Chapter 14
Power Management and Energy Scavenging

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ABSTRACT
Contemporary computing requires long battery life, low energy operation, and compact, low cost, light platforms, all at the same time. Good power management is often the determinant for success. Main traditional power management development areas are architectural power/performance features, low power circuits, power electronics or power delivery, and thermal management system design. These areas are reviewed in the first part of this chapter. Next, energy scavenging is introduced as a recently proposed power management field with great potential for development. Available energy sources around a computing platform, and associated scavenging technologies are reviewed in Section 2. The final section of the chapter emphasizes a full system approach for effective integration of energy scavengers to practical computing platforms through proper case studies.

INTRODUCTION
The development of integrated microprocessor chip in 1971 enabled the Personal Computer (PC). Moore’s Law has correctly predicted the seamless technology advancement of doubled transistor count on a chip every 18 months, while the transistors themselves have shrunk to smaller size devices with every generation. Computer architects developed advanced features to utilize the additional transistors to improve performance. The circuit designers simultaneously took advantage of the smaller devices to build faster circuits. Integration of computer hardware into fewer components (chips) was accomplished with every technology process generation due to the increased number of smaller transistors. One of the side effects of the integration was the...

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reduction in overall system power dissipation due to the elimination of glue-logic between components, and the fact that each transistor could be switched on/off with less power. Computer quickly stopped being an expensive machine in a laboratory reserved for privileged scientists, and starting 1990s, segmentation took on a new turn in the computer industry to address emerging usage models, making computers available to virtually everyone. Some computers evolved into mobile tools that travel along with us, and help with our daily personal and occupational tasks. Some turned into entertainment centers with emphasis on multi-media performance. Some continued their evolution on traditional high performance computing with the main mission to achieve more scientific computations per unit time. Yet others were simple-task dedicated little processing engines forming the building blocks of the increasingly automated and digitized eco-system around residential, industrial, health, education, transportation, communication, and other sectors of our civilization.

The end of the 20th century brought along the quick realization that power management had to receive as much focus as performance in computing, if not more. Four fundamental trends in computing are worth highlighting as the main reasons behind this realization:

1. As the first trend, the logarithmically increasing power density due to the compaction of transistors pushed the limits of the system cooling solutions to the extent that heat sinks in PCs reached unmanageable size, and fans became disturbingly noisy. Power management in general purpose and high performance computing was identified as a crucial development area (Borkar, 1999) due to the need for more performance, and the cooling challenges in electronic systems. Commercial thermal management solutions in microprocessors (Ma, 2003) were reported around the same time. The work on better thermal management was naturally driven by desire for more performance. However, ergonomic issues like temperatures experienced by the computer users around computer systems (especially portable ones), and fan noise also started to be included as design parameters. It was not feasible to switch to a higher cost cooling technology in PCs due to the market pressures. This caused the computing industry to take on what is known as a “right hand turn” with the beginning of the 21st century. Design targets started including power dissipation as a fundamental constraint, which required traditionally performance focused design engineers to include power verification into every step of the design process.

2. The second trend was not as abrupt as the first, but was marked by the steady phenomenal increase in the market share of the mobile PCs. Battery life and hence the energy efficient operation of computers became a prudent system attribute, which in turn drove new design features, such as low power operation modes for individual components including microprocessor, graphics, memory, and the rest. More capable power management solutions had to be offered within the package of mobile system technologies (Chinn, 2003). Satyanarayanan (2005) highlighted that “energy is the only perishable resource” in mobile computing, and contemplated the problem of avoiding dead batteries. In addition to hardware and software enhancements to improve energy efficiency, he offered replenishing the battery’s energy through external actions as a viable option.

3. The third trend was even more steady and long coming than the second was. It gradually became obvious that computing would be ubiquitous. The world would be a collection of embedded systems constantly sensing environmental conditions and stimulations,