國立交通大學

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碩 士 論 文

多電荷幫浦系統及可切換級數負電壓產生器之設計及生醫晶片應用

Design of Multiple-Charge-Pump System and Stage-Selective Negative Voltage Generator for Biomedical Applications

研 究 生: 林曉平 (Shiau-Pin Lin)

指導教授: 柯明道教授 (Prof. Ming-Dou Ker)

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摘要

近年來，結合生醫科學與半導體電子，電刺激技術已廣泛應用於醫療方面，藉由電刺激脈波來刺激神經或肌肉，協助患者恢復身體的某些功能。由於生物組織的阻抗較高，刺激器在輸出電刺激時，組織兩端等效地看到一高電壓，故在生醫晶片中需要產生一高電壓供應器給予刺激器。

生物體治療過程中，電極與組織間的錯位可能造成阻抗的變化，抑或是刺激的療效促使電刺激規模的改變。眾多因素導致刺激器所需要的供應電壓源範圍由數伏特至數十伏特不等，故用以驅動刺激器電路的高壓產生器要能夠隨刺激狀況的調整來提供不同電壓值。

相較於電感式直流電壓轉換器，切換電容式直流電壓轉換器（又名電荷幫浦，Charge Pump）可以在不使用外掛元件之條件下，依據不同架構、電容耦合與開

關切換，將電壓位準由低壓轉換為正高壓或負高壓，且在輸出電流負荷下穩定提供電壓，此特性相當適合應用並整合於植入式生醫元件。

基於生醫應用與整合考量，本論文提出一多電荷幫浦系統以及一可切換級數負電壓產生器。針對單端架構之刺激器欲輸出正、負電刺激，本論文提出之多電荷幫浦系統需同時提供足夠且穩定的正、負高電壓，在 0.18-μm 1.8-V/3.3-V CMOS 低壓製程下，使用之電荷幫浦架構沒有閘極可靠度的疑慮，分別可產生±9 V 之高電壓且耐受 5.5mA 輸出電流供給刺激器輸出端使用，以及–2.7 V 之低電壓且耐受 1mA 輸出電流供給刺激器控制電路使用。為了適應刺激器之供應電壓範圍變動與提高電荷幫浦之功率轉換效率，本論文提出之可切換級數負電壓產生器藉由改變電荷幫浦串接級數，減少電荷傳遞路徑上的寄生效應造成過多的功耗，使閉迴路系統能在–0.3 V 至–8.8 V 大範圍的直流電壓準位達到穩壓，最大輸出 5.5mA 電流，並維持較高的效率，此電路已於 0.25-μm 2.5-V/5-V/12-V CMOS 高壓製程下實現並驗證成功。

Design of Multiple-Charge-Pump System and Stage-Selective Negative Voltage Generator for Biomedical Applications

Student: Shiau-Pin Lin **Advisor: Prof. Ming-Dou Ker**

Institute of Electronics

National Chiao-Tung University

Abstract

With the evolution of biomedical science and electronics, many stimulators have been extensively employed as an electrical stimulation treatment in medicine. Electrical stimulation has been proven to recover some physical functions of patients. During stimulation, the equivalent voltage on tissues is high. Therefore, a high voltage generator is needed to serve as a sufficient and stable power source to support stimulus system.

During the therapeutic process, the dislocation between tissues and electrodes may cause the variation of impedance. Also, the effectiveness of the stimulation may induce the change of stimulus scales. Therefore, the required supply for stimulators varies from several volts to tens of volts. It is important for the high-voltage generator to vary along with the stimulus conditions.

Compared to an inductive converter, a capacitive converter (also named as charge pump) is preferred for implantation and integration in biomedical applications. Without any off-chip components, charge pump can generate positive or negative higher voltage from a lower voltage.

Based on these considerations, a multiple-charge-pump system and a stage-selective negative voltage generator are proposed in this thesis. Circuit design to implement a multiple-charge-pump system in a low-voltage standard CMOS process is proposed, that can successfully support the desired power sources for implantable monopolar biphasic stimulators. Without gate-reliability issues, it can provide stimulators with three power sources of +9 V, −9 V, and −2.7 V, simultaneously. It can regulate the output voltage sources (±9V) with a maximum loading current of 5.5mA for stimulus drivers. Another −2.7-V voltage and 1-mA current is for the control circuits of the stimulator. The chip has been fabricated in a 0.18-μm 1.8-V/3.3-V CMOS process, as well as successfully verified in in-vivo animal tests with stimulator together. Besides, a stage-selective negative voltage generator is realized in a 0.25-μm 2.5-V/5-V/12-V CMOS process. It is designed to cover a wide output voltage range from −0.3 V to −8.8 V within maximum output current of 5.5mA. The negative voltage generator with a reconfigurable cascaded architecture is needed to reduce excessive power consumption and further improve the power conversion ratio.