Reducing Household Energy Use through Innovative ARM Powered® Smart Meters

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Smart meters are new, all-digital metering devices that precisely track energy usage and transmits the data directly to the utility company. Since these new meters help manage usage more efficiently and reduce costs, governments and utility companies around the world are moving quickly to install them in households everywhere.

Over time, as these smart meters become part of a larger network that includes home appliances, wireless communications, and the Internet, the benefits will be even greater. Utility companies will be able to maximize their infrastructure with targeted power production, and consumers will have detailed information that helps them manage their everyday household use to become more efficient and contribute to combating the damaging effects of global warming.

ARM and their partners are developing a range of low-power, low-cost solutions for smart meters. These highly integrated SoCs use the power-efficient ARM Cortex-M processor family with optimized physical IP, and are produced in the industry proven TSMC 0.18-µm, ultra-low-leakage process. They can be used in standalone smart meters or in appliances that combine power monitoring with other tasks. The meter concept can further extend to a variety of applications, including industrial, consumer and medical systems.

Smart Meters

Increased concern over global warming, volatility in oil pricing, and the recent downturn in the economy have made energy conservation a pressing issue for everyone. Consumers are finding that simple changes, like washing clothes in cold water, lowering the thermostat, or waiting for off-peak hours for better rates, can have an impact. They're selecting appliances and electronics that use less power, and are changing their habits to reduce usage.

Governments are also starting to get involved, using their resources and legislative powers to encourage homes and businesses to conserve more and reduce their emissions of greenhouse gases. In the US, for example, the Energy Policy Act of 2005 introduced subsidies for alternative and renewable energy sources, like wind, solar, wave, and geothermal, and extended daylight savings time by several weeks. It required utility companies with annual sales of more than 500 million kWh to consider time-based rates and smart metering options, and created a demand-response program that rewards commercial buildings that curtail usage at peak times. It also introduced tax breaks for people who make energy-saving improvements to their homes.

Another program in the US, called Energy Star, is a joint program of the US Environmental Protection Agency and the US Department of Energy, designed to help homes and businesses save money and protect the environment through energy-efficient products and practices. In place since 1992, the program is starting to show real results. According to the program website (energystar.gov), in 2007, through the help of Energy Star product labeling and savings guidelines, Americans saved $16 billion on their utility bills while avoiding greenhouse gas emissions equivalent to 27 million cars.

Utility companies, for their part, are looking for better ways to monitor and manage energy usage for greater efficiency and lower overall cost. Smart meters, also known as Automatic Meter Readers or AMRs, are giving utility companies more control over their networks and making them more responsive to outages. They're also making it possible to gather real-time information about energy usage, so consumers can, ultimately, have access to detailed information that will help them make better-informed decisions about energy consumption.

The Move to Smart Meters

The transition to smart meters has only just begun, but experts agree that utility companies around the world are set to move very quickly with new installations. According to Datamonitor, only 6% of households in Europe and North America have smart-metering devices installed today. By 2012, however, they predict that 89% of US and 41% of European households will be equipped with smart meters. In California, the state-wide utility company PG&E expects to have 9.3 million smart-metering devices installed by 2011, with 5.1 million for electricity and 4.2 million for gas. And, on a global level, ARM, the leader in microprocessor IP, predicts that 130 million units will be installed annually by 2013.

The new smart meters offer several benefits. They're more reliable because electronic meters can be designed to tolerate higher levels of mechanical stress, and they can withstand the reactive and non-linear loads that cause problems in traditional, electromechanical meters. They also let utility companies manage their networks better and respond to outages faster.

Repair crews don't have to patrol entire circuits to locate a problem, with smart meters they can identify where there's an outage with pinpoint accuracy. Utility personnel make fewer house calls, too, because service can be turned on or off remotely.

When equipped with a microcontroller, a smart meter can be configured to monitor other factors, such as power strength and quality. The system can also be programmed to implement time-based metering, with different rates for peak and off-peak usage.

When connected to a network, via wired or wireless connectivity, smart meters can report measurements directly to the utility company, so there's no need for roving personnel to read meters. That lowers cost and simplifies the preparation of monthly bills. Readings can also be taken more than once a month, and usage can be reported with a breakdown, showing peak and off-peak usage, instead of a simple lump sum.

Networked meters can also direct usage data, in real-time, to databases that consumers can access via the Internet. Figure 1, gives a sample setup to support this kind of reporting. The network, known as an Advanced Metering Infrastructure or AMI, has a wireless smart meter sending data to a local wireless transceiver installed on a power pole. The data makes its way to the utility company, where it's stored in a data warehouse and posted on the Internet. Consumers can access their data online, for a simple, paperless way to track usage.

Several companies, including Google, are already prototyping interfaces for online power meters. The prototypes receive data from smart meters and energy-management devices, and present the data in an easy-to-read, web-based graph.

In the ideal scenario, the online meters provide detailed information about consumption. They identify the source of usage, showing exactly which appliances are using the energy.

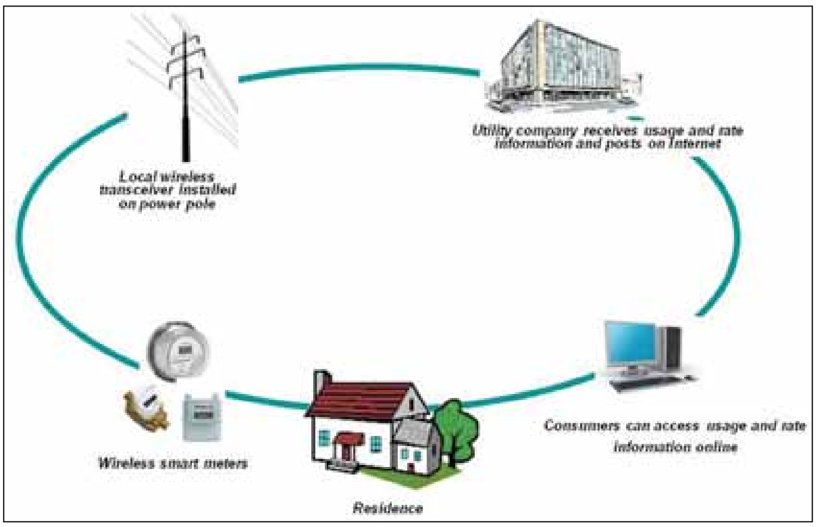

Figure 1 - Smart Meter Network

With labels for specific appliances - clothes dryer, furnace, refrigerator, TV, web server, hot tub, outdoor lights - the readings let consumers see exactly how much energy they're using, and why.

They can know, at a glance, if it's the pot boiling on the stove or the extra load of laundry that's causing a spike in usage. They can make the connection between energy consumption and personal habits, changing how or when they perform routine tasks to conserve more.

The greatest savings are achieved, of course, when every household appliance is connected to the network. Figure 2 shows a sample configuration, with next-generation appliances, equipped with powermonitoring and connectivity functions, linked to the metering network.

Taking the next step, appliances can be configured to provide their own energy-saving recommendations. A washing machine equipped with smart-metering technology can, for example, be programmed to recommend different times for starting a wash, so the consumer can take advantage of lower rates. The machine can be set to turn on automatically at the specified time, and can report to the user how much money they've saved by rescheduling the operation.

The complete AMI infrastructure, with smart meters, smart appliances, and smart user interfaces, may not be here today, but it's on the horizon. As new meters become commonplace, and consumers start having online access to usage data, the companies that make the household appliances, electronics, and lighting fixtures will be motivated to add functions that supply data to the metering network.

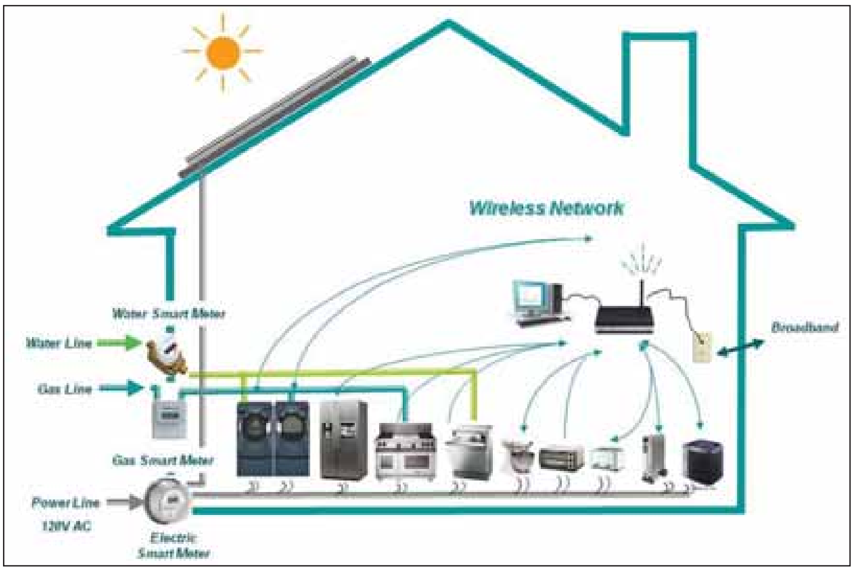

Figure 2 - Home Network Configuration

Design Considerations

Since standalone smart meters are needed on a global scale and in very high volumes, they have to be as cost-effective as possible. The metering SoCs need to be inexpensive to produce - under $5 is a reasonable goal - and they also need to be reliable and inexpensive to replace.

At present, real-time processing performance is less critical, since data currently only needs to be read several times a day; however power consumption and connectivity interfaces are vital. Meters that aren't connected to an electrical line need to run for five to ten years without a battery change, and all meters, whether they're battery operated or not, need to be able to transmit data over a variety of technologies, from ZigBee and Bluetooth to Wi-Fi, RF, cellular and satellite. Small size is important, too, to keep costs low and make it easier to convert existing metering setups to new formats.

Most of these requirements - low cost, low power, and wide connectivity - are the same for appliances that incorporate power-monitoring and networking functions. Manufacturers are looking for high integration, too, since many of their machines combine several inexpensive 8-bit MCUs.

A typical washing machine, for example, might use separate MCUs for motor control, wash cycles, and the user interface. Replacing these several MCUs with a single 32-bit SoC that performs all the necessary functions, including the added power monitoring and connectivity functions, can deliver real savings.

It can simplify design, increase efficiency, and lower overall cost. Moving to a single processor architecture also reduces software overhead, since there's just one software engine to be used, and makes it easier to reuse software in future designs.

Industry organizations and governments will also play a role in development. The goal of worldwide deployment underscores the need for standards and common industry interfaces. The whole metering network needs to work seamlessly, and everything needs to be plug-and-play.

The ARM Solution: Low Cost, Low Power

ARM is enabling technologies for smart meters and smart appliances, and has targeted its development to address both markets. By combining three things - the ARM Cortex CPU architecture, physical IP from ARM and third parties, and the TSMC .18uLL Embedded Flash process - ARM has engineered cost-effective solutions for standalone meters and appliances that integrate smart-metering functions.

Figure 3 on the next page shows the SoC solutions for two smart meters, one for use with electricity and one for gas or water. Both SoCs use an ARM Cortex-M family processor, the latest ARM microprocessor architecture. Recognized for its outstanding computational capabilities and exceptional system response, the Cortex-M processor family delivers high performance with low manufacturing costs and enhanced energy efficiency. A minimal Cortex-M3 processor implementation requires only 40K gates, delivers 1.25 DMIPS/MHz on the Dhrystone 2.1 Benchmark, and uses clock gating and integrated sleep modes to reduce power at no loss of performance. The Cortex-M3 processor also offers a long list of features for system design and software development. To make finalizing designs easier, configurable debug can be accessed via a Serial Wire or JTAG interface, and the enhanced system debug has optional ETM for real-time instruction trace capabilities. Writing software is easier, too, with 100% C coding that includes interrupt handlers and boot code. There's no assembler code required, and the application envelope covers everything from low cost microcontrollers to analog and mixed-signal applications.

The recently introduced ARM Cortex-M0 processor extends the Cortex processor family with the smallest, lowest-power ARM processor ever developed. It brings substantial savings in system cost with exceptionally low power, gate count, and code footprint, while remaining compatible with the feature-rich Cortex-M3 processor. It consumes as little as 85 microwatts/MHz in an area of under 12k gates when using the ARM standard cell library on a 0.18-µm, ultra-low-leakage process.

For smart meters that require less processing capability and simpler microcontroller functions, the Cortex-M0 processor saves cost and reduces power. The Cortex-M0 processor is also a good choice for smart appliances, since it offers a cost-effective way for manufacturers to increase integration while expanding functionality.

Combining a Cortex-M processor with ARM's physical IP serves to reduce the die area and lower the silicon cost. The highly dense architecture of the ARM memory compilers, processor-optimized 1024x32 and 512x32 single-port register file instances, and the Ultra High Density Standard Cell Library also contribute to create the smallest footprint possible. Industry-leading core density results in smaller memories, while fewer pinouts and reduced power consumption make it possible to house the SoCs in less-expensive packages.

The ARM Free Library Program gives designers another way to reduce costs. It provides design teams with a wide selection of 0.18-µm products, all downloadable, free of charge, from the ARM website. Every product in the Free Library is high-quality IP, designed using the ARM Process-Perfect Design Methodology, and licensed for use by the specified ARM foundry.

Using ARM physical IP for smart-meter SoCs saves cost, and power. The ARM Power Management Kit (PMK) libraries, available for the TSMC 0.18-µm uLL Embedded Flash processes, minimize power consumption in several ways. They support dynamic operation of functional blocks at multiple voltages, to achieve optimal power tradeoffs. The power gates and isolation cells enable a sleep mode. To ensure fast wake-ups, the libraries are equipped with data-retention flip-flops and always-on cells. Biasing cells provide connections for well-back biasing and reduce leakage even further.

Added power savings can come from the low-power memory instances. The core and periphery use separate VDD/VSS supplies, and the memories support retention mode. Also, using the PMK power-gating cells makes external power gating possible.

Process technology, when combined with processor architecture and physical IP, plays an essential part in reducing power consumption. By using the TSMC 0.18-µm uLL Embedded Flash process, the SoCs reduce typical leakage in the order of 8x compared to ones produced in a generic 0.18-µm process. ARM low-power memory instances, tuned for Cortex-M family processors, deliver up to 18x lower leakage than their generic 0.18-µm counterparts. Using the ARM Ultra High Density Standard Cell Library cuts leakage by up to 10x. During standby operations, core leakage can be lowered even further by using the Cortex wake-up interrupt controller and the PMK library.

Other Metering Applications

The basic idea behind the ARM SoCs - having a low-cost, low-power way to monitor and transmit usage data - has potential in other metering applications, beyond energy usage. Water utilities can use smart meters to regulate consumption in areas where water is a scarce resource, and large buildings can use smart meters in their heating, ventilation, and air conditioning (HVAC) systems to make them run more efficiently.

Smart meters can also be used in standalone systems, such as motor controllers, blood-pressure monitors, blood glucose meters, thermostats, and solar units, to improve accuracy and increase efficiency on a smaller scale.

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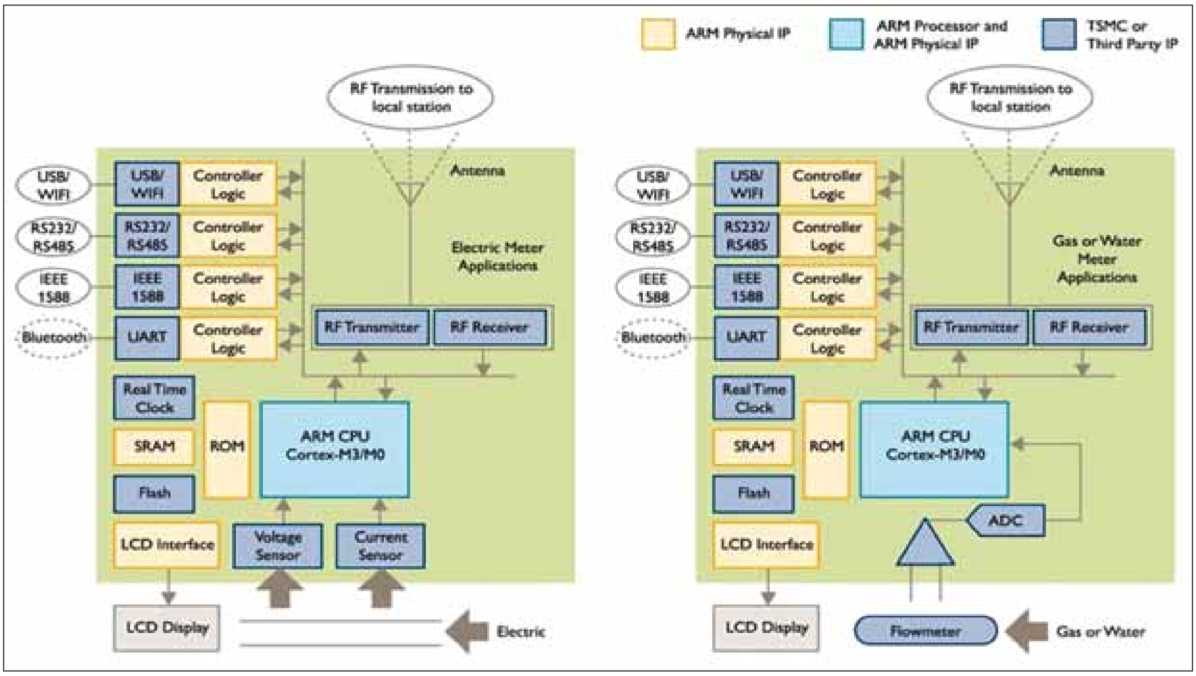

Figure 3 - ARM-based Smart Meters