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When Extending Battery Life, Two Processors are Often Better Than One

Teaming an ultra-low power MCU with a performance-optimized DSP can give systems designers a competitive edge

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Abstract

The push for lower power, battery-operated, higher performance systems is undeniable. In terms of battery power, consumers want their portable electronics to "do more with less," and industrial products are moving toward battery operation as well.

Digital signal processors (DSPs) are frequently used in applications that require high performance, leading to higher clock speeds. Any processor that runs quickly and integrates millions of transistors is a candidate for aggressive design initiatives to keep power consumption at a minimum.

Over the past decade, architectural innovations and power-saving strategies have pushed DSP processing power to increase in millions of instructions per second (MIPS) and other performance metrics at a dizzying pace. Consequently, the battery life of DSP-based systems such as cell phones and ultra-portable music players has steadily risen in large part because of these higher performance DSPs.

Continued next column

Audio headsets and other portable consumer audio devices are key examples of applications that require optimal power efficiency. Industrial and medical products are also moving toward highly functional and highly integrated portable devices. These devices have many of the same power requirements as ultra-portable consumer devices.

While DSPs have made great strides, microcontroller (MCU)-based systems have also been under pressure to reduce power. Compared to DSPs, MCUs have some inherent advantages in lowering power dissipation, such as fewer transistors, lower clock rates and often lower operating voltages.

The standby current for a modern, power-optimized MCU is measured in nanoamperes compared to microamperes for DSPs. While DSPs deliver far greater performance than MCUs, they have also been aggressively power-optimized but there is a limit to what chip designers can do.

Conventional Wisdom

The conventional wisdom among system design engineers when it comes to extending battery life is "one chip is better than two chips." The reasons are fairly straightforward. Chip-to-chip communication consumes more power than on-chip communication, and two chips will inevitably have more transistors than a single chip that integrates equivalent functionality. But conventional wisdom may not always be correct.

As DSPs began integrating on-chip functions such as accelerators, application-specific communications modules and networking peripherals, they became much more capable and useful to system designers. But when the chip is turned on – or kept on – simply to execute simple housekeeping or supervisory procedures, considerably more power is dissipated than the function itself really requires.

The average current consumption of a system determines battery life, not the instantaneous current consumption at any given time. Thus, to extend the battery life, the average current consumption must be reduced. Typical high-end processors have clock scaling and other power-saving features for when they are running, but they do not do well at saving current consumption when they are not in use. Many high-performance processors consume 50 – 100+ micro-amps in halt mode. While these current consumption figures may look acceptable at a first glance, keep in mind this is while the processor is powered, but is not capable of performing any task without being restarted externally.

Remaining in a low-power state capable of responding to stimuli or performing system or supervisory tasks consumes tens of milli-amps on these processors and other higher-end processors. This means that for a system relying on the high-end processor for supervisory tasks, battery life can be measured in mere days.

However, if the system and supervisory functions were implemented in a device that was also capable of power-managing the main processor, then the average current consumption can be significantly reduced for the system.

In certain applications, using an MCU in a system-supervisory role for a DSP can be a very smart design decision. Deciding when a dual-processor system architecture is the right choice depends on many factors. The application itself is the most important because most designs also have space and cost constraints that must be considered.

For example, power-supply monitoring, reset supervision and power-supply sequencing are some of the most basic supervisory functions a system requires. Many of today's SoCs have multiple power rails that must be sequenced at power-up for proper operation. Fixed-function devices are available that perform these functions all in one package. But the fixed-function device cannot do anything else for the system, and cannot turn off the main processor when it is not needed. Replacing the fixed-function device with a small, low-power microcontroller provides the added capability to power-manage the main processor, while implementing the sequencing, monitoring and supervision functions.

A low-pin count, low-power microcontroller is ideally suited to this type of function. For example, Texas Instruments offers the MSP430F20x1 and MSP430F20x2 devices. These are 14-pin microcontrollers with a comparator and 10-bit analog-to-digital converter (ADC) respectively. They each have stand-by current consumptions under 1 micro-amp and consume only a few hundred micro-amps when running.

Figure 1 on the following page shows an example of small microcontroller power-sequencing and power managing a main processor. A software routine on the microcontroller enables the main processor regulators in the proper order and uses its internal ADC to verify when the supply rail has reached the proper voltage. When the main processor is not needed,

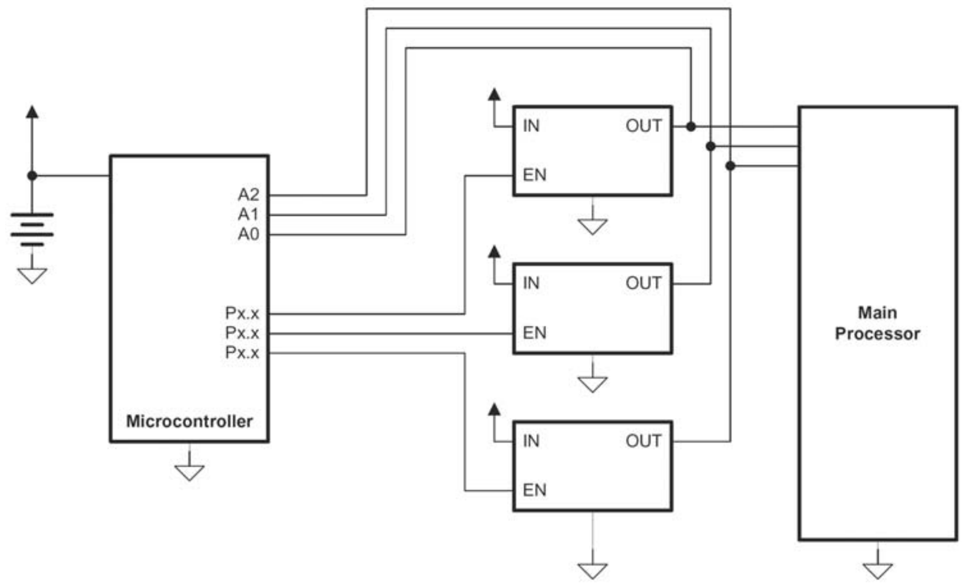

Figure 1. Small microcontroller power-sequencing and power managing a main processor

the shut-down feature of the regulators can be employed turning off the main processor and saving the 70 micro-amps to several milliamps consumed by the main processor.

A better understanding of how DSPs and MCUs separately optimize power is a key factor when making an informed design decision about how they might work even better together. By using two ultra-low power processors – both designed to maximize power efficiency while offering distinct performance, integration and cost advantages – for main processor duties and supervisory functions, designers can extend battery life beyond what just one low power processor could achieve.

DSP Power

DSP chip designers have implemented numerous power-saving techniques. Most of these techniques – such as lowering operating voltages and dividing the chip into multiple clock domains – are executed in the background. System designers do not have much, if any, control over these features and can simply enjoy the benefits.

During the DSP selection process, however, a system designer exercises a great deal of influence over how applications will perform. Four important features to consider when selecting the best DSP include:

- **Look for large on-chip memory.** Depending on how much power the application is likely to use on a regular basis, extra power is expended every time a memory call is executed off chip. If external DRAM is used, it has to be powered continuously, which is a constant power drain.

- **Select a DSP with a high degree of control over peripherals because that translates directly into additional power savings.** Several DSPs can automatically power down on-chip peripherals when the peripheral is inactive or they may allow the system designer to manually manage peripheral status. But this feature has degrees of granularity.
- **Choose a DSP that offers multiple standby states.** The more options there are, the more energy will be saved over time.
- **Select a DSP that offers development software specifically designed to optimize power utilization and minimize power consumption.** The tool should provide the ability to scale the chip's voltage and frequency easily, manage power states and measure and analyze power consumption so optional design scenarios can be evaluated.

While DSPs can do a good job of extending battery life, other aspects of their power consumption are beyond the control of both the chip and the designer. This is mainly due to the DSP's fabrication process, which must necessarily favor performance.

By their very nature, the transistors of high-performance IC processes have more leakage current. Chip designers and process engineers can exert some control over the total power consumed with techniques, such as using low-leakage transistors if power consumption is higher priority than performance. These measures are helpful but do not change the fundamentals of the situation.

Transistor leakage is important because a system's average current consumption – not instantaneous power at any given time – determines battery life and device transistor leakage will always be a fixed power draw. To lengthen battery life, the average current consumption must be reduced.

The power-saving features of DSP mentioned above do a good job when the chip is running. But there is not much a chip designer can do about the large numbers of high-performance transistors leaking current while the DSP is in, for example, standby mode. The only way to stop the leakage is to turn the transistors off completely, and that usually means the chip must be restarted externally.

MCU Power

The best starting point for optimizing an MCU for low-power operation is to manufacture it in an ultra-low power process. This reduces transistor leakage current to surprisingly low values. Just as a high-performance process negatively affects the power consumption of DSPs, semiconductor processes optimized for low power limit the MCU's peak processing performance.

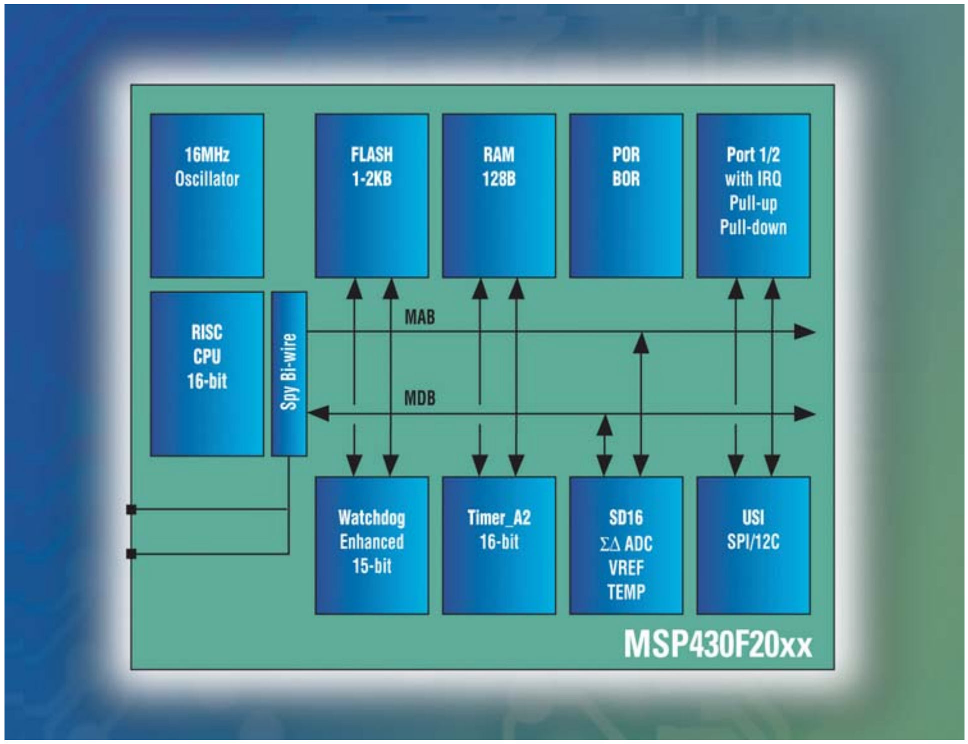

Figure 2. MSP430F20xx MCU block diagram

The most obvious limitation is clock rate. Texas Instruments MSP430F20xx low pin-count MCU series (see Figure 2) can deliver a 500 nano-amp standby mode with a maximum speed of 16 MHz by utilizing unique very low-power oscillator (VLO) technology. The VLO technology allows the MSP430F20xx MCU to be totally self-clocked in an ultra-low power standby mode with self-wakeup capability using no external components. This enables systems such as fire detectors or home thermostats to operate from the same battery for over a decade.

The industry-leading 500 nano-amp standby is achieved with all device failsafe features active including zero-power brown-out reset (BOR) allowing both ultra-low power and extremely reliable systems. Prior to VLO, designers had been forced to use external crystals or oscillator circuits to achieve ultra-low power standby. Using no external components, the VLO reduces systems component count and costs as well as reducing space, all critical requirements for portable applications. By comparison, the TMS320C5506 DSP, for example, uses 10 µA in standby, a factor of more than 20 to 1.

An effective IC design strategy for reducing power is to use intelligent peripherals. Historically, MCU peripherals have been driven by software executed by the CPU. This can be effective but also means the CPU is always active. By designing interrupt-driven peripherals that require the least amount of software servicing, the CPU can be in standby or idle mode most of the time.

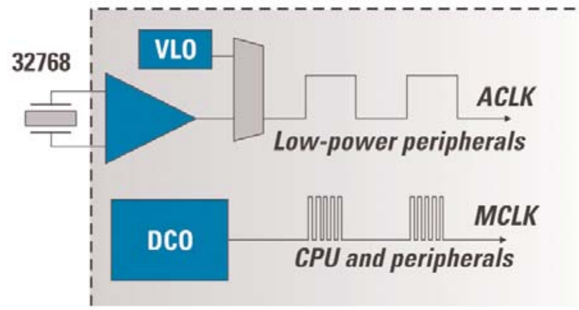

Figure 3. For MCU power efficiency, two clocks are better than one

System designers should also look for MCUs that have automatic input channel scanning on their ADCs, hardware start-of-conversion triggers and DMA data-transfer mechanisms. These features also help automate repetitive data sampling and minimize the time the CPU is running.

An MCU's clock system can also make major contributions to the cause of power conservation. For example, Figure 3 shows two clocks operating from a single crystal.

The low-frequency Auxiliary Clock (ACLK) is used by the MCU's low-power peripherals. An external 32-KHz oscillator is typically used for low-frequency, low-power operation, which allows for real-time clock functionality. A high-speed, digitally controlled oscillator (DCO) sources the master clock (MCLK) that is used by the CPU and high-speed peripherals.

In addition to the power saved by using a low-speed clock for some peripherals, TI's MSP430 MCUs integrate a very-low power oscillator (VLO) on-chip to source the ACLK. In its standby power operating mode (LPM3), the MSP430 device typically consumes less than 1 µA of current with ACLK still running and all interrupts enabled.

In addition, the DCO can be active and fully stable in less than 1 µs with no intermediate steps. This enables "instant on" high-performance processing without the long start-up time needed for a second crystal or two-speed start-up. This is not only a time saver, but also conserves power.

Dual-Processor Power

As previously mentioned, the integration of functions such as accelerators, application-specific communications and networking peripherals put a DSP at a power-consumption disadvantage when it comes to executing simple functions.

MCUs are better suited than DSPs, for example, at keeping a real-time clock or managing battery-charging procedures. Off-loading these functions to an MCU adds to the DSP's MIPS budget, which is also important.

The results delivered by a two-processor architecture can be quite striking. For example, a hypothetical system that relies on the high-end processor for supervisory tasks would probably have its battery life measured in days. That is, a typical NiMH AA battery is rated at 2500 mAh. An average current of only 1 mA would deplete AA batteries in 119 days. Raise the average current to 10 mA and the batteries are dead in about 12 days.

A few of the system or supervisory functions that can contribute to power optimization by using a dual-processor system include:

- Real-time clock keeping
- Power-supply sequencing
- Power-supply monitoring and reset
- Keypad or human interface management
- Battery management
- Display management

The real-time clock function has already been discussed in the section describing MCU power-saving techniques. Using the MCU to supply a clock for the DSP is a simple extension of this principle.

Managing DSP Power

Many modern DSPs have multiple power rails that must be sequenced at power-up for proper operation. Typically, these are a core power rail, a DDR power rail and an I/O power rail. Although fixed-function devices can be used to perform power sequencing, that is the extent of their capabilities.

Replacing the fixed-function device with a small, low-power microcontroller (TI's MSP430 MCU) as shown in Figure 4 provides the capability to power-manage the main processor (TI's TMS320C550x DSP) by implementing the sequencing, monitoring and supervision functions.

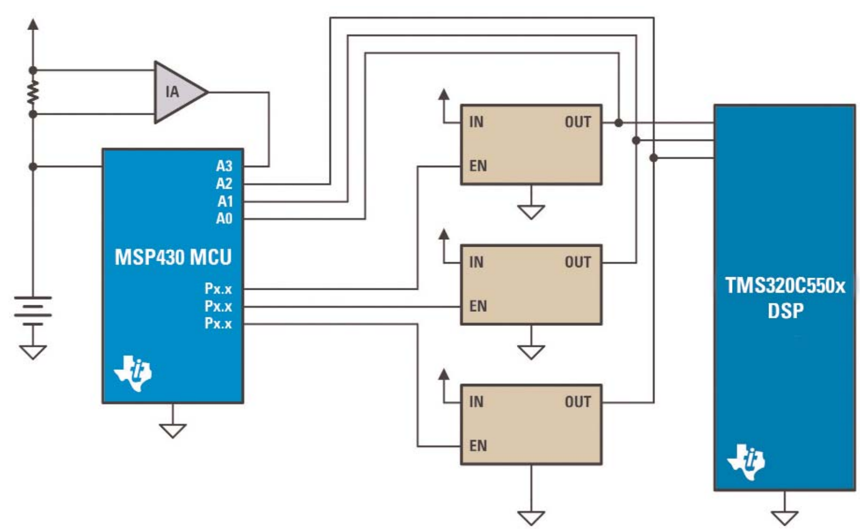

Figure 4. DSP power sequencing using an MCU

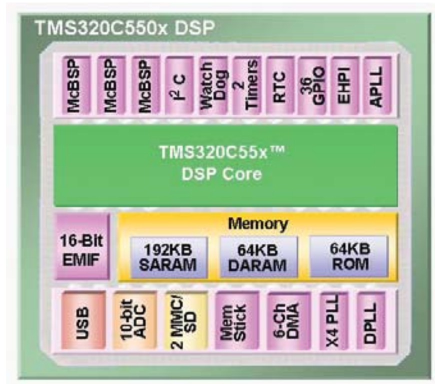

Figure 5. TMS320C550x DSP block diagram

Figure 5 above shows the features of the C550x DSP. A software routine on the MSP430 MCU enables the C550x DSP regulator circuits in the proper order. The MSP430 uses its internal ADC to verify when the supply rail has reached the proper voltage. When the C550x is not needed, the shut-down feature of the regulators can be employed turning off the main processor.

In fact, the MCU can control both the DSP's voltage and frequency by communicating directly with VXO to control the voltage or with a PLL to control the frequency. The obvious benefit is that when the DSP has finished a compute-intensive task, the MCU can put the DSP into a valid standby mode.

The monitoring process is bi-directional. That is, the MCU can probe the DSP to see how busy it is. In this mode it operates as an intelligent controller. On the other hand, the DSP's internal monitoring capabilities can also be called into play. Since it can both read and write to the MCU, the DSP can inform the MCU that it was to slow down or speed up its clock, depending on the application needs.

Human Interface Management

While the power consumed by the DSP can be reduced through interaction with the MCU instead of handling some simple tasks internally, even greater benefits can be realized by systems designers who offload some supervisory tasks that would have to be performed by the DSP in a one-processor system to the MCU.

MCUs can easily handle the requirements of keypad operation with much less power consumption than a DSP. A standby current of 500 nano-Amps, for example, is far less than that of a DSP, but by implementing an interrupt to the DSP only after a key is pressed and released, the MCU can avoid power created by stuck key current drain, a not-uncommon occurrence in some handheld equipment.

Having the MCU manage the user's display is another task within the capabilities of a 16-MHz MCU. For even greater energy efficiency, the MCU should have an integrated segment-based LCD driver that can handle four multiplexed data streams.

In addition, the MCU should have integrated functions to handle standard SPI, UART, I^2C or RF communications with the peripheral, and it would be able to auto start from a low-power mode without polling.

Battery charging and charge management is another supervisory function that typically uses a fixed-function device, but can be done with a microcontroller. The microcontroller's ADC is used to measure the voltage; timers and software manage the charge; and pulse-width-modulated outputs provide the charging waveforms. Vendors' application reports often show how this function is performed with their microcontrollers, and they often provide the code examples as well. For example, application report "Li-Ion Battery Charger Solution Using the MSP430," application report number SLAA287, can be downloaded from the Texas Instruments website and provides the solution for the MSP430 products.

Once the system is partitioned, the MCU and DSP must be connected in a way in which they can communicate. Much of the data the MCU acquires in its interactions with peripherals has to be shared with the DSP, of course, and places some specification requirements on the MCU. Look for one that has at least 16 GPIO ports to support inter-processor communication. On-chip SPI and I^2C interfaces are also a requirement and a 10-bit ADC will be needed for battery charging.

In most systems, a simple protocol can be constructed consisting of basic commands given from the DSP to the microcontroller. In some cases when the main processor and microcontroller are sourced from the same vendor, application reports and canned solutions may already exist to marry the two.

Two such examples exist for connecting MSP430 microcontrollers to Texas Instruments DSPs: application report SLAA174 and report SPRA639A. The latter describes and shows connecting an MSP430 to a TMS320C54x™ DSP via its host port interface as shown in Figure 6.

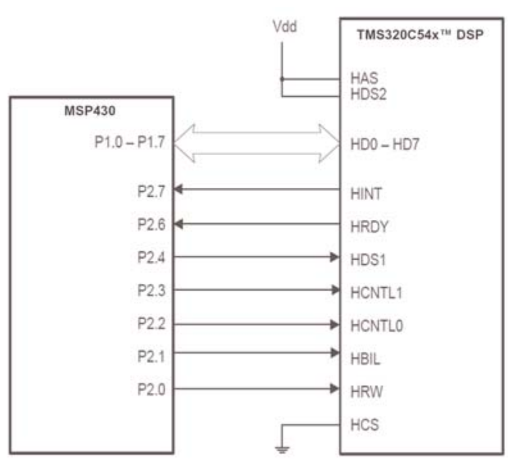

Figure 6. Host port interface connects MSP430 to a TMS320C54x DSP

Conclusion

DSPs have made major strides in reducing power but are limited in what they can achieve by the high-performance processes used to fabricate them. They are particularly vulnerable to power loss due to transistor leakage when the chip is in idle or standby modes. Ultimately, it is up to the designer to determine whether to use one or two processors for their application depending on their calculations, measurements and tradeoffs between a DSP and/or MCU.

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