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Design of Internal Startup Circuit for Implantable Pacemakers using Energy Harvesting Technique

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Abstract - A pacemaker is a small battery operated device that helps the heart to beat in a regular rhythm. It contains a powerful battery, electronic circuits, and computer memory that jointly generate electronic signals. One of the main problems about pacemakers is their batteries. Since the capacity of the batteries is limited, it limits the pacemakers lifetime. The other method to power up the implanted pacemaker is harvesting thermal energy is presented. The designed power supply includes an internal startup circuit and does not need any external battery. The startup circuit having a prestart up charge pump (CP) and a startup boost converter. The prestart up CP used to achieve a high efficiency and reduced voltage drop as well as increased circuit performance consists of a multi feedback ring oscillator. The startup boost converter utilizes a modified maximum PowerPoint tracking scheme (MPPT). According to LTSPICE simulation results, a 40 mV provided from a thermoelectric generator (TEG) and generate an output voltage up to 1.5V. The results show that a power consumption of 1.32pW is obtained from the output of the startup boost converter.

***Keywords* - Pacemakers, battery, Thermal Energy Harvesting, TEG, pre-startup circuits, startup converter**

1. Introduction

In worldwide nearly 3 million people having pacemakers, and annually over 6, 00,000 pacemakers are fixed. Generally, a pacemaker is fixed to treat slow heart beating, which is called bradycardia. When the heart beat is too slow, the human brain and the body do not get adequate blood flow and a kind of symptoms may occur [4]. After five years, a surgical process is wanted to replace the battery of the pacemakers. The major drawback regarding the pacemakers is its batteries. As the potential of the battery is limited, it limits the lifetime of pacemakers. In addition, nearly 60% of pacemakers are associated with its batteries as show in Fig. 1.A pacemaker is a small device, about the size of a half Dollar piece, implanted just below the collarbone.

Although it weighs just about an ounce, a pacemaker contains a powerful battery, electronic circuits, and computer memory that together generate electronic signals. The signals, or pacing pulses, are carried along thin insulated wires, or leads, to the heart muscle.

Fig.1 Battery with pacemaker

One of the different method is used to replace the battery in pacemaker by using energy harvesting technique Harvesting ambient heat energy using thermoelectric generators (TEGs) [11] is a convenient means to supply power to body-worn and industrial sensors, especially pacemakers.

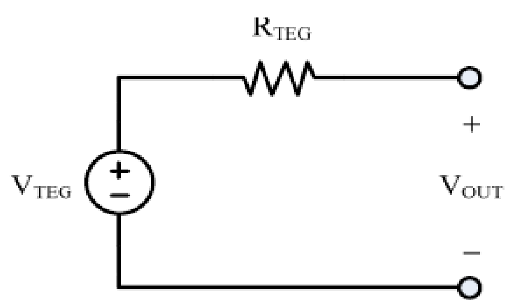

Fig.2 TEG circuit

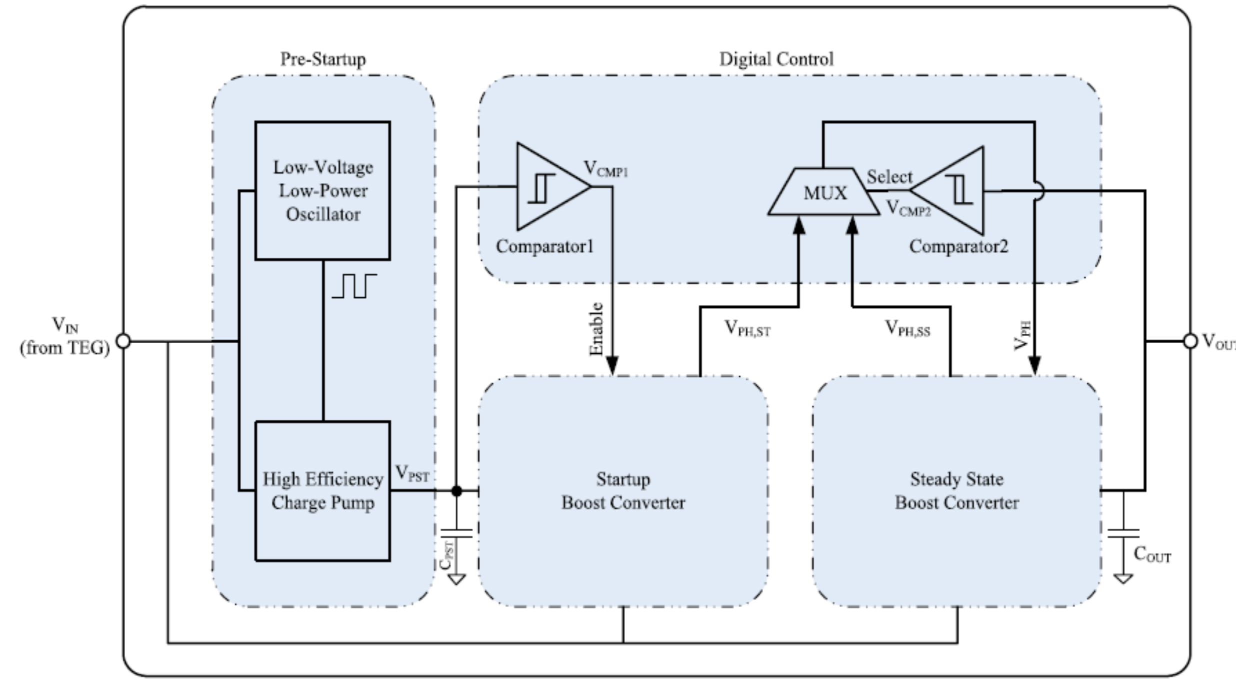

Fig.3 Existing architecture of Thermal energy harvesting system

A thermoelectric generator converts thermal energy into electrical energy due to the body temperature. This process depends on the physical way of seebeck effect. Using TEGs for implantable applications limits the output voltage to25mV to 50 mV for temperature differences of 1–2 K. Using energy harvesting Techniques, thermoelectric generator is used to supply the power to pacemaker without the aid of a battery.

Several existing systems [8] use a battery an initial high voltage energy input to kick-start operation of the system from this low voltage. Additionally, changing internal conditions cause the voltage and power generated by the TEG to vary, efficient control circuits that can adjust and extract the maximum possible power out of these systems.

The rest of this paper is organized as follows. In Section II, the TEG energy harvesting system architecture is presented. In Sections III and IV, existing and proposed system are Described. Simulation results are shown in Section V. Finally, conclusion is given in Section VI.

2. Existing System

The existing method of TEG consisting an ultra low-voltage low-power oscillator and charge pump for startup the other circuit. The boost converters are used to power up the application devices.

Fig.3 shows the architecture of the TEG energy harvesting system. The output voltage of 40mV is applied to the input of above system from thermoelectric generator. Now consider a pre-startup circuit that includes an ultralow-voltage low-power oscillator and high efficiency charge pump. The ultralow-voltage low-power oscillator, that generates the necessary clock phases for a charge pump system. A high-efficiency charge pump is used to increase the input voltage to the complete circuit to operate successfully.

The boost coveters are used to provide a maximum power to the load. The output voltage of the thermoelectric generator (TEG) is applied to the input of Charge pump. Accordingly, Charge pump start to charge a small internal capacitor (C_{PST}) placed at its output and the capacitor voltage (V_{PST}) start to rise. When V_{PST} reached a predefined value, the output of the comparator 1 (V_{CMP1}) sets.

This comparator is used to leads the startup boost converter (SUBC) to work. The startup boost converter provides the essential clock phases for the steady-state boost converter (SSBC), as the SSBC output voltage (V_{OUT}) does not arrive at a preset value. If SSBC achieved a predefined value, the output of the comparator 2 (V_{CMP2}) sets and the ordinary operation of the system begins. In this ordinary operation, the SSBC generates a clock phases itself. A multiplexer is used to decide on the source of the required phases for the SSBC based on the V_{CMP2}, whether from SUBC ($_{VPH,ST}$), or a self-generated one (VPH,SS). In ordinary operation, the SSBC no longer requires the pre-startup charge pump and Startup boost converter, so it can continue to work on its own. It is designed so that V_{OUT} becomes a voltage is presented [6].

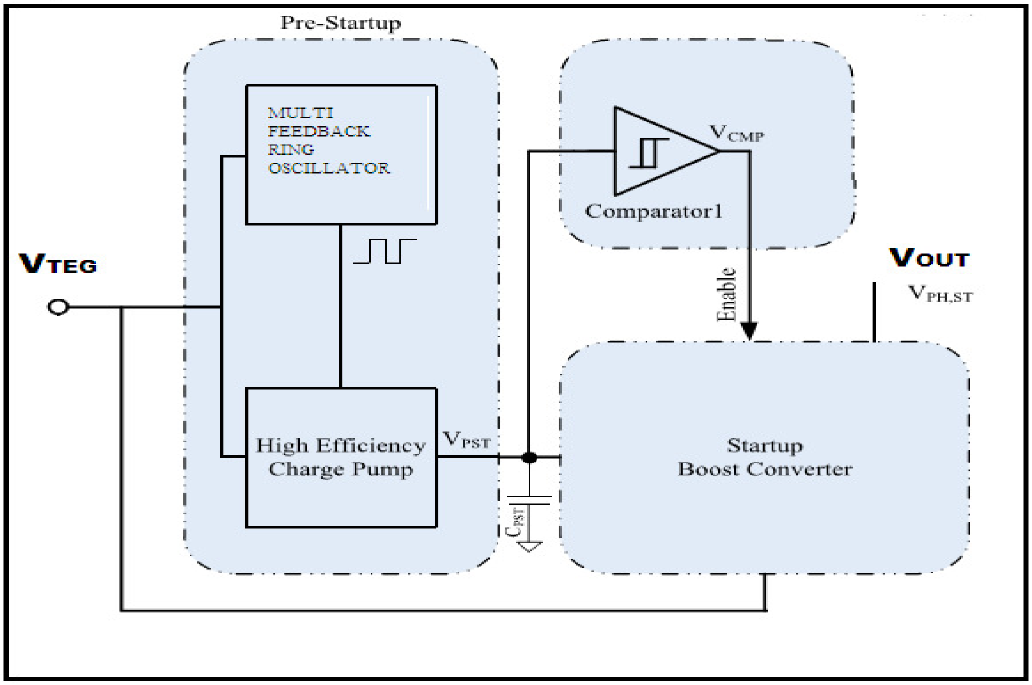

Fig.4 Proposed architecture of TEG

If, for any cause, V_{OUT} falls out of the range of the output voltage, directly, the SUBC becomes active and charges the output voltage until it comes within the range. This method automatically does not need vibration to start up, which is attractive. This limits the application and limiting the cost. The 95-mV startup input voltage is fairly high since the output voltage of a TEG is limited to 40–60 mV.

3. Proposed System

3.1 TEG Architecture

Fig.4 shows the architecture of the proposed thermoelectric energy harvesting system. The output voltage of 40mV is applied to the input of the pre-startup circuit. The pre-startup circuit includes a multi feedback ring oscillator and charge pump. The multi feedback ring oscillator is used to generate the required clock phases for a charge pump circuit. A charge pump is used to extent the input voltage for startup boost converter circuit to operate effectively. The output voltage of the TEG is applied to the input of multi feedback ring oscillator. The MFRO is used to generate a necessary clock phase for the charge pump circuit and in order to reduce noise characteristics for startup circuit. The MFRO output fed into the CP Consequently, CP begins to charge a small internal capacitor. The internal capacitor used to the output load of charge pump, it placed at the output of CP. When the capacitor delivered a specific output voltage at the time the digital control of comparator 1 can set. This comparator is used compare a low and high phase for startup boost converter. This startup boost converter has a constant charge time circuit, which is used to control the speed of boost converter circuit. Finally these circuits provide a available power to the load circuit. This circuit cannot fail within over load condition.

3.2 Pre-Startup Circuits

3.2.1 Multi feedback ring oscillator

The multiple feedback loop ring oscillator and delay cell with high oscillation voltage. It is an object of the present development to implement a new ring oscillator for the VCO of a high speed Phase Locked Loop and a proper delay cell with a high speed and low noise. The component is composed of multiple feedback loop ring oscillator that 4 delay cells which have the first and second main input stages, the first subsidiary and the second subsidiary input stages, the third subsidiary and forth subsidiary input stages, the first output stage and the second output stage is connected to the main ring and subsidiary ring. As show in Fig.5.The present development has advantages that it can be operated in high speed, it can improve noise characteristics. It has low power sensitivity;

there is no power noise because there is no variation of a supply voltage. In addition, to minimize power consumption, minimum-size inverters are used. The output buffer consists of a chain of inverters. The chain includes eight inverter-based buffers.

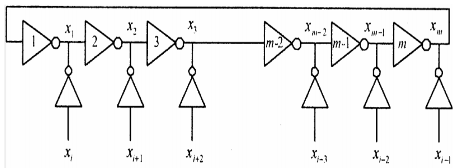

Fig.5 Multi feedback ring oscillator

3.2.2 Charges pump circuit

Fig.6 shows that the charge pumps circuit. This multi feedback ring oscillator can correctly control output swing, although it has a disadvantage that the power noise characteristic is bad because an output is linked to a power line directly through a small impedance triode transistor. To reduce an output swing is a clamping of output voltage of diode is other method. If we connect a gate and a drain of transistor, transistor is in a saturation region the diode can be used. If a diode turns on, the voltage of both terminals of a diode is proportional to the square root of a current (I), and a voltage dropping of diode is very small, so it can be used as a voltage clamping which fixes an output voltage to a exact voltage.

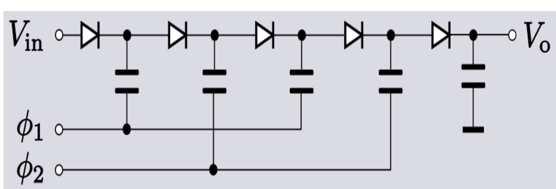

Fig.6 Charge pump

4. Startup Boost Converter structure

The boost converter is used to step up technique an input voltage to some higher stage, required by a load. This exclusive capability is achieved by storing energy in an inductor and releasing it to the load at a higher voltage stage. When using boost regulators this main highlights some of the more common pitfalls. These contain maximum possible output current and voltage, short circuit behavior and basic layout issues.

The references at the end of this document provide exceptional overviews of the action of a boost regulator; and should be consulted if the reader is not familiar with the basic action of this type of Converter. Fig. 6 shows a diagram of an ideal boost converter and its equivalent circuit in each phase [11]. A new Maximum power point tracking (MPPT) method is introduced as show in Fig.7.

The Maximum power point (MPP) is an operating point in boost converters. MPP based on maximizing the stored power in the inductor. Depending on maximum power point, at which maximum power is delivered to the load. Then again, it does not consider the ON resistances of the switches as well as the series resistance of the inductor.

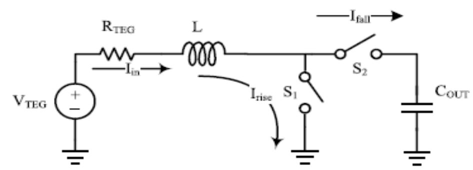

Fig.7 ideal Boost converter

The parasitic effects are considered, MPP will be changed. The maximum available power can be delivered to the boost converter is,

$$P_{AVA,\,MAX} = V_{TEG}^2/4 \text{ x } R_{TEG} \ldots\ldots\ldots (1)$$

The output voltage of a boost converter is,

$$V_{OUT} = VIN\ (T_{rise} + T_{fall}) / (T_{fall}) \ldots\ldots\ldots (2)$$

The output of the comparator 1 controls the activity of the oscillator. When *V*CMP1 is low, the oscillator is inactive. When it becomes high, the oscillator starts its operation. As the SUBC and the SSBC both need a similar oscillator, one oscillator is shared between them to reduce power consumption.

5. Simulation Results

To assess the proposed structure, the power supply with internal startup circuit includes a pre-startup circuit and startup boost converter is designed and simulated in LTspice. The designed startup circuit is used to supply the available power for a pacemaker. Therefore, the startup boost converter should convert the input voltage 40mV of the TEG up to 1 to 1.15V and the power consumption is 1.32pW to the load. A 50mV input voltage generates from a thermoelectric generator with a help of power sources and load resistance depends on thevenin's circuit. This can applied to the MFRO, which is used to generate a required clock phase and reduce a noise characteristic for the charge pump circuit is shown in Fig.8.

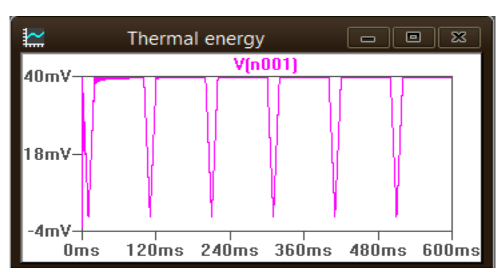

Fig.8 MFRO wave form

The charge pump circuit input is depends on the input of the multi feedback oscillator. The charge having a capacitor is a energy stored factor, which is used to increased a input voltage up to 300mV in the pre-startup state is shown in Fig 9.

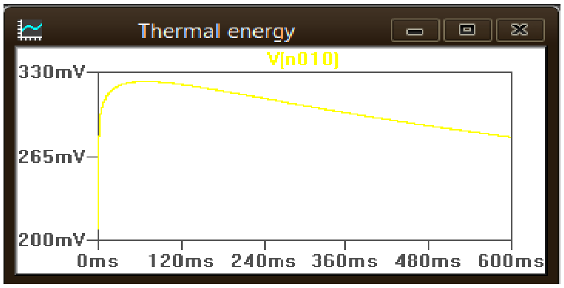

Fig.9 Charge pump waveform

When the output voltage is high in the charge pump at the time the compactor 1 is set it depends on the digital control unit. This is used to compare a low or high phase for the circuit and enables the boost converter circuit to work properly. If comparator compare to set a high value the boost converter can generate a proper voltage and deliver an available power to the load resistance this input is depends on output of charge pump circuit. This generates an output voltage 1.15Vand the consume power is 1.32pW.this is shown in Fig.10

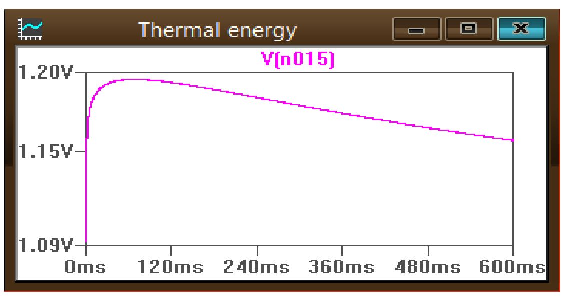

Fig.10 Startup boost converter waveform

From above result the startup circuit power consumption is low compare to existing system and also reduces a voltage drop as well as increase a circuit performance.

6. Conclusion

The designed power supply with the internal startup circuit for pacemaker is presented in this paper. A multi feedback oscillator and a Charge Pump (CP) have been designed and simulated in LTspice, which enable the circuit to start up from input voltages up to 300mV. Applying a 300mV input voltage from pre-startup charge pump, which generate an output voltage of the startup boost converter is 1.15V and consume power is 1.32pW under 50kilo ohm load conditions. In future work, the steady state boost converter with multiplexer circuit is added to the startup boost converter to analysis the overall circuit performance and reducing the power consumption.

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