

# A Bridgeless Boost Rectifier for Low-Voltage Energy Harvesting Applications

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**Abstract** - Conventional ac–dc converters for energy harvesting and conditioning usually consists of two stages. A diode bridge rectifier typically forms the first stage, while the second stage is a dc–dc converter to regulate the rectified ac voltage to a dc voltage. However, the diode bridge would incur considerable voltage drop, making the low-voltage rectification infeasible. To overcome these drawbacks, CMOS diodes with low voltage drops are investigated in the bridge rectifiers, to substitute conventional p-n junction diodes. Such reported diodes include diode-connected passive MOSFET, which adopts threshold voltage cancellation techniques, and MOSFET, which is actively controlled by a comparator. In either case, the low-voltage-drop diode techniques require either additional bias networks or external comparators. Thus, both the complexity and the power loss of the circuitry would increase. Some converters reported in the literature use transformers as the first stage boosters to overcome the voltage drop in semiconductor devices. However, the size of the transformer could be unacceptably large in low-frequency energy harvesting applications. In this project, a single-stage ac–dc power electronic converter is proposed to efficiently manage the energy harvested from electromagnetic microscale and mesoscale generators with low-voltage outputs. The proposed topology combines a boost converter and a buck-boost converter to condition the positive and negative half portions of the input ac voltage, respectively. Only one inductor and capacitor are used in both circuitries to reduce the size of the converter. A 2 cm × 2 cm, 3.34-g prototype has been designed and tested at 50-kHz switching frequency, which demonstrate 71% efficiency at 54.5 mW. The input ac voltage with 0.4-V amplitude is rectified and stepped up to 3.3-V dc. Detailed design guidelines are provided with the purpose of minimizing the size, weight, and power losses. The theoretical analyses are validated by the experiment results by using DPCM techniques.

**Keywords:** Bridgeless, Boost Rectifier, Low-Voltage, Energy Harvesting, Applications, MOSFET, dc–dc converter.

## I. INTRODUCTION

A new bridgeless boost rectifier, shown in Fig.1.1, which is a unique integration of boost and buck-boost converters, is proposed in this project. When the input voltage is positive, S1 is turned ON and D1 is reverse biased, the circuitry operates in the boost mode. As soon as the input voltage becomes negative, the buck-boost mode starts with turning ON S2 and reverse biasing D2. MOSFETs with bidirectional conduction capability work as two-quadrant switches to ensure the circuitry functionality in both positive and negative voltage cycles. This topology was introduced in for piezoelectric energy harvesting applications.

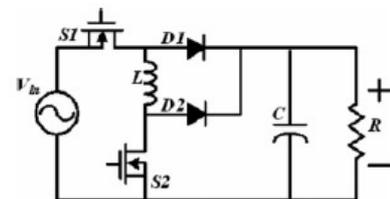


Figure 1: Bridgeless boost rectifier for low-voltage energy harvesting

## II. EXISTING SYSTEM

Kinetic energy harvesters convert mechanical energy present in the environment into electrical energy. The past decade has seen an increasing focus in the research community on kinetic energy harvesting devices. Typically, kinetic energy is converted into electrical energy using electromagnetic, piezoelectric, or electrostatic transduction mechanisms. In comparison to electrostatic and piezoelectric transducers, electromagnetic transducers outperform in terms of efficiency and power density. In this study, electromagnetic energy harvesters are considered.

A general diagram of an electromagnetic generator is demonstrated in Fig. where  $k$  is spring stiffness constant;  $m$  is the proof-mass;  $DE$  and  $DP$  represent electrical and parasitic dampers, respectively. Essentially, the energy harvesting system consists of a spring, a proof mass, and an electrical damper. The extrinsic vibrations excite the internal oscillation between the proof mass (magnet) and electrical damper

(coils). The internal oscillation produces a periodically variable magnetic flux in the coil, which induces a corresponding alternating output voltage.

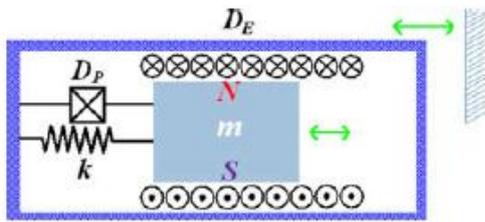


Figure 2: General diagram of an electromagnetic micro generator

In energy harvesting systems, power electronic circuit forms the key interface between transducer and electronic load, which might include a battery. The electrical and physical characteristics of the power conditioning interfaces determine the functionality, efficiency, and the size of the integrated systems. The power electronic circuits are employed to

- 1) Regulate the power delivered to the load, and
- 2) Actively manage the electrical damping of the transducers

So that maximum power could be transferred to the load. The output voltage level of the micro scale and mesoscale energy harvesting devices is usually in the order of a few hundred mill volts depending on the topology of device. The output ac voltage should be rectified, boosted, and regulated by power converters to fulfill the voltage requirement of the loads. Nonetheless, miniature energy harvesting systems have rigid requirement on the size and weight of power electronic interfaces. Conventional ac–dc converters for energy harvesting and conditioning usually consists of two stages. A diode bridge rectifier typically forms the first stage, while the second stage is a dc–dc converter to regulate the rectified ac voltage to a dc voltage (Fig. 2.2).

**Drawbacks**

However, the diode bridge would incur,

- 1) Considerable voltage drop and more component power losses,
- 2) Low-voltage rectification infeasible, very Low efficiency and Larger in size.

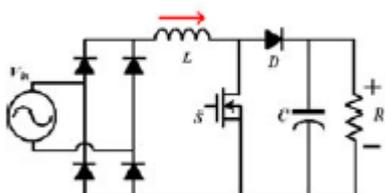


Figure 3: Boost rectifier

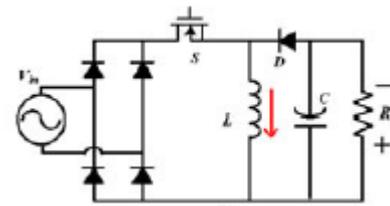


Figure 4: Buck-Boost rectifier

To overcome these drawbacks, CMOS diodes with low voltage drops are investigated in the bridge rectifiers, to substitute conventional p-n junction diodes. Such reported diodes include

- 1) diode-connected passive MOSFET, which adopts threshold voltage cancellation techniques, and
- 2) MOSFET, which is actively controlled by a comparator.

In either case, the low-voltage-drop diode techniques require either additional bias networks or external comparators. Thus, both the complexity and the power loss of the circuitry would increase. Some converters reported in the literature use transformers as the first stage boosters to overcome the voltage drop in semiconductor devices. However, the size of the transformer could be unacceptably large in low-frequency energy harvesting applications. Another approach to maximize the conversion efficiency in low voltage rectification is to use bridgeless direct ac–dc converters. Those topologies either use bidirectional switches and split capacitors, or two parallel dc–dc converters to condition positive and negative input voltages separately. For the split-capacitor topologies [Fig.2. 3(a)–(c)], due to the low operation frequency of specified micro generators, the capacitors have to be large enough to suppress the voltage ripple under a desired level. The increased size and number of energy storage components make those topologies impractical due to the size limitation of energy harvesters.

**III. PROPOSED SYSTEM**

A new bridgeless boost rectifier, shown in Fig., which is a unique integration of boost and buck-boost converters, is proposed in this paper. When the input voltage is positive, S1 is turned ON and D1 is reverse biased, the circuitry operates in the boost mode. As soon as the input voltage becomes negative, the buck-boost mode starts with turning ON S2 and reverse biasing D2. MOSFETs with bidirectional conduction capability work as two-quadrant switches to ensure the circuitry functionality in both positive and negative voltage cycles. This topology was introduced for piezoelectric energy harvesting applications. A detailed analysis of discontinuous conduction mode (DCM) is provided along with the averaged large signal modeling.

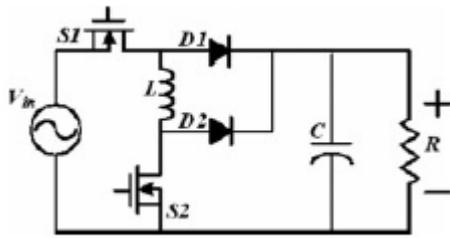


Figure 5: Proposed bridgeless boost rectifier for low-voltage energy harvesting

### Advantages

1. High efficiency and fastest switching time.
2. Less Number of components used in Circuit.
3. High performance and duty cycle time reduced.
4. Size and cost low.
5. Very low voltages can boost in this proposed system.
6. Maximum conversion efficiency.
7. Requires only minimum number of passive components for energy storage.

### IV. LITERATURE REVIEW

G. D. Szarka, B. H. Stark, and S. G. Burrow, "Review of power conditioning for kinetic energy harvesting systems," *IEEE Trans. Power Electron.*, vol. 27, no. 2, pp. 803–815, Feb. 2011. Kinematic energy harvesters convert mechanical energy present in the environment into electrical energy. The past decade has seen an increasing focus in the research community on kinetic energy harvesting devices. Typically, kinetic energy is converted into electrical energy using electromagnetic, piezoelectric, or electrostatic transduction mechanisms which consumes more power and big in size. Hence losses also high.

R. Vullers, R. van Schaijk, and I. Doms, "Micropower energy harvesting," *Solid-State Electron.*, vol. 53, no. 7, pp. 684–693, Jul. 2009. In comparison to electrostatic and piezoelectric transducers, electromagnetic transducers outperform in terms of efficiency and power density. In this study, electromagnetic energy harvesters are considered for further study. A general of an electromagnetic generator where  $k$  is spring stiffness constant;  $m$  is the proof-mass;  $DE$  and  $DP$  represent electrical and parasitic dampers, respectively. Essentially, the energy harvesting system consists of a spring, a proof mass, and an electrical damper. The extrinsic vibrations excite the internal oscillation between the proof mass (magnet) and electrical damper (coils). The internal oscillation produces a periodically variable magnetic flux in the coil, which induces a corresponding alternating output voltage. In energy harvesting systems, power electronic circuit forms the key interface between transducer and electronic load, which might include a battery.

A. Harb, "Energy harvesting: State-of-the-art," *Renewable Energy*, vol. 36, no. 10, pp. 2641–2654, Oct. 2011. The electrical and physical characteristics of the power conditioning interfaces determine the functionality, efficiency, and the size of the integrated systems. The power electronic circuits are employed to 1) regulate the power delivered to the load, and 2) actively manage the electrical damping of the transducers so that maximum power could be transferred to the load. In this due to component losses efficiency is less which unable to boost the low voltages.

S. Cheng, N. Wang, and D. P. Arnold, "Modeling of magnetic vibrational energy harvesters using equivalent circuit representations," *J. Micromech. Microeng.*, vol. 17, no. 11, pp. 2328–2335, Nov. 2007. The output voltage level of the microscale and mesoscale energy harvesting devices is usually in the order of a few hundred millivolts depending on the topology of device. The output ac voltage should be rectified, boosted, and regulated by power converters to fulfill the voltage requirement of the loads. Nonetheless, miniature energy harvesting systems have rigid requirement on the size and weight of power electronic interfaces.

### V. PRINCIPLE & OPERATING MODES

In electromagnetic energy harvesters, the internal oscillation between coils and magnet produces a periodically variable magnetic flux in the coil, which induces a corresponding output voltage. The power electronics interface (PEI) is employed to supply constant voltage and to deliver power to the load. In order to facilitate and simplify analyses, it is assumed that the input impedance of the PEI is significantly larger than the internal impedance of energy harvesting device. The induced voltage could be assumed to be a low amplitude sinusoidal ac voltage source. As the frequency of vibration source and induced voltage (usually less than 100 Hz) is much less in comparison to that of the switching frequency (around tens of kHz), the induced ac voltage can be assumed as a constant voltage source in each switching period. In this paper, a 0.4-V, 100-Hz sinusoidal ac voltage source is adopted to emulate the output of the electromagnetic energy harvester.

The DCM operating modes of the proposed boost rectifier are shown in Fig. Each cycle of the input ac voltage can be divided into six operation modes. Modes I–III illustrate the circuit operation during positive input cycle, where  $S1$  is turned ON while  $D1$  is reverse biased. The converter operates as a boost circuit during Modes I–III, while switching  $S2$  and  $D2$ . The operation during negative input cycle is demonstrated in Modes IV–VI, where  $S2$  is turned ON while  $D2$  is reverse biased. In these modes, the converter operates similar to a buck-boost circuit.

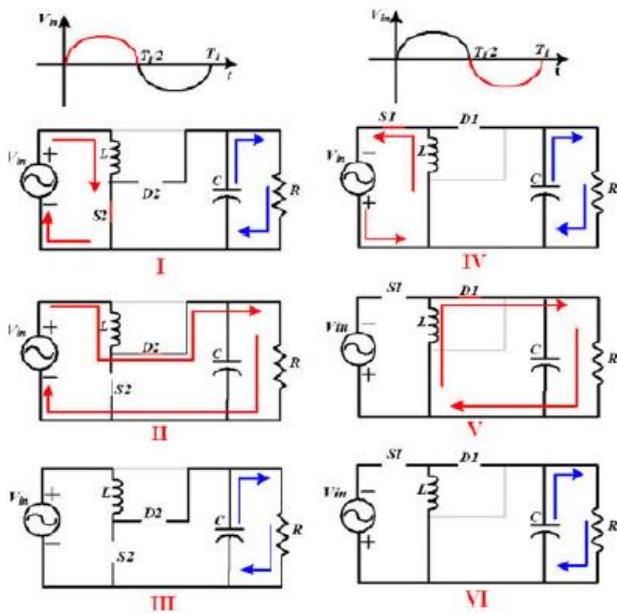


Figure 6: Operating modes of the proposed boost rectifier

### Mode I

This mode begins when S2 is turned ON at t0. The inductor current is zero at t0. The turn on of S2 is achieved through zero current switching (ZCS) to reduce switching loss. Inductor L is energized by the input voltage as both S1 and S2 are conducting. Both diodes are reverse biased. The load is powered by the energy stored in the output filter capacitor C.

### Mode II

S2 is turned OFF at t1, where t1 - t0 = d1Ts, d1 is the duty cycle of the boost operation, and Ts is the switching period. The energy stored in the inductor during Mode I is transferred to the load. The inductor current decreases linearly. During this mode, switching loss occurs during the turn on of diode D2.

### Mode III

D2 is automatically turned OFF as soon as the inductor current becomes zero at t2 (t2 - t1 = d2Ts). This avoids the reverse recovery loss of diode. The load is again powered by the stored energy in the capacitor. The converter would return to Mode I as soon as S2 is turned ON, if the input voltage is still in positive cycle.

### Mode IV

During the negative input cycle, Mode IV starts as soon as S1 is turned ON at. ZCS condition can also be achieved by ensuring the converter operation in DCM. The energy is transferred to the inductor L again, while the output filter capacitor C feeds the load.

### Mode V

At S1 is turned OFF, where - = Ts, is the duty cycle of the buck-boost operation. The energy stored in the inductor during Mode IV is transferred to the load. The inductor current decreases linearly. During this mode, switching loss occurs during the turn on of the diode D1.

### Mode VI

When the inductor current decreases to zero at Ts), D1 is turned OFF at zero current. The load is continuously powered by the charge stored in the output capacitor. The converter would return to Mode IV as soon as S1 is turned ON, if the input voltage is still negative. According to the analyses of operation modes, the switches are turned ON with ZCS and the diodes are turned OFF with ZCS. Due to the DCM operation, the input current sensor can be eliminated and switching loss can be reduced. Moreover, the control scheme of DCM operation is relatively simpler. Since the circuit size can be reduced and the efficiency can be enhanced, DCM operation is more suitable than continuous conduction mode (CCM) operation.

## VI. DESIGN PROCEDURE

If the voltage gain is much larger than unity, according to (17) and (18), the boost and buck-boost operations share the same duty cycle D, which is determined by the boost ratio (Vo/Vm), the inductance of the inductor L, and the switching frequency fs. Equation (19) defines the commutation relationship of the duty cycle of the proposed boost/buck boost converter,

$$D = d_1 = d'_1 = \frac{2V_o}{V_m} \sqrt{\frac{L f_s}{R}}$$

The boost ratio is defined according to the specific application, while the load resistance R is dependent on the output power level. With the specified power and voltage demands, the inductance is designed according to the desired range of duty cycle and switching frequency. The larger the switching frequency is, the smaller the inductance would be. In order to design a smaller inductor with purpose of obtaining smaller size and weight, a higher switching frequency is preferred. However, the higher the switching frequency is, the higher the switching loss would be. A tradeoff between the size of inductor and the switching loss should be taken into account in the design process.

Both the boost and buck-boost operations of the converter provide the same inductor current ripple, which can be expressed as,

$$\Delta i_L = \frac{v_{in}(t)DT_s}{L}$$

The maximum current ripple corresponds to the peak input voltage. According to previous analyses, the inductor, diodes, and MOSFETs share the same value of current ripple, which is defined in the following equation:

$$\Delta i_{L,max} = \frac{V_m DT_s}{L}$$

From the current ratings of all those components could be found. The voltage ratings of the MOSFETs and diodes are normally chosen higher than  $V_o$  with an appropriate margin for safe operation. The turn-on resistances of MOSFETs and the forward voltage drop of diodes are the major components, which impact the efficiency.

### Control Strategy

For a dynamic EM energy harvester system, if the external excitation frequency is different from the intrinsic resonance frequency, the PEI should be able to match its input impedance with the internal impedance of the harvester so that maximum power point (MPP) could be tracked. This paper proposed a new topology, which has the maximum power point tracking (MPPT) capability. However, the main objective of this paper is to introduce the circuit topology, which is capable of satisfying the voltage requirement (3.3V) of an electronic load. Thus, a voltage feedback control loop is utilized to regulate the load voltage. The simplified scheme of the controller and power stage is illustrated in Fig. The converter is designed to operate in DCM. The output voltage is filtered by a passive low-pass filter and then fed to the analog-to-digital converter (ADC) of the controller.

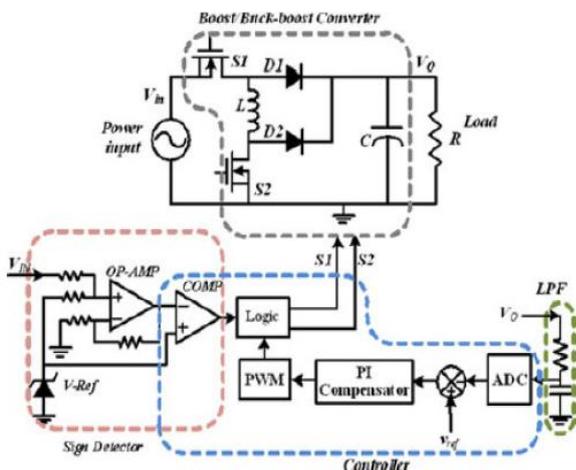


Figure 7: Control circuit for the proposed converter

### VII. RESULTS AND LOSS ANALYSIS

A single stage ac–dc topology for low-voltage low-power energy harvesting applications is proposed in this project. The topology uniquely combines a boost converter and a buck-boost converter to condition the positive input cycles and negative input cycles, respectively.

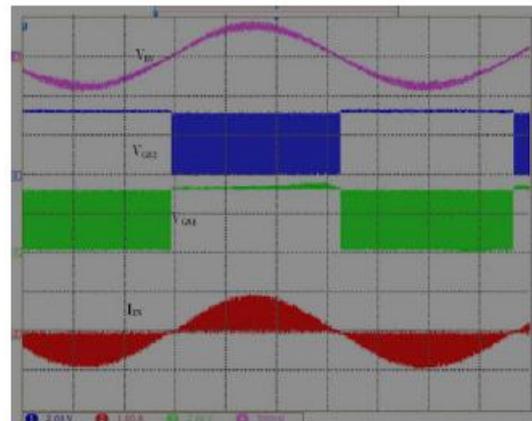


Figure 8: From top to bottom: oscillograms of input voltage (0.5 V/div), boost gate pulse (2 V/div), buck-boost gate pulse (2 V/div), input current (1 A/div); time 4 ms/div, R = 200 Ω

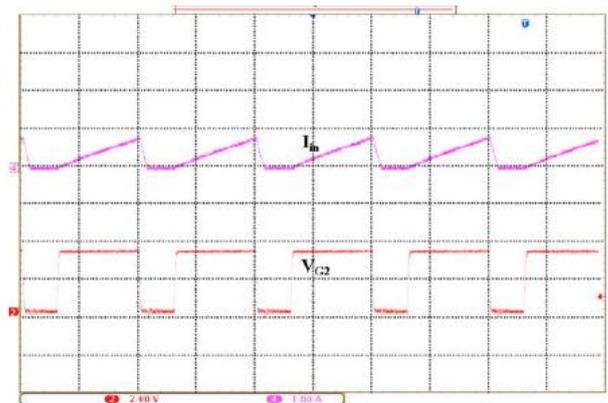


Figure 9: From top to bottom: oscillograms of input current (500 mA/div), boost gate pulse (2 V/div); time 10 μs/div, R = 200 Ω

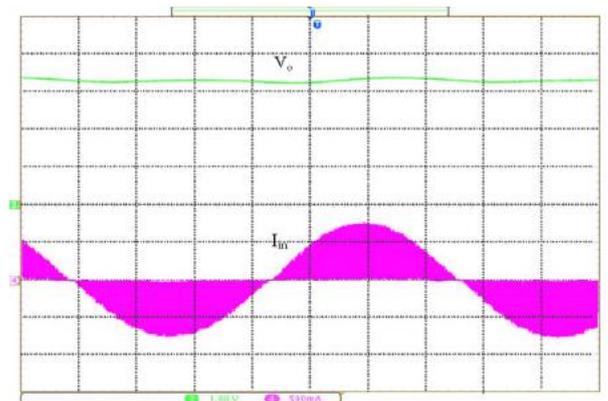


Figure 10: From top to bottom: oscillograms of output voltage (1 V/div), input current (500 mA/div); time 4 ms/div, R = 300 Ω

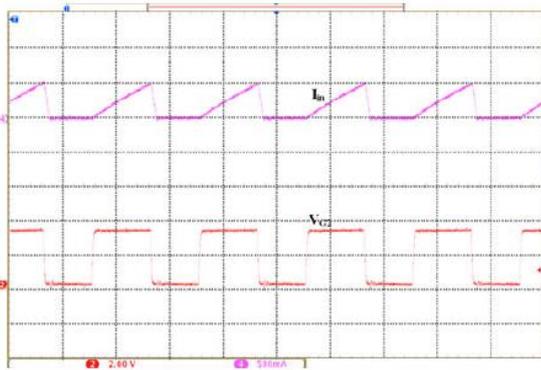


Figure 11: From top to bottom: oscillograms of input current (1 A/div), boost gate pulse (2 V/div); time 10  $\mu$ s/div, R = 300  $\Omega$

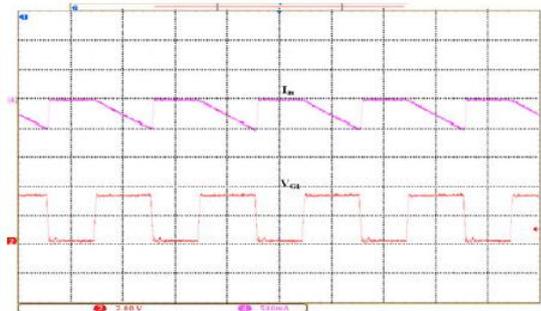


Figure 12: From top to bottom: oscillograms of input current (1 A/div), buckboost gate pulse (2 V/div); time 10  $\mu$ s/div, R = 300  $\Omega$

S2 operates as the low-side switch with  $V_{GS2} = V_{G2}$ , while S1 operates as the highside switch with  $V_{GS1} = V_{G1} - V_{in}$ . In this case, due to small amplitude of input voltage, the minimum value of  $V_{GS1} = V_{G1} - V_M = 2.9$  V is still sufficient to turn on the S1 with low conduction resistance. Thus, both S1 and S2 could be directly driven by the digital output of the controller. The energy harvester is emulated by a signal generator cascaded with a high-pass filter, and a high current voltage follower (OPA548). The power source is programmed to have 0.4-V amplitude and 100-Hz frequency. A mill watt scale test is carried out in order to verify the theoretical analyses and simulations of the proposed topology. However, this proposed topology is not specifically limited to be used in milli watt applications; it would also work in microwatt applications. 200- $\Omega$  resistive load is chosen to demonstrate the power transfer capability of the designed PEI prototype. With 200- $\Omega$  resistive load, the converter is capable of tightly regulating output voltage and delivering 54.5 mW to the load. During the positive input cycle, S1 is turned ON, while S2 is driven by the boost control scheme. When the circuit operates in the negative input cycle, S2 is turned ON, while S1 is controlled under the buck-boost conditioning strategy. The printed circuit board (PCB) is designed to minimize the lower Packaging overhead. In the case of much lower power levels, it is possible to use components with least packaging overhead or in bare die form to further reduce the

size and weight of the circuit. A highly compact power electronic interface prototype has a PCB size of  $2 \times 2$  cm<sup>2</sup> and weighs 3.34 g. The component design details and electrical parameters are summarized in Table.

Parameter	Calculated Value	Measured Value
Duty cycle (R= 200 $\Omega$ )	0.65	0.72
$\Delta I_{DL,MAX}$ (R = 200 $\Omega$ )	1.1 A	1.02A
Duty cycle (R = 300 $\Omega$ )	0.56	0.60
$\Delta I_{DL,MAX}$ (R = 300 $\Omega$ )	0.95 A	0.84 A

The duty cycle (for R=200 $\Omega$  & 300  $\Omega$ ) of both active and passive components are estimated according to the experiment data and the parasitic parameters offered in Table. Due to ZCS operation, the switching losses are minimized. The conduction loss dominates in the total conversion losses. Both the quiescent and dynamic losses of each IC are also estimated according to the provided corresponding data sheet.

### Hardware Pulse Generation from DSO

ZCD-ZCD (Zero Crossing Detector) is generated with reference to the input sine wave of the bridgeless boost rectifier. Below image explains how ZCD is generated.

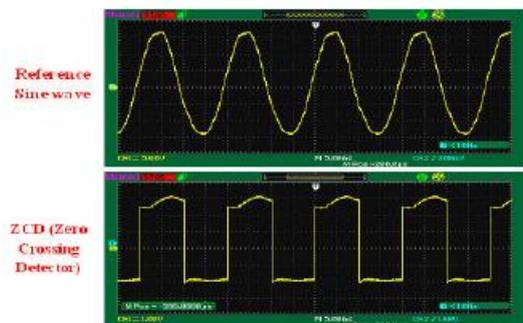


Figure 13: ZCD Wave form generation

**PWM with reference to ZCD-** PWM (Pulse Width Modulation) is generated with reference to ZCD. This PWM is given to bridgeless boost converter for switching MOSFET. It is explained below with an image.

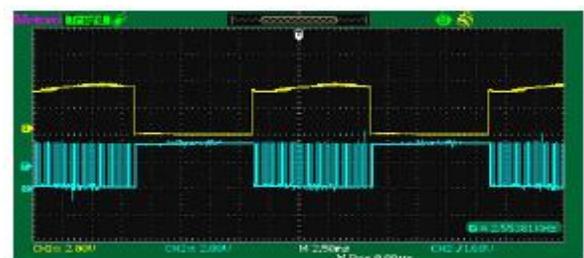


Figure 14: PWM for M1 (MOSFET) with reference to ZCD

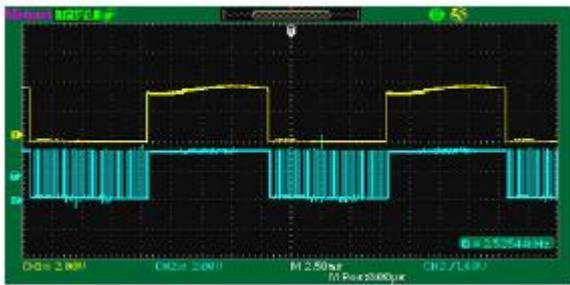


Figure 15: PWM for M2 (MOSFET) with reference to ZCD

**Comparison between two PWM**-The pulse which is given to the bridgeless boost converter MOSFET (switching devices) are of exact opposite these switching pulses are compared and explained below.

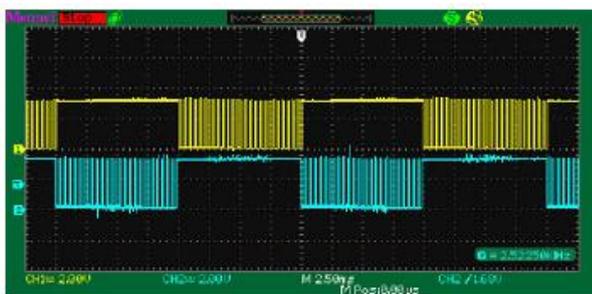


Figure 16: Comparison between PWM of M1 and M2 (MOSFET)

### VIII. CONCLUSION

A single stage ac–dc topology for low-voltage low-power energy harvesting applications is proposed in this project. The topology uniquely combines a boost converter and a buck-boost converter to condition the positive input cycles and negative input cycles, respectively. Only one inductor and one filter capacitor are required in this topology. A compact 2 cm×2 cm, 3.34-g prototype is boosts the 0.4-V, 50-Hz ac to 3.3-V dc. Output voltage is tightly regulated at 3.3 V through closed-loop voltage Control. The state-of-the-art low-voltage bridgeless rectifier, this study employs the minimum number of passive energy storage components, and achieves the maximum conversion efficiency. Depending upon input voltage 0.4 V to 5V, 50 Hz ac voltage the output voltage level 10V to 24 V with high efficiency. The measured conversion efficiency is 71% at 54.5mW. In comparison to state-of-the-art low-voltage bridgeless rectifiers, this study employs the minimum number of passive energy storage components, and achieves the maximum conversion efficiency. The future will be focused on investigating and designing integrated three-phase power electronic interfaces for electromagnetic energy harvesting.

### REFERENCES

- [1] S. Roundy, P. K. Wright, and J. Rabaey, “A study of low level vibrations as a power source for wireless sensor nodes,” *Comput. Commun.*, vol. 26, no. 11, pp. 1131–1144, Jul. 2003.
- [2] M. El-hami, P. Glynne-Jones, N. M. White, M. Hill, S. Beeby, E. James, A. D. Brown, and J. N. Ross, “Design and fabrication of a new vibration based Electro mechanical power generator,” *Sens. Actuators A: Phys.*, vol. 92, no. 1–3, pp. 335–342, Aug. 2001.
- [3] S. P. Beeby, R. N. Torah, M. J. Tudor, P. Glynne-Jones, T. O’Donnell, C. R. Saha, and S. Roy, “A micro electromagnetic generator for vibration energy harvesting,” *J. Micromech. Microeng.*, vol. 17, no. 7, pp. 1257–1265, Jul. 2007.
- [4] R. Vullers, R. van Schaijk, and I. Doms, “Micropower energy harvesting,” *Solid-State Electron.*, vol. 53, no. 7, pp. 684–693, Jul. 2009.
- [5] C. B. Williams, C. Shearwood, M. A. Harradine, P. H. Mellor, T. S. Birch, and R. B. Yates, “Development of an electromagnetic micro-generator,” *IEE Proc. Circuits Devices Syst.*, vol. 148, no. 6, pp. 337–342, Jun. 2001.
- [6] G. D. Szarka, B. H. Stark, and S. G. Burrow, “Review of power conditioning for kinetic energy harvesting systems,” *IEEE Trans. Power Electron.*, vol. 27, no. 2, pp. 803–815, Feb. 2012.
- [7] S. G. Burrow and L. R. Clare, “Open-loop power conditioning for vibration energy harvesters,” *Electron. Lett.*, vol. 45, no. 19, pp. 999–1000, Sep. 2009.
- [8] S. Cheng, N. Wang, and D. P. Arnold, “Modeling of magnetic vibrational energy harvesters using equivalent circuit representations,” *J. Micromech. Microeng.*, vol. 17, no. 11, pp. 2328–2335, Nov. 2007.
- [9] R. Dayal and L. Parsa, “A new single stage AC-DC converter for low voltage electromagnetic energy harvesting,” in *Proc. IEEE Energy Convers. Congr. Expo.*, Atlanta, GA, USA, Sep. 2010, pp. 4447–4452.
- [10] P. D. Mitcheson, T. C. Green, and E. M. Yeatman, “Power processing circuits for electromagnetic, electrostatic and piezoelectric inertial energy scavengers,” *Microsyst. Technol.*, vol. 13, no. 11–12, pp. 1629–1635, Jan. 2007.
- [11] X. Cao, W.-J. Chiang, Y.-C. King, and Y.-K. Lee, “Electromagnetic energy harvesting circuit with feedforward and feedback DC–DC PWM boost converter for vibration power generator system,” *IEEE Trans. Power Electron.*, vol. 22, no. 2, pp. 679–685, Mar. 2007.

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