Providing Battery-Free, FPGA-Based RAID Cache Solutions

WP-01141-1.0 White Paper

RAID adapter cards are critical data-center subsystem components that ensure data storage and recovery during power outages. Current battery-backed designs create green issues around hazardous waste disposal as well as shelf life and maintenance issues. Recent advances in FPGA and flash-memory technologies support lower power memory backup designs that are powered by batteries or "green" ultra capacitors. This white paper provides an overview of the supporting component technologies that can support such an environmentally-friendly data recovery solution.

Introduction

Increased data processing and storage demands are challenging traditional ways of maintaining data integrity in data centers. Increasing performance demands from applications in enterprise finance and Web 2.0 coupled with green environmental requirements are causing data-center designers to look for more cost-effective, alternative approaches to today's battery-backed data recovery systems.

RAID adapter cards, a critical component of data-center servers and storage complexes, traditionally rely on battery-charged recovery circuitry to preserve the integrity of data during server power outages. Burdened by hazardous disposal and total cost of ownership (TCO) issues like field maintenance, system designers are looking for battery-free RAID adapter solutions that are more power efficient without impacting performance and data-integrity specifications.

A battery-free RAID adapter design approach for protecting and restoring data during such power conditions is discussed in this white paper. Advancements in FPGA, flash memory, and capacitor technologies have enabled a lower power, nonvolatile memory backup solution that supports a battery-free environment and the benefits thereof. This white paper provides an overview of the supporting component technologies that can support such an environmentally-friendly data recovery solution.

Green Trends for Enterprise Data Centers

Increasing data-center performance demands under constrained power budgets are creating management issues in power management, system cooling costs, and preservation of data integrity. These factors further contribute to the TCO of running these data centers. In addition, regulatory agencies are mandating green standards that stipulate data-center power reductions and strict rules for battery materials disposal.

101 Innovation Drive
San Jose, CA 95134
www.altera.com

Power outages across server farms can result in data loss or even worse, undetected error conditions within the host application. To remedy these problems, companies have developed RAID adapter cards that provide a data recovery mechanism during such power outages. The issue with current RAID adapter products is that they are powered by batteries. Table 1 addresses many of the constraints associated with battery backup systems.

Table 1. Power Constraints Associated with Battery-Backup Systems

Battery Limitations	Issue
Shelf life	One year maximum or 500 cycles
Disposal and handling	Hazardous waste management
Data storage capacity	Up to 72 hours
Down time	Charge time of up to 6 hours
Replacement cost	Field time and materials
Environmental specifications	>90 days, ambient temperature <30°C

To address the these battery limitations, RAID adapter card designers have been investigating green technologies like ultra capacitors and how to develop RAID adapter designs that accommodate them. Ultra capacitors have many green advantages, including:

- Compact size
- Can be charged and discharged rapidly an almost unlimited number of times, and therefore do not require the cost and maintenance in replacing like batteries
- Do not contain hazardous substances that can contaminate the environment, unlike batteries

To support this green power technology, more power-efficient RAID adapter component technology is required, specifically with the FPGA circuit controller and flash memory.

Convergence of Technologies

The challenges for developing a more power-efficient data recovery design lies within the principal circuit components, namely FPGAs, such as Altera® Cyclone® III devices, for circuit management, data control, and the flash memory for data storage and retrieval upon power recovery. Each of these components must support a power budget specified by the data recovery and restore circuit of the RAID adapter card.

Determining the FPGA and flash memory specifications is a function of the DRAM density that is backed up during a power outage (e.g., 2 to 8 GB) and the time available to store this data into flash memory, where the time constraint is driven by the available energy from either a battery or alternate green energy source like ultra capacitors.

With lithium-ion battery-backed designs, data can be stored over a period of 48 to 72 hours. This approach requires field resource maintenance to address the power outage within this timeframe without losing the data that was stored in flash memory by the battery-backed RAID adapter backup circuit. Furthermore, battery disposal must be factored into the cost of supporting this type of design.

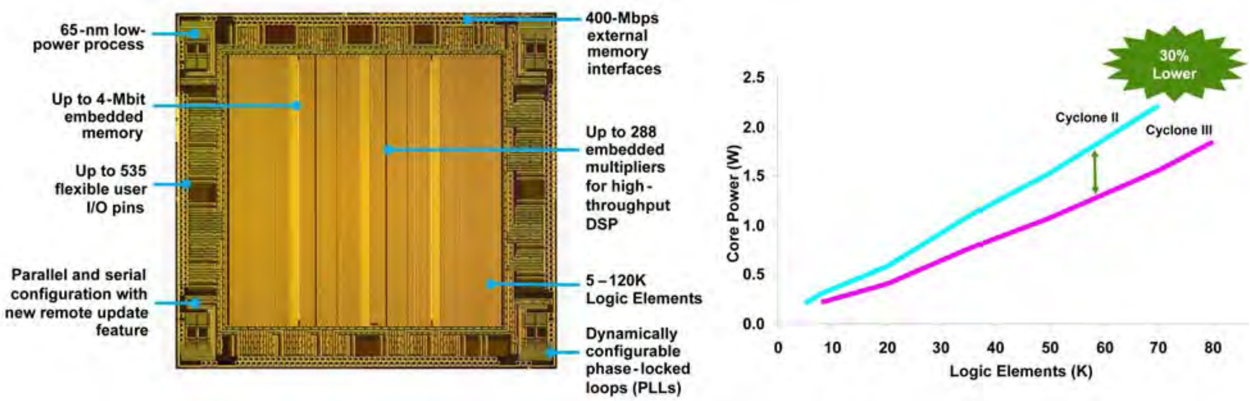
Power efficiency and performance advancements in FPGA and flash-memory technology now make it possible to develop effective data recovery circuits in RAID adapter cards that can be charged from alternative charging sources like ultra capacitors.

FPGA Technology

The process technology used in Altera FPGAs has moved downward from the 65-nm node to the 40-nm node. Sharing the cusp of the technology curve with standard cell ASICs and full-custom designs in microprocessor and associated chipsets, FPGAs are now being used in volume-production computer and storage applications like high-performance computing (HPC), I/O virtualization, high-speed serial interface bridging, and memory backup/restore functions.

In addition, the latest advancements in FPGA architecture design (Figure 1) and supporting power simulation tools have allowed increasing FPGA logic densities to be offered without the penalty of increased power consumption.

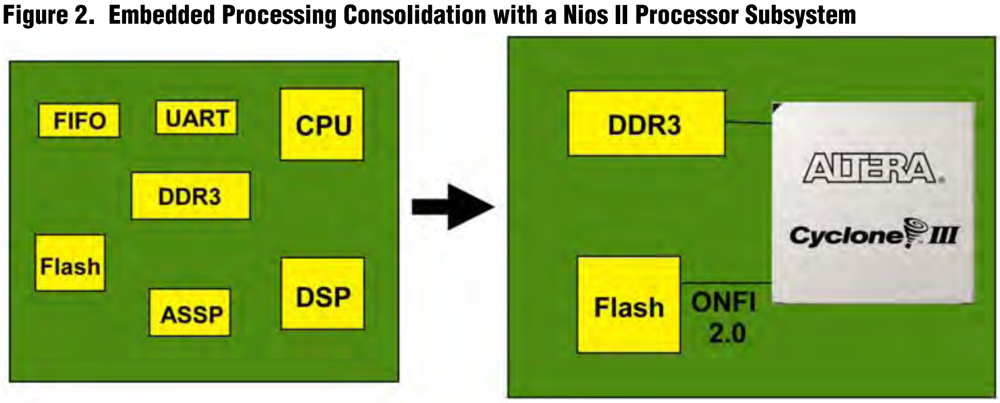
Figure 1. FPGA Architecture of the Cyclone III and Its Low-Power Attributes



Embedded processing, once limited to ASIC implementations, is now available as an option in production FPGAs. As an example, Altera offers the Nios® II configurable processor core that supports up to 340 DMIPS with a single instantiation. The power saving benefit of a soft core processor over external microprocessors and microcontrollers further contributes to a more power-efficient data-recovery circuit.

In a RAID adapter memory backup circuit (Figure 2), the Nios II embedded processor controls the operating state of the DIMM and data movement between the DRAM blocks and flash memory.

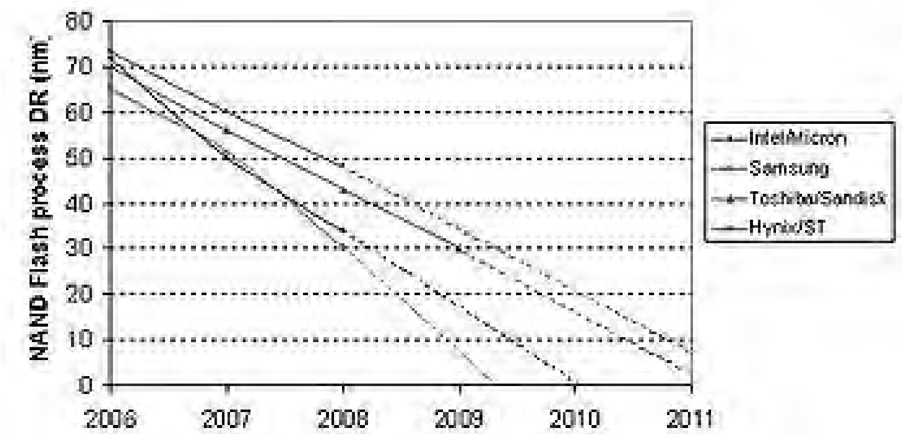
Figure 2. Embedded Processing Consolidation with a Nios II Processor Subsystem



Flash Memory

Flash memory technology has accelerated past Moore's Law by greater than doubling the density/performance every 18 months. Exponential demand for increased flash memory capacity driven by new consumer all-in-one phones is expected to move flash technology to the 20-nm node by late 2010 (Figure 3). NAND flash provides read/write characteristics similar to hard disk drive sectors with lower power, lower cost ($/GB), and environmental robustness.

Figure 3. Process Technology Node Projections for Flash Memory



Source: Wikipedia "Flash Memory", GNU Free Documentation License

Furthermore, the ONFI 2.0 FLASH interface, supporting bandwidths up to 200 MB/s, provides an impressive step in data link speeds, thereby enabling RAID adapter memory recovery for DRAM capacities up to 8 GB using ultra capacitor charging circuitry.

These advances in flash memory technology directly support the need of a RAID adapter recovery circuit that protects increasing DRAM densities while supporting minimal power requirements, thus enabling alternate green energy sources like ultra capacitors.

Charging Circuit Options

Many current RAID adapter products are powered by batteries, but the industry is moving towards the more environmentally friendly ultra capacitors.

Batteries

Lithium-ion batteries are the predominant charging source for today's memory backup products. The single advantage of continuing to use batteries for RAID adapter cards is the maturity and wide adaptation of this technology mitigates reliability concerns using newer, alternative technologies like ultra capacitors.

However, the disadvantages are significant. Companies do not want to incur the overhead costs with hazardous-waste battery disposal, nor do they want to staff field teams to address server data recovery prior to the energy depletion from the battery.

Ultra Capacitors

Ultra capacitors, also known as electric double-layer capacitors, were once only applicable to industrial applications with short-burst energy requirements like engine control and turbine generators. However, recent technology advances have supported smaller form factors and densities enabling higher volume applications like RAID adapter cards.

In the past, a one Farad capacitor would be a housed in a formidable container certainly not suited for space-constrained environments like RAID adapters. Today's ultra capacitors (Figure 4) can supply sufficient short-term energy bursts in smaller packages.

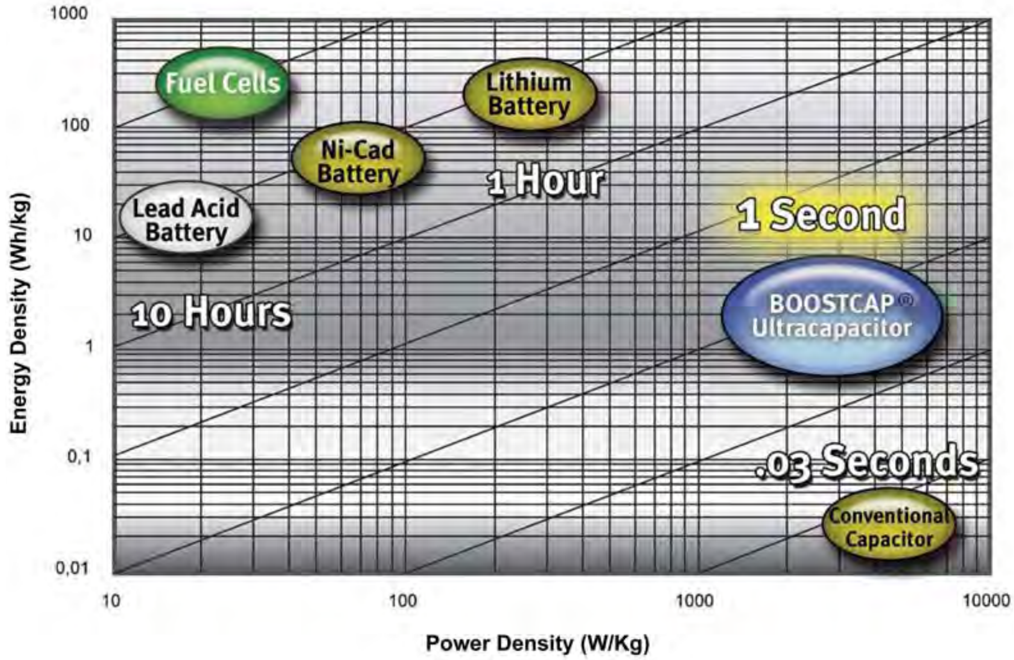
Figure 4. Ultra Capacitors

Source: Courtesy of Maxwell Technologies

Ultra capacitors are environmentally friendly. They consist mainly of carbon and aluminium and contain no heavy metals. There are no hazardous disposal issues associated with ultra capacitors as with batteries. Ultra capacitors also have a longer shelf life. This is important to RAID adapter applications where power outages may be infrequent. In addition, ultra capacitor recharging can be done in approximately 20% less time.

The Ragone Chart illustrated in Figure 5 shows the suitability of ultra capacitors for applications that require quick delivery of their rated energy density. There are trade-offs, using traditional lithium-ion batteries for is best for higher energy density requirements while capacitors offer lower energy densities, but compensate with higher power density attributes. Ultra capacitors offer a compromise between these two technologies with an increased energy density over conventional capacitors, while still delivering greater power densities than lithium-ion batteries.

Figure 5. Ragone Chart Comparing Battery and Ultra Capacitor Technologies



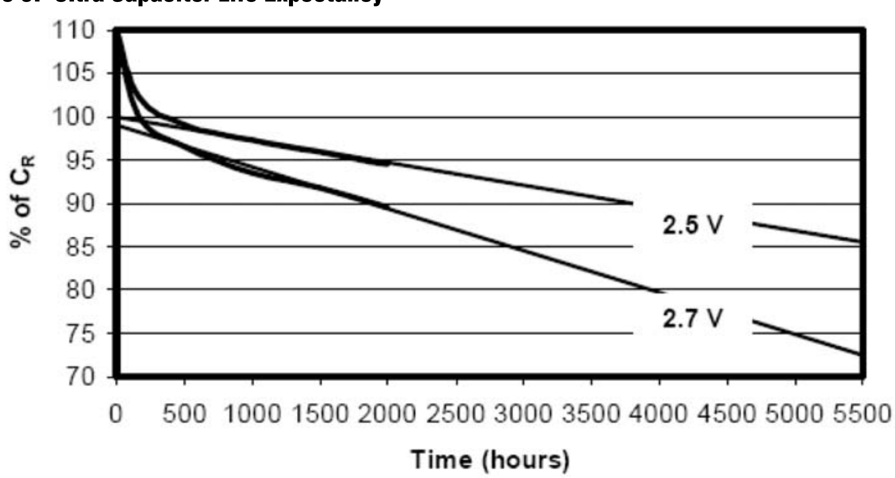
RAID adapter card specifications require short bursts of energy to provide sufficient power density for backing up data during power-down conditions. Capacitor technology supports these energy requirements through the physical law of

$$\text{Energy (Joules)} = \frac{1}{2} \times \text{Capacitance} \times \text{Voltage}^2$$

Ultra capacitors suppliers (i.e., Maxwell Technologies) can support power densities greater than 1 kW/Kg in compact packages.

There are some concerns that RAID adapter card designers should be aware of when employing ultra capacitors. Life expectancy will degrade as a function of voltage and temperature. Figure 6 shows how capacitor life expectancy is reduced by 50% for each 10°C rise in temperature. Therefore, it is prudent to remove the ultra capacitor module from any intense source of heat, such as a microprocessor and supporting power circuitry.

Figure 6. Ultra Capacitor Life Expectancy

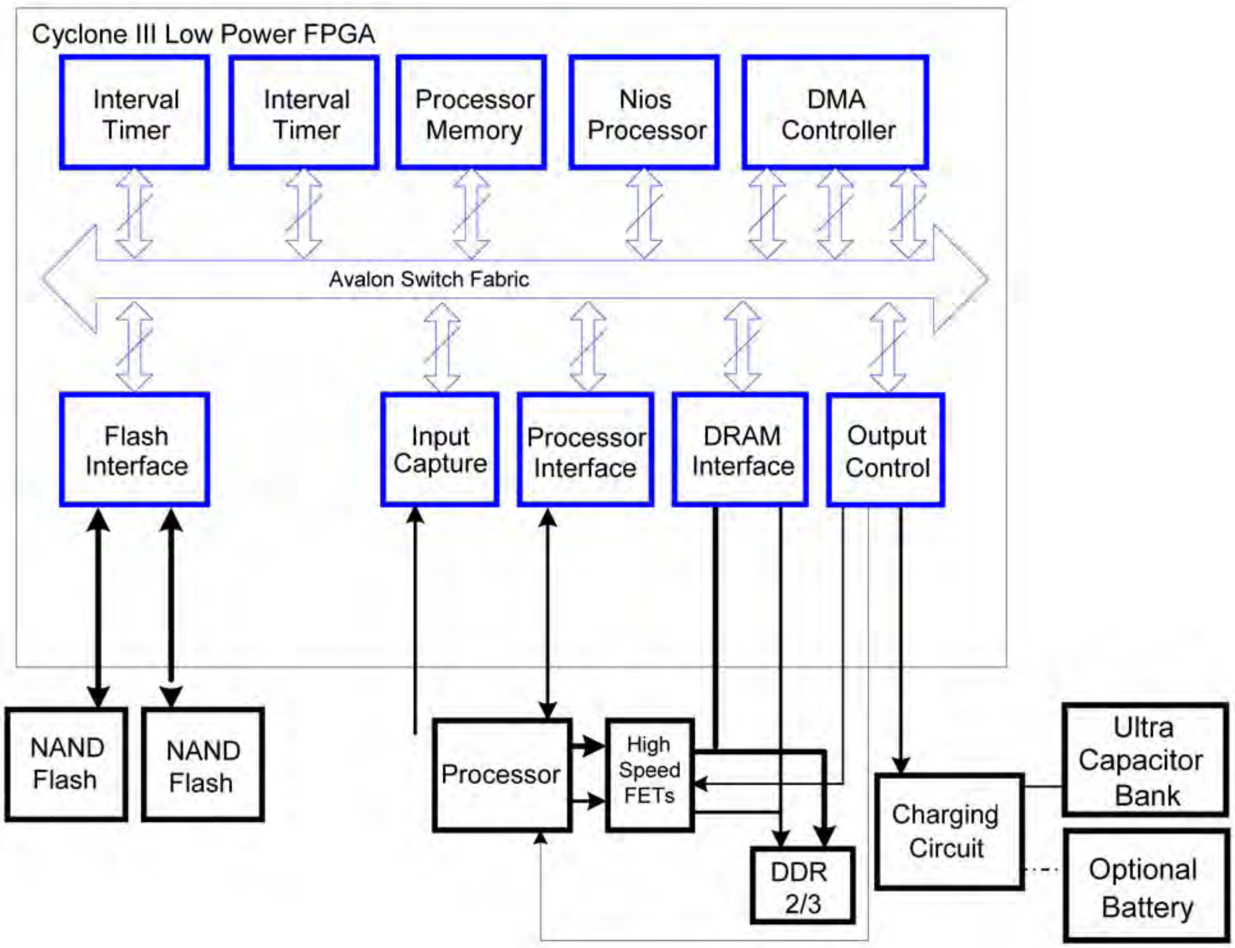


Source: Courtesy of Maxwell Technologies

Green Memory Backup Solution Example

As described in the previous section, power efficiency improvements in FPGA, flash memory, and ultra capacitor technologies have enabled a more power-efficient design compared to present day battery-backed products. Figure 7 illustrates an example RAID adapter memory backup circuit. During a power outage, the microprocessor will send a power-down signal to a low-power Cyclone III FPGA that initiates and manages the recovery circuitry. The FPGA functions as a management controller with an advanced embedded processor, a custom DDR3 controller with custom ONFI host interface, and an I^2C bus.

Figure 7. RAID Adapter Memory Recovery Design



The primary benefits of the FPGA are derived from a higher performance, lower power architecture versus external processor-based designs. The power savings benefit is achieved through a variety of techniques that are commonly used to reduce device power, including multiple device threshold voltages and variable channel lengths in the gates that allow slower circuits to consume less power. Banks of nonvolatile flash memory perform the data storage function to recover the DRAM array data during a power outage. Table 2 describes the functions and benefits of the primary components in this design

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Table 2. Primary Components of Memory Backup Design

Component/Circuit	Function	Benefit
Cyclone III FPGA	Circuit management and control	Low power (40 nm), DDR3 memory, and ONFI flash control
High-speed switching FETs	DDR3 switch signaling	Switching with noise suppression
ONFI NAND flash	Memory cache	2-8GB, matches DRAM density
DDR3 DRAM	Memory source	2-8GB
Charging circuit	Low power, green energy supply	Ultra capacitor bank with optional battery supply
Processor	Power good signal	Circuit toggle

Conclusion

RAID adapter cards are critical data-center subsystem components that ensure data storage and recovery during power outages. Current battery-backed designs create green issues around hazardous waste disposal as well as shelf life and maintenance issues. Recent advances in FPGA and flash-memory technologies support lower power memory backup designs that are powered by batteries or ultra capacitors. Ultra capacitors provide an environmentally friendly alternative to battery usage, which is an advantage for data-center designers that are being challenged to find lower power, green alternatives without sacrificing data integrity and performance.

Further Information

- Computer and Storage:
  www.altera.com/end-markets/computer-storage/cmp-index.html
- Maxwell Technologies:
  www.maxwell.com
- "Flash memory"
  http://en.wikipedia.org/wiki/Flash_memory

Acknowledgements

- David McIntyre, Senior Business Unit Manager, Computer and Storage Business Unit, Altera Corporation

Document Revision History

Table 3 shows the revision history for this document.

Table 3. Document Revision History

Date	Version	Changes
July 2010	1.0	Initial release.