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A Practical, Easy-To-Implement Energy Harvester For BLE Modules And Other Applications

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Sustained market interest in greener, more sustainable electronics has been driving technical innovation and adoption. As these solutions continue to evolve and exhibit greater efficiency and reliability, implementation continues to grow. Energy-harvesting power sources are one such solution.

Energy harvested power used in ultra-low power (ULP) applications is more practical than ever thanks to three prevailing trends:

- An ever-increasing field of ULP electronics.
- Growing numbers of cost-effective power management ICs (PMICs) well-suited for energy harvesting applications.
- Ever more energy-harvesting-hardware options, ranging from small solar cells to thermal electric generators (TEGs) and motion-based recovery devices.

This article builds upon two prior investigations of supercapacitors and tantalum capacitors used to power ULP devices with harvested energy. The first is a technical paper, "Tantalum and Supercapacitors Enable Maintenance-Free Microcontrollers,"[1] which used a solar cell as a harvester to illustrate how easy it is for a ULP microcontroller to manage its own power—its charge and power conversion operations—within the microcontroller package. It also illustrated the practicality of tantalum capacitors used in a bootstrap configuration for wake-up and prioritization functions, and identified various sizes of supercapacitors for energy source and hold-up functions.

The second is an article, "Supercapacitors Support Miniature Energy Harvester ICs in Powering ULP Devices,"[2] which concentrated on evaluating an energy harvesting controller IC. It demonstrated the performance and characteristics of an energy-scavenging/harvesting controller IC using an electronic load to represent an equivalent ULP IC load and showed use cases for prismatic-cell supercapacitors, radial-can supercapacitors, and extended-value tantalum capacitors.

For this investigation into supercapacitors for energy-harvesting applications, we used the same power conversion and management IC featured in the second work[2] to extract power from a small solar cell. That energy was then used to power a Bluetooth Low Energy (BLE) module that measures the voltage of the storage capacitor as well as the regulated voltage supplied to the BLE module, and then sends those voltage values to a PC for data logging. This configuration provides a real-world example of an energy-harvesting system and demonstrates how easy it is to configure.

Power Conversion IC

As in the previous article,[2] the e-peas AEM10330 energy harvester[3] was selected for exclusive investigation because of its complex electrical capabilities, which are contained within a small 5.0- x 5.0- x 0.8-mm quad-flat no-lead (QFN) package. Implementing the AEM10330 was simple, requiring just five additional components—three capacitors, one inductor, and an optional Li-ion battery or supercapacitor at the storage (STO) pin—all of which fit within a 180-mm^2 board area. (See Fig. 1 and the table.)

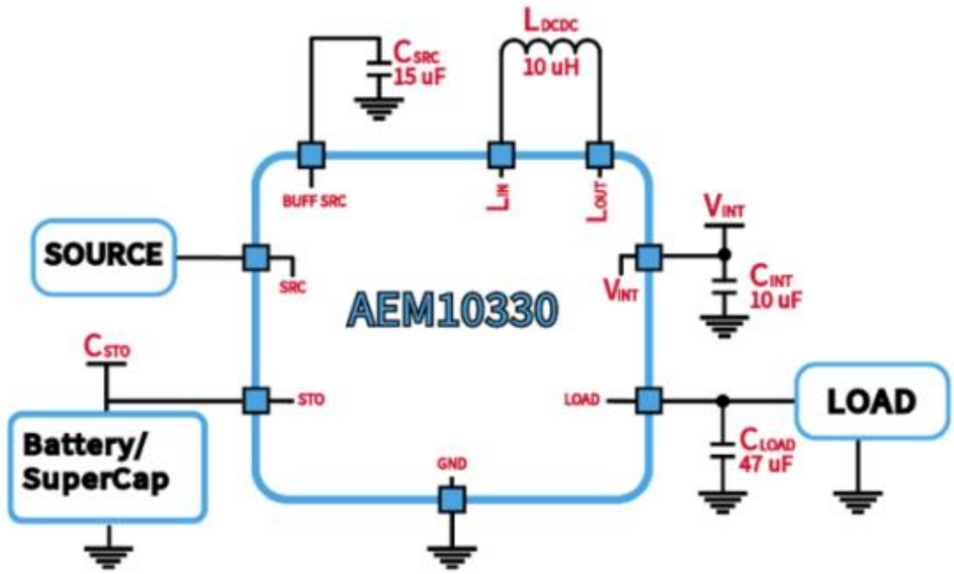

Fig. 1. The energy harvester schematic.

Table. The energy harvester bill of materials (BOM).

Component location	Description	Part number	Board area (mm^2)
IC	Energy harvester	AEM10330	25
C_{load}	47 µF, 6.3 V, 20%, X5R, 0603 MLCC	KGM15CR50J476MT	1.28
C_{INT}	10 µF, 6.3 V, 20%, X5R, 0402 MLCC	KGM05CR50J106MH	0.5
C_{SRC}	22 µF, 6.3 V, 20%, X5R, 0402 MLCC	KGM05DR50J226MH	0.5
L_{DCDC}	10 µH, 20%, IDC = 1.7 A, DCR < 0.13 Ω	LMMN0605M100MTCS	30
Supercap	10 F, +30%/-10%, 3 V	SCCT20E106SRBQ	122.72

This IC has an energy harvesting function, as well as a regulation function and a charge storage role. It receives power from an energy harvesting source—in this case, a small solar cell (although, a TEG or piezo recovery device would also work), regulates that energy, and then sends it to a load—in this case, a BLE transmitter module.

The BLE module is configured to measure the voltage of the storage capacitor and the voltage at the output of the solar panel. The module then wirelessly transmits those two voltages to the PC, sending the data in a beacon fashion so any PC within the receiving zone can download it. Each energy harvesting beacon has its own specific ID, so if there are many within a PC's reception range, users can program the PCs to download data from specific beacons.

System Configuration And BLE Module

We used a small 3-cm x 4-cm solar cell as an energy harvesting source to drive the e-peas AEM10330 energy harvesting module, which has connections for an external storage bank or battery source. We also connected a 10-F radial-can supercapacitor to an external PCB to highlight the role of an energy storage capacitor. The resulting three blocks—solar cell, AEM10330 converter board, and external 10-F SCC series capacitor board—formed a power source for the data acquisition beacon board, and we affixed those blocks to a larger carrier

PCB for ease of demonstration (see Fig. 2).

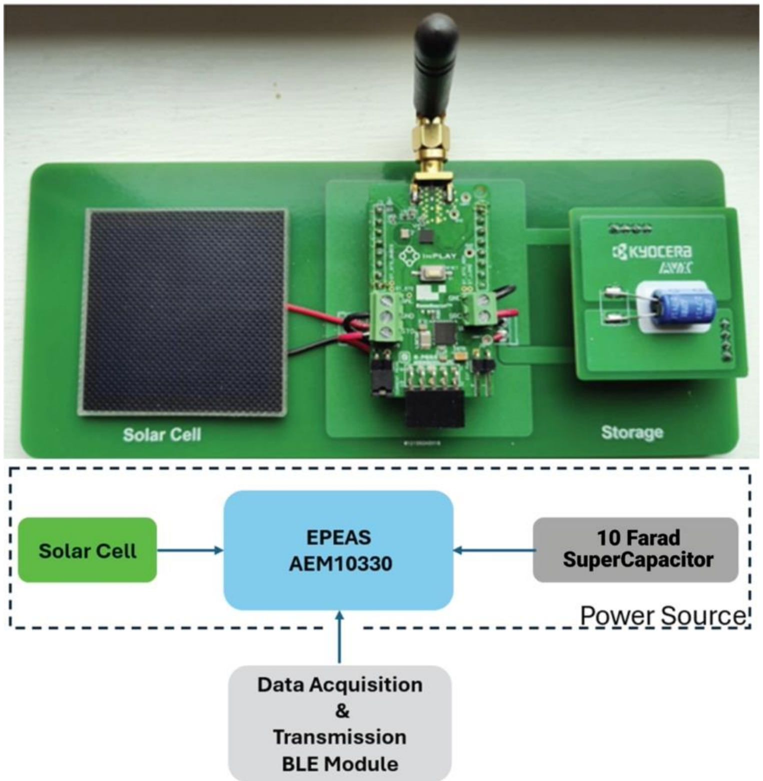

Fig. 2. A photograph and block diagram of the energy harvester and BLE measure/transmit system.

The center board in Fig. 2 consists of a BLE beacon stacked on top of the AEM10330 PMIC board to save space. The BLE board is an InPlay IN1BN-DKA0-AEM100-C1.

This beacon periodically sends a single transmission with a packet of data known as an advertisement. We created a custom code application to listen for the BLE advertisement, and decode the voltage data at the solar cell's feed to the PMIC and at the supercapacitor feeding the AEM-10330. This decoded data can then be graphed and displayed on a PC to illustrate the overall system's capabilities.

Discussion Of Results

We wrote code designed to plot the received BLE module data and display the voltage level of the solar cell and supercapacitor. A capture example was chosen and appears in Fig. 3. The solar cell's output naturally varies in accordance with the incident solar intensity. An infinite number of solar intensity examples exist.

The event depicted in Fig. 3 is the result of solar capture during a period of low sunlight, which is reflected in the low voltage measurement. Naturally, as sunlight levels decline further the storage capacitor's voltage will eventually drop as the panel's output voltage falls below the operational window of the e-peas device. However, the measurement shown demonstrates the ability of this system to function even in relatively poor lighting conditions.

The practicality of powering a working BLE module has been proven by the fact that this data acquisition and transmit module is easily powered by the e-peas module with supercapacitors connected to its external energy storage terminals. End users have many different options when selecting supercapacitors for this application.

They can choose a single radial can, as we did for this investigation, or a small supercapacitor module rated for 5 V to 5.4 V.

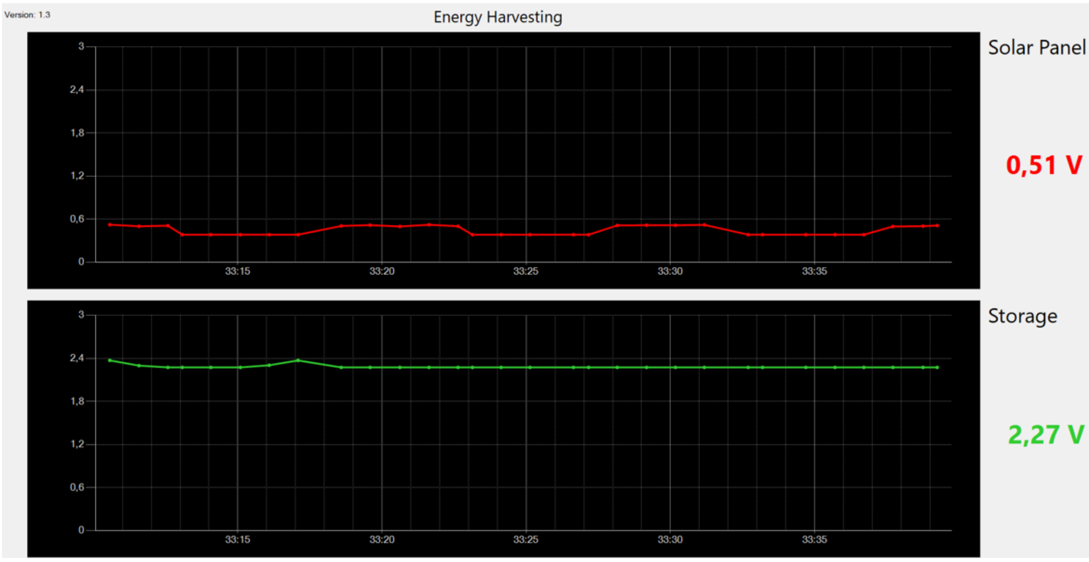

Fig. 3. A PC screen capture of solar panel and supercapacitor voltage data received from the BLE module.

Supercapacitor Options

There are generally two types of small supercapacitor modules: multiple radial cans encapsulated in shrink-wrap tubing and multiple radial cans encapsulated in a plastic shell with an epoxy-filled end. The plastic-shell epoxy-filled supercapacitor modules exhibit enhanced reliability when used in applications with elevated temperatures and/or high humidity.

Typical physical sizes for the heat-shrink tube parts range from 6.3 mm to 12.5 mm in individual can diameter. Those cans are then packaged to create modules with widths spanning 14 to 32 mm, heights up to 33 mm, lead spacing of 11.5 mm or 13.5 mm, and typical capacitance values up to 15 F. The hard-shell modules have a shell-plus-can diameter of 9.5 mm, a fixed width of 18.5 mm, heights up to 24 mm, a lead spacing of 11.5 mm, and capacitance values up to 1.5 F.

Whether you choose a single-can supercapacitor or a supercapacitor module, its lifetime will be impacted by a combination of the operating voltage and operating temperature according to the following time-to-failure equation:[4]

$$t \propto V^n \text{ x } e^{\left(\frac{-Q}{kT}\right)}$$

in which V is the operating voltage, Q is the activation energy in electron volts (eV), k is the Boltzmann constant in eV per Kelvin (K), and T is the operating temperature in Kelvin (K). Typical values for the voltage exponent n are between 2.5 and 3.5, and for the activation energy Q are between 1.0 to 1.2 eV, within the normal operating temperature range of -40°C to +65°C.

The industry standard for supercapacitor end-of-life is when the equivalent series resistance (ESR) increases to 200% of the specified value and the capacitance drops by 30% from the specified value. Typically, a supercapacitor shows an initial jump in the ESR value and then levels off.

However, if the supercapacitors are exposed to excessive temperatures, the ESR will show a continuous increase in ESR values, indicating additional degradation. Extreme cases, where the temperature or voltage is substantially higher than the rated specifications, can cause the part to vent and experience an even faster degradation of capacitance and ESR.

Single-can supercapacitors are a popular choice for designers since they can be connected in series-parallel fashion with PCB traces at virtually no cost and balancing circuitry can be added in accordance with end-customer needs. The power density of miniature 3-V radial-can supercapacitors is in the 1,850- to 4,050-W/kg range, and the energy density is in the ~1.1 to 5.1-Wh/kg range. However, engineers have maximum flexibility to choose single-can supercapacitors or supercapacitor module energy storage reservoirs for designs powered by energy harvesting sources given that both deliver high capacitance values in small packages.

Summary

Utilizing energy harvesting to power small electrical loads is now practical and easy given expanded component options. Harvested energy sources can even be considered in applications that require high-quality power[5] and reliability[6] given the ready availability of high-performance building blocks, such as automotive-qualified supercapacitors. These supercaps provide designers with enhanced performance based upon optimized designs and stable production processes.

Supercapacitors have been shown to have the ability to replace batteries as the power source for Bluetooth low energy modules and can provide a near-infinite number of charge/discharge cycles of harvested power with zero battery replacement requirements. Small-module supercapacitors are expected to gain popularity in future designs due to their 5-V ratings, high capacitance values, and small sizes.

References

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About The Authors

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Prior to joining AVX, Ron worked as a product engineer and, later, a product engineering manager in the electronics division at Corning Glass Works. In these roles, he supported the development, production, and sale of pulse-resistant capacitors, high-temperature capacitors, and radiation-resistant capacitors, developed high-frequency test methods, and co-developed high-temperature test systems. Ron earned his BSEE from Clarkson College of Technology (now Clarkson University). He can be reached at ron.demcko@kyocera-avx.com.

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For more on energy harvesting designs, see How2Power's Design Guide, and do a keyword search on "energy harvesting". For more on capacitor selection for power design, see the "Component" category and select "Capacitors".