

Ultra-Low-Voltage Input Power Converters Support Energy Harvesting

Harvesting energy is now practical using ICs that can aid in capturing small amounts of energy and transform it into a useful power source.

With electronic circuits now capable of operating at microwatt levels, it is feasible for them to be powered using non-traditional sources. This has led to energy harvesting, which provides the power to charge, supplement, or replace batteries in systems where battery use is inconvenient, impractical, expensive, or dangerous. It can also eliminate the need for wires to carry power or transmit data.

Energy harvesting can power smart wireless sensor networks used to monitor and optimize complex industrial processes, remote field installations, and building HVAC systems. In addition, otherwise wasted energy from industrial processes, solar panels, or internal combustion engines can be harvested for useful purposes. Key to energy harvesting is a power converter that can operate with ultra-low-voltage inputs.

Now that we have described why it is feasible and what it can do, how does energy harvesting actually work? Put simply, it is a process that captures, accumulates, and stores

minute amounts of energy as a power source. Typical energy-harvesting inputs include:

- Solar power
- Thermal energy
- Wind energy
- Salinity gradients
- Kinetic energy

Today, energy harvesters do not typically produce enough energy to perform mechanical work; however they can provide enough power to support low-energy electronics. In most cases, the “fuel” for energy harvesters is naturally present and may be considered free. Using natural sources in remote areas for energy harvesting is an attractive alternative to inconvenient utility and battery power. These natural energy sources may be available maintenance-free for a lifetime. Energy harvesting can also be an alternative energy source that supplements the primary power source and enhances its reliability.

Energy harvesters are intended for applications that require very low average power but also need periodic pulses of higher load current. For example, in many wireless sensor applications the circuitry is only powered to make measurements and transmit data periodically at a low duty cycle. Energy harvesting is becoming more feasible today because of the increased efficiency of devices used to capture, store, and produce electrical energy. This can be accomplished with very efficient,

very-low-voltage input step-up converters. Also, improved low-voltage, high-efficiency microprocessors may allow them to become participants in energy-harvesting systems.

ENERGY HARVESTING IC

Linear Technology’s LTC@3108, a highly integrated dc-dc converter, is intended for energy harvesting. It can harvest surplus energy from extremely low-input-voltage sources such as thermoelectric generators (TEGs), thermopiles, and small solar cells.

The circuit in Fig. 1 uses a small step-up transformer to boost the input voltage to an LTC3108, providing a complete power management solution for wireless sensing and data acquisition. It can harvest small

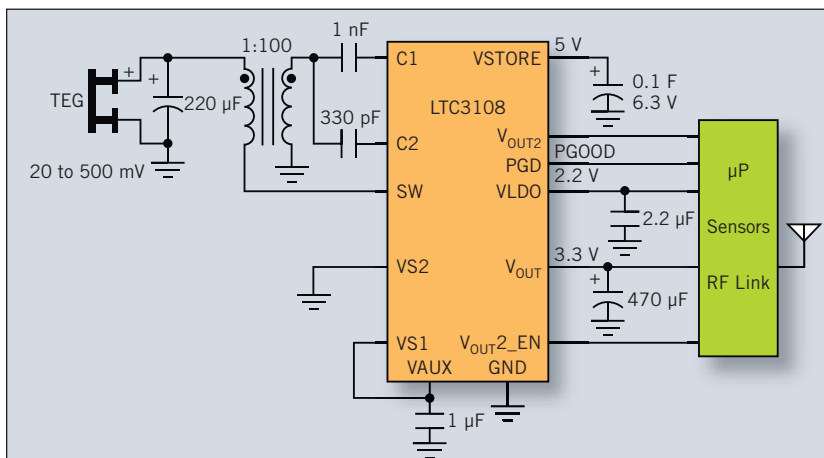


Fig. 1. A wireless remote-sensor application powered from a Peltier cell employs the LTC3108 to harvest energy for the remote sensor.

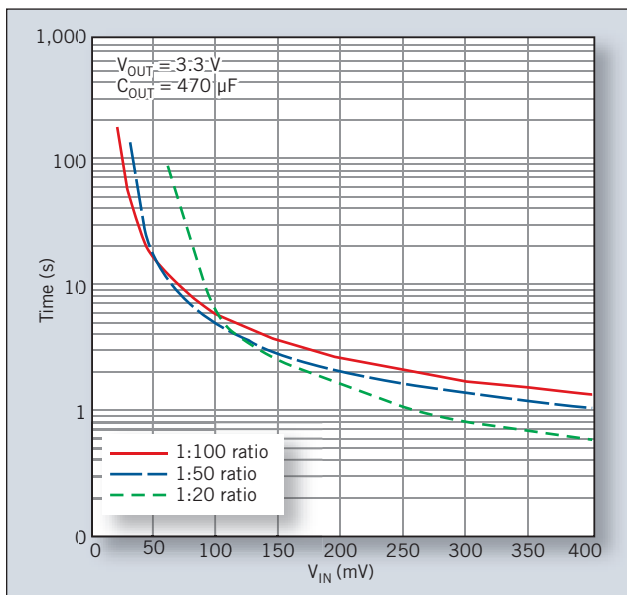


Fig. 2. V_{OUT} charge time vs. V_{IN} for input transformers with three different turns ratios.

temperature differences and generate system power instead of using traditional battery power. The LTC3108 comes in a small, thermally enhanced, 12-lead DFN or a 16-lead SSOP.

The LTC3108 uses a MOSFET switch to form a resonant step-up oscillator using an external step-up transformer and a small coupling capacitor. This allows it to boost input voltages as low as 20 mV, to levels that high enough to provide multiple regulated output voltages for powering other circuits. The frequency of oscillation is determined by the inductance of the transformer's secondary winding and is typically in the range of 20 to 200 kHz. For input voltages as low as 20 mV, a primary-secondary turns ratio of about 1:100 is recommended. For higher input voltages, this ratio can be lower.

Ac voltage produced on the secondary winding of the transformer is boosted and rectified using an external charge-pump capacitor (from the secondary winding to pin C1) and rectifiers internal to the LTC3108. The rectifier circuit feeds current into the VAUX pin, providing charge to the external VAUX capacitor and the other outputs.

LDO OUTPUT

A 2.2-V LDO can support a low-power processor or other low-power ICs. The LDO is powered by the higher value of either VAUX or V_{OUT} . This enables it to become active as soon as VAUX has charged to 2.3 V, while the V_{OUT} storage capacitor is still charging. In the event of a step load on the LDO output, current can come from the main V_{OUT} capacitor if VAUX drops below V_{OUT} . The LDO requires a 1- μF ceramic capacitor for stability.

Larger capacitor values can be used without limitation, but will increase the time it takes for all the outputs to charge up. The LDO output is current limited to 4 mA typical.

For pulsed-load applications, size the V_{OUT} capacitor to provide the necessary current for a pulse on load. The capacitor's value will be dictated by the load current, duration of the load pulse, and the voltage droop the circuit can tolerate. The capacitor must be rated for whatever voltage has been selected for V_{OUT} by VS1 and VS2 (See Table).

There must be enough energy available from the input voltage source for V_{OUT} to recharge the capacitor during the interval between load pulses. Reducing the duty cycle of the load pulse allows operation with less input energy. The VSTORE capacitor may be a very large value (thousands of microFarads or even Farads) to provide holdup at times when input power may be lost. This capacitor can charge all the way to 5.25 V (regardless of the settings for V_{OUT}), so ensure that the holdup capacitor has a working voltage rating of at least 5.5 V at the temperature for which it will be used. Fig. 2 plots the time for voltage to build up to its final value for a given input voltage and the input transformer turns ratio. The LTC3108's extremely low quiescent current (less than 6 μA) and high-efficiency design ensure the fastest possible charge times for the output reservoir capacitor.

As listed in the Table, the main output is pin-selectable via VS1 and VS2 for one of four fixed voltages (2.35, 3.3, 4.1, or 5 V) to power a wireless transmitter or sensors. A second switched output can be enabled by the host to power devices that do not have a micro-power shutdown capability. The addition of a storage capacitor provides continuous power even when the input energy source is unavailable.

A PowerGood (PGOOD) comparator monitors V_{OUT} . The PGD pin is an open-drain output with a weak pull-up (1 M Ω) to the LDO voltage. Once V_{OUT} charges to within 7% of its regulated voltage, the PGOOD output goes high. If V_{OUT} drops more than 9% from its regulated voltage, PGD goes low. PGD output is designed to drive a microprocessor or other chip I/O and is not intended to drive a higher-current load such as an LED. Pulling PGOOD up externally to a voltage greater than VLDO will cause a small current to be sourced into VLDO. PGOOD can be pulled low in a wire-OR configuration with other circuitry.

V_{OUT2} is an output that can be turned on and off by the host, using the V_{OUT2_EN} pin. When enabled, V_{OUT2} is connected to V_{OUT} through a 1.3- Ω P-channel MOSFET switch. This output, controlled by a host processor, can be used to power external circuits such as sensors and amplifiers that do not have a low-power sleep or shutdown capability. V_{OUT2} can be used to power these circuits only when they are needed.

PIEZOELECTRIC ENERGY HARVESTING

Linear Technology's LTC3588-1 is a complete energy-harvesting solution optimized for low-energy sources, including piezoelectric transducers. The LTC3588-1 (Fig. 3) integrates a low-loss, full-wave bridge rectifier with a high-efficiency buck converter to harvest ambient vibrational energy via piezoelec-

MAIN LTC3588 OUTPUT VOLTAGE (V_{OUT}) BASED ON VS1 AND VS2 CONNECTIONS		
VS2	VS1	V_{OUT}
GND	GND	2.35
GND	VAUX	3.3
VAUX	GND	4.1
VAUX	VAUX	5.0

tric transducers and then convert it to a well-regulated output to power micro-controllers, sensors, and converters.

The LTC3588-1 operates from an input voltage range of 2.7 to 20 V, suiting it for a wide array of piezoelectric transducers, as well other high-output impedance energy sources. Its high-efficiency buck dc-dc converter delivers up to 100 mA of continuous output current, and even higher pulsed loads. Its output can be programmed to one of four (1.8, 2.5, 3.3, or 3.6 V) fixed voltages to power a wireless transmitter or sensor. Quiescent current is 950 nA with the output in regulation (at no load), maximizing overall efficiency.

The LTC3588-1 interfaces directly with a piezoelectric or alternative ac power source, rectifies the voltage waveform, and stores harvested energy in an external storage capacitor while dissipating excess power via an internal shunt regulator. An ultra-low quiescent current (450 nA) undervoltage lockout mode with a wide hysteresis window enables charge to accumulate on the storage capacitor until the buck converter can efficiently transfer a portion

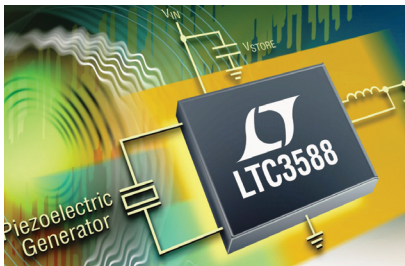


Fig. 3. The LTC3588-1 employs a high-efficiency buck converter to harvest ambient vibrational energy via piezoelectric transducers, and then convert it to a well-regulated output for use by other components.

of the stored charge to the output. In its no-load sleep state, the LTC3588-1 regulates the output voltage, consuming only 950 nA of quiescent current while continuously charging the storage

capacitor. Requiring minimal external components, the LTC3588EDD-1 is available in a 3- x 3-mm DFN, while the LTC3588EMSE-1 comes in a thermally enhanced MSOP-10 package. 