DESIGN A BATTERY-LESS POWER MANAGEMENT SYSTEM THROUGH ENERGY HARVESTING CIRCUIT

YAP JIM HUI

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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This report is submitted in partial fulfillment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

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Disahkan oleh:
Dr. WONG YAN CHIEW
Pensyarah Kanan
Fakulti Kejuruteraan Elektronik & Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
Hang Tuah Jaya
76100 Durian Tunggal, Melaka

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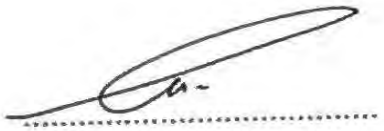
Signature : 

Supervisor Name : DR.WONG YAN CHIEW

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For my father and mother, my supervisor, Dr. Wong Yan Chiew, and my friends.

ABSTRACT

Thermoelectric energy harvesting is a promising way of replacing battery in many low power devices such as Wireless Body Area Network (WBAN), animal tracking system, biomedical implant devices and etc. Due to its ability in converting thermal gradient into an usable electrical energy, it has been applied to harvest waste body heat to power up low power devices such as WBAN. However, the thermal gradient between body temperature and ambient temperature can only achieve from one to four degree Celsius. One degree Celsius produces thirty millivolts. Therefore, in this work, Complementary Metal-Oxide-Semiconductor (CMOS) voltage booster and a dynamic closed loop power management is designed and integrated to boost a 30mV from output of TEG to a regulated 1.2V. Digitally control oscillator is designed to control the switching period of transistors in voltage booster. Besides, RF rectifier is utilized to act as a start-up mechanism for voltage booster and power up subsequent circuits in dynamic closed loop power management. Low Dropout Voltage Regulator is designed to regulate 1.2V. At last, Power on Reset is used to monitor the power down of the system. With these energy harvesting circuits, a battery-less power management system is proposed. The design is developed in Silterra 130nm technology by using Cadence software.

ABSTRAK

Termoelektrik penuaian tenaga merupakan cara yang sesuai untuk menggantikan bateri dalam aplikasi yang menggunakan tenaga rendah seperti alat rangkaian untuk badan tanpa wayar, sistem pengesanan haiwan, alat bioperubatan dan lain-lain. Disebabkan kemampuannya yang dapat menjana tenaga melalui perbezaan haba ,ia telah digunakan untuk menuai sisa haba badan untuk membekal tenaga kepada alat rangkaian untuk badan tanpa wayar. Walau bagaimanapun, perbezaan haba antara suhu badan dan sekeliling hanya mencapai 1 hingga 4 celsius darjah. Satu darjah celsius memberikan tiga puluh millivolts.Oleh itu, Complementary Metal-Oxide-Semiconductor (CMOS) penggalak voltan dan pengurusan tenaga dinamik telah direka dan disepadu untuk meningkatkan 30mV dari TEG kepada 1.2V. Digital kawalan pengayun direka untuk mengawal tempoh pensuisan transistor dalam penggalak voltan. RF penerus digunakan untuk penggalak voltan dan memandukan litar lain dalam pengurusan tenaga dinamik. Pengatur voltan rendah keciciran telah direka untuk mengawal selia 1.2V. Akhirnya, litar penepatan semula kuasa digunakan untuk memantau tenaga sekiranya tenaga tidak cukup untuk cip. Dengan litar penuaian tenaga, sistem pengurusan tenaga tanpa bateri telah direka dalam teknologi 130nm Silterra dengan menggunakan perisian Cadence.

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Lastly, I would like to sincerely thank my beloved parents and friends for their unceasing moral support and encouragement during my study.

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LIST OF SYMBOLS AND ABBREVIATIONS

CCM	:	Continuous Conduction Mode
CMOS	:	Complementary Metal-Oxide-Semiconductor
CP	:	Charge Pump
DC	:	Direct Current
DCM	:	Discontinuous Conduction Mode
DET	:	Detector
DRC	:	Design Rule Check
DS	:	Decision Switch
EMF	:	Electro Motive Force
FET	:	Field-effect Transistor
FSM	:	Finite State Machine
IoT	:	Internet of Things
LDO	:	Low Dropout Voltage Regulator
LVS	:	Layout Versus Schematic
MUX	:	Multiplexer
NMOS	:	N-type Metal-Oxide-Semiconductor
PGS	:	Pulse Generator Steady-state

PMOS	:	P-type Metal-Oxide-Semiconductor
PoR	:	Power on Reset
RF	:	Radio Frequency
SoC	:	System on Chip
TEG	:	Thermoelectric generator
WBAN	:	Wireless Body Area Network
ZCS	:	Zero Current Switching

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CHAPTER 1:

INTRODUCTION

1.1 Project Background

A Wireless Body Area Network (WBAN) is one type of wireless sensor node devices to monitor health condition. This device has a great potential in healthcare as it eliminates the inconvenience of having wires around the patient's body and enhances the quality of health monitoring system at home. Low power consumption is a crucial factor for such applications due to the life time of portable batteries. It is expected to operate for long durations but the limited node lifetime has become the major concern in the widespread deployment of WBAN. Leakage of battery residual is another issue if the WBAN is put beneath our skin or inside our body.

For this reason, a battery-less power management system through energy harvesting circuit is proposed and developed in a 130nm Silterra process technology. Energy harvesting technique is utilized to realize battery-free operation. Thermoelectric energy harvesting is the emerging technology in these few years as it is able to harvest energy from the environment and give a usable electrical energy. This topic has been widely discussed because the demand of low power and small size electronic consumer devices are increasing. Using of Thermoelectric generators (TEGs) to harvest energy is one of the great interests recently. TEG is a solid state device converts the temperature gradient into electrical energy. TEG works on the principle of the Seebeck effect, when the junctions formed by joining two dissimilar current carrying conductors are maintained at different temperatures, an electro motive force (EMF) is generated in the circuit.[1] By comparing with other existing energy harvesting techniques, thermoelectric energy harvesting is more feasible as TEG has no moving part, noiseless operation and long lifespan. Recovering from the waste heat energy like body heat to electrical energy is a promising way of replacing batteries. However, the voltage generated from the TEG is very low.

Therefore, CMOS voltage booster and the dynamic closed loop power management are the main design in this work to realize an integrated power management unit for completely battery-free application.The CMOS voltage booster is built with the digital control oscillator. For the dynamic closed loop power management, it includes the integration of RF rectifier, CMOS voltage booster, digitally control oscillator, comparator and voltage reference. Low-Dropout Voltage Regulator (LDO) and Power on Reset (PoR) are the additional circuits to be integrated together with the dynamic closed loop power management. The schematic

and layout are designed and developed in Silterra 130nm process technology in Cadence to form a battery-less power management system.

1.2 Problem Statement

With the increasing number of wearable electronic devices, biomedical implants and the advent of Internet of Things (IoT), the demand for power supplies has surged. In recent years, WBAN has made a great potential in medical field. But due to the limited node lifetime, it becomes the crucial concern and also the bottleneck of the development of WBAN application. Although WBAN just need a small battery, frequent charging is required and therefore reduces the wearable compliance. A bulky battery is the size consideration where it is inconvenient to bring or make the application non-wearable. A battery-less power management system through energy harvesting technique thus prolong the node lifetime. Voltage booster is one of the critical blocks in energy harvesting system to provide sufficient energy to load from low harvested energy. The start-up voltage of voltage booster as well as the stability of functionality in the varying environment is the concern. One of the common approaches to implement voltage booster is switch-mode charge pump circuit. Since there are many power switches are used in this type of converter, a complex control circuit is required to control power switches which consume much power. Conversion efficiency is well depends on the timing on-off of the switches. However, continuous conduction mode increases the switching losses as it will discharge output capacitor during switching period when inductor current flows negatively. Start-up mechanism is important to ensure the voltage booster works at initial stage. Previously there are some works that use batteries or mechanical switches to kick start the CMOS voltage booster. However for a fully battery free operation, this way is not preferable.

1.3 Objectives

The main objectives of this project are:

I. To identify the key design parameters in battery-less power management system through energy harvesting circuit.
II. To design a CMOS voltage booster for battery-less power management system.
III. To analyze the performance of the CMOS voltage booster in different operating conditions
IV. To analyze the performance of the integrated battery-less power management system.

1.4 Scope of Project

In this project, the design of the CMOS voltage booster consists of digitally control oscillator which utilizes the DCM. The minimum supply voltage of the CMOS voltage booster is 30mV which is obtained from the output voltage of TEG. The target output voltage from CMOS voltage booster is 1.2V. CMOS voltage booster is integrated together with the rectifier, comparator, voltage reference and digitally control oscillator to form dynamic closed loop power management in order to regulate the 1.2V. LDO and PoR are redesigned to operate at 1.2V. A battery-less power management system is analyzed based on the regulated output voltage from CMOS voltage booster. The schematic and layout of the integrated circuit are designed and developed in Silterra 130nm process technology by using Cadence software.