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電子研究所

碩 士 論 文

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Master Thesis

時差頻擾動刺激器電路設計以應用於非侵入式神經調控

Circuit Design of a Non-Invasive Temporal Interference Stimulator for Application in Neurological Modulation

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摘要

近年來，隨著科技的發展與進步，大腦神經退化疾病逐漸成為全球關注的焦點，並且在各種臨床與研究領域中獲得了更多重視。除了傳統的藥物治療以及侵入式的物理治療方式，非侵入式的電刺激治療作為一種新興的療法，旨在提供一種更加安全、低風險的替代方案，從而減少傳統療法可能帶來的危險性和副作用。

為了符合目前生醫相關的應用，本篇論文使用 TSMC 0.18um CMOS HVG2 BCD 製程，提供一個可以產生特定頻率且可以達到輸出振幅正負 5V 的雙通道時差頻擾動刺激器。本刺激器可以藉由輸入訊號的控制，選擇不同的頻率組合，並根據需要來調整輸出振幅，以達到生醫所需之規格。

本篇論文亦提出了基於 TIS 刺激的相關電極與豬隻組織介面模型之數值分析，並以此模型為基礎進行刺激器輸出負載的設計。最終，通過使用等效電路模型進行驗證，確認該刺激器可達到生醫所需之刺激規格，確保其在實際應用中的安全性。此外，本刺激器的設計主要基於非侵入式交流電刺激(tACS)原理，且在進行活體動物量測實驗的過程中，成功確認該刺激器能夠產生有效的電刺激，並且藉由輸入訊號控制，促使豬隻大腦產生低頻訊號，對豬隻受損神經刺激。

關鍵詞/字 ── 非侵入式、時差頻擾動刺激器、失智症、神經退化疾病、神經調節

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Abstract

In recent years, neurodegenerative diseases have garnered global attention as technological advances continue to drive research and clinical innovations. Beyond traditional pharmacological treatments and invasive procedures, non-invasive electrical stimulation therapy has emerged as a promising alternative that offers enhanced safety and a lower risk profile, thereby mitigating many of the side effects associated with conventional treatments.

To address the demands of modern biomedical applications, this thesis introduces a dual-channel temporal interference stimulator (TIS) developed using the TSMC 0.18 μm CMOS HVG2 BCD process. The TIS chip is capable of generating precise frequency combinations and delivering an output amplitude of ±5 V, with the ability to adjust parameters based on input signals to meet specific biomedical requirements.

Furthermore, the thesis presents a numerical analysis of pigs' electrode-tissue model based on TIS stimulation. This analysis informed the design of the stimulator's output load. The stimulator's performance was subsequently validated using an

equivalent circuit model, confirming that it meets the necessary biomedical stimulation specifications and is safe for practical applications. The design is principally based on the principles of non-invasive transcranial alternating current stimulation (tACS). In vivo animal experiments have successfully demonstrated that the TIS chip can generate effective electrical stimulation, whereby controlled input signals induce low-frequency signals in the pig's brain, thereby stimulating damaged neural tissues.

Keywords — Non-invasive, temporal interference stimulator, TIS, Dementia, neurodegenerative diseases, neuromodulation