International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 8, No. 4, December 2017, pp. 1943~1947
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v8i4.pp1943-1947

Vibration based Energy Harvesting Interface Circuit using Diode-Capacitor Topologies for Low Power Applications

Amirul Adlan Amirnudin, Farahiyah Mustafa, Anis Maisarah Mohd Asry, Sy Yi Sim
Department of Electrical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

Article Info

Article history:

Received Aug 18, 2017
Revised Nov 16, 2017
Accepted Nov 30, 2017

Keyword:

DC-DC boost converter
Diode-capacitor topologies
Energy harvesting
Interface circuit
Low power energy

ABSTRACT

A battery-less energy harvesting interface circuit to extract electrical energy from vibration has been proposed in this paper for low power applications. The voltage doubler integrated with DC – DC boost converter circuits were designed and simulated using MultiSIM software. The circuit was then fabricated onto a printed circuit board (PCB), using standard fabrication process. The Cockcroft Walton doubler was chosen to be implemented in this study by utilizing diode-capacitor topologies with additional RC low pass filter. The DC – DC boost converter has been designed using a CMOS step - up DC – DC switching regulators, which are suitable for low input voltage system. The achievement of this interface circuit was able to boost up the maximum voltage of 5 V for input voltage of 800 mV.

Corresponding Author:

Farahiyah Mustafa,
Department of Engineering Technology,
Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia,
86400 Parit Raja, Batu Pahat, Johor, Malaysia.
Email: farahiyah@uthm.edu.my

1. INTRODUCTION

Power consumption is a key limitation in many state of the art electronic systems today, varying from mobile telecommunication to laptop and desktop computers. It also has a huge influence towards the evolving applications like ambient intelligence and sensor networks, some of which are powered separately and wirelessly. As the result, new design techniques and system are created to control and limit power consumption [1].

Energy harvesting is the process where battery replacement is impossible or the location is not favorable, such as embedded sensors in buildings, medical implants and remote sensors. In a general energy harvesting system, there must be a transducer that harvests energy and converts it into electrical power [2]. The transducer can be an antenna, a piezoelectric device, a solar cell, a fuel cell, a wind turbine, and many other forms. Some of the most popular energy extraction used in electronic devices today is vibrant, radio frequency (RF) and thermal energy extraction. A research studied presents power management techniques that enable some of the most efficient power conversion circuits published to date [3].

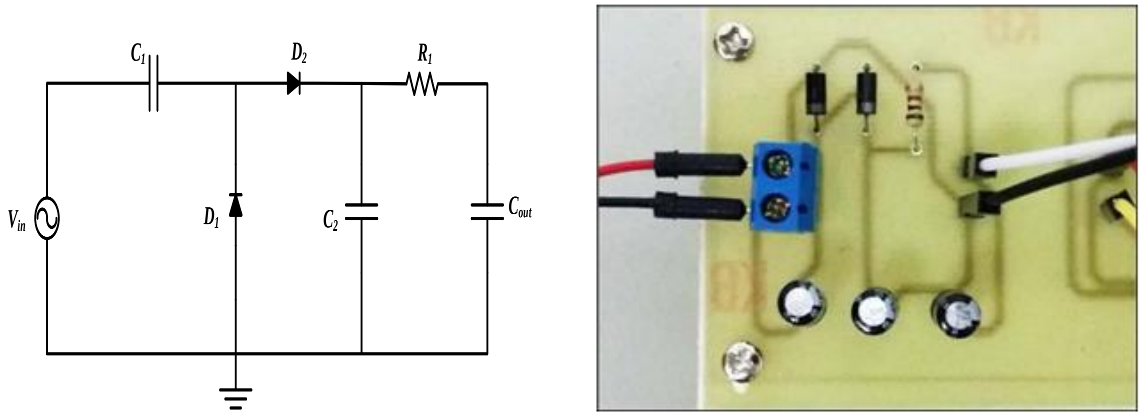
The vibration energy harvesting operation starts with extracting mechanical vibration energy from the environment and rectifying the alternating current (AC) voltage produced and converting it into a direct current (DC) voltage. There are three types of vibration to electrical energy conversion including electromagnetic, piezoelectric and electrostatic but piezoelectric is the most highlighted [4]. Piezoelectric materials are materials that can transform mechanical energy into electrical energy and vice versa. When the material is subjected to vibration there is a potential difference between its terminals, which can be stored and then used [5].

The electrical energy from a piezoelectric transducer coupled to a vibration system is usually very low, depending on load and in AC, which makes the energy storage in capacitors or batteries impossible. Therefore, it is necessary to develop an interface circuit that makes the conversion to DC with low consumption and reduced losses. There are now plenty of research on methods of gaining higher voltage output for energy harvesting projects. There are step-up transformer, voltage multiplier circuit and boost converters. These methods are ideal for many applications. Though, this study is focused on using diode-capacitor topologies. The AC voltage is converted to DC, double and then being rectified. This design proposed for the AC voltage of the piezoelectric transducer to enter the voltage doubler circuit, then to the boost rectifier before being stored for the temporary storage device such as supercapacitor.

In this study, the design and development of voltage doubler AC/DC converter for low power energy harvesting applications was reported. The DC – DC boost converter was also developed to step-up the voltage received by the voltage doubler. This energy is stored in an energy storage circuit. The interface circuit was simulated using MultiSIM software and the characterization was carried out in order to check the capability of the circuit to work as energy harvesting circuit

2. RESEARCH METHOD

The voltage doubler is an electrical circuit that converts AC electrical power from a lower voltage to a higher DC voltage. This circuit will receive the output from the energy harvesting unit and converts it from AC to DC while increasing its voltage to a higher level. The output of the voltage doubler is then boosted up to a higher level via DC – DC Boost Converter. In this study, the piezoelectric generator was used as an energy harvesting unit to be connected to the interface circuit. Then, the voltage is converted via the voltage doubler, AC to DC. The output voltage from the voltage doubler will be increased using DC – DC boost converter.

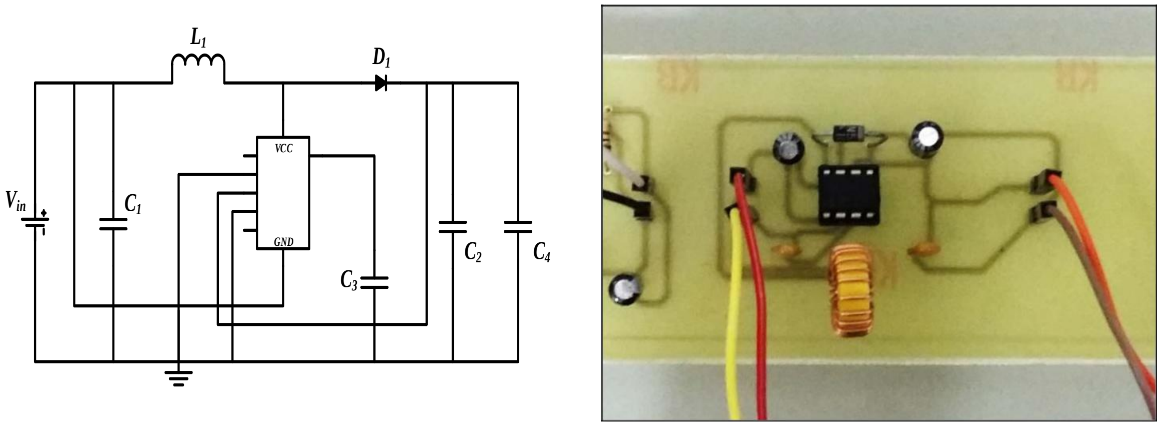


(a) (b)

Figure 1. (a) Schematic and (b) PCB of voltage doubler circuit with low-pass filter

In standard applications, a piezoelectric generator usually has a very low output of roughly 800 mV. With the implementation of voltage doubler, the voltage source from any generator producing AC source like the piezoelectric can be rectified to DC output with a slight increase in voltage. Figure 1 shows the schematic and printed circuit board (PCB) circuit of the voltage doubler including low-pass filter. The voltage doubler was constructed using two diodes and two capacitors. The low-pass filter uses a resistor and a capacitor. The voltage doubler converts the AC input voltage into a higher DC output during both positive and negative half cycle. In the negative half cycle of the sinusoidal input waveform, diode, D_1 is in forward biased condition and allows the capacitor, C_1 to charge up to the peak value of the input voltage, V_{in} and stores the charges and remains fully charged. In the positive half cycle condition, diode D_1 is reverse biased disallowing capacitor, C_1 to discharge. At the same time, diode, D_2 is forward biased and causing capacitor, C_2 to charge up. Due to the prior charged capacitor, C_1 storing V_{in}, it causes the capacitor, C_2 to charge twice the amount of V_{in} of the input voltage. Then, the voltage across capacitor C_2 can be calculated as, $V_{out} = 2\ V_{in}$, where V_{in} is the peak value of the input voltage [6].

Figure 2 shows the schematic and PCB circuit of the DC – DC boost converter circuit. The operation of the boost converter is relatively straightforward. When the switch is in the ON position, the inductor, L_1 output is connected to ground and the voltage, V_{in} from V_1 is placed across it. The inductor current increases at a rate equal to V_{in} / L. When the switch is placed in the OFF position, the voltage across the inductor changes and is equal to $V_{out} – V_{in}$. Current flow in the inductor decays at a rate equal to $(V_{out} – V_{in}) / L$ [7]. The voltage doubler circuit and the DC – DC Boost converter circuit is combined onto a single PCB as shown in Figure 3. The output voltage and current were measured and recorded.



(a) (b)

Figure 2. (a) Schematic and (b) PCB of DC – DC boost converter circuit

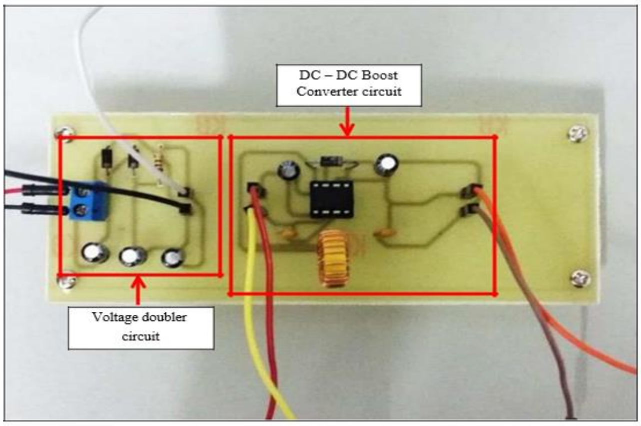


Figure 3. PCB layout of energy harvesting circuit

4. RESULTS AND ANALYSIS

The piezoelectric generator used in this study can produce a sinusoidal AC voltage up to 800 mV amplitude and vibration frequency of 1 kHz. The input waveform has confirmed in AC of 1.78 V_{rms} as shown in Figure 4. The voltage doubler used in this project has the ability to change the voltage from AC to DC while slightly increasing the voltage output.

Figure 5 shows the measurement result of voltage doubler circuit. The output voltage of 3.11 V_{rms} was measured. The output waveform was confirmed in DC form. The oscilloscope is then connected to the DC – DC boost converter circuit. The DC-DC boost converter was used in order to significantly increase the output voltage of the voltage doubler circuit while maintaining the voltage in DC form. The measured result of 5 V was obtained as shown in Figure 6. The output waveform is in DC with current value of 200 mA was measured using light emitting diode (LED) as a load.

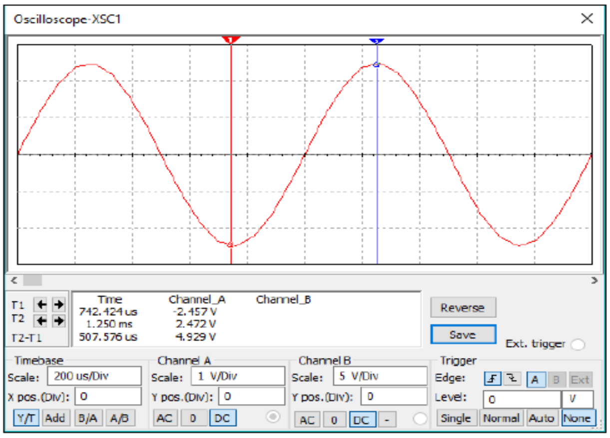


Figure 5: Output waveform of voltage doubler circuit

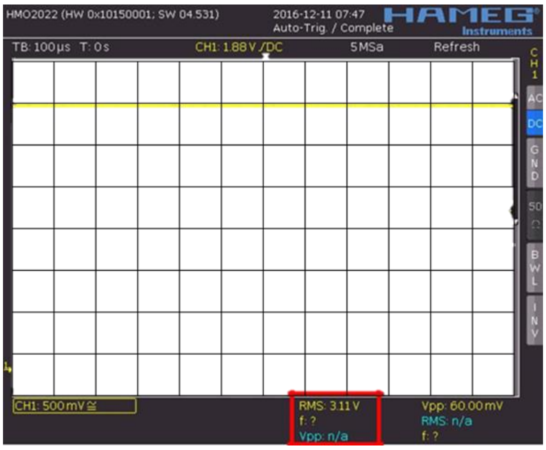


Figure 6. Output waveform of DC – DC Boost converter circuit

Table 1 summarizes the simulation and measurement results of the interface circuit. The efficiency of the interface circuit was calculated to be 91.8 %. The output value for the voltage doubler between the simulation and measurement had slightly different due to the losses of voltage. This output is then connected become the input for DC-DC converter and it output is 5 V same as the expected output. The output waveform is in DC with current value of 200 mA. The expected value and the measurement value are equal.

Table 2 shows the comparison between this study and previous study. The highest output voltage and efficiency was achieved compared to the other research. The input voltage for proposed design is low, but it can boost up the voltage up to 5 V. The proposed design was using the simplest circuit design to convert the AC-DC voltage with highest input voltage for DC-DC converter of 3.11 V was measured. Although the proposed design also used the voltage doubler circuit in order to convert the AC-DC voltage, but with some modification made, the highest output voltage of 5 V was achieved.

Table 1. Simulation and experimental results of the interface circuit

Circuit	Simulation			Experimental		
	V_{in}	V_{out}	I_{out}	V_{in}	V_{out}	I_{out}
Voltage Doubler	1.78 V_{rms}	3.60 V	300 mA	1.78 V_{rms}	3.11 V	350 mA
DC – DC Converter	3.60 V	5.00 V	200 mA	3.11 V	5.00 V	200 mA
Efficiency		92.6 %			91.8 %	

Table 2. Comparison between previous study and this study

Harvesting Model	Input Voltage (V_{in})	Output Voltage (V_{out})	Output Power (P_{out})	η (%)
AC-DC rectifier, voltage regulator and DC- DC converter [8]	0.3 AC	1.67 V	-	80 %
Voltage doubler and two buck boots converter [9]	0.54 AC	3.40 V	54 mW	-
Voltage doubler and bridgeless rectifier [4]	1.9 V_{rms}	3.00 V	90 mW	71 %
This study	0.8 V_{rms}	5.00 V	100 mW	91.8 %

5. CONCLUSION

The interface circuit for piezoelectric energy harvesting has been presented in this paper. The voltage doubler used the Cockroft Walton doubler topology were successfully converted the AC input into higher DC output. The DC – DC converter used CMOS step-up DC – DC switching regulators effectively boosted the input of the Cockroft Walton doubler circuit to 5 V. The conversion efficiency is calculated to be 91.8 %. The proposed interface circuit can be used to power up devices that are compatible with the output of the interface circuit. Future work includes optimization of the rectifying circuit to operate more efficiently can be made.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the supports of the Malaysian Ministry of Higher Education (MOHE) through FRGS Research Grant No. 1615 and the Universiti Tun Hussein Onn Malaysia through Short Term Grant No. U541.

REFERENCES

[1] L. Benini, *et al*., "Wireless Sensor Networks: Enabling Technology for Ambient Intelligence," *Microelectronics Journal*, pp. 1639-1649, 2006.
[2] L. Triet, *et al*., "Radio Frequency Power Harvester," *United States Provisional Patent,* DBI0529223, 2007.
[3] E. Lefeuvre, *et al*., "Piezoelectric Energy Harvesting Device Optimization By Synchronous Electric Charge Extractions," *J. Intell. Mater. Syst. Struct,* pp. 865-876, 2005.
[4] R. M. Mahidur and R. Sarker, "Vibration Based Piezoelectric Energy Harvesting Utilizing Bridgeless Recitifier Circuit," *Jurnal Kejuruteraan*, pp. 87-94, 2016.
[5] F. S. Souza, "Power Harvesting System using Piezoelectric Transducers," *Master Degree in Electrical Engineering, Engineering College of Ilha Solteira*, 2011.
[6] N. Roscoe and M. Judd, "Harvesting Energy from Magnetic Fields to Power Condition Monitoring Sensors," *IEEE Sensors Journal*, pp. 2263–2270, 2013.
[7] R. V. Begum, *et al*., "Nine Level H-Bridge Grid Connected Inverter Operated Photovoltaic Module using Matlab," *IOSR Journal of Electrical and Electronics Engineering*, vol. 12, pp. 7-16, 2017.
[8] M. R. Shaker, *et al*., "Designing a Battery-Less Piezoelectric based Energy Harvesting Interface Circuit with 300 mW Startup Voltage," *Journal of Physics*, pp. 1-8, 2012.
[9] G. Mohammad, *et al*., "Development of Piezoelectric Mirco-Energy Harvesting System using Voltage Doubler," *ARPN Journal of Engineering and Applied Sciences*, 2016.