Getting More for Less

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Taking ultra low power to the extreme can help designers get 20 years or more up-time from a single cell battery.

The deployment of 'energy sensitive applications' is increasing and it refers to devices that must – for a variety of reasons – operate for extended periods of time from a single battery. Typically this includes applications such as energy metering, sensor networks or other forms of environmental monitoring, where the duty cycle of the device is low and is therefore expected to operate for many years without user intervention.

Many of these devices will use the popular CR2032 coin cell; a 3V lithium/manganese dioxide primary cell. Working to an end-point voltage of 2V with 5.6kΩ load, these cells have a typical capacity of 230mAh, which equates to a discharge of about 0.5mA, giving them a lifetime of around 400hours. However, this design of cell has a self-discharge rate of around 0.25µA, meaning it has a shelf-life of up to 20 years. Between these two extremes lie energy sensitive applications; devices that can operate at low voltages, consuming minimal current, yet providing reliable, sustainable functionality. It is clear, therefore, that any application hoping to achieve a similar active life from a single cell will need to be able to sustain an average demand of around 0.25µA.

Figure 1: A new generation of gas, electricity and water metering products will be expected to report their readings regularly for billing and resource-management, while operating unattended for as long as two decades.

The reason why such a long lifetime is needed relates to the application area. Often this emerging class of device is aimed at consumers, where the retail price can't support battery replacement. It may also refer to applications that are deployed to inaccessible areas and must therefore operate reliably, for many years, without additional power. Importantly, it is a growing application area and one that has created demand for extremely low power integrated solutions.

Historically these applications would comprise a low power microcontroller that is tasked with providing all of the computing effort needed, while also managing its own sleep cycles to conserve power. Microcontrollers are typically physically small in terms of transistor count and it follows that their design minimizes both active power consumption and passive leakage – a significant concern in ultra low power design, particularly as the process node shrinks. The microcontroller in these applications will ideally spend as much time as possible in a sleep mode; up to 99.9% of the time is not uncommon for devices that are charged simply with making rudimentary measurements periodically.

Predominantly, therefore, this approach focuses on lowering the amount of power conserved during those periods of sleep and in this respect technology has reached an impasse in terms of the levels of power conservation they can achieve.

Fundamentally this approach is also challenged in terms of the limits in active power consumption it can achieve, based on the product of the power required per processing clock cycle and the number of clock cycles needed to complete the processing tasks.

With demand building for ever longer up-times, the industry is now looking at the problem holistically, taking into account how energy is used not only in sleep modes, but in every mode of operation. Developing solutions tailored more closely to the way in which these applications consume resources enables the development of products that can operate for 10, 15 or even 20 years from a single primary battery cell.

EFM32 @ 3 V	EM0 "Run Mode"	EM1 "Sleep Mode"	EM2 "Deep Sleep Mode"	EM3 "Stop Mode"	EM4 "Shutoff Mode"
Current Consumption	180 µA/MHz	45 µA/MHz	0.9 µA	0.6 µA	20 nA
Wake-up Time	-	0	2 µs	2 µs	160 µs
CPU	On	-	-	-	-
High Frequency Peripherals	Available	-	-	-	-
Low Frequency Peripherals	Available	Available	Available	-	-
CPU and RAM Retention	On	On	On	On	-
Power-on Reset, Brown-out Detector	On	On	On	On	On

Figure 3: A key attribute of the EFM32 Gecko microcontrollers is the choice of energy modes it offers the user; for example, in the complete shut-off mode current consumption is just 20nA, and only 900nA while in deep sleep mode (maintaining power-on reset, brown-out detector, real-time clock and retains RAM content and CPU state.)

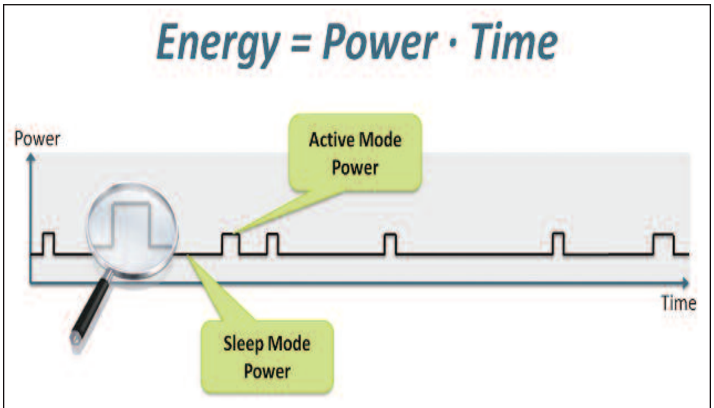

Figure 2: With a finite amount of charge available over the lifetime of a cell designers need to minimize the product of current and time over all phases of the MCU's operation – not only does every microamp count but so too does every microsecond that every action takes.

Changing Perceptions

Due to the positioning of microcontrollers, developers in this energy sensitive product sector have relied heavily on 8-bit devices. Microcontrollers carry out relatively simple tasks, relatively efficiently and so it was natural that they would be the preferred design-in for this emerging application area, where the need for processing muscle was initially limited. However as this market segment has developed it has seen increased demand for processing power, causing the microcontrollers to move out of their optimal zone of operation. The need for more sophisticated data management, interfacing and communications means that resource-limited microcontrollers can no longer deliver the highest efficiency in terms of performance and power consumption.

When faced with the need for more processing power, the natural progression would be to move to a 32-bit architecture. However this class of processor carries the perception of having higher transistor counts and consequently higher levels of static/leakage power. In truth the ARM Cortex™-M3 processor, when implemented in an extremely low leakage process, can match or improve upon the static/leakage current figures of a typical 8-bit microcontroller.

Irrespective of the static leakage, the power consumed by any core during active processing will contribute significantly to the overall power budget. In operation, the implementation of the ARM Cortex-M3 processor used by Energy Micro in its first product range, the EFM32 Gecko, consumes as little as 180µA/MHz during normal operation, significantly lower than competing architectures or other implementations of the Cortex-M3 processor. Energy Micro has achieved this by careful implementation of the low leakage process, coupled with the overriding design objective of maintaining low power operation.

Essentially, the majority of active current consumed by CMOS transistors occurs during switching. Through the development of an advanced gated synchronous clock structure, the EFM32 architecture maintains minimal bit toggling at all times, significantly reducing the amount of transistors switching needlessly. This has a dramatic effect on active power and it extends through the bus architecture, even to the way the core executes from program memory. The architecture was designed to facilitate operation directly from Flash memory, which delivers further significant power savings through a reduction in memory access.

Another significant advantage of the Cortex-M3 processor is the advanced sleep modes it offers, which are augmented further in the EFM32. As these devices will spend the majority of their operational lifetime in a sleep mode, it makes sense to offer as much flexibility as possible in the sleep modes available. The EFM32 offers five sleep modes ranging from 180µA/MHz in 'run mode' (EM0) to just 20nA in 'shutoff mode' (EM4).

The power profile of any microprocessor comprises two main elements, the baseline power – which includes the power used by functional blocks such as voltage regulators and current bias generators – and the frequency dependent element. Energy Micro's approach has been to pay particular attention to the baseline power consumption, such that it doesn't suffer at lower frequencies, as some architectures can.

The Cortex-M3™ processor-based EFM32 family focuses not only on lowering the core's power consumption, then, but also that of the supporting architecture. Functional blocks such as regulators, comparators and oscillators must all be designed with the application in mind; moving to and from sleep modes requires these functional blocks to also enter a power saving status and it is a general truism that the deeper the sleep mode the longer it takes to bring a device back up to full speed.

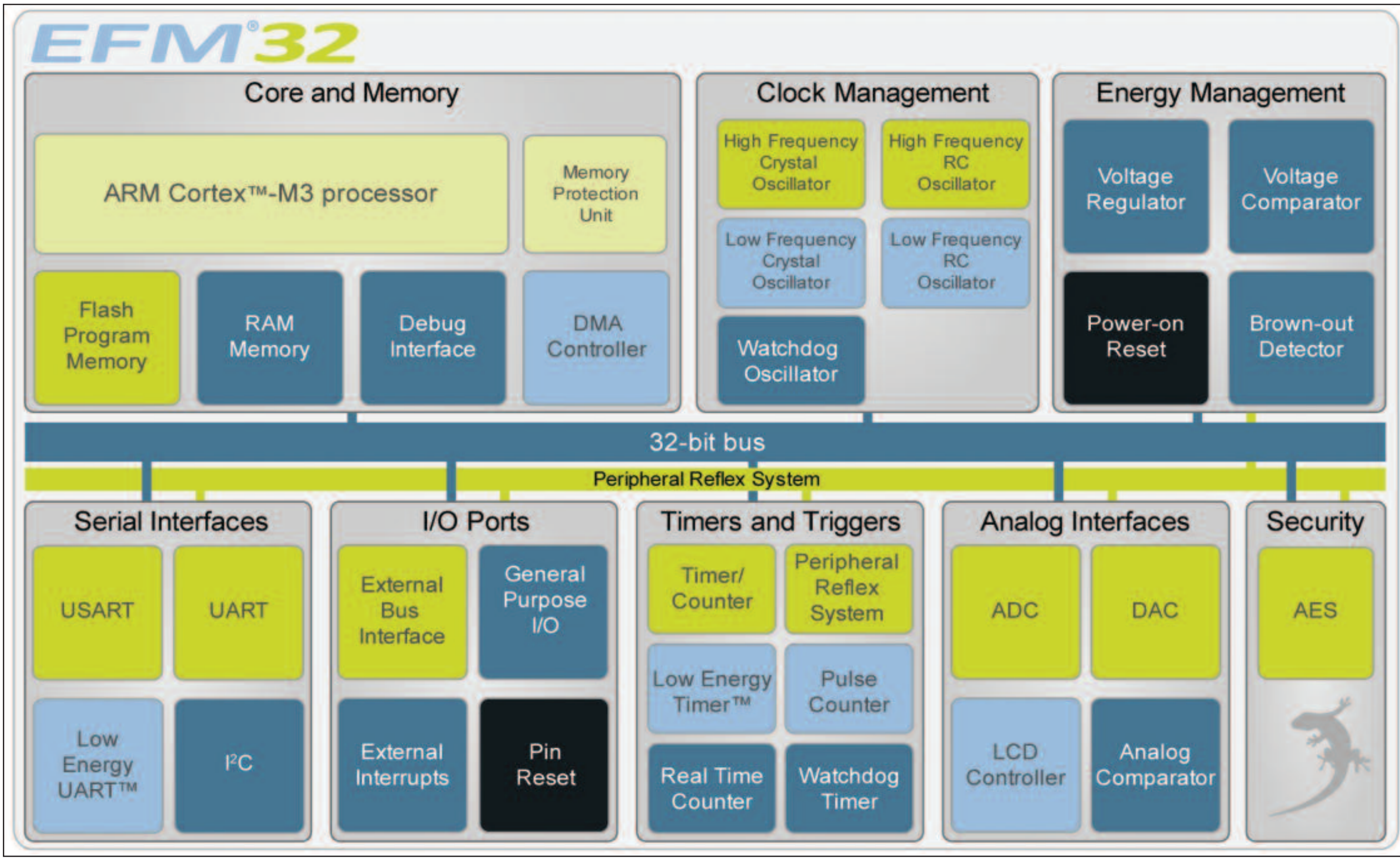

Figure 4: The EFM 32 Gecko's unique architecture provides a wide range of peripheral function blocks purpose designed for low power operation. The 4 x 40 segment LCD controller for example runs at just 550nA.

The EFM32 uses a total of six custom designed oscillators which provide a fast wakeup time, allowing the core to start processing quicker from a sleep mode. It achieves this by using internal RC oscillators with a start-up time of just 0.5 µs. This enables the core to wake, evaluate and execute tasks from sleep much more quickly – and therefore power-efficiently – than other devices.

Developing a device with this in mind allows for the optimum combination of sleep mode features, providing the user with maximum flexibility during application development. A more capable core will require less processing time than a less powerful solution, such that the total power is reduced.

Couple with that the ability to move quickly and efficiently between sleep modes and the result is a power curve that remains significantly lower than its competitors'.

In order to enable developers to make best use of the optimal sleep states, the EFM32's development kit comes complete with an Advanced Energy Monitoring system, a facility which continuously measures current in the power rail using an analog-to-digital converter to measure the voltage drop across a series resistor. This measurement is integrated to depict accurately the power used over time, allowing real life use-cases to be optimized for low power operation.

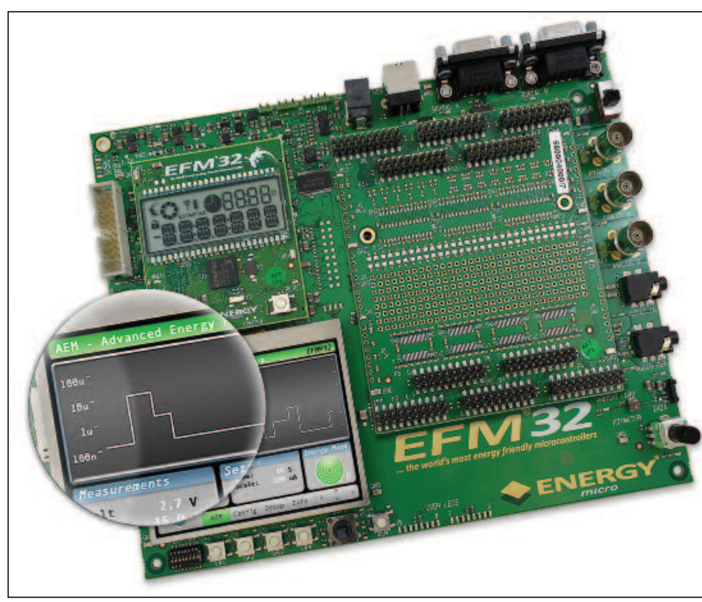

Figure 5: Energy Micro's development kits for the EFM32 Gecko MCU family provide users with a unique Advanced Energy Monitoring (AEM) system. Via a large in-built LCD screen and preconfigured GUI, AEM enables users to accurately view a prototype application's current consumption data in real-time, enabling early identification and removal of adverse energy drains.

While the Cortex-M3 core is capable of performing a vast array of tasks in software, low power operation dictates that some functions can be still be handled more power-efficiently in hardware. The peripherals developed for the EFM32 were designed to operate autonomously; without the need for the core's intervention. Using a sophisticated interconnect matrix, the 'periperal reflex system', the EFM32's peripherals are able to carry out relatively complex functions without waking the core from its sleep mode. In a typical application, that may be routinely making a measurement using the ADC for example. The EFM32 features a low level driver library that allows the Cortex-M3 processor to configure the peripherals for autonomous operation, such that once configured they can perform many tasks without waking the core.

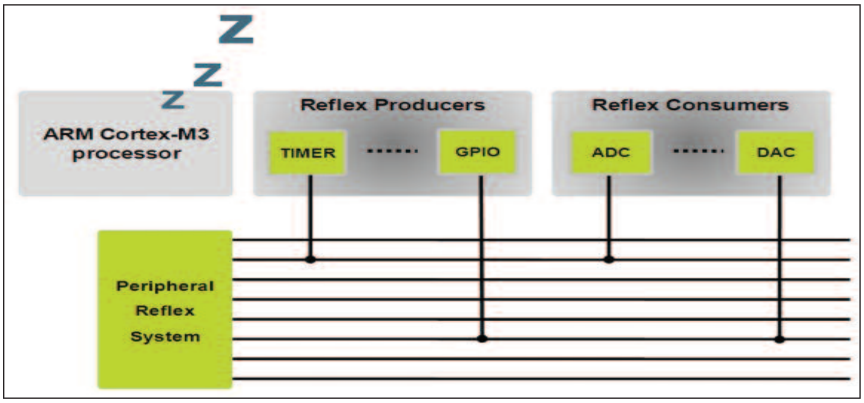

Figure 6: Using Energy Micro's 'peripheral reflex system' – a sophisticated interconnect matrix - simple tasks such as initiating data conversions and storing the results can be carried out without waking the 32-bit processor core at all.

Using hardware acceleration also enables other processor-intensive functions to be offloaded, hence promoting deeper sleep states. For example, the EFM32 implements a hardwired AES encryption block, a function that is increasingly used to protect even the most mundane data. While the AES encryption algorithm is not a challenging task for the Cortex-M3 processor, by handing it off to a hardware acceleration block it saves even more processor cycles and, therefore, more than makes up for the nominal but additional transistor count it represents. Demand for ultra low power devices that couple superior processor performance with class-leading power saving features is increasing at an exponential rate, and is anticipated to continue as the number of applications that can exploit their features expands. Combining the popularity of the ARM architecture, the efficiency of the Cortex-M3 processor and the performance of the Thumb®-2 instruction set creates a compelling solution and an ideal platform for the development of future, ultra low power solutions. Energy Micro's holistic approach to developing low power solutions will continue, based on the ARM architecture and its own expertise in ultra low power design.

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