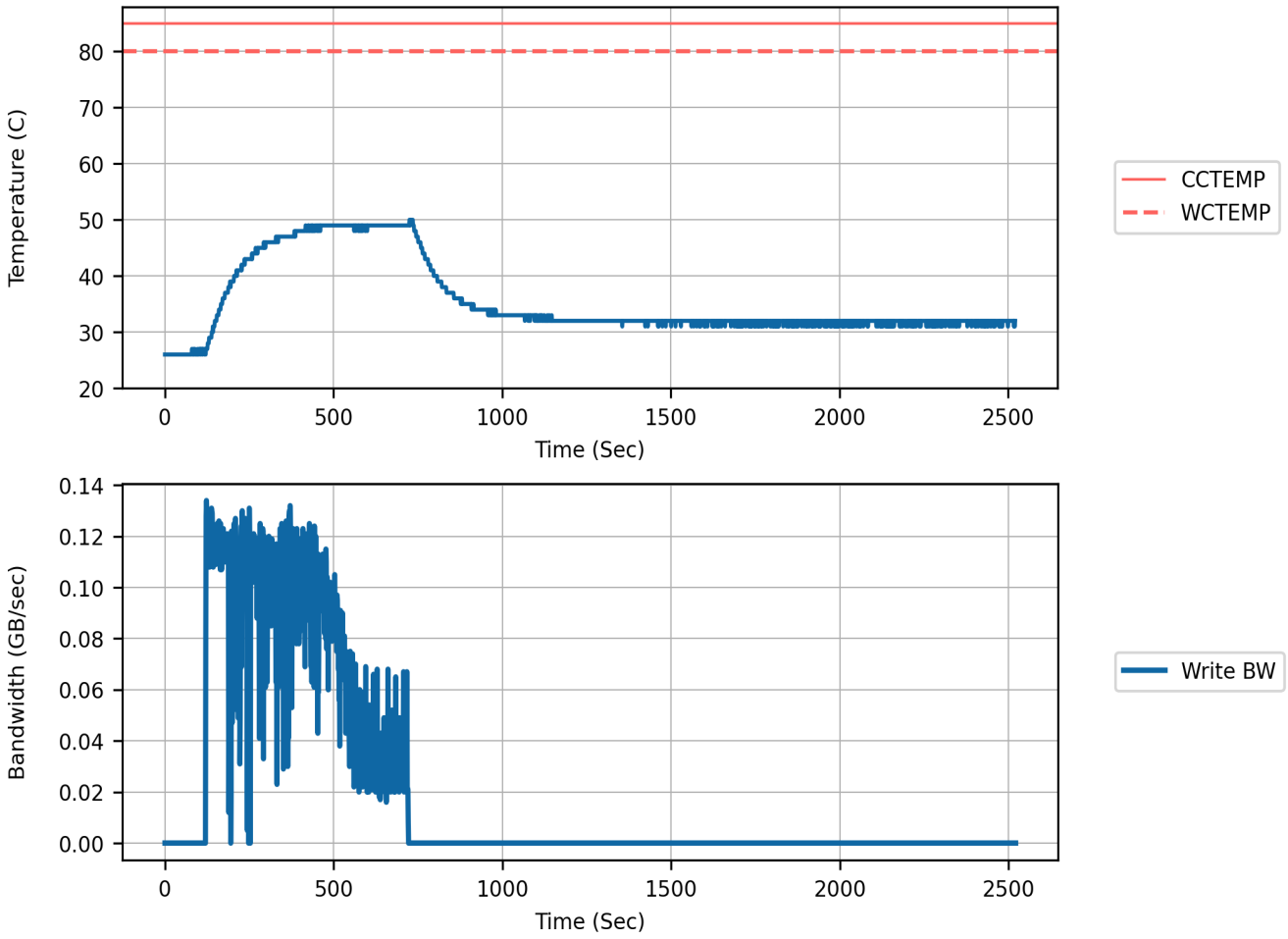
## RANDOM WRITES

These plots are for writes using random addressing, block size of 4 KiB, and queue depth of 1.

### IO Bandwidth



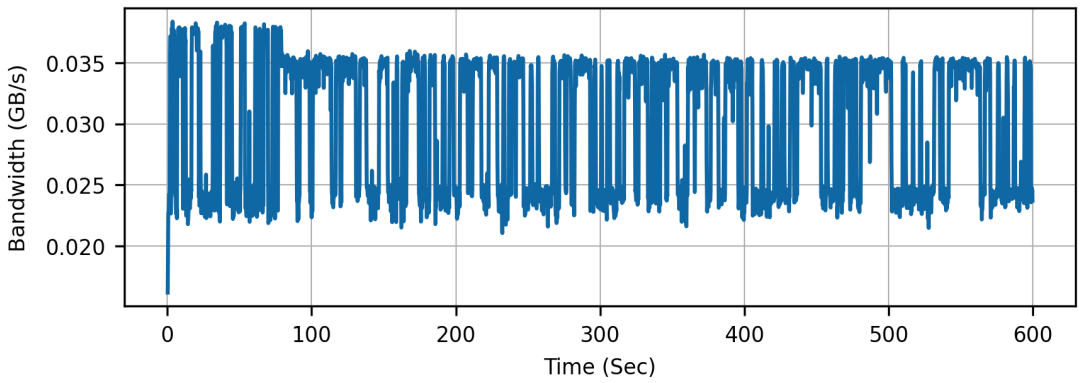

### Temperature and IO Bandwidth (Including Idle)



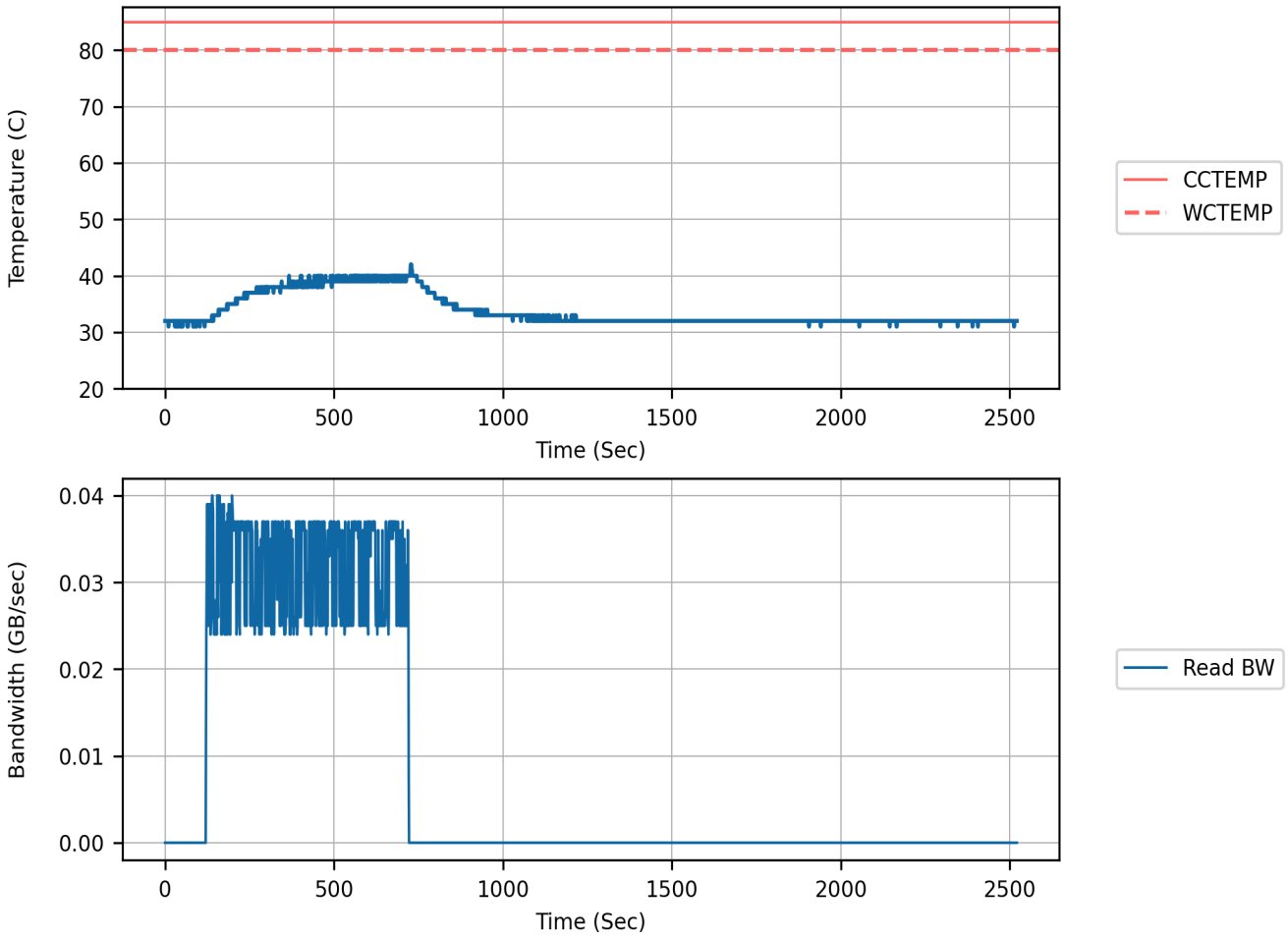
## RANDOM READS

These plots are for reads using random addressing, block size of 4 KiB, and queue depth of 1.

### IO Bandwidth



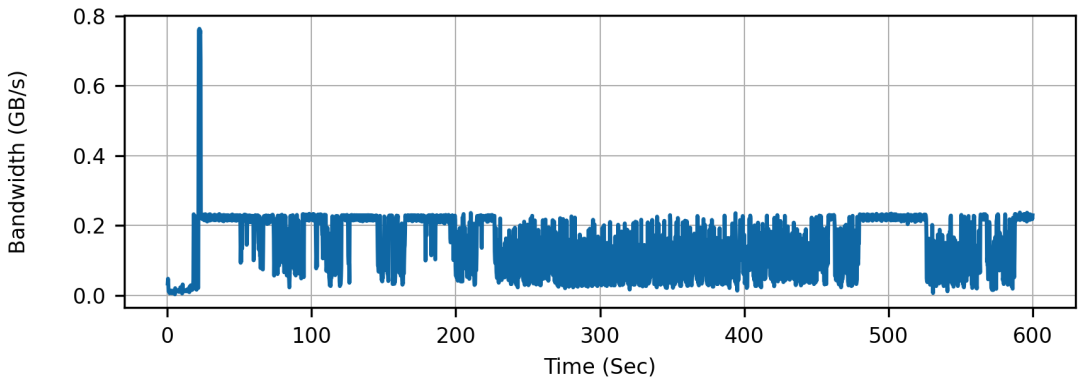

### Temperature and IO Bandwidth (Including Idle)



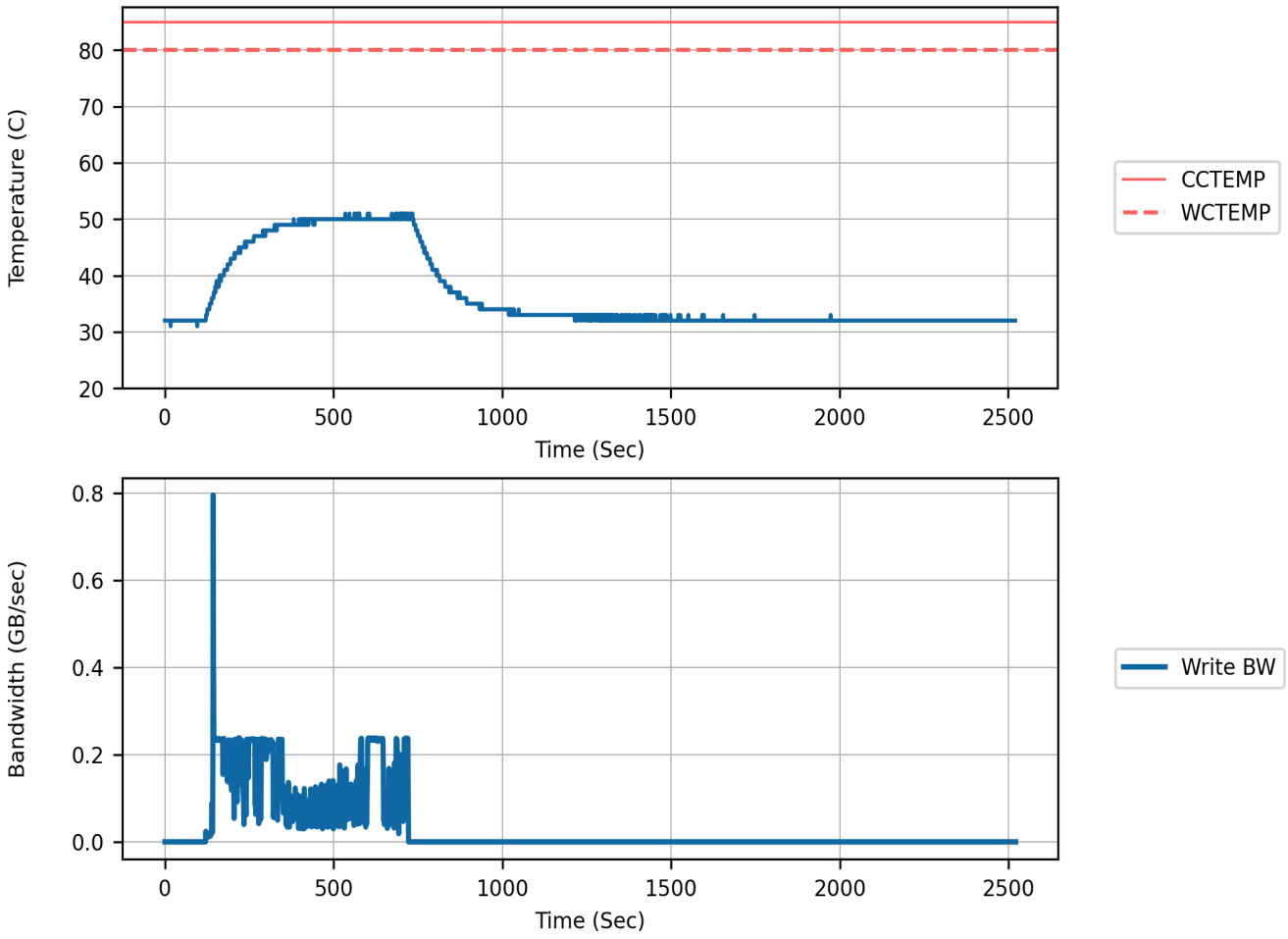
## SEQUENTIAL WRITES

These plots are for writes using sequential addressing, block size of 128 KiB, and queue depth of 32.

### IO Bandwidth



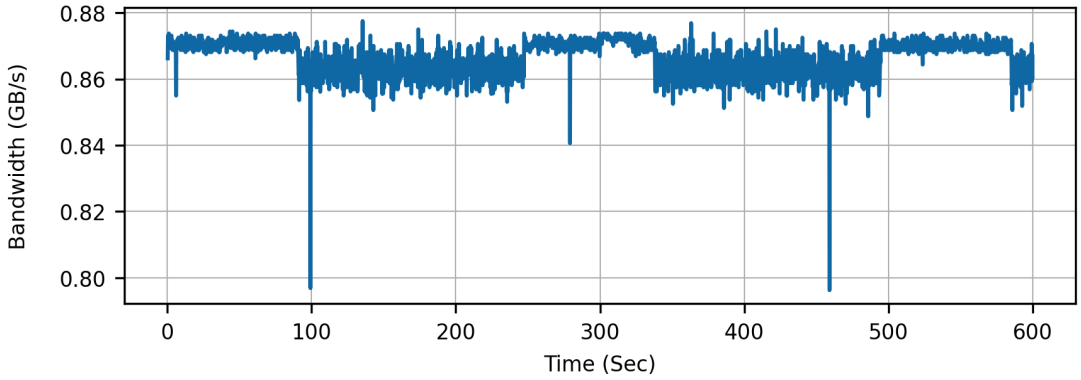

### Temperature and IO Bandwidth (Including Idle)



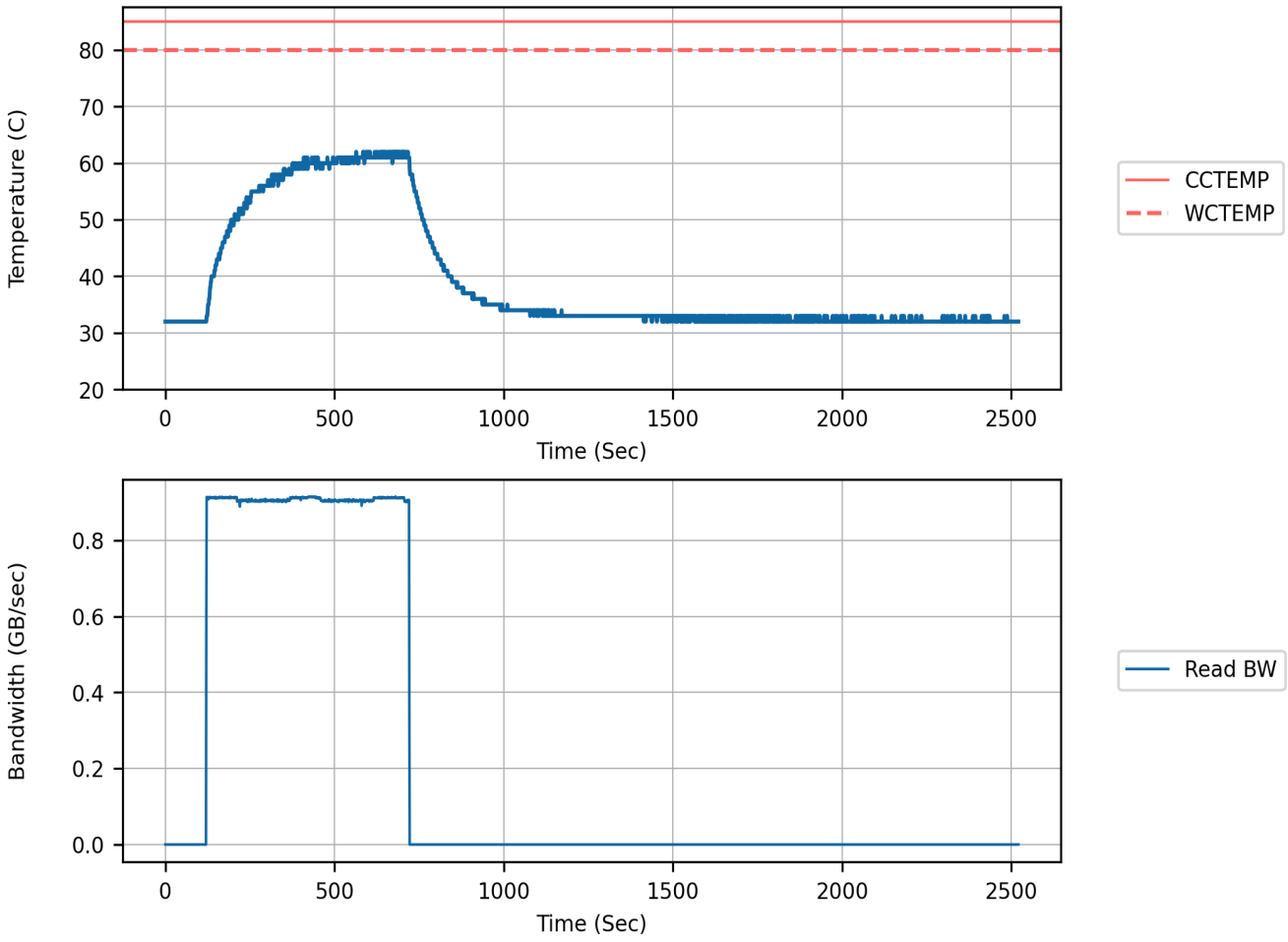
## SEQUENTIAL READS

These plots are for reads using sequential addressing, block size of 128 KiB, and queue depth of 32.

### IO Bandwidth




### Temperature and IO Bandwidth (Including Idle)



# TEST 900: DRIVE PARAMETER CHANGE

| | | |
|---|---|---|
| REQUIREMENTS | 7 | |
| PASSED | 6 | 85.7% |
| FAILED | 1 | 14.3% |

| STARTED | ENDED | DURATION |
|---|---|---|
| Aug 20, 2022 - 14:52:33.121 | Aug 20, 2022 - 14:52:33.192 | 0:00:00.070 |

| ID | REQUIREMENT | RESULT |
|---|---|---|
| 001 | There shall be no critical warnings | PASS |
| 002 | Static parameters, such as Model Number, shall not change | PASS |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | PASS |
| 004 | Media and Data Integrity Errors shall not increase | PASS |
| 007 | Change in Power On Hours shall be within 1 hour of actual time change | FAIL |
| 162 | Admin Command average latency shall be less than 50 mS | PASS |
| 163 | Admin Command maximum latency shall be less than 500 mS | PASS |

## DESCRIPTION

This test verifies drive parameters change as expected across two readings. Static parameters, such as Model and Serial Number, are verified not to change. SMART counter parameters, such as Power-On Hours, are verified not to decrease or reset.

For the complete list of parameters, refer to the file nvme.info.json. In this file, static parameters have the compare type 'exact' and counter parameters 'counter'.

## RESULTS

One or more requirements failed verification and are listed in the table above.

The start information was read at the beginning of this test run on August 19, 2022 at 19:46:41. The end information was read on August 20, 2022 at 14:52:33. The time difference between the two reads is 19:05:51. The reported difference in Power On Hours is 6.097581944444443.

A total of 302 static parameters were verified not to change. A total of 22 counter parameters were verified not to decrement or reset.

No Critical Warnings were asserted. Media and Data Integrity Errors did not increase.

# APPENDIX A: REQUIREMENT RESULTS

A requirement can be verified multiple times within a test run or even within a test. The table below lists the results for each attempt to verify a requirement.

| ID | NAME | PASS | FAIL |
|---|---|---|---|
| 001 | There shall be no critical warnings | 57 | 0 |
| 002 | Static parameters, such as Model Number, shall not change | 61 | 0 |
| 003 | SMART counters, such as Data Written, shall not reset or decrement | 61 | 0 |
| 004 | Media and Data Integrity Errors shall not increase | 28 | 0 |
| 005 | IO reads and writes shall complete without errors | 849 | 0 |
| 006 | IO reads and writes shall complete without data corruption | 139 | 0 |
| **007** | **Change in Power On Hours shall be within 1 hour of actual time change** | **0** | **1** |
| 008 | Thermal throttle time shall not increase | 7 | 0 |
| 110 | Percentage Used shall be less than 80% | 1 | 0 |
| 111 | Available Spare shall be 100% | 1 | 0 |
| **112** | **Percentage Written shall be less than 80%** | **0** | **1** |
| 113 | Percentage Warranty Used shall be less than 80% | 1 | 0 |
| 114 | Previous Self-Test failures shall be 0 | 1 | 0 |
| 115 | SMART media and integrity errors shall be 0 | 1 | 0 |
| 116 | Percentage throttled shall be less than 1.0% | 1 | 0 |
| **117** | **Critical composite temperature time shall be 0** | **0** | **1** |
| 150 | SMART attribute Data Written shall be within 512,000 bytes of data written | 1 | 0 |
| 151 | SMART attribute Data Read shall be within 512,000 bytes of data read | 1 | 0 |
| 160 | Admin Commands shall reliably complete without error | 33 | 0 |
| 162 | Admin Command average latency shall be less than 50 mS | 89 | 0 |
| **163** | **Admin Command maximum latency shall be less than 500 mS** | **86** | **3** |
| **200** | **Short Self-test result is 0 (no errors)** | **2** | **2** |
| **201** | **Short Self-test run time less than specified** | **2** | **2** |
| 202 | Short Self-test progress is monotonic | 4 | 0 |
| **203** | **Short Self-test progress is roughly linear (Coeff > 0.8)** | **3** | **1** |
| 204 | Short Self-test Power-On Hours match hours reported in log page 2 | 4 | 0 |
| 205 | Short burst Random Read, QD32, 4KiB, bandwidth must be more than 0.2 GB/s | 2 | 0 |
| 210 | Extended Self-test result is 0 (no errors) | 2 | 0 |
| 211 | Extended Self-test run time less than specified | 2 | 0 |
| 212 | Extended Self-test progress is monotonic | 2 | 0 |
| 213 | Extended Self-test progress is roughly linear (Coeff > 0.8) | 2 | 0 |
| 214 | Extended Self-test Power-On Hours match hours reported in log page 2 | 2 | 0 |

| | | | |
|---|---|---|---|
| **220** | **Long burst Sequential Write, QD32, 128KiB, bandwidth must be more than 1.0 GB/s** | **0** | **2** |
| **221** | **Long burst Sequential Read, QD32, 128KiB, bandwidth must be more than 1.0 GB/s** | **0** | **2** |
| **401** | **Temperature at end of long burst IO shall be within 5C of temperature when IO started** | **5** | **3** |
| **402** | **Average latency of slowest 1,825 IO shall not increase more than 20% with concurrent SMART reads** | **0** | **1** |
| **410** | **Timestamp shall not stop counting** | **0** | **2** |
| **411** | **Timestamp shall be within 1.0 hour of host timestamp** | **0** | **1** |
| **412** | **Timestamp changes shall be within 1.0 % of host time change** | **0** | **1** |
| **413** | **Timestamp count is linear (Coeff > 0.99)** | **0** | **1** |
| 505 | The read disturb effect shall not cause functional failures | 1 | 0 |
| 506 | Temperature Cycle IO Stress shall complete without errors | 1 | 0 |
| 900 | PCIe bus width must be x4 | 1 | 0 |
| **901** | **PCIe bus speed must be Gen3 8.0GT/s** | **0** | **1** |
| 902 | Firmware activation without reset must be supported | 1 | 0 |
| 903 | RTD3 Entry Latency (RTD3E) must be less than 10,000,000 uS | 1 | 0 |
| 905 | Power State 0 Maximum Power (MP) must be less than 8 Watts | 1 | 0 |

# APPENDIX B: REFERENCES

1. NVMe Specification, https://nvmexpress.org/developers/nvme-specification/

2. fio, https://fio.readthedocs.io/en/latest/index.html

3. nvmecmd, https://www.epicutils.com

4. Write Cache. Some drives, typically TLC and QLC drives, reserve a portion of the NAND flash to operateas single level cells (SLC). The write latency of SLC is much lower than multiple level cells (MLC, TLC, QLC). Therefore, an SLC write cache can significantly improve write performance until the cache fills up. The downside is SLC has much lower capacity than multiple level cells. Because of this, drives may dynamically reduce the amount of SLC cache as the drive fills up in order to meet the specified size. Running continuous writes results in the cache filling up and performance dropping significantly. The point where performance drops indicates the size of the SLC cache.

5. Garbage collection. When the drive needs to erase blocks in preparation for writing new data. The latency to erase a block and then write data is much higher than writing data. Empty drives contain large numbers of erased blocks that can be written too without any overhead to erase the block. Running continuous writes results in the drive running out of erased blocks causing it to continuously erase blocks with old data before new data can be written. This results in a performance drop.

6. Thermal throttling. Occurs if the drive temperature rises too high. In this case, the drive reduces performance until the drive temperature returns to the desired range.

7. What SMART Stats Tell Us About Hard Drives, Backblaze blog, https://www.backblaze.com/blog/what-smart-stats-indicate-hard-drive-failures/

# APPENDIX C: PARAMETER VALUES

| NAME | DESCRIPTION | VALUE |
|---|---|---|
| 128-bit Host Identifier | Controller support for 128-bit Host Identifier, from CTRATT | Not Supported |
| ANA Group Identifier Maximum (ANAGRPMAX) | Maximum value of a valid ANA Group Identifier for any controller in the NVM subsystem | Not Supported |
| ANA Transition Time (ANATT) | Maximum seconds for transition between ANA states or that the controller reports the ANA change state | Not Supported |
| Abort Command Limit (ACL) | Maximum number of concurrently executing Abort commands supported by the controller | 5 |
| Admin Vendor Specific command handling | Admin Vendor Specific Commands use standard format or vendor specific format, from AVSCC | Not Vendor Specific |
| Aggregation Threshold (THR) | Feature 08h: Recommended minimum number of completion queue entries to aggregate per interrupt vector before signaling an interrupt to the host | 1 |
| Aggregation Time (TIME) | Feature 08h: Recommended maximum time that a controller may delay an interrupt due to interrupt coalescing | No Delay |
| Arbitration Burst (AB) | Feature 01h: Number of commands that may be executed at one time from a particular Submission Queue as power of 2 (2^n) | 4 (2^4=16) |
| Associated Function Type | Controller associated with SR-IOV virtual function or PCI function type from CMIC | PCI |
| Asymmetric Namespace Access Change Notices | Controller support for asynchronous events Asymmetric Namespace Access Change Notices, from OAES | Not Supported |
| Asymmetric Namespace Access Reporting | Support for Asymmetric Namespace Access Reporting from CMIC | Not Supported |
| Asynchronous Event Request Limit (AERL) | Maximum number of concurrently outstanding Asynchronous Event Request commands supported by the controller | 8 |
| Atomic Write Unit Normal (AWUN) | Size of write in logical blocks guaranteed to be written atomically across all namespaces with any supported namespace format during normal operation | 1 |
| Atomic Write Unit Power Fail (AWUPF) | Size of write in logical blocks guaranteed to be written atomically across all namespaces with any supported namespace format during a power fail or error condition | 1 |
| Autonomous Power State Transition | Autonomous Power State Transition support, from APSTA | Supported |
| Autonomous Power State Transition Enable (APSTE) | Feature 0Ch: Autonomous power state transitions. Also see APSTA | Enabled |

| | | |
|---|---|---|
| Available Space Below Threshold | Critical Warning: Available spare space has fallen below the threshold | No |
| Available Spare | Normalized percentage (0 to 100%) of the remaining spare capacity available | 100 % |
| Available Spare Threshold | Available spare threshold indicated as a normalized percentage (0 to 100%) | 10 % |
| Block Erase Sanitize | Controller support for block sanitize, from SANICAP | Supported |
| Command Retry Delay Time 1 (CRDT1) | If DNR is 0 and CRD is 01b in the Completion Queue Entry, indicates the command retry delay time | 0 (0 mS) |
| Command Retry Delay Time 2 (CRDT2) | If DNR is 0 and CRD is 10b in the Completion Queue Entry, indicates the command retry delay time | 0 (0 mS) |
| Command Retry Delay Time 3 (CRDT3) | If DNR is 0 and CRD is 11b in the Completion Queue Entry, indicates the command retry delay time | 0 (0 mS) |
| Commands Supported and Effects Log Page | Controller support for log page attribute Commands Supported and Effects Log Page, from LPA | Supported |
| Compare NVM Command | Controller support for the Compare NVM command, from ONCS | Supported |
| Compare and Write Fused Operation | Controller support for the Compare and Write fused operation, from FUSES | Not Supported |
| Composite Temperature | Current composite temperature of the controller and namespace(s) associated with that controller | 28 C |
| Composite Temperature Over Threshold | Feature 04h: Composite Temperature over threshold limit | 80 C |
| Composite Temperature Under Threshold | Feature 04h: Composite Temperature under threshold limit | -5 C |
| Controller Busy Time | Time the controller is busy with I/O commands | 16,447 Min |
| Controller ID (CNTLID) | NVM subsystem unique controller identifier associated with the controller | 1 |
| Controller Type (CNTRLTYPE) | Specifies the controller type (I/O, Discovery, or Administrator) | I/O Controller |
| Controller Vendor | Controller vendor from PCI lookup: https://pcisig.com/membership/member-companies | Sandisk |
| Critical Composite Temperature Threshold (CCTEMP) | Temperature that indicates a critical overheating condition (e.g. possible data loss, device shutdown, extreme throttling, or permanent damage) | 85 C |
| Critical Composite Temperature Time | Time controller is operational and Composite Temperature is greater than the Critical Composite Temperature Threshold | 2 Min |
| Critical Warnings | Controller has asserted one or more critical warnings | No |

| | | |
|---|---|---|
| Crypto Erase | Crypto erase supported as part of secure erase, from FNA | Not Supported |
| Crypto Erase Sanitize | Controller support for crypto sanitize, from SANICAP | Not Supported |
| Current Number Of Errors | Current number of error entries in Log Page 1 | 0 |
| Current Number Of Self-Tests | Current number of self tests reported in log page 6 | 20 |
| Current Power State (PS) | Feature 02h: Current power state of the controller | 4 |
| Current Self-Test Completion | Percentage of the device self-test operation that is complete | 0 |
| Current Self-Test Operation | Status of the current device self-test operation | No Test In Progress |
| Data Read | Data Read in GB calculated from Data Units Read | 372,736.500 GB |
| Data Units Read | Number of 512,000 byte data units read from the controller; does not include metadata | 728,000,976 |
| Data Units Written | Number of 512,000 byte data units written to the controller; does not include metadata | 243,007,747 |
| Data Written | Data Written in GB calculated from Data Units Written | 124,419.966 GB |
| Dataset Management NVM Command | Controller support for the Dataset Management NVM command, from ONCS | Supported |
| Deallocated or Unwritten Logical Block Error Enable (DULBE) | Feature 05h: Deallocated or Unwritten Logical Block error enabled for the namespace | Disabled |
| Device Self-test Command | Controller support for Device Self-test Command, from OACS | Supported |
| Directive Send and Directive Receive Commands | Controller support for Directive Send and Directive Receive Commands, from OACS | Not Supported |
| Disable Normal (DN) | Feature 0Ah: Host specifies AWUN and NAWUN are not required and controller shall only honor AWUPF and NAWUPF | Not Supported |
| Doorbell Buffer Config Command | Controller support for Doorbell Buffer Config Command, from OACS | Not Supported |
| EG Available Space Below Threshold | Critical Warning: One or more Endurance Groups available spare space has fallen below the threshold | No |
| EG Critical Warnings | One or more Endurance Groups has asserted one or more critical warnings | No |
| EG Reliability Degraded | Critical Warning: One or more Endurance Groups reliability degraded due to significant media or internal errors | No |
| EG in Read Only | Critical Warning: One or more Endurance Groups media has been placed in read only mode | No |
| Enable Host Memory (EHM) | Feature 0Dh: Controller may use host memory buffer when enabled. See HMPRE | Enabled |

| | | |
|---|---|---|
| Endurance Group Event Log Page Change Notices | Controller support for asynchronous events Endurance Group Event Log Page Change Notices, from OAES | Not Supported |
| Endurance Group Identifier Maximum (ENDGIDMAX) | Maximum value of a valid Endurance Group Identifier for any controller in the NVM subsystem | 0 |
| Endurance Groups | Controller support for Endurance Groups, from CTRATT | Not Supported |
| Error Log Page Entries (ELPE) | Maximum number of Error Information log entries stored by the controller | 256 |
| Extended Data for Get Log Page | Controller support for log page attribute Extended Data for Get Log Page, from LPA | Supported |
| Extended Device Self-test Time (EDSTT) | Nominal time in minutes to complete extended device self-test when in power state 0 | 44 Min |
| FRU Globally Unique Identifier (FGUID) | Globally unique identifier for the Field Replaceable Unit (FRU) | 000000-00000000000000000000000000 |
| Firmware Activation Notices | Controller support for asynchronous events Firmware Activation Notices, from OAES | Supported |
| Firmware Activation Notices Enable | Feature 0Bh: Asynchronous event notification sent to host for Firmware Activation Starting. Also see OAES | Enabled |
| Firmware Activation Without Reset | Controller support for firmware activation without a reset, from FRMW | Supported |
| Firmware Active Slot | Firmware slot that loaded the active firmware, from AFI | 1 |
| Firmware Commit and Image Download Commands | Controller support for Firmware Commit and Image Download Commands, from OACS | Supported |
| Firmware Pending Slot | Firmware slot to be activated at the next controller reset, from AFI | Not Reported |
| Firmware Revision (FR) | Currently active firmware revision | 211070WD |
| Firmware Slot 1 Read Status | Firmware slot 1 read only or read/write, from FRMW | Read/Write |
| Firmware Slot 1 Revision | Revision of firmware in this slot, see Firmware Revision for Slot # (FRS#) | 211070WD |
| Firmware Slot 2 Revision | Revision of firmware in this slot, see Firmware Revision for Slot # (FRS#) | |
| Firmware Slots | Number of firmware slots supported by controller, from FRMW | 2 |
| Firmware Update Granularity (FWUG) | Minimum granularity and alignment of the data provided in the Firmware Image Download command | 4 KiB |
| Format All Namespaces | Format (excluding secure erase) applies to all namespaces in an NVM subsystem, from FNA | Not Supported |

| | | |
|---|---|---|
| Format NVM Command | Controller support for Format NVM Command, from OACS | Supported |
| Get LBA Status capability | Controller support for the Get LBA Status capability, from OACS | Not Supported |
| High Priority Weight (HPW) | Feature 01h: Number of commands that may be executed from the high priority service class in each arbitration round | 1 |
| Highest Version Detected | Highest NVMe version detected based on supported features | 1.4.0 |
| Host Controlled Thermal Management (HCTMA) | Controller support for host controlled thermal management | Supported |
| Host Memory Buffer Minimum Descriptor Entry Size (HMMINDS) | Minimum usable size of a Host Memory Buffer Descriptor Entry | No limitations |
| Host Memory Buffer Minimum Size (HMMIN) | Minimum size that the host is requested to allocate for the Host Memory Buffer feature in 4KiB units | 823 (3,292 KiB) |
| Host Memory Buffer Preferred Size (HMPRE) | Preferred size that the host is requested to allocate for the Host Memory Buffer feature in 4KiB units | 51,200 (204,800 KiB) |
| Host Memory Buffer Size (HSIZE) | Feature 0Dh: Size of host memory buffer allocated in memory page size units | 8,192 |
| Host Memory Descriptor List Address (HMDLAL) | Feature 0Dh: Lower 32 bits of the physical location of the Host Memory Descriptor List for the Host Memory Buffer | 0x07856000 |
| Host Memory Descriptor List Address (HMDLAU) | Feature 0Dh: Upper 32 bits of the physical location of the Host Memory Descriptor List for the Host Memory Buffer | 0x00000001 |
| Host Memory Descriptor List Entry Count (HMDLEC) | Feature 0Dh: Number of valid Host Memory Descriptor Entries | 8 |
| Host Memory Maximum Descriptors Entries (HMMAXD) | Number of usable Host Memory Buffer Descriptor Entries | 8 |
| Host Read Commands | Number of read commands completed by the controller | 9,598,589,573 |
| Host Timestamp | Host number of milliseconds since midnight, 01-Jan-1970, UTC | 1,660,963,601,957 mS |
| Host Timestamp Decoded | Host date and time | 2022-08-19 19:46:41.957 DST |
| Host Write Commands | Number of write commands completed by the controller | 5,328,909,298 |

| | | |
|---|---|---|
| IEEE OUI Identifier (IEEE) | Organization Unique Identifier (OUI) for the controller vendor: http://standards-oui.ieee.org/oui/oui.txt | 00-1b-44 |
| Keep Alive Support (KAS) | Granularity of the Keep Alive Timer | Not Supported |
| LBA Status Information Notices | Controller support for asynchronous events LBA Status Information Notices, from OAES | Not Supported |
| Low Priority Weight (LPW) | Feature 01h: Number of commands that may be executed from the low priority service class in each arbitration round | 1 |
| Maximum Completion Queue Entry Size | Maximum Completion Queue entry size when using the NVM Command Set in bytes reported as a power of two (2^n), from CQES | 4 (2^4=16) |
| Maximum Data Transfer Size (MDTS) | Maximum data transfer size between host and controller in units of minimum memory page size as a power of two (2^n) | 7 (2^7=128) |
| Maximum Number Allowed Namespaces (MNAN) | Maximum number of namespaces supported by the NVM subsystem | 0 |
| Maximum Outstanding Commands (MAXCMD) | Maximum number of commands that the controller processes at one time for a particular queue | Not Supported |
| Maximum Submission Queue Entry Size | Maximum Submission Queue entry size when using the NVM Command Set in bytes reported as a power of two (2^n), from SQES | 6 (2^6=64) |
| Maximum Thermal Management Temperature (MXTMT) | Maximum temperature host may request in the Thermal Management Temperature 1 and 2 fields of Set Features command | 85 C |
| Maximum Time for Firmware Activation (MTFA) | Maximum time the controller temporarily stops processing commands to activate the firmware image | 5,000 mS |
| Media and Data Integrity Errors | Number of occurrences where the controller detected an unrecovered data integrity error | 0 |
| Media in Read Only | Critical Warning: Media has been placed in read only mode | No |
| Medium Priority Weight (MPW) | Feature 01h: Number of commands that may be executed from the medium priority service class in each arbitration round | 1 |
| Minimum Thermal Management Temperature (MNTMT) | Minimum temperature host may request in the Thermal Management Temperature 1 and 2 fields of Set Features command | 0 C |
| Model Number (MN) | Model number for the NVM subsystem assigned by the vendor | WDC WDS250G2B 0C-00PXH0 |
| NVM Set Identifier Maximum (NSETIDMAX) | Maximum value of a valid NVM Set Identifier for any controller in the NVM subsystem | 0 |
| NVM Sets | Controller support for NVM Sets, from CTRATT | Not Supported |

| | | |
|---|---|---|
| NVM Subsystem Controllers | Single or multiple controllers contained in NVM subsystem from CMIC | Single |
| NVM Subsystem NVMe Qualified Name (SUBNQN) | The NVM Subsystem NVMe Qualified Name | nqn.2018-01.com.wdc:nguid:E8238FA6BF53-0001-001B448B49BC0ECB |
| NVM Subsystem PCIe Ports | Single or multiple PCIE ports contained in NVM subsystem from CMIC | Single |
| NVME MI Send/Receive Commands | Controller support for NVME MI Send/Receive Commands, from OACS | Not Supported |
| Namespace 1 ANA Group Identifier (ANAGRPID) | ANA Group Identifier of the ANA group of which the namespace is a member | Not Reported |
| Namespace 1 Active LBA Format | Index of LBA format that namespace is formatted with, from FLBAS | 0 |
| Namespace 1 Atomic Boundary Offset (NABO) | The LBA on this namespace where the first atomic boundary starts | 7 |
| Namespace 1 Atomic Boundary Size Normal (NABSN) | Atomic boundary size in logical blocks for this namespace for the NAWUN value | 7 |
| Namespace 1 Atomic Boundary Size Power Fail (NABSPF) | Atomic boundary size for this namespace specific to the Namespace Atomic Write Unit Power Fail value | 7 |
| Namespace 1 Atomic Compare & Write Unit (NACWU) | Namespace specific size of the write operation in logical blocks guaranteed to be written atomically for a Compare and Write fused command | Same as ACWU |
| Namespace 1 Atomic Write Unit Normal (NAWUN) | Namespace specific size of the write operation in logical blocks guaranteed to be written atomically during normal operation | 7 |
| Namespace 1 Atomic Write Unit Power Fail (NAWUPF) | Namespace specific size of the write operation in logical blocks guaranteed to be written atomically during a power fail or error condition | 7 |
| Namespace 1 Atomic Writes | If supported NAWUN, NAWUPF, and NACWU used instead of AWUN, AWUPF, and ACWU fields, from NSFEAT | Supported |
| Namespace 1 Capacity (NCAP) | The maximum number of logical blocks that may be allocated in the namespace | 488,397,168 |
| Namespace 1 Deallocate Bit in Write Zeros | Controller support for the Deallocate bit in the Write Zeros command for this namespace, from DLFEAT | Supported |
| Namespace 1 Deallocate Guard Field | Guard field for deallocated logical blocks that contain protection information is set to the CRC for the value read from the deallocated logical block, from DLFEAT | Not Supported |

| | | |
|---|---|---|
| Namespace 1 Deallocate Logical Block Value | Values read from a deallocated logical block and its metadata, from DLFEAT | All 00h |
| Namespace 1 Endurance Group Identifier (ENDGID) | Endurance Group with which this namespace is associated | Not Supported |
| Namespace 1 Exclusive Access All Registrants Reservation | Namespace supports the Exclusive Access - All Registrants reservation type, from RESCAP | Not Supported |
| Namespace 1 Exclusive Access Registrants Only Reservation | Namespace supports the Exclusive Access - Registrants Only reservation type, from RESCAP | Not Supported |
| Namespace 1 Exclusive Access Reservation | Namespace supports the Exclusive Access reservation type, from RESCAP | Not Supported |
| Namespace 1 Extended Data LBA | If supported metadata is transferred at the end of the data LBA, creating an extended data LBA, from FLBAS | Not Supported |
| Namespace 1 Format Percent Complete | Percentage of the Format NVM command that remains to be completed, from FPI | 0 |
| Namespace 1 Format Progress Indicator | Namespace supports the Format Progress Indicator, from FPI | Supported |
| Namespace 1 Globally Unique Identifier (NGUID) | 128-bit value that is globally unique and assigned to the namespace | e8238fa6bf530001-001b44-8b49bc0ecb |
| Namespace 1 IEEE Extended Unique Identifier (EUI64) | 64-bit IEEE Extended Unique Identifier (EUI-64) that is globally unique and assigned to the namespace | 001b44-8b49bc0ecb |
| Namespace 1 IO Optimize Fields | Fields NPWG, NPWA, NPDG, NPDA, and NOWS are defined for namespace and should be used for I/O optimization, from NSFEAT | Not Supported |
| Namespace 1 Ignore Existing Key Specification | Ignore Existing Key is used as defined in revision 1.2.1 or 1.3+ of NVMe specification, from RESCAP | 1.2.1 or earlier |
| Namespace 1 LBA 0 Data Size (LBADS) | LBA data size in power of two (2^n) | 9 (2^9=512) * |
| Namespace 1 LBA 0 Relative Performance (RP) | Relative performance of this LBA format relative to other LBA formats | Good Performance * |
| Namespace 1 LBA 1 Data Size (LBADS) | LBA data size in power of two (2^n) | 12 (2^12=4096) |
| Namespace 1 LBA 1 Relative Performance (RP) | Relative performance of this LBA format relative to other LBA formats | Better Performance |

| | | |
|---|---|---|
| Namespace 1 Logical Block Error | Controller support for the Deallocated or Unwritten Logical Block error for this namespace, from NSFEAT | Not Supported |
| Namespace 1 Metadata Transfer Buffer | Metadata transferred as part of a separate buffer that is specified in the Metadata Pointer, from MC | Not Supported |
| Namespace 1 Metadata Transfer Extended LBA | Metadata being transferred as part of an extended data LBA, from MC | Not Supported |
| Namespace 1 NGUID/EUID Not Reused | If supported non-zero NGUID and EUI64 fields for this namespace are never reused by the controller, from NSFEAT | Not Supported |
| Namespace 1 NVM Capacity (NVMCAP) | Total size of the NVM allocated to this namespace in bytes | 250,059,350,016 |
| Namespace 1 NVM Set Identifier (NVMSETID) | The NVM Set with which this namespace is associated | Not Supported |
| Namespace 1 Number of LBA Formats (NLBAF) | Number of supported LBA data size and metadata size combinations supported by the namespace | 2 |
| Namespace 1 Optimal IO Boundary (NOIOB) | Optimal IO boundary in logical blocks for this namespace | Not Reported |
| Namespace 1 Optimal Write Size (NOWS) | Size in logical blocks for optimal write performance for this namespace | 1 |
| Namespace 1 Persist Through Power Loss | Namespace supports the Persist Through Power Loss capability, from RESCAP | Not Supported |
| Namespace 1 Preferred Deallocate Alignment (NPDA) | Recommended alignment in logical blocks for the Dataset Management command with the Attribute ■Deallocate bit set to 1 | 1 |
| Namespace 1 Preferred Deallocate Granularity (NPDG) | Recommended granularity in logical blocks for the Dataset Management command with the Attribute ■Deallocate bit set to 1 | 1 |
| Namespace 1 Preferred Write Alignment (NPWA) | Recommended write alignment in logical blocks for this namespace | 1 |
| Namespace 1 Preferred Write Granularity (NPWG) | Smallest recommended write granularity in logical blocks for this namespace | 1 |
| Namespace 1 Protection First | Namespace supports protection information transferred as first eight bytes of metadata, from DPC | Not Supported |

| | | |
|---|---|---|
| Namespace 1 Protection Information Enabled | Type of Protection Information enabled, if any, from DPS | Disabled |
| Namespace 1 Protection Information First | Protection information, if enabled, is transferred as the first eight bytes of metadata, from DPS | Last 8 Bytes |
| Namespace 1 Protection Last | Namespace supports protection information transferred as the last eight bytes of metadata, from DPC | Not Supported |
| Namespace 1 Protection Type 1 | Namespace supports Protection Information Type 1, from DPC | Not Supported |
| Namespace 1 Protection Type 2 | Namespace supports Protection Information Type 2, from DPC | Not Supported |
| Namespace 1 Protection Type 3 | Namespace supports Protection Information Type 3, from DPC | Not Supported |
| Namespace 1 Shared | Namespace may be attached to two or more controllers in the NVM subsystem concurrently (i.e., may be a shared namespace), from NMIC | Not Supported |
| Namespace 1 Size | Total calculated size of the namespace in GB | 250 GB |
| Namespace 1 Size in GiB | Total calculated size of the namespace in GiB (1024*1024*1024) | 232.9 GiB |
| Namespace 1 Size in LBA (NSZE) | Total size of this namespace in logical blocks | 488,397,168 |
| Namespace 1 Thin Provisioning | If supported the Namespace Capacity reported may be less than the Namespace Size, from NSFEAT | Not Supported |
| Namespace 1 Utilization (NUSE) | Current number of logical blocks allocated in the namespace | 488,397,168 |
| Namespace 1 Write Exclusive All Registrants Reservation | Namespace supports the Write Exclusive - All Registrants reservation type, from RESCAP | Not Supported |
| Namespace 1 Write Exclusive Registrants Only Reservation | Namespace supports the Write Exclusive - Registrants Only reservation type, from RESCAP | Not Supported |
| Namespace 1 Write Exclusive Reservation | Namespace supports the Write Exclusive reservation type, from RESCAP | Not Supported |
| Namespace 1 Write Protected | Namespace is currently write protected due to any condition | No |
| Namespace Attribute Notices | Controller support for asynchronous events Namespace Activation Notices, from OAES | Not Supported |
| Namespace Granularity | Controller support for reporting of Namespace Granularity, from CTRATT | Not Supported |

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|---|---|---|
| Namespace Management and Attachment Commands | Controller support for Namespace Management and Attachment Commands, from OACS | Not Supported |
| No-Deallocate Inhibited (NDI) | Controller support for No-Deallocate Inhibited (NDI), from SANICAP | Supported |
| No-Deallocate Modifies Media After Sanitize (NODMMAS) | Indicates if media is modified by controller after a sanitize command started with No-Deallocate After Sanitize bit set to 1, from SANICAP | Media not modified |
| Non-Operational Power State Permissive Mode | Controller support for temporary exceeding power in non-operational power state for background operation, from CTRATT | Supported |
| Non-Operational Power State Permissive Mode Enable (NOPPME) | Feature 11h: Controller may temporarily exceed the power limits of any non-operational power state to run controller initiated background operations | Enabled |
| Non-zero ANAGRPID | Controller support for a non-zero value in the ANAGRPID field of the Namespace Management command, from ANACAP | Not Supported |
| Number Of Failed Self-Tests | Number of self tests that failed in log page 6 | 0 |
| Number of ANA Group Identifiers (NANAGRPID) | Number of ANA groups supported by this controller | Not Supported |
| Number of Error Information Log Entries | Number of Error Information log entries over the life of the controller | 1 |
| Number of Namespaces (NN) | Number of valid namespaces present for the controller | 1 |
| Number of Power States Support (NPSS) | Number of NVM Express power states supported by the controller | 5 |
| OS Location | Drive location reported by the Operating System | /dev/nvme0 |
| One Self-Test | Support for one device self-test at a time per system or per controller, from DSTO | Per System |
| Overwrite Sanitize | Controller support for overwrite sanitize, from SANICAP | Not Supported |
| PCI Device ID | PCI device identifier assigned for the device | 0x5009 |
| PCI Location | PCI bus address in the system | Bus 1, device 0, function 0 |
| PCI Rated Speed | Maximum PCI bus speed the device is rated for | Gen3 8.0GT/s |
| PCI Rated Width | Maximum PCI bus width the device is rated for | x4 |
| PCI Speed | Current PCI bus speed | Gen1 2.5GT/s |
| PCI Subsystem Vendor ID (SSVID) | Company vendor identifier assigned by PCI SIG for the subsystem | 0x15B7 |
| PCI Vendor ID (VID) | Company vendor identifier assigned by PCI SIG for the controller | 0x15B7 |

| | | |
|---|---|---|
| PCI Width | Current PCI bus width in lanes | x4 |
| PCIe Management Endpoint (PCIEME) | NVME MI: NVM Subsystem contains a Management Endpoint on a PCIe port | Not Supported |
| Percentage Used | Vendor specific estimate of the percentage life used, can exceed 100% | 17 % |
| Permanent Write Protect | Controller support for the Permanent Write Protect state, from NWPC | Not Supported |
| Persistent Event Log | Controller support for log page attribute Persistent Event Log, from LPA | Supported |
| Persistent Event Log Size (PELS) | Maximum reportable size for the Persistent Event Log | 64 KiB |
| Persistent Memory Unreliable | Critical Warning: Persistent Memory Region has become read-only or unreliable | No |
| Power Cycles | Number of power cycles | 154 |
| Power On Hours | Number of power on hours | 1,799 |
| Power State 0 Active Power (ACTP) | Largest average power over 10 seconds in this power state with workload from Active Power Workload (APW) | 1.8 Watts |
| Power State 0 Active Power Workload (APW) | Workload used to calculate maximum power for the active power state | Workload #2 |
| Power State 0 Entry Latency (ENLAT) | Maximum entry latency in microseconds associated with entering this power state | Not Reported |
| Power State 0 Exit Latency (EXLAT) | Maximum exit latency in microseconds associated with exiting this power state | Not Reported |
| Power State 0 Idle Power (IDLP) | Typical power consumed over 30 seconds in this power state when idle | 0.63 Watts |
| Power State 0 Idle Time Prior to Transition (ITPT) | Feature 0Ch: Idle time that occurs in this power state prior to transitioning to the Idle Transition Power State in milliseconds | 100 mS |
| Power State 0 Idle Transition Power State (ITPS) | Feature 0Ch: Power state to autonomously transition to after exceeding Idle Time Prior to Transition (ITPT) | 3 |
| Power State 0 Maximum Power (MP) | Maximum power consumed in this power state | 3.5 Watts |
| Power State 0 Non-Operational State (NOPS) | Controller does not process I/O commands in a Non-Operational State | False |
| Power State 0 Relative Read Latency (RRL) | Relative read latency associated with this power state | 0 |
| Power State 0 Relative Read Throughput (RRT) | Relative read throughput associated with this power state | 0 |

| | | |
|---|---|---|
| Power State 0 Relative Write Latency (RWL) | Relative write latency associated with this power state | 0 |
| Power State 0 Relative Write Throughput (RWT) | Relative write throughput associated with this power state | 0 |
| Power State 1 Active Power (ACTP) | Largest average power over 10 seconds in this power state with workload from Active Power Workload (APW) | 1.6 Watts |
| Power State 1 Active Power Workload (APW) | Workload used to calculate maximum power for the active power state | Workload #2 |
| Power State 1 Entry Latency (ENLAT) | Maximum entry latency in microseconds associated with entering this power state | Not Reported |
| Power State 1 Exit Latency (EXLAT) | Maximum exit latency in microseconds associated with exiting this power state | Not Reported |
| Power State 1 Idle Power (IDLP) | Typical power consumed over 30 seconds in this power state when idle | 0.63 Watts |
| Power State 1 Idle Time Prior to Transition (ITPT) | Feature 0Ch: Idle time that occurs in this power state prior to transitioning to the Idle Transition Power State in milliseconds | 100 mS |
| Power State 1 Idle Transition Power State (ITPS) | Feature 0Ch: Power state to autonomously transition to after exceeding Idle Time Prior to Transition (ITPT) | 3 |
| Power State 1 Maximum Power (MP) | Maximum power consumed in this power state | 2.4 Watts |
| Power State 1 Non-Operational State (NOPS) | Controller does not process I/O commands in a Non-Operational State | False |
| Power State 1 Relative Read Latency (RRL) | Relative read latency associated with this power state | 0 |
| Power State 1 Relative Read Throughput (RRT) | Relative read throughput associated with this power state | 0 |
| Power State 1 Relative Write Latency (RWL) | Relative write latency associated with this power state | 0 |
| Power State 1 Relative Write Throughput (RWT) | Relative write throughput associated with this power state | 0 |
| Power State 2 Active Power (ACTP) | Largest average power over 10 seconds in this power state with workload from Active Power Workload (APW) | 1.5 Watts |

| | | |
|---|---|---|
| Power State 2 Active Power Workload (APW) | Workload used to calculate maximum power for the active power state | Workload #2 |
| Power State 2 Entry Latency (ENLAT) | Maximum entry latency in microseconds associated with entering this power state | Not Reported |
| Power State 2 Exit Latency (EXLAT) | Maximum exit latency in microseconds associated with exiting this power state | Not Reported |
| Power State 2 Idle Power (IDLP) | Typical power consumed over 30 seconds in this power state when idle | 0.63 Watts |
| Power State 2 Idle Time Prior to Transition (ITPT) | Feature 0Ch: Idle time that occurs in this power state prior to transitioning to the Idle Transition Power State in milliseconds | 100 mS |
| Power State 2 Idle Transition Power State (ITPS) | Feature 0Ch: Power state to autonomously transition to after exceeding Idle Time Prior to Transition (ITPT) | 3 |
| Power State 2 Maximum Power (MP) | Maximum power consumed in this power state | 1.9 Watts |
| Power State 2 Non-Operational State (NOPS) | Controller does not process I/O commands in a Non-Operational State | False |
| Power State 2 Relative Read Latency (RRL) | Relative read latency associated with this power state | 0 |
| Power State 2 Relative Read Throughput (RRT) | Relative read throughput associated with this power state | 0 |
| Power State 2 Relative Write Latency (RWL) | Relative write latency associated with this power state | 0 |
| Power State 2 Relative Write Throughput (RWT) | Relative write throughput associated with this power state | 0 |
| Power State 3 Active Power (ACTP) | Largest average power over 10 seconds in this power state with workload from Active Power Workload (APW) | Not Reported |
| Power State 3 Active Power Workload (APW) | Workload used to calculate maximum power for the active power state | No workload |
| Power State 3 Entry Latency (ENLAT) | Maximum entry latency in microseconds associated with entering this power state | 3,900 uS (0.003 sec) |
| Power State 3 Exit Latency (EXLAT) | Maximum exit latency in microseconds associated with exiting this power state | 11,000 uS (0.011 sec) |
| Power State 3 Idle Power (IDLP) | Typical power consumed over 30 seconds in this power state when idle | 0.02 Watts |

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|---|---|---|
| Power State 3 Idle Time Prior to Transition (ITPT) | Feature 0Ch: Idle time that occurs in this power state prior to transitioning to the Idle Transition Power State in milliseconds | 2,000 mS |
| Power State 3 Idle Transition Power State (ITPS) | Feature 0Ch: Power state to autonomously transition to after exceeding Idle Time Prior to Transition (ITPT) | 4 |
| Power State 3 Maximum Power (MP) | Maximum power consumed in this power state | 0.02 Watts |
| Power State 3 Non-Operational State (NOPS) | Controller does not process I/O commands in a Non-Operational State | True |
| Power State 3 Relative Read Latency (RRL) | Relative read latency associated with this power state | 3 |
| Power State 3 Relative Read Throughput (RRT) | Relative read throughput associated with this power state | 3 |
| Power State 3 Relative Write Latency (RWL) | Relative write latency associated with this power state | 3 |
| Power State 3 Relative Write Throughput (RWT) | Relative write throughput associated with this power state | 3 |
| Power State 4 Active Power (ACTP) | Largest average power over 10 seconds in this power state with workload from Active Power Workload (APW) | Not Reported |
| Power State 4 Active Power Workload (APW) | Workload used to calculate maximum power for the active power state | No workload |
| Power State 4 Entry Latency (ENLAT) | Maximum entry latency in microseconds associated with entering this power state | 5,000 uS (0.005 sec) |
| Power State 4 Exit Latency (EXLAT) | Maximum exit latency in microseconds associated with exiting this power state | 39,000 uS (0.039 sec) |
| Power State 4 Idle Power (IDLP) | Typical power consumed over 30 seconds in this power state when idle | 0.005 Watts |
| Power State 4 Idle Time Prior to Transition (ITPT) | Feature 0Ch: Idle time that occurs in this power state prior to transitioning to the Idle Transition Power State in milliseconds | Disabled |
| Power State 4 Maximum Power (MP) | Maximum power consumed in this power state | 0.005 Watts |
| Power State 4 Non-Operational State (NOPS) | Controller does not process I/O commands in a Non-Operational State | True |

| | | |
|---|---|---|
| Power State 4 Relative Read Latency (RRL) | Relative read latency associated with this power state | 4 |
| Power State 4 Relative Read Throughput (RRT) | Relative read throughput associated with this power state | 4 |
| Power State 4 Relative Write Latency (RWL) | Relative write latency associated with this power state | 4 |
| Power State 4 Relative Write Throughput (RWT) | Relative write throughput associated with this power state | 4 |
| Predictable Latency Event Log Change Notices | Controller support for asynchronous events Predictable Latency Event Log Change Notices, from OAES | Not Supported |
| Predictable Latency Mode | Controller support for Predictable Latency Mode, from CTRATT | Not Supported |
| RTD3 Entry Latency (RTD3E) | Typical latency to enter Runtime D3 in microseconds | 1,000,000 uS (1.000 sec) |
| RTD3 Resume Latency (RTD3R) | Typical latency resuming from Runtime D3 in microseconds | 500,000 uS (0.500 sec) |
| Read Recovery Levels | Controller support for Read Recovery Levels, from CTRATT | Not Supported |
| Read Recovery Levels Supported (RRLS) | Controller supported Read Recovery Levels | 0x0000 |
| Recommended Arbitration Burst (RAB) | Recommended number of commands that may be executed at one time from a particular Submission Queue as a power of two (2^n) | 4 (2^4=16) |
| Reliability Degraded | Critical Warning: Reliability degraded due to significant media or internal errors | No |
| Replay Protected Memory Blocks (RPMBS) | Replay Protected Memory Blocks store data to a specific memory area in an authenticated and replay protected manner | Not Supported |
| Report ANA Change state | Controller is able to report ANA Change state, from ANACAP | Not Supported |
| Report ANA Inaccessible state | Controller is able to report ANA Inaccessible state, from ANACAP | Not Supported |
| Report ANA Non-Optimized state | Controller is able to report ANA Non-Optimized state, from ANACAP | Not Supported |
| Report ANA Optimized state | Controller is able to report ANA Optimized state, from ANACAP | Not Supported |
| Report ANA Persistent Loss state | Controller is able to report ANA Persistent Loss state, from ANACAP | Not Supported |

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|---|---|---|
| Required Completion Queue Entry Size | Required Completion Queue entry size when using the NVM Command Set in bytes reported as a power of two (2^n), from CQES | 4 (2^4=16) |
| Required Submission Queue Entry Size | Required Submission Queue entry size when using the NVM Command Set in bytes reported as a power of two (2^n), from SQES | 6 (2^6=64) |
| Reservations | Controller support for reservations, from ONCS | Not Supported |
| Root PCI Device ID | PCI device identifier assigned for the root device | 0xA340 |
| Root PCI Location | PCI bus address for the root device | Bus 0, device 27, function 0 |
| Root PCI Vendor ID | PCI vendor identifier assigned for the root device | 0x8086 |
| SGL support in NVM command | SGL support for the NVM Command Set | Not Supported |
| SMART Critical Warning Notices Enable | Feature 0Bh: Asynchronous event notifications sent to host for SMART Critical Warnings | 0x00 |
| SMART/Health Log Page per Namespace | Controller support for log page attribute SMART/Health Log Page per Namespace, from LPA | Not Supported |
| SMBus Management Endpoint (SMBUSME) | NVME MI: NVM Subsystem contains a Management Endpoint on an SMBus/I2C port | Not Supported |
| SQ Associations | Controller support for SQ Associations, from CTRATT | Not Supported |
| Save/Select Fields in Features Command | Controller support for Save and Select Fields in Features Command, from ONCS | Supported |
| Secure Erase All Namespaces | Secure erase applies to all namespaces in an NVM subsystem, from FNA | Not Supported |
| Security Send and Security Receive Command | Controller support for Security Send and Security Receive Command, from OACS | Supported |
| Self-Test 1 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,780 |
| Self-Test 1 Result | Result of Self-Test | Passed |
| Self-Test 1 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 1 Type | Type of Self-Test (short, extended or vendor) | Extended Test |
| Self-Test 10 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,766 |
| Self-Test 10 Result | Result of Self-Test | Passed |
| Self-Test 10 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 10 Type | Type of Self-Test (short, extended or vendor) | Extended Test |

| | | |
|---|---|---|
| Self-Test 11 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,766 |
| Self-Test 11 Result | Result of Self-Test | Passed |
| Self-Test 11 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 11 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 12 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,766 |
| Self-Test 12 Result | Result of Self-Test | Passed |
| Self-Test 12 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 12 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 13 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,764 |
| Self-Test 13 Result | Result of Self-Test | Passed |
| Self-Test 13 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 13 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 14 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,764 |
| Self-Test 14 Result | Result of Self-Test | Passed |
| Self-Test 14 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 14 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 15 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,764 |
| Self-Test 15 Result | Result of Self-Test | Passed |
| Self-Test 15 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 15 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 16 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,764 |
| Self-Test 16 Result | Result of Self-Test | Passed |
| Self-Test 16 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 16 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 17 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,764 |
| Self-Test 17 Result | Result of Self-Test | Passed |
| Self-Test 17 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 17 Type | Type of Self-Test (short, extended or vendor) | Short Test |

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| Self-Test 18 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,764 |
| Self-Test 18 Result | Result of Self-Test | Passed |
| Self-Test 18 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 18 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 19 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,764 |
| Self-Test 19 Result | Result of Self-Test | Passed |
| Self-Test 19 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 19 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 2 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,779 |
| Self-Test 2 Result | Result of Self-Test | Passed |
| Self-Test 2 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 2 Type | Type of Self-Test (short, extended or vendor) | Extended Test |
| Self-Test 20 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,764 |
| Self-Test 20 Result | Result of Self-Test | Passed |
| Self-Test 20 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 20 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 3 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,779 |
| Self-Test 3 Result | Result of Self-Test | Passed |
| Self-Test 3 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 3 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 4 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,779 |
| Self-Test 4 Result | Result of Self-Test | Passed |
| Self-Test 4 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 4 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 5 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,779 |
| Self-Test 5 Result | Result of Self-Test | Passed |
| Self-Test 5 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 5 Type | Type of Self-Test (short, extended or vendor) | Short Test |

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| Self-Test 6 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,779 |
| Self-Test 6 Result | Result of Self-Test | Passed |
| Self-Test 6 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 6 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 7 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,771 |
| Self-Test 7 Result | Result of Self-Test | Passed |
| Self-Test 7 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 7 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 8 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,771 |
| Self-Test 8 Result | Result of Self-Test | Passed |
| Self-Test 8 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 8 Type | Type of Self-Test (short, extended or vendor) | Short Test |
| Self-Test 9 Power On Hours | Number of power-on hours at the time the device self-test operation was completed or aborted | 1,767 |
| Self-Test 9 Result | Result of Self-Test | Passed |
| Self-Test 9 Result Code | Numeric code returned by Self-Test | 0 |
| Self-Test 9 Type | Type of Self-Test (short, extended or vendor) | Extended Test |
| Serial Number (SN) | Serial number for the NVM subsystem assigned by the vendor | 2035A0805352 |
| Size | Total calculated size in GB | 250 GB |
| Size in GiB | Total calculated size in GiB (1024*1024*1024) | 232.9 GiB |
| Subsystem Vendor | Subsystem vendor from PCI lookup: https://pcisig.com/membership/member-companies | Sandisk |
| Telemetry Log Notices | Controller support for log page attribute Telemetry Log Notices, from LPA | Supported |
| Telemetry Log Notices Enable | Feature 0Bh: Asynchronous event notification sent to host for when telemetry data available. Also see LPA | Disabled |
| Temperature Over/Under Threshold | Critical Warning: A temperature is over or under a temperature threshold | No |
| Thermal Management Temperature 1 (TMT1) | Feature 10h: Temperature the controller transitions to lower active power states or other vendor specific actions while minimizing the impact on performance | Disabled |
| Thermal Management Temperature 1 Count | Number of times the controller transitioned to lower power active power states or performed vendor specific thermal management actions while minimizing the impact on performance | 0 |

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|---|---|---|
| Thermal Management Temperature 1 Time | Number of seconds controller had transitioned to lower power active power states or performed vendor specific thermal management actions while minimizing the impact on performance | 0 Sec |
| Thermal Management Temperature 2 (TMT2) | Feature 10h: Temperature the controller transitions to lower active power states or other vendor specific actions regardless of the impact on performance | Disabled |
| Thermal Management Temperature 2 Count | Number of times the controller transitioned to lower power active power states or performed vendor specific thermal management actions regardless of the impact on performance | 0 |
| Thermal Management Temperature 2 Time | Number of seconds controller had transitioned to lower power active power states or performed vendor specific thermal management actions regardless of the impact on performance | 0 Sec |
| Time Limited Error Recovery (TLER) | Feature 05h: Limited retry timeout value | No Timeout |
| Timestamp | Feature 0Eh: Number of milliseconds since controller reset or host value (midnight, 01-Jan-1970, UTC) | 1,660,912,816,227 mS |
| Timestamp Decoded | Feature 0Eh: Either date or time since controller reset depending on timestamp origin | 2022-08-19 05:40:16.227 DST |
| Timestamp Feature | Controller support for Timestamp in Features Command, from ONCS | Supported |
| Timestamp Origin | Feature 0Eh: Timestamp is time from controller reset or host programmed value | Host Programmed |
| Timestamp Stopped | Feature 0Eh: Timestamp may have stopped counting in some conditions (e.g. non-operational power states) | True |
| Traffic Based Keep Alive Support | Controller support for restarting the Keep Alive Timer if an Admin command or an I/O command is processed during the Keep Alive Timeout Interval, from CTRATT | Not Supported |
| UUID List | Controller support for reporting of a UUID List, from CTRATT | Not Supported |
| Unchanged ANAGRPID | ANAGRPID field does not change while the namespace is attached to any controller, from ANACAP | Not Supported |
| Unsafe Shutdowns | Number of unsafe shutdowns | 23 |
| Vendor Specific Command Configuration | NVM Vendor Specific Commands use vendor specific or other format defined in NVMe specification, from NVSCC | Not Vendor Specific |
| Verify NVM Command | Controller support for Verify NVM Command, from ONCS | Not Supported |
| Version (VER) | NVMe version: https://nvmexpress.org/developers/nvme-specification/ | 1.4.0 |
| Virtualization Mgt Command | Controller support for Virtualization Mgt Command, from OACS | Not Supported |
| Volatile Backup Failed | Critical Warning: Volatile memory backup device, if present, has failed | No |

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| Volatile Write Cache (VWC) | Presence of a volatile write cache, from VWC | Supported |
| Volatile Write Cache Enable (WCE) | Feature 06h: Volatile write cache enable | Enabled |
| Volatile Write Cache Flush All NSID | Volatile Write Cache (VWC) flush command behavior if the NSID value is set to FFFFFFFFh, from VWC | Supported |
| Warning Composite Temperature Threshold (WCTEMP) | Temperature that indicates an overheating condition where controller operation continues | 80 C |
| Warning Composite Temperature Time | Time controller is operational and Composite Temperature is greater than or equal to Warning Composite Temperature Threshold and less than the Critical Composite Temperature Threshold | 57 Min |
| Workload Hint (WH) | Feature 02h: Type of workload expected for a given power state | 0 |
| Write Protect Namespace States | Controller support for No Write Protect and Write Protect namespace write protection states and may support the Write Protect Until Power Cycle state and Permanent Write Protect namespace write protection states, from NWPC | Not Supported |
| Write Protect Until Power Cycle | Controller support for the Write Protect Until Power Cycle state, from NWPC | Not Supported |
| Write Uncorrectable NVM Command | Controller support for the Write Uncorrectable NVM command, from ONCS | Supported |
| Write Zeroes NVM Command | Controller support for the Write Zeroes NVM command, from ONCS | Supported |
| Time Throttled | Total time throttled in seconds | 3540 |
| Namespace 1 Active LBA Size | Size in bytes of the active LBA for Namespace 1 | 512 |