

Using the EnerChip[™] CC in Energy Harvesting Designs

EnerChip CC Overview

Cymbet EnerChip[™] solid state batteries are highly rechargeable energy storage devices packaged in low profile, surface mount, solder reflowable packages. Their low self-discharge, high charge-discharge cycle life, and ability to accept very low input charging current combine to make them ideally suited as energy storage devices in low power applications. These include backup power sources for real-time clocks, microcontrollers, and memory chips to maintain operation during periods when main power is interrupted. EnerChips are also well suited as energy storage devices for wireless sensor nodes where energy is harvested from ambient power sources. The integrated battery and power management circuitry included in the EnerChip CC products provides supply voltage threshold detection, an automatic energy storage switchover function, and EnerChip charge-discharge control circuitry - all in a compact surface mount package that includes the EnerChip storage device. Figure 1 depicts the EnerChip CC surface mount package and the CBC-EVAL-10 development module designed for evaluating the EnerChip CC devices in energy harvesting applications.

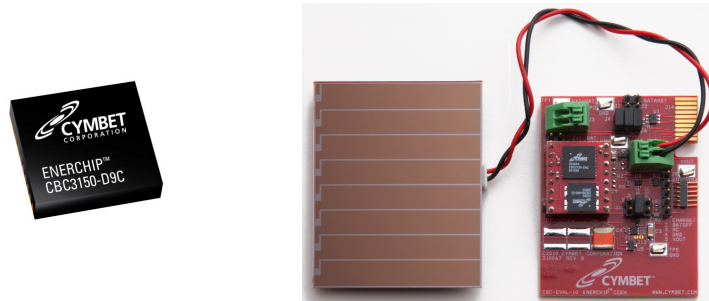


Figure 1. EnerChip CC CBC3150 (left) and the CBC-EVAL-10 Energy Harvesting Evaluation Kit (right)

EnerChip CC Energy Harvesting

The EnerChip CC can be configured to collect energy from transducers such as low power photovoltaic (PV) cells and use that harvested energy to charge the integrated EnerChip and deliver self-sustaining power to components such as microcontrollers, sensors, and radios in wireless systems. Figure 2 illustrates a typical implementation of the EnerChip CC in energy harvesting applications. In order to make most efficient use of the power available from the transducer (for example, a PV cell), it is necessary to know the electrical characteristics including voltage and peak power point of the transducer being used. This Application Note describes a low cost energy harvesting circuit using the EnerChip CC to collect, convert, store, and deliver to the

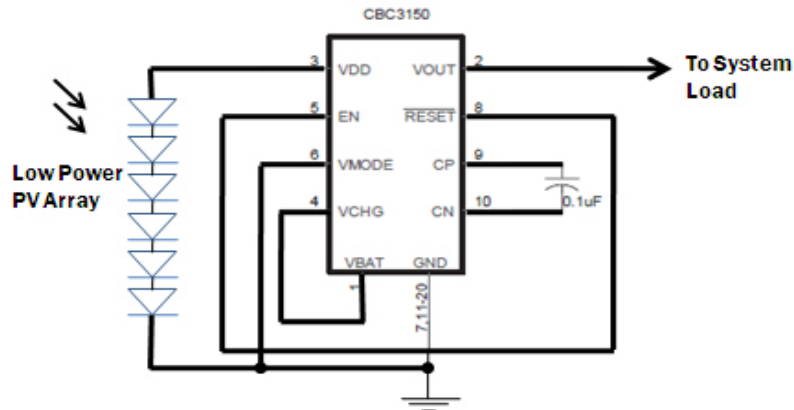


Figure 2. Implementing Energy Harvesting with the EnerChip CC CBC3150

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system components the energy available from power transducers such as small photovoltaic cells.

EnerChip CC Description and Operation

The EnerChip CC is a multi-functional circuit that serves two primary application purposes:

- Backup power source with integrated power management for real-time clocks, SRAM, and microcontrollers
- Energy harvesting, power management, and energy storage in wireless network systems

The EnerChip CC delivers power to the system load from either the main supply or the integrated EnerChip rechargeable storage cell.

Functional elements of the EnerChip CC are:

- Internal charge control circuit that converts a wide range of input voltages to a tightly regulated battery charging voltage;
- Battery cutoff circuit that disconnects the load from the embedded EnerChip when the discharge voltage reaches a preset limit;
- Output pin that can be used to drive an interrupt line on an MCU to indicate that the system is operating in battery-backed mode;
- A voltage detection circuit allowing a user-selectable threshold trip voltage;
- A control line that enables and disables the internal charge pump that can be controlled externally to reduce power consumption when the internal EnerChip does not need to be charged.

Figure 3 illustrates the functional blocks of the EnerChip CC. The only required external component is the flying capacitor - typically 0.1uF to 0.47uF. In normal operation, VDD passes directly through to VOUT by way of a 2.5 Ohm (typical) pass transistor. When VDD drops below the switchover threshold (as determined by the voltage on VMODE), the internal energy storage device - the EnerChip - delivers power to the load through VOUT at a nominal voltage of 3.3V (unregulated). An internal charge pump regulates the EnerChip charging voltage at 4.1V. To reduce power consumption, the charge pump can be disabled by forcing ENABLE to a logic low. Additional EnerChips may be appended to the VCHG pin for incremental energy storage. The EnerChip CC operates over a supply range of 2.5V to 5.5V. See EnerChip CC data sheets for a more complete description of the circuit functions, operating modes, and specifications, including EnerChip device characteristics.

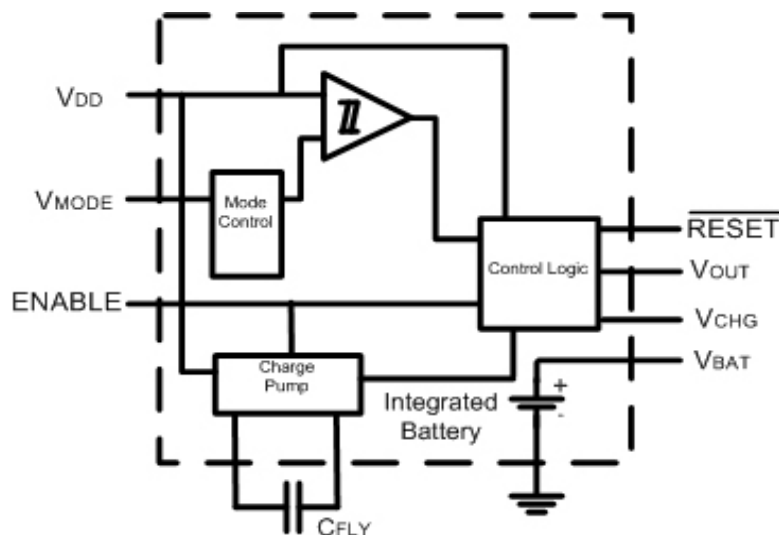


Figure 3. Block Diagram of the EnerChip CC Energy Storage Device with Integrated Power Management

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In addition to the intrinsic features of the EnerChip CC, the CBC-EVAL-10 makes provision for system-level requirements in energy harvesting applications, including:

- Energy harvesting circuitry that matches the impedance of photovoltaic cells to ensure maximum power transfer to system load and on-board energy storage devices
- Integrated battery management that controls battery charging and discharge cutoff, ensuring maximum service life of on-board storage cells
- Provision for additional energy storage (primary or rechargeable batteries) with switchover control circuit to meet application requirements
- Regulated output voltage with user-configurable voltage settings
- Input/output headers for connection to system components such as radios and microcontrollers

The following sections describe energy harvesting concepts and methods of configuring the EnerChip CC as a low cost energy harvesting, storage, and delivery device in low power wireless systems.

Energy Harvesting Design Considerations

Energy harvesting refers to the collection of ambient energy in one form and conversion to another form - for example, the conversion of ambient light to electrons using PV cells. The energy is typically then stored in a highly rechargeable storage reservoir - such as the EnerChip - and delivered to other system components such as MCUs, sensors, radios, and so forth. A typical application is a wireless sensor node that: measures any number of environmental variables (e.g., temperature, proximity, pressure, humidity), processes the information, and sends it via a wireless radio link to a central location or another wireless node.

The reliability of traditional batteries over years of operational life can be poor. Consequently, designers have long sought alternative means of providing power to wireless systems. Energy harvesting, coupled with solid state energy storage, is now a viable alternative in many operating environments. The average power consumed by a wireless sensor node is often on the order of a few microwatts to a few tens of microwatts. The average power is often dominated by standby currents of the MCU, radio (where applicable), and sensor itself. The radio transmit and/or receive duty cycle, if kept to a low percentage, will not generally have an overwhelming effect on the average power consumption of the sensor node. With proper system design, most or all elements of the system can be put into low power standby modes to reduce the average power consumption and therefore permit cost-effective power transducers like small PV cells to be used for collecting power in low ambient light.

Other design considerations include managing start-up power associated with linear devices when being powered by a 'soft' supply such as a small PV cell in low light. For example, MCUs and radios, if not powered up with a robust power supply, can enter high current states that prevent the system from ever reaching a stable operating condition due to the limited power available from the supply.

Pulse currents demanded by radios can also render the system inoperable if not properly managed with output capacitance and proper system configuration. Additionally, it is often advantageous to disconnect sensors themselves from the power supply when not actively acquiring signals. This can result in a significant reduction in average power consumption and lower the requirement for bulky power transducers and energy storage devices. In some cases, it is necessary to utilize power-on reset circuits to ensure the load is not connected to the supply until sufficient charge is injected into an output capacitor to overcome the start-up problems described above. Linear dropout regulators (LDOs) must be carefully selected to ensure they do not place a burdensome load on the limited power available from the energy harvesting source.

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When converting power from the source to the load, such as from a PV cell to an active electronic load, impedance matching is essential to efficient power conversion. By matching the impedance between the source and load, maximum power transfer is achieved. Conversely, any mismatch in impedance from the power source to the load presented it will result in wasted power. As shown in Figure 4, the peak power output of a PV cell occurs at a point on a nonlinear voltage-current (V-I) curve. Extracting power from the PV cell at an operating point well away from the peak power point results in greatly diminished power output. Consequently, proper impedance matching is critical to efficient circuit operation. Various impedance matching circuits are available to the designer.

The power curve of Figure 4 is typical of a low power PV cell used in energy harvesting applications. Electrical impedance of the cell varies strongly as a function of ambient light. As illustrated, the power curve is highly nonlinear; connecting an electrical load to the PV cell that is not matched to its impedance results in inefficient power transfer to that load.

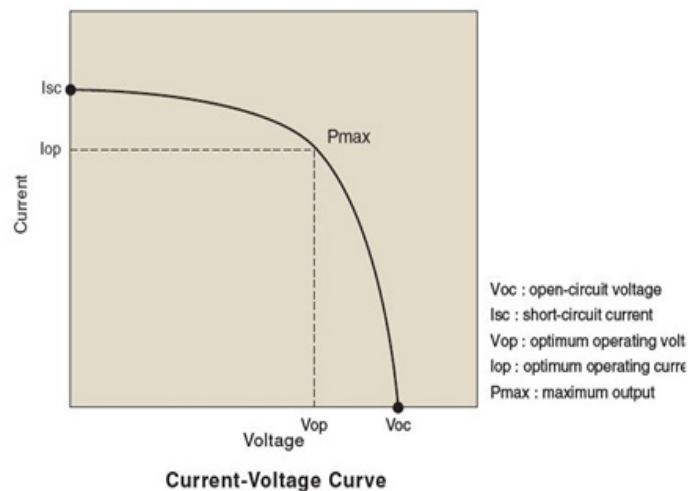


Figure 4. Typical Power Profile of a Photovoltaic Cell

Choice of a particular design depends on many factors, including:

- the nature of the system elements (e.g., capacitive, inductive, resistive) and the rate at which the elements change over time with variations in ambient conditions;
- the amount of power being coupled from source to load;
- conversion efficiency needed for proper circuit operation;
- and the relative cost of implementing a given circuit.

The designer often must consider all of these factors when selecting a particular energy harvesting design topology. The following section describes a circuit that relieves the designer of the complexity associated with making those calculations.

EnerChip CC Energy Harvesting Circuit

As illustrated in Figure 5, the EnerChip CC can be configured to operate in an energy harvesting mode that tracks the peak power point of the transducer (e.g., PV cell) by dynamically adjusting the duty cycle of the internal charge pump - increasing the duty cycle with higher input power, decreasing it with lower input power. This is accomplished by connecting the RESET/ output to the ENABLE input. In so doing, the load presented to the transducer varies in response to changes in transducer output characteristics. As the transducer drive current diminishes at a given voltage, its impedance is raised.

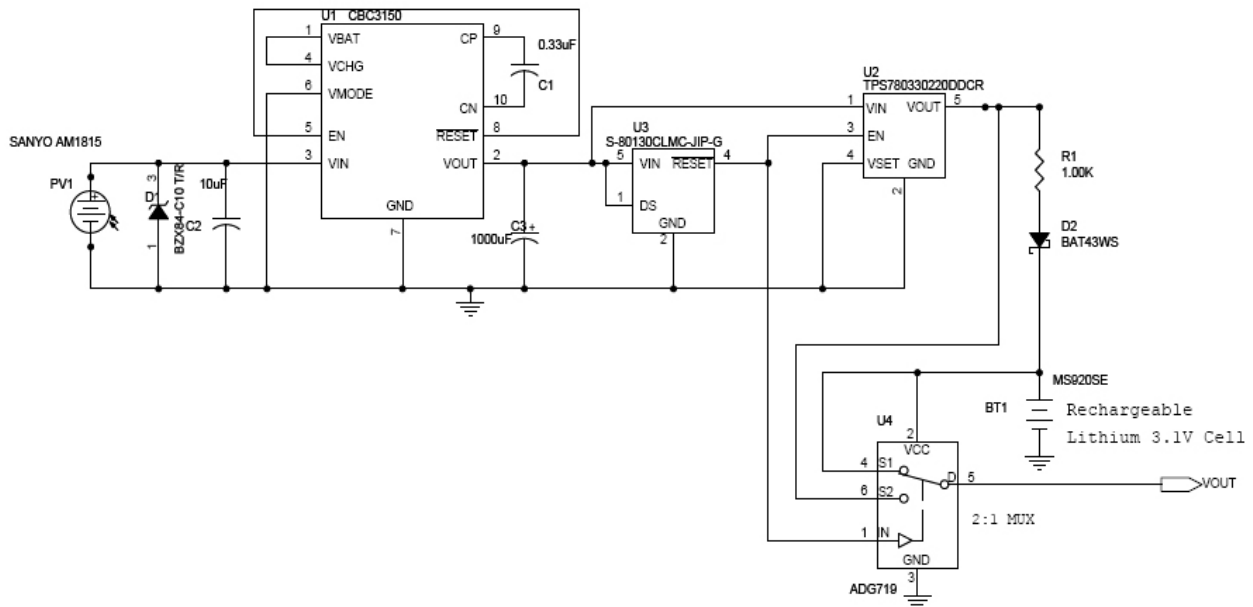


Figure 5. EnerChip CC EH Energy Harvesting Schematic

As the EnerChip CC loads the transducer output, the voltage at VDD decreases, until the point that the supply threshold trip point 3.0V (as determined by GND level of the VMODE pin) is reached. At that point, the RESET/ line is forced low, which in turn disables the charge pump, thereby increasing the effective impedance presented to the transducer. A higher impedance attached to the transducer allows the transducer voltage to rise, repeating the cycle. Thus, the duty cycle of the charge pump is dictated by the transducer I-V characteristics. Ideally the threshold detect trip point will be set to the voltage at which the transducer operates at its peak power point. VMODE has two discrete threshold switchover settings VDD and GND (GND in this case) as well as the option for setting it to an arbitrary level through use of an external resistor divider. In the latter mode, it is important to select resistor values that do not place a burdensome load on the supply. See the EnerChip CC CBC3150 DS-72-03 or CBC3112 DS-72-04 data sheets for recommendations on resistor values to use on the VMODE pin.

Figure 5 depicts an energy harvesting implementation using the CBC3150 power management IC. The circuit in Figure 5 is useful for some energy harvesting applications where start-up currents of radios and microcontrollers will place a load on a relatively underpowered transducer that can not be overcome without additional circuitry incorporated to manage the transition of power from the transducer to the load. This schematic uses a power-on reset circuit that enables operation of the output regulator only after the capacitance is fully charged. This scheme allows for a sufficient burst of charge into the load to overcome the start-up power barrier.

Another scenario shown in Figure 5, includes a larger, external battery (shown as BT1 either a rechargeable or primary cell) that is used when the CBC3150 energy storage is insufficient to operate the circuit for prolonged periods when ambient power from the transducer is not available. In this case, the service life of external battery that would often have to be used as the main energy storage device can be extended by months or years through the use of energy harvesting. The constant background current drain otherwise eats away at the battery capacity. With energy harvesting, the external battery can be used only intermittently as ambient power is not present, or as the source of higher pulse currents.

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Depending on the output of the transducer and the voltage requirement for the system load, the input shunt diode and the output regulator might or might not be necessary. The circuit of Figure 6 includes the shunt regulator, power-on reset circuit, and input shunt diode typical of an energy harvesting application circuit using PV cells, but excludes the external battery.

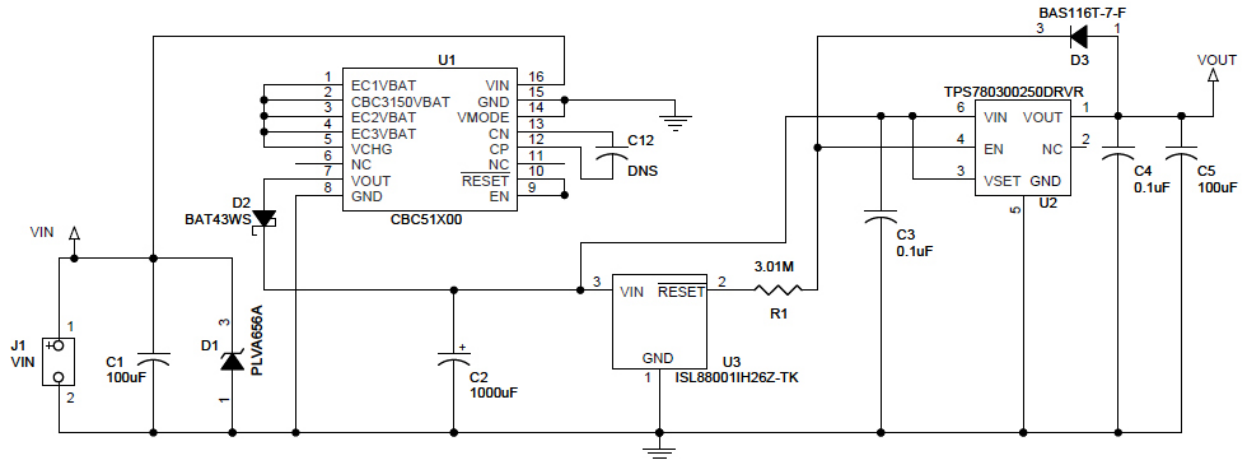


Figure 6. EnerChip CC EH Energy Harvesting Circuit as Implemented in the CBC-EVAL-09

Case Study

When designing a ‘batteryless’ power system using energy harvesting, it is essential to know the system power requirements, including cumulative standby power of all system components, transmit/receive power and duty cycle where applicable, and run-time requirements during periods when ambient power might not be available for harvesting.

A common scenario is a wireless sensor node that measures temperature in a room every several minutes and reports the temperature to a centralized receiver via a short range radio link. Total power consumption can be broken down as follows:

1) Microcontroller in standby mode	1uA
2) Temperature sensor	500nA
3) A/D conversion for temperature measurement	50uA x 20ms
4) Radio standby current	2uA
5) Radio transmit pulse	20mA x 20ms
6) Temperature measurement duty cycle	once per 5 minutes
7) Transmit duty cycle	once per 5 minutes
8) Average current required by energy harvesting and power management circuit, including EnerChip at >90% state-of-charge and assuming the charge pump is active 50% of the time	15uA

Total average power is the sum of the above, calculated based on a system voltage of 3.3V.

$$\begin{aligned} \text{Pavg.} &= 3.3\mu\text{W} + 1.65\mu\text{W} + (165\mu\text{W} \times 20\text{ms}/300 \text{ sec.}) + 6.6\mu\text{W} + (66\text{mW} \times 20\text{ms}/300 \text{ sec.}) + 49.5\mu\text{W} \\ &= 65.5\mu\text{W}. \end{aligned}$$

The total energy consumed in any 24-hour period, using the foregoing assumptions, is:
 $65.5\mu\text{W} \times 24 \text{ hours} \times 3600 \text{ sec./hour} = 5.7 \text{ Joules}.$

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Thus, the input power from the PV cell, less any conversion losses, must be greater than 65.5uW, assuming the PV cell is illuminated continuously. If less power is available, the duty cycle of the EnerChip CC charge pump will decrease proportionally, effectively decreasing the load to the PV cell as its output power drops in response to a lower ambient light level.

When no ambient power is available, the EnerChip CC consumes only 40nA (to power the EnerChip cutoff circuit), resulting in an average system power consumption of:

$$65.5\mu\text{W} - 49.5\mu\text{W} + 132\text{nW} = 16\mu\text{W}.$$

Supposing the system operates in battery-backed mode for 12 hours per day, the total energy storage capacity required is:

$$16\mu\text{W} \times 12 \text{ hours} \times 3600 \text{ sec./hour} = 0.69 \text{ Joules}.$$

Two EnerChips rated at 50uAh each will deliver power to the circuit for 12 hours when discharged to a 50% state-of-charge.

Using the EVAL-10 EnerChip CC Solar Energy Harvesting Eval Kit and Support

The Cymbet CBC-EVAL-10 Evaluation Kit can be used to easily prototype the circuit shown in Figure 5.

Information on the EVAL-10 can be found at <http://www.cymbet.com/content/products-evaluation-kits.asp> and are in stock at any of our Distributors.

The EnerChip CC can be configured to operate as an efficient, low cost energy harvesting circuit that includes solid state energy storage as the energy reservoir to power the system components when ambient power is not available for harvesting.

For assistance in designing your system to effectively harvest energy from a power transducer in a specific environment, contact Cymbet Applications Engineering.

Ordering Information

EnerChip Part Number	Description	Notes
CBC-EVAL-05	EnerChip CC Evaluation Kit	A CBC3112 and a CBC3150 on 24-pin module for experimentation
CBC3150-D9C	EnerChip CC 50uAh with Integrated Power Management	Parts sold tube or tape-and-reel
CBC-EVAL-10	EnerChip CC EH Evaluation Kit	EnerChip CC board with PV panel and CBC51100 EnerChip module

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