IOP Publishing J. Neural Eng. 23 (2026) 016015 https://doi.org/10.1088/1741-2552/ae3a1c

Journal of Neural Engineering

RECEIVED
7 September 2025

REVISED
5 January 2026

ACCEPTED FOR PUBLICATION
19 January 2026

PUBLISHED
30 January 2026

PAPER

Temporal interference stimulator realized with silicon chip for non-invasive neuromodulation

Yun-Yu Li, Nan-Hui Huang and Ming-Dou Ker*

Institute of Electronics, National Yang Ming Chiao Tung University, Hsinchu City 300093, Taiwan
* Author to whom any correspondence should be addressed.

E-mail: mdker@nycu.edu.tw

Keywords: beat frequency, carrier frequency, *in-vivo* animal test, neuro-modulation, non-invasive stimulation, temporal interference stimulation

Abstract

Objective. Temporal interference stimulation (TIS) has emerged as an innovative and promising approach for non-invasive stimulation. While previous studies have demonstrated the efficacy and performance of TIS using benchtop instruments, a dedicated system-on-chip for TIS applications has not yet been reported. This work addresses this gap by presenting a design for a TIS chip that enhances portability, thereby facilitating wearable applications of TIS. *Approach.* A miniaturized dual-channel temporal interference stimulator for non-invasive neuro-modulation is proposed and fabricated in a 0.18 μm CMOS BCD process. The TIS chip occupies the silicon area of only 2.66 mm^2. It generates output signals with a maximum amplitude of $\pm$5 V and reliable frequency, with programmable input parameters to accommodate diverse biomedical applications. The carrier frequencies of the generated signals include 1 kHz, 2 kHz, and 3 kHz, combined with beat frequencies of 5 Hz, 10 Hz, and 20 Hz. This results in a total of nine available operation modes, enabling effective TIS. *Main results.* The proposed chip has effectively generated temporally interfering signals with reliable frequency and amplitude. To validate the efficacy of the TIS chip, *in-vivo* animal experiments have been conducted, demonstrating its ability to produce effective electrical stimulation signals that successfully elicit neural responses in the deep brain of a pig. *Significance.* This work has replaced the bulky external stimulator with a fully integrated silicon chip, significantly enhancing portability and supporting future wearable clinical applications.

1. Introduction

Recent advances in the study of neurodegenerative diseases have substantially propelled the development of therapeutic strategies. Traditional treatment modalities primarily include pharmacological treatments and electrical stimulation therapies. Although pharmacological treatments can alleviate specific symptoms, some patients exhibit limited responsiveness or drug resistance. Consequently, electrical stimulation therapies have been developed and adopted as an alternative or complementary approaches. Among these, deep brain stimulation (DBS) is a prominent invasive technique that entails surgically implanting electrodes into targeted deep brain regions to deliver precise electrical signals and restore impaired neural functions [1]. Various system-on-chip applications for DBS have been reported, aiming to provide more convenient and accessible therapeutic solutions [2–4]. However, the necessity of brain surgery introduces significant procedural risks and costs, which remain major concerns for many patients. In addition, the complexity and maintenance of implanted devices can also reduce patient compliance and acceptance of DBS therapy.

By contrast, a novel non-invasive electrical stimulation technique, known as temporal interference stimulation (TIS), avoids the need for surgical intervention and greatly reduces the risks commonly associated with invasive treatments. TIS is categorized under the transcranial alternating current stimulation [5]. The fundamental principle of TIS was first demonstrated by Grossman *et al.* [6], who showed that neurons in the living mouse brain respond to the