Technologies For Optimized Power Management

White Paper

OVERVIEW

With each new generation of portable devices, consumers expect to be able to go longer between charging sessions. However, demands for new features such as enhanced multimedia capability or high-resolution color graphics require more power than ever. To keep product form factors from growing in size due to larger batteries, engineers are constantly challenged to squeeze more efficiency into battery-powered systems and drive further miniaturization through aggressive integration designs.

Freescale's approach to power management is comprehensive and scalable, with hardware- and software-based solutions including power management integrated circuits (ICs), Smart Speed™ and eXtreme Energy Conservation™ (XEC). These tiered solutions target the most cost-sensitive market segments from high-end, smart, multimedia-rich communication and personal assistant devices to low-end, voice-only phones. Our goal is to cover system needs at either end of the feature spectrum and all points in between with integrated solutions—from the "undoubtedly impressive" to the "ultimately practical."

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The Case for Power Management

From fuel-cell cars to MP3 players, energy conservation is growing more important for many machines that we use every day. Exceptional power management is especially important in portable electronic devices such as cell phones and digital cameras. No one wants their phone to run out of power during an important call, or to haul packs of extra camera batteries around on a vacation trip. As electronic devices become more sophisticated and feature-rich, their applications demand more power and their hardware takes up more space. At the same time, consumers are demanding smaller, sleeker and cooler designs.

Power management is one of the top technical issues that manufacturers and designers face. Consumers want devices that are smaller and smaller yet do more and more, which poses a technical challenge. Each new feature that you add to an electronic device will consume more power. Yet consumers don't want a bulky battery adding size and weight to their slim gadgets, and designers don't want to cut back on features to accommodate a big battery.

The solution is to work smarter, not harder. Freescale Semiconductor uses intelligent software and hardware to maximize power while minimizing battery drain. Because it is possible to realize the same performance with a smaller battery, designers literally have more room to innovate. We understand power management and the infinite variety of portable applications. With a strong focus on advanced integrated power management, our products can help simplify and speed design and enable rich and versatile features important in today's wireless devices. We never forget the bottom line: long battery life, a tiny footprint and cost-effectiveness for big value.

We have engineered several power-saving technologies and platforms, including:

- **Power management integrated circuits**: Freescale's power management and user interface (PMUI) ICs provide coordinated power sequencing, low-consumption standby modes and seamless power switching in smart mobile entertainment devices. These highly integrated ICs allow OEMs to replace up to seven separate ICs with one powerful power management system. This saves both money and valuable space that can then be used to support applications.

- **Smart Speed™ technology**: In Freescale's family of i.MX multimedia applications processors, the Smart Speed Switch brings true parallelism to the system, resulting in more effective data per CPU cycle. This means that a Freescale processor can provide performance that is equal to or better than a processor that has a higher clock speed. In an average processor, higher clock speed means greater battery drain—so being able to provide the same performance at lower clock speeds is a power advantage.

- **eXtreme Energy Conservation (XEC) software**: Freescale's XEC technology is a comprehensive ready-to-use energy saving solution. It has the system intelligence and connections to exploit on-chip power-saving features effectively, designed for applications and devices that require an additional level of power management technology. XEC is optimized for Freescale's wireless platforms and is delivered as part of the customized operating system software provided with a chipset's OS board support package. Because XEC will run on many of these platforms and is designed to take advantage of each chipset's particular features, energy savings will vary by use case.

Power Management ICs

In our electrically driven world, we are all trying to get more work done using less power, either to save battery life or just to cut electricity bills. Freescale has more than 20 years of experience developing sophisticated power management integrated circuits that do just that—and more. Our power management ICs provide the means to create more power-efficient applications, and their integrated functionality enables more flexible and economical designs.

Today's cellular and portable consumer electronics are feature-rich and offer enhanced performance over previous generations. Smart power devices are the system foundation to meet demands for longer battery life and operation. Freescale's heritage and leadership in power management solutions extends back to the earliest days of wireless products. Our highly integrated power management ICs provide coordinated power sequencing, low consumption standby modes and seamless power switching. The higher integration levels enabled by Freescale's SMARTMOS™ technology bring extended functional content to include a host of convenience features and user interface capabilities.

Modern power management designs require more sophistication than traditional supply conditioning and distribution. For example, powering off unused functions except when they are needed is critical to stretch battery life in portable products.

Coordinated wake-up sequences can further optimize battery lifetime, compared to turning components on all at once, by controlling the associated current surges as various circuits are fired up. Dynamic voltage scaling, in conjunction with other advanced power-saving techniques such as frequency scaling and power gating, is becoming increasingly important in advanced systems.

Freescale's power management chipset portfolio includes:

- **MC13783** power management and audio component for GSM, GPRS, EDGE, UMTS and non-cellular devices

- **MC13890** power management and audio component for GSM, GPRS, EDGE, CDMA and non-cellular devices

- **MC13883** integrated charger, USB On-the-Go transceiver and carkit interface

- **MC13790** power management component for 2G/2.5G power supply and battery management

On-Chip Power Management

Low-dropout (LDO) regulators with integrated pass field-effect transistors (FETs), high-efficiency switching regulators and Lithium-Ion (Li Ion) battery chargers are at the heart of the power management core. Integrating discrete functions such as regulators not only improves board area and reduces system cost, but also allows coordinated control by a logic core with a direct link to the system processor and software. Leading-edge power management and user interface (PMUI) ICs may also include a host of additional functions such as full-featured audio paths with analog, digital and power audio interfaces; touch screen support; coin cell backup supply switching and charging; backlight and fun light LED drivers; and a USB transceiver. Highly integrated PMUI ICs enable ease of design for engineers and manufacturers with minimal development effort, and allow consumers to enjoy feature-rich portable handheld products.

An example of next-generation PMUI functions is targeted to support the emerging USB carkit interface. The CEA-936-A carkit standard is driving new capabilities for battery charging, data communications and audio routing through a standard mini-USB connector. Suitably equipped products will allow users to charge their batteries directly from a PC or car stereo through a USB cable or plug-in cradle. Hands-free phone calls or stereo playback can be directly interfaced to a carkit-capable stereo. The MC13783 is a power management, user interface and audio component for GSM, GPRS, EDGE, UMTS, mobile

gaming devices and personal media players. It is ideally suited for Freescale's i.MX31 multimedia applications processor and is included in the i.MX31 application development system.

The Right Design Approach
To successfully design a portable product, power management should be one of the very first design considerations. This helps to ensure a strong foundation of power-efficient hardware and software for the best battery life. The system complexities can be considerably reduced by using a highly integrated PMUI IC that bundles one or more processor interfaces for access and control of the various blocks.

Cost and area optimizations can also be achieved with highly integrated PMUI devices, incorporating the aforementioned functional blocks into a single IC, and can eliminate discrete devices or low-integration ICs, saving both board space and electronic bill of materials. This also simplifies the procurement process by reducing the number of vendors spread across a given product, and can improve yield through part count reduction.

Smart power devices will continue to drive advances in power efficiency and enable new interface capabilities in portable products. Intelligent and comprehensive power management designs are essential in maintaining or extending battery lifetime as new features are added and product performances are enhanced.

SMARTMOS™ Manufacturing Technology
Freescale power management ICs are manufactured using our proprietary SMARTMOS™ technology. This hybrid process enables high-density integration of analog/mixed-signal, highly efficient power MOSFETs and complex digital circuitry on a single die. Since its introduction almost two decades ago, SMARTMOS technology has undergone continual development to improve its capabilities.

SMARTMOS technology allows Freescale's power management IC solutions to incorporate load protection, high-power efficiency and multiple outputs—even as die sizes shrink—without eroding overall device performance. Our power management portfolio of linear regulators, switching regulators and hot swap controllers can be integrated with other components to help developers create more efficient products with extended battery life, increased flexibility in design and reduced board space.

Applications Processors With Smart Speed™

Engineered for use in smartphones, portable media players, mobile gaming consoles, ultra-portable computers, wireless PDAs and many other handheld wireless applications, Freescale's i.MX family of applications processors is a leading solution. Based on ARM® core technology, the i.MX family of applications processors delivers power performance that is crucial in today's multimedia devices while simultaneously conserving demands on the battery.

Freescale's i.MX31 and i.MX31L multimedia applications processors are built using Smart Speed technology—with some powerful enhancements. Our dynamic process temperature compensation (DPTC) mechanism measures reference circuits' delays dependent on the process speed and temperature. The DPTC then lowers the voltage to the minimum level needed to support the current operating frequency. Automatic dynamic voltage frequency scaling (DVFS) allows on-the-fly frequency adjustment according to the current performance requirements of the system. The automatic DVFS hardware mechanism monitors the processor load and controls the supply voltage and the frequency with minimal software and operating system involvement. By lowering the frequency it is possible to lower the operating voltage (on-the-fly as well), dramatically reducing power consumption.

A New Way to Measure Speed and Power

Microprocessors have long been classified, rated, differentiated and marketed based on their clock speed, measured in kilohertz, megahertz, and now even in gigahertz. In the age of the wired device, cranking up the clock speed—and therefore the power consumption—was a perfectly acceptable way to increase processor performance, because a computer can get all the power it needs from a standard wall outlet. However, in the new age of mobile devices where the need shifts to power consumption, clock speed is no longer an adequate way to measure processor power.

Effective cycles per instruction (eCPI)[1] is a different and more relevant way to benchmark processor performance for mobile devices. Freescale uses eCPI to measure the performance of the i.MX31 and i.MX31L applications processors. Our Smart Speed technology, measured using eCPI, makes it possible for the efficient 532 MHz i.MX31 applications processors to take advantage of parallelism to operate at the equivalent performance of a 3 GHz processor—yet minimize power consumption.

The lower the eCPI, the more efficient the processor is at performing the application—and this saves on the system's battery. In an architecture with a general-purpose processor where the clock speed is increased, the eCPI will generally be in the range of 1.4 to 1.7. In a second architecture that adds general-purpose execution units (GEUs) such as CISC, RISC or DSP processors to retrieve instructions and data from memory, the eCPI measurement improves to around 1. The best measurement of eCPI, below 1, comes from an architecture that uses specialized execution units (SEUs) to run tasks more efficiently. SEUs need few or no instructions transferred from memory, use memory more efficiently, and therefore use less power than GEUs. This means, for example, that when you compare a general-purpose architecture with an eCPI of 1.5 with an architecture that uses SEUs and has an eCPI of 0.25, it may be possible that the SEU-based architecture will only need 1/6th of the MHz rating for the two processors to operate at equal speeds.

Engineered for Efficiency

Freescale's i.MX31 and i.MXL applications processors use the following techniques to save power:

- **Dynamic process temperature compensation (DPTC)** dynamically adjusts the supply voltage relative to the current temperature and the manufacturing process used.

- **Dynamic voltage frequency scaling (DVFS)** reduces operating voltage to the minimum level needed to support only the minimum operating frequency required by applications at any given moment. The i.MX31 and i.MX31L bring the concept to new heights by introducing an automatic hardware mechanism for DFVS control that requires minimum CPU resources and software complexity in the operating system and drivers.

- **Three separate power domains**—the ARM CPU, peripherals, and the phase-lock loops (PLLs)—provide the ability to save power in one domain while the others remain functional.

- **Power gating** provides the ability to shut down the entire IC (hibernate) or only the most power-hungry ARM® platform power domain in standby mode. Independent low-power modes for different power domains include the following modes:

  - Stop: Clocks off

  - Doze: Turn off the clocks/PLL

  - Hibernate: Power down

  - State retention: Retain ultra-low voltage

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[1] "Use effective cycles/instruction as a true CPU benchmark" by Mike Olivares and Brian Beasley, *Portable Design*, May 2005

- **Active well biasing** reduces standby leakage by up to 15 times by lowering the well voltage of the transistor. Standby leakage is a great concern in sub-micron manufacturing processes' IC designs in the semiconductor industry.

- **Careful and power-friendly IC design** with three levels of clock hierarchy, enabling shutting down clocks to the parts of logic that are not used by the running application.

- **Technology choice** for optimum trade-offs between speed and low-power, high-performance, yet with leaky transistors (low voltage threshold) versus ultra-low power semiconductor circuits (high voltage threshold) for functional modules with modest performance requirements.

Freescale's MC13783 power management and audio component is the optimized companion IC to support the power-saving functions of the i.MX31 and i.MXL.

eXtreme Energy Conservation

Gradual improvements in battery technology have not kept pace with the power consumption demands of the latest handheld electronic devices. Next-generation rich multimedia mobile phones that use the high-bandwidth 3G cellular radio network consume more power than ever. Hardware designers are using advanced power-saving techniques to help minimize IC and system power consumption. Yet these techniques will not yield significant power savings without intelligent energy conservation software to exploit them effectively.

Freescale's eXtreme Energy Conservation (XEC) software is a multi-phase, multi-generational project to develop advanced power-saving software technology for Freescale wireless mobile platforms. Based on advanced runtime performance algorithms, XEC uses a standardized software framework that supports multiple concurrent predictors, policies, power cost rules, etc. It runs as system software with commercial operating systems. The XEC solution targets more potential areas for energy savings—such as IC-specific low-power modes and LCD panel hardware—so it can provide potentially better energy savings than competitor solutions.

XEC is transparent to application programs and middleware, unless that software is optimized as a "power aware" application; in that case, the application could communicate its power needs to XEC. Using advanced techniques, XEC dynamically discovers each piece of software's required performance, sets hardware power management features (DVFS, multiple low-power idle modes, etc.) for just-enough performance and minimal power waste, and achieves much more energy savings than traditional techniques. Adapting leading-edge university research, XEC has performance predictors, real-time cost-benefit analyzers, policies and a policy manager and many other advanced algorithms.

Manufacturer Benefits

Power reduction is an increasingly important consideration for wireless device manufacturers. Consumers are demanding more and more features in ever-slimmer devices. Putting more integrated circuits and applications into these shrinking devices increases manufacturers' costs. Because XEC helps reduce power consumption, manufacturers can use smaller batteries to get the same power, and this helps reduce costs. Design effort can also become faster and simpler, because designers don't have to engineer so aggressively for reduced power consumption—XEC is an out-of-the-box solution that is designed to help with that complex step. Designers also don't need to modify applications to run with XEC, because XEC is designed to work with the operating system to manage the performance needs of those programs.

The XEC production software will be provided with those operating systems supported by Freescale for its wireless chipsets including Symbian™, Linux® and Microsoft® CE. In general, XEC is transparent to the product end user, except for the XEC Policy Manager which manufacturers can optionally use to expose policies to end users for limited high-level control of power settings. Manufacturers can also

customize software modules within XEC or tune factory-set systems parameters for optimal performance in their environments.

System Approach to Power Management

Superior energy conservation requires a systematic solution to advanced power management. Freescale is involved in many approaches to power management, including:

- Advanced silicon processes

- Design methodologies

- Power-optimized IC features

- Power-optimizing software tools

- Power-aware application programs

- Power-optimized software

- Intelligent runtime software

For our power-managed platforms, Freescale is taking an architectural approach, and is creating a generic software/hardware XEC framework with APIs and hardware interfaces. Its purpose is to help maximize the portability of XEC technology across SPS platforms and support scalability across customers' product tiers.

Prediction-based software control of power-saving techniques is an immature technology and is just starting to emerge within the mobile wireless industry. As yet there are no existing, widely accepted power management standards among mobile device manufacturers, operating system vendors, semiconductor companies and others. Freescale wants to work with industry players and standards bodies to help create open standards in this area—standards that help drive down costs but yet are flexible enough to allow individuals to differentiate.

XEC Framework

The XEC framework isolates the algorithmic components known as performance predictors from the details of the specific platform OS and hardware. It contains platform-specific mechanisms for controlling and monitoring hardware power-saving technologies such as DVFS. It also provides common API interfaces for power-aware application programs and replaceable XEC modules like the performance predictors.

Because performance predictors may operate concurrently, a predictor arbiter arbitrates between multiple predictors to resolve which of their performance-power recommendations to select at any given time. The arbiter is programmable, so that the priority of any one performance predictor may be changed during normal operation depending on the runtime circumstances. Another framework component called the policy manager, acting as an agent for the product user, dynamically selects a policy (from a group of policies) that sets the criteria for trading off performance, power and energy in general or for specific situations or programs.

The XEC framework uses platform-specific power-cost rules to determine when and if to transition a particular hardware module from its current power state. Finally, the framework has an OS adaptation layer containing OS-specific code. Its purpose is to minimize the porting effort and configuration management problems for migrating the XEC software between the operating systems on which it runs.

Multi-Generational XEC for Multiple Platforms

Energy conservation technology is not a one-time solution. For the foreseeable future, the energy demands of new and exciting software programs on mobile devices could outstrip the capability of battery technology to match those demands in a small and lightweight form. To meet user expectation of battery recharge cycle times, system designers must continue to find innovative ways of reducing power waste while meeting instantaneous performance needs. Freescale's XEC technology is architected to be extensible for future enhanced generations and easily deployable across multiple hardware platforms and operating system software.

As the capabilities of mobile devices such as 3G handsets continue to expand, developers encounter more challenges with product size and battery life. Freescale's power management portfolio addresses both issues with unmatched levels of integration and power control. We're enabling OEMs to push the envelope of product sophistication, form factor and function.

eXtreme Energy Conservation: Advanced Power-Saving Software for Wireless Devices

Freescale Semiconductor