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碩 士 論 文

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Master Thesis

微縮化之無線供電雙相電流刺激器以供植入式神經刺激應用

A Wirelessly Powered Biphasic Current Stimulator for Implantable Biomedical Neurostimulation

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摘要

阻塞型睡眠呼吸中止症是一種常見的睡眠障礙，隨著積體電路以及生醫電子技術的進步，現在可以使用植入式的神經刺激裝置來調節舌頭的運動。藉由此裝置產生出電刺激並刺激舌下神經可讓舌頭前伸，暢通患者的呼吸道，以達到治療的效果。

本篇論文提出了一個無線功率傳輸的神經刺激晶片，利用 T_X 和 R_X 的共振電感與電容，以 13.56 兆赫的頻率共振用以傳遞能量來提供植入式神經刺激裝置的正常運作，取代了鋰電池的使用，使患者可以從定期的手術中解脫。

本神經刺激晶片利用台積電 0.18 微米的製程實現，晶片總面積為 1764×1115 平方微米，利用全波整流器和低壓差線性穩壓器將線圈共振所傳入的能量轉成 3.3 伏特的定電壓做為晶片內部的電源。固定轉導偏壓電路搭配數位-類比轉換器用來產生不同大小的參考電流後，利用電流鏡將其放大至所需的刺激脈衝強度。最後透過控制訊號產生器所產生的訊號來控制刺激驅動電路將刺激送至輸出通道。結合被動放電電路的功能，讓此刺激器能夠在符合安全規範的情況下對神經進行刺激。

此外，考量到生醫應用上希望是比較小的裝置尺寸，本論文最後也提出了可以實現微縮化裝置的方法。利用晶粒與微縮化的 PCB 和金屬打線的方式，在相當小的尺寸下完成功能的實現。能產生出(i)刺激頻率 30Hz (ii)刺激強 0.1 mA~2.5 mA (iii)刺激波寬

10μs~620μs 等大範圍的雙相電流刺激。並已完成了電性與生物膠中的功能驗證。

總結而言，本文提出的具無線功率傳輸的刺激晶片，能夠根據不同的應用場景來提供適當的刺激參數。只需要與適當的共振電感電容來進行無線功率傳輸，就能夠自動且順利進行所期望的電流刺激。

關鍵詞/字 — 雙相電流刺激、植入式刺激器、神經刺激、生物膠仿生量測、無線供電生物醫療裝置

A Wirelessly Powered Biphasic Current Stimulator for Implantable Biomedical Neurostimulation

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Abstract

Obstructive sleep apnea (OSA) is a common sleep disorder. With advancements in integrated circuits and biomedical electronics technology, implantable neural stimulation devices are now available to regulate tongue movement. These devices generate electrical stimulation to stimulate the hypoglossal nerve with the lithium battery power.

This thesis presents a wirelessly powered neural stimulation chip. The system utilizes the resonance of inductors and capacitors in both the transmitter (T_X) and receiver (R_X), resonating at a frequency of 13.56MHz to transfer energy and power the neural stimulation device, eliminating the need for lithium batteries and freeing patients from regular surgical procedures.

The neural stimulation chip is implemented using TSMC 0.18-μm process technology, with a total chip area of 1764 × 1115 square micrometers. The chip converts the energy transferred by the coil resonance into a stable 3.3V supply using a full-wave rectifier and a low dropout regulator (LDO) to power the internal components. A constant transconductance bias circuit, along with a digital-to-analog converter (DAC), is used to generate reference currents of various magnitudes. These currents are then amplified to the required stimulation pulse intensity via a current mirror. Finally, the stimulation driver circuit, controlled by signals from the control signal generator, delivers the stimulation pulses to the output channels. The passive discharge circuit ensures the stimulator complies with safety regulations during nerve stimulation.

Considering the need for smaller device sizes in biomedical applications, this thesis also proposes a method for miniaturization. Using a combination of silicon chip and a miniaturized PCB, the system achieves full functionality within a compact size and is capable of generating a wide range of biphasic current stimulation: (i) stimulation frequency of 30 Hz, (ii) stimulation current ranging from 0.1 mA to 2.5 mA, and (iii) stimulation pulse width from 10μs to 620μs. The electrical performance and functionality have been verified in biomimetic agar gel.

In summary, the stimulation chip presented in this thesis can deliver appropriate stimulation parameters based on various application scenarios. With suitable resonant inductors and capacitors, wireless power transfer enables the chip to perform the desired current stimulation automatically and wirelessly.

Keywords — Biphasic current stimulator, implantable stimulator, neurostimulation, agar gel imitation test, wirelessly-powered biomedical device.