IoT provokes change in ultra-low-power MCUs

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Introduction

The ultra-low-power (ULP) microcontroller (MCU) market has seen an immense transformation. In the past 25 years, the industry has made a very purposeful effort toward energy conservation. With an increased emphasis on battery-powered applications and options to include wireless connectivity technology, ULP MCUs are a basic requirement.

Released in March 2014, the ULPBench™ benchmark helped standardize ULP parameters, providing a methodology to reliably and equitably measure MCU energy efficiency. Before that time, there were not any options to compare two MCUs that both claimed to be ULP. The ULPBench working group within the Embedded Microprocessor Benchmark Consortium (EEMBC®) organization set out to define and publish a tool set of standardized benchmarks that would enable developers to compare MCUs from different vendors and feature sets [central processing unit (CPU) power consumption, peripheral implementations, etc.]. The release of the ULPBench CoreProfile, a benchmark tool for ULP MCUs, was the first step toward solving this problem. The tool provides a numerical score based on pre-determined conditions; the higher the score, the lower the power consumption. This tool has been instrumental in qualifying ULP leaders in the industry. This score demonstrates how the gap in ULP power consumption in the MCU industry has diminished over time.

Although the ULP score gap across MCU vendors has dropped, the need for lower power not only continues to persist, but is expected to increase in the coming years, especially as applications get smarter. Although these tools have effectively introduced a technical standard in the industry, the fact is that the end application needs significant power savings to make a difference. In this paper, we'll discuss how the foundation of peripheral intelligence in the TI SimpleLink™ MCU portfolio is addressing a change in the industry, enabling designers of sensor-based applications to further differentiate their products with increased intelligence without compromising ULP requirements.

The big three

The three main vectors that influence the power profile of a MCU include:

- Performance.
- Memory.
- Leakage.

Historically, a low-power MCU also implied lower performance; vendors initially offered multiple power states, at which point leakage current significantly contributed to the overall system power. Evaluating operating current in milliwatts per megahertz (mW/MHz) and sleep-mode leakage had become increasingly difficult given that MCUs offered multiple power states. There was no standard way to describe, specify or characterize low-power operations until the ULPBench benchmark came along.

ULPBench uses two main knobs to evaluate the big three vectors that influence the power profiles in an MCU: the CPU and real-time clock. This benchmark has the MCU perform a fixed, defined task of active work once a second and sleep the remainder of that same second. Each processor performs the same workload. Many applications that need ULP performance have long periods of hiatus with short intervals of response to multiple events. In such applications, three main factors influence platform reliability:

- Wake-up time.
- Wake-up energy and peak current.
- Execution time.

The ULPBench benchmark mainly focuses on the parameters above, creating a baseline so designers can select the right platform. The [foundation of ULPBench] is:

- Comparability: make it easy to compare devices.
- Transparency: make all measurements and the setup process transparent.
- Reproducibility: make it easy to for anyone to reproduce the benchmark scores.

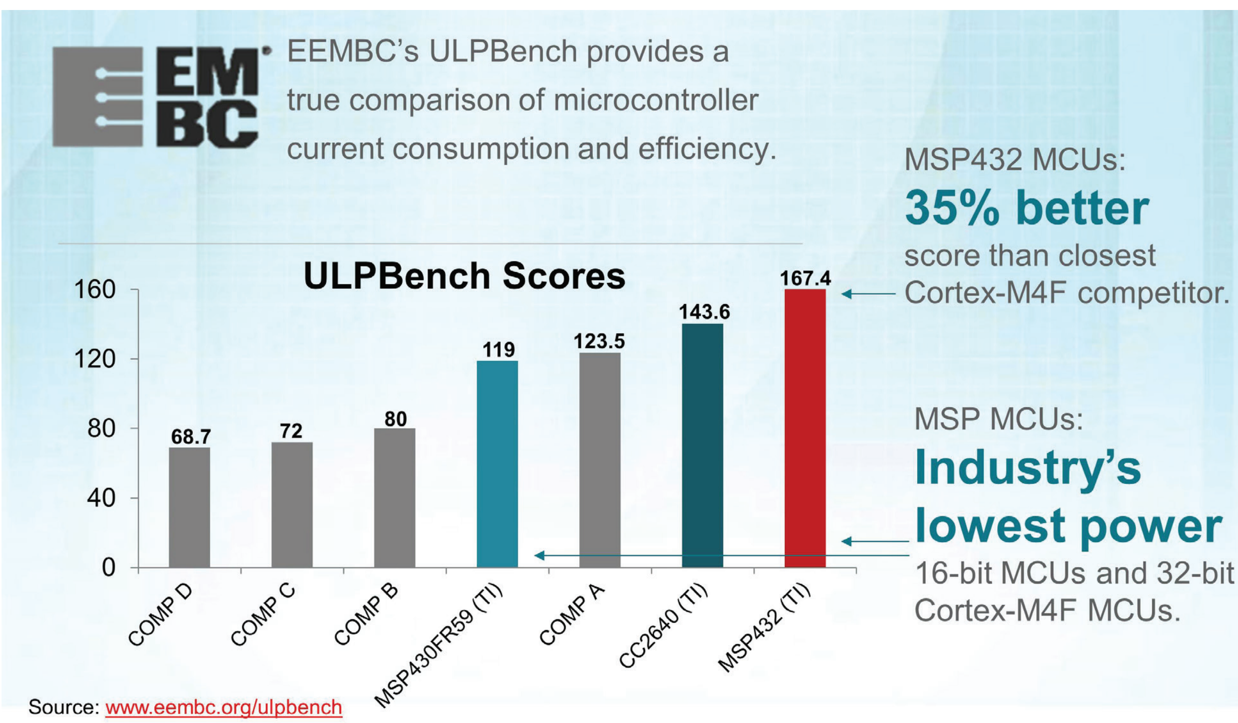

Figure 1. *MSP432™ MCUs at launch in March 2015 highlighted the low ULPBench scores.*

ULPBench score has been used for marketing purposes to highlight TI's ULP leadership in recent product announcements. For instance, at the time of launch, the Texas Instruments MSP432™ platform was the lowest-power ARM® Cortex®-M3 or -M4 solution available in the market.

Sensor-to-cloud applications

While the big three continue to make up a large share of ULP applications, with an increasing need for sensing and measurement in applications, designers cannot ignore overall system power. The EEMBC group is working through the next level of benchmarking with a focus on peripherals (Peripheral Profile) as they identify the same gaps outlined in the paper thus far.

One of the biggest challenges in the definition of the Peripheral Profile benchmark is the identification of the most common feature set. For example, a 14-bit analog-to-digital converter (ADC) might require more energy than an 8-bit converter, or could become more power-efficient while delivering significantly higher resolution and accuracy. Limiting the benchmark to a fixed ADC resolution will, on the other hand, exclude a lot of devices without this resolution. And then there's the resolution vs. the effective number of bits. For example, an ADC might deliver a 12-bit result, but maybe only 10 bits are of value. Comparing two devices with very different value propositions undermines the quality of the benchmark, and hence the score that a designer can benefit from when making vendor decisions. This approach will always result in a compromise.

What is the future of benchmarks in ULP? ULP is now mainly technology driven, and most semiconductor vendors now build devices with mostly comparable results. Process structure size determines the active current, meaning that smaller structures give smaller active currents when combined with well-designed CPU cores. Another concern is standby current, which has a negative impact on the structure size of the silicon: smaller structure sizes increase leakage current. Special low-leakage processes help keep leakage current well controlled in most chip-manufacturing foundries. Implementing power gating (supported by design tools) also controls leakage current.

TI SimpleLink microcontrollers – ULP sensing and measurement

To discuss ULP sensing and measurement, let's look at case studies across the TI SimpleLink MCU portfolio. **Figure 2** highlights various building automation applications, which includes sensing and measurement technology. The breadth of TI's SimpleLink MCU options with wired and wireless connectivity facilitates a discussion of ULP application use cases, all leveraging one single development platform.

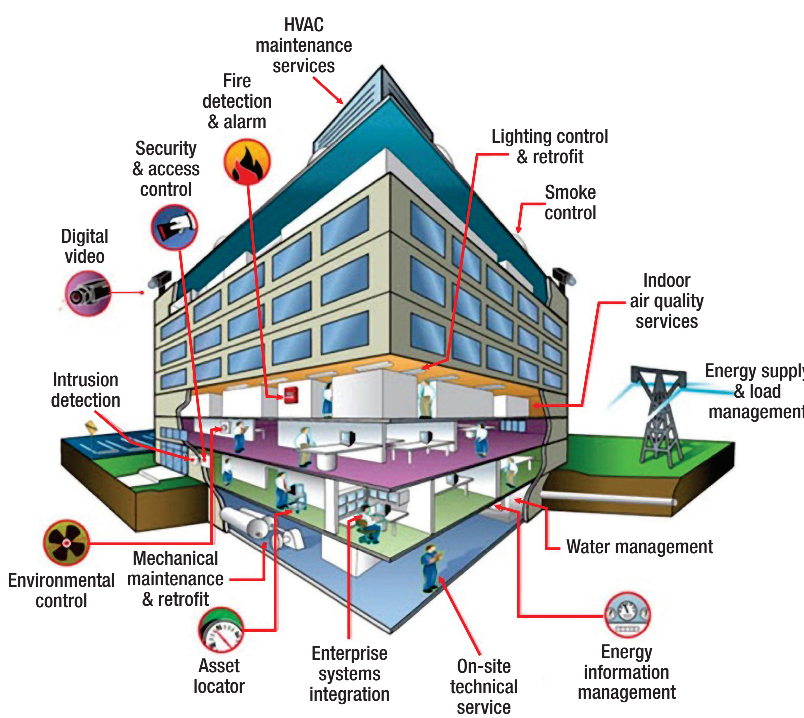

***Figure 2**. Building automation system.*

Developing a wired weather station with sensing using a high-resolution ADC

The SimpleLink MSP432 MCU family is TI's latest addition to its portfolio of efficient ULP mixed-signal MCUs. MSP432 MCUs feature the ARM Cortex-M4 processor (**Figure 3**) in a wide configuration of device options including a rich set of analog, timing and communication peripherals, thereby catering to many application scenarios where both efficient data processing and enhanced low-power operation are paramount.

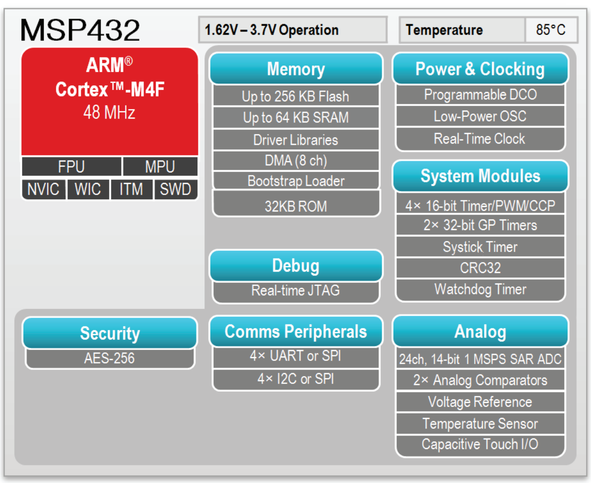

***Figure 3**. SimpleLink MSP432 MCU with 14-bit ADC.*

With a 14-bit ADC, the SimpleLink MSP432 MCU meets the system's sensing requirements for measuring analog signals with a high resolution and sampling rate. A 14-bit ADC with 1MSPS could sense temperature and oxygen levels in a building automation weather station. Having the ADC integrated in the ULP MCU provides a low-power ADC solution for sensing and offers the flexibility to program the sensors, leveraging the Cortex-M4F core in the process.

Connected weather station

Wi-Fi®

System power consumed by any application depends on its operational use case. For instance, a Wi-Fi network processor may be always connected or connect intermittently to transmit data. Or it could be event-triggered, in which case it may spend most of its time in sleep mode. Efficient programming of the SimpleLink Wi-Fi CC3220 wireless MCU in these various low-power modes maximizes its low-power operational efficiency (**Figure 4**).

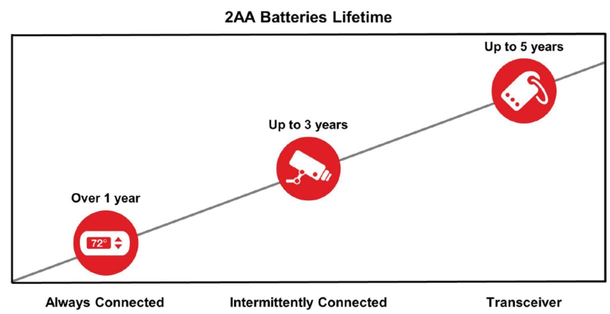

***Figure 4**. The impact on battery life for various applications using a SimpleLink CC3220 wireless MCU.*

Additionally, the SimpleLink CC3220 wireless MCU has two separate execution environments: a user application-dedicated ARM Cortex-M4 MCU, and a network processor MCU to run all Wi-Fi and Internet logical layers. In a weather station application use case, the application's MCU can be used 100% toward the weather station application, while the network processor core is configured for the low-power use (**Figure 5**).

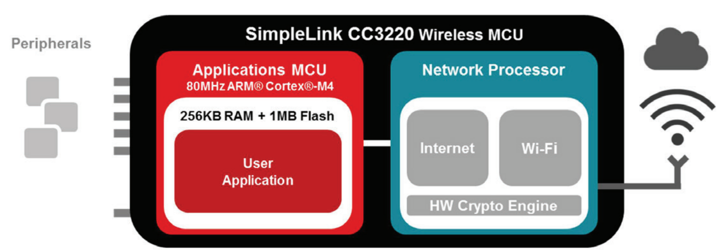

***Figure 5**. Block diagram of a SimpleLink CC3220 wireless MCU.*

The CC3220 MCU has integrated technology to help optimize energy consumption in various Wi-Fi networks and devices. The SimpleLink connection manager enables autonomous and fast Wi-Fi connections, eliminating the need for the application MCU to be in active mode, draining additional energy. The CC3220 wireless MCU also includes flexible Wi-Fi provisioning with SmartConfig™ technology, access point mode with connection up to four stations and Wi-Fi protected setup (WPS2) options.

Bluetooth® low energy

Along with the Cortex-M3 core running at 48 MHz, the SimpleLink Bluetooth low-energy CC2640R2F device (**Figure 6**) includes a ULP sensor controller. This 16-bit CPU is coupled with peripherals like an ADC, analog comparators, Serial Peripheral Interface (SPI)/I^2C and capacitive touch. It runs autonomously when the rest of the system is in standby mode and interfaces with external analog or digital sensors in a very-low-power manner. In a weather station, the sensor controller performs the sensing while the system is in low-power mode. The main Cortex-M3 core and radio-frequency (RF) transmission are enabled based on the weather station application demand, ultimately lowering the power consumption of the system versus having the ARM Cortex-M3 manage and complete all tasks.

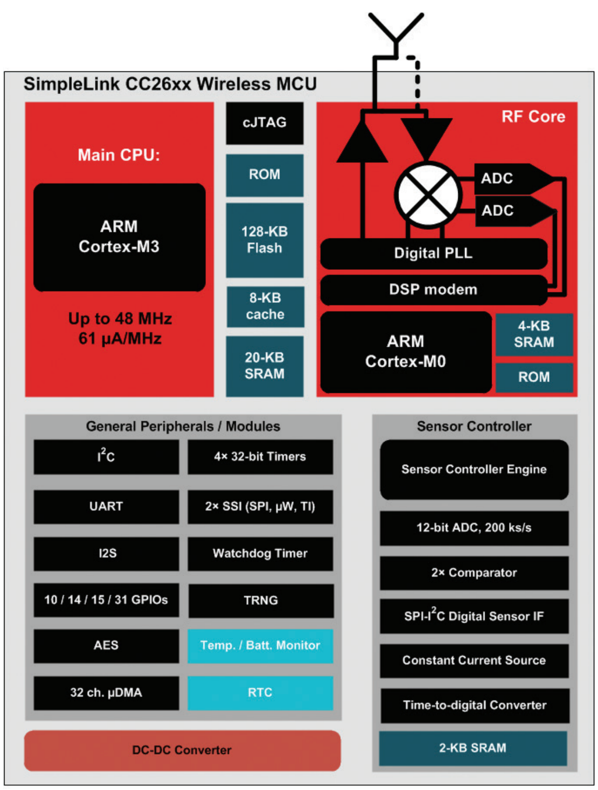

***Figure 6**. SimpleLink CC26xx wireless MCU functional diagram.*

The CC2640R2F wireless MCU is also optimized for 2.4-GHz frequency operations and is integrated with a Bluetooth low energy controller and host libraries embedded in read-only memory (ROM) and running partially on an ARM Cortex-M0 processor. This architecture improves the overall system performance and power consumption and frees up significant amounts of Flash memory for the application itself. Traditionally, the peak drain caused by high transmit and receive currents of wireless solutions puts constraints on the batteries, or significantly affects battery life. With the CC2640R2F wireless MCU's very low peak currents at around 6 mA (with receive and transmit at a 0 dBm output), there are no longer any limitations on traditional CR2032 batteries; designers can even use smaller batteries.

Sub-1 GHz

Built on the same platform as the Bluetooth low energy CC2640R2F wireless MCU, the SimpleLink Sub-1 GHz CC1310 wireless MCU is based on a tri-core architecture where the operations are efficiently partitioned between the MCU cores to optimize power performance. The main ARM Cortex-M4F CPU takes care of the protocol and applications, an ARM Cortex-M0 core handles the low-level radio interface and the innovative TI ultra-low-power sensor controller core allows the main CPU to remain in standby while this 16-bit core efficiently performs operations with single-digit, micro-ampere current consumption. This unique architecture allows the CC1310 wireless MCU to achieve tens of kilometers in range while maintaining ultra-low-power consumption, enabling the system to run for up to ten years on a coin cell battery.

The unique characteristics of Sub-1 GHz technology and the ultra-low power design of the CC1310 wireless MCU make the device uniquely qualified for many applications including, for example, a weather station. A weather station may require remote sensor nodes outside of the building or home that must run for many years and maintain a small form factor. Additionally, the TI-15.4 Stack within the SimpleLink CC13x0 SDK, a complete Sub-1 GHz star networking solution with built-in security and frequency hopping, was designed with low power optimization in mind delivering a complete, ultra-low power Sub-1 GHz solution.

A weather station application often requires a centralized dashboard where users can send and receive sensor data from the cloud. This presents the difficult design challenge of implementing a Sub-1 GHz-to-Wi-Fi gateway. The **SimpleLink Sub-1 GHz Sensor to Cloud reference design** solves this problem with an end-to-end solution enabling cloud connectivity for sending and receiving sensor data over a long-range, Sub-1 GHz star network.

The solution is built on the SimpleLink platform including the CC1310 wireless MCU, TI-15.4 Stack software and CC3220 Wi-Fi device.

TI's SimpleLink MCUs (**Figure 7**) offer the broadest portfolio of wired and wireless ARM-based MCUs with industry-leading features including low power and robust, integrated security to support more than 10 differentiated wired and wireless protocols. These devices are developed around a single software foundation providing 100% code reuse within SimpleLink software development kits (SDKs). Designers can invest in software development once and reuse it across multiple SimpleLink platforms and applications. TI's unified tool chain delivers faster development with free software tools, training and support to start designs immediately.

As the application requirements evolve one can easily add functionality such as Wi-Fi or Bluetooth low energy to a product later with reduced development efforts and without compromising on the application ULP requirements.

TI provides a comprehensive set of application programming interfaces (APIs) that go beyond peripheral configuration to offer full-featured

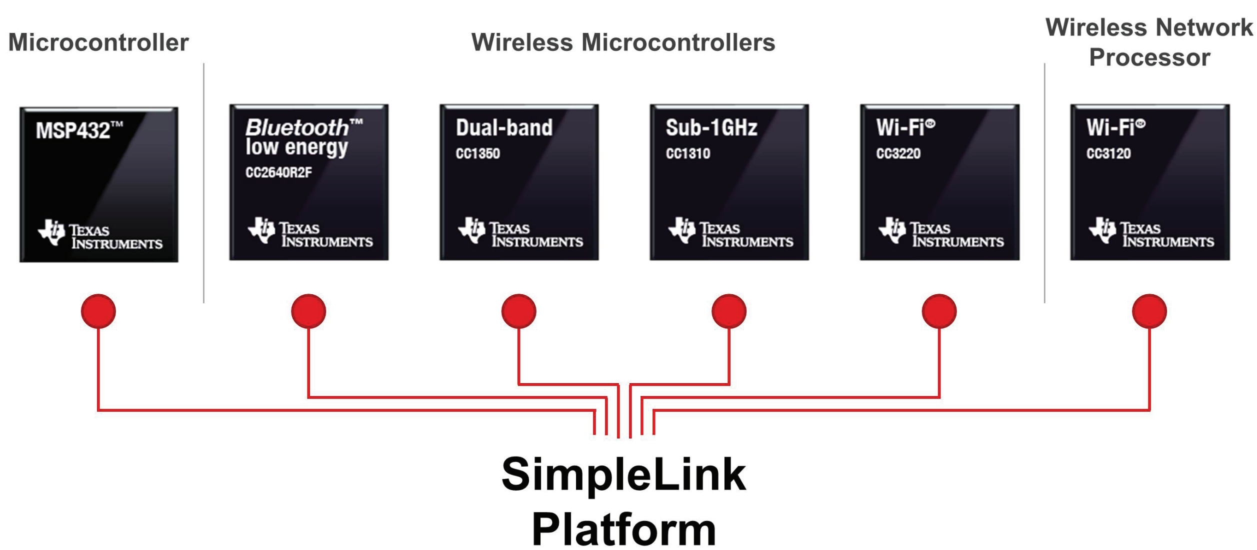

***Figure 7**. SimpleLink MCUs and network processors.*

functionality encapsulated in easy-to-use code. These standardized Portable Operating System Interface (POSIX)-compliant APIs interface with TI drivers, the essential building blocks of your application, to make development easy and enable complete code portability across all SimpleLink products.

For more detailed information about TI's SimpleLink MCU platform, as well as software and hardware tools, see www.ti.com/simplelinkulp.

Conclusion

With an ever-increasing need for advanced sensing and measurement, the system complexity of Internet of Things (IoT) devices is increasing exponentially. Energy conservation policies are requiring that product developers provide increased complexity with smaller energy consumption. Solving the needs for ULP will inspire a new wave of innovation. By selectively tailoring intelligence to the peripherals based on the end application, TI SimpleLink MCUs are transforming the ULP landscape.

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