

White Paper



Practical Power Comparison

MC9S08LL16 MCU offers 70 percent reduction

1 A Practical Power Comparison Reveals Freescale MC9S08LL16 MCU Offers 70 Percent Reduction

Battery life is an important criterion for many small, portable or hand-held electronic devices. These devices often sport a segment liquid crystal display (LCD), which shows operational status and can also be a handy digital clock when in standby mode. Freescale Semiconductor has an ideal solution for such devices in the MC9S08LL microcontroller (MCU) family.

The S08LL MCUs are designed expressly for very-low-power applications and, even though they are 8-bit MCUs, they have enough processing capability to rival the performance of popular 16-bit MCUs having low-power reputations. The S08LL16 actually reduces power consumption by 70 percent compared to competitive alternatives. This is enough to drop its power needs below the self-discharge losses from the battery itself.

This paper looks at the relevant features of the S08LL16, discusses some of the reasons it requires so little power and compares its performance to a popular low-power alternative.

2 Benefits of Low Power in Segment LCD Applications

Small LCD screens appear on all kinds of electronic equipment these days to help users with the complicated products. The screens might give instructions, monitor system status, show operational/functional progress or give results. The LCD is typically powered at all times, even in standby modes, to give status, battery condition or just time-of-day to show that they are ready to go, whether the equipment is in use or on its way to the job site.

Battery-operated equipment cannot afford to shorten battery life due to this LCD, and even mains-powered equipment is scrutinized for power consumption so that when it is “off” there is almost no current being used. In fact, battery life and power consumption overall are critical, or at least growing, concerns for most electronic equipment manufacturers. Increasingly stringent green certification standards will increase the attention. Imagine how cutting power consumption by 70 percent would change the notion of a lot of today’s electronics.

The frequency of charging or changing the battery is an important factor in the usefulness, value and competitiveness of the equipment. With modern soft power switches on even the simplest equipment, some power is being used just to monitor whether the “on” button is pushed. The electronics must not drain the batteries while in a powered-down state or the equipment will be useless when it is most needed.

Wide varieties of small electronic devices that make use of segment LCD screens are in particularly power-sensitive applications. Utility meters, hand-held instruments, home medical devices, thermostats, exercise equipment and timers are some examples. Others are listed in **Figure 1**. Many of these are very high volume, consumer-oriented devices, but others, such as the display on a printer, might be associated with another, larger piece of electronic equipment.

Figure 1 Typical Applications for MC9S08LL16

- Battery-operated hand-held devices
- Portable health care devices
- Glucose monitors
- Blood pressure monitors
- Thermostats
- Alarms/clocks
- Exercise equipment
- Personal diagnostics
- Calculators
- Displays on automotive, office equipment and consumer electronics
- Low-end utility metering
- ZigBee® nodes with display
- Scrolling text displays
- Portable medical devices
- Multi-meters
- Kitchen appliances

2.1 Key Issues

Careful design and use of the right components will assure a fully functional instrument, complete with the necessary status and operational information display, that will still accommodate very long battery life. Common to all of these applications, and critical to power concerns, are the LCD controller, time-of-day clock and the overall structure of the MCU running the instrument. The MCU needs to be just powerful enough, without being overrun with performance that isn't utilized.

Accuracy is critical for a real-time clock. Maintaining accuracy while running at the lowest possible power requires a more precise timer than is normally provided for simple periodic wake-ups from sleep. Counters that wake up the processor to update the time of day often fire off every second. However, the longer the time between interrupts, the longer the MCU can remain in a low-power state. The S08LL16 can wait a little over a minute before interrupting the processor, accommodating clocks that don't display seconds while offering the lowest possible power consumption.

LCDs are wonderful power-saving displays, and over the last couple of decades technical advancements have confirmed LCDs as the only real option in battery-operated equipment. For small displays, segment LCDs offer crisp screens with infinite possibilities for unique images and layout organization, making them ideal for space-constrained applications. These displays may draw only 900 to 1500 nA of power with the display on and an incredible 700 nA with the image off. The LCD controllers and drivers need to be properly designed to similarly minimize power or any savings as the glass itself will be overwhelmed by the power consumed to drive the signals.

It can be surprising how much time many of these products spend in standby mode and how much total energy can be consumed in that state. Many products die while they are asleep, waiting for their next use, which can frustrate users who find the battery is expended when they want to use the device. Since the MCU actually needs full performance for an extremely short period of time, the power consumption at high-frequency full-operation is a really a secondary concern.

Probably most important in conserving energy is to build the entire MCU with saving power as the guiding concept from the very beginning. Low-power strategies for operating the processor and peripherals and implementing the system and circuits using power-saving techniques are the best ways to conserve power, both locally as well as across the entire chip. Minimizing the number of external components required in addition to careful execution of the board-level design will also contribute to conserving the battery life of the system—and the MCU at the heart of the system can impact these decisions as well.

The Freescale S08LL16 MCU is an ideal solution for minimizing power consumption in segment LCD-based equipment to maximize battery life. As a self-contained system-on-a-chip (SoC), very few additional components are necessary to make up a complete product.

3 MC9S08LL16: Extremely Low-Power 8-bit MCU

The S08LL16 was specially designed to run with extremely low power consumption, taking into consideration a number of advanced power-saving and system-optimization concepts: Direct drive of the LCD minimizes components, and low-voltage operation greatly reduces power consumption. Clock management blended with software operation optimizes current use. Specialized functions reduce the time the circuitry must be powered, and minimized packaging and signal leads simplify circuit board design. All of these features in the S08LL16 combine to create a platform that reduces a small system's power consumption by 50–70 percent compared to competitive alternatives. That is enough to more than double the battery life of the end applications.

The S08LL16 is an 8-bit MCU executing the widely used HCS08 instruction set. It can be run up to 20 MHz and in a voltage range of 3.6 down to 1.8 volts. The S08LL16 has 16 KB of flash (S08LL8 has 8 KB) matched with 2 KB of RAM. Multiple clock sources allow the right balance between power consumption and timing accuracy. Various clock modes, regulator states, power modes and peripheral switches help the user control power in software according to system demands.

Unique peripherals on the S08LL16 (see block diagram in **Figure 2**) include an 8-channel analog-to-digital converter (ADC) that offers 12-bit resolution to sensors and analog inputs. LCDs of 28 segments with 4 backplanes or 24 segments with 8 backplanes can be driven directly from the chip with contrast control and a simplified “blink” function to save power. A special time-of-day module can wait as long as 63 seconds before waking the processor to update the clock and can run with the LCD driver in an extra-low-power mode.

Figure 2 Block Diagram of the Freescale Semiconductor MC9S08LL16 Microcontroller

9S08LL16 Block Diagram		
S08 Core	LVD	I ² C
Flash Size 16K Dual 8K Arrays	KBI	SCI
	COP	ICS
2K RAM	SPI	TOD
	Comparator	8-ch., 12-bit ADC
ICE + 08BDM	LCD Driver 8 x 24	2 x 2-ch. 16-bit Timer

One of the continuing advantages of 8-bit MCUs compared to 16- and 32-bit varieties is their small size, and that translates into lower power consumption. 8-bit data is moved and manipulated with fewer transistors than 16- or 32-bit data. Reading out a line of flash that is only 8 bits wide may turn on only half the cells that 16 bits requires. Decoding and executing simpler 8-bit instructions is less complex than larger instructions, and as long as the required operations are straightforward, then the programs can be just as short.

In the peripheral area, most operations are 8-bit in nature: serial transmissions, parallel I/O, timers and status. Overall, fewer transistors mean fewer power sinks when they are active and fewer current leaks when they are turned off. Generally, if the job can be performed with an 8-bit MCU, it will use less power than a 16- or 32-bit MCU.

3.1 LCD Driven Directly from the Microcontroller

The entire family of Freescale S08L MCUs has an LCD controller built in that directly interfaces to monochrome segment-based LCDs. It generates the necessary front plane and backplane signals to activate the LCD display.

The S08LL16's LCD module can drive large segment LCDs in its 8x mode (up to 192 segments) but offers a 4x mode for more flexibility in smaller LCDs (up to 112 segments). Regarding flexibility, many pins on the MCU can be rearranged for the convenience of the circuit board designer or to minimize electro-magnetic (EMI), crosstalk and signal interference or power consumption.

The LCD controller is completely independent of the processor and keeps driving the LCD display in all power modes. Therefore, unless the chip is in reset, the screen will display without attention from the rest of the MCU. LCD data values are stored in the LCD driver at the pads nearest the actual glass to minimize the power needed to push them to the display. The result is that the LCD driver uses an incredibly low 750 nA of current.

There is even a special blink feature on the LCD module. This allows desired segments on the LCD to be turned on and off at 1/8s, 1/4s, 1/2s, 1s, 2s, 4s and 8s intervals to either draw attention to that part of the display or simply to conserve the power during the 50 percent off cycle. Since blinking is performed in a small part of the LCD module, it too runs without having to fire up the processor, buses or the rest of the MCU.

4 A Practical Power Consumption Comparison

Before designing a very low-power electronic product that maintains a segment LCD in both on and standby modes and features a time-of-day clock, a practical investigation of the system's power consumption must be undertaken. For a system that essentially boils down to an MCU, that means understanding the power behavior of MCUs to determine the best candidate.

The S08LL16 MCU from Freescale is designed specifically to consume the lowest possible power in its quiescent state yet to still be capable of handling the minimal operations typical for a battery-powered device, including driving

a segment LCD and keeping the time-of-day clock up-to-date. It is only an 8-bit MCU, but it can be demonstrated to be just as capable as a 16-bit MCU while power consumption by up to 70 percent, setting a new standard in low power functionality.

Measuring power is only meaningful if it applies to the practical use of a target application. Studying the specifications to ascertain the fine details about any chip's power consumption under numerous conditions can lead to an incomplete analysis. For instance, specifications for Texas Instruments' MSP430 device, commonly considered a very-low-power 16-bit MCU, do not include the loading of the LCD glass.

Looking at the applications most likely to take advantage of an extremely low-power MCU, a few key factors should be considered:

- The device is in standby mode nearly all of the time
- An LCD will be operating at all times
- A time-of-day clock will be maintained
- The device must always be ready to jump into full operational mode
- Battery life is a significant selling point

Consider such an application as a residential thermostat or a personal medical device. Some of the S08LL16's peripheral assignments for a thermostat can be seen in **Figure 3**. An example of a glucose analyzer is shown in **Figure 4**. Reviewing the operation of either of these in terms of time, performance and power will show the power flow and amount of power needed.

Figure 3 Residential Thermostat with LCD Display, Driven by an MCU

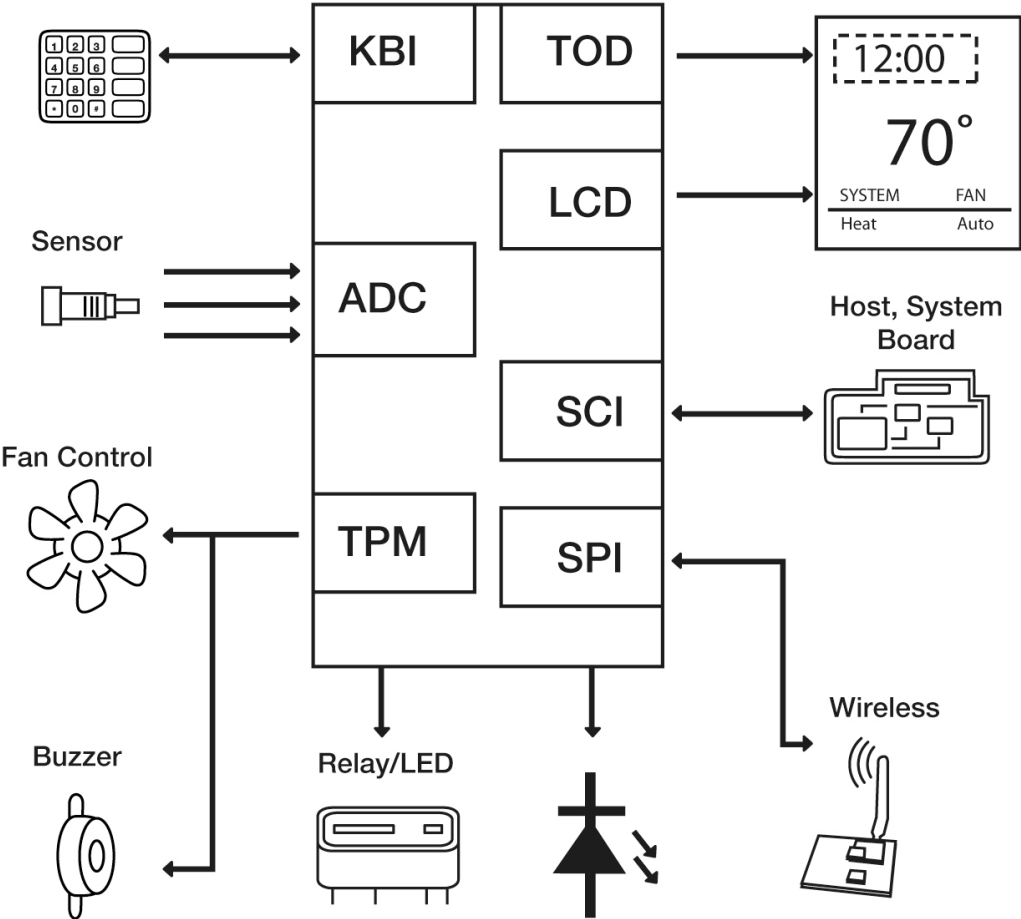
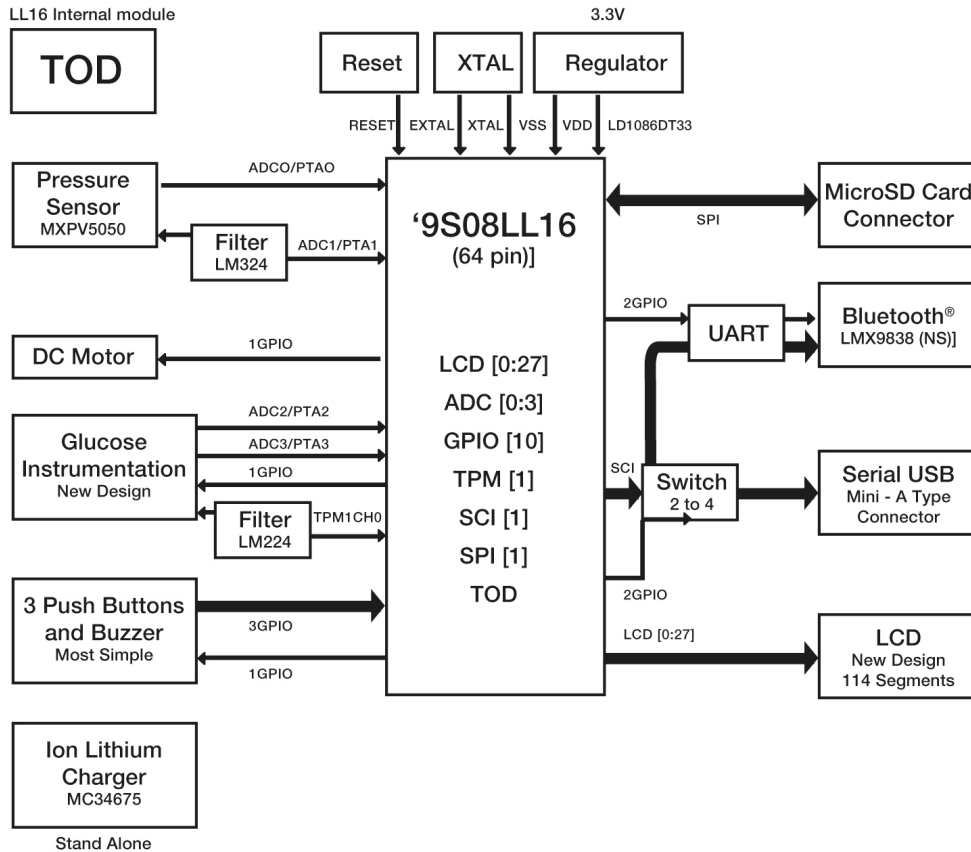


Figure 4 Example of a Glucose Meter Using a MC9S08LL16 Microcontroller



A thermostat may check the temperature every five seconds while holding the current temperature, time and mode on the display. A glucose meter might check its buttons every second to see if the user wants to turn the device on or run a sample. To update the time-of-day clock, a one-second interrupt is all that is needed (two-second interrupt if using the LCD's blink mode). A real-time clock or a free-running timer would be set to wake up the processor when the counter times out. Meanwhile the device may display the time of day or results from the most recent data capture. The wait time between periodic interrupts will be the MCU's lowest power mode, Stop2 in the S08LL16, because only the time-of-day timer and LCD driver are activated.

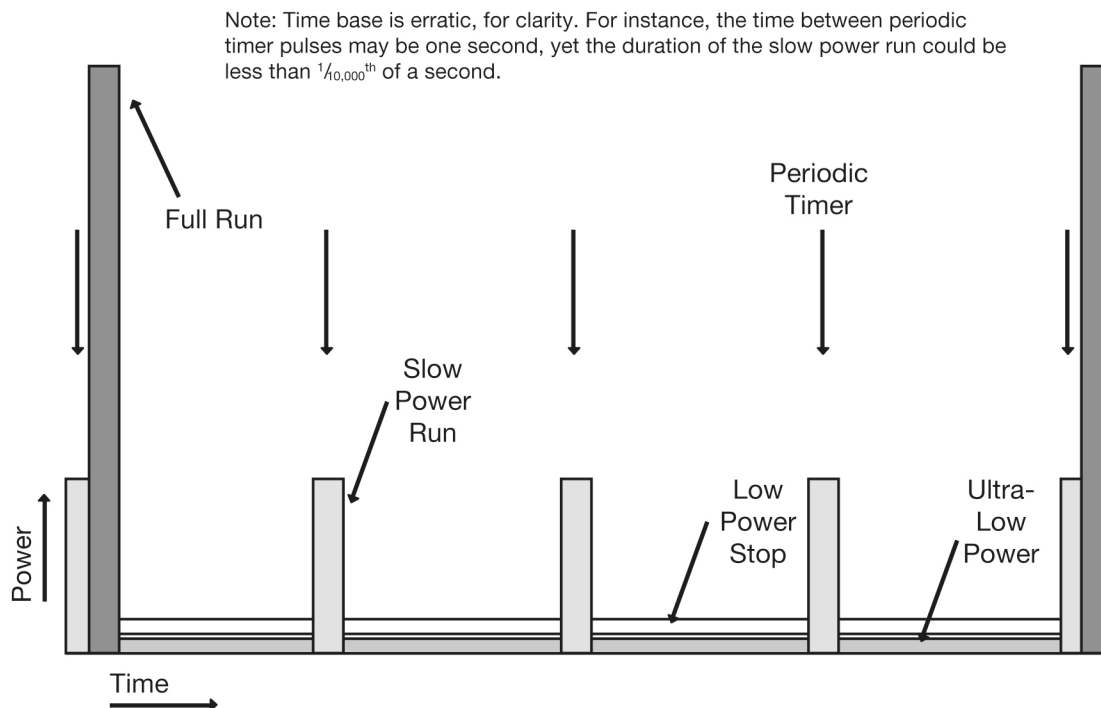
When the timer interrupt wakes up the MCU, it will wake up the clock circuits, load the registers and machine state and start the main program. When the work is done, the register and state information is preserved in memory, and the MCU is put back into a stop (off) state. The time it takes to start the interrupt and return to the stop state contributes to the power consumed. The way the programs start and end influence this, but the design of the MCU also impacts the time, and quicker is always better.

Finally, how fast the main program is run will affect the power consumption. Incrementing the time clock is a very simple activity, and the processor completes it quickly. The S08LL16 has a special power-optimized mode, and updating and testing counters are ideal to run at that speed. For a thermostat, the MCU might take a temperature reading while it is awake and look for changes from the displayed temperature. If the temperature hits a set-point, the MCU may spin up to full throttle to activate the HVAC (heating-ventilation-air conditioning) system. In a glucose meter, if a button is depressed, the MCU may run up to 20 MHz to begin analyzing sugar in the blood sample.

The MCU will consume less power at 10 MHz than it will at 20 MHz, but if running at 20 MHz means it can finish its task in half the time, the power consumption is better. However, due to some "hurry-up and wait" situations, running at 20 MHz can sometimes save only 40 percent of the time and thus will consume more power. Careful assessment of many activities within the program and resources used around the chip are needed to determine whether or not to run full speed.

Figure 5 aids in understanding the power consumed in the different operation phases. Normally, the systems are in standby mode, waiting for something to do. It is in this state, which the user perceives as “off,” where only the LCD and the timer are active. The standby mode occurs in the white spaces between the vertical bars of the illustration when power is at the low power or ultra-low power level.

Figure 5 Typical Power Profile of a Small MCU-Controlled Device



For the periodic wake-ups for updating the time-of-day clock or scanning buttons to see if the operator is turning on the device, high performance is probably not critical. The MCU can run in a power-optimized mode during these simple activities. These are the low bars in the illustration and power consumption is rather low here.

When the temperature meets its set-point or the operator is pushing a button, then the device must jump into action. To run the primary program (start a motor or analyze blood sugar, for instance) the MCU will run near its maximum clock frequency to do the work quickly and then shut down. This will minimize power consumption. It is possible that maximum performance is not needed for a task due to naturally-slow responses from a resource. For instance, if the MCU is just reading an ADC, the processor and bus might save a lot of energy by running at a slower speed that better matches the ADC speed.

Figure 5 is actually an exaggeration of the timeline, because the time between interrupts is quite long compared to the time spent in a run mode.

5 Measuring Power

Putting some real numbers into the activities described above reveals that the most significant figures are the time and the power consumption while the chip is in standby mode. Consider a blood glucose meter. Assume that it is in use evaluating blood samples for 5 minutes a day. There are 1,440 minutes in 24 hours, so if the meter is in full use for 5 minutes, that leaves 1435 minutes for the meter to be in standby mode: 99.653 percent of the time. If the meter is in full use for 2 minutes, the meter is in standby mode: 99.861 percent of the time.

The data sheet values for worst-case current consumption in full run mode and low-power standby mode are shown in **Figure 6** for the Freescale MC9S08LL16 and the Texas Instruments MSP430. The average current use of these example applications is calculated based on the time the MCU is run in the different modes. The results show Freescale’s S08LL16 requires only 11.1 μA for a 2 minute run and down to 5.1 μA for a half-second run of the program. When translated into battery life, the S08LL16 will outlive a MSP430 by 36.1 percent and 44.4 percent, respectively.

This means a pair of AA batteries running a S08LL16-based product would last 9.4 years compared to only 6.5 years if it was based on the MSP430.

Figure 6 Power Consumption over Time for Selected MCUs

	MC9S08 LL16 @ 3.6v	TI 430-4618 @ 2.2v	MC9S08 LL16 @ 3.6v	TI 430-4618 @ 2.2v	MC9S08 LL16 @ 3.6v	TI 430-4618 @ 2.2v		
Run Current	5,600.	6,400.	5,600.	6,400.	3,900.	650.	uA	
Run Time	2.	2.	0.5	0.5	0.0015	0.0036	min	
Standby Current	3.3	9.8	3.3	9.8	3.3	9.8	uA	
Standby Time	1,438.	1,438.	1,439.5	1,439.5	1439.9985	1439.9964	min	
Effective (avg) Current	11.1	18.7	5.2	12.0	3.3	9.8	uA	
Power @ 3.6v, 25C	39.9	67.2	18.9	43.3	11.9	35.3	uW	
Battery Life*, AA	15.4	11.3	21.3	14.8	23.7	16.3	years	2850 mAh
Battery Life*, AAA	6.8	5.0	9.4	6.5	10.4	7.1	years	1250 mAh
Battery Life*, CGR17500	4.5	3.3	6.2	4.3	6.9	4.7	years	830 mAh
Extended Life	36.1%		44.4%		45.6%			
PWM Channels	3	5						
<small>* calculated, with self-discharge assumed to be 10uA Run and Standby Current as reported in Data Sheet, except for 3900 and 650 uA values which are measured on board described in text.</small>								

These calculations, however, are only based on values reported in the data sheets. More accurate results can be obtained if actual measurements can be used from a real product. The difficult part of this exercise is putting together comparably equipped systems for both MCUs.

To stay on an even footing, components from an MPS430 starter kit are used. The kit's LCD glass is removed and configured for use with the S08LL16. This assures identical output drives by both MCUs. The real-time clock, or time-of-day program for the other MCU, is modified for use by the S08LL16, using the S08LL16's special timers. Then the two systems—one with the original MPS430 in it and one using the S08LL16—are started and measurements are taken.

The amount of time each processor spends performing the time-of-day update operation is noted so the duration of the run cycle is correct for each MCU. The current consumed while updating the time-of-day by each MCU is measured. The current is also recorded while each chip is in standby mode with the LCD being driven and the timer running. This gives the background power for when the application appears to be off. All of these actual time and current values are shown in **Figure 6** in the right-hand columns.

The S08LL16 takes much greater current to run the time-of-day update program, but completes the task in half the time it takes the MPS430. However, this program only runs for a total of a quarter of a second over an entire day, so this subtotal turns out to be inconsequential. In fact, 99.999% of the time, the system is in standby mode. This is where the two MCUs separate.

The S08LL16 requires only 3.3 uA of current in standby, one-third of what the MPS430 consumes. This essentially becomes the current draw for the entire life of the application. When attached to a battery, the battery will last 70 percent longer in the system when using the S08LL16 microcontroller. In fact, the S08LL16 standby current is so low that natural losses by the battery overwhelm the drain on it due to the circuitry connected to it. The battery would last only a little longer if it was never taken out of its original package!

6 Fundamental Low-Power Design

It is not easy to design a truly low-power microcontroller. It takes a methodical process of squeezing out power from tiny corners of circuits as well as across the entire chip, without sacrificing performance. Design decisions at the system level have broad implications in power consumption, yet careless operation and circuit design of individual peripherals can result in an unexpected power drain as well. Instruction set efficiency can impact how often memory must be accessed. Fetching long lines from memory can waste power if branching makes the prefetching superfluous.

User code can also have a big impact on power consumption in both execution efficiency and by leaving unused peripherals or circuits active when they are not needed.

To squeeze the power consumption of the S08LL16 down to just 3.3 uA in standby mode, yet still keep a time-of-day timer running and the LCD enabled, required making many design choices and improvements in many circuits. The accumulation of all of the features and techniques enumerated below is what has driven an unprecedented 70 percent reduction in power consumption found in the S08LL16.

The S08LL16 is a highly integrated MCU with both traditional and specialized peripherals dedicated to the types of functions likely to be needed in a power-sensitive, LCD-based piece of electronic equipment. With the 8-bit HCS08 processor at its core, this chip would clearly qualify as a system-on-a-chip (SoC). The more circuitry put on a single chip, the less energy is wasted pushing signals between chips across circuit board traces that are picking up capacitance. Every buffer and long wire not only adds delay but consumes power as well.

MCUs traditionally include base-line peripherals and a memory system to feed the processor. The S08LL16 is distinctive in that it includes on-chip circuits, like LCD drivers and buffers, that are normally external parts. External chips may have mismatches in the input, output and voltage requirements, further wasting power. A highly integrated SoC offers other advantages, such as a smaller footprint, lower costs, fewer vendors and system integrity.

A number of the peripherals on the S08LL16 were designed with the expressed goal of reducing power consumption when the system is in a quiescent mode. Considering the applications for which the S08LL16 was designed and recognizing the functions that are most likely to be utilized in that very power-reduced state, special attention was paid to the real-time clock and LCD circuits. Just tending to the time-of-day clock can consume enough power to drain a battery, and driving the LCD panel also requires its share of power

7 Peeking into the Time-of-Day Clock

The typical time-of-day clock triggers the processor hundreds of times a second to update the time-of-day counters. Each interrupt involves quite a bit of activity (and power) that can be avoided if most of those interrupts are eliminated. The time-of-day module on the S08LL16 only alerts the processor every quarter of a second, every second or, using the match register, up to every 63 seconds, to perform an update and check for services the processor may need to make. This flexibility minimizes wasted power without limiting the ability of the operating system to manage its tasks. Even saving pointers, registers and the stack for return to the quiescent state consumes power that is greatly reduced by using less frequent interruptions.

The time-of-day peripheral logic was designed to run at just 2 Hz rather than the usual bus clock frequency to minimize power in the time-of-day module. Additionally, the clock to the reset synchronizer has been gated so it can be shut off to reduce unnecessary power consumption. Power consumption in the time-of-day module is so critical to long term battery life that extra effort was put into implementing that circuitry with custom routing and custom synthesis software. Even the clock traces between the external oscillator or internal clock sources and time-of-day module were kept as short as possible to minimize capacitance.

8 Keeping the LCD Up

In many ways the LCD controller is a very important part of the S08LL16. In the target applications, the MCU will drive an LCD all the time, whether the equipment is active or sleeping. Minimizing power to maintain the LCD is paramount to limiting overall power consumption. A number of techniques were implemented to minimize the power driving the LCD.

The internal voltage reference for the LCD is typically on all the time. However, rather than constantly drawing current, the S08LL16 conserves power by employing a refreshed reference voltage using a reference capacitor that is refreshed with a low-power oscillator in conjunction with a refresh counter.

A very-low-power comparator was optimized for use in the charge pump for the LCD peripheral. In addition, full non-overlapping clocks further improve charge pump efficiency.

The S08LL16 is especially well-suited for low-power LCD glass. The driver circuit has been shrunk to optimize for low-power glass. LCD switches are grounded before the LCD bias levels are changed. Also, low-power waveforms are used because they require less drastic signal transitions and do so less frequently.

Finally, the data for the LCD is held at the location closest to the LCD. Rather than having registers deep within the chip, data for the LCD is preserved at the pad cell. This eliminates the drive necessary to overcome loading between a centralized register and the I/O pins. It allows a reduction in the LCD driver voltage domain.

9 Additional Power-Conserving Circuit Design Techniques

A number of other circuit design techniques were utilized in the S08LL16 to minimize power consumption overall. A very-low-power oscillator was built that drops current by 10 times compared to earlier methods. Designing a switched capacitor resistor with very high resistance into the oscillator drops current use to a mere 500 nA.

Inputs on the pins are capacitively coupled to the chip, preventing pad leakage from getting to the internal circuits. The output of the on-chip voltage regulator has been lowered from 2.42 to 2.15 volts. Additionally the voltage drop across the regulator is further lowered, minimizing power wasted from dropout in low-power run mode. Previous methods were only effective for data retention in the RAM. The new regulator dramatically reduces power consumption, even at full run.

A new stop mode reduces the time needed to wake up to service an interrupt from 110 microseconds to just 6 μ s. That's over 100 μ s less time that the chip needs to be fully powered to get started on an interrupt service routine. Going back to sleep is similarly shorter.

10 Saving Power Throughout the Chip

Accurate synthesis of the clock trees on the chip revealed that 40 percent of the power used by peripheral modules is lost in the clock trees, so the ability to turn off clocks when modules are unused saves considerable energy. When peripherals are not being used, they can be shut off, optimizing power around the task being performed at the moment. This can have a significant impact even in full run mode.

Additional S08LL16 power-saving features include a variety of possible clock sources. These clock inputs can be of different frequencies to match system needs. The MCU includes a very accurate internal clock generator driven from a 32.678 crystal or a looser 1 KHz internal clock reference and can make use of external clock sources while letting software determine how to switch between different clocks.

By sharing the current reference, 100 nA of current is saved in the oscillator and sharing bandgap saves transistors, die size and current in the run mode.

The flash memory is not a trivial power sink, so methods to reduce flash power have a real impact. The flash in the S08LL16 will stay powered only for a short period when the processor is operating at a low frequency. Low frequency reads from the flash latch the data and then power to the flash is automatically removed. Furthermore, clocks to the RAM, flash and peripherals are optimized for power according to the needed processor performance level.

While designing the S08LL16 MCU, in addition to functionality and performance simulations a careful power-use simulation aided oscillator path routing and enabled fine tuning the clock gating effectiveness.

At the most basic semiconductor level, the S08LL16 MCUs are manufactured on Freescale's low-voltage, lowest-power fabrication process, letting it run at only 1.8 volts with extremely low transistor leakage. The process also allows a chip with the capabilities of the S08LL16 to consume a mere 450 nW. Still, the MCU can run 20 MHz while allowing very accurate (12-bit) analog circuits to be integrated on the digital chip.

11 User-Managed Power Considerations

The power supply to an S08LL16 MCU can run as high as 3.6 volts, typical for much of today's electronics, or as low as 1.8 volts while still maintaining accurate clocks and analog-to-digital conversion. The 1.8 volt level is important because most "1.5 volt" batteries drain slowly down to 0.9 volts as they are used, but once that 0.9 volt mark is hit they deteriorate rapidly. Thus, to optimize the power a system will draw from typical batteries, the electronics should run at a multiple of 0.9 volts. A pair of AAA batteries will nicely supply power to an MCU that can run well down to 1.8 volts, but competitive MCUs can rarely operate that low. Additionally, since voltage is squared when computing power, the difference between running at 2.2 volts and 1.8 volts is nearly 50 percent.

Generally, the MCU should be run as fast as practical when in its most active state and then shut down as quickly as possible. Waiting on peripherals to respond can be a lengthy process, so slowing down the processor while waiting on

a slow resource can conserve power. Obviously, using the low power, wait and stop modes as much as possible is advantageous. Think about the program when the system is supposed to be low power. Minimize subroutine calls and their power-robbing overhead. On the other hand, continually polling wastes “awake” time and energy. Interrupting a low-power system in wait mode is usually more power efficient.

Certainly it’s important to only have the peripherals running that are needed at the moment. But the state of the peripheral can influence its power consumption, so be careful to check its operation and start-up configuration. Be aware of the power drain of input and output pins and leave them in states that require the least power. The keen eye even watches port positions that may exist on the chip but may not be connected to pins in reduced-pin package configurations. Be sure those are not driving thin air! Watch for code that is designed for more-fully-configured chips that will waste time and current managing phantom circuits.

Know the processor when writing the programs. The HCS08 is particularly effective accessing table contents, so do table look-ups rather than complex calculations. Watch if there are test conditions that can truncate calculations early to save power. And as mentioned elsewhere, use 8-bit rather than 16-bit data when possible. Minimize switching transistors.

Special S08LL16 clock generator modes can slow down the clock without losing the frequency lock for a fast reliable startup. But when using the frequency-locked loop, selecting the lowest multiplier and divider combination for the desired frequency can save power. An external clock mode requires the least power from the MCU.

These techniques along with the multiple stages of power-saving modes throughout the chip allow fine-grain control of power according to the needs of the system.

12 Applications Advantaged by Extremely-Low Power Consumption

When the power consumption of an intelligent chip falls to new lows, the chip’s use in a number of applications can change the use and perception of those applications. Some of these applications are listed in **Figure 1**. Consider personal health care items and other small consumer products. Changing the battery can be a nuisance in many consumer products, and extending the time between changes can really improve the perception of those products. If a glucose meter or blood pressure monitor can go eight to ten years before its battery needs changing—longer if it will run on a lithium coin cell—batteries are no longer a concern.

There are many reasons to think that eight to ten years is longer than the life expectancy of a device: it may get lost or broken, it may get too dirty to be used, styles may change or technology may advance (hopefully). Before the battery runs out, the device may no longer be needed, or further improvements simply make it obsolete. Eight to ten years is a long time for electronic equipment.

If an additional feature can be added to a product, like displaying the time or date when the device is unused, the product is a little more attractive. The constant display of the time or date gives the consumer confidence that the device is operational and not dead due to battery failure. Even larger equipment that may be plugged into the wall can be improved when an MCU keeps an informational display active even when the system has essentially powered down. Instructions, status or just time-of-day again gives the user a level of comfort without burdening a power supply. The segment displays driven by the S08LL16 can contain rich graphics as well as text. When the single-chip MCU is essentially all the semiconductor electronics required in the device, application size is minimized as well as price.

In the industrial trade, utility meters, thermostats, volt-ohm meters and many forms of building automation devices will find new life with a battery that seems to last forever. Plus, if only small amounts of power are needed by the MCU, it might be obtained from solar cells, harvested from motion or borrowed without notice from neighboring sources, such as USB, Ethernet or mains connections.

LCD displays on industrial applications go a long way toward helping with maintenance and troubleshooting when useful status information is constantly displayed. As mentioned, the displays can be customized to use rich graphics as well as text. For applications where occasional self-test, periodic reporting or similar self-starting capabilities are needed, the time-of-day clock module permits reliable wake-up while burning almost no power waiting for the next interrupt.

Many wireless applications are coming to life now with intelligent mesh networking. These applications are troublesome if they require frequent battery replacement or extensive cabling to obscure locations. Employing small, low price and extremely low-power MCUs can help make the network more user friendly, cost effective and nearly maintenance free. Again, LCD displays, driven by the MCU, can show status, data or just time-of-day to add functionality and convenience to the network devices. Periodic or timed wake-up, triggered by the time-of-day module in the S08LL16, can be especially useful in remote wireless applications.

13 Reduce Power Consumption by a Remarkable 70 Percent

Many applications, especially battery-operated ones, must be sensitive to power consumption. The MC9S08LL16 is an 8-bit MCU designed to minimize power consumption while providing 20 MHz processing performance to applications that make use of a free-running timer or time-of-day counter and benefit from a small, always-on segment-LCD screen. Taking advantage of numerous power-reducing design techniques, the S08LL16 MCU has achieved a dramatic 70 percent reduction in power consumption when compared to competitive alternatives—enough to extend battery life for a typical application to nearly 10 years. That is longer than the expected lifetime of most portable applications and nearly 50 percent longer than competitive MCUs can manage. Even MCUs that are commonly considered to be low power leaders are shown to fall short of the MC9S08LL16 MCU.

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