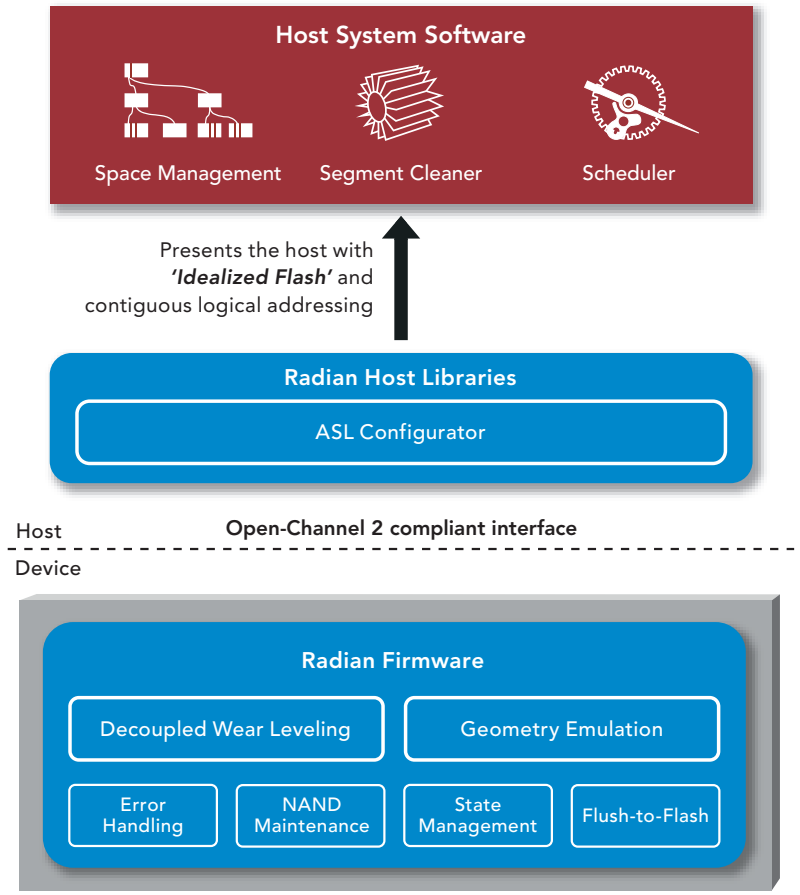
Radian®
MEMORY SYSTEMS

Radian Memory Systems Open-Channel 2 solution

Radian Memory Systems' SSD implementation with an Open-Channel 2* compliant interface



Radian brings some of its innovative Cooperative Flash Management (CFM) technology into its unique SSD implementation that has an Open-Channel 2 compliant interface:

'Idealized Flash'

- Geometry emulation abstracts NAND geometry and vendor-specific attributes
- Maintains alignment to the physical memory array
- Abstracts device's internal management of bad blocks
- Presents *'Idealized Flash'* to the host

ASL Configurator

- Address Space Layout configurator presents hosts with contiguous logical addressing (no gaps) for direct access by modern host software stacks
- Can subdivide NAND memory into iso-boxes that appear like independent block devices
- Optimizes opposing performance and efficiency trade-offs unique to Flash memory

Cooperative and *'Decoupled'* Wear Leveling

- Controller generates wear related metrics and makes them accessible to the host
- Different host-owned, memory controller-owned and shared cooperative modes to offload and simplify host controlled wear leveling
- Enables vendor supported warranties

Cooperative and *'Decoupled'* NAND Maintenance

- Device handles low level NAND maintenance activities for data retention and to prevent disturbs
- Performs these activities cooperatively under deterministic host scheduling to minimize unpredictable latency spikes

*Open-Channel Specification Revision 2.0, January 29, 2018

Several years ago, Radian Memory Systems pioneered a new approach to Flash memory management known as Cooperative Flash Management (CFM). Publicly released in 2015, the company's first CFM product, Symphonic™...

> *"…redistributes functionality and responsibilities between the host system and SSD. Built on the premise of operating in host address space, Symphonic leverages the intelligent segment cleaning and macro scheduling that the host is already performing. This enables the host to control and schedule processes such as garbage collection, but offloads process execution and lower level media management to the SSD."***

Starting with its new RMS-350 SSD, Radian will be offering a configuration that leverages some of its innovative CFM functionality into an implementation that is compliant with the new Open-Channel 2 interface specification. This functionality includes Radian technology such as ***'Idealized Flash'***, the ***ASL Configurator, Cooperative and 'Decoupled' Wear Leveling, Cooperative and 'Decoupled' NAND Maintenance***, and several other specialized Radian features that uniquely enable delivering a data center class SSD product that has an Open-Channel 2 complaint interface.

Geometry Emulation = *'Idealized Flash'*

Radian's geometry emulation virtualizes the topology of the NAND, exporting an emulated version of the device geometry that maintains symmetric alignment through to the physical memory. This technique is based upon hierarchal address virtualization that transparently handles and abstracts various NAND properties and programming requirements, including geometry and vendor-specific attributes.

Bad Block Management
The device firmware performs bad block management, where bad blocks (erase units) are transparently remapped from erase units held in reserve. This swapping of erase units is handled deterministically without impacting the host.

NAND Agnostic with Forward Compatibility
The result is that the device presents the host with an idealized view of the NAND's underlying physical structures, i.e., *'Idealized Flash'*, so from the host's perspective the Flash storage is largely NAND agnostic. And in combination with Radian's ASL Configurator, this functionality can provide Forward Compatibility to help 'future proof' system software from evolutionary changes in NAND geometry to support different NAND devices.

ASL Configurator

Contiguous Addressing
Exposing geometry in Flash to a host can result in gaps or holes in addressing, particularly if Flash resources are not all power-of-two quantities, as is typically the case with TLC NAND. Located in a host library, Radian's Address Space Layout (ASL) configurator mitigates these gaps, in part by converting physical sub-address into virtual sub-addresses.

The ASL Configurator resolves this, and other addressing anomalies and restrictions, to present hosts with easy to use, contiguous, logical block addressing. Radian's RMS-350 implementation leverages the benefits of Radian's ASL Configurator technology while still providing compliance with the Open-Channel 2 interface specification.

Direct Access Model – FTL or No FTL
Radian's solution simplifies building host FTLs, but more importantly, enables direct access to the Flash device by many modern storage software stacks without having to go through any intermediary FTL.

Configurable iso-boxes
Utilizing hierarchical address virtualization, the Radian ASL Configurator can subdivide the SSD's physical NAND memory into groups of structural elements, e.g., combinations of dies, channels, erase units (blocks), pages, etc., to create discrete performance-isolated storage regions, or iso-boxes. In addition to being based upon capacity, these iso-boxes can be configured upon characteristics in terms of endurance and I/O bandwidth, predictable I/O latency, cleaning

ASL Configurator *(continued)*

policies, deterministic scheduling or other combinations of desired metrics via parameterized descriptions. The iso-boxes are then presented to the host as logical block addresses, or namespaces, and thus appear much like independent block devices.

Optimizing Tradeoffs: Erase Segments and Write Stripes

NAND Flash arrays have an inherent tradeoff between performance and efficiency constraints. Configuring erase segments and write stripes to be wide and shallow will increase bandwidth, but will also increase write amplification and collisions that induce latency spikes. Alternatively, configuring erase segments and write stripes to be narrow and deep will reduce write amplification and latency spikes, but will also reduce bandwidth.

Radian's ASL Configurator provides different parameterized profiles that optimize *Address Space Layout*, and hence these two opposing objectives, to obtain the configuration that best matches the application requirements. Isolated storage regions (iso-boxes) of variable sizes can be configured within a Radian SSD, and each iso-box can be configured with a different ASL profile.

Preserves host data layout

Radian's hierarchical address virtualization, used in the Geometry Emulation and ASL Configurator, ensures that the host's data placement is preserved through to the media within the physical bounds of the SSD's iso-boxes.

Cooperative and *'Decoupled'* Wear Leveling

Radian's Cooperative Wear Leveling engine supports a variety of modes involving host-owned, memory controller-owned, or shared wear leveling configurations, enabling hosts to take on varying degrees of responsibility. The Radian wear leveling engine has command logic to track wear as part of metadata, along with a range of variables accounting for factors such as program/erase cycles, and to provide this information to the host.

This approach enables the host to directly assume scheduling of many flash management functions that might otherwise interfere with (i.e., compete with) host-directed writes, such as garbage collection, data relocation, and so forth. Because the host, or a host FTL, is in control of garbage collection and likely to be log structured, writes will inherently tend to level wear in flash memory. If over time, certain units of memory are determined to represent disproportionately high or low wear relative to overall memory, wear leveling can then be performed.

The Radian memory controller maintains information for each erase unit which tracks memory usage and data based on that stored information which is made accessible to the host. A number of measures can be used, such as a detection of a difference in EU wear for a given memory range exceeding a predetermined threshold.

Alternatively, a statistical measure can also be used (e.g., statistical variance) to inherently apply a weighted measure across the entire memory range. A threshold can be defined as a default by the flash memory controller and/or can be dynamically programmed by the host (e.g., by asynchronous command). Wear leveling processes can be executed when an associated management condition is triggered when a specific, tracked parameter exceeds the predefined threshold.

Cooperative and *'Decoupled'* Wear Leveling *(continued)*

In certain modes, when the condition occurs, the memory controller immediately alerts the host, typically providing information that triggered the alert. When the host receives alerts, it can issue queries as necessary to the memory controller, such as to what units are most suitable for allocation based on wear considerations. The host can also monitor data to detect the occurrence of one or more threshold conditions relative to wear.

***'Decoupled'* Wear Leveling mode**

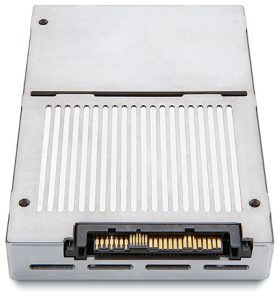
In conventional Flash Translation Layers (FTLs), the wear leveling process is often integrated with garbage collection processes and algorithms. Radian's *'Decoupled'* Wear Leveling mode is an optional mode of Radian's cooperative, memory controller-owned configuration that is driven by Radian's device firmware, and while it operates cooperatively and in a coherently aligned manner with host driven data movement and scheduling, it is effectively decoupled from the host's garbage collection algorithm.

Cooperative and *'Decoupled'* NAND Maintenance

Radian's Cooperative and *'Decoupled'* NAND Maintenance firmware provides modes with varying degrees of host involvement. Because the SSD is in a superior position to manage NAND programming constraints, media properties and error handling. Radian firmware provides data scrubbing for background data integrity checks based on EDC or additional data integrity metadata. The Radian firmware also performs these functions along with offloading metadata generation and process execution.

By gathering statistics needed to manage flash maintenance operations, the memory controller will notify the host when maintenance is required. This type of cooperation enables the host to directly assume *scheduling* of many flash management functions that might otherwise interfere with (i.e., compete with) host-directed writes, such as garbage collection, data relocation, and so forth.

The Radian memory controller also tracks the need for maintenance operations independently for each iso-box. As the host receives information for maintenance operations in respective iso-boxes, the host can issue commands selectively in a manner so as to independently schedule these operations for the respective iso-boxes, where performance of the maintenance operations by the Radian memory controller in one iso-box is unconstrained by performance or maintenance operations occurring in another iso-box.



RMS-350
Dual or Single Port U.2 NVMe SSD
Up to 12GB User NV-RAM
Up to 12TB Flash

*Open-Channel Specification Revision 2.0, January 29, 2018

**Symphonic Product Brochure and Data Sheet – Published/Copyright August 2015

www.radianmemory.com/patents

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