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Research Article

Design of Self-Powered WMD using Multi-Source Energy Harvesting Technique.

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ABSTRACT

People can prevent illness and maintain their health in daily life through Wearable Medical Devices (WMDs), which continuously track health conditions. Low reliability, high battery consumption, and huge dimensions are just a few of the problems with wearables. One key challenge is to provide a reliable power supply. This paper presents a Multi-Source Energy Harvesting Technique to extend the lifetime of batteries in WMDs that combines four different ambient energy sources such as light, Radio Frequency (RF), vibrations, and temperature differences. It contains two main parts, namely energy conversion circuitry and Power Management Unit (PMU). In the first part of our proposed design, the solar energy conversion circuitry boosts the 0.7 V input voltage to 1.6 V at the output. The RF energy conversion circuitry converts 200 mV (2.45 GHz) AC source into 800 mV. A very low input of 200 mV is converted to 1 V by the thermal energy conversion circuitry. The input from a piezoelectric source which is 700 mV, 200 Hz AC signal is converted to 1 V DC signal at the piezoelectric energy conversion circuitry. In the PMU, the outputs from individual harvesters are combined into a 5 V DC which is then regulated into a 3.3 V. Finally, the regulated voltage is divided into three output voltages 1.8 V, 1 V, and 0.5 V as required by WMD sub components such as signal-processing unit, AFE unit, and sensor unit. The proposed technique is implemented schematically in 90-nm CMOS technology using the Cadence Virtuoso design tool and analyzes several parameters such as transistor count, power consumption, start-up time, and efficiency. From the results, it is evident that our proposed design provides better results in terms of lesser propagation delays, fewer transistor counts, and high voltage conversion ratios.

Keywords: Wearable Medical Devices, Analog Front End (AFE), Multi-Source Energy Harvesting, Solar; Thermal; RF; Piezoelectric, Power Management Unit (PMU), CMOS, and Cadence Virtuoso.

1. INTRODUCTION

A survey conducted by the World Health Organization (WHO) shows that by the year 2030, 1.56 billion adults will be living with high blood pressure (BP). Also, that report said that the leading cause of death globally arises due to cardiovascular diseases (CVDs) which have been estimated 17.9 million lives each year. The early detection and management of medical problems can have a major impact on healthcare costs and survival rates. Medical professionals can now identify ailments earlier than ever due to bio-medical technologies. Biomedical devices can be categorized as wearable and implantable therapeutic devices [1,2]. A WMD is a self-contained, non-invasive object that carries out a specific therapeutic or diagnostic purpose. A Wearable Medical Device (WMD) is a risk-detection

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device that has to be small, light, and comfortable to wear. Smartwatches and bands are the most popular wearables on the market, according to statistics from the [3] Vandrico Wearable Index. One key challenge in WMD is providing a reliable power supply. Batteries have been the primary source of power supply for medical devices, but their use has been quite inconvenient. Also, Batteries are fairly huge and have a finite amount of capacity; as a result, they cannot be used as a constant source of power. Furthermore, they must be regularly maintained, recharged, and replaced, which is both costly and time demanding. Energy harvesting techniques that can capture energy from human activity as sustainable power sources [4] helped to solve this limitation.

One of the most challenging aspects of implementing energy harvesting is ensuring that the wearable device has constant power. If the energy harvesting system is only supplied by one or two sources, it will be unable to provide a continuous supply of power to the wearable devices for continuous monitoring in the event of unavailability of these energy sources [5,6]. Solar and thermal energy sources completely rely on the environment and might change from time to time depending on the conditions. The intensity of piezoelectric and thermal energy harvesters varies significantly over time. As a result, combining energy from numerous sources proves to be a more dependable method of ensuring a constant power supply. The fundamental benefit of hybrid energy harvesting is that it can extract energy from any of the sources available. This significantly increases the system's efficiency [7]. Most of the previous energy harvesting techniques [8-9] were either based on a single energy source or a hybrid, which combined energy from up to three sources only. The several sorts of energy sources, such as electromagnetic, thermal, kinetic, and others, are depicted in our proposed diagram in Fig. 1. By using energy harvesting circuits, WMD sub-components such as sensor, AFE and signal processing units are getting self-powered.

2. Proposed Design Methodology For Energy Harvesting of WMD

The proposed multi-source energy harvesting technique for wearable devices harvests energy from four different energy sources: solar, RF, thermal, and piezoelectric. The block diagram of the proposed system is shown in Fig 1.

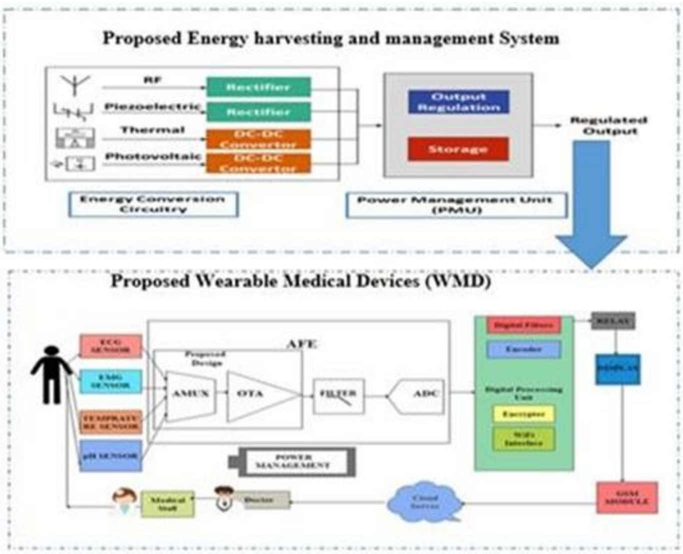

Fig 1. Block Diagram of the Proposed Multi-Source Energy Harvesting CMOS Technique

An energy conversion circuitry consisting of rectifiers and DC-DC converters is implemented. The voltages from individual harvesters in the energy conversion circuitry are to be combined and given to the Power Management Unit (PMU) which then performs output regulation and storage. Finally, regulated outputs from the PMU are given as supply to three different blocks in the WMD such as Analog Front End (AFE), signal processing unit, and sensor unit.

2.1 Solar and Thermal Energy Harvesting Using Dc-Dc Boost Converter) : Solar panels produce very low DC power, which makes it impossible to use them directly for any useful application. Some kind of boosting system

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is needed for the conversion of low energy into high. The energy conversion system consists of a low-voltage pulse generator, pulse booster, and DC-DC boost converter.

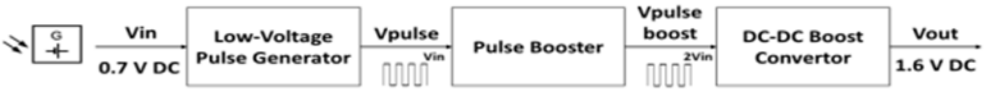

Fig. 2. Block Diagram of Proposed Solar Energy Conversion Circuitry

Fig 2. shows the block diagram and schematic design of the proposed solar energy conversion circuitry. The low-voltage pulse generator and pulse booster may operate at 0.7 V supply voltage since they are in weak inversion mode. The voltage from the solar transducer is given to a low-voltage pulse generator which generates clock pulses. The pulse booster will double the amplitude of the clock pulse from the low-voltage pulse generator. The boosted pulse is then delivered to a step-up converter, resulting in a boosted voltage of 1.6 V that is stored in a capacitor.

Thermo Electric Generators (TEG) are solid-state semiconductor devices that convert a temperature difference and heat flow into a useful DC power source. Because the DC power generated by a TEG is so low, it cannot be used directly for any useful application. For the conversion of low energy to high energy, some form of boosting mechanism will be necessary.

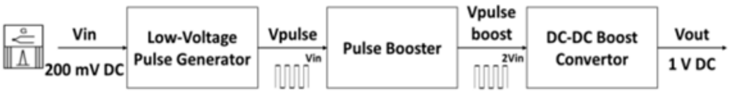

Fig. 3. Block Diagram and of Proposed Thermal Energy Conversion Circuitry

The block diagram of the suggested thermal energy conversion circuitry are shown in Fig.3. A low-voltage pulse generator receives the voltage from the thermal transducer and creates clock pulses. The pulse booster doubles the amplitude of the clock pulse from the low-voltage pulse generator. The boosted pulse is then delivered to a step-up converter, which produces a boosted voltage of 1.6 V which is then stored inside a capacitor.

3. Power Management Unit : Because of the limitations and unpredictability of power sources in energy harvesting, Power Management Units (PMU) are necessary to store and utilize the harvested energy most efficiently. The PMU extracts and regulates the harvested energy from the Energy Harvesting source and then delivers a required amount of voltage to the subsequent blocks in the end device. The two main blocks that make up the PMU are the voltage regulator and the energy storage element.

4. Proposed AFE Design : The proposed AFE consists of 29 transistors and consumes 2.62pW power from 0.8V supply voltage. The CMOS AFE circuits proposed there needed 0.8 V of power, which is supplied by a proposed energy-harvesting PMU.

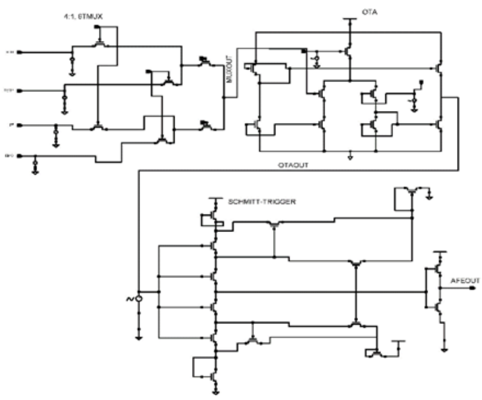

Fig 4. Circuit diagram of 90-nm Proposed Analog Front End (AFE) design for Wearable Medical Devices

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5. Results and Discussion : Cadence Virtuoso tools provide a powerful design environment, which has been used in this research to analyze it.

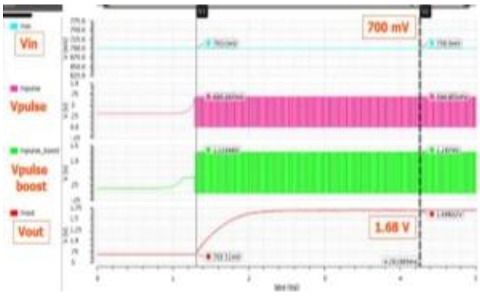

Fig. 5(a)

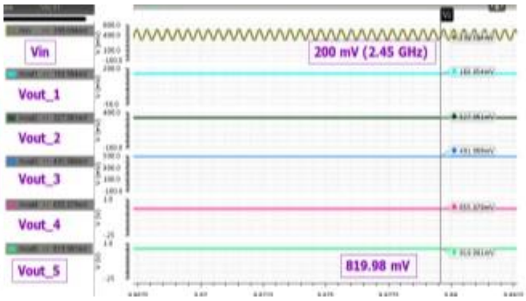

Fig.5(b)

Fig.5(a) shows the output waveforms of the solar energy conversion circuitry. Fig.5(b). Output waveforms of RF energy conversion circuitry.The 700-mV input voltage (Vin) has been used in the pulse generator to obtain a pulse signal of the same amplitude (Vpulse). The amplitude of the pulse signal is doubled by the pulse booster (Vpulse_boost). Finally, 1.6 V output voltage (Vout) is obtained and stored in the capacitor. The start-up time of the energy harvesting is around 1.3ms.

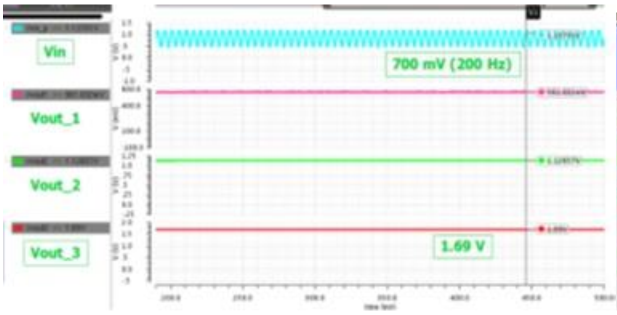

Fig 6(a)

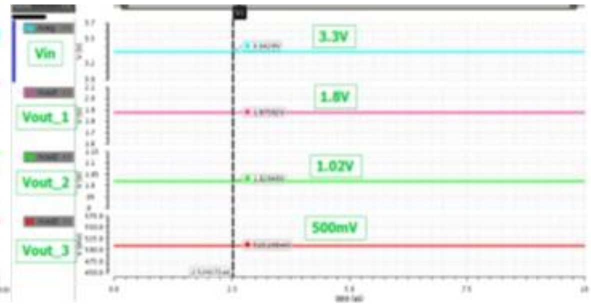

Fig 6(b)

The output waveforms of the rectifier design in piezoelectric energy conversion circuitry are shown in Fig 6(a). The first stage of the rectifier receives an input voltage (Vin) of 700 mV (200 Hz). By rectification and boosting, an output voltage of 1.6 V is achieved in the third stage. The 3.3 V regulated voltage from the regulator (Vin) has been divided into three different voltages such as 1.8 V, 1 V, and 0.5 V by the voltage divider, as shown in Fig 6(b).

6. CONCLUSION

A multi-input energy harvesting system that harvests energy from four different ambient sources is proposed to extend the lifetime of the battery in WMD. The proposed system has been implemented in 90 nm CMOS technology and using Cadence Virtuoso software. First, differential rectifiers and DC-DC boost converters are used to implement the energy conversion circuitry for the four separate sources using minimum transistors and a power supply of 0.7 V. Then, the Power Management Unit is implemented using 90-nm CMOS technology to regulate the harvested energy. The suggested system takes advantage of four different ambient energy sources, including solar, thermal, radio frequency, and piezoelectric. Which generates 5 V power, resulting in the production of 50% more energy than previous energy harvesters with minimum delay. In the future, we would like to implement solar, thermal, RF, and piezoelectric energy transducers and the layout design of the whole system for wearable biomedical devices.

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