Non-linear AC-DC Converter for Piezoelectric Energy Harvesting Power Supplies

PEHPS-PCB3

Description

The PEHPS-PCB3 includes an AC-DC converter and a buck converter to adapt the AC power from piezoelectric transducers with maximum efficiency for supplying electronic circuits.

The modified parallel SSHI converter employed in the AC-DC converter provides higher efficiencies than a diode bridge. The buck converter with a hysteresis control generates a regulated output voltage between 1.2 V and 25 V for input voltages between 6 V and 42 V.

Features

- High efficient rectifier for piezoelectric transducers with buck converter
- Input voltage range: 4 V to 60 V for AC-DC conversion with unregulated DC output voltage
- Input voltage range: 6 V to 42 V for AC-DC conversion with regulated DC output voltage
- DC regulated output voltage range: 1.2 V to 25 V

Applications

- Energy Harvesting with piezoelectric elements
- Energy Harvesting from vibrations
- Battery-free power supply for sensors, wireless sensor networks and low power RF devices

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Pin Configuration

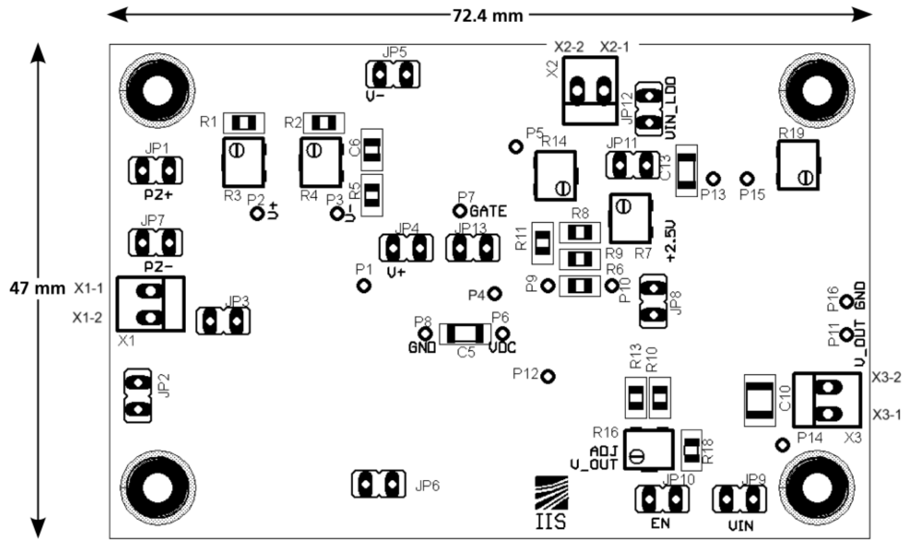

Fig. 1: Dimensions of the PEHPS-PCB3 and location of some of its components

Pin number	Pin name
X1-1	PZ1
X1-2	PZ2
X2-1	OUT1
X2-2	GND
X3-1	GND
X3-2	OUT2

Electrical Characteristics

The absolute maximum ratings of V_{PZ} and V_{OUT1} depend on jumper JP9:

V_{PZ}

- JP9 open 60 V
- JP9 closed 42 V

V_{OUT1}

- JP9 open 57.3V
- JP9 closed 40V

Parameter	Symbol	Conditions	Min.	Max.	Unit
Piezoelectric Input Voltage	V_{PZ}	JP9 open	4	60	V
		JP9 closed	6	42	V
Unregulated DC Output voltage range	V_{OUT1}	JP9 open		57.3	V
		JP9 closed		40	V
Regulated DC Output Voltage	V_{OUT2}		1.2	25	V

Table 1. Electrical characteristics of the PEHPS-PCB3

Typical Performance Characteristics

The output power (pins X2-1, X2-2) as a function of the load connected for different topologies employing a piezoelectric element (P-876.A12 from the company Invent GmbH at 16.7 Hz) is displayed in Fig. 2. The AC curve is obtained connecting the piezoelectric element to a resistor without any rectification. The diode bridge curve is measured connecting the piezoelectric element to a diode bridge for the rectification of the piezoelectric power. The PEHPS-PCB3 curve is obtained employing the PEHPS-PCB3.

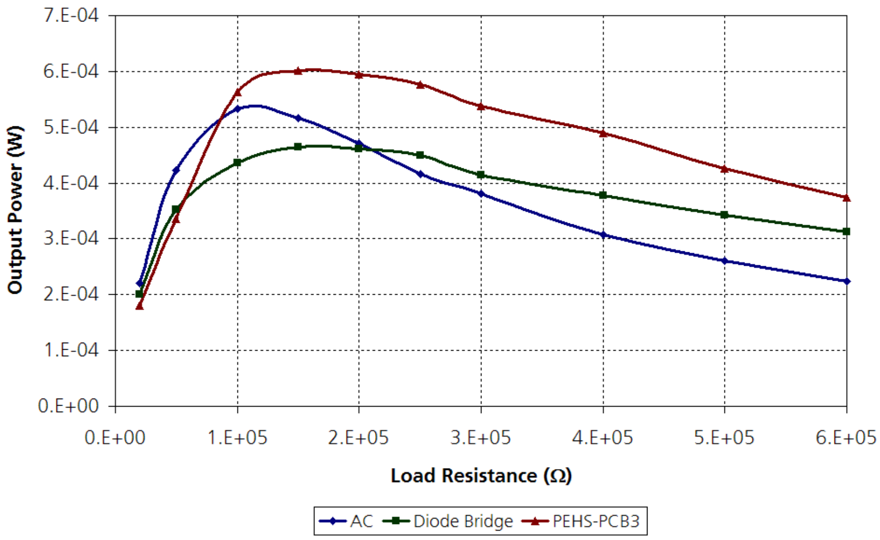

Fig. 2: Harvested power as a function of the load for different topologies employing a piezoelectric element at 16.7 Hz.

Block Diagram

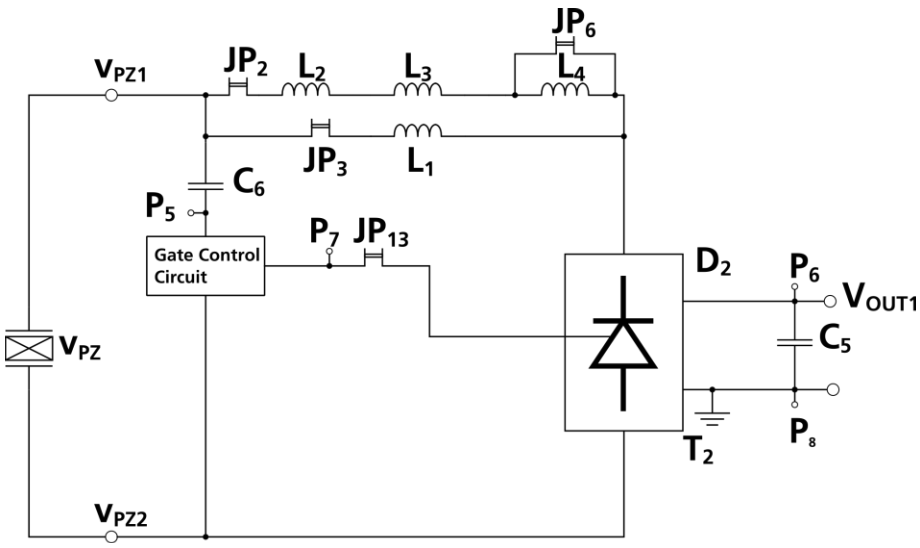

Fig. 3: SSHI AC-DC converter

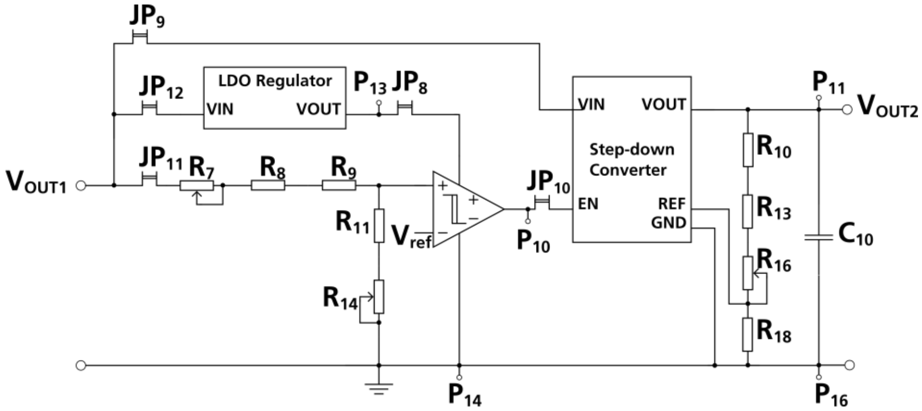

Fig. 4: Schematic for the DC regulated output voltage

Pins and Jumpers Functionality

X1 is the connector for the piezoelectric element.
X2 is the output connector of the SSHI AC-DC converter. It provides an unregulated DC output, OUT1.
X3 is the regulated output voltage OUT2 of the buck-converter placed after the AC-DC converter.
JP3 connects the inductor L1 to the SSHI converter.
JP2 connects inductor L2 and L3 to the SSHI converter.
JP6 short-circuits inductor L4.
JP12 connects the input of the linear regulator to the unregulated output OUT1.
JP8 connects the output of the linear regulator to the positive supply of the comparator with hysteresis.
JP11 connects the unregulated output OUT1 to the input of the comparator with hysteresis.
JP9 connects the unregulated output OUT1 to the input of the step-down converter.
JP10 connects the output of the comparator with hysteresis to the enable pin of the step-down converter.

Detailed Description

Two block diagrams of the PEH-PCB3 are shown in Fig. 3 and 4. The board consists of a modified parallel SSHI converter that rectifies the AC power provided by the piezoelectric transducer and a buck converter that reduces the rectified voltage. A control circuit switches the two MOSFETs of the rectifier bridge. This control circuit is frequency dependent which implies that capacitor C_6 has to be adjusted.
It is possible to connect four different inductors to the SSHI converter in order to test which configuration is more efficient for the piezoelectric transducer and the mechanical energy applied.
Capacitor C_5 is the output capacitor of the unregulated DC output voltage of pins X2-1 and X2-2 and filters the rectified signal. For the case of a vibration of 17 Hz, the filter capacitor of the series SSHI converter is C_5 = 4.7 μF but the same capacitance provides a substantial output voltage ripple for the case of 3 Hz, and therefore C_5 =14 μF is appropriate.

The buck converter with low quiescent current provides a regulated output voltage. This buck converter is enabled via a low-power comparator with hysteresis to harvest the power of the piezoelectric transducer at its maximum power point. The threshold voltages of the comparator can be slightly modified through trimmers R_7 and R_{14} and are set to 5.5 V and 11 V. If another threshold voltage is needed, new values for resistors R_7, R_8, R_9, R_{11} and R_{14} have to be found following these equations:

$$R_7 + R_8 + R_9 = 4.3\times10^6\left(\frac{V_{HB}}{2.5}\right)$$

$$R_{11} + R_{14} = \frac{1}{\dfrac{V_{THR}}{1.182\cdot(R_7+R_8+R_9)} - \dfrac{1}{R_7+R_8+R_9} - \dfrac{1}{4.3\times10^6}}$$

where V_{HB} is the hysteresis band voltage and V_{THR} is the higher-lever trip value of the hysteresis comparator.

The regulated output voltage delivered on pins X3-2 and X3-1 is 5V and can be slightly modified through trimmer R_{16}. If another output voltage is required, the values of R_{10}, R_{13}, R_{16} and R_{18} have to be modified employing the following equation:

$$R_{10} + R_{13} + R_{16} = R_{18}\left(\frac{V_{OUT}}{1.21} - 1\right)$$

Capacitor C_{10} is the output capacitor for the regulated DC output voltage.

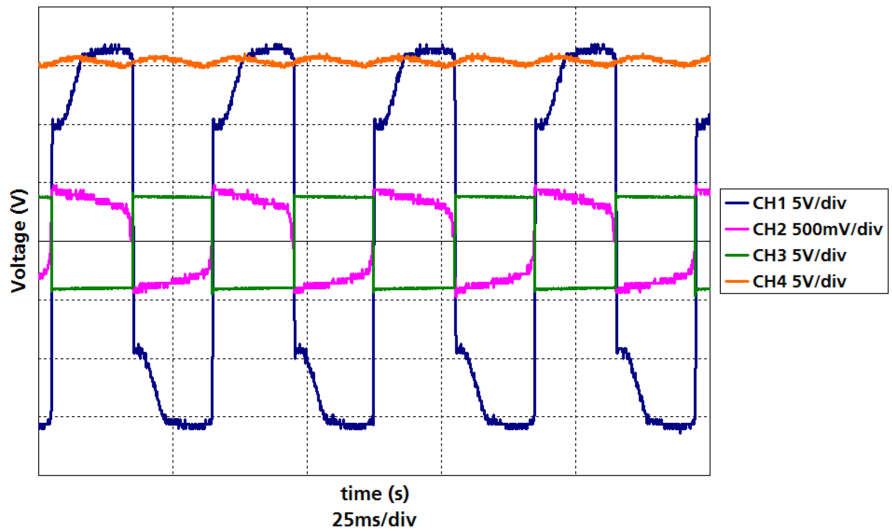

Fig. 5: Steady-state operation of the AC-DC rectifier

Fig.5. shows the steady-state operation of the AC-DC converter where CH1 is the piezoelectric voltage V_{PZ}, CH2 corresponds to the signal on the test point P5 of Fig. 3, CH3 is the gate control signal that corresponds to test point P7 on Fig. 3 and CH4 is the unregulated DC output voltage V_{OUT1}.

Fig. 6 shows the steady-state operation of the regulated output voltage on pins X3-1 and X3-2 when the unregulated output voltage is always higher than the lower-level trip value of the hysteresis comparator. CH1 is the piezoelectric voltage V_{PZ}, CH2 is the unregulated output voltage V_{OUT1}, CH3 is the EN pin of the step-down converter and CH4 is the regulated output voltage V_{OUT2}.

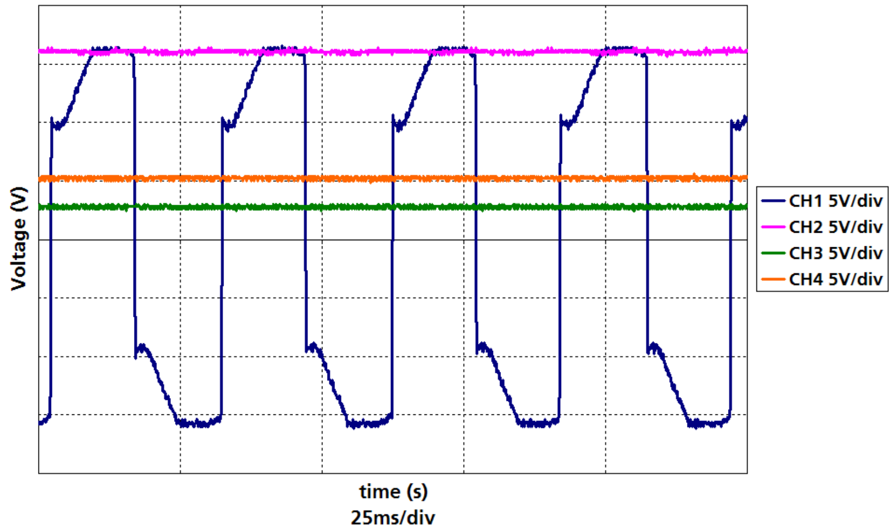

Fig. 6: Steady-state operation of the regulated output voltage on pins X3-1 and X3-2

Fig. 7 presents the steady-state operation of the regulated output voltage for the case that the unregulated output voltage swings to lower voltages than the lower-lever trip value of the hysteresis comparator. This situation makes possible to work in the maximum power point of the power harvested by the piezoelectric element. CH1 is the unregulated output voltage V_{OUT1}, CH2 is the EN pin of the step-down converter and CH3 is the regulated output voltage V_{OUT2}.

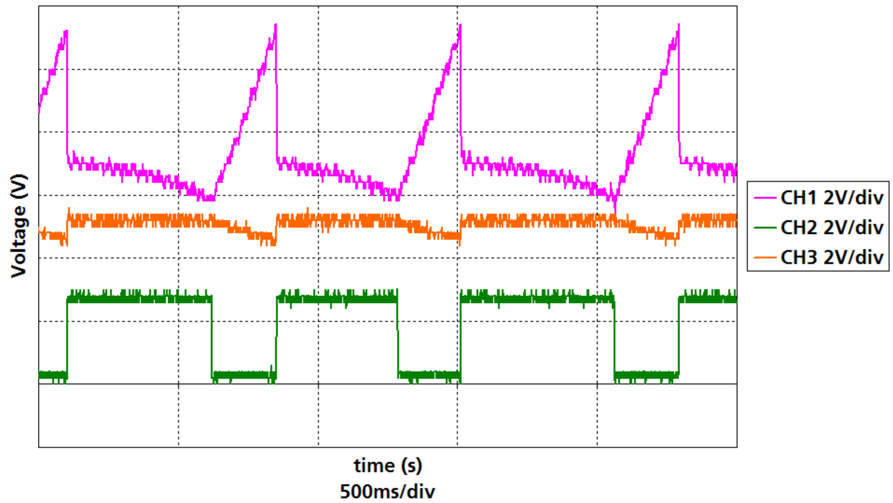

Fig. 7: Steady-state operation of the regulated output voltage on pins X3-1 and X3-2