國立交通大學

電子研究所

碩士論文

實現於低壓製程中
具有級數切換功能之高壓產生器
High-Voltage Generator with Multi-Stage Selection in Low-Voltage CMOS Process

研 究 生：游力瑾 (Li-Chin Yu)

指導教授：柯明道教授 (Prof. Ming-Dou Ker)

中 華 民 國 一〇六 年 十 月

實現於低壓製程中
具有級數切換功能之高壓產生器

High-Voltage Generator with Multi-Stage Selection in Low-Voltage CMOS Process

研 究 生：游力瑾　　Student: Li-Chin Yu

指導教授：柯明道教授　　Advisor: Prof. Ming-Dou Ker

國 立 交 通 大 學

電子研究所

碩 士 論 文

A Thesis
Submitted to
Institute of Electronics
College of Electrical and Computer Engineering
National Chiao Tung University
in Partial Fulfillment of the Requirements
for the Degree of
Master of Science
in
Electronics Engineering
October 2017
Hsinchu, Taiwan, Republic of China

中 華 民 國 一〇六 年 十 月

實現於低壓製程中
具有級數切換功能之高壓產生器

學生：游 力 瑾　　　　　　指導教授：柯 明 道 教授

國立交通大學

電子研究所

摘要

隨著生醫電子的發展，電刺激技術已被證明可藉由電流刺激來有效恢復身體的某些功能，例如視網膜、電子耳、癲癇抑制等。在輸出電流刺激時，由於生物組織的阻抗較高，所以在刺激時在組織兩端會有高電壓，故在生醫晶片中不僅需要刺激器還需要一高電壓產生器。電刺激所需電源電壓會隨著不同的應用而有所不同，範圍由數伏特至數十伏特，故用來驅動刺激器電路的高電壓產生器要能夠隨組織阻抗變化提供不同電壓值。電荷幫浦易整合於單晶片的特性相當適合應用在植入式生醫元件，然而，在輸出大範圍電壓時仍會面臨功率轉換效率低落的挑戰。

本篇提出可應用於低壓製程之電荷幫浦級數控制器電路，可以有效控制輸入電荷由旁路電晶體抑或是由電荷幫浦通過。透過在級數控制電路中耐高壓之單刀雙擲開關(HV-SPDT)，即使使用低壓電晶體元件，皆可有效地使所有電晶體都操作於安全電壓

(V_{DD})內。搭配使用三級的交叉耦合電荷幫浦並且藉由脈衝頻率調制(Pulse Frequency Modulation, PFM)回授控制使電壓穩在目標電壓之方式,配合整體系統應用隨組織阻抗變化調整最適合之級數，大幅提升電荷幫浦於大輸出電壓範圍之效率，節省整體生醫晶片系統之功率消耗。而對於植入式生醫晶片所需考量的問題諸如可靠度、系統集成度、矽晶圓面積成本等問題皆於此電路中被考慮。取代使用高壓元件，本電路使用低壓製程實現，有效提升在植入式生醫晶片的製程整合。

級數控制器與電貿幫浦整體電路在 0.18μm 1.8V/3.3V 低電壓製程下實現，輸入電壓 3.3V 時，提供 3.3V-12.5V 大範圍的輸出電壓，在最重載 3.5mA 下，維持高功率轉換效率。經由實驗驗證，不同輸出電壓 4.875, 8.1, 10.8V，各在 3.5, 1.5, 0.5mA 的輸出電流下，使用級數控制調整至合適的級數，整體轉換效率皆可維持在 60%以上。對比於沒有級數控制的電貿幫浦，最高可提高 36%之功率轉換效率。

High-Voltage Generator with Multi-Stage Selection in Low-Voltage CMOS Process

Student: Li-Chin Yu **Advisor: Prof. Ming-Dou Ker**

Institute of Electronics
National Chiao-Tung University

Abstract

With the development of bioelectronics, electrical stimulation had been proven to effectively restore some physical functions of patients by such as retinal prosthesis, cochlear implant and suppression of epileptic seizure. Since the impedance of tissues is large, the voltage between tissues would be high when the stimulator driver delivers stimulus current through tissues. Therefore, a high voltage generator is needed in electrical stimulation. However, in various tissues and different application, the impedance varies, the required supply varies. The high voltage generator should provide different voltage from a few volts to tens of volts according to the loading impedance. Although a charge pump without off-chip device is a suitable candidate for high voltage generator in implantable medical device (IMD), it still faces a difficult problem of serious power conversion efficiency drop in the attempt to provide wide output voltage range.

In this thesis, a stage selection circuit that only utilizes standard low-voltage transistors for multi-stage charge pump is presented. The proposed stage selection circuit is able to select which charge pump stage to pump or bypass. Moreover, even though charge pump and stage selection circuit are all fabricated in low voltage process, the proposed HV-SPDT

(High-Voltage Single-Pole-Double-Throw) cell in stage selection circuit can make sure the maximum voltages across the terminals of any transistor are kept within the normal supply voltage (V_{DD}). By implementation with a 3-stage cross-couple charge pump and regulation by pulse frequency modulation (PFM), proper supply voltage according to load demand could be provided by adjusting the number of charge pump stages and PFM control regulated at target voltage (V_{TG}). The degradation of power efficiency under wide output demand can be overcome. Furthermore, numerous challenges such as reliability, system integration, and silicon area cost are also considered for a fully implantable medical device. The characteristic of using standard low-voltage transistors instead of high-voltage transistors improves the integration advantage with other biomedical digital controller into a system-on-chip (SoC).

The prototype of implementation with the stage selection circuit and charge pump provides a wide output range of 3.3-12.5V and 0-3.5mA load from a 3.3V input source with efficiency generally beyond 60%. The measurement results of power efficiency at output voltage 4.875, 8.1, 10.8V, by using optimal stage number, can reach beyond 55% under 3.5, 1.5, 0.5mA output current. With this technique, the maximum efficiency enhancement reaches up to 36% at output voltage 5.77V selecting 1-stage instead of 3-stage in simulation. The stage selection circuit and charge pump circuit are fully on chip and had been fabricated in TSMC 0.18μm 1.8-V/3.3-V CMOS process.