White Paper

Freescale Energy-Efficient Solutions: Enabling a New Generation of Applications

Abstract

As a recognized leader in embedded energy-efficient solutions, Freescale technologies are enabling a new generation of applications that deliver on demand for increased performance and functionality on ever-smaller power budgets. Based on decades of experience across a broad landscape of applications, Freescale understands unique customer needs for energy efficiency and optimizes solutions accordingly.

The Freescale Energy-Efficient Solutions program and mark highlight Freescale products that excel in effective implementation of energy-efficient technologies or deliver market-leading performance in the application spaces they are designed to address. Freescale's energy-efficient product solutions include microcontrollers, processors, sensors, digital-signal controllers and system basis chips optimized for high performance within the constrained energy budgets of their target applications. Our solutions enable automotive, industrial, consumer and networking applications and are truly energy efficient by design.

This paper provides an introduction to the thinking and principles behind Freescale energy-efficient solutions. Additionally, this paper highlights and discusses best-in-class examples from across the Freescale solutions portfolio:

- **Kinetis L series microcontrollers:** The world's most energy-efficient entry-level MCUs.

- **i.MX 6 series applications processors:** Feature-packed multicore processor solutions that balance high performance and low-power/low-thermal needs.

- **Xtrinsic sensors:** Sophisticated devices with power management technologies that help users address the ongoing issue of increasing functionality without sacrificing battery life.

- **Freescale system basis chips:** Breakthrough automotive and industrial solutions that achieve critical power and safety standards while improving energy efficiency.

Energy Efficient Solutions
by Freescale ™

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The Design Challenge

It's a balancing act. Manufacturers are trying to create products that push the limits of speed and functionality, yet they are expected to run on next to nothing. Tip the high-performance/low-power balance too far to one side and you will not satisfy the consumers who demand both performance and efficiency with few, if any, compromises.

One may think this balancing act applies only to portable devices—a tablet that runs all day but can download any video in seconds and store hundreds like it. But that's not true. Plugged or unplugged, applications designed today must consider the total cost of using energy and the impact any excess will have on the environment. For instance, many connected devices will draw power continuously but may actually "work" for only a few minutes, seconds or even microseconds. Therefore, it's just as important to optimize products for energy efficiency while they sleep as it is while they work. Consumers and businesses alike cannot afford to pay for any wasted energy.

As any engineer knows, no two applications are the same. Similarly, there is no single power-reduction technique that is able to meet all the system requirements for energy minimization or "one size fits all" solution to minimizing power consumption relative to processing capacity. The trick is to effectively combine architectural, platform and circuit techniques, system and application software, process technology and design methodology and tools to intelligently develop semiconductor designs for energy-efficient operation in all applications.

Freescale has a rich history of monitoring emerging application trends and developing just-right solutions for customers with constrained power budgets. Freescale's Energy-Efficiency Target (Figure 1) illustrates how these technologies and techniques are integrated into the full

Freescale Energy Efficiency Target

Figure 1: The Freescale Energy Efficiency Target is a holistic approach to energy management, where interaction among the technologies and techniques is critical to achieve optimal energy savings.

development process designed to achieve optimal energy efficiency. Each area of technology can be optimized toward more efficient operation while still contributing to overall performance goals in application-specific scenarios. This unified development process aims to maximize energy efficiency as an essential ingredient for any high-performance automotive, networking, industrial or consumer system.

Hot Topic: Energy Efficiency and The Internet of Things (IoT)

Embedded technology is fueling the rapid rise of the so-called Internet of Things—billions of smart, connected "things" communicating with devices, machines, environments and more to make life better and easier. Applications like life-saving portable medical devices sending real-time data to doctors and connected home smart energy systems reducing power use when no one is detected in the home are already in use. But we have barely scratched the surface of how the IoT will impact practically every aspect of daily life.

To deliver on the promise of the IoT, even basic applications will now be expected to perform data processing, communication, digital user-interface enablement and more to meet marketplace demands. And greater functionality demands more complex, energy-consuming processing from battery powered and "plugged" devices alike.

Freescale helps to bring the full potential of the IoT to life, delivering intelligence everywhere so designs and whole systems can scale and interact seamlessly, even with constrained power budgets. As a key player in the Internet of Things landscape, Freescale combines hardware, software and services, along with key partnerships and expertise, to simplify the design of intelligent systems and accelerate innovation for the Internet of Things.

Learn more at **freescale.com/IoT**.

Freecale Energy-Efficient Technology at Work

High-efficiency embedded technology helps engineers develop automotive, networking, industrial and consumer applications that meet or exceed user expectations for low-power, low-cost operation. The benefits are seemingly endless, including longer operating times for portable applications, more efficient data centers, more responsive smart energy grids, and improved fuel economy for hybrid electric vehicles, to name but just a few.

Energy-Efficient Solutions by Freescale are specifically designed to aid the evolution of a connected, more energy-efficient world by producing highly optimized platforms to help customers create the next generation of energy-efficient products and services.

This paper highlights four of Freescale's best-in-class examples of energy-efficient solutions that reach across consumer, automotive and industrial applications:

• Kinetis L series microcontrollers

• i.MX 6 series applications processors

• Xtrinsic sensors

• Freescale system basis chips

The World's Most Energy-Efficient, Entry-Level MCU: Kinetis L Series Microcontrollers

Innovation Spotlight

"From the early days of Kinetis L series MCU development, we challenged ourselves to think differently about energy efficiency. The team utilized Freescale's long history of MCUs across a wide range of applications and designed a platform from the ground up that would be ultra-low power and easy to use, while also providing flexibility to meet the needs across applications. The result was a game-changer, empowering customers to look beyond the data sheet to optimize the power consumption profile across all aspects of their application."
–Eduardo Montañez, Freescale Microcontrollers System Architect

Built on the ARM® Cortex®-M0+ processor, the most energy-efficient ARM processor available, Kinetis L series MCUs take ultra efficiency to unprecedented levels for 32-bit MCUs. Kinetis L series MCUs were clearly demonstrated to be the world's most energy-efficient, entry-level MCUs when participating in a head-to-head energy efficiency benchmark challenge with three respected 16-bit low-power MCUs from competitors.

Each MCU was powered by an identical charging circuit and optimized for low-power operation. MCUs performed a repetitive cycle of EEMBC CoreMark® iterations followed by a
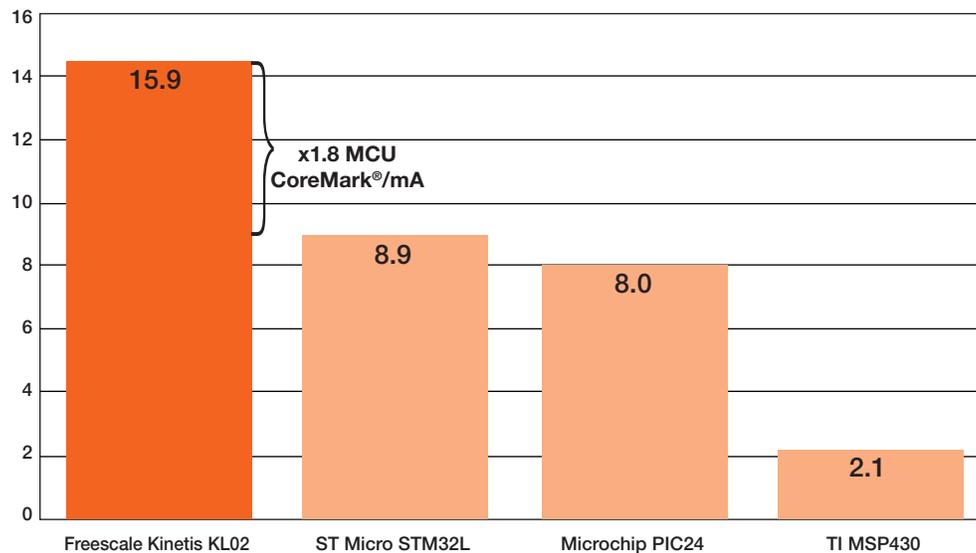
Energy Efficiency Demo: Results

Figure 2: The Kinetis KL02 MCU with its combination of superior processing power with excellent low-power operation shines through with a measured figure of 15.9 CoreMark/mA.

Chart Footnotes:
Head-to-Head Challenge of July 29 2013
Freescale KL02 Part Number: MKL02Z32CAF4R
*CoreMark 1.0: 106.38 /IAR for ARM V6.50.2 --debug --endian=little --cpu=Cortex-M0 -e -- fpu=None -Ohs --use_c++_inline/ Code in internal FLASH, Data in internal RAM, Stack/ Processor operating frequency = 48 MHz, operating voltage = 3.3 V
ST Microelectronics STM32L Part Number: STM32L151RBT6
*CoreMark 1.0: 93.45/IAR for ARM V6.50 --debug --endian=little --cpu=Cortex-M3 -e --fpu=None -Ohs --use_c++_inline/ Code in internal FLASH, Data in internal RAM, Stack, 64bit access enabled/ Processor operating frequency = 32 MHz, operating voltage = 3.3 V
Microchip PIC24 Part number: PIC24FJ128GA310
*CoreMark 1.0: 29.41/ MPLAB IDE v8.31 -g -Wall -O3 -funroll-loops/ Code in internal FLASH, Data in internal RAM/ Processor operating frequency = 32 MHz, operating voltage = 3.3 V
TI MSP430 Part number: MSP430F5529
*CoreMark 1.0: 16.23/ Code Composer Studio 5.1.1 -O3--opt_for_speed=5/ Code in internal FLASH, Data in internal RAM/ Processor operating frequency = 25 MHz, operating voltage = 3.3 V

five-second deep sleep period, continuing until the last MCU remained active. Kinetis L series MCUs were the last ones standing with superior energy efficiency versus competitors. Kinetis L series MCUs combination of superior processing power with excellent low-power operation shone through with a measured figure of 15.9 CoreMark/mA, significantly greater than its closest rival (see Figure 2).

Kinetis L series MCUs, a recent product launch from the Kinetis portfolio, represent a significant step-change in capability and efficiency compared with competitive entry-level MCUs and delivers significant efficiency gains across the Initialization, Control and Compute phases. Notice the energy savings showing in Figure 3 by comparing the L series MCUs energy curve in orange versus other competitive products energy curve in gray.

Kinetis L series MCUs earns its "world's most energy-efficient, entry-level MCU" status through an elegantly designed, comprehensive family of solutions and a platform built with energy efficiency as a core driver. Taking the low-power features of the Cortex-M0+ processor to the next level, Kinetis L series product solutions bring superior flexibility and scalability while delivering even lower low-power entry points than comparable MCUs.

In the development of Kinetis L series MCUs, the focus centered around a seemingly simple concept: How do you collect data without CPU intervention, then quickly wake up the MCU, process functions as quickly and efficiently as possible and go back to sleep? The result is significant energy reduction under the curve across the board (see Figure 3), achieved through a combination of the Cortex-M0+ processor, ultra-low-power modes for multiple use cases, watt-saving architectural techniques and a range of autonomous, power-smart peripherals.
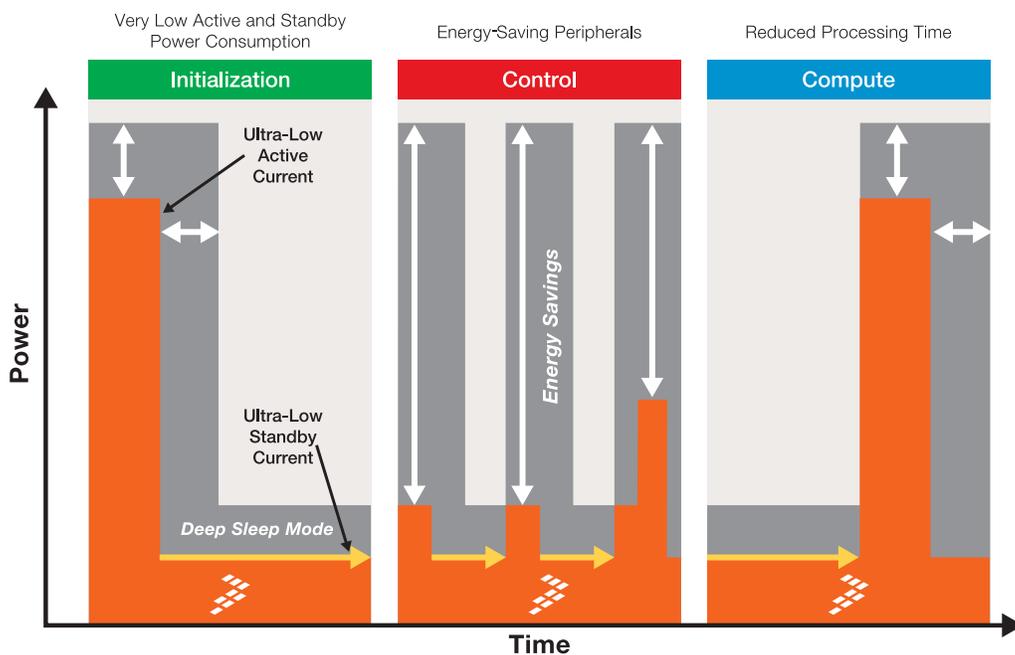
Energy Efficiency: Energy = Power x Time

Figure 3: Kinetis L series MCUs are designed to deliver substantial efficiency gains across all phases of the application: Initialization, Control and Compute.

Kinetis L series MCUs deliver significant gains in efficiency by expanding the three traditional power modes to an innovative 10 flexible modes (see Table 1) that support numerous application use cases. The expanded power mode options enable Kinetis L series energy-saving peripherals to do more with less power by maintaining functionality even when the MCU is in deep sleep modes. In traditional MCUs, the main clock and processor core must be activated to perform even trivial tasks such as sending or receiving data, capturing or generating waveforms or sampling analog signals. Kinetis L series peripherals are able to perform these functions without involving the core or main system, drastically reducing power consumption and improving battery life.

The Kinetis L series MCUs also excel in energy efficiency due in large part to an innovative architecture that incorporates and improves upon several low-power features of the Cortex-M0+ processor that are often not fully optimized in other microcontrollers.

Kinetis MCUs are supported by a market-leading enablement bundle from Freescale and ARM third-party ecosystem partners. Designed to simplify and accelerate development, this portfolio of software and tools can help further energy savings by offering additional code

Ultra-Low-Power Modes

	Mode	Definition
RUN	**Run**	MCU can be run at full speed. Supports Compute Operation clocking option where bus and system clock are disabled for lowest power core processing and energy-saving peripherals with an alternate asynchronous clock source are operational.
	VLP Run (VLPR)	MCU maximum frequency is restricted to 4 MHz core/platform and 1 MHz bus/flash clock. Supports Compute Operation clocking option. LVD protection is off and flash programming is disallowed.
SLEEP	**Wait**	Allows all peripherals to function while CPU goes to sleep, reducing power consumption. No Compute Operation clocking option.
	VLP Wait (VLPW)	Similar to VLP Run, with CPU in sleep to further reduce power. No Compute Operation clocking option.
DEEP SLEEP	**Stop**	MCU is in static state with LVD protection on. Energy-saving peripherals are operational with Asynchronous DMA (ADMA) feature that can wake-up DMA to perform transfer and return to current mode when complete. AWIC detects wake-up source for CPU. Lowest power mode with option to keep PLL active. Partial stop clocking options for more peripheral functionality available.
	VLP Stop (VLPS)	MCU is in static state with LVD protection off. Energy-saving peripherals are operational with ADMA feature. AWIC detects wake-up source for CPU.
	LL Stop (LLS)	MCU is in low leakage state retention power mode. LLWU detects wake-up source for CPU including LPTMR, RTC, TSI, CMP, and select pin interrupts. Fast <4.3 us wake-up. LLS mode not supported on some products.
	VLL Stop 3 (VLLS3)	MCU is placed in a low leakage mode powering down most internal logic. All system RAM contents are retained and I/O states held. LLWU controls wake-up source for CPU similar to LLS mode.
	VLL Stop 1 (VLLS1)	Similar to VLLS3 with no RAM retention. Register file retention available on some products.
	VLL Stop 0 (VLLS0)	Pin wakeup supported. LPTMR, RTC, TSI and CMP wake-up supported with external clock. No RAM retention. Register file retention available on some products. No 1 kHz low power oscillator (LPO). Optional POR brown-out detection circuitry.

Table 1: Kinetis L series MCUs expands beyond typical run, sleep and deep sleep modes with power options designed to maximize battery life in varying applications.

optimization, power debugging and more. Engineers can speed up their design cycle using these industry-standard development tools, many of which offer evaluation versions.

• CodeWarrior Suite for MCUs V10.x (Eclipse) Integrated Development Environment (IDE)

• Processor Expert software configuration tool

• IAR Embedded Workbench®, ARM Keil® MDK, Atollic and GCC development tools

• Complimentary Freescale MQX™ Lite RTOS

To get started with Kinetis L series MCUs, the Freescale Freedom development platform is a small, low-power, cost-effective evaluation and development system perfect for quick application prototyping and demonstration of Kinetis MCU families. The platform offers an easy-to-use, mass-storage device mode flash programmer, a virtual serial port and classic programming and run control capabilities.

For more information on Kinetis L series MCUs, please see **Freescale Energy-Efficient Solutions: Kinetis L Series MCUs White Paper**.

Thermal Management and Multicore: i.MX 6 Applications Processors

Innovation Spotlight

"*With smarter, smaller, multifunctional devices, thermals are a challenge across the board. The number-one way to generate less heat is to consume less power. i.MX 6 series processors are built with multiple features specifically designed to enhance multitasking/high-power processing while minimizing power use. Freescale also has a number of software, tools and resources to help you build a comprehensive plan to minimize power use, maximize peak performance and manage thermals.*"–Kyle Fox, Freescale Product Manager, i.MX Applications Processors

Freescale's energy-efficiency expertise and offerings span single-core as well as multicore solutions. Multicore technology presents a new breadth of possibilities for application development but poses significant efficiency challenges at the same time. i.MX 6 series of multimedia applications processors deliver scalable multicore solutions with a holistic toolkit of integrated features, software and support to help designers surmount these challenges.

Based on this deep expertise in balancing power and performance in battery-powered devices, the i.MX 6 series of multimedia-focused products offers designers a truly high-performance processing platform optimized for the lowest power consumption. The multicore i.MX 6 series family integrates several power management features (see Figure 4) to increase its energy efficiency and thermal management capabilities.

i.MX 6 Series Power Management Features

• Temperature Monitor

• Temperature Aware DVFS

• Temperature Aware CPU Pool Management

• Clock and Power Gating

• DDR (MMDC) and I/O Power Optimizations

Figure 4: i.MX 6Quad applications processors integrate many power management features to optimize energy efficiency.

The energy-efficiency features of i.MX processors are critical for design success, but Freescale also provides design resources that complete another essential piece of the design puzzle—managing thermals. All processors generate heat, and applications are demanding more work from the CPU over longer periods of time.

With designing any tightly integrated device, thermals—and the cost to dissipate them—can become an issue if heat generation is not carefully considered in the early stages of development. Even with an energy-efficient processor solution, high-performance processing and concurrent functions often require more power, which means more heat must be dissipated via cooling techniques (see Figure 5). This particularly applies to extremely small devices like wearables as well as larger systems such as automotive infotainment systems.

Recommended Cooling Techniques Per Application Profile

Power Usage	Application(s)	Cooling Technique(s)
<1 W	Very basic applications, email	Air cooling may suffice for larger form factors.
2 W	Play video, single application at a time	*Decreasing form factor size*
3–4 W	Play 3D video, gaming, more than one application	
>5 W	Running video, 3D, multiple apps and IO concurrently	Added heat spreader likely required for smaller form factors.

Figure 5: Form factor, size and application processing requirements determine the required cooling techniques.

Early in the development process, significant time and money can be saved by considering these five areas related to power and thermal management:

1) Is the application activity profile more industrial or more consumer-like?

In other words, is it always on or nearly always on? Or does it only have to run fast for a very short period of time and then sleep for long periods?

The activity profile of the application can have a significant impact on the thermal management techniques and thermal design power. The main types of activities can be classified as follows:

- Short bursts of intensive processing followed by long intervals of the IC/system being idle. This type can in most cases automatically regulate the heat without much external intervention.

- Long bursts of intensive processing followed by long intervals of the IC/system being idle. This type may require some external intervention such as software thermal management during the time of processing.

- Continuous high-performance usage. This type, without any idling, can cause the system temperature to rise making it necessary to have other forms of thermal management.

The key is to develop a complete understanding of the maximum continuous thermal dissipative profile as early in the design process as possible. To phrase it simply, "Know your profile."

2) Consider the entire lifecycle of the device. Where will it be stored? Where will it need to operate? How will it be shipped?

Some aspects of the complete product life cycle are frequently overlooked during the planning process. Problems can be avoided by carefully considering how the device will be manufactured, shipped, stored and operated during its entire life.

Thermal management becomes a challenge especially when operating in a high ambient temperature environment. It is not always possible to constrain the environment ambient operating temperature to ensure it is at or below a given temperature.

i.MX applications processors offer three different qualification levels for consumer, industrial and automotive applications. Consumer qualification is best for highest frequency use, while industrial qualification is best suited for long duration (or "always on") applications in harsh environments. Automotive qualification provides the best environmental support, including the broadest temperature range of −40 °C to +125 °C.

3) What is the desired thinness of the product? How much printed circuit board (PCB) space or LCD mechanical fixture space is available? How tightly grouped are the high-power processors (e.g., CPU, memory, wireless, flash memory)?

Historically, the main processor was the most energy-hungry component of a typical embedded computing system. However, processors such as the i.MX 6 series have become more energy efficient and more effective at managing their own power consumption.

In contrast, memory energy consumption has been growing as multicore CPUs with multiple hardware accelerators require increasing double data rate (DDR) memory bandwidth and capacity. The main system memory can consume significant power and generate significant heat in active modes. Therefore, we must consider the thermal impact of components on the system board, including power management integrated circuits (PMICs) or external LDO regulators; radio frequency (RF) components such as power amplifiers, transmitters and modems; LCD, LED and OLED displays; and high-speed memories and transceivers.

In devices that are not as constrained by space, more solutions can be deployed with less concern about heat dissipation. Thinner, smaller devices have a harder time dissipating heat from all sources (e.g., CPU, memory, wireless, PMIC, etc.) and need careful component placement to minimize thermal overlap.

An important feature of the i.MX 6 series which assists in "making room" for other components on the PCB is the integration of a partial PMIC onto the processor. The i.MX 6 series incorporates most of the components of a PMIC. This enables the processor to be powered by as few as three voltage rails versus the traditional nine to 12 rails of other processors. This means designers can utilize a greatly simplified power management subsystem for the processor, potentially reducing bill-of-material (BOM) costs and enabling more room on the PCB for other components.

The bottom line is that when considering a thin or small size device, designers must carefully think about component placement and how the resulting component heat blooms will combine

or interact with the rest of the system. Ultimately this will help determine what types of material will be needed to dissipate the resulting heat, which is addressed in the next section.

4) What materials are being considered for heat dissipation?

A conduction heat path between the package and the system enclosure may not sufficiently cool high-power components for extended operations. Heat spreaders can transport heat from the die to the PCB, product chassis or a heat sink (if the product design form factor permits). From there, the heat is dissipated to the local environment. They act essentially as a heat transport channel to move thermal energy to a desired location. The goal is to use these "heat transports" to even out the overall temperature profile of the system from nonuniform power generators by conducting and dissipating that heat so that the overall system does not get too hot in any one spot.

Heat spreaders serve three primary purposes:

• Touch temperature reduction

• High-power/hot-component temperature reduction/cooling

• Shielding heat

While a metal heat sink is commonly used for managing thermals, it has some drawbacks. For example, if a metal heat sink is attached to the processor and then to the top of the enclosure, it can generate a hot spot on the enclosure. Metals can also be large, costly, commodity-price driven and interfere with desired product thinness.

There are other alternatives to consider. Copper is commonly used because it can be molded to direct heat to desired locations and is quite thin. However, copper is extremely expensive and in high demand on global markets. Graphite paper is extremely efficient at transferring heat from one location to another and is highly recommended for several reasons as a smart choice to transfer heat away from the processor. It is extremely thin and can be cut into any shape so that thermals are directed to wherever the designer wishes them to be. Additionally, graphite paper can be much cheaper than metal alternatives like copper.

Graphene is another new material that may revolutionize product form factors. Andre Geim and Kostya Novoselow discovered this remarkable material that is one-atom thick, more conductive than copper, 1,000 times more conductive than silicon, stronger than diamond and yet very flexible[1]. Graphene is now in several pilot products and poised for broad market availability.

i.MX 6 series applications processors offer two packaging options which can add to flexibility in choosing thermal management solutions. Automotive and industrial "lidded" versions contain a metal lid covering the processor and are more robust for hotter and harsher environments. The consumer "non-lidded" version exposes the back side of the processor die and lowers the z-axis height for space-constrained designs. Non-lidded devices make it easier to attach custom heat spreaders in a thin form factor.

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[1]Stefanie Blendis. CNN.com http://edition.cnn.com/2013/10/02/tech/innovation/graphene-quest-for-first-ever-2d- material/index.html?hpt=hp_bn6

5) What design resources are available to make the design process go as smoothly as possible?

Understanding your human resource capabilities can help you double-check questions or concerns during development. When assessing and evaluating your resource roster, keep in mind these helpful sources for more information:

- Freescale-provided resources: Additional documentation, software and tool resources, training videos and materials are available at **www.freescale.com/imx6series**.

- **www.imxcommunity.org**: The i.MX community is a great resource where fellow i.MX developers and users share knowledge, tips and code. The site also features technical information and strategies from Freescale product experts.

- Ecosystem partners: Freescale works with a number of trusted partners who have developed solutions to simplify the design process and aid power and thermal management. Leveraging these resources can save significant time and product cost. Visit **freescale.com/partners**.

For more information on managing thermals with i.MX 6 series, see **Freescale Energy-Efficient Solutions: i.MX 6 Series Processors White Paper.**

Companion Solutions to i.MX 6 Series: PF Series of Power Management ICs

Freescale enables a system-level approach to applications processor power management with the PF series of power management ICs (PMICs) optimized to work seamlessly in systems based on i.MX 6 single-, dual- and quad-core applications processors. i.MX 6 series applications processors integrate multiple power management functions previously handled by discrete PMICs, which allows the PF series of PMICs to incorporate more system-level power management functionality. With low quiescent current, integrated high-efficiency switching regulators, exceptional configurability and quick-turn programmability, the PF series of PMICs makes it easy for the designer to optimize power efficiency for a specific application and they are ideal for a host of applications. These include feature-rich smart mobile devices, automotive infotainment systems and highly power-sensitive platforms, including portable medical devices, IP headphones, home security systems, IPTV controllers, tablets and home energy management solutions. Learn more at **freescale.com/pmic.**

Utilizing Sensors to Optimize Power Consumption: Xtrinsic Sensing Solutions

Innovation Spotlight

"Setting aside their primary missions of monitoring system and environmental states, sensors play a dramatic role in conserving energy at the system level. At power levels as low as a few microwatts, low power accelerometers can control systems consuming many orders of magnitude more power. Smart algorithms can use inputs from various sensors to disable components not needed for the current task at hand, even to the point of switching to lower power algorithms until something interesting occurs to wake the system.

We designed the Xtrinsic MMA955x family with an eye to optimizing both the sensor power, as well as the power consumption of the system in which it resides. The signal conditioning

circuits were reworked from the bottom up. ADC conversions can be initiated via simple timers. The integrated 32-bit MCU and associated subsystems were designed for fast wakeup and sleep times. We used the lowest power memories we could find. The result is a sensor smart enough to schedule its own operation, process the results of ADC conversions, and intelligently determine when to wake up the rest of the system."–Mike Stanley, Systems Engineer, Freescale Analog and Sensor Group

With over three decades of continuous sensor innovation, Freescale sensor products have helped make the world a safer, efficient and more interactive place. Increasing system functionality in portable electronic systems has traditionally occurred at the expense of higher power consumption and shorter battery life. However, sensors designed for low power consumption at both the device and system levels have helped reverse this trend while adding additional features and functionality.

Built on our heritage of sensor innovation, Freescale's Xtrinsic sensing solutions offer increased levels of modular integration combined with multiple sensor inputs, logic and other building blocks to bring greater decision making capability to the overall sensing solution. Multiple sensor inputs are leveraged within the platform to perform multiple application functions, often at lower power than previously required. Several product offerings from the Xtrinsic sensor portfolio are featured best-in-class examples of Freescale energy-efficient solutions.

Exploring Design Approaches

System power consumption has a direct relationship to feature content, particularly in the case of battery-powered portable products, where features and battery size are critical in helping suppliers differentiate their products.

Let's consider the example of smartphones (See Table 2). Improved battery life occurs with either a larger battery, lower current-consuming components and low-current strategy or a combination. It is worth noting from the testing cited in Table 2 that the smartphone with the largest battery did not have the highest current draw and, even with a large feature set, it had the longest life. In contrast, the smartphone with the smallest battery had the shortest battery life and the lowest current draw.

Average Current Consumption for Smartphones

Smartphone	Battery Life[1] Hours	Battery Size (mAh)	Current (Ave) (mA)
Motorola DROID RAZR MAXX	14.88	3300	222
Motorola DROID RAZR HD	9.62	2530	263
Samsung Galaxy S® III	9.40	2100	223
Motorola DROID 4	9.08	1785	197

[1]According to CNET testing

Table 2: Battery life versus battery size and average current draw (power consumption) for four popular smartphones based on recent testing [1, 2, 3]. The current consumption is strictly a calculation based on Iave = battery size/battery life.

How is this achieved? Sensors can enable a number of power-saving techniques in a smartphone design. One common example is a sensor places the smartphone in a very low-power mode based on user inactivity. The inactivity is detected through motion sensing by the accelerometer that also provides the screen rotation function. In addition to this system

power-saving function, design of the sensor can contribute to reduced power consumption at the sensor and system level.

Freescale has established three different design approaches utilizing sensors to provide design flexibility for customers looking to achieve specific design goals for their products:

Type 1: Achieving the Lowest Sensor Power Consumption

The first approach to a low-power-consumption design targets the sensor itself. The sensor can have one or more lower power states such as a shutdown mode and an extremely low power operating mode. In many instances, the operation of this type of sensor is directly controlled by the system designer in the end application. As a result, it provides many power consumption advantages.

The advantage of this design approach is readily apparent in environments with very low duty cycle requirements and a long time between samples. In appropriate situations, it is often the option with lowest power consumption on the market. An example of a category of applications where this strategy applies includes industrial and supply chain monitoring where the sensor only needs to be powered on when the product is moving and not when it is in the warehouse.

Type 2: Smart Sensing for Low-Power Consumption

A second method for achieving low-power uses integrated digital logic in the sensor design. Frequently called "smart sensing," the added digital capability can be used to enable the sensor to perform its own internal power management. This approach has been used in accelerometers, pressure sensors and magnetometers.

An accelerometer with integrated digital logic is an example of how lower power considerations can be taken to the next level in this approach. With added logic, the sensor performs its own internal power management and data can be sampled as required. Beyond simple shaking of the device to power it on or off, more complex tasks such as double taps or a rotational shake with the direction of rotation initiating one command versus another allow the sensor to initiate a variety of useful functions.

The main applications for this low-power sensing approach are end products where portrait/landscape detection is desired, such as cell phones or tablet computers. An accelerometer with this capability can provide the desired functionality as well as sophisticated power management for minimum power consumption.

Type 3: Integrated MCU/Sensor Operation

In the third design approach for low-power sensing, the sensor utilizes the local computing capability of an MCU. This functionality can be achieved in the same package or simply by taking into account the joint/system-level operations of these two components. Known as "local compute capability," this system-level methodology can offload sensor-based (and other) computations from the system application processor even further than the second low-power approach.

For example, for a primary system that uses 100 to 1,000 times as much power, a local MCU that can perform the required computations (and allow the other processor to go into a lower

power mode) delivers a significant power savings at the system level, resulting in savings that justify adding the smaller MCU. Unlike the second case that provided interrupt capability for basic functions such as portrait/landscape transition, a FIFO buffer or similar functions, in this last case, all of the computations can be performed internally providing the full capability of a sensor hub.

A typical application or use case is a pedometer that must always be on to obtain the required amount of data to calculate the number of steps, distance and other values on a continuous basis. This type of capability cannot be integrated with a cell phone without significantly decreasing battery life since the phone would essentially always have to be on. In contrast, the local compute method has much lower power consumption than the primary computing system in the phone. This makes the pedometer a viable application and avoids battery life as a limiting factor. A free or low-cost downloaded app that counts steps using the phone's integrated accelerometer costs battery life for the cell phone. This same functionality built into the phone using an integrated sensor hub could provide the pedometer capability while the phone's primary processor and display are powered off.

Based on the level of digital control, these three low-power management strategies provide users alternatives for minimizing power consumption and optimizing battery life. Table 3 shows a comparison of the techniques using accelerometer, pressure sensor and magnetometer values from each product's data sheet. When sensor measurements require more complex computing, offloading the main processor that methods 2 and 3 enable provides substantially greater system-level power consumption savings.

Accelerometer, Pressure Sensor and Magnetometer

Type	Power Reduction Method	Example Sensor Product	Sensor Type	Lowest Current Consumption	Level of Digital Control
1	Lowest sensor power consumption	MMA8491Q	Accelerometer	400 nA at 1 Hz sample rate	Low
2	Smart sensing with integrated digital logic	MMA865xFC	Accelerometer	6 µa in lowest power mode	Medium
3	Integrated MCU/ sensor operation	MMA9550	Accelerometer	2 µa in STOPnc mode with internal clocks disabled	High
2	Smart Sensing with integrated digital logic	MPL3115A2	Pressure	8 µa in highest speed mode (oversample = 1)	Medium
2	Smart Sensing with integrated digital logic	MAG3110	Magnetometer	8.6 µa in active/2 µa in standby	Medium
3	Integrated MCU/ sensor operation	MPXY8xxx	Pressure	0.36 µa in Stop1 mode	High

Table 3: Comparison of three power-saving approaches/methodologies

Freescale Xtrinsic sensors feature customizable software that extends sensor use cases through algorithms and analysis to reduce complexity and provide processing assistance. And design time can be accelerated through the use of Freescale software and development kits, including the Sensor Toolbox, Tower System modules for sensors and more. They allow users to more readily develop their own code to achieve the lowest power for a specific application.

For more information about Freescale low-power sensing solutions, see **Low-Power Sensing: Energy-Efficient Power Solutions White Paper**.

Energy Efficiency and Safety in Industrial and Automotive Applications: Freescale System Basis Chips

Innovation Spotlight

"*In developing more efficient power management solutions for automotive applications, Freescale's goal was to help OEMs reduce power losses to improve fuel economy and meet CO2 emissions reductions, while supporting the market evolution to 32-bit architectures and contributing to increased system functional safety. The resulting family of Freescale system basis chips provides a unique combination of energy-efficient features that optimize energy consumption while helping our customers meet stringent safety mandates.*"–David Lopez, Freescale Product Line Manager, Analog Mixed-Signals & Power Division

Achieving power, efficiency and safety are particularly critical in automotive applications. Freescale, combining more than 20 years of experience in developing sophisticated power management integrated circuits and decades of automotive expertise, has developed a unique family of analog automotive ICs that meet the high bar for efficiency and safety standards. These standards apply not just to automotive, but to many industrial applications as well.

There are numerous energy-efficiency advantages in utilizing power management IC solutions, namely, the capability to optimize energy utilization during run and low power modes, minimize the energy losses during conversion, reduce energy consumption during standby mode and minimize battery discharge. System basis chips (SBCs), part of the Freescale analog standard product family and a featured Freescale energy-efficient product solution, combine power management ICs with low standby currents, high efficient switch mode power supply, enhanced voltage range for improved availability and robust physical layers for in-vehicle networking (CAN and LIN) to cover a wide array of automotive and industrial segments (see Figure 6).

A System Basis Chip (SBC) Explained

Complete Ecosystem
- Simplify customer usage (e.g., MCU attach, software drivers, thermal prediction tools, safety documentation, etc.)
- Provide EMC compliance reports to support full OEM acceptance

System Management
- Energy Savings: Manage low power modes, sense critical analog information to optimize energy consumption
- Functional Safety: Monitor, diagnose safety-critical parameters and support fail-safe modes

SBC Ecosystem

System Management

Power Management

Physical Layer

Power Management
- Supply MCU, CAN and other loads in LDO and/or DC/DC
- Extended product capability in current or voltage

Physical Layer
- Transmit digital information across physical network (in line with automotive OEM standards (e.g., electrical, EMC, ESD)
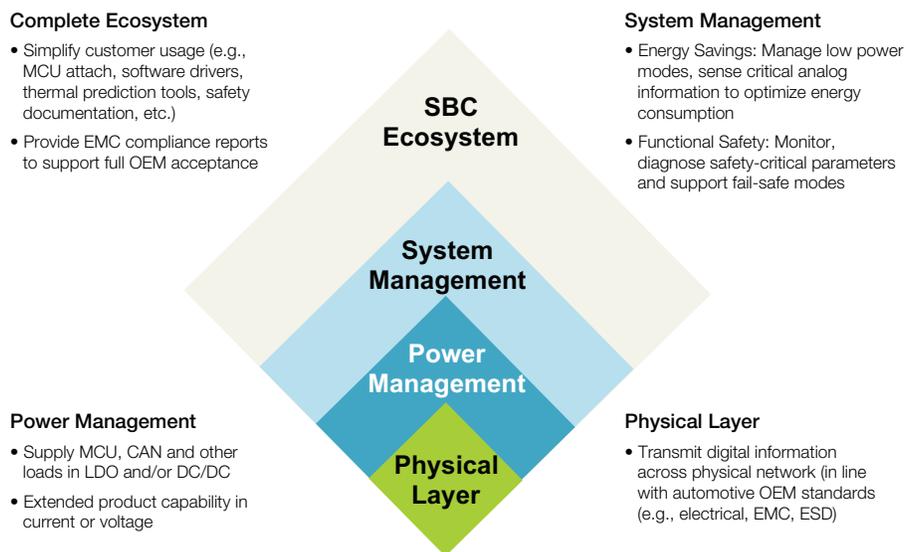
FIGURE 6: System basis chips provide power management with low standby currents, high efficient switch mode power supply, improved voltage range for improved availability and robust physical layers for in-vehicle networking (CAN and LIN).

System basis chips are the ideal companion chip for microcontrollers in many electronic control unit (ECU) applications requiring energy-efficient designs, other automotive applications such as body, electric power steering, engine management systems, transmissions, inverters and battery management systems as well as industrial applications, particularly motion-control, safety-critical applications such as elevators, mobile machines, factory automation, robotics, aerospace and defense and renewable energy.

Managing energy use requires sensing the environment, making the appropriate decision when power will be reduced and executing as fast as possible in order to secure application supply or allow sufficient time for the MCU to execute critical data savings. For that purpose, SBCs are able to directly measure the battery voltage *before* the reverse battery protection and quickly generate an interrupt to inform the MCU about critical voltage levels. System basis chips also aid the MCU in determining the energy management strategy based on analog-world sensing. The right interaction between analog and MCU technology can help designers develop innovative energy-efficient and smart energy solutions.

Let's examine a transportation application use case. Freescale system basis chips provide efficient power management solutions in vehicles which, in turn, enable a chain reaction of benefits. SBC devices offer the ability to replace LDO power supplies with DC/DC at the ECU level while maintaining the same performance. With up to 100 ECUs per platform, a vehicle using less energy through DC/DC conversion contributes to an overall system reduction of fuel required to generate electrical power. Thus, improving power efficiency at the individual application level leads to a reduction in overall vehicle power needs, minimizing fuel usage and lowering CO_2 emissions levels. When the effect is taken cumulatively across millions of vehicles, the global impact is significant.

We can consider additional cases where SBCs positively impact global energy savings. When a vehicle is in use but a specific application within the vehicle is not in use, system basis chips can set the application in low power mode, leading to overall reduction in energy use. In addition, when the vehicle is parked, SBCs can activate a low-power mode that helps to limit battery discharge and improve car wake up autonomy.

In case of electric cars, efficiency is directly linked to mobility (i.e., the number of kilometers/ miles that can be driven with a full charged battery). Embedded systems are requiring technology leakage be as low as possible in standby modes for electric vehicles. This is accomplished through software, which reduces functionality when unnecessary, and through analog solutions, which help "sense" the application and limit energy usage when the application is ON but also when the application is OFF.

The system basis chip offers the right tradeoff between system oriented integration and standard product strategy to support multiple application use cases and can adapt its functionality to support these energy savings conditions.

Key Features of Freescale System Basis Chips

System basis chips are thoughtfully designed to combine a number of key features focused on efficiency, safety and connectivity (see Figure 7). Freescale analog products utilize our industry-leading SMARTMOS process, a mixed-signal technology that helps to tackle energy losses. This analog process includes trench isolation that helps to drastically improve the robustness of system basis chips (design for EMI, design for ESD), while reducing quiescent

current through low-power design techniques. This technology provides a well-balanced integration of power, analog and digital to target energy-efficient designs.

The latest Freescale MC33907/33908 SBC also includes a DC/DC power supply architecture to improve energy conversion versus linear drop out, or LDO (85% to 90% efficiency with DC/DC versus a 35% efficiency with LDO). This system architecture is based on a cascaded DC/DC including an upfront 440 kHz DC/DC pre-regulator, which is always connected to battery, and a 2.4 MHz DC/DC to supply latest MCU core technologies down to 1.2 V.

From a low-power architecture standpoint, SBC devices include energy care supply bias techniques with specific management of low power modes (LPMs) through dedicated architecture for run mode and for low power modes. Such design techniques contribute to achieve best-in-class low quiescent current (15 µA only for MC33903/4/5 using LDO and 30 µA for MC33907/8 using DC/DC in LPM). During low-power mode, SBCs switch off power supplies to minimize system current consumption, and allow system wake up through network connections (CAN, LIN) or through I/O wake-up pins.

Freescale offers an extensive portfolio of enablement tools and solutions, including system basis chips, MCUs, software and more. These resources can help designers find and implement the best solution for their application more quickly and easily.

For more information about Freescale system basis chips, visit **freescale.com/analog**.

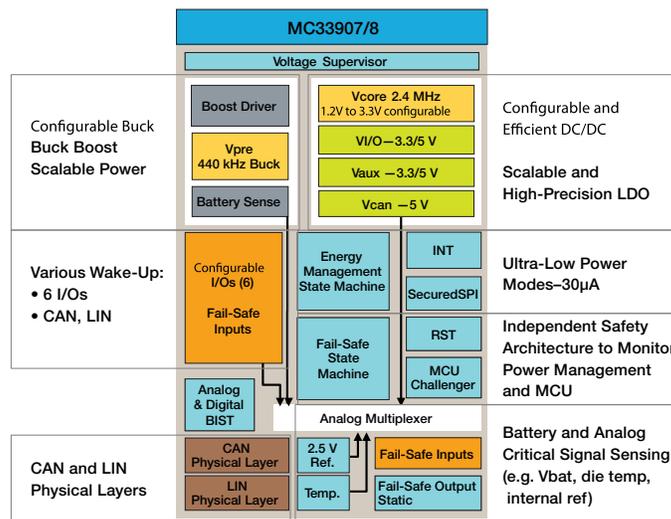## Freescale MC33907/8 System Basis Chip

Figure 7: Block diagram and key energy-efficient features of Freescale MC33907/8 system basis chips with buck boost DC/DC.

Conclusion

With out-of-the-box thinking, Freescale is opening new doors for embedded systems and the promise of the Internet of Things through proven leadership in energy efficiency. Whether the need is for extended battery life, portable performance, reduced energy costs or compliance with energy standards, Freescale's diverse portfolio of embedded energy-efficient product solutions is enabling a new generation of applications to achieve the perfect balance of power and performance.

For more information, visit **freescale.com/energyefficiency**.

For more information, please visit freescale.com