EH02

Vibration Energy Harvesting IC with 3.3V output regulation and Maximum Power Point Tracking System

Features

- Input operation range 3.7V to 18V
- Output current up to 100mA
- Integrated AC-DC voltage doubler rectifier
- Integrated DC-DC Buck converter
- Adaptive energy harvesting circuit to set piezo at maximum power point
- Output regulated voltage 3.3V
- Suitable for low power applications (<5mW)

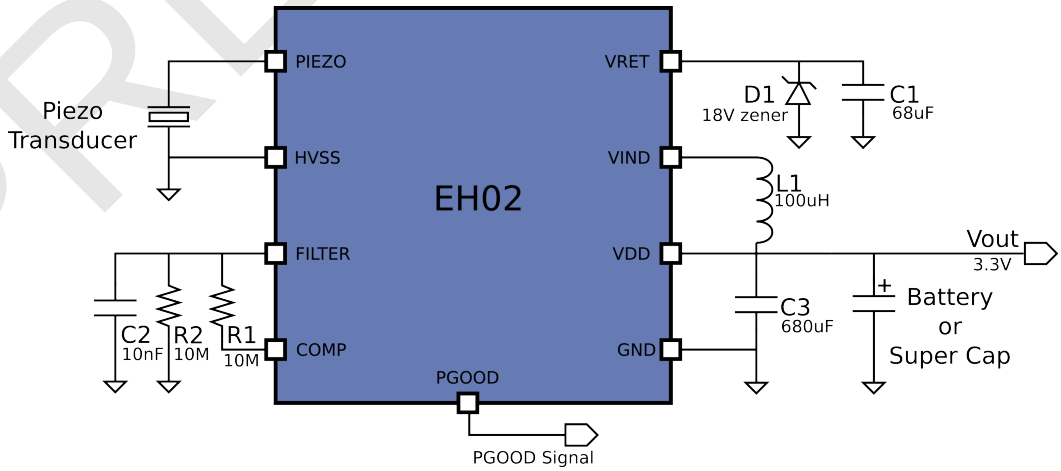
Description

EH02 is a complete power management solution for a variety of kinetic energy harvesting applications. It has a low loss AC-DC Voltage Doubler Rectifier and a high efficiency Buck converter. It is fit for energy harvesting solutions enabled by piezoelectric or electric-mechanical transducers. The EH02 has an analog controller that uses the transducer voltage as a feedback and regulates the rectified voltage to adaptively improve the extracted power.

Applications

- Piezoelectric energy harvesting
- Low power battery charging
- Tire pressure sensors
- Industrial monitoring network sensors
- Wearable applications

Typical Application



Absolute Maximum Ratings

Parameter	Range
VPIEZO, VRET, VIND Voltage	-0.6V to 18 V
VDD, COMP, FILTER Voltage	0 V to 3.3 V
Junction Temperature	+125 °C
Operation Temperature Range	-40 °C to +125 °C
Storage Temperature Range	-65 °C to +125 °C

Electrical Characteristics

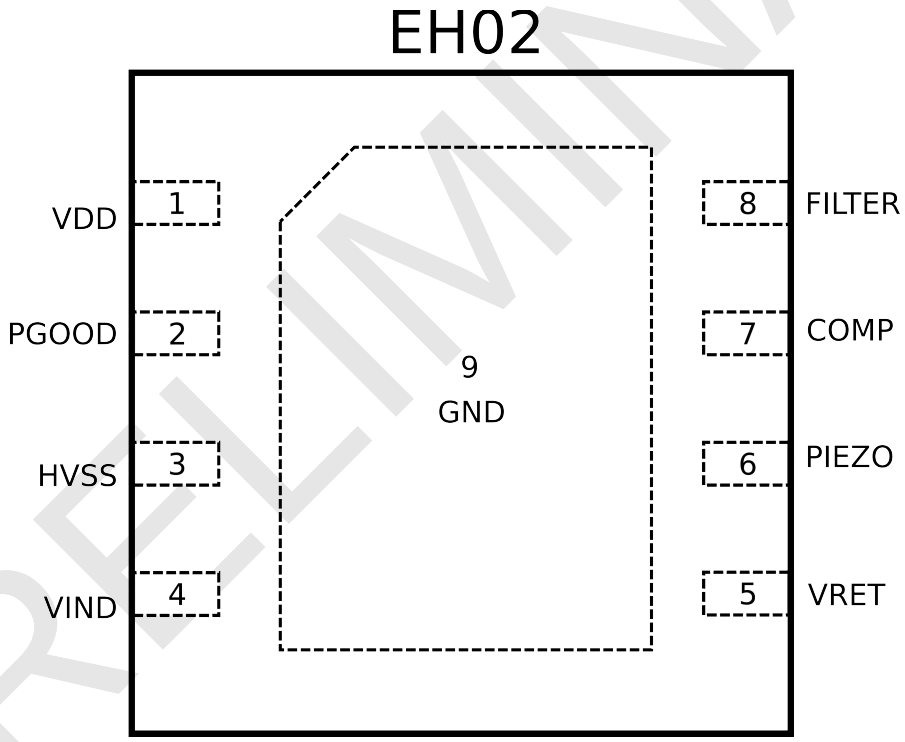
Parameter	Conditions	Min	Typ	Max	Units
PIEZO voltage				18V	V
PEZO pin current				1.36	mA
Power-on-Reset Voltage Hysteresis		2.7		2.9	V
VDD pin regulated voltage		3.0	3.3	3.33	V
VDD pin Ripple Voltage			150		mV
VDD pin current				100	mA
PMOS Switch resistance			1.88		Ω
Oscillator frequency			200		kHz
Oscillator Duty Cycle			50		%
Under-Voltage Lockout Voltage Hysteresis		6.9		7.3	V
BandGap Voltage Reference			1.27		V
PGOOD pin voltage			3		V
PGOOD pin voltage hysteresis			10		mV
External Zener Diode Protection				18	V
Power Consumption				100	µA
Stand by Consumption				2	µA
Operation Temperature		-40	27	125	°C

Pin Functions

Pin	Function	Notes and Additional Requirements
VDD	Output Rectified Voltage	Output regulated voltage at 3.3V. Connect an external capacitor (~680µF) from this pin to ground.
GND	Ground connected to Low Voltage Supply	Connect to PCB ground plate.
HVSS	Ground connected to High Voltage Supply	Connect to PCB ground plate.
VIND	Inductor pin	Connect to 100µH inductor between this pin and VDD pin.
VRET	Piezo Rectified Voltage	Connect an external capacitor (~68µF) and 18V Zener diode from this pin to ground to protect the IC against over voltage.
VPIEZO	Piezo Input Voltage	Connect to a piezoelectric or electromechanical transducer.
COMP	Comparator Output	Connect to a resistor (10MΩ) between this pin and FILTER pin.
FILTER	Filter Output pin	Connect to a resistor (10MΩ) between this pin and COMP pin. And a capacitor (10nF) and a resistor (10MΩ) to ground.
PGOOD	PGOOD Signal	Signal to an external CI to indicate output voltage level. Connect to a capacitive load.

Pin Configuration

Number	Name	Description	Type	Direction	Max. Voltage	Max. Current
1	VDD	Output Rectified Voltage	Power	O	3.3V	100mA
2	PGOOD	PGOOD Signal	Analog	O	3.3V	
3	HVSS	Ground connected to High Voltage Supply	Power	I/O	0V	
4	VIND	Inductor pin	High Voltage	I/O	18V	
5	VRET	Piezo Rectified Voltage	High Voltage	I/O	18V	
6	VPIEZO	Piezo Input Voltage	High Voltage	I/O	18V	1.36mA
7	COMP	Comparator Output	Analog	O	3.3V	
8	FILTER	Filter Output pin	Analog	I	3.3V	
9	GND	Ground connected to Low Voltage Supply	Power	I/O	0V	



Principle of Operation

EH02 is a complete power management solution for a variety of kinetic energy-harvesting applications. It has an AC-DC Voltage Doubler Rectifier and a high efficiency Buck Converter. It provides a small and simple solution to obtaining power from vibration or movement energy. It is fit for energy harvesting solutions enabled by piezoelectric or electromechanical transducers. The EH02 has an analog controller that uses the transducer voltage as a feedback and regulates the rectified voltage to adaptively improve the extracted power. The output DC-DC Buck converter keeps output regulated at 3.3V and is capable of provide up to 100mA of current. The rectified input voltage has a protective clamp to a maximum of 18V.

Features

EH02 system has numerous features, such as:

- Under-Voltage Lockout: Monitors the input voltage and enables the system to operate when voltage is higher than 7.3V (high threshold), and disables when it is lower than 6.9V (lower threshold).
- PGOOD Signal: Indicates to an external device that VDD voltage is over than 3V.
- MPP Tracking: The system adjust the input rectified voltage to extract maximum power from transducer connected to input.
- Power-on-Reset: Monitors VDD pin voltage and enables system to start-up when it is over than 2.9V. If VDD pin voltage is lower than 2.9V, the system is put in a disable mode until there is enough voltage at VDD pin to start up the system.

Start-up Operation Mode

Start-up Operation Mode is characterized by the system initialization. This happens when the VDD pin voltage is higher enough to power the system. When VDD pin voltage is lower than 2.9V, the energy from piezo input is distributed to both capacitors, at VRET pin and VDD pin, until reach the minimum voltage to start-up.

MPP Tracking Operation Mode

The EH02 starts to tracking the Maximum Power Point of some piezoelectric transducer connected to PIEZO pin if the VDD pin voltage is higher enough to start-up the system and if there is enough energy on PIEZO input voltage, so VRET pin voltage should be higher than 7.3V.

Output Regulation Operation Mode

The VDD pin output voltage is regulated in 3.3V using an hysteretic feedback. This operation mode is enabled only after system start-up and MPP Tracking starts. If there is enough energy on PIEZO pin input, the system starts to regulate the output VDD pin voltage. Buck converter switching signal has duty cycle fixed in 50%, the Output Voltage Regulator controls the oscillator signal to regulate the output voltage.

Performance Characteristics

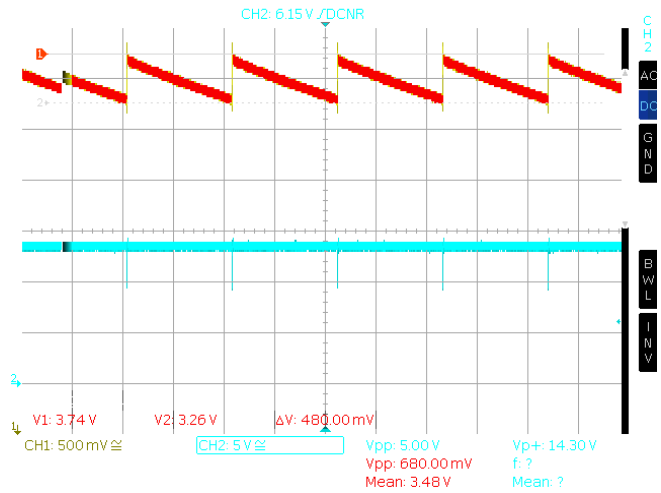


Illustration 1: Output voltage regulation. VDD pin (yellow) and PIEZO pin (blue) voltage signals.

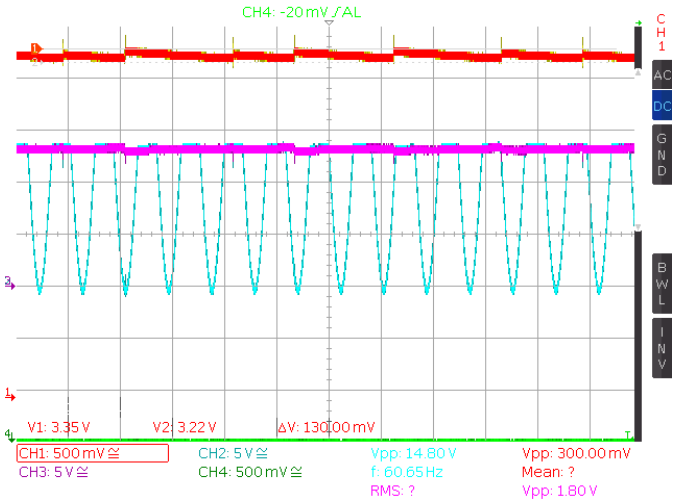


Illustration 2: Output voltage regulation. VDD pin (yellow), PIEZO pin (blue) and VRET (pink) voltage signals.

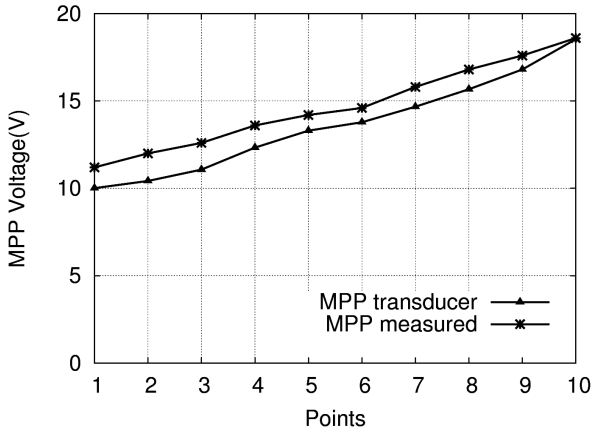
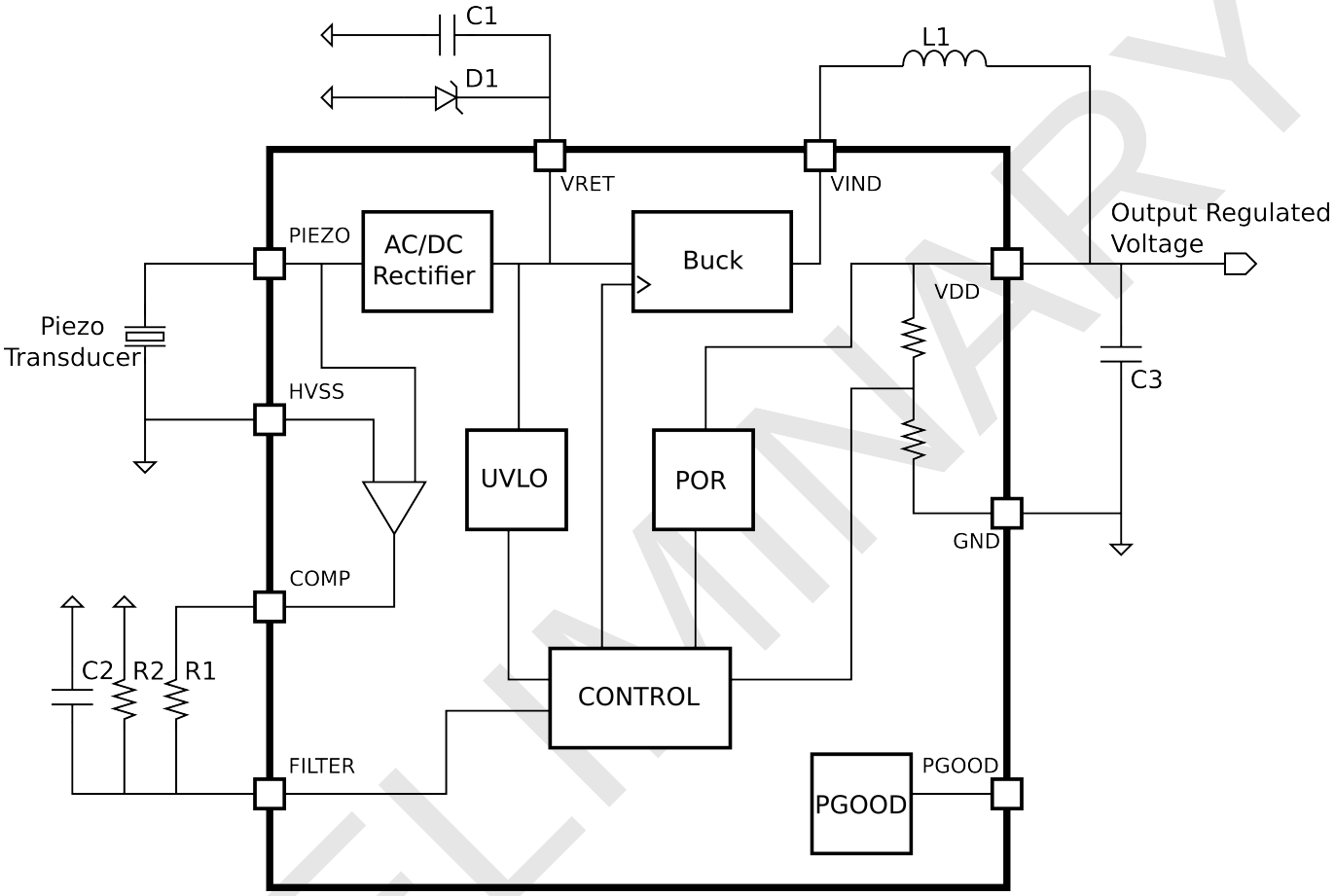


Illustration 3: MPP Tracking Efficiency (MFC8528 transducer)

Simplified Block Diagram



Functional Description

AC/DC Rectifier: The EH02 has a full wave rectifier through PIEZO and HVSS inputs that rectifies a AC signal from a piezoelectric or other electromechanical transducer. The rectified voltage is stored in an external capacitor connected to VRET pin, which also works as input capacitor of buck converter.

Output Converter: The Buck converter steps down 18V rectified input voltage from VRET pin to 3.3V at its output terminal, VDD pin, transferring the available input power as efficient as possible, considering a maximum output current of 100mA. The buck converter has a hysteretic voltage algorithm to control the output voltage through internal feedback.

The buck converter is composed by power transistors, drivers, a dead time generator, a comparator to detect reverse current from output through inductor. A Start-up logic keeps the PMOS closed and NMOS opened during the start up. The converter switching frequency is defined by oscillator frequency which is approximately 200

kHz with duty cycle of 50%. Output voltage presents low ripple, so converter output can be used directly as a power source for other devices, or could be used to charge super caps or batteries.

Input Control: The EH02 regulates the VRET input voltage to achieve the Maximum Power Point of piezo transducers connected to PIEZO input pin. There is a control system that is responsible to track the piezoelectric transducer maximum power point. The duty cycle of the piezo input voltage is filtered generating a DC voltage proportional to the period in which the piezo voltage is positive. According to Illustration 4, we see that as lower the load, higher the duty cycle, or the period in which piezo voltage is positive. A piezoelectric transducer connected to AC-DC Doubler rectifier with no load has its rectified peak voltage equals to twice the piezo open circuit voltage. In this situation, the duty cycle is maximum. The lower the rectified voltage, the lower is the proportional DC voltage filtered from piezo input voltage. This voltage is used to control the switch signal sent to Buck converter, rectifying output and input piezo voltages.

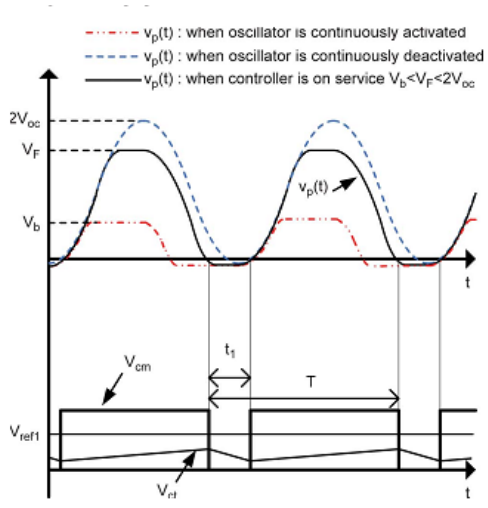


Illustration 4: Control of rectified input voltage

The Maximum Power Point of a piezoelectric transducer is in half of higher rectified voltage. Using a Doubler AC-DC rectifier, the MPP is found when the rectified voltage is equal to open circuit voltage. So, input control system keeps the input rectified voltage at MPP when the filtered DC voltage is related with a 50% duty cycle of the AC input signal.

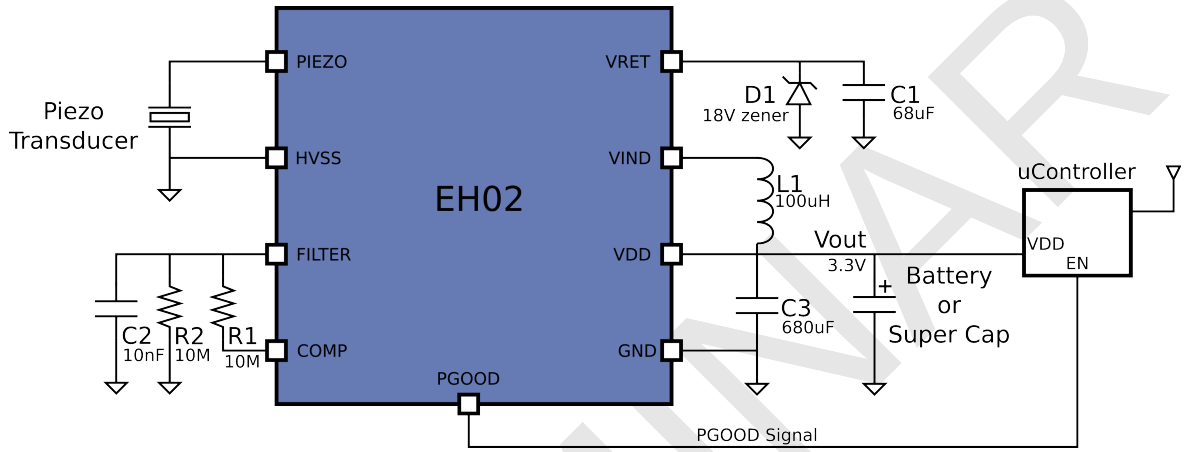
Under Voltage Lockout: The UVLO block was designed to monitor the input rectified voltage. The system starts working only if the UVLO signal is high. This is done to ensure that buck could keep the output rectified in 3.3V. A built-in hysteresis, as the input voltage is increasing, ensures that device does not turn off intermittently near the threshold voltage. The UVLO high threshold voltage is 7.3V and the low threshold voltage is 6.9V.

Power on Reset: The Power-on-Reset (POR) is connected to VDD pin voltage and enables system to regulate output voltage and starts system MPP tracking. High threshold voltage is 2.9V and low threshold voltage is 2.7V. During start-up, the input capacitor connected to PIEZO pin is directly connected to the capacitors at VRET and VDD pins. As the generated input energy is stored in both capacitors, the voltage at VDD pin will increase until a voltage level that POR starts-up the system.

PGOOD: The PGOOD block generates a signal to an external microcontroller or another circuit signalizing the power energy state at VDD pin. Its purpose is to indicate to an external device that the power supply is ready to be used. If the PGOOD signal goes down, the external device could goes into sleep mode or shutdown until PGOOD signal goes high again. The PGOOD signal prevents the device from attempting to operate on improper voltages and damaging itself.

Typical Application

Piezoelectric Energy Harvester powering a Microcontroller with a Wireless Transmitter



The primary application of EH02 is to harvesting energy from piezoelectric transducers. Piezoelectricity is a characteristic of some materials that has the capability to generate energy from deformation, and the opposite result is also true. The crystal structure of this materials aligns their intern dipoles generating potential difference. There is a wide variety of composites, ceramics or polymers with different ranges of power and voltage, working in different frequency ranges, each one has interesting characteristics for different applications. Some piezoelements could be found from manufactures on Table below.

Manufactures	Country
Midé Technology Corporation	Meddord, MA, USA
Smart Materials Corporation	Dresden, Germany
PI (Physik Instrumente) Ltd.	Karlsruhe, Germany
MicroStrain Inc.	Willston, VT, USA
EoPLEX Technologies Inc.	San Joes, CA, USA
Advanced Cerametrics Inc.	Lambertville, NJ, USA
Arveni	Bron, France
MicroGen Systems	Rochester, NY, USA
Measurement Specialties	US, Europe and China
Morgan Advanced Materials	Southampton, UK

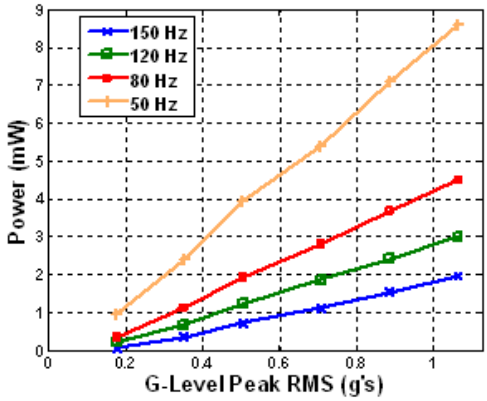


Illustration 5: V20W Midé Piezoelectric Vibration Energy Harvester

The EH02 system captures energy from an electromechanical transducer and transform to a voltage compatible to another system like sensors, microcontrollers or wireless systems. Normally, systems with these requirements need a higher amount of energy than a piezoelectric transducer could produce, but the EH02 system accumulate the harvested energy in an output capacitor or battery during a long time and burst this energy when the system needs to send an information or measure an environment data.

Component Suggestions

The following table summarizes the external components that should be used to achieve the best performance for efficiency and output currents specified.

#	Part	Manufacturer Part Number	Description	Vendor
1	R1	RC1206FR-0710ML	Thick Film 10MOhms 250mW 1% SMD	Yageo
2	R2	RC1206FR-0710ML	Thick Film 10MOhms 250mW 1% SMD	Yageo
3	L1	27104C	100uH 0.35uA SMD Inductor	Murata Power Solutions
4	C1	EEEFPV680XAP	68uF 35V Aluminum SMD Capacitor	Panasonic Electronic Components
5	D1	MMSZ5248B	18V 50mW SMD Zener Diode	Fairchild Semiconductor
6	C2	CC1206KRX7R9BB103	10nF 50V 10% Ceramic X7R SMD Capacitor	Yageo
7	C3	4SVP680M	680uF 4V 20% Aluminum SMD Capacitor	Panasonic Electronic Components

Package Description

DD Package 8-LEAD 3mm x 3mm Plastic DFN. Exposed pad PAD 9 (GND) must be soldered to PCB.

(Dimensions in mm)