

The Design of Self Starting Regulator Using Step-Up Converter Topology for WSN Application

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Abstract: - Continuous monitoring is very important for chronic patient, elderly or who was under supervision for recovery from an acute event or surgical. For this Wireless Sensor Network give a solution for continuous health monitoring and able to wirelessly monitoring patient conditions at any time. It is able to generate early warning if received unwanted signal from the patient as well. As known, Wireless Sensor Network is only consumes a little power to turn it on and energy harvesting is able to power up this devices without using the batteries. Continuous monitoring needs a continuous and uninterruptable power source. Hence, energy harvesting is one of the options of the solutions. However, up till now the energy harvesting still develop a low output voltage which is not enough to power on the wireless sensor network. Therefore, this paper proposed a new technique called a self starting DC to DC converter which is able to boost up the input voltage as low as 0.4V to the output voltage of 5.1V. The circuit efficiency is up to 92% which is verified by simulation using LTspice tools. Hardware implementation will be done in future work.

Key-Words: - Continuous monitoring, Wireless Sensor Network, energy harvesting, low output, DC to DC converter, LTspice tool

1 Introduction

Continuous monitoring of patients outside the hospital environment is already developed on previous research and the potential applications of the findings is able to save lives, create valuable data for medical research, and cut the cost of medical services[1]. Wireless sensor network (WSN) provides the technology that has potential solution to this issue. WSN is consists a number of sensor nodes that been placed in multiple places and it has capability to do multi-hop networking so that the data will be transmitted and received in the real time data and able to give early warning to the medical officer in case of critical life happen to the patient. The main problem nowadays arise when batteries is no more practical to be used to power up the WSN. It is quite troublesome to replace the old batteries every time the power runs out.

The solution of this problem is using energy harvesting which is very popular amongst the researches today and a lot of research has been done in order to feed low power applications such as wireless sensor network (WSN). Energy harvesting is energy that been collect from the surrounding environment and then convert it into electrical forms. There are various sources of energy

harvesting also known as energy scavenging that can be easily found at anywhere and anytime such as salinity, vibration, RF energy and many more and most of them deliver a very low input voltage which is less than 1V. The voltage supplied is too low in order to power on the WSN[2] thus suitable DC to DC converter is needed to boost up the voltage to the required voltage so that it will be enough to supply the WSN.

In [3] can be seen that the researchers have found the solutions of the main issues of the boost converter. This gave ideas for the current researcher what things to aware of and what can be improved with current technology. There are also findings in [4] that become consideration of designing the dc to dc converter in this paper. It mentions about the state of the art of low voltage and low power converters. It presents the advantage of using energy harvesting to design a self-powered converter topologies which is more suitable compared when using a battery systems, a traditional way.

The selection of DC to DC converter is very critical as it must to make sure that the design of DC to DC converter is able to operate with input voltage even low than 1V. The improvement that been done in this project consist of two parts, first

instead of using single inductor as presented in[3][5], here magnetic couple-inductor topology has been presented. The purpose of using magnetic couple inductor is to achieve high step-up gain. In [6], the author has prove that the step-up gain increased by adjusting the turn ratio and winding stages of the coupled inductor.

The second improvement in this project was in regulator circuit part where MOSFET has been used to regulate the output voltage. The advantage of using MOSFET compared to linear regulator is that the loss power dissipation can be reduced and this will increase the efficiency of the circuit.

2 Design Consideration

The converter input is actually come from the harvested energy which is already been converted to DC from AC through AC to DC rectifier circuit. As been known the harvested energy is very low voltage thus a reliable low voltage DC to DC Converter is needed to boost up the input voltage so that can be used for any load application. Table. 1 below shows the basic requirements of the designing of DC to DC converter that need to be met in this project.

Table. 1 Specification of DC to DC converter of 1kΩ resistor load

	Min	Typical	Max
Input Voltage, V_{in} (V)	0.15	0.45	0.75
Input Power, P_{in} (mW)	0.005		2
Output Voltage, V_{out} (V)	1.7		11.0
Output Power, P_{out} (mW)	2.89		121
Efficiency, η (%)	75	87	92

Fig.1 below shows the schematic design of low voltage of DC to DC converter with 1kΩ resistor load and it can be seen that the circuit is divided by four stages which are the main circuit, start-up circuit, oscillation circuit and regulator circuit and these will be discussed in below subsection separately.

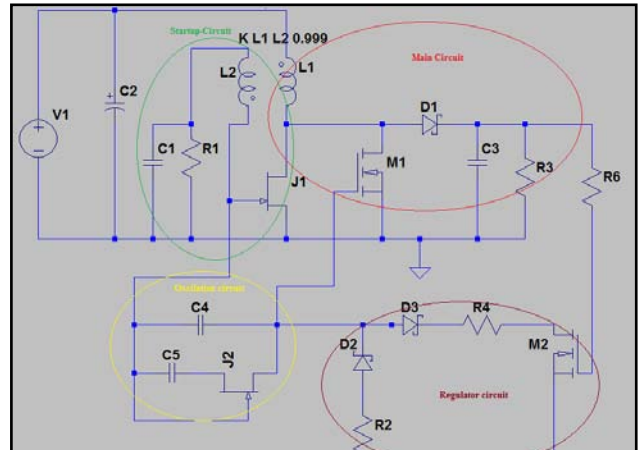


Fig.1 Schematic design of low input voltage of DC to DC converter circuit with 1kΩ resistor load

2.1 Main circuit

In main circuit, the basic step-up converter topology has been used to boost up the low harvested input voltage. Fig.2 shows the basic simplify circuit diagram of the step up and also known as boost converter.

The circuit operation will be started when there are the on and off at the switching cycle. The operation of this converter will continuously as long as there is a power. At the first cycle, the switch closes as shown in Fig. 1a, the current flow in inductor will increases linearly. While in second cycle, the switch is open as can be seen in Fig. 1b. The current will flow through the forward bias diode, D so that the current as well as the energy will go to capacitor, C and charge the capacitor. The current will quickly drops at this moment and this process will be keep repeating at the certain frequency.

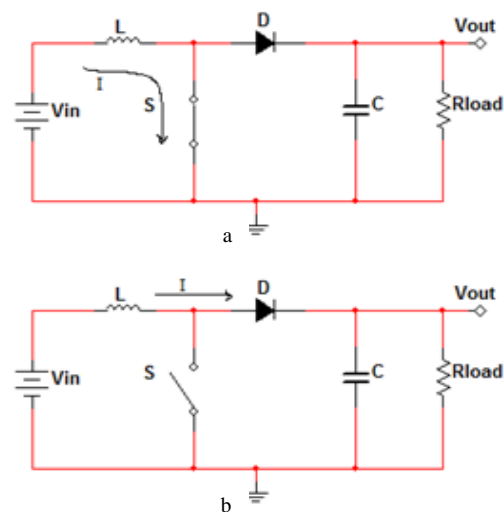


Fig.2 basic circuit diagram of step up converter

The equation involved in this topology converter is shown in below algorithm:

When the switch, S closed for the dt seconds the equation will become:

$$\frac{di_L}{dt} = \frac{V_{in}}{L}$$

At $(dt-1)$ seconds, the switch, S open:

$$\frac{di_L}{dt} = \frac{(V_{in} - V_{out})}{L}$$

Since the average voltage across L is zero:

$$V_{L_{avg}} = D.V_{in} + (1 - D).(V_{in} - V_{out}) = 0$$

$$V_{out} \cdot (1 - D) = V_{in} + D.V_{in} - D.V_{in}$$

$$V_{out} = \frac{V_{in}}{(1 - D)}$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{1 - D}$$

2.2 Start-up circuit

For the start up circuit, JFET, J1 as shown in Fig.2 has been used to start the converter since the JFET are able to operate with a zero gate voltage and also has a low gate threshold voltage.

The JFET, J1 will conducting the converter with the input voltage that known very low which is come from the energy harvesting sources such as vibration and salinity. The voltage then will keep increasing as well as the current that flows through the J1 and this will induce the secondary winding which is L2. The capacitor, C1 will be charged to negative voltage and then be stored to switch on the JFET. The current at first winding, L1 now decreased and will induced a positive voltage over second winding, L2 and negative voltage over the JFET, J1 and this will switched off the J1.

2.3 Oscillation circuit

In the oscillator circuit part, the parallel connection of C4 and C5 with JFET, J2 has been used and this also can be seen in Fig. 1 in yellow circle. The parallel connection will helps the converter to start to oscillate even at low input voltage. This circuit will generate the pulse width modulation (PWM) that will drive the main switching device, MOSFET (M1) so that the converter will working as desired

with a certain frequency that been produced by this circuit.

During the steady state, the voltage in first winding of the coupled inductor will same as the input voltage ($V_1 = V_{in}$) during the T_{on} and during the T_{off} the $V_1 = V_{in} - V_{out}$. L1 and L2 is ideally coupled then $V_2 = nV_1$.

During the T_{on} the voltage at the secondary winding and the PWM voltage is in positive voltage while the capacitor, C4 will charging and decrease the PWM voltage until it reaches the threshold voltage of the MOSFET, M1 and will be turns off.

During the T_{off} , the capacitor, C4 will discharges until the current through the diode, D1 of the main circuit down to zero. Fig. 3 below shows the theoretical illustration of the circuit operation and the simulation results can be seen in Fig.4 at the results and discussion part.

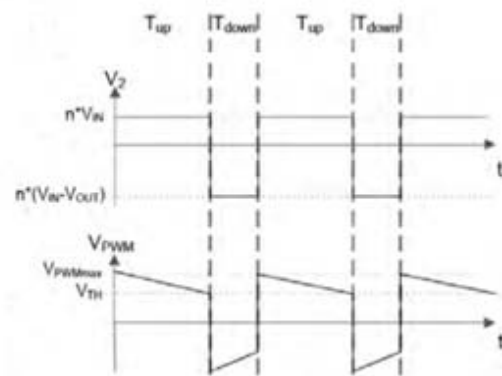


Fig. 3 Theoretical waveforms of self - oscillation circuit[7]

2.4 Regulator circuit

The purpose of this circuit is to generate the regulated output voltage by modifying the switching frequency of the converter that will drive the MOSFET, M1.

One MOSFET, M2 has been added to act as switching regulator to vary the regulated output voltage in response to the input and the output voltage changes. The gate M2 will be supplied by the output voltage and this will helps to vary the duty cycle to maintain a constant regulated output voltage.

As for diode selection, D1, D2 and D3 the schottky diodes is been used as it is known has zero bias voltage and also has low threshold voltage to make sure that the circuit design is working for low input voltages. The simulation result will be shown in results and discussion section.

3 Results and Discussion

The simulation was done by using LTSpice tools for the schematic drawing to get the output results. Fig.4 shows the simulation results of the oscillation circuit. It can be seen that it almost the same as the theoretical illustration as in Fig.3.

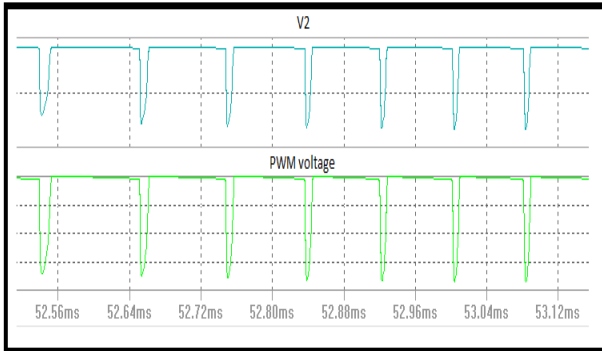


Fig. 4 Simulation results of V2 and PWM voltage

For the voltage input of 0.4V, the circuit is able to boost up to 6.3V output voltage within 16ms. This can be seen in Fig. 4. While in Fig.5, it shows the input voltage is 0.6V and the output voltage is 7.7V within 10ms. The efficiency of this circuit is about 92% which is improved from the previous work in [5][8][7].

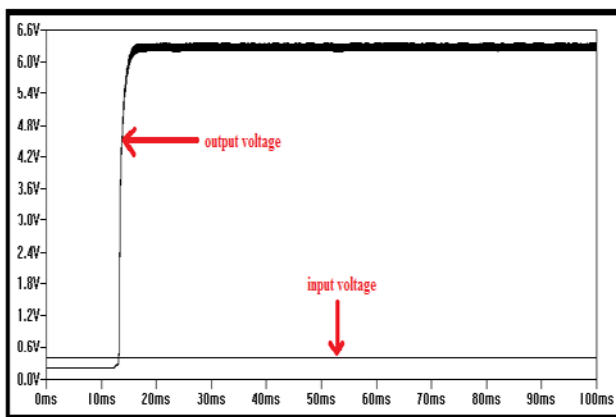


Fig.5 The result of 0.4V input voltage

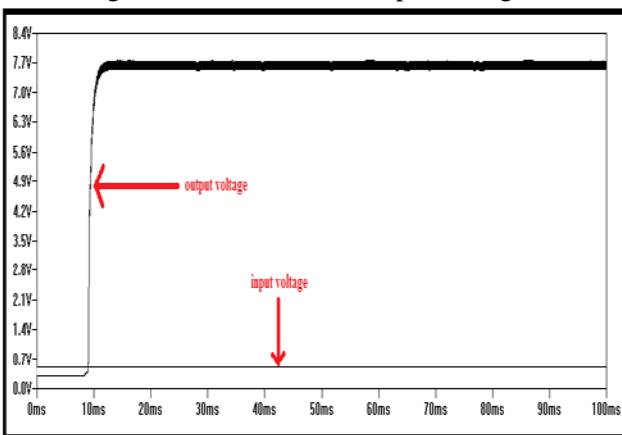


Fig.6 The result of 0.6V input voltage

In [5], the efficiency of the finding is approximately 50% and able to provides regulated 1V output voltage. The authors use a novel digital gate timing control techniques. While in [8] the authors succeed to build up the circuit of 70% efficiency and the output voltage up to 2V as well. The authors are using the same method as [7] but different ways of designing regulator part which they are using MOSFET regulator topology. In [7] the researchers is able to improved the design by achieved circuit efficiency up to 74% and able to produces above 2V output voltage depending on the condition of the load. The method that been used in their research is the modified of boost converter based on the transformer which is use the secondary winding to control the switch that been connected serially with the primary winding.

And in this project it is proven that it has improved from the previous work based on the simulation results that been captured in this section. The improvement in regulator part has given a lot of different to the output voltage as well as the output power. The circuit design gives a high duty cycle of the frequency and this is giving the high output voltage as can be seen in the simulation result.

Table.2 below shows the full results of output voltage in response of varies input voltage from 150mV up to 750mV. From the table, the gain for the circuit can be obtained and it shows that the gain is within 11 to 15.

Table 2 Gain for the different input voltage

Input voltage, V_{in} (mV)	Regulated output voltage, V_{out} (V)	Gain, $\frac{V_{out}}{V_{in}}$
150	1.7	11.33
250	3.3	13.20
350	5.3	15.14
450	7.0	15.56
550	8.1	14.73
650	9.5	14.62
750	11.0	14.67

4 Conclusion

The main improvement of this project is at the regulator circuit part where we manage to optimize the circuit design as well as to improve the output voltage and increase the efficiency of the circuit. This can be proof by comparing to the previous research that been discussed before in results and discussion part. The output power calculated is up to 121mW for 1kΩ resistor load and this is enough to supply on the WSN and also can be applied to

power on other applications such as security monitoring, automobile as well as industrial applications. As a conclusion we can see that this converter topology is able to boost up the input voltage as low as 0.15V and the efficiency of the circuit is up to 92% which is very high and this will be verified in real application for the hardware prototype production in future work.

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