Pulse-Width Modulated Temporal Interference Stimulation in a Hodgkin-Huxley Axon

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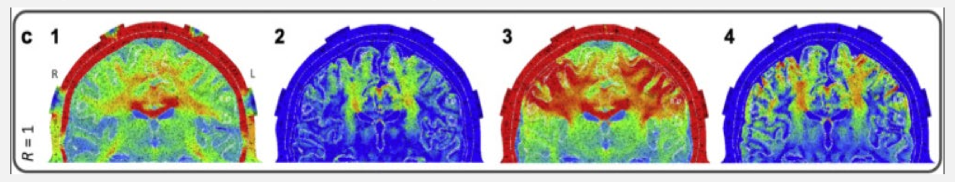
INTRODUCTION

- Neurological disorders like Parkinson's Disease (PD) and essential tremor impair voluntary movement
- Deep Brain Stimulation (DBS) with chronically implanted electrodes effectively alleviates symptoms but requires neurosurgery [1]
- Temporal Interference Stimulation (TIS) is a novel noninvasive technique that offers the potential for some degree of targeting precision [2]
- **This study investigates TIS using asymmetrical pulse waveforms to explore their effects on neural modulation**

BACKGROUND

- Standard TIS delivers two different high-frequency sinusoidal currents that constructively interfere to create a low-frequency envelope

Figure 2. Max field strength of 0.77 V/m found for TIS



- TIS increases amplitude modulation in targeted, deep regions compared to the superficial cortex directly under the electrodes, confirming its increased focality [4].
- Maximum field strength for TIS maxed out at 0.77 V/m, which is too weak for suprathreshold excitation [4]
- Pulse-Width Modulated TIS (PWM-TI) varies carrier-field pulse-width signals
- PWM-TI has been shown to evoke neuronal responses [3], but details are under-explored

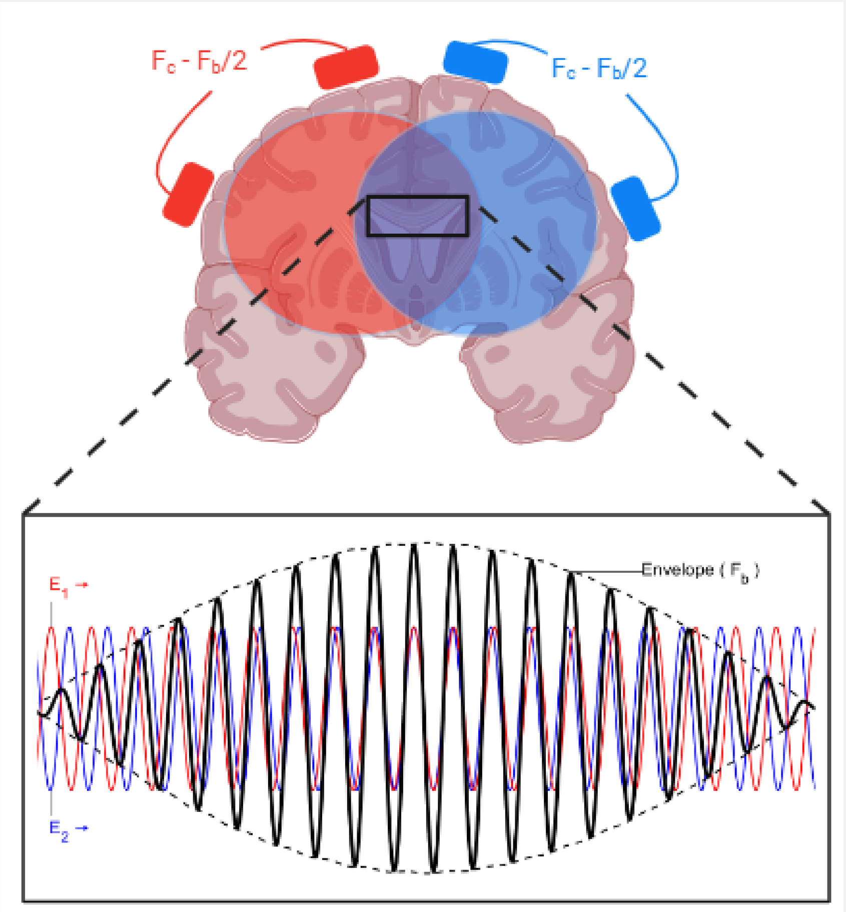


Figure 1. Envelope Modulation of the TI Signal

REFERENCES and ACKNOWLEDGEMTS

- [1] Deuschl et al., *Mov. Disord.*, vol. 21, no. S14, 2006.
- [2] Grossman et al., *Cell*, vol. 169, no. 6, 2017.
- [3] Luff et al., *Brain Stimulat.*, vol. 17, no. 1, 2024.
- [4] Rampersad et al., *NeuroImage*, vol. 15, no. 202, 2019.
- This work supported by the National Institute of Neurological Disorders and Stroke of the NIH, under award R01-NS133229.

METHODS

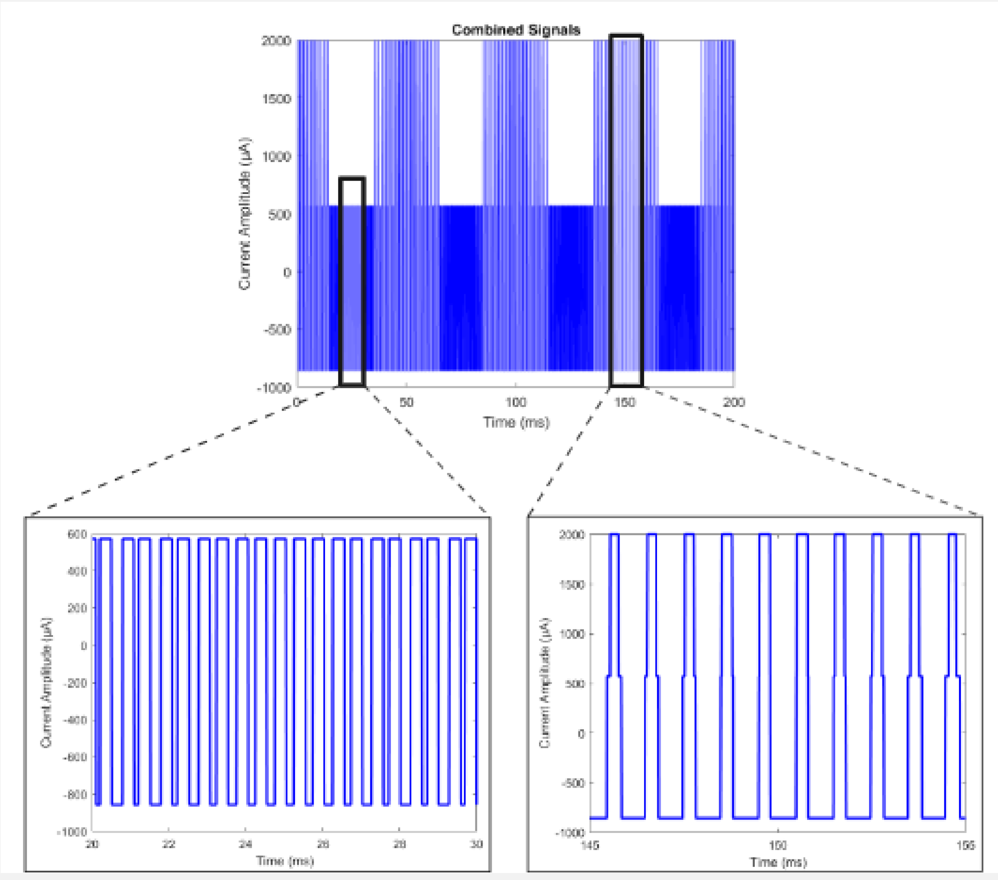
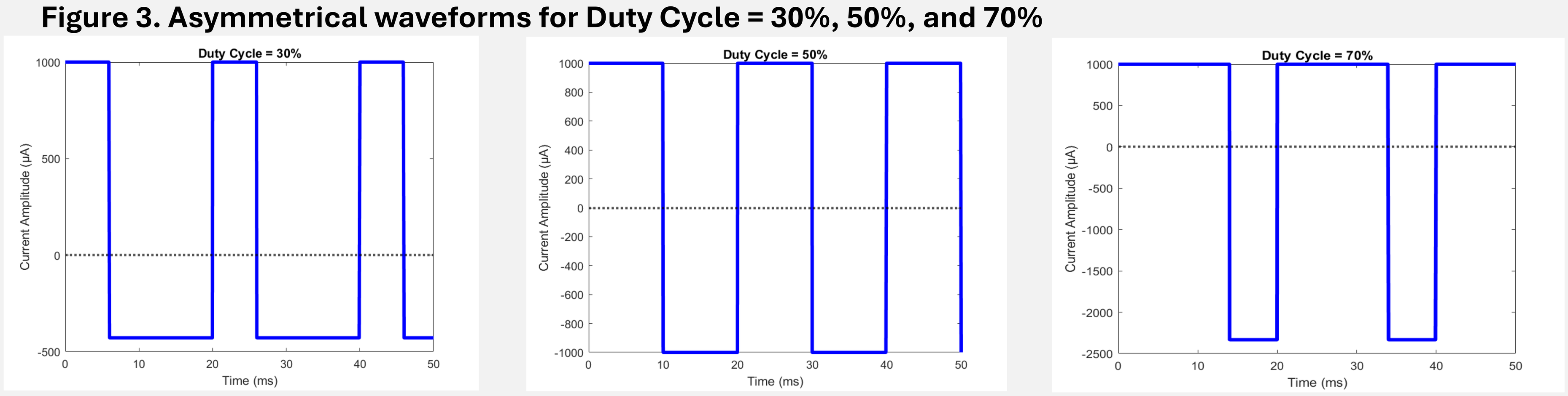


Figure 4. Combined asymmetrical PWM-TI Signal

Figure 3. Asymmetrical waveforms for Duty Cycle = 30%, 50%, and 70%



- Simulations were performed in MATLAB 2024a
- A function was created that takes in input current, creates an asymmetrical pulse wave, and outputs the extracellular voltage created by the waveform
- The extracellular voltage in then applied to a Hodgkin-Huxley axon
- MATLAB's ode15s solver is used to compute membrane voltage across each compartment over time

RESULTS

- Shows axonal spiking when varying beat frequencies are applied
- 5% above rheobase (red), and 5% rheobase (blue)
- Beat frequency of 50 Hz evokes an action potential with the least amount of current applied

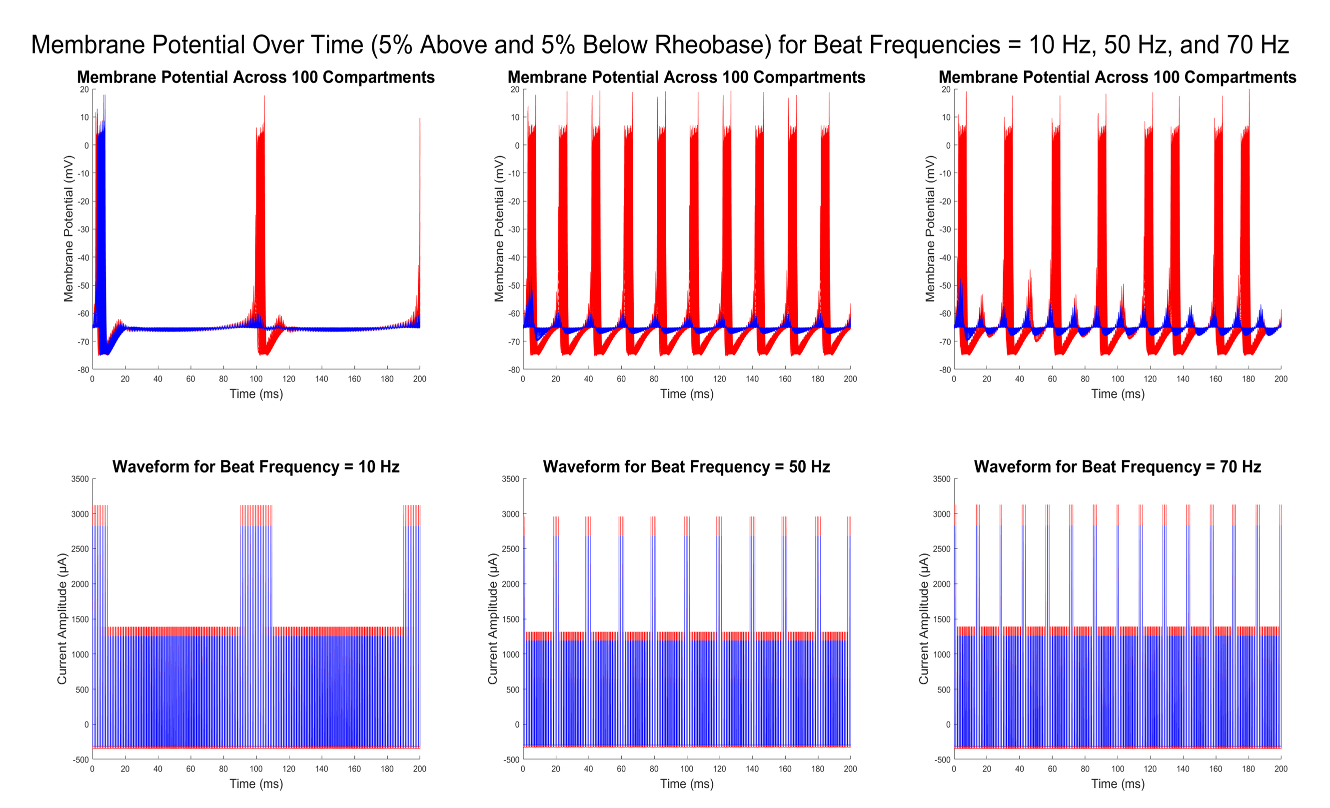
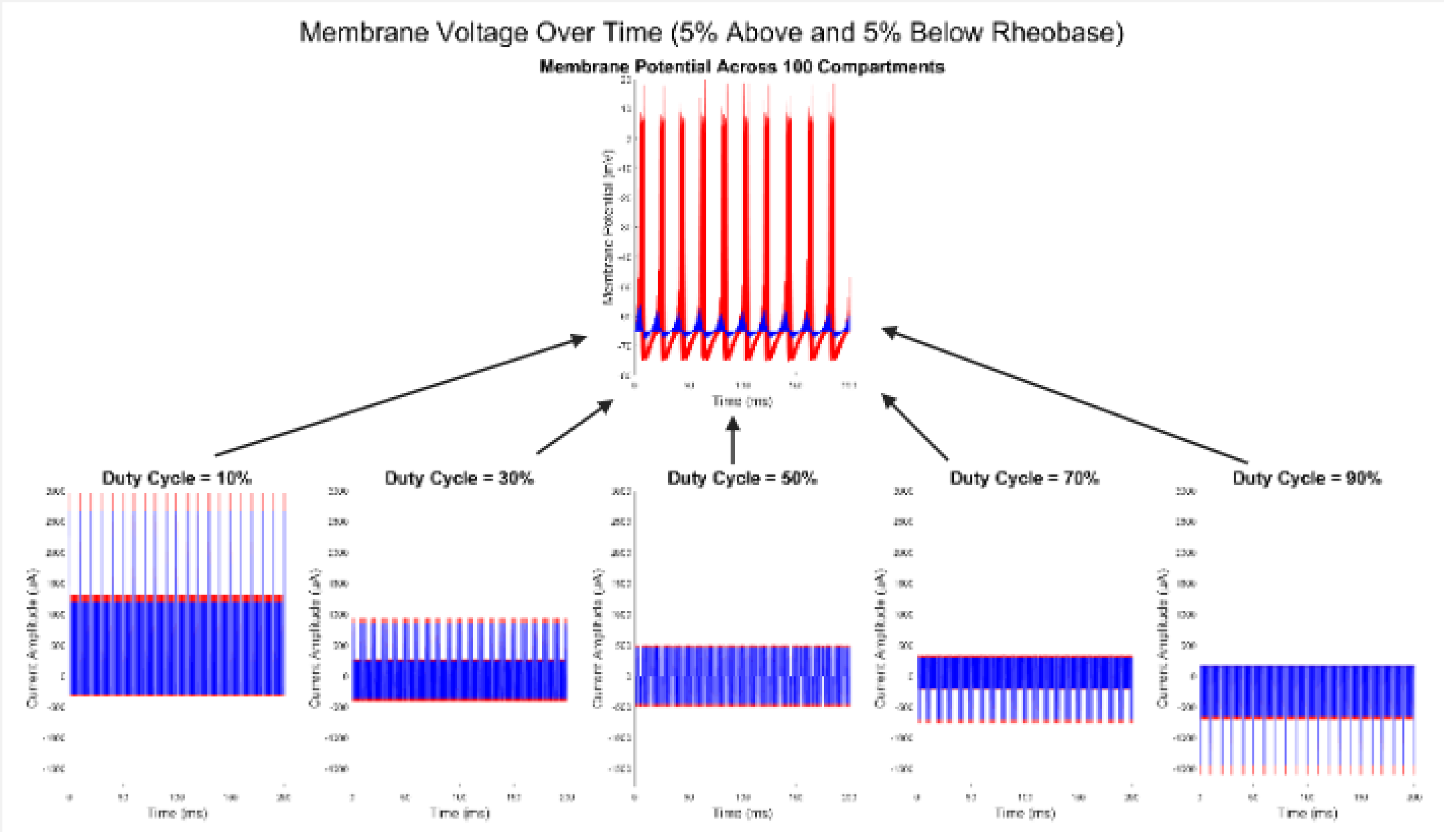


Figure 5

Figure 6



- Shows axonal spiking when varying the duty cycle
- 5% above rheobase (red), and 5% rheobase (blue)
- Duty cycle of 50% requires the minimum current amplitude

FUTURE DIRECTIONS

- Investigate the effects of duty cycle for fixed charge per phase (cf. peak current amplitude)
- Investigate the use of two bipolar electrode pairs (cf. two monopolar electrodes)