Flash Endurance and Retention Monitoring

An in-situ and Field Testing Method

Steven R. Hetzler
IBM Fellow, Mgr. Storage Architecture Research

Blog: http://drhetzler.com/smorgastor
Predicting Wearout and Retention

- Wear leveling prevents direct measurement of endurance and retention
  - Block virtualization obscures PE cycle, age, location
- Beneficial to measure the behavior at the system level
  - Can perform cost-effective preventative maintenance
  - Can adjust usage to favor strong devices over weak
  - Can perform incoming parts test and verify device behavior
    - Not all devices behave the same
Monitor Data Defined

- A selected set of reserved blocks
  - To be written with known monitor data
    - Good idea to include a real-time stamp!
  - Not wear leveled
  - Read/erase/write all controlled directly
    - Raw read (ECC off) – allows testing beyond ECC
  - Always at PE cycles > user data PE cycles

- Samples the error rate surface
- Measures end of life limits early
  - Time until reliability limit reached with current workload
- Enables 100% incoming parts test
Distribution of erase blocks as a function of PE cycles at some time

This distribution moves to the right over time due to write activity and wear leveling
Monitor data access distribution is at higher PE cycle count
- Provides information on device behavior in advance of user data
- Always kept ahead of the user distribution
  - Cycled and aged to sample error rate behavior
• Can also have a small set of factory qualification data
  • Pre-cycled to expected limit
  • Can measure longer retention times
  • Can put cycle past expected limit to test headroom
Monitor Data Behavior

- After further PE cycles, user distribution move to right
  - Monitor data cycled to remain ahead of user distribution

These are canary blocks *ahead* of the user data
Practical Aspects

- Impact can be minimal
  - 0.1% monitor data should be adequate
    - 256MB on a 256GB device
  - 0.1% impact on write and erase to keep ahead
  - Monitor data cycles once for every 1,000 data PE
  - 256GB 5k PE, 5 Year device (= 1,280PB writes)
    - 700GB/day write limit, so need 2.7 MD cycles /day

- Time to End of Life (EOL) can be measured

- Qualification blocks can have longest age
  - Pre-cycle at incoming test
  - Once retention limit is exceeded, can cycle again to improve stats
What are the Bit Error Limits?

- System designed to a sector loss rate
  - Compute the associated bit error rate

<table>
<thead>
<tr>
<th></th>
<th>SAS HDD</th>
<th>eSSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOPS (4kB)</td>
<td>250</td>
<td>30,000</td>
</tr>
<tr>
<td>Equiv. MB/S</td>
<td>1</td>
<td>120</td>
</tr>
<tr>
<td>NRRE bit interval spec</td>
<td>1e16</td>
<td>1e18*</td>
</tr>
<tr>
<td>Mean Y/sector loss</td>
<td>320</td>
<td>260</td>
</tr>
</tbody>
</table>

- *JESD218 spec is same as SAS HDD = 2.6Y MTTDL
  - Important spec is time to fail, not bits to fail
- See [http://drhetzler.com/smorgastor](http://drhetzler.com/smorgastor) for more details
• Compute limiting BER based on device ECC
• For 3xnm device data here, 15 bit BCH
  • 4,096 data bits + 195 check bits/sector = 4,291b
  • For random failures (!) compute from binomial
  • $p_{Fail} = \frac{4291}{1e18} = 4.1e^{-15}$
  • $BER_{tgt} = 2.11e^{-4}$ (just invert the binomial)
• You can do this for any ECC
• Convert to a bit error count/MD sample
  • Here, 16x1MB erase blocks (128Mbits)
  • BCH 15: 28,300 error bits
  • BCH 29: 91,268 error bits
  • BCH 60: 146,297 error bits
• Monitor data set cycled to PE 6,000
  • Data collected for 18 days – read 10 times per hour
  • 2x 24 hour gaps with no reads (to measure read disturb)
  • Directly measured the retention limit – here 10 days
The Tests

• 3xnm SSDs
  • Spec 1 year retention @ 5,000 PE @ 60C
  • Raw data shown here as 70C to limit aging
    • Effect is the same, values will change somewhat
  • Device supports monitor data interface

• 2 erase block stripes per MD sample
  • 16 erase blocks/stripe (128Mbits each)
  • 3 samples in the set
  • PE Cycles
    • 3,000, 4,000, 6,000
  • Real time aging up to 20 days
3xnm Data at PE 3,000

- Raw read (no ECC) because some sectors are over the legal limit

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August 2013
Can do a functional fit: \( E = h(Age^k)(Reads^g) + b \)

- Allows projection to different read rates

Limit projected at 50 days without idles
3xnm Data at PE 4,000

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3xnm Data at PE 4,000

- Idles measure read disturb, but require projection
- To user data read rates

Limit projected at 17 days without idles

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3xnm Data at PE 6,000

![Graph showing Bit Errors per Stripe against Data Age (Days) for two sets, Set 1 and Set 2, at PE 6,000.](image)
Curves cross at 6 and 8 days (8 and 9 w/o idle)
The RPE Chart

- Retention vs. PE cycles at reliability limit
  - Combines data from Monitor Data sets
  - Blocks in the “In Spec Zone” should be fine

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**Retention vs. PE Cycles at Reliability Limit**

- **Retention (Days)**
  - 0
  - 50
  - 100
  - 150
  - 200
  - 250
  - 300
  - 350

- **PE Cycles**
  - 0
  - 2,500
  - 5,000
  - 7,500
  - 10,000

**In Spec Zone**

40C Set 1
Combined temperature curves here from lab.

- Likely to see aggregate temperatures in the field.

This device is retention challenged:
- 1 year @ 1,000 cycles
- 1 month @ 3,000 cycles
We can plot the scatter-gram of the user access patterns.

Retention headroom can be measured for each block.
Estimating Variance

- Weakest blocks dominate EOL – can estimate from MD
  - Tracks to the RPE chart – sample size at a given PE increases as sets cycle
  - Can also combine with ECC correction counts from user data
    - Will help the estimate, and to spot outliers
Summary

• Monitor data makes it possible to measure endurance and retention
  • Provide an interpolated end of life measurement
  • Within a device, or at the system level
  • Measuring data age works best with real-time clock
  • System level interface changes:
    • Select set of blocks, direct read (raw)/write/erase
• Integrators can verify devices against specs
  • Parts can be sorted
• Systems and devices can take remedial action
  • Feedback to data management (e.g. refresh policy)
  • Provides estimate of safe power-off duration