Low Voltage Booster Energy Harvesting

Advanced Linear Devices, Inc.

While the practice of energy harvesting has emerged from the laboratory and established legitimacy over the last few years, the electronic circuitry used in energy harvesting systems continues to advance in order to capture power from ever lower-voltage and lower-energy sources in order to fulfill the promise of powering embedded systems with energy harvesting. While potentially useful sources such as thermoelectric generators and single photovoltaic cells can generate potential energy, they tend to produce moderate current at very low voltages, which make the capture and usage of energy from these sources very difficult. Furthermore, most techniques available to date require substantial compromises such as stacking a multiple of these energy sources on top of each other.

Ultra low voltage voltage-booster circuitry can be designed to boost these low voltage sources to useful operating voltages, making these sources more practical for system design.

Energy harvesting seems to have taken off and continues to generate interest for a wide variety of practical applications and embedded systems. Since energy harvesting often requires a multidisciplinary approach in bringing systems to market, there is an opportunity for the electronics industry to provide the specialized circuitry for this nascent field.

“Unlike the general electronics industry that is braced for a negative impact from today’s subprime market conditions, various energy harvesting technologies and related power management ICs are poised for rapid and profitable growth in 2009,” Linnea Brush, Senior Research Analyst, Darnell Group. “A convergence of several factors including new government regulations and economic incentives is resulting in a favorable environment for wireless sensor systems incorporating power sources based on energy harvesting.”

One of the primary missions with energy harvesting remains the same - enable freedom from charging batteries and refueling other conventional power sources by accumulating power generated by ambient sources. Piezoelectric elements, for example, are well established in supplying power to embedded systems operating in the 3-Volt to 5-Volt range.

Circuits that capture, accumulate and store energy from Sub 0.5-volt sources require special design considerations. By examining the unique properties of ultra low voltage sources, a new benchmark can be established for developing the circuitry that make these sources a practical power supply for a range of embedded systems.

To start with, energy harvesting circuitry must capture energy from sources producing less than 200 mV. We are expecting this demand for solutions using thermoelectric generators and single photovoltaic cells and other sources.

A single solar cell puts out in the neighborhood of .4 to .5V depending on lighting conditions. But once it starts generating electricity, the optimal power-generating voltage for the single solar cell is about half of that. This means that the electronics must be able to work with about 0.2V to 0.25V. Experimental data suggest that it’s necessary to have from .2V to .3V operating voltage to draw any useful power from a single solar cell and an energy harvesting electronics would have to work at a lower voltage range so it would cover the low end of a solar cell’s output.

Thermoelectric energy generators consist of thermocouples that are arranged together by hundreds of strands. It is possible to generate 100 to 200 mV using TEGs. These device can put out up to a few hundred micro-amps in power in the form of high current and low voltage. The very low voltages that TEGs generate needs to be converted to higher voltages and lower currents in order to be useful for most electronic applications. This conversion requires an ultra low-voltage voltage-booster.

Energy harvesting modules now on the market operate in the range of +/-5.0V down to +/- 4.0V and they burn about .9 uW at maximum power. The design demands efficiency and typical power will be much less than that. These modules typically achieve about 90 percent energy efficiency.

For ultra low voltage energy harvesting sources, the maximum input should be +/- 1.0V and the minimum input should be as low as +/- 0.1V. Once a voltage goes below one volt, things get interesting because the voltage approaches zero. To design a circuit with a range of .1V or .2V to 4V is a 40X improvement, so it becomes apparent why energy boosting is so essential in circuit design.

To draw a comparison, many engineers may remember the old television booster circuits which could boost 5, 10 or 20 volts to up to 20,000 volts if it was needed. Energy harvesting circuitry works similarly but all the circuitry has to be scaled down to this ultra low input voltage level.

One approach to design circuits that are up to the task is to use components that have very precise design specifications and thresholds. The use of precision gate trimming in the manufacture of these devices is one of the ways to achieve these specifications. The level of precision and the level of operating voltage and current are the new frontier in this space. Currently, ultra low threshold voltage MOSFETS are used in energy harvesting circuits, but now even zero threshold MOSFETs should be considered for ultra low voltage module design.

A key requirement for this ultra low-voltage voltage-booster is to make the circuit internally self-powered. In other words, you can’t work with .1V and expect the circuit to need a 1-Volt power supply in an energy harvesting system. This problem is non-trivial as an energy source that puts out a very low voltage often starts putting out current (i.e. power) also at a very low current level as well. Therefore it is a goal to have an ultra low-voltage voltage-booster that requires a minimal amount of startup power at the lowest possible voltage as well.

Another key design consideration is high energy capture capacity. With adequate efficiency, the energy harvesting module has to retain the captured energy and store it. To make the circuitry useful for providing practical output it would have to be able to power CMOS logic circuits such as microprocessors, wireless sensor networks and others. It also has to have a long, projected operating life so designers should plan for greater than 30 years or greater, ideally approaching system operating life. Even though the circuitry will have no wearable parts, it should be designed to outlast the life of the system. Two other design considerations are unlimited charge and discharge cycles and Super Cap or battery storage capability.

While ultra low voltage energy sources are driving the design of the circuits, it’s important to remember the primary mission of energy harvesting modules. It is the process of capturing, accumulating, and storing energy from a variety of energy sources that produce only waste energy. They cannot supply adequate power for any kind of useful purpose until an electronic system is designed to capture that ultra low voltage and/or energy and put it to use. An older-term for this practice is energy scavenging.

One of the purposes of energy harvesting is to effectively manage this small trace of harvested energy to power a variety of sensor circuits. But since the energy available is often very minute and unpredictable, most of the initial target applications are intermittent duty-cycle applications. This gives whatever energy available time to accumulate while a microprocessor or a sensor circuit is in sleep-mode. This type of system needs to be in the sleep mode, wake up to perform its duty and then go back into sleep mode. If an application requires high energy and high duty cycle, and the energy demand approaches or exceeds the energy available from a particular environment, then energy harvesting techniques are probably not suitable for its power supply design.