MEDIUM VOLTAGE RANGE ENERGY HARVESTER APPLICATION USING BOOST CONVERTER

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ABSTRACT

Energy obtained from the surrounding is usually very low and scarce. Such energy can be found from the vibration, solar and heat to name few. Often this energy is less than 1.5 V. Based on this motivation, DC-DC boost converter circuit is choose and design to convert low energy to sufficient amount to be used in normal circuit device and system application. This paper introduces a medium range output voltage using conventional DC-DC boost converter for low input supply range. Simulation has been done and compared with the experiment results. The purpose of this paper is to show the possibility of conversion very low energy to up to 50 V and to discuss a brief operation involved. A linear 4 V to 49 V output voltage trend was obtained from the experiment, under low switching frequency, 2 kHz. The targeted input used in this paper is between 0.1 V to 1.5 V suitable for energy harvesting purpose.

Keywords: energy harvesting, low voltage, low frequency, boost converter, low power consumption.

INTRODUCTION

Having a source, powered by lost energy from the environment or any other similar operated system, product or machine is a promising on going and future trend for research. This source can be made by harvesting energy from vibration, light, sound, water, or any temperature different. It is then converted into usable electrical energy by a power stage and is regulated to produce a constant power supply. Recent research breakthrough from Duke University has shown that WiFi energy can also be harvested to charge the battery [1].

The operation range for normal IC or low voltage device is in the range of 1.2-3.3 V [2-3]. Usually the input is less than 1 V. By using multilevel boost converter as in [4], a several tens of voltage can be stepped up to 110-220 V range for normal house appliance or for high voltage device. Many researches have also been reported focusing in very high power applications which go beyond 300 V especially for the hybrid cars in the automotive industry [5-6]. However, these high power applications requires more than ten times of the input voltage for their boost converter circuit, which is not suitable to be used in energy harvesting technique that requires a very low supply.

An AC cascaded boost implemented in [3] has combined the circuit with a differential oscillator, a voltage clamp, and a feedback circuit. Even though the input is very low (0.25 mV) the circuit can boost the output to 3.3 V at its final stage. Unfortunately it is very difficult to maintain the efficiency of proposed architecture. This is because, it requires additional diodes in its oscillator, and a voltage clamp (by using the charge pump) to further control the operation range to make sure the positive and negative input range is within the acceptable limit. This sacrifices the overall area of the circuit. The large number of diodes that were used in the circuit can contribute to conduction power losses, thus, reduces its efficiency. At the same time the end voltage is also low regardless of the complexity of the system.

Another technique is reported to use multiphase boost converter. This method combines a number of boost converters stacked in parallel arrangement to obtain the same 48 V output voltage. The technique has proven to produce a constant efficiency of more than 90 % throughout the operation load and a promising high frequency of operation. The N-multiplication of high frequency depends on the N-number of boost phase. This multiphase technique is however as shown in [7] has supplied a very large supply of 36 V input voltage which is not suitable for low voltage application. Another work by Huang *et al.* [8] have used the normal boost converter circuit by self-starting feed forward technique and super capacitor enhancement circuit to stepped up 1.2 V input voltage to 7-9 V output with changes in duty cycle. However both references have used fixed input amplitude.

This paper introduce a medium output voltage range using conventional boost converter to convert low input voltage such from energy harvester in range of 0.1-1.5 V. Results have shown a successful boost converted up to 50 V of output voltage. This paper is arranged in the following format; previous works related to the power stage circuit are discussed in Section I. Section II described methodology used in this paper. Results of the circuit simulation and experiments are presented in section III followed by the conclusion in Section IV.

METHODOLOGY

Switch power boost converter always give an output voltage greater than its input voltage. A normal DC-DC boost circuit configuration consists of inductor L, schottky diode, load capacitor C, and switch circuit S_W. Circuit configuration using NMOS transistor, M_S is used for switching purpose and a low power loss Schottky barrier diode is used to replace the normal diode as shown in Figure-1. It is proven that by using MOSFET to replace the diode can reduce the conduction loss. However, it requires complicated circuit to balance the secondary signal.

Research in [9] have used PMOS transistor to replace the diode to benefit from the low threshold voltage V_T, MOS transistor diode, hence, reducing the total power loss during circuit switching. Though for low frequency purpose the simple method using Schottky diode with low forward voltage of 0.3 V is reasonable for this type of application in reducing the power loss. Some works have also used active diode to further reduce the power loss in its AC/DC converter [10-12]. However this method has its own disadvantage of large area consumption. Therefore in this work, we only require the DC supply to avoid the complex conversion from AC to DC.

The transistor switch is turned ON and OFF depending on the mode of operations at switching frequency, $f_s = 1/T$. Basically, there are two modes of operation for boost converter [13-15], and the operation can be either one of the transition time: i) a continuous mode and ii) a discontinuous mode.

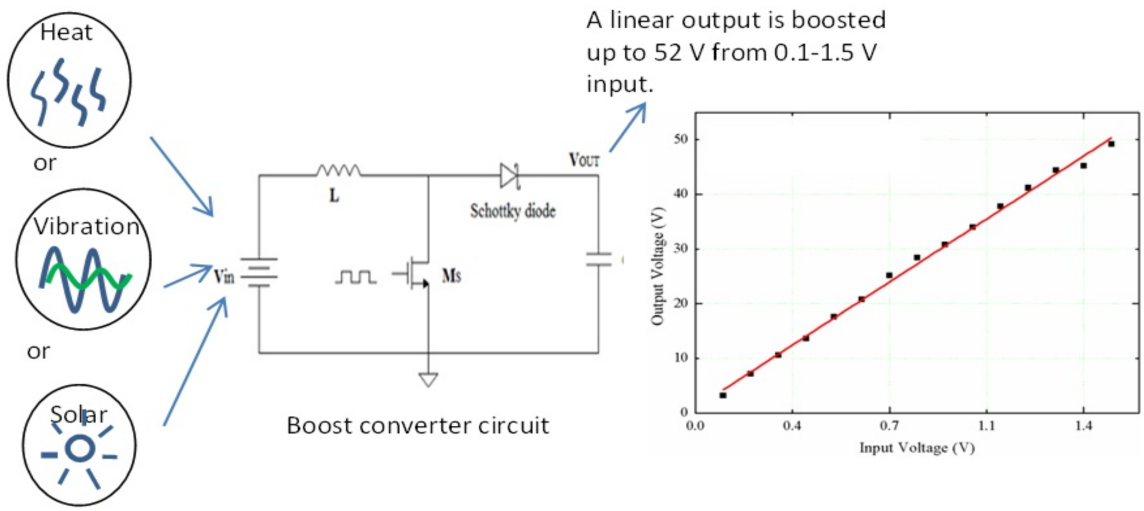

Figure-1. Conventional boost circuit suitable in medium voltage output range for energy harvesting purpose. Results show dotted lines is the experimental results and straight linear line is from simulation output.

CONTINUOUS MODE: WHEN SWITCH IS HIGH STATE

A continuous mode starts when transistor M_S, is turned ON and conducting a pulse. The diode transistor at this time is turned OFF and is reversed biased. A charge is being stored and inductor current is drawn into the inductor, L. The inductor current, I_L will ramp up linearly during the time interval of t_{ON}. The relation between the ON state and the output voltage is as Equation (1). The output voltage depends on the duty cycle, switching frequency, ripple current, and inductance.

$$V_{IN} = L\frac{I_{max} - I_{min}}{t_{ON}} = \frac{\Delta I}{t_{ON}}L = \frac{\Delta I}{DT}L \quad (1)$$
$$when\ ,0 < t < t_{ON}$$

DISONTINUOUS MODE: WHEN SWITCH IS LOW STATE

In a discontinuous mode, transistor M_S is switched OFF. Inductor voltage reverses its polarity in order to maintain its constant current since current in the inductor cannot change instantaneously. Inductor voltage starts to build up its energy and when this charge is higher than the combined energy in transistor diode and load capacitor, the inductor delivers its voltages to the load capacitor through the diode transistor. Voltage at the output capacitor is higher than the input voltage. During this time, t_{OFF} inductor current falls linearly from I_2 to I_1 and the state of inductor current will decide the operation mode [15]. Equation (2) shows the relationship of the variable when time is OFF state.

$$V_{OUT} - V_{IN} = \frac{\Delta I}{t_{OFF}}L = \frac{\Delta I}{T - t_{ON}}L = \frac{\Delta I}{t_{ON}(1-D)}L \quad (2)$$
$$where\ ,t_{OFF} = T - t_{ON}\ ,when\ ,t_{ON} < t < T$$

RESULTS

The boost circuit with values as shown in Figure-1 is simulated using Pspice simulation tool. Due to the low voltage characteristic of the surrounding, the input voltage amplitude is chosen to vary in between 0.1 to 1.5 V and the simulation is done using frequency 1 to 50 kHz range. The rise and fall time is chosen to be 2.9 µs at a period of 1 ms as obtained from the experiment. Each parameter value chosen for the boost converter simulation is listed in Table-1.

In this work, several attempts have been made to get the best parameter values of the inductor, and the switching frequency for a particular load. Figure-2 shows the switching transistors pulses at the rate of 500 µs or 2 kHz. At every interval of the ON state, charge is being built up at the load capacitor. For high efficiency purpose, the diode should be ultrafast recovery diode [14]. As soon as the transistor switch is at the ON state, the inductor current starts increasing linearly across the diode after the first interval starts and there is no current across the diode.

When the switch is OFF, the diode will start conducting and some charge is supplied to the load. Inductor current is continuously decreasing until the switch is turned ON. Diode at this time, does not allow current to flow in the opposite direction. This explains the sudden peak in diode current and it remains zero at other peak of Figure-2(b). Current at inductor is built up when the switch is turned ON and not conducting otherwise.

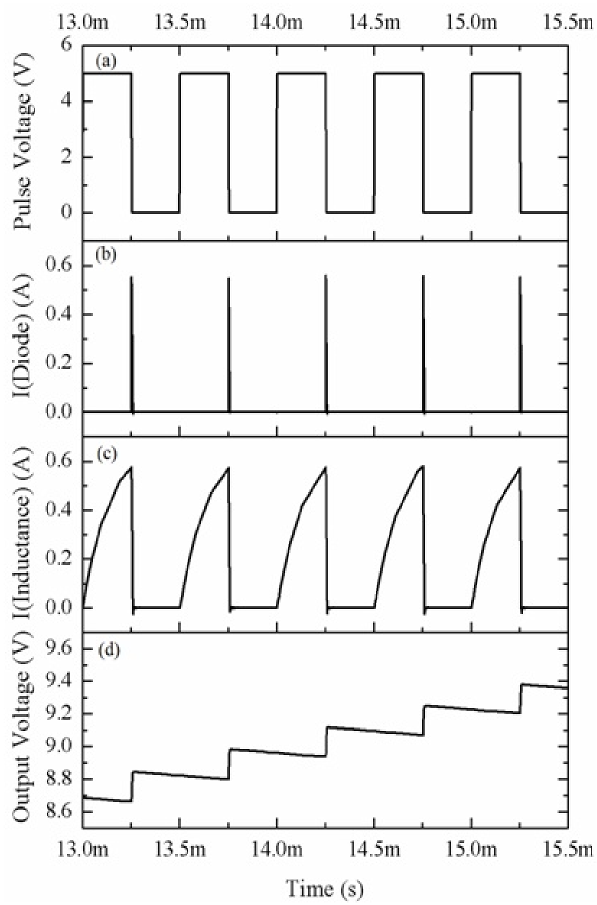

Figure-2. Results of (a) the switching frequency pulse voltage (b) current through Schottky diode (c) inductor's current (d) output voltage.

Every time the diode is at forwarded state or while the switch is not conducting for a period of *T*, the output voltage is built up and stabilized after sometimes.

Based on the ripple current, ΔI, of Eqn. (3), where $\Delta I = I_2 - I_1$. Inductance is inversely proportional to the ripple current. The larger the value of the ripple current or the peak current, the greater saturation of inductor stress on the MOSFET [14]. Thus, it is better to choose lower value of ripple current and consequently will give reasonable value of inductance, *L*

$$\Delta I = \frac{(V_{OUT} - V_{IN} - V_D)}{L} t_{OFF} \quad (3)$$

CONCLUSIONS

The conventional boost converter can be used to boost very low voltage to produce varying output voltage. In order to boost this large voltage variation, it requires proper design of circuit parameters such as the inductor and switching frequency parameter; duty cycle, as well as rise and fall times of the switching pulse, and duty cycle. The experiment results show a wide linear output up to 50 V is boosted from 0.1-1.5 V input. By properly design for a medium voltage range application, the design parameters values are L = 100 μH, D = 50 %, CL = 10 μF, and f = 2 kHz under RL = 10 kΩ load. The final wide range medium power application in low frequency system is essential for the benefit of various applications such in automotive, energy harvesting, home appliance, and wireless measurement system.

Table-1. Description of component parameters.

Component	Type and description	Value
Inductor, *L*	Toroidal core inductor, Bourns, PM2120-101K-RC.	100 μH
Mosfet	NMOS transistor, Intersil.	IRF530N
Diode	Schottky diode, ON Semiconductor.	1N5822
Capacitor, *C*	Aluminum Electrolytic Capacitor	10 μF
Resistor, *R*	Axial lead resistor	10 kΩ
Input Voltage, V_{in}	DC Voltage	0.1-1.5 V

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