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White Paper

Freescale Energy-Efficient Solutions: Kinetis L Series MCUs

The world's most energy-efficient entry-level MCUs redefine low power standards

Abstract

The Kinetis MCU portfolio offers exceptional low-power performance with smart feature integration, peripheral sets, and scalability. Kinetis L series MCUs, a recent product launch from the Kinetis portfolio, represents a significant step-change in capability and efficiency compared with competitive entry-level MCUs and delivers significant energy efficiency gains. Key applications for the Kinetis L series MCU portfolio include: Consumer devices, smart grid and smart metering, building control and medical/healthcare.

Several Kinetis MCU families, including Kinetis L series, are featured best-in-class examples of Freescale Energy-Efficient Solutions. The Energy-Efficient Solutions mark highlights 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 MCUs, 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.

Learn more at **Freescale.com/energyefficiency**

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Energy Efficient Solutions™
optimized for low power

Introduction

Within the new era often referred to as the Internet of Things (IoT)—the billions of "smart", connected applications and devices in use today and expected in the coming decade—embedded technology is no longer just about the mechanical production of basic goods. The Internet of Things is an era of data and control automation, where connected devices and end nodes gather information and communicate with "smart" systems to solve real time problems (e.g. automatically adjusting a thermostat when the system senses no one is home). And it is in the roots of embedded technology where sensing, processing, and connectivity come together to help the IoT become a reality.

As the demand for this level of functionality, connectivity and portability has increased exponentially, mass-market battery technology has not experienced technological advances to keep pace. And end nodes, often battery-powered, must have extremely long battery life to be reliable and keep costs low. Despite the critical role of energy budgets in determining the finished designs for new products, the market will not allow manufacturers to compromise on performance. Designers are challenged to do more on the same, or even lower, energy budgets.

Holistic Approach to Energy Efficiency

As more "smart technology" products demand a longer list of functionality needs, determining energy efficiency by simply looking at raw datasheet numbers no longer provides an adequate benchmark. Energy budgets have to factor in "low power", or how much current is drawn during specific functions, as well as the larger factor of "energy efficiency," or power use over time. In other words, we must examine how much total power is being consumed over time to complete assigned tasks.

In an embedded system where low power is king, the goal is to be more energy-efficient across the multiple tasks necessary to complete the application. These tasks can typically be summarized in three phases: Initialization phase, Control phase (which can include data collection, communication and control), and the Compute phase. To reduce energy across these phases the equation is simple; do more with less power and time (energy = power x time). This is achieved by true optimization of not just one phase, but in all.

There are three keys to achieving energy savings across all phases. First, there must be very low active and standby power consumption. Second, there must be energy saving peripherals that are intelligent enough to collect, process and store data without ever waking up the CPU. Third, processing time in the compute phase must be reduced in order to get back into deep sleep mode and start the whole sequence again.

Freescale examined all phases and aspects of the MCU to answer a bigger question: How can you do more with less power? Incorporating this holistic view of energy efficiency was still somewhat novel to the marketplace. Freescale worked to help customers capitalize on the advantages in this new approach.

Kinetis L Series: The World's Most Energy-Efficient 32-bit MCUs

Capitalizing on decades of experience in monitoring emerging application trends and developing solutions for customers, Freescale is committed to supplying energy-efficient product solutions across a broad spectrum of applications. The Kinetis MCU portfolio offers exceptional low-power performance with smart feature integration, peripheral sets, and scalability. Several Kinetis MCU families, including Kinetis L series, are featured best-in-class examples of Freescale Energy-Efficient Solutions.

Kinetis L series MCUs, a recent product launch from the Kinetis portfolio, represents 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 1 by comparing the L series energy curve in orange versus other competitive products energy curve in gray.

Energy Efficiency: Energy = Power x Time

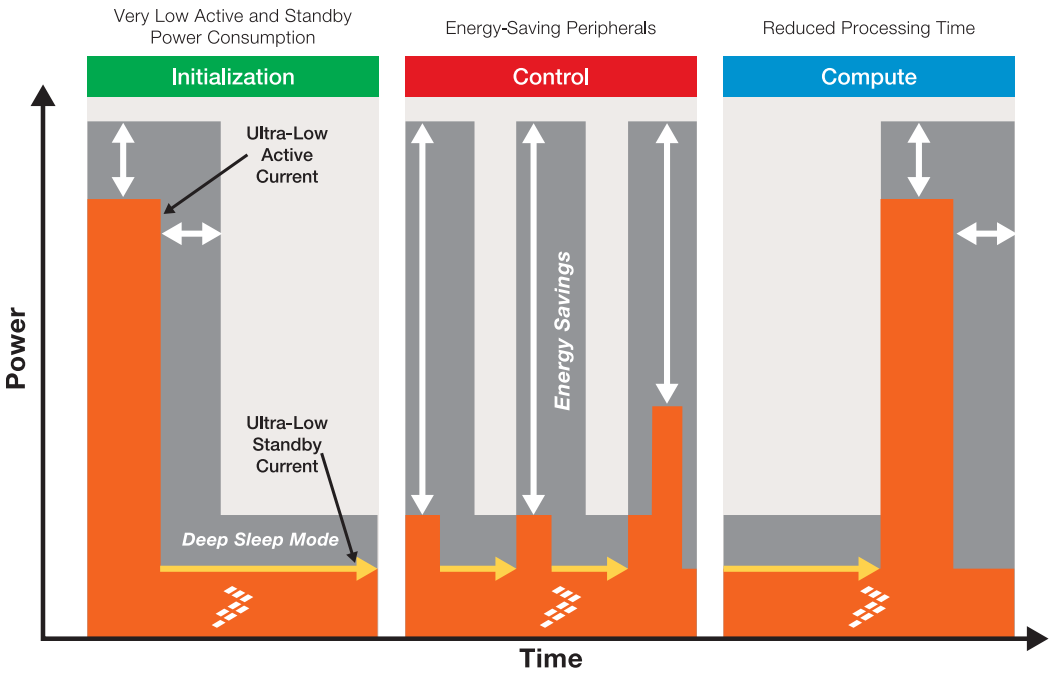

Figure 1: Kinetis L series MCUs are designed to deliver substantial efficiency gains across all phases of the application: Initialization, Control and Compute.

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. L series achieves this through an elegantly designed, comprehensive family of solutions that take the low-power features of the Cortex-M0+ processor to the next level, bringing superior flexibility and scalability while delivering even lower low-power entry points than comparable MCUs.

In the development of Kinetis L series, 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 (Figure 1), 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.

Breakthrough Design: 10 Flexible Power Modes

Traditional MCUs have historically utilized only three power modes: Run, sleep and deep sleep. However, this “one-size-fits-all” philosophy is not optimal in embedded products where there are differing power profiles. Freescale design teams conducted a thorough and thoughtful analysis, utilizing decades of Freescale experience with MCUs examining a range of potential applications, and aggregating scenarios based on common use cases.

The result: Kinetis L series MCUs delivered significant gains in efficiency by expanding the three traditional power modes to 10 flexible modes that support numerous application use cases and, thus, reducing the area underneath the energy curve. As you move down the deep sleep modes the MCU begins to power gate more logic and memory and also reduce the energy-saving peripheral functionality.

Kinetis L Series MCUs: 10 Flexible Power Modes

Kinetis Power Modes	Recovery Time	KL02 Measured Idd @ 3 V and 25 C
RUN	–	75 uA/MHz*
VLPR	–	36 uA/MHz**
WAIT	–	3.2 mA @ 48 MHz
VLPW	–	93.4 uA @ 4 MHz
STOP	4 us	255 uA
VLPS	4 us	1.9 uA
LLS[a]	**N/A**	**N/A**
VLLS3	42 us	1.2 uA
VLLS1	93 us	600 nA
VLLS0	95 us	161 nA/346 nA

* Compute Operation enabled: 3.6 mA @ 48 MHz core/24 MHz bus
** Compute Operation enabled: 144 uA @ 4 MHz core/1 MHz bus
[a] Available on select Kinetis L series devices

Table 1: Kinetis L series MCUs expand the traditional power modes to 10 flexible modes that support numerous application use cases.

Ultra-Low-Power Modes Modes

Expands beyond typical run, sleep and deep sleep modes with power options designed to maximize battery life in varying applications

	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 2: Primer on Power Mode Terminology

Efficiency Gains Through System Architecture Innovation

Kinetis L series MCUs excel in energy-efficiency due in large part to an innovative architecture, which incorporates and improves upon several low-power features of the ARM Cortex-M0+ processor that are often not fully optimized in other MCUs. For instance, to help streamline the initialization phase of the application, there is a bit manipulation engine (BME) which improves cycle time and code size by an average of 40 percent when performing bit-oriented math operations on peripherals. The BME encodes functions like OR, AND, XOR, bit field insert and bit field extract. In contrast, a traditional 32-bit processor would require several instructions to execute the equivalent read-modify-write operation.

Another example of an innovative feature is the low-power boot option, which is included to reduce power spikes during the boot sequence or deep sleep wake-up. This is particularly useful in systems where battery chemistry limits the allowable peak current (e.g. those that use lithium-ion batteries). Safe-stating conditions can also be achieved easily by zero leakage I/O and peripheral clock gating configurations that avoid excess leakage current.

Built using Freescale's innovative, award-winning flash memory technology, Kinetis L series MCUs offer the industry's lowest-power flash memory implementation. This improves upon the conventional silicon-based charge storage approach by creating nano-scale silicon islands to store charge instead of using continuous film, thereby enhancing the flash memory's immunity to typical sources of data loss.

Power-Smart Peripherals

Kinetis L series MCUs implement low-power intelligence within the peripherals and allows them to operate autonomously in deep sleep mode with an alternative clock source. L series peripherals function as "mini cores," able to perform tasks without involving the core or main system, drastically reducing power consumption and improving battery life. For example, Kinetis L series MCUs include an asynchronous DMA (ADMA) wake-up feature that allows certain peripherals to request a DMA transfer in stop and VLPS modes. The ADMA module will execute a data transfer between the peripheral and memory without having to return to run modes or request processor intervention. This allows continuous operation of the peripheral in a deep sleep state where data can be passed to/from data arrays in SRAM until enough has been collected for processing. Other competitive products would be required to wake-up into full run mode to activate a peripheral and complete the data collection phase later to return to a deep sleep mode.

For example, refer back to Figure 1. With Kinetis L series MCUs, the data collection phase starts in deep sleep mode and shows three periodic events triggered by a low power timer. The timer triggers the start of low power ADC conversions where the result is compared to a pre-programmed threshold value using the built-in compare feature in ADC. A feature like this avoids the need to store a result if the value is not within the desired parameter. Notice the first two events do not trigger the result to be stored. However, the last one does and, instead of waking up the CPU to store the data, there is a much smaller energy spike. This is possible because L series energy-saving peripherals supports an asynchronous DMA wake-up feature that can store the ADC result to SRAM for later processing while the CPU is still sleeping. Once the DMA transfer is completed the MCU automatically returns to the deep sleep mode. Once sufficient data has been collected or transmitted using the low power UART, the CPU can then "wake up" and begin the compute phase. This is just one example of the available energy-saving peripherals of Kinetis L series MCUs.

In order to capitalize on the energy efficiency that deep sleep power modes afford, smart integration of peripherals is paramount. 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.

Energy-Saving Peripheral Application Use Cases

ADC	Periodically sample an analog sensor, perform compare functions and hardware averaging
UART	Continuously transmit and receive data to/from a radio IC or other MCU
Timer/PWM	Dynamically control a motor or detect external pulses
Real-time clock	Perform time keeping and recognize alarm events
Touch sensor interface	Detect touch from user interaction with capacitive buttons, sliders, etc.
Segment LCD	Display user information to segment displays with alternate screens and blinking mode

Simplified Software and Tools

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 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, 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.

Kinetis L Series MCUs Wins in Head-to-Head Competition

In a head-to-head energy efficiency benchmark challenge with three respected 16-bit low-power MCUs from competitors, L series proves that it is the world's most energy-efficient entry-level MCU. 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 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 on next page).

Energy Efficiency Demo: Results

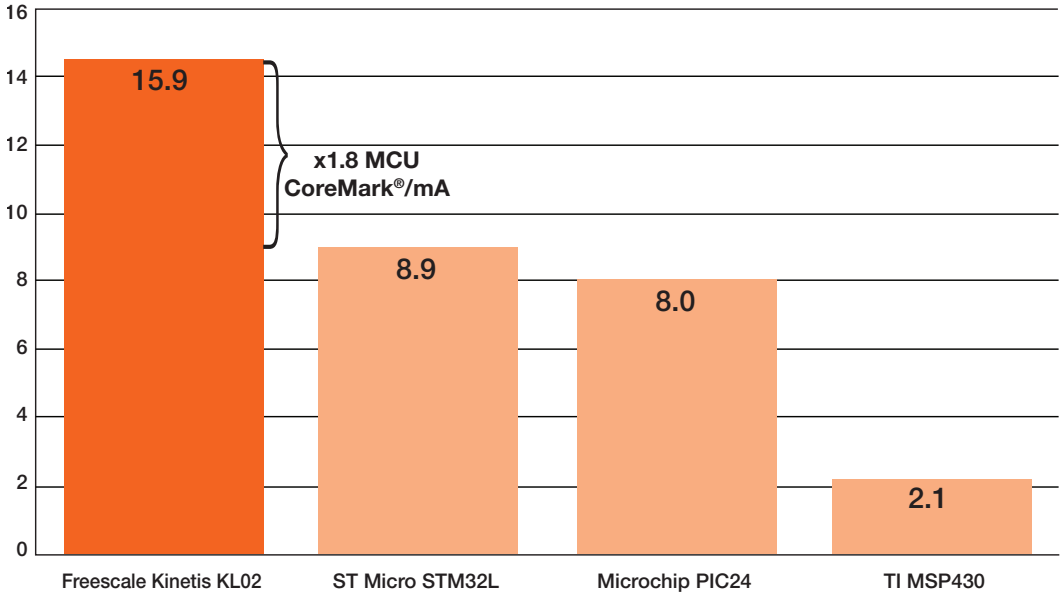

Figure 2: The Kinetis KL02 MCU with its combination of superior processing power with excellent low-power operation shines through with a measured figure of 15.9 CoreMark/mA.

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.--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 = 48MHz, operating voltage = 3.3V

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=32MHz, operating voltage=3.3V

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=32MHz, operating voltage=3.3V

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

Conclusion

With out-of-the-box thinking, Freescale is opening new doors for embedded systems and the promise of the Internet of Things through the proven energy efficiency leadership of Kinetis L series MCUs. 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, please visit freescale.com/Kinetis/Lseries

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