MSP432™ microcontrollers: Bringing high performance to low-power applications

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The new 32-bit MSP432 MCU platform from Texas Instruments leverages its more than 20 years of low-power leadership and expertise to provide maximum performance with optimal power efficiency. This MSP432 MCU platform is built around the high performance ARM® Cortex®-M4F core, featuring DSP extensions and an integrated floating-point engine. It is the most power-efficient processor available today.

Texas Instruments has been a primary innovator of technology for embedded developers who are designing low-power applications. TI's ultra-low-power MSP430™ microcontroller (MCU) family serves as the core in an extensive range of applications on the market today. Its 16-bit architecture and extremely low sleep current make it ideal for battery-operated devices, especially coin cell and energy harvesting applications.

While the market requires better power performance, it also continuously demands more functionality from devices. The challenge many developers face today is maintaining or improving battery operating life while simultaneously increasing a device's capabilities. Adding to this challenge are the tightly constrained energy limitations placed on designs. For many devices, it is not feasible to increase battery size or capacity; this means developers need to achieve higher performance within the same power footprint if battery life is not to be compromised.

In addition to these challenges, the market demands new product releases meet aggressive deadlines, even though system design continues to become more complex. Developers need a comprehensive set of hardware and software tools that enable them to extract the maximum performance at the lowest possible power.

Finally, there needs to be room for future expansion as applications continue to integrate greater functionality. As MCU portfolios expand to address these needs, there must be seamless portability of both driver-level and application code across platforms.

An MCU designed for optimizing low power and high performance

TI has recently expanded the low-power foundation of its MSP430 MCU platform to include higher performance levels without sacrificing power budgets. Based on the 32-bit ARM® Cortex®-M4F core, the new MSP432 MCU platform leverages TI's low-power design expertise to provide maximum performance with optimal energy efficiency. This MCU is the most power-efficient Cortex-M4F-based platform available today[1], with a ULPBench score of 167.4

The MSP432 MCU platform also offers embedded developers a complete silicon, software and ecosystem solution that enables them to bring innovative products to market quickly. With the addition of the MSP432 MCU platform, the MSP MCU product line now provides a complete portfolio, from ultra-low power 16-bit flash and FRAM-based MCUs to high performance, low power 32-bit ARM Cortex-M4F devices.

The MSP432 MCU platform is built around the high performance ARM Cortex-M4F core, featuring DSP extensions and an integrated floating-point engine.

[1]Based on the Embedded Microprocessor Benchmark Consortium (EEMBC) ultra-low-power benchmark (ULPBench) scores posted as of 03/24/2015.

This 48MHz core supports the full ARM instruction set (M0+, M3, and M4) with optimizations such as advanced instructions that enable the Cortex-M4F core to outperform Cortex-M0+ solutions by 50 percent based on CoreMark performance.

MSP432 MCUs enable developers to optimize performance without compromising their power budget. MSP432 MCUs consume only 95µA/MHz in active mode and 850nA in standby mode (including RTC). This is especially important in ultra-low-power embedded applications where leakage current is critical to battery life, such as industrial and building automation, industrial sensing, industrial security panels, asset tracking and consumer electronics where both efficient data processing and enhanced low-power operation are essential. For example, MSP432 MCU's ultra-low-power LPM3 standby current as low as 850nA is well-suited for applications like flow metering where a single battery may have to last 20+ years in the field. It also provides an ideal architecture for existing MSP430 MCU embedded developers looking for additional performance, TI's TM4C-based designers looking for lower power or smaller-sized ARM Cortex-M4F options, or ARM developers looking for the optimal balance of low power and high performance.

Striking the balance between low-power and high performance

The excellent performance and power efficiency of MSP432 MCUs are achieved through three dimensions of innovation: its ARM Cortex-M4F core and MSP432 performance optimizations, TI's low-power DNA, and its optimized software offering and comprehensive toolsets.

ARM Cortex-M4F core and MSP432 performance optimizations

There are several key advantages the Cortex-M4F core brings to the MSP MCU portfolio (Figure 1):

- **32-bit performance:** MSP432 MCUs increase performance by moving from 16-bit processing to 32-bits. This enables systems to perform more work with each instruction, whether by moving data twice as quickly or processing complex algorithms with fewer instructions.
- **Four times the power efficiency:** The MSP432 platform, with its Cortex-M4F core, provides up to twice the performance of Cortex-M3 solutions depending on the complexity of the application, while consuming only half the power. This means MSP432 MCUs can perform up to four times the amount of work for the same power as competitive Cortex-M3 solutions. MSP432 MCUs achieve a Coremark score of 3.41, defined by ARM as the score for an optimal implementation.
- **Integrated signal processing:** The integrated DSP engine and floating-point core in MSP432 MCUs enable a multitude of high-performance applications that require compute-intensive functionality, including signal conditioning and sensor processing. In addition, the Cortex-M4F executes floating-point code approximately 10 times faster than the Cortex-M3.
- **Standardized core:** By moving to a standardized core, MSP432 MCUs give developers more flexibility in terms of the large ARM ecosystem and wider variety of off-the-shelf software available.

TI has maximized the performance and efficiency on MSP432 MCUs by incorporating numerous high performance peripherals and features (Figure 1). Combined, these reduce power consumption by enabling the MCU to perform more work in fewer cycles.

- **128-bit flash buffer pre-fetch:** The MSP432 MCU platform employs predictive instruction pre-fetching to read up to eight instructions at a time. By pre-fetching instructions, this feature reduces the number of accesses to flash to load program

code. Because the flash has two wait states at 48 MHz, this in turn reduces the overall number of wait states, thus speeding execution.

- **1 MSPS ADC:** This fast, 14-bit analog-to-digital converter (ADC) provides five times the sampling speed of the fastest MSP430 MCU, while retaining low-power operation (only 375uA at full speed). With up to 32 channels for simultaneously sampling, MSP432 MCUs can read data quickly, enabling the processor to minimize sampling time and complete operations faster.
- **8-channel DMA:** By supporting eight DMA channels, MSP432 MCUs are able to offload more memory transactions from the CPU. In addition, having more channels simplifies configuration as well as gives embedded developers greater flexibility in how they optimize memory operations.
- **Bit-banded SRAM and peripheral access:** MSP432 MCUs assign every SRAM and register memory bit a unique 32-bit address, enabling developers direct access to individual SRAM and register bits. This simplifies and accelerates bit-based operations; rather than having to perform a read/modify/write sequence to change a single bit, this action can be completed with a single write. In addition, the SRAM provides single-cycle access at 48 MHz.
- **Nested vector interrupt controller (NVIC):** The NVIC uses tail-chaining to optimize the delay between multiple interrupts, resulting in faster interrupt switching.
- **Advanced cryptographic accelerators:** Hardware-based AES-256 security protects data transmissions without adversely impacting power consumption.
- **ROM-based drivers:** The driver library associated with MSP432 MCUs has already been programmed into ROM. At 48 MHz, the MCU can execute from ROM every cycle, compared to up to three cycles for flash. This results in faster execution and lower power consumption without consuming available code space. The driver

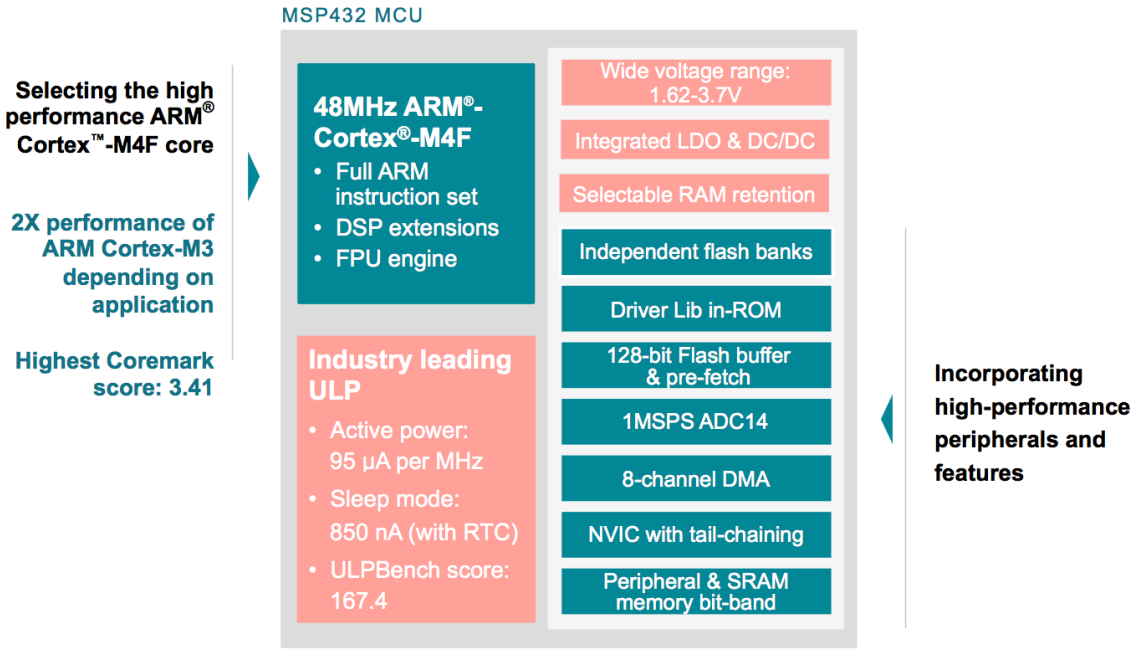

Figure 1: *The MSP432 MCU high performance peripherals and features complement the high performance ARM Cortex-M4F core to enable the maximum performance for low-power applications.*

MSP432 MCUs	Active	LPM0	Low-Frequency LPM0	LPM3	LPM3.5 (Shut down w/ RTC)	LPM4.5 (Shut down w/o RTC)
Current	95 µA/MHZ (DCDC); 166 µA/MHz (LDO)	65 µA/MHz (DCDC); 100 µA/MHz (LDO)	70 µA	850 nA	<670 nA	<100 nA

Table 1: *Low-power modes on the new MSP432 MCU platform.*

library source code is also provided under open-source BSD license, providing developers with the option to further customize to their specific application requirements.

- **Simultaneous flash read/write:** Traditionally, flash memory is implemented as a single bank. This means any erase will stall execution of the application. MSP432 MCUs offer a dual-bank flash. With two banks, the CPU can read/execute in one bank while erasing in the other, thus avoiding stalls. This is especially useful for Internet of Things (IoT) devices with limited memory and power availability. While erasing, such as is necessary when updating firmware or data logging, the device can execute at the same time. By taking less time to perform these functions, power consumption is reduced. In addition, MSP432 MCUs also include secure memory regions to protect both code and data from external attacks.

MSP's low-power DNA

MSP432 MCUs are built using the same low-power DNA and expertise of 16-bit MSP430 MCUs to make the most efficient core implementation. This means power efficiency is paramount, enabling the MSP432 MCUs to establish a new standard of 32-bit low-power and performance.

These new MSP432 MCUs have been optimized for power in both its silicon and software implementation (Figure 2). Several capabilities reduce overall power consumption:

- **90 nm process node technology:** The TI-developed 90 nm process node technology enables low-active power consumption and low-leakage operation.
- **Flexible low-power modes:** MSP432 MCUs support five low-power modes to enable low-power consumption.
- **Fast time-to-wake:** MSP432 MCUs can switch from LPM3 to active mode in less than 10 µs, typical.
- **Wide operating voltage range:** By supporting a wide voltage range from 1.62 to 3.7 V, the MSP432 MCU platform can be scaled to match the particular battery in use and eliminate external regulation. Many MCUs also scale performance with voltage; as the voltage drops, the MCU's core can only operate at a reduced frequency. This increases power consumption since the MCU must stay awake longer to perform an equivalent amount of work. With MSP432 MCUs, however, the core is able to operate at full speed at the lowest voltage. Thus, operating at a lower voltage gives a true and full improvement in power efficiency. Furthermore, flash can also be accessed at 1.62V.
- **Integrated LDO and DC/DC:** To further increase power efficiency and reduce design complexity and cost, MSP432 MCUs integrate both a low-dropout regulator (LDO) and DC/DC convertor. When the LDO is used for power regulation, the system is capable of faster switching between sleep and active modes. When the DC/DC

convertor is used, the system can achieve efficiency up to 95 percent. Typically, developers have to choose between using either an LDO or DC/DC convertor for all use cases. By providing two options for power regulation, developers can dynamically optimize regulation based on the current mode of operation. When the system is in a standby mode of operation, for example, the LDO can be used to minimize wake time. For operating modes or use cases where active current plays a larger role in power consumption, the DC/DC convertor can be used.

- **Selectable RAM retention:** The low-power MSP432 MCU platform provides individual control of its eight RAM banks. This enables developers to be able to turn off those banks that are currently not needed and whose data does not need to be preserved. For example, when the system is sleeping, RAM banks used as scratch pads or to buffer data are not in use and can be turned off.
- **Setting a new power-efficiency standard** Understanding the real-world power efficiency of an MCU early in the design process is critical. Today's developers face countless challenges while searching for the best ultra-low-power MCU for their design. Having to select among multiple MCU vendors and products makes selecting the best ultra-low-power device very challenging. The Embedded Microprocessor Benchmark Consortium (EEMBC) ultra-low power benchmark (ULPBench) now provides a standard way to compare power performance on any microcontroller.

With a score of 167.4 ULPMarks, the MSP432 MCU platform achieves the highest ULPBench score for any Cortex-M3 or Cortex-M4F MCU available today. This means it provides more performance for the power than any other processor of its type in the industry, including Cortex-M0+, -M3, -M4, and -M4F cores or other 8-, 16- and 32-bit proprietary cores.

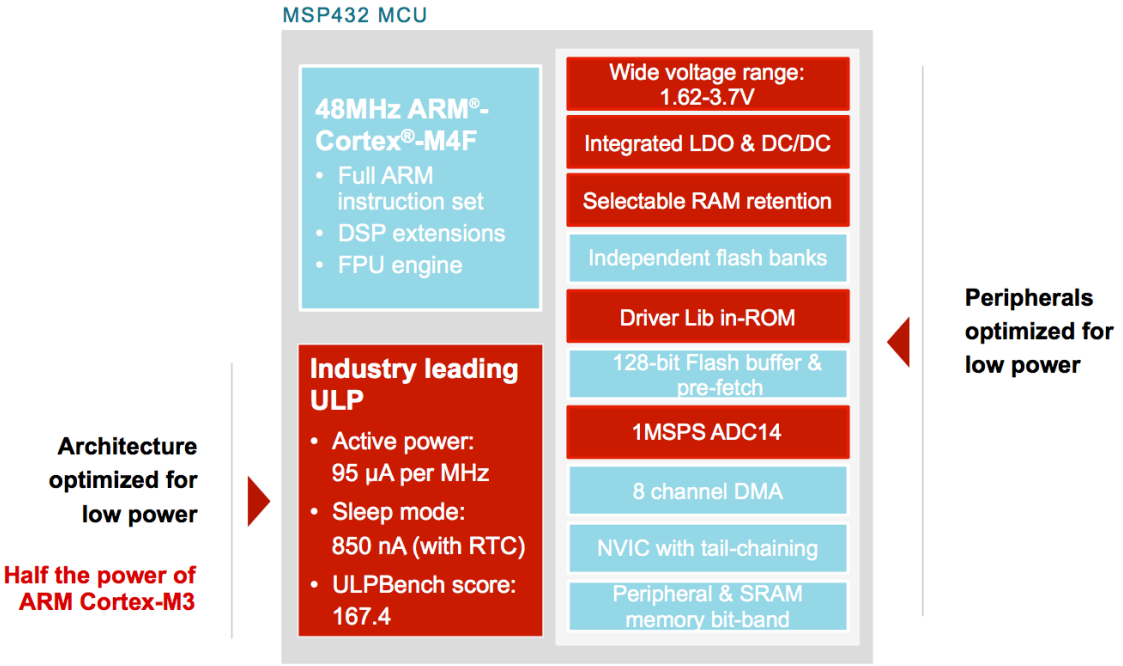

Figure 2: *MSP432 MCUs have been optimized for power in both its architecture and peripherals.*

Optimized software offering and comprehensive toolsets

While an MCU's architecture itself may be efficient, it is how easily developers can access this efficiency that determines a system's actual power consumption and operating life. To aid developers in both simplifying development and designing systems for power efficiency, TI has optimized its software and tools with power in mind.

- **Rapid prototyping:** Developers can evaluate the performance and power efficiency of MSP432 MCUs for themselves with a LaunchPad development kit. Priced at $12.99, this rapid prototyping kit is a cost-effective way to experience the advantages of the MSP432 MCU architecture firsthand. A full suite of add-on daughter-boards called BoosterPacks – including displays, wireless, MicroSD, and sensor hubs, enable developers to extend their evaluation of the MSP432 MCU platform to specific applications.

- **EnergyTrace™+ Technology:** EnergyTrace+ technology is a powerful design tool that enables developers to profile an application's real-time power consumption with an accuracy of ± 2 percent. Not only does it evaluate overall power efficiency, it correlates power consumption to the actual code that uses the power. This enables developers to determine how and where power is being consumed so they can direct their optimization efforts to those areas that will yield the most gains. EnergyTrace+ technology is built into the LaunchPad development platform and provides a high level of visibility into application power consumption.

- **ULP Advisor™:** TI has also extended its ULP Advisor software to support the specific capabilities of the MSP432 MCU platform. ULP Advisor is built upon TI's more than 20 years of ultra-low-power expertise and offers suggestions to developers on how to adjust application code and improve power efficiency.

- **MSPWare™ software:** In conjunction with the launch of MSP432 MCUs, TI has released a new version of MSPWare software. MSPWare serves as a single-point resource of comprehensive technical materials for accelerating MSP-based designs (Figure 3). Materials include detailed application notes, code examples, training and videos. To further simplify design, MSPWare software is available in your browser through CCS Cloud, or on the desktop ready to use with TI's Code Composer Studio™, IAR's Embedded Workbench, and Keil µVision integrated development environments (IDEs). This also includes support for Energia.

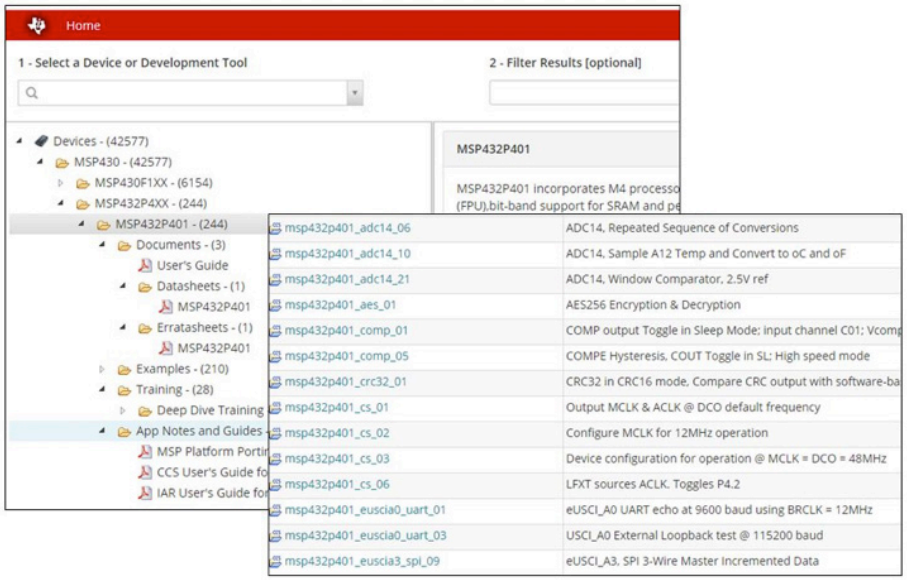

Figure 3: *The latest release of MSPWare supports the MSP432 MCU platform and provides a single-point resource of comprehensive technical materials and code examples to accelerate design.*

- TI's new Cloud Development Ecosystem enables developers to run TI's Code Composer Studio and Resource Explorer from a browser. The LaunchPad kit connects to the computer via a USB cable and the TI cloud website will automatically install any drivers required to access the board. Demo applications and example code can be accessed and downloaded to development boards in just minutes for an immediate out-of-box experience. Embedded developers can now create software in the cloud as well as access more than 20,000 sample applications online to jumpstart designs.

- **ARM Ecosystem:** Developers can also speed development using tools and design assistance available through both the TI and ARM third-party ecosystems. The MSP432 MCU platform is supported by several full-featured development environments, ARM CMSIS software libraries, as well as by TI RTOS, freeRTOS and Micrium µC/OS. These real-time operating systems can help developers maximize performance in multi-threaded applications to reduce overall power consumption.

The architecture for an entire product line

The MSP432 MCU platform extends TI's low-power MSP MCU portfolio, enabling applications built around 16-bit MSP430 MCUs to scale to higher levels of performance without requiring a complete system redesign. The MSP432 MCU platform also provides a power-optimized roadmap for existing ARM Cortex-M developers with low power needs.

Applications requiring a scalable portfolio

With MSP432 MCUs, the low-power MSP family of MCUs can support extended product lines or hierarchical applications such as sensor networks. For example, a first-generation fitness watch based on an MSP430 MCU might have tracked exercise time and calories. To remain competitive or to address new markets, a next-generation watch might introduce heart rate monitoring, activity detection, GPS for positioning, Bluetooth® Smart for wireless connectivity or a more complex display supporting color or graphics. All of these require additional processing capability, which is now available through the 32-bit MSP432 MCU platform based on the ARM Cortex-M4F core.

MSP432 MCUs also enable embedded developers to support increasing complexity in a product line. For example, with the emergence of the IoT, sensor networks like those in a factory or other industrial applications have become more complex. An aggregator needs to be able to connect to sensors (e.g. via Sub-1GHz connectivity) and send data up to a centralized management panel (e.g. via Wi-Fi). Thus the aggregator needs to support multiple protocols, requiring more memory and performance. Furthermore, an aggregator can add intelligence. In this way, it processes data, evaluates it and even makes decisions such as triggering an alarm if a threshold is exceeded.

The 16- and 32-bit MSP MCU portfolio can support this entire product line. Various MSP430 MCUs are ideal for individual sensor nodes running on batteries. The MSP432 platform provides the processing and power efficiency to support an intelligent hub with control panel, user interface and display.

MSP430 to MSP432 MCU porting

As part of the MSPWare software package, developers also have access to the MSP432 MCU Platform Porting Guide. This guide outlines how to port existing MSP430 MCU designs to take advantage of MSP432 MCU's 32-bit bus and peripherals. This usage and porting guide suggests areas of application code to review when migrating to 32 bits.

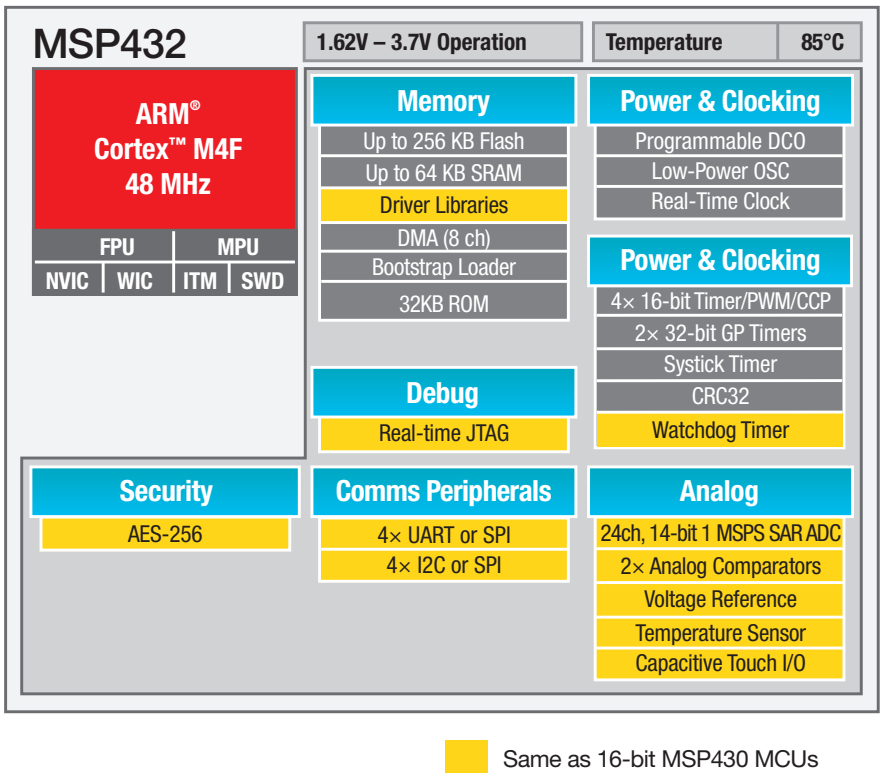

Figure 4: *Porting to the MSP432 platform from MSP430-based designs is simplified since the MSP432 MCU retains many of the key peripherals of the MSP430 MCU's architecture (shown in yellow)*

MSP432 MCUs retain many of the key peripherals of the MSP430 MCU architecture (Figure 4 shows all peripherals in yellow that are the same between the two architectures), so porting peripheral code is greatly simplified. TI has also kept register and low-power peripherals names consistent to enable designs to be easily ported among the more than 450 low-power MSP MCUs.

For new designs, developers can use the MSPWare driver library with its proven and production-ready drivers to greatly speed development. For embedded developers who have created their own register-level drivers, MSPWare encapsulates both register-level and library drivers. Experienced ARM developers can also leverage their knowledge of ARM's Cortex-M Software Interface Standard (CMSIS) functions to develop code.

MSP432 MCUs: low power at its best, performance at its core.

Developers need an architecture that can scale to higher levels of computing and analog performance without adversely impacting power efficiency. They also need to be able to do this while leveraging existing MCU development investment and expertise. As the world's lowest power ARM Cortex-M4F MCU, MSP432 MCUs simultaneously boost performance and decrease power consumption by more than 50 percent. Developers are able to leverage their existing investment and expertise in the MSP430 MCU architecture to easily scale application performance. With its expanded development ecosystem, developers can achieve seamless portability between 16-bit MSP430 and 32-bit MSP432 MCU designs. In addition, they can

optimize power efficiency and maximize performance with TI's extensive selection of easy-to-use MSP and ARM hardware and software tools.

With the addition of MSP432 MCUs, the low-power MSP microcontroller portfolio gives developers a wide choice of processors, enabling developers to optimize for low-power and high performance and the flexibility to easily port between 16-bit and 32-bit architectures. In addition, as the flagship device in the MSP's growing low-power 32-bit ARM processor portfolio, the MSP432 MCU family will offer increasing levels of analog and memory integration to address new application segments.

Get started evaluating this new 32-bit low-power MCU platform with the MSP432 LaunchPad and MSPWare software by visiting www.ti.com/msp432.

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