Waveform Generator for Temporal Interference Stimulation Setup

Julian Piller

Supervisors: Prof. Dr. Thomas Niederhauser, MSc Lukas Geisshüsler
Institution: Bern University of Applied Sciences, Institute for Human Centered Engineering HuCE
Examiners: Prof. Dr. Thomas Niederhauser, Prof. Dr. med. Dr. phil. Andreas Häberlin

Introduction

Conventional non-invasive electrical stimulation techniques cannot selectively stimulate deeper target structures without unintentionally stimulating superficial structures near the electrodes. Temporal interference stimulation (TIS) may overcome this limitation by applying multiple signals with high, nearly identical frequencies, resulting in a low-frequency interference envelope. Under the assumption that nerves do not respond to high-frequency stimulation, the excitation of deeper structures is synchronized with the low-frequency envelope. [1] To further investigate TIS, a versatile stimulator with an included arbitrary waveform generator was developed and characterized in this work, allowing for the application of multichannel TIS for in vitro and in vivo applications. In addition, a model was developed to visualize and better understand TIS within a 3D volume.

Materials and Methods

The analytical model was based on the equations defined in [1]. Different TIS configurations were simulated to understand the influence of various parameters. The stimulator requirements were based on previous studies for different TIS applications and standards. Synchronized, arbitrary waveforms were generated with a direct digital synthesis (DDS) IC with integrated memory, controlled by a system-on-chip (SoC). The output current source was based on a Howland current pump. Finally, the developed stimulator was first characterized and then used in an in vitro setup to investigate interference patterns.

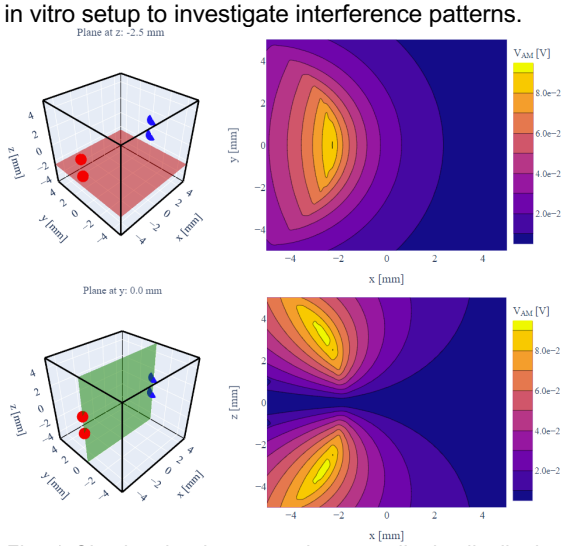

Fig. 1 Simulated voltage envelope amplitude distribution with two electrode pairs and an unequal current ratio.

Results

The simulation results were consistent with the findings from previous studies. The stimulator output current range has a safety limit of 80 mA and was able to drive a bipolar current of around 10 mA up to 100 kHz with a load resistance of 1 kΩ. The output voltage measurement circuit allowed measurements ranging from -270 to 270 V and can be extended up to ±400 V. The median relative error of the custom waveform generator's output frequency was 0.01%. The output current SNR value was greater than 30 dBc. The safety measures (e.g., emergency switch and current limitation) were tested successfully. The interference patterns generated with the stimulator in an in vitro setup were consistent with the corresponding simulation results.

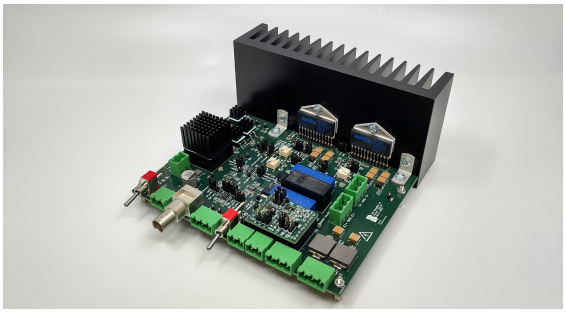

Fig. 2 Output stage with integrated measurement section, safety measures, and filtering and preamplification stage.

Discussion

The model was validated with results from previous studies and measurements. It provides a good basis for the visualization and understanding of new TIS configurations. It can be included in an optimization algorithm in the future to find initial parameters for maximum interference steering and focality enhancement. The versatile stimulator allows the investigation of different TIS applications. The integrated custom waveform generator provides a compact and precise solution for multichannel use.

References

[1] Mirzakhalili et al., Biophysics of Temporal Interference Stimulation. Cell Syst. 2020;11(6):557-572.e5.doi:10.1016/j.cels.2020.10.004

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