



On-Demand Power® Technology:
Application and Technical Brief for a Wireless Sensor

Packet Digital, LLC

Scope

This document details the monitoring and assessment capabilities of the Packet Digital PowerSage™ advanced power management controller for embedded systems. The PowerSage family of power management integrated circuits is based on Packet Digital's patented On-Demand Power® technologies, delivering just-in-time, just-enough energy based on real-time system demands.

The technologies in this document may be covered by one or more of the following US patents: 7228446, 7312646, and 7337335.

Power Management Approach

The fundamental approach of On-Demand Power is to monitor critical signals of communication from the microprocessor and between the microprocessor and peripherals. The intent is to correlate the activity of the circuitry to the system's demand for energy. An accurate correlation between activity and system demand allows the PowerSage autonomous power management unit (PMU) to dynamically adjust system voltages and clock frequencies unobtrusively, without interrupting operation or requiring specific software commands. Figure 1 illustrates the monitoring of communications by the PowerSage PMU.

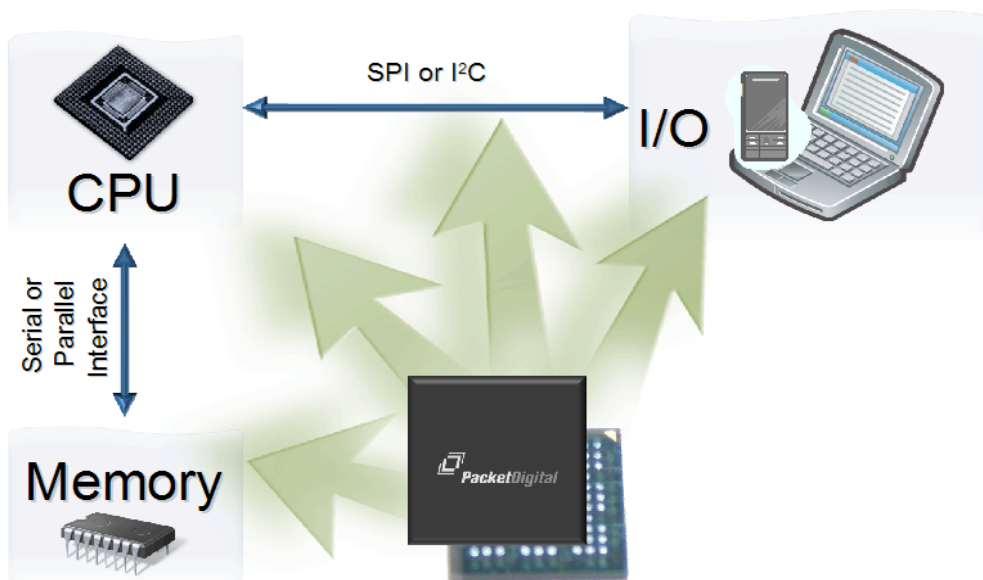


Figure 1: PowerSage monitors signals to dynamic adjust power delivery.

This approach differs from other power management technologies that are inherently processor-centric. Conventional power management technologies focus on the processor as the target for dynamic voltage and frequency scaling. A review of available processor-centric dynamic power management methods shows commonalities that inherently limit the effectiveness. These trends include, but are not limited to:

- The processor may not be the dominant energy user. Even substantial savings of energy on the processor have little overall improvements to the system. In smart phone applications, the display and power amplifier circuitry often use far more energy than the applications processor. Figure 2 illustrates the energy consumption by major functional block by a laptop computer during the playback of an audio compact disc. In this application, the processor uses approximately 3.25W, whereas the rest of the system uses nearly 16W. A system level power management method has 6x the effectiveness of a processor-centric power management method.

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- Processor-centric power management methods are not easily ported to new applications. New designs are limited by the ability for conventional power management circuitry to be integrated. If the capabilities are not added by the silicon designers, system developers are unable to add or modify areas to be managed.
- Processor-centric functions may be largely software-based, which will be slower and less efficient than hardware based solutions. Additionally, the software design requires design and validation, which may slow the time-to-market and decrease revenue opportunities.
- Processor-centric power management is largely based on usage models and predictions for operations, specifically in cellular handsets. If the usage models differ from actual operation, then the battery life suffers due to inefficiencies. Market research suggests that cellular handsets will have open access on applications, allowing users to add and remove applications from their smart phones much like they can add and remove software programs from their personal computers. In that model, usage models are ineffective, as there is no way to accurately predict the way that a consumer would use their phone if the types of functions and applications are unknown (and the amount of energy that each application may consume.)

Packet Digital's On-Demand Power technologies trace back to the fundamentals of electronic power management. Although different systems have radically different power management profiles and demands, the dynamic power dissipation, P_D of digital systems is governed by the equation:

$$P_D \propto V_{DD}^2 \cdot f \cdot C_L \cdot N$$

where V_{DD} is the power supply voltage, f is the clock frequency, C_L is the load capacitance, and N is the number of gates switching. If we can reduce the frequency and the supply voltage, we reduce the dynamic power dissipation.

The supply voltage and clock frequencies are dictated by voltage regulation and oscillators. The control of the voltage regulation and oscillators can be moved to a system that allows adjustment of supply voltages and clock frequencies *outside the processors and peripherals* to control the dynamic power dissipation. Packet Digital has developed autonomous dynamic power management by monitoring bus communications and system signals to determine the activity level (or N , in the previous equation) with the intent of scaling the supply voltages and frequencies accordingly.

Application in a Simple Wireless Sensor

Packet Digital designed a small wireless sensor as part of a dynamic active network. This device acts as an RF beacon, broadcasting radio frequency identification, temperature, and status information every 500 ms, using a ChipCon 2400 as the 2.4 GHz transmitter. The design of the wireless sensor was very similar to the reference design for the ChipCon 2400 (<http://www.ti.com/lit/zip/swrr020>), with the removal of the RS-232 interface and the change to a Texas Instruments MSP430 microprocessor.

The conventional power management design used a Texas Instruments TI7530 low dropout (LDO) regulator fixed at an output of 3.4 volts. The MSP430 used various software techniques to reduce the power consumption, without ever going into a very deep sleep mode. The processor was always enabled to respond to interrupts and to become active at the end of the 500 ms interrupt window.

The wireless sensor was powered via the USB port of a host computer, with a data acquisition card connected to National Instruments Labview connected to the same USB port. The voltage is plotted versus time, as is the instantaneous and average power consumption. Figure 3 shows the plots, without dynamic voltage or frequency scaling. The red indicator on the average power consumption dial shows an average of approximately 21 mW.

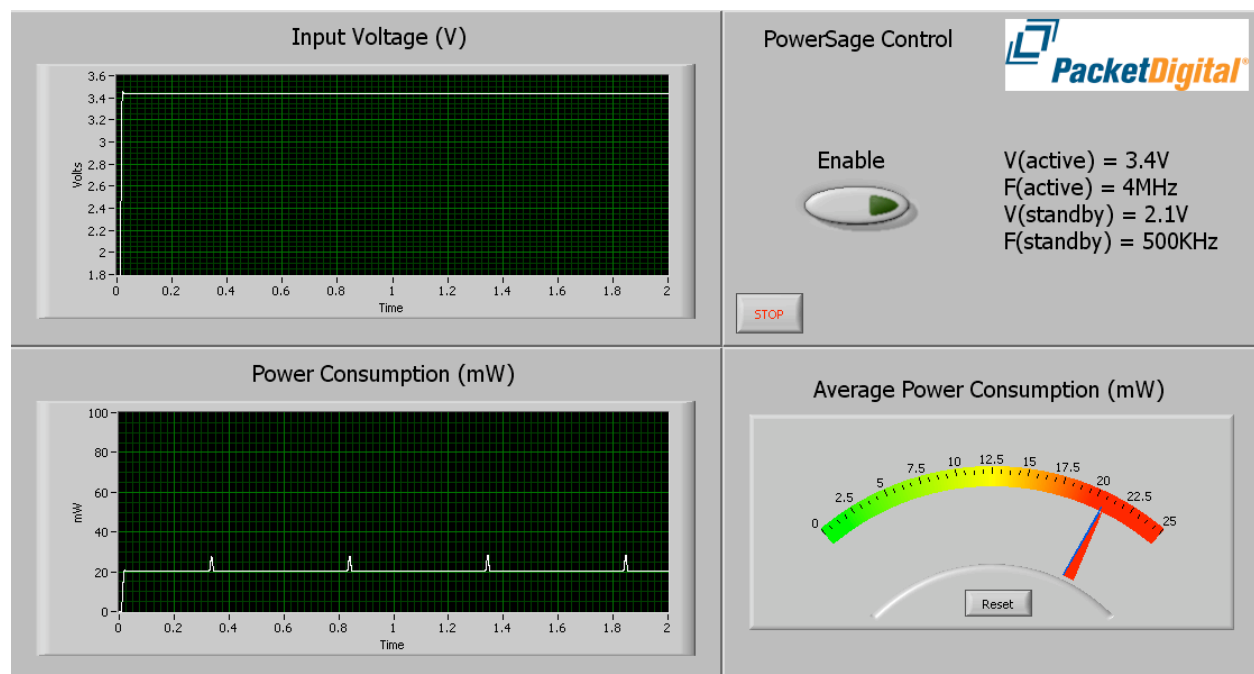


Figure 3. Power Dissipation of Wireless Sensor with ODP circuitry disabled

On-Demand Power circuitry is built into the wireless sensor, monitoring the bus activity between the MSP430 and the CC2400 transceiver. In this application, the system is in a low activity state for a majority of the time, with high periods of activity during the times of transmission. By monitoring the I/O pins of the processor and the activity on the bus between the processor and the transceiver, the ODP circuitry can dynamically adjust the clock frequency (from 4 MHz to 500 kHz) and the supply voltage (from 3.4 V to 2.1 V) in accordance to the system needs. The result is a great improvement in battery life, offering large reduction in power consumption from a baseline design that is utilizing state of the art power management. Figure 4 shows the same dashboard, with ODP circuitry enabled. A blue indicator is added to the average power consumption dial, showing the power dissipation of approximately 4.5 mW.

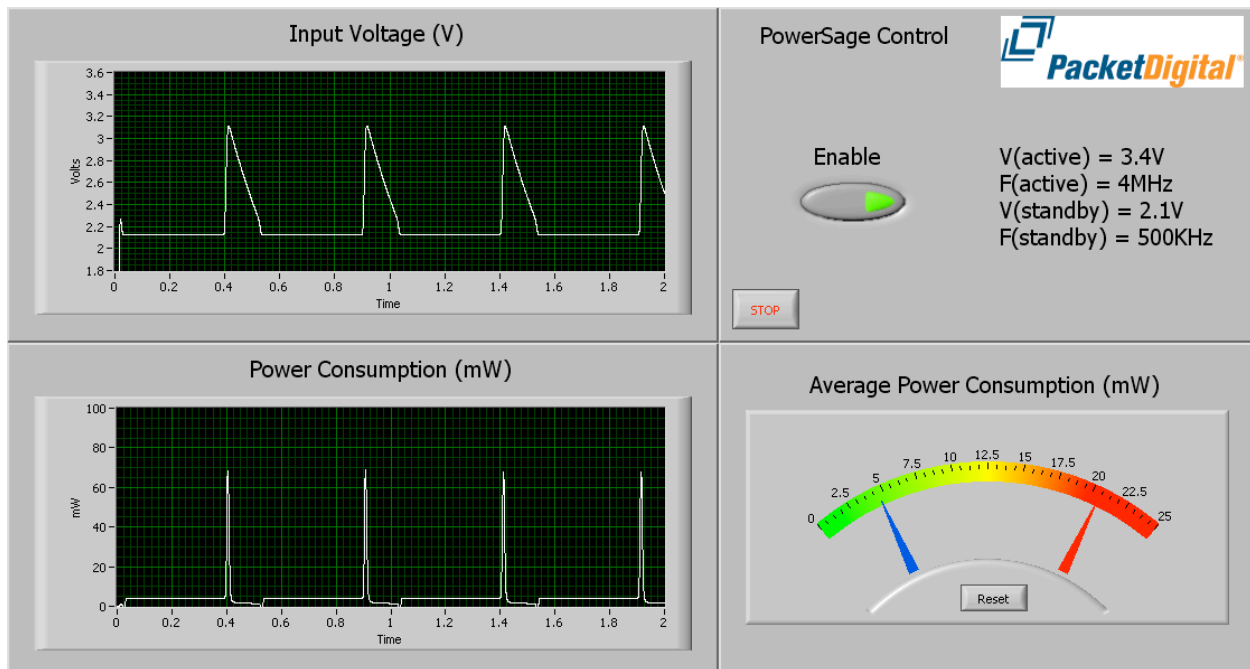


Figure 4. Power Dissipation of a Wireless Sensor ODP circuitry enabled.

The instantaneous spikes shown on the dashboard when ODP circuitry is enabled may be mitigated with an improved power distribution network. Additional decoupling capacitors in the reference design would remove the transient spikes and reduce the instantaneous demand.

In this application, a single voltage domain and frequency domain is dynamically controlled by ODP circuitry. *Without the microprocessor being aware of the frequency and voltage scaling* - ODP circuitry reduces power consumption by more than 75%. Moving the dynamic power management outside of the microprocessor provides system level savings for maximum battery life extension. The Packet Digital PowerSage PSG1211 provides the autonomous system level power management for wireless systems and simple devices with a single clock frequency (from 1 Hz to 64 MHz) and a single adjustable supply voltage rail.

Conclusions:

On-Demand Power technologies expand upon the best power management aspects of conventional systems, but improve performance considerably over any other solution. The system level approach is critical to give the maximum operational life and enables additional features, greater miniaturization, or lower cost of design and operation.

The core concept of monitoring and assessing activity and demand is independent of the application, operating system, architecture, and packaging. ODP circuitry and the PowerSage intelligent PMU monitors serial and parallel communications buses to determine when to scale system voltages and clock frequencies. This approach is inherently scalable to new processors, transceivers, memories, and peripherals.

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Packet Digital has demonstrated this on simple single-function devices and complex multi-function platforms with a wide range of applications. In all cases, battery life is greatly increased, helping meet consumer demand and improve competitive advantage.